STRUCTURE REHABILITATION MANUAL

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STRUCTURE REHABILITATION MANUAL ENQUIRES

To all users of the: **STRUCTURE REHABILITATION MANUAL (SRM)**

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The *Bridge Deck Rehabilitation Manual* was first published in 1983 and was replaced by the inaugural *Structure Rehabilitation Manual* in 1988. The 1988 edition included procedures for condition surveys and rehabilitation of above-grade concrete components of bridges. Since its inception, this Manual has undergone several revisions, with the most recent being Revision No. 10 issued in 2007.

This revision, No. 11, represents a major update, incorporating substantial changes from the previous edition along with significant reorganization to improve the overall format and structure of the Manual. These revisions also enhance cross-referencing and integration with other Ministry documents.

Part 3 in previous versions covered contract document preparation, such as contract quantities and supplementary notes to designers to support standardization of contract drawings. All Part 3 appendices have been moved to their relevant chapters in the *Contract Design, Estimating, and Documentation (CDED) Manual*.

A high-level summary of the changes introduced in this revision is provided in the Record of Revisions tables.

Record of Revisions

This Structure Rehabilitation Manual dated Month 2026 includes Revision #11 and supersedes the previous edition. Changes from the previous edition are summarized as follows:

Part 1 – Condition Assessment

Revision #11 (Current Edition)	Previous Edition (2007)	Notes
P1-1 General	Section 1.1	
P1-2 Levels of Condition Assessment		New.
P1-2.1 Level 1 Condition Assessment		New.
P1-2.2 Level 2 Condition Assessment		New.
P1-2.3 Level 3 Condition Assessment		New
P1-3 Requirements for Identifying Designated Substances	Section 2.13	Updated to incorporate Bridge Office Design Bulletin dated October 26, 2010.
P1-4 Requirements for Engineering Surveys on Rehabilitation Projects		New.
P1-5 Requirements for Barrier Wall Dowel Investigations		New. Replaces Bridge Office Memo 2017-06.
P1-6 Requirements for Structural Steel Investigations		New.

Revision #11 (Current Edition)	Previous Edition (2007)	Notes
P1-7 Requirements for Environmental Classification Testing		New.
P1-8 Requirements for Detailed Visual Inspections	Sections 1.1.1	
P1-8.1 Inspection using Unmanned Aerial Vehicles		New.
P1-9 Requirements for Detailed Condition Surveys	Sections 1.1.2	
P1-9.1 General		
P1-9.2 Surface Deterioration Mapping	Section 2.2	
P1-9.3 Delamination Mapping	Section 2.2	
P1-9.4 Corrosion Potential Survey	Section 2.3	
P1-9.5 Concrete Cover Survey	Section 2.4	
P1-9.6 Miscellaneous	Section 2.5	Clarified requirements for EJ, Bearings, Drainage and asphalt thickness measurements.
P1-9.7 Concrete Cores and Physical Testing	Section 2.6	
P1-9.7.1 Number of Cores on Asphalt-Covered Bridge Decks	Sections 2.6.1, 4.3.13.2, 4.3.13.3, 4.3.13,4	Reorganized, updated.
P1-9.7.2 Physical Testing of Cores from Bridge Decks	Section 5.2	Revised.
P1-9.7.3 Number of Cores and Physical Testing from Concrete Components, Excluding Bridge Decks	Section 2.6.2	Revised.
P1-9.7.4 Physical Testing Methods and Requirements	Section 5.2	
P1-9.7.4.1 Photographs and Description	Section 5.1	
P1-9.7.4.2 Test for Compressive Strength	Section 5.2.1, 5.4.1	
P1-9.7.4.3 Test for Chloride Content	Section 5.2.2, 5.4.3	Clarified calculation of background chloride.
P1-9.7.4.4 Test for Air Void System (AVS)	Section 5.2.3, 5.4.2	
P1-9.7.4.5 Test for Carbonation		New.
P1-9.7.4.6 Retention of Samples	Section 5.5	
P1-9.8 Asphalt Sawn Samples and Large Asphalt Strips	Section 4.3.14	Revised.
P1-9.8.1 Large Asphalt Strips	Section 2.7	

Revision #11 (Current Edition)	Previous Edition (2007)	Notes
P1-10 Requirements for Ground Penetrating Radar (GPR) Surveys	Section 1.1.3	Rewritten.
P1-11 Non-Destructive Testing (NDT) Methods		New.
P1-A1 Field Guidelines for Conducting Detailed Condition Surveys	Sections 1.2, 3, 4, Appendix 1D	
P1-A2 Coring Requirements for Exposed Concrete Decks		
P1-A3 The Report	Section 6	Reorganized, updated.
P1-A4 Review of the Report	Section 7	Reorganized, updated.
P1-A5 Example Grid Layouts for Detailed Condition Surveys	Appendix 1B	
P1-A6 Standard Forms	Appendix 1C	Reorganized, updated.

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Part 2 – Rehabilitation Strategies

The following sections have been revised:

Revision #11 (Current Edition)	**Previous Edition (2007)**	**Notes**
P2-1 Principles for Rehabilitation Decision-Making		New.
P2-1.1 Review of Data	Section 1.2.1	
P2-1.2 Rehabilitation Strategy	Section 1	Reorganized and updated. Replaces Bridge Office Memo BO-2015-01: Strategic Asset Management 2015-2018.
P2-1.2.1 Background		
P2-1.2.2 Preservation Management		
P2-1.2.3 Structural Rehabilitation		
P2-1.2.3.1 Holding Strategies		
P2-1.2.3.2 Major Rehabilitations		
P2-1.2.3.3 Superstructure or Full Structure Replacement		
P2-1.3 Design and Service Life	Section 1.3.4	Rewritten and updated policy on life-cycle cost analysis (LCCA).
P2-1.4 Considerations	Section 1.3.5	Updated and incorporated 2013-08-20 Bridge Office Bulletin: Design and Evaluation of Foundations.
P2-2 Rehabilitation Considerations by Structural Element		
P2-2.1 Superstructure Components		
P2-2.1.1 Bridge Deck	Section 3.3 & Appendix 2C.	Updated and simplified ‘decision’ flowcharts.
P2-2.1.2 Bridge Soffit	Section 3.3.2	
P2-2.1.3 Bridge Deck Fascia	Section 3.3.3	
P2-2.1.4 Barriers (Railings Systems and Walls)	Section 3.6	Updated. Replaces Bridge Office Memorandum 2019-01.
P2-2.1.5 Sidewalks, Curbs and Medians	Section 3.7 & 3.8	
P2-2.1.6 Approach Slabs	Section 3.10	
P2-2.2 Substructure Components	Section 3.5 & Appendix 2D.	Updated and simplified ‘decision’ flowcharts.
P2-2.2.1 Ballast Walls	Section 3.9	
P2-2.2.2 Wingwalls		Updated and incorporated Bridge Office Design Bulletin dated May 4, 2011.
P2-2.3 Buried Structures		New.
P2-3 Rehabilitation Treatments		
P2-3.1 Concrete Removal	Section 1.3.1.3	Updated policy re: removing sound chloride-contaminated concrete.

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P2-3.2 Concrete Patch Repairs	Section 2.2, 2.3, 2.4.1 & Appendix 2B.	Updated.
P2-3.3 Overlays	Section 2.4.3	Updated.
P2-3.4 Refacing and Jacketing	Section 2.4.2	Updated.
P2-3.5 Component Reconstruction		Updated.
P2-3.6 Concrete Crack Repairs	Section 4.0 & Appendix 2F	Updated.
P2-3.7 Concrete Coating	Section 2.4.4	Updated.
P2-3.8 Cathodic Protection	Section 2.4.6, 2.4.7, 2.4.10	Updated.
P2-3.9 Expansion Joints	Section 9.2	Updated.
P2-3.10 Bearings	Section 9.3	Updated.
P2-3.11 Waterproofing	Section 2.4.5	Updated.
P2-3.12 Repairs and Strengthening using Fibre Reinforced Polymers (FRP)	Section 2.4.9	Updated.
P2-3.13 Repairs to Prestressed & Post-Tensioned Components		New.
P2-3.14 Repairs to Structural Steel	Section 5.0	New.
P2-3.15 Post-Installed Adhesive Anchors into Concrete (Dowels)		New.
P2-3.16 Liners for Structural Culverts		New.
P2-3.17 Deck Top Rehabilitation using Short-Term Closures		New.

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Part 3 – Contract Preparation (2007)

Previous Edition (2007)	CDED	
A1 Concrete Removal	B-928	
A2 Structural Removal and Miscellaneous Removal	B-928	
A3 Abrasive Blast Cleaning		
A4 Concrete Placement		
A5 Concrete Overlays		
A6 Concrete Refacing / Concrete Refacing, Form and Pump		
A7 Patching Concrete Components		
A8 Concrete Crack Repairs	B-932	
A9 Concrete Sealers		
A10 Steel Reinforcement	B-905	
A11 Installation of Dowels		
A12 Steel Barrier Railing / Parapet Wall Railing		
A13 Embedded Work in Structure		
A14 Expansion Joints	B-920	
A15 Bearings	B921 & B922	
A16 Cathodic Protection		
A17 Access to Work Area		
A18 Temporary Support and Jacking		
A19 Deck Drainage		
A20 Structural Steel	B-911 (Coating)	
A21 Bridge Deck Waterproofing	B-914	

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INTRODUCTION

The Structural Rehabilitation Manual is the Ministry's primary design document for repair and rehabilitation of highway structures. It is not intended to describe repair methods for the remediation of defects arising from new construction. Although this Manual is written primarily for Ministry projects, it may also be used by municipalities and consulting engineers engaged in structural rehabilitation work throughout Ontario.

While this document focuses mainly on bridges, the techniques and methodologies described herein may also be applicable to other highway structures, including tunnels, culverts, retaining walls, overhead sign supports, and noise barriers, with the application of appropriate engineering judgement. Building structures governed by the Ontario Building Code are not addressed in this Manual.

This Manual is intended to be used by practicing engineers and supports rehabilitation scoping and design. It is organized into two parts.

Part 1: Condition Assessments provides requirements for sampling and testing, field investigation procedures and reporting. The types and extent of condition surveys have been updated to reflect the current state of the Ministry's inventory and are organized into three levels of assessment. Ground penetrating radar has been re-introduced for bridge deck investigations based on continued advancement in the technology. In addition to the conventional inspection and testing methods, Part 1 also outlines other investigation technologies that may be used to further define structural condition and deterioration, supporting informed engineering decision-making during rehabilitation scoping and design.

Part 2: Rehabilitation Selection describes the key factors to be considered when defining a rehabilitation scope, including functionality, service life, structural condition, construction disruption, the availability of labour, equipment, and materials, etc. Although each bridge rehabilitation project presents unique challenges, many common elements and considerations exist across projects. Updates to Part 2 emphasize these commonalities, outline established practices, and provide background information on emerging trends, ongoing research, and other relevant considerations to support informed engineering decision-making. Part 2 is reorganized to better align with the design process, beginning with overall rehabilitation strategy and service life design, and is further subdivided into sections addressing common bridge components and rehabilitation treatments currently used on highway structures in Ontario.

PART 1 – CONDITION ASSESSMENTS

CONDITION ASSESSMENTS

P1-1 General

The purpose of a condition assessment is to quantify and document the overall condition of a structure to establish the scope of rehabilitation that may be required. Findings may also provide information for a structural evaluation of the load carrying capacity of the bridge as described in the latest edition of the *CSA S6 Canadian Highway Bridge Design Code (CHBDC).*

The most common methods the Ministry uses to assess the condition of a structure are:

- Detailed visual inspection. Refer to Section P1-8 Requirements for Detailed Visual Inspection.
- Detailed condition survey. Refer to Section P1-9 Requirements for Detailed Condition Survey.
- Ground penetrating radar (GPR) survey. Refer to Section P1-10 Requirements for Ground Penetrating Radar.

A condition assessment may involve carrying out one or more of the methods described above and/or as described in Section 1.1.3 Inspection of Structures in the *Ontario Structure Inspection Manual (OSIM)*. Condition assessments must be carried out with a plan for worker safety, safety of the travelling public and comply with the *Occupational Health and Safety Act*.

The inspection, testing, and investigation requirements outlined in this Manual represent the minimum standards expected for Ministry projects. These requirements are intended to establish a consistent baseline; however, they shall not limit the scope of work where additional information is necessary to support sound engineering decision-making. Engineers are expected to exercise professional judgment and modify, supplement, or expand the prescribed procedures as required to obtain sufficient data for accurate condition assessment, rehabilitation scoping, and design.

When a condition assessment identifies any critical defects or deterioration, the Owner shall be immediately notified in writing. For actively progressing performance deficiencies, the designer shall notify the Owner to discuss potential options for ongoing monitoring or supplementary investigations.

P1-1.1 Review of Data

Prior to undertaking any condition assessment, all available background information shall be reviewed to identify data gaps and determine the need for additional inspections or investigations. Where information is incomplete or unavailable, supplementary investigations shall be planned accordingly.

Investigations that require lane or shoulder closures, particularly on high-volume corridors, may present operational challenges; however, these challenges do not justify delaying or deferring required investigative work. Accurate data is often most critical at sites where access is difficult, and forgoing investigations increase risk and cost during construction. Investigations and data gathering shall be completed early in the design process to support reliable engineering decisions and effective risk mitigation.

CONDITION ASSESSMENTS

P1-2 Levels of Condition Assessment

Previous editions of this manual specified a detailed condition survey for most bridges in advance of their rehabilitation. That approach reflected historical uncertainties associated with materials, design standards, and construction practices used in Ontario bridge construction, particularly for bridges built between the 1950s and 1970s.

Advancements in bridge materials, design methodologies, and construction practices since the 1970s have improved the reliability and performance of Ontario bridges. As a result, a uniform condition assessment approach is no longer required for all structures.

This edition of the Manual adopts a graduated, risk-based approach by introducing multiple levels of condition assessments. The required level of condition assessment shall be selected based on bridge type, age, construction details, exposure conditions, and the scope of the proposed rehabilitation work.

The minimum condition assessment requirements associated with each assessment level are summarized in Table 1.

Table 1 – Minimum Condition Assessment Levels and Their Requirements.

✓ Included as part of the requirements for the specified condition assessment level.
○ Optional, not included unless specified.

Condition Assessment Level	Level 1	Level 2	Level 3	Applicable Section(s)
Year of Original Construction	**After 1985**	**Before 1985**	**Before 1985**	
Reinforcement Type	**Any**	**Any**	**ECR**	
Detailed Visual Inspection	✓	✓	✓	P1-8
Deterioration & Delamination Mapping	✓	✓	✓	P1-9.2 & P1-9.3
Corrosion Potential Survey	○	✓	n/a	P1-9.4
Concrete Cover Survey	○	✓	✓	P1-9.5
Asphalt Sawn Samples	○	✓	✓	P1-9.8
Ground Penetrating Radar (GPR) Survey	○	○	✓	P1-10
Concrete Core Samples & Tests				P1-9.7
Compressive strength	○	✓	✓	P1-9.7.4.2
Air void system	○	✓	✓	P1-9.7.4.4
Chloride content profiling	○	✓	✓	P1-9.7.4.3
Carbonation	○	○	○	P1-9.7.4.5
Alkali-aggregate reaction (AAR)	○	○	○	P1-9.7.3
Delayed ettringite formation (DEF)	○	○	○	P1-9.7.3
Additional Testing or Investigations				
Designated Substances testing	○	○	○	P1-3
Engineering survey	○	○	○	P1-4
Barrier dowel investigation	○	○	○	P1-5
Structural steel investigation	○	○	○	P1-6
Environmental classification (water and/or soil) testing	○	○	○	P1-7
Additional Non-Destructive Tests				
Infrared thermography	○	○	○	P1-11.1
Impact echo and/or pulse velocity	○	○	○	P1-11.2
Engineering laser scan	○	○	○	P1-11.3

Findings provide the basis for determining suitable repair or rehabilitation approaches. Whether the objective is to evaluate alternative treatments, confirm the need for corrosion mitigation measures, assess the feasibility of surface treatments, or determine whether partial or full reconstruction is warranted, these investigations provide the essential data connecting assessment findings to rehabilitation decisions.

The investigations listed in Table 1 represent those described in this Manual and are not exhaustive. Any of these methods, and additional techniques not covered in this Manual, may be included at any assessment level when required to verify conditions or obtain information necessary for sound engineering decision-making. The requirements shall be specified in the Service Provider's scope of work.

CONDITION ASSESSMENTS

P1-2.1 Level 1 Condition Assessment

A Level 1 condition assessment shall consist of a detailed visual inspection carried out in accordance with the inspection requirements of the OSIM and the defects shall be documented through surface deterioration and delamination mapping (refer to Sections P1-9.2 Surface Deterioration Mapping and P1-9.3 Delamination Mapping). A Level 1 condition assessment does not include requirements for physical sampling and testing.

At a minimum, a Level 1 condition assessment shall be completed for bridges constructed after 1985 that are scheduled to undergo their first rehabilitation.

In 1978, the Ministry introduced a corrosion protection policy that established standards for bridge deck waterproofing using hot-applied rubberized asphalt membrane, asphalt-impregnated protection boards, and two lifts of asphalt as the riding surface. By the mid-1980s, this waterproofing system had become standard across Ontario, and it remains the Ministry's current practice.

Bridges constructed after 1985 were generally constructed with the Ministry's current bridge deck waterproofing system at initial construction. These bridge decks are generally in good condition as they approach their first rehabilitation. Bridge decks of this era may incorporate black steel reinforcement, epoxy-coated reinforcing steel (ECR), stainless steel reinforcement, or fibre-reinforced polymer (FRP) reinforcement.

If a bridge was constructed after 1985 but its deck was not waterproofing during initial construction, a Level 2 condition assessment shall be carried out.

P1-2.2 Level 2 Condition Assessment

A Level 2 condition assessment shall consist of a detailed condition survey including, as a minimum, the following activities:

- Detailed visual inspection.
- Surface deterioration and delamination mapping.
- Sampling and laboratory testing of concrete.
- Corrosion potential survey (for decks with black reinforcing steel).
- Concrete cover measurements.

The Level 2 condition assessment is a new term introduced in this edition; in the previous edition, the equivalent activity was commonly referred to as a "detailed condition survey" or "bridge deck condition survey (BDCS)".

At a minimum, a Level 2 condition assessment shall be completed for bridges constructed prior to 1985 with bridge decks reinforced using either black reinforcing steel or ECR steel. These structures are generally approaching their second major rehabilitation and may or may not have been waterproofed at the time of initial construction.

Corrosion potential surveys are only applicable for decks reinforced with black reinforcing steel. A Ministry review showed that AC resistance measurements for decks reinforced with ECR steel do not reliably correlate with its chloride content or observed defects. Accordingly, AC resistance testing is no longer required for decks reinforced with ECR steel. Detailed condition survey requirements are described in Section P1-9 Requirements for Detailed Condition Survey.

P1-2.3 Level 3 Condition Assessment

A Level 3 condition assessment consists of a ground penetrating radar (GPR) survey in addition to the requirements of a Level 2 condition assessment.

A Level 3 condition assessment may be considered for bridges constructed prior to 1985 with bridge decks reinforced using ECR steel.

The GPR survey provides contour mapping of relative chloride ingress within the bridge deck, similar to a corrosion potential mapping for decks reinforced with black steel, along with other measurements.

GPR survey requirements are described in Section P1-10 Requirements for Ground Penetrating Radar.

P1-3 Requirements for Identifying Designated Substances

Design and Contract Standards Office memorandum #2014-05 (October 20, 2014) outlines the Ministry's obligations under Ontario's *Occupational Health and Safety Act* to identify and disclose any Designated Substances present at a project site prior to the commencement of work. MTO is legally required to document and disclose these substances in the contract documents through SSP 101F21.

Ontario Regulation 490/09 identifies eleven Designated Substances: 1) Acrylonitrile, 2) Arsenic, 3) Asbestos, 4) Benzene, 5) Coke Oven emissions, 6) Ethylene Oxide, 7) Isocyanates, 8) Lead, 9) Mercury, 10) Silica, and 11) Vinyl Chloride.

MTO recognizes that arsenic, asbestos, lead and silica were widely used in past highway and bridge construction and may still be present within project limits. Additionally, benzene may be present in certain coatings, such as coal tar epoxy, or as a result of spill or contamination from adjacent properties.

For structural work, a thorough review of all available documentation, including original and as-built drawings, contract documents, correspondence, and historic records, is required to identify potential Designated Substances. The following parameters may guide the determination of whether further investigation is warranted, noting that these guidelines are not exhaustive, and engineering judgment is required:

- Determine if reinforcing steel is epoxy-coated, which may contain lead.
- Assess whether the structure contains, or is likely to contain, asbestos in components such as ducts, wall drains, or bearings, based on available information or best judgment. Refer to Section P1-3.1 Identifying Asbestos.
- Confirm whether existing paint on structural steel may contain lead.
- For wood structures, evaluate whether treatments may have included arsenic.

Where documentation does not provide certainty, field sampling and testing of suspected materials shall be undertaken.

P1-3.1 Identifying Asbestos

This section replaces Bridge Office Design Bulletin dated October 26, 2010.

Asbestos is a designated substance according to *Ontario Regulation 490/09*. It is a requirement under the *Occupational Health and Safety Act* that all owners of construction projects must disclose to the contractor the presence of designated substances in any component of the facility so that the contractor can take appropriate precautionary measures to protect their workers. MTO is obliged to comply with this requirement and the Ministry's duty of care may also extend to its own employees and the public who might be near the work area.

When there are embedded utility ducts in the deck or sidewalk that may interfere with the rehabilitation work, the condition assessment shall include sampling and testing of the duct material wherever possible (usually samples can be taken at the expansion joint gap) to confirm the presence of asbestos.

There are other materials and products used in bridge construction prior to the late 1970s that may contain asbestos, including epoxy mortar or paste, insulations, bearing components, and load distribution boards such as 'Transite Panels', and asphalt.

Before conducting a condition assessment, the Environmental Contaminant Waste Specialist retained to carry out the work shall carefully review the existing bridge drawings to identify any materials and products used in the bridge construction that may contain asbestos. If accessible and practical, suspect materials shall be sampled and sent to a qualified laboratory for testing. Materials that are suspect but not accessible shall be documented. The rehabilitation contract documents shall identify all asbestos-containing materials used in the original bridge construction, including those confirmed through testing, and those known to contain asbestos based on product name and type but not accessible for sampling and testing. When a material is confirmed to be asbestos and testing is practicable, samples shall be tested to determine whether the asbestos is friable or non-friable.

P1-4 Requirements for Engineering Surveys on Rehabilitation Projects

An engineering survey shall be undertaken for bridge rehabilitation projects whenever existing geometric, structural, or site information is insufficient to accurately support its design and construction.

Survey work is typically required when one or more of the following conditions apply:

- Original contract drawings or records are missing, incomplete, or unreliable, or where discrepancies are suspected between recorded information and field conditions.
- Construction staging, access, or temporary works depend on precise knowledge of clearances, elevations, or adjacent terrain. In such cases, obtain cross-sections extending

along the full length of the staging limits beyond the structure and cross-sections taken directly on the structure itself.

- Existing deterioration such as deformation, or settlement may affect design assumptions or construction sequencing.
- Potential interference with adjacent infrastructure such as roadway, utilities, watercourse, railway, or other structures that requires confirmation of relative position and elevation.
- Rehabilitation work that modifies the geometry or alignment of the deck, such as:
  - Changes to the deck profile or alignment.
  - Changes affecting vertical or horizontal clearances.
  - Changes to the crossfall, crown or superelevation.
- Rehabilitation work involving bearing replacements. Survey required to verify clearances for jacking and critical dimensions of bearings, pedestals, shoe plates, and related features.
- Rehabilitation projects that include widening.
- Rehabilitation projects where accurate dimensional information is critical, such as where culvert lining is being considered. Refer to Section P1-11.3 Engineering Laser Scanning.

The type and extent of surveying, such as hard point, topographical, and/or 3D model / photogrammetry, etc., shall be proportionate to the scope and complexity of the rehabilitation work.

P1-5 Requirements for Barrier Wall Dowel Investigations

This section replaces Bridge Office Memorandum #2017-06, dated December 21, 2017.

Barrier wall dowels and cantilever reinforcement form critical structural load paths that are essential to ensuring the integrity and performance of bridge barrier systems. These reinforcement elements are required to resist vehicular impact forces acting on the barrier wall and, in specific deck-edge configurations, to provide primary longitudinal tension reinforcement for both the deck overhang and the barrier wall element.

These dowels and reinforcing bars are typically placed at or below the horizontal construction joint located at the base of the barrier wall. In this location, they are susceptible to chloride exposure, moisture infiltration, and construction-joint deficiencies that can lead to localized corrosion. Such deterioration may progress without detection because it is not reliably identifiable through visual inspection alone, creating a latent risk to structural performance and long-term durability.

P1-5.1 Identification of Susceptible Details

Corrosion may occur through multiple mechanisms and both black steel and epoxy-coated reinforcement are susceptible. As part of the scoping for a condition assessment, deck edge and barrier wall details shall be reviewed to determine whether they pose an exceptional risk to corrosion. Factors that increase the risk of corrosion include:

- Poor concrete and waterproofing quality at the construction joint.
- Poor drainage and long-term exposure to ponding and chlorides (e.g., low end of a super elevated deck, sites with water-stops behind the dowel layer).
- Large overturning dead load moments and/or narrow reinforcing lever arm.

P1-5.2 Policy on Investigation Requirements

A barrier wall dowel investigation shall only be required when any of the following conditions are met:

- Significant leaking and staining at the construction joint are present.
- The bridge contains barrier wall, curb or sidewalk cantilever details that pose an exceptional risk of corrosion.

Where a barrier wall dowel investigation is required, the deck condition survey shall include exposing dowels or rebars at two locations, each approximately 0.75 m in length, at the base of the barrier wall or curb to assess their condition.

Exposure locations shall be selected at areas exhibiting visible signs of potential corrosion or distress, including but not limited to rust staining, cracking, or delamination.

These requirements establish a risk-based approach to barrier wall dowel investigations and are intended to focus investigative efforts on structures with an elevated likelihood of corrosion and potential loss of structural capacity. Engineering judgement shall be employed to identify cases of exceptional concern.

P1-5.2.1 Rationale (Informative)

A Ministry review of historical deck edge and barrier wall details had identified certain configurations that were potentially susceptible to hidden corrosion-related deterioration. These findings were documented in *Bridge Office Report BRO-060: Corrosion of Dowels and Rebars at Base of Barrier Walls on Bridge Decks (2017).* As a result, investigations were required for all barrier walls with those susceptible details.

A recent Ministry review of barrier wall dowel investigation data, from approximately 60 sites, found measurable section in only a small number of structures, and where present, it was generally minor. It concluded that the barrier and curb-on-deck details outlined in *Bridge Office Report BRO-060*, including those subjected to sustained overturning moments, did not demonstrate deteriorations that would warrant elevated concern or continued targeted dowel investigations.

P1-6 Requirements for Structural Steel Investigations

Structural steel investigations may be required to determine steel grade and weldability, to identify existing deficiencies and susceptible fatigue details.

Structural steel grade should be determined using the available original plans or mill certificates. If the steel grade cannot be identified from the original construction documents, *CSA S6 CHBDC* provides assumed structural steel strengths based on age of construction. The chemical composition, particularly carbon content has a significant impact on the weldability of steel. For bridges built with historic structural steel designations where the chemical composition requirements are uncertain, it is prudent to complete sampling and testing. Testing during the design stage, may include chemical analysis, optical emission spectrometry or other means to assess the steel's weldability. A small sample of drill shavings or coupon is generally sufficient for chemical analysis.

Requirements related to fatigue inspections are not covered in this Manual but can be found in the Ministry's 2017 *Fatigue Inspection Guidelines for Steel Bridges* [1].

P1-7 Requirements for Environmental Classification Testing

Environmental conditions testing, as specified in the Durability and Sustainability section of *CSA S6 CHBDC*, shall be carried out only when required to support the rehabilitation design or to resolve uncertainty regarding site exposure conditions. Such testing is not required to assess the effects of environment exposures on existing elements unless explicitly stated.

Testing is required where there is insufficient data to establish durability parameters needed for the design of rehabilitation treatments. At a minimum, testing shall be conducted at any substructure location where components in direct contact with water or soil exhibit abnormal or excessive deterioration indicative of severe environmental conditions. Where a continuous waterbody is in contact with multiple substructure elements, a single representative sampling location is permitted. Continuous substructure elements shall be sampled once every 50 m length (e.g., refacing of a long rigid frame) to capture local variations. Seasonal fluctuations shall be captured by a minimum of three sampling windows at least three months apart.

For metal culverts and projects where the scope may include culvert lining, soil and water and soil testing, shall be carried out in accordance with the requirements listed in the latest version of the Ministry's *Structural Manual*.

P1-8 Requirements for Detailed Visual Inspections

The detailed visual inspection shall be carried out by the engineer directly responsible for the design. A detailed visual inspection is an element-by-element visual assessment of material defects, performance deficiencies, and maintenance needs of a structure. At a minimum, a "close-up" arms length inspection shall be carried out for all readily accessible above-grade surfaces that do not require enhanced access and equipment (e.g., lane closures, lift equipment, or mobile platforms).

The inspection shall include a "close-up" assessment of a representative portion of all elements that are in good condition, while all elements in fair or poor material condition states, as defined in OSIM, as well as any elements whose condition has not been established through previous inspections, require full "close-up" assessment. Any enhanced access needs, such as lane closures or the use of mobile platforms, shall be implemented as specified in the Service Provider's scope of work.

A detailed visual inspection shall be carried out according to the procedures and requirements of the OSIM, however, the findings do not need to be produced into an OSIM report unless explicitly required. Defects shall be characterized in accordance with the descriptions in the latest OSIM. Caution should be exercised when assessing the overall condition of a component through only visual inspections, as hidden defects, and other properties, such as concrete cover, asphalt thickness, and chloride content, cannot be determined. Enhanced OSIM Inspections and/or additional investigations shall be carried out when specified in the Service Provider's scope of work.

Where a structure has previously been inspected according to the OSIM, the Ministry will supply the Service Provider with the latest inspection data. The type and extent of deterioration should be visually assessed and compared to the previous reports. Additional deterioration or repairs that have been made since the previous inspection should be recorded, and the condition states of the components should be adjusted accordingly.

When specified, short term lane or shoulder closures required to access the superstructure with work platforms and aerial bucket lift equipment shall be provided to access a representative portion of the structure, with priority given to areas exhibiting the most severe or critical conditions.

P1-8.1 Inspection using Unmanned Aerial Vehicles

A hands-on visual inspection may be supplemented using Unmanned Aerial Vehicles (UAVs), commonly referred to as "drones", for areas that are difficult to access, when specified. OSIM provides guidance on the practical limitations of drones on Ministry projects. Flight limitations described in OSIM shall be strictly adhered to.

When UAVs are flown in a predetermined, spatially linked flight pattern and high-resolution video is recorded, the resulting imagery can provide a valuable visual record of the structure for use in rehabilitation design. UAVs may be equipped with sensors, and some have acoustic sounding capabilities calibrated for delamination and crack detection. When paired with high quality optical imaging and photogrammetry benchmarked to ground control points, it is possible to create a three-dimensional digital twin of the structure as another useful tool for design.

P1-9 Requirements for Detailed Condition Surveys

P1-9.1 General

A detailed condition survey consists of visual inspections, in-situ measurements, sampling, and laboratory tests. It typically involves recording surface deterioration and delamination, taking concrete cover measurements and corrosion potential (half-cell) readings, cutting asphalt sawn samples, extracting concrete cores, completing laboratory tests on those cores to identify material properties and defects. Additional specialized testing may also be required as part of the survey, if specified.

This section provides background information on data collection, sampling, and testing requirements for detailed condition surveys and provides guidance on preparing terms of reference for the work.

The requirements for field sampling and data collection, and the number and type of laboratory tests on those samples, may vary from structure to structure. Guidelines are given in this section to assist in determining these requirements and in preparing the Service Provider's scope of work. The type, extent of data collection, and testing shall be specified the scope of work.

A detailed condition survey includes:

- Surface deterioration and delamination mapping.
- Concrete cover survey.
- Corrosion potential survey for bridge decks and components with black reinforcing steel.
- Concrete core samples and tests.
- Asphalt sawn samples.
- Ground penetrating radar survey, if applicable.

Generally, the bridge deck and components are delineated in a grid pattern, and measurements, samples, and observations are completed and recorded with respect to the grid layout. Guidelines for carrying out a detailed condition survey are described in Appendix P1-A1 Field Guidelines for Conducting Detailed Condition Surveys.

A detailed condition survey is typically carried out in support of anticipated rehabilitation work and should preferably be carried out no more than two years prior to the proposed rehabilitation. Where a project is deferred and the original condition survey is more than four years old, an updated survey may be required.

Bridge decks and components with cathodic protection, including impressed current systems or embedded sacrificial galvanic anodes, as described in Section P2-3.8 Cathodic Protection, require special considerations during their inspections such as de-energizing impressed current systems beforehand and locating embedded cathodic protection hardware to prevent damage to system components during sampling.

Inspection and testing of cathodic protection systems require trained and certified personnel with qualifications beyond those required for condition surveys. When condition surveys are required for cathodically-protected bridge decks, the Region should coordinate with the Structures Office to establish site-specific inspection and testing requirements.

When detailed condition surveys of very large bridge decks (>4,000 m^2) are required, consideration should be given to limiting the cores and sawn samples to representative portion(s) of the deck. When access or traffic protection is a major consideration for detailed condition surveys of soffits or substructures, the survey could be limited to the area(s) where major deterioration is expected.

P1-9.2 Surface Deterioration Mapping

Surface deterioration mapping is an inspection of material defects and deterioration according to OSIM requirements, where defects are measured where accessible (or otherwise estimated), categorized, and recorded on a grid sheet. Common defects and deterioration that occur in the materials used in structures are described in the OSIM.

P1-9.2.1 Criteria for Deterioration Mapping

As summarized in Table 2, surface deterioration mapping of the wearing surface (asphalt or concrete), deck soffit and other bridge components shall be included as part of a detailed condition survey.

Table 2 – Criteria for Surface Deterioration Mapping.

	Additional Criteria (If applicable)	Survey Type	Warrant
Bridge Decks	Deck Top	First Time	Always
		Update	
	Soffit	First Time	
		Update	
Other Components	-	First Time	Always
		Update	

P1-9.2.2 Significance of Results

Surface defects are quantified, categorized, and recorded on a grid sheet. Surface defects are often symptoms of underlying material and/or performance issues. The type, location, quantity and severity of deteriorations influence the choice of rehabilitation strategies.

P1-9.3 Delamination Mapping

Delamination mapping is a part of the broader surface deterioration mapping, focusing specifically on identifying and outlining delaminations, which are then used for estimating removal quantities (Refer to Section P2-3.1 Concrete Removal). It is a hands-on physical assessment to identify delaminations within concrete components, typically by sounding the concrete surface using a chain drag or hammer tapping. Identified delaminated areas are documented on a grid sheet. For components that require specialized access equipment to sound, hands-on delamination mapping is not required unless specified.

P1-9.3.1 Criteria for Delamination Mapping

For bridge decks, delamination mapping shall be included for all exposed concrete surfaces of the deck top including curbs, medians, sidewalks, inside faces of concrete barrier/parapet walls, expansion joint end dams, and exposed concrete within asphalt sawn samples on asphalt-covered decks.

For bridge deck soffits, delamination mapping shall be specified when any of the following conditions apply:

- More than 10% of the soffit area is exhibiting deterioration, or
- More than 10 square metres of the soffit area is exhibiting deterioration, or
- Removal quantities significantly influence staging design. For example, when long-term closures are not feasible and accurate estimates of working days per lane are required based on patch-repair locations and quantities.

Soffit areas susceptible to delamination include ends of the deck under expansion joints, areas adjacent to construction joints, cantilever edges, and areas under round voids in post-tensioned structures.

For other components, a delamination survey shall be carried out on all exposed concrete components that are accessible without specialized access equipment (e.g., specialized equipment such as: boat, aerial work platform, etc.). A delamination survey of areas requiring specialized access equipment shall be specified when:

- Removal quantities significantly influence staging design, similar to the conditions described for soffits.
- Deterioration is extensive, and the resulting removal quantities are expected to influence the repair approach, such as whether to patch or reface.

Significant concrete patch repairs have been observed on soffits of voided slab bridges, typically appearing as long strips directly beneath the voids. In some cases, these repairs are necessary due to poor concrete conditions. If the void tubes were tied down too low during construction, insufficient space was left for aggregates to flow through them. This results in a thin layer of concrete, consisting of mostly paste beneath the voids, that is prone to deterioration and often require extensive repairs. However, the area beneath the voids is prone to 'false positives.' When sounding with a hammer, the concrete directly beneath the voids may produce a hollow or delaminated tone simply because of the reduced thickness relative to adjacent areas. Caution must be exercised when assessing soffits of voided slab bridges.

When delamination mapping is required on the deck soffit and/or components that require specialized access equipment, it shall be specified in the Service Provider's scope of work.

Criteria for delamination mapping in each case is summarized in Table 3.

Table 3 – Criteria for Delamination Mapping.

	Additional Criteria (If applicable)	**Survey Type**	**Warrant**
Bridge Decks	Deck Top	First Time	Always
		Update	
	Soffit	First Time	Conditional
		Update	
Other Components	Accessible	First Time	Always
		Update	
	Requires Specialized Access Equipment	First Time	Conditional
		Update	

P1-9.3.2 Significance of Results

Delaminated areas are quantified and recorded on a grid sheet. The extent and location of delamination is a primary factor in selecting an appropriate rehabilitation strategy. Localized repairs may be undertaken where delamination is minor and isolated; however, widespread delamination warrants consideration of more comprehensive rehabilitation treatments or replacement.

The extent and location of repairs relative to travelled lanes are critical for developing staging configurations and accurately estimating the duration of traffic impacts.

P1-9.4 Corrosion Potential Survey

A corrosion potential survey is used to measure corrosion activities of uncoated reinforcing steel. It is carried out according to the requirements of latest *ASTM C876 (Standard Test Method for Corrosion Potentials of Uncoated Reinforcing Steel in Concrete)*. Corrosion activities are measured by comparing the potential of the reinforcing steel with the potential of a standard copper-copper sulphate reference cell.

P1-9.4.1 Criteria for Corrosion Potential Survey

For bridge decks reinforced with black steel, a corrosion potential survey shall be included as part of a detailed condition survey (Level 2 condition assessment). However, for some older decks with black, smooth, round bars, it is not possible to carry out a half-cell survey as there is no continuity between the bars.

A corrosion potential survey is normally not carried out on the deck soffit. However, a limited survey may be considered for areas where the deck soffit is deteriorating due to leaking expansion joints, construction joints, salt splash, and where a delamination survey would be carried out.

A corrosion potential survey shall be specified for the inside concrete faces of concrete barriers, curbs, sidewalks, and medians if significant spalling and corrosion staining have been observed.

A corrosion potential survey may be carried out on piers and abutments that exhibit deterioration (e.g., spalling, delamination, rust-stained cracks, etc.) on more than 10% of the total component area. Typically, these components are located under open expansion joints, joints that are leaking, or in areas where these components are exposed to salt splash. The corrosion potential survey can be limited to the areas of chloride exposure.

When a corrosion potential survey is required on components other than the deck top, it shall be specified in the Service Provider's scope of work.

Criteria for a corrosion potential survey in each case is summarized in Table 4.

Table 4 – Criteria for Corrosion Potential Survey.

	Additional Criteria (If applicable)	**Survey Type**	**Warrant**
Bridge Decks with Black Steel	Deck Top	First Time	Always
		Update	
	Soffit	First Time	Conditional
		Update	
Bridge Decks with Epoxy Coated Steel	Deck Top	First Time	Always*
		Update	
Other Components with Black Steel	-	First Time	Conditional
		Update	

**On bridge decks with epoxy coated reinforcing steel, a half-cell survey cannot be carried out as there is no electrical continuity between the different reinforcing bars. However, localized half-cell readings are taken at core and sawn sample locations where the rebar ground connection and the half-cell reading are at the same rebar.*

P1-9.4.2 Significance of Results

Corrosion potential readings are measured and recorded on a grid. These readings are then used to construct a contour plot of areas with low, uncertain, and high probability of corrosion.

The numerical values obtained using a copper-copper sulphate half-cell are indicative of conditions listed below:

- If potential readings over an area are numerically less than -0.20 V, there is a greater than 90% probability that no reinforcing steel corrosion is occurring in that area at the time of measurement.
- If the potential readings over an area are in the range -0.20 V to -0.35 V, corrosion activity of the reinforcing steel in that area is uncertain.
- If potential readings over an area are numerically greater than -0.35 V, there is a greater than 90% probability that reinforcing steel corrosion is occurring in that area at the time of measurement.

It is important to recognize that these interpretations are probabilistic in nature. Corrosion potential readings do not directly measure corrosion rate or confirm the actual presence or absence of corrosion damage. Corrosion potential results shall be reviewed together with concrete core test results, asphalt sawn-sample observations, deterioration mapping, and all other available condition data to ensure proper correlation and to avoid over-reliance on any single type of measurement.

P1-9.5 Concrete Cover Survey

A concrete cover survey is a non-destructive measurement of the concrete cover of the outer layer of reinforcing steel. The concrete cover over the outer layer of reinforcing steel is measured using an approved cover-meter and recorded.

Most cover-meters rely on the magnetic properties of steel to measure the disturbance in a magnetic field and correlate the magnitude of the disturbance to the size of the bar and its distance from the probe. They cannot be used on components reinforced with non-metallic materials such as fibre reinforced polymers (FRP) bars. Ground penetrating radar or other non-destructive means may be used to measure concrete cover for non-magnetic components.

The cover meter shall have a digital read out for measurement of cover and an audio signal indicating detection of reinforcing steel bars in concrete with cover up to 150 mm. The accuracy of the meter shall be ± 5% of full scale.

P1-9.5.1 Criteria for Concrete Cover Survey

For exposed bridge decks with metallic reinforcement, a concrete cover survey shall be carried out on the deck top. On asphalt-covered decks, concrete cover measurements are taken at the core and sawn sample locations and large asphalt strip removal locations (if applicable).

A concrete cover survey shall be carried out on exposed concrete components of the bridge deck such as concrete curbs, sidewalks, medians, and the inside faces of concrete barriers.

For deck soffits and other components, a concrete cover survey shall be specified when a corrosion potential survey has been specified for the same component or area.

Criteria for a concrete cover survey in each case is summarized in Table 5.

Table 5 – Criteria for Concrete Cover Survey.

	Additional Criteria (If applicable)	Survey Type	Warrant
Bridge Decks with Metallic Reinforcement	Deck Top	First Time	Always
		Update	Not Required
	Soffit	First Time	Conditional
		Update	
Other Components with Metallic Reinforcement	-	First Time	Conditional
		Update	
Bridge Decks and Components with Non-Metallic Reinforcement	-	First Time	Conditional
		Update	

P1-9.5.2 Significance of Results

Cover-meter surveys are carried out concurrently with corrosion potential surveys because each provides complementary information: concrete cover indicates the level of protection, while corrosion potential indicates the level of corrosion risk. Together, these results help determine the appropriate rehabilitation approach.

P1-9.6 Miscellaneous

Surveys of expansion joints, bearings, and drainage components are included as part of first-time and update detailed deck condition surveys.

On waterproofed decks with asphalt wearing surfaces where a corrosion potential survey is carried out, asphalt thicknesses shall be measured at every grid point and at sample locations. Waterproofing thicknesses are measured at sample locations.

When a corrosion potential survey is not specified, asphalt thicknesses shall be measured at sample locations.

P1-9.7 Concrete Cores and Physical Testing

Concrete coring and testing are carried out as part of a first-time, detailed condition survey of bridge decks. The need for coring and testing for update surveys is determined on an individual basis for each structure. The minimum and maximum number of cores required are described in this section.

The requirements for coring and testing of components other than bridge decks are determined on an individual basis. Normally, no more than three cores are required from each component.

The diameter of the cores is typically 100 mm. However, smaller diameter (75, 50 or 25 mm) cores may be specified in areas with closely spaced reinforcing steel where it is structurally undesirable to core through the reinforcing steel. Cores shall not be specified for circular pier columns with spiral steel as these cores cannot be obtained without cutting through the spiral rebars.

The extracted concrete cores shall be tested for strength, chloride content, and air void system (in some cases). The purpose of the physical testing program is to assess the quality and durability of the concrete. The number of cores tested varies with the size of the component and the degree of deterioration.

P1-9.7.1 Number of Cores on Asphalt-Covered Bridge Decks

The number of cores taken on asphalt-covered bridge decks is specified in Table 6. The number of cores is based on deck area. On decks with black reinforcing steel, the total number of cores required will not be known until a corrosion potential survey is completed. Likewise, for decks with epoxy-coated steel where a GPR survey specified, the total number of cores will not be known until the GPR survey is completed. Coring requirements for exposed concrete decks are described in Section P1-A2 Coring Requirements for Exposed Concrete Decks.

Table 6 – Number of Concrete Cores on Asphalt-covered Bridge Decks.

	Deck Area (m^2)	Basic	Extra	Min.	Max.
First-Time Survey	< 300	6	1 per 25 m^2 **	6	10
	300 to 1,000	10	1 per 25 m^2 **	10	20
	> 1,000	1 per 100 m^2 *	1 per 50 m^2 **	15	-
Update Survey	**Deck Area (m^2)**	**Basic**	**Extra**	**Min.**	**Max.**
	< 300	3	1 per 50 m^2 **	3	5
	300 to 1,000	5	1 per 100 m^2 **	5	10
	> 1,000	1 per 500 m^2 *	1 per 100 m^2 **	7	-

** Number of 'basic' cores for decks larger than 1,000 m^2 is based on the total deck area.*
*** Number of 'extra' cores is based on area of high corrosion potential (more negative than -0.35V) and areas of high signal attenuation identified by GPR (if applicable).*

Generally, half of the 'basic' cores and all 'extra' cores shall be taken in 'high risk' areas where deterioration is evident or suspected, including:

- Adjacent to curbs, medians, and barrier walls.

- Adjacent to expansion joints and near deck ends.
- Along vehicle wheel paths.
- Areas of poor drainage.
- Areas above soffit defects (e.g., delamination, wet spots, etc.).
- Areas with cracks or 'bottom up' asphalt defects.
- Areas with corrosion potential more negative than -0.35 V.
- Areas with high signal attenuation based on GPR survey (if applicable).

The remaining cores shall be taken in 'low risk' areas throughout remainder of the bridge deck to provide a complete representation of its condition.

Example: Consider a first-time survey of an 800 m^2 asphalt-covered bridge deck with black reinforcing steel. Corrosion potential survey indicated approximately 60 m^2 of high corrosion potential area.

A total of 12 cores are required: 10 basic cores and 2 extra cores.

Seven cores (half of the 'basic' cores (10 / 2 = 5) and all the 'extra' cores (2)) should be taken in 'high risk' areas and the remaining 5 cores should be in 'low risk' areas.

Additional requirements for concrete core locations include:

- For multi-span structures, at least two cores shall be taken from each span.
- For widened structures, a sufficient number of cores shall be taken from old and newer portions of structures to carry out the required physical testing.
- For post-tensioned decks with circular voids, all cores shall be taken at solid web areas between voids where the cables are sufficiently deep to avoid being damaged by coring.
- Normally, cores are not to be taken within sawn sample areas except where a core without reinforcement, for compressive strength testing, cannot be obtained otherwise.

In some cases, additional cores on the bridge deck may be specified and shall be identified in the Service Provider's scope of work. These additional cores do not count toward the maximum number of cores shown in Table 6.

Curbs, Sidewalks, Barrier Walls, and Approach Slabs

A minimum of two (2) cores shall be taken from curbs, sidewalks, medians, and inside faces of barrier walls when a corrosion potential survey is specified for these components. These cores shall be taken in sound areas with high corrosion potential. For barrier walls and sidewalks, at least one (1) of the cores shall be taken to expose the condition of the rebar.

One (1) core shall be taken to confirm the presence of an approach slab. The approach slab core shall be located near the approaching end to determine the asphalt thickness and confirm severity of settlement.

When a Large Asphalt Strip Removal is Specified

When a large asphalt strip is removed as part of the condition survey and the deck was previously rehabilitated with an overlay, a minimum of one (1) core shall be taken in an area that sounds hollow by chain-drag to assess the bond between the overlay and deck slab.

P1-9.7.2 Physical Testing of Cores from Bridge Decks

Where concrete appears uniform and of good quality, only the minimum number of cores specified in Table 7 shall be tested for compressive strength. Where a bridge deck has been widened, cores shall be tested from the original and new portions.

For multi-span bridges, a minimum of two (2) cores per span shall be tested for chloride content. For bridge decks with black steel, cores should be tested for chloride content from both areas with corrosion potential more negative than -0.35 V, and more positive than -0.35 V. To emphasize high corrosion potential areas, more cores are tested from those areas.

An air void system (AVS) test is not required for structures built prior to 1958 because the concrete can be assumed to be non-air entrained.

On exposed decks with scaled concrete, at least one (1) core shall be tested for AVS from the area of scaling.

The number of cores to be tested for bridge decks is summarized in Table 7.

Table 7 – Number of Cores to be Tested from Bridge Decks.

Test	Deck Area (m^2)	Number of Tests		
		First-Time Survey		Update Survey
		Min.	Max.	
Compressive Strength	< 300	1	2	1 (optional)
	300 to 1,000	2	4	
	> 1,000	2	4	
Chloride Content for Decks with Black Steel	deck area with CP between 0.0 to -0.35V	1 per 250 m^2 (min. 2)	8	1 per 250 m^2 (min. 2)
	deck area with CP more negative than -0.35V	1 per 30 m^2 (min. 2)	8	1 per 60 m^2 (min. 2)
Chloride Content for Decks with ECR steel	< 300	2	3	2
	300 to 1,000	1 per 125 m^2	6	3
	> 1,000	1 per 125 m^2	15	3
Air Void (after 1958)	< 300	1	1	1 (optional)
	300 to 1,000	2	2	
	> 1,000	3	3	

P1-9.7.3 Number of Cores and Physical Testing from Concrete Components, Excluding Bridge Decks

The following criteria shall be used to determine when coring and physical testing are required on concrete substructure components:

- When a corrosion potential survey is carried out on a substructure component, a minimum of two (2) cores shall be taken from that component for chloride analysis.
  - However, cores shall not be specified for circular pier columns with spiral steel as these cores cannot be obtained without cutting through the spiral rebar.
  - Cores shall be taken in sound areas with high corrosion potential. For barrier walls and sidewalks, at least one (1) of the cores shall be taken to expose the conditions of the rebar.
  - Additional cores may be specified for chloride testing for large elements, and those with widespread deterioration.
- If the structure was constructed after 1958 and the surface of a component is showing extensive scaling, a minimum of one (1) core from that component shall be taken for air void system testing.
- Cores may be taken to determine the presence of Alkali–Aggregate Reaction (AAR) in concrete elements. AAR is typically indicated by pattern/map cracking, spalling and delamination caused by the swelling of reactive aggregates. These symptoms are most concerning in elements with reactive aggregates or prolonged moisture exposure, which can accelerate AAR. If AAR is suspected, core sampling and a petrographic investigation shall be undertaken to confirm its presence and extent. AAR is not a widespread phenomenon in Ontario; the MTO introduced its pre-approved aggregate sources list in 1986, as a result, structures built prior to this date may have a greater likelihood of containing reactive aggregates.
- Cores may be taken to determine the presence of Delayed Ettringite Formation (DEF) in concrete elements. Signs of DEF include extensive map cracking, spalling or delamination caused by expansive internal pressures. When these defects appear in elements that are prone to high concrete hydration temperatures, such as large mass concrete components or elements produced using steam curing, core sampling shall be specified, and a petrographic investigation undertaken to first rule out related expansion effects due to AAR. Microstructural analysis with scanning electron microscope may also be required to confirm the presence of DEF. Contact the Ministry’s Engineering Materials Office, Concrete Section for further information.
- An investigation of carbonation of concrete surfaces exposed to the atmosphere may be undertaken to determine the extent of carbonation penetration into the concrete cover. Carbonation-induced corrosion occurs when carbon dioxide reacts with calcium hydroxide in the cement paste, decreasing the pH and de-passivating the reinforcing steel. Low atmospheric CO_2 generally results in slow progression through the concrete cover; however, several risk factors can accelerate this process, including low concrete cover, high concrete permeability, cracking, and high concentration of CO_2. When specified, carbonation sampling shall consist of a minimum of three (3) cores, 75 mm diameter x 75 mm deep, taken from the following components:
  - A minimum of one (1) core from the soffit over roadways.
  - Exposed abutment wall or wingwall; and/or

- Vertical face of barrier wall; and/or
- Surfaces of pier caps, where possible.

P1-9.7.4 Physical Testing Methods and Requirements

All tests shall be completed in laboratories approved by the Ministry. A list of laboratories approved for testing can be obtained from the Ministry's Technical Publications website, depending on the type of test. Specific requirements for typical testing are listed in Table 8.

Table 8 – Test Method and Laboratory Requirements.

Test	**Compressive Strength**	**Chloride Content**	**Air Void System**
Test Method	MTO LS-410	MTO LS-417	MTO LS-432
Laboratory Approval	Ministry	Ministry	Ministry

P1-9.7.4.1 Photographs and Description

All cores shall be transported from the site for examination and testing. Each core shall be described and photographed, except those taken from approach slabs. Each photograph shall be in colour and shall include no more than one core. Photographs shall be taken in a studio environment against a neutral background. The cores shall be arranged to show significant deterioration, unusual features, and, where possible, embedded reinforcement. Cores shall be photographed without the identification markings on the core face. Multiple views (using mirrors) are not acceptable. In some cases, wetting the cores may improve the contrast and emphasize defects such as cracks and voids.

A sketch is required to show the overall dimensions of each core, the location and orientation of reinforcement, and significant defects (i.e., delaminations, breaks due to coring, and type of cracking). The sketch shall illustrate the same view of the core as the photograph. The dimension for thickness of waterproofing membrane shall not include the thickness of protection boards.

In most cases, the description above of each core is sufficient. However, where there is evidence of reaction, deleterious aggregates, extensive cracking, or other types of physical distress, this shall be noted in the description so that the Ministry can consider the need for a petrographic examination to determine the concrete's mineralogical and chemical characteristics.

P1-9.7.4.2 Test for Compressive Strength

Cores for testing compressive strength should preferably be free of reinforcement, though this may not always be possible. The compressive strength results shall be compared with the strength specified on the original drawings. Historical test results have generally shown that the actual strength to be higher than the specified strength for most MTO bridges.

Significance of Results

Wide variations in strength may indicate local areas of deterioration. It should be noted that concrete damaged by frost action, usually exhibited as horizontal cracks in the upper portion of the core, may register a high compressive strength but still be of poor quality.

P1-9.7.4.3 Test for Chloride Content

The chloride profile of concrete cores is determined by analyzing the chloride ion concentration of alternating 10 mm thick horizontal sections cut from the core to a depth of 90 mm. Each section is pulverized, and the average chloride concentration of each slice is determined through chemical analysis.

Only cores that do not contain delaminations and are not required for other testing shall be tested for chloride content profile.

For at least one core per structure, the chloride content of slices near the 90 mm depth should have similar values. If values are not similar, additional slices should be tested beyond the 90 mm depth for one of the cores tested until values are similar in two consecutive slices. This is to establish the ‘background’ chloride level.

The chloride content of the concrete is usually highest near the surface. Where the test results produce an unexpected profile through the thickness of the concrete, another determination shall be made with the contingency test slices to verify anomalous values.

For decks that have been overlaid, the chloride profile shall be established down to the level of the top reinforcement in the original concrete instead of terminating at 90 mm from the top of the overlay.

Significance of Results

The chloride threshold value necessary to de-passivate embedded steel and permit corrosion (in the presence of oxygen and moisture) has been taken in the past to be 0.20% by mass of cement. This corresponds to a chloride content of 0.025% by mass of concrete for a typical cement content of 300 kg/m^3. Review of research literature reveals that there are a range of values reported as the chloride threshold to de-passivate steel and 0.025% by mass of concrete is a conservative lower bound.

Interpretation of chloride values is complicated by the fact that all mix ingredients contain chloride ions, but some of which are bound and not available to initiate corrosion. The subject is further complicated in southern Ontario because the dolomitic limestone aggregates from the Niagara Escarpment contain relatively large amounts of chloride ions - typically 0.12% by mass of aggregate for aggregates from the Amabel formation, and 0.08% for aggregates from the Lockport formation. However, the chloride ions from the Amabel and Lockport dolomites do not enter the pore water solution and thus do not contribute to corrosion of embedded reinforcing steel. There must be movement of chloride ions out of the aggregate and into the cement paste, and pore solutions in contact with the embedded reinforcing steel for chlorides in aggregate to cause corrosion of said steel. The extremely large pore size of the dolomite results in a low degree of saturation, even at high humidity, and makes it difficult to transport significant quantities of chloride ions into the pore solution.

By mass of concrete, the dolostone from the Amabel formation of the Niagara Escarpment contributes approximately 0.05% chloride to a mix, but these chloride ions are not available to initiate corrosion. By comparison, if 2% calcium chloride dehydrate by weight of cement is used as an admixture, it contributes approximately 0.13% chloride ions by mass of concrete, and a substantial proportion of this chloride ion is available to initiate corrosion.

The actual measured values of acid-soluble chloride content should be given in the report. The role of 'background' chlorides, which are measured by the test method but do not contribute to corrosion, shall be considered in preparing the summary of significant findings. It is therefore necessary to correct the results for the background chloride content.

The background chloride content for the component surveyed shall be taken as the average of the lowest values for all the cores tested for chloride content profile from that component. The lowest value should be similar in two successive slices of a core. Once background chloride levels are reached, there will be some fluctuation in the background chloride content between successive slices. Normally, the background value should not exceed 0.07% by mass of concrete.

If a previous condition survey has been carried out, the previous chloride data shall be reviewed for comparison purposes. The lowest value should be compared with the anticipated background value, considering the type of aggregate and admixture used before it is accepted as the background value.

The background chloride content shall be deducted from all chloride content test results for that component to determine the depth of chlorides that contribute to corrosion. An example of determining the corrected chloride content is given in Table 9. In the example below, the corrosion of reinforcing steel can occur if the concrete cover to reinforcing steel is less than 70 mm.

Table 9 – Example for Determining and Adjusting for Background Chloride.

Horizon (mm)	C1 Total (%)	C1 Corrected (%)	C2 Total (%)	C2 Corrected (%)	
0 - 10	0.307	0.266	0.325	0.284	
20 - 30	0.207	0.166	0.219	0.178	
40 - 50	0.101	0.060	0.152	0.111	
60 - 70	0.066	0.025	0.082	0.041	concrete cover
80 - 90	**0.036***	-0.005	**0.033***	-0.008	
100 - 110	**0.040***	-0.001	**0.046***	0.005	
120 - 130	**0.047***	0.006	**0.044***	0.003	

**The background chloride content was established using the average background values from all cores tested. Background chloride for this example is the average of the last three chloride contents of each core = (0.036+0.040+0.047+0.033+0.046+0.044) ÷ 6 = 0.041%.*

The Head of Concrete Section in MTO's Engineering Materials Office may be consulted for assistance with the analysis to determine when background chloride levels are reached.

P1-9.7.4.4 Test for Air Void System (AVS)

Where an air void determination is required, either the Linear Traverse or the Modified Point Count Method may be used. The values of air content, specific surface, and spacing factor shall be reported. Paste content may be determined by measurement (Modified Point Count Method) or from the original mix proportions. Where the paste content is not known, it is to be assumed to be 27%, but this assumption must be noted.

Significance of Results
Air entrainment creates tiny air pockets within the concrete microstructure. These voids improve the performance of the concrete against freeze-thaw actions by providing reservoirs for freezing water to escape to as the volume of freezing water increases. Air void system test results are not used on their own in selecting a rehabilitation strategy for a bridge deck / component.

Concrete is normally considered to be properly air entrained if the following criteria are met:

- Minimum air content of 3.0%.
- Maximum spacing factor of 0.200 mm.
- Specific surface of not less than 24 mm^2/mm^3.

Concrete is considered as marginally air entrained when two of the three criteria are met; otherwise, it is considered as not air entrained.

P1-9.7.4.5 Test for Carbonation

Where cores for carbonation are specified, cores shall be split in the lab and phenolphthalein shall be applied to the fractured surface. The depth of carbonation shall be measured in accordance with EN 14630, RILEM CPC-18 or another approved method.

Significance of Results
Carbonation of concrete generally occurs slowly over time with the carbonation front advancing inward from exposed surfaces. As carbonation progresses, the pH of the concrete decreases and destabilizes the passive oxide film protecting embedded reinforcing steel. Once the carbonation front reaches the depth of reinforcement, the likelihood of corrosion initiation increases, particularly in the presence of moisture.

P1-9.7.4.6 Retention of Samples

All cores, pieces of cores, and unused pulverized material shall be retained for six months after written acceptance of the Condition Survey Report by the Ministry.

P1-9.8 Asphalt Sawn Samples and Large Asphalt Strips

Asphalt sawn samples shall be taken when a detailed condition survey is carried out on an asphalt-covered deck. The number of sawn samples is determined based on deck area and field conditions as specified in Table 10.

Table 10 – Number of Asphalt Sawn Samples on Asphalt-Covered Bridge Decks.

	Deck Area (m^2)	Basic	Extra	Min.	Max.
First-Time Survey	< 300	6	1 per 25 m^2 **	6	10
	300 to 1,000	10	1 per 50 m^2 **	10	20
	> 1,000	1 per 200 m^2 *	1 per 100 m^2 **	15	
Update Survey	**Deck Area (m^2)**	**Basic**	**Extra**	**Min.**	**Max.**
	< 300	3	1 per 50 m^2 **	3	6
	300 to 1,000	5	1 per 100 m^2 **	5	10
	> 1,000	7	1 per 150 m^2 **	7	15

** Number of 'basic' sawn samples for decks larger than 1,000 m^2 is based on the total deck area.*
*** Number of 'extra' sawn samples is based on area of high corrosion potential (more negative than -0.35V) and areas of high signal attenuation identified using GPR (if applicable).*

Sawn samples shall be a minimum of 250 mm x 250 mm and are used to assess the condition of the concrete deck, the presence and condition of waterproofing materials, and to check the cover to reinforcing steel. The samples are removed by dry sawing to determine if, and how much moisture is present beneath the asphalt.

Sawn samples shall be taken from areas with signs of deterioration and areas most susceptible to deterioration, including:

- Adjacent to curbs, medians, and barrier walls.
- Adjacent to expansion joints and by deck ends.
- Areas of poor drainage.
- Areas above soffit defects (e.g., delamination, wet spots, etc.).
- Areas with asphalt defects (e.g., surface cracking, rutting, poor joint, etc.).
- Areas with corrosion potential more negative than -0.35V.
- Areas with high signal attenuation based on GPR survey (if applicable).

In the previous edition, asphalt sawn samples were taken from both 'good' and 'poor' areas of the bridge deck, differentiated by corrosion potential. Taking sawn samples from 'good' areas, i.e., with corrosion potential between 0.0 to -0.35V and no visible signs of deterioration, provides limited usefulness for condition assessment.

In this edition, asphalt sawn samples are no longer located solely by corrosion potential. All sawn samples shall be taken from deteriorated areas and areas with high likelihood of deterioration as described above. This approach ensures that sawn samples are used to confirm observed surface defects and to correlate subsurface conditions with the corrosion potential survey, improving the robustness and consistency of the overall condition assessment.

P1-9.8.1 Large Asphalt Strips

Removal of a large 1.5 m x 6.0 m asphalt strip is optional and shall be specified for decks based on the following conditions:

- Bridges showing significant areas of leaching, cracking, and wetness on the soffit.
- Bridges with an asphalt wearing surface but that is not waterproofed.
- Post-tensioned decks with circular voids but no transverse post-tensioning.
- Areas that are suspected to have top surface deteriorations based on low cover.

P1-10 Requirements for Ground Penetrating Radar (GPR) Surveys

P1-10.1 General

Ground penetrating radar has seen significant advancements in research and practice in the past decade. The latest research demonstrates improved accuracy when coupled with specific post-processing requirements (depth correction). The Ministry has re-introduced this non-destructive evaluation (NDE) method into structure investigations.

A ground penetrating radar survey consists of scanning a reinforced concrete bridge deck surface (other reinforced concrete surfaces may also be scanned) with specialized GPR equipment.

The GPR equipment transmits a short pulse of low power electromagnetic energy into the concrete deck and records a series of reflections over a very brief time interval. These reflections occur at changes in material properties (dielectric permittivity), including discontinuities, throughout the depth of the reinforced concrete deck or component. A series of these records is recorded at a certain distance interval in a direction that is generally perpendicular to the top upper layer reinforcing bars in the structure. The series of reflections are typically recorded to produce a profile along the length of the bridge deck over transverse reinforcing bars. In cases where the top upper reinforcing bars are longitudinal, the GPR data must be recorded across the deck width or lane width as necessary. This data can then be analyzed to produce contour maps and histograms of the estimated concrete cover, asphalt thickness, and relative chloride ingress.

GPR may also be used to gather other information, such as rebar spacing and layout, location of post tensioning ducts and strands.

P1-10.1.1 GPR for Bridge Deck Condition Surveys

The purpose of this section is to discuss how to assess the condition of bridge decks by using GPR to map areas of different corrosion risks, similar to the corrosion potential plots from half-cell surveys.

The reflections recorded by the GPR transmitter also captures changes such as the interface between asphalt and concrete and/or the interface between concrete and rebar. Multiple layers of asphalt concrete can usually be identified, and sometimes debonded concrete overlays and even deck delamination can be observed if the separation between layers is large, and suitable conditions exist. Multiple records are typically recorded as a line scan or profile over distance at a certain spacing or number of records per metre.

Energy loss in GPR signals (attenuation) is mainly attributed to the changes in the conductivity of the material. In mature concrete decks, this is typically related to the chloride presence but can be caused by other conductive contaminants such as clay minerals.

Chlorides tend to penetrate the deck either by diffusion in uncracked concrete or through surface opening cracks. As the chloride content builds up and extends deeper into the concrete, the conductivity is increased, which increases the rate of signal loss in the GPR signal passing through it. Increases in moisture content of the concrete will increase its relative dielectric constant, which reduces the speed of the GPR signal through it and increases the measured arrival time of a reflection. Corrosion damage in reinforced concrete decks generally results in cracking which will enable higher moisture and chloride content. The overall result of these changes causes weakened reflection amplitudes and an increase in the two-way travel time [2].

Prior to 2007, most GPR based deck condition surveys relied on identifying either reflection shape characteristics or reduced amplitudes from reinforcing bars and/or the underside of the deck to predict the existence of corrosion. Experience has shown that the results found by strictly following these earlier approaches have not been proven accurate when it comes to predicting locations of deteriorated concrete and estimating approximate construction repair quantities.

More recently, research has found that the variability and inaccuracy of the data has been linked to variations in as-built cover thickness and inherent beam spreading losses which are not correlated with the condition of the bridge deck [3]. Thus, the technique of “depth correction” was developed to compensate for this and has been shown to be effective in correcting for these losses [3].

In addition to producing contour maps of concrete cover and asphalt thickness, the variation in relative chloride ingress levels (i.e., corrosion risk) can be mapped and quantified when using the depth-correction method.

P1-10.1.2 GPR Assessment of Other Components

GPR can be used for a variety of reasons other than the condition assessment of a bridge deck. These other reasons include:

- Estimating rebar cover and deck thickness.
- Identifying rebar location and spacing.
- Locating post tensioning tendons.
- Identifying void locations.

These assessments can be used on most concrete components, including the substructure, barriers, and soffits. Typically, these locations do not require a GPR condition survey because they are readily accessible for delamination surveys and other more traditional survey techniques. However, the designer may consider a GPR survey if it’s critical to the evaluation and determination of the rehabilitation strategy.

P1-10.2 GPR System Types

There are two commonly used types of GPR systems within the industry today; air-coupled and ground-coupled systems. Both systems come with advantages and disadvantages, and both require highly qualified operators specializing in this type of radar technology.

Vehicle mounted air-coupled systems allow for data collection within traffic flow and require little to no traffic control. For this system, the antennas are mounted at a fixed distance away from the bridge surface, thereby increasing the amount of coverage per pass of the system. The speed at which the data is collected depends on the transmission, sampling, and spatial data resolution [2]. The antenna beam pattern in air-coupled surveys illuminates a relatively wide area, generating reflections from the upper and lower reinforcing bar mats, rather than individual bars.

Ground-coupled systems maintain contact with the bridge deck and are typically mounted to a walk-behind cart which provides high resolution mapping of the deck conditions [2]. Given the nature of a walk-behind cart, these types of investigations will often be governed by the traffic control requirements and lane closure windows. However, given higher levels of control in positioning the antenna and the slower speed involved, ground-coupled surveys provide higher spatial accuracy, sampling frequency, and resolution compared to air-coupled surveys.

Ground-coupled systems are preferred as they produce higher resolution maps and more accurate interpretations of the spatial distribution of chloride, both over and into the deck surface. Therefore, where GPR is specified, a ground coupled GPR shall be used.

P1-10.3 GPR Limitations

GPR surveys shall not be applicable to bridge decks that are cathodically protected with a conductive asphalt layer, or any other treatment that would lead to the results of the GPR survey being inaccurate. The application of de-icing salts during winter can greatly increase surface chloride levels that may negatively influence the results [4]. Therefore, GPR scanning shall not be performed during the winter months. Accumulation of water, snow, and ice on the deck surface can also influence the measured time delay and amplitudes of reflection in the data. Dry to damp conditions are suitable for GPR based deck condition surveys. Areas of ponded water must either be removed from the deck surface or disregarded in the survey data.

A GPR survey shall not be specified when the structure contains:

- Wearing surfaces containing steel slag.
- Steel fibre reinforced concrete.
- Decks with GFRP reinforcement.
- Steel stay-in-place forms.

The list above is non-exhaustive and the Engineer specifying the survey shall carefully review the details of the bridge deck to ensure a GPR survey is appropriate.

Other factors alone may not completely restrict the use of the technology, but they will require a more rigorous post-processing procedure to account for such variations. Given the high sensitivity in data analysis, the expertise of the GPR Service Provider will be more heavily relied upon to produce reliable results if there are:

- Decks with severely deteriorated asphalt or significantly non uniform asphalt or overlay thicknesses.
- Decks with significant variations in transverse rebar sizes and arrangements (typically not a concern for most structures).

In the circumstances above, the GPR Service Provider shall indicate how these variations have been accounted for in the scanning and post processing of the data.

P1-10.4 GPR Requirements

A GPR survey should be performed on asphalt paved or exposed concrete decks in accordance with the criteria defined herein. For the purposes of this section, the survey shall be capable of providing information related to bridge deck condition (relative chloride ingress), in the form of top upper rebar reflection amplitudes with associated depth correction. The survey shall also be capable of identifying asphalt thickness, concrete cover to rebar, and arrangement of rebar (if requested).

When a GPR survey for deck condition assessment is specified, it shall be performed using the following criteria:

- Ground-coupled GPR system.
- Antenna centre frequencies from 1.5GHz to 2.6GHz.
- Spatial resolution between 200 scans per metre.
- Approximate spacing of 0.5 metres between profiles, or as per manufacturers recommendations.
- Scans shall be recorded perpendicular to the shallowest layer of reinforcing steel. Particular attention shall be made when scanning bridge decks with transitioning reinforcement (i.e., skewed ends).
- A single, uniform, and constant gain is applied across the measured time range for each record.
- Data shall be presented with signal amplitude data recorded in decibels.
- All GPR data shall be depth corrected according to Section P1-10.4.1.1 GPR Depth Correction Requirements.

P1-10.4.1 GPR Depth Correction

In the sections above, the idea of “depth correction” was introduced as a required method for post processing.

As the signal propagates into the material and reflections are transmitted back to the receiving antenna, different types of signal losses are encountered. As previously discussed, intrinsic losses are attributed to an increased chloride concentration within the cover layer (conductive losses). Other losses that have nothing to do with deck condition, such as beam spreading, are also encountered and cannot be ignored. The impact of varying concrete cover and asphalt thickness is the main reason depth correction is required. Thicker materials increase the distance travelled by the GPR signal, and the losses due to beam spreading. If beam spreading losses are not accounted for, a deeper rebar in good condition may appear similar to a shallower bar in poor condition as more losses were encountered along the travelled distance.

There are several means of conducting depth correction, all with varying methods, accuracy, and limitations. The Ministry, given its re-integration of GPR into this Manual, has proposed to present criteria rather than a specific technique due to variability in "proprietary methods" within the industry.

A summary of selected works in academia has been provided, though this does not in any way limit the findings of other research that has been conducted by not referenced here.

The basis of what is considered current practice for depth correction is found by examining each bridge deck individually. Using the data collected, a method developed by Barnes and Trottier [5] proposes to use a statistically robust sample of sound concrete found at the 90th percentile of all data, at any given two-way travel time as the basis for correction. Several similar methods, and the one described above, are proposed in the research paper as possible methods for enhancing the then current *ASTM D6087-08 (Standard Test Method for Evaluating Asphalt-Covered Concrete Bridge Decks using Ground Penetrating Radar)*. There are limitations associated with this technique as it assumes that at least 10% of the bridge deck is in good condition and this can lead to inaccuracies if the entire deck is either in poor or near perfect condition [6].

Subsequent research [6] proposed the idea of separating the losses contributing to the depth effects into two components: the geometric and dielectric losses, and the conductive losses. The first component was addressed by comparing attenuation results to a data set collected by scanning 24 sound bridge decks as part of a previous study. The second component was addressed by linearly normalizing the data based on the respective two-way travel time. The current limitation with this approach is that the reference values used in step one was based on bare concrete decks. For this approach to be utilized on asphalt decks, a pre-determined amplitude relationship must be determined.

Other more recent studies have sought to use actual wave velocity through the concrete to determine the depth of each rebar. With the actual rebar depth known, the depth correction is therefore based on signal amplitude and rebar depth using the same 90th percentile regression line to account for the depth effects as well as surface anomalies [7].

P1-10.4.1.1 GPR Depth Correction Requirements

Various techniques and methods exist within the industry to account for the inherent variability in depth effects. Given the variability, the Ministry has set the following criteria that establishes the baseline of what the applied depth correction technique must account for:

- Geometric spreading losses.
- Dielectric losses.
- Conductive losses (concrete deterioration).

Geometric spreading losses mean amplitude reduction resulting from spreading losses as the electromagnetic wave travels.

Dielectric losses mean the attenuation of the electromagnetic wave amplitude in a pure dielectric material (no free charges moving between atoms or molecules).

Conductive Losses occur when a bridge deck becomes infused with chlorides, increasing the electrical conductivity as more free charges are present. As the wave energy propagates through the material, eddy currents are developed due to the presence of free charges and some energy is dissipated as heat [6].

P1-11 Non-Destructive Testing (NDT) Methods

The NDT methods described in this Section are not exhaustive but are technologies that have been used on Ministry projects, to varying extents. These methods may be used to augment or confirm, but not replace, the hands-on requirements of a deterioration and delamination survey. They also provide supplementary information that may be required in certain situations and is not typically obtained through a “standard” detailed condition survey.

There are new and emerging methods for condition assessments, and it is not practical to establish requirements for each one. However, it is prudent to carry out these new techniques alongside an established method to compare their performance and assess their applicability for broader use.

P1-11.1 Thermal Cameras

Infrared thermography (IRT) is a technique used to detect infrared energy emitted by objects. The amount of infrared energy an object emits is proportional to its surface temperature. A thermal camera, the most common IRT device, captures this infrared energy and converts it into a temperature image using colour bands to show temperature variations.

Defects in concrete, such as delaminated areas, act as insulated air pockets within the concrete. As the ambient temperature increases, the concrete temperature increases from the surface inward. Defects trap in the heat while the surrounding sound concrete conducts the heat throughout the component, resulting in temperature variations across the surface. A high-quality thermal camera can capture these small temperature differences in the appropriate environmental conditions.

Thermal cameras can be a great tool for inspections, but there are limitations. They are reliant on differences in surface temperature, so small or deep defects can be difficult to detect. Wind, rain, exposure to sunlight, proximity to water, and other environmental factors can affect the temperature distribution across a surface and interfere with imaging. Thermal cameras work best when there is a significant temperature gradient to create a strong enough differential in surface temperatures.

Detector Types

Most handheld thermal cameras use uncooled microbolometer sensors, which change their electrical resistance with temperature and does not require external cooling. By contrast, some specialized thermal cameras use cooled detectors, such as indium antimonide or indium gallium arsenide. These detectors can measure very small temperature differences but must be cooled to extremely low temperatures to minimize thermal noise. This cooling process requires an external cooling system and power source.

Cameras with cooled detectors can work in the mid-wave (3 to 5 μm) or even the short-wave (1 to 3 μm) infrared range, providing higher sensitivity and are used for specialized aerospace, manufacturing or research applications.

Handheld thermal cameras typically operate in the long-wave infrared range of 8 to 14 μm and are suitable for most inspection applications.

Resolution

The resolution of a thermal camera refers to the number of pixels used to capture a photo. A higher resolution means the image contains more details, more pixels provide more information, improving the accuracy of the temperature measurements. A thermal resolution of 640x480 or higher is preferred.

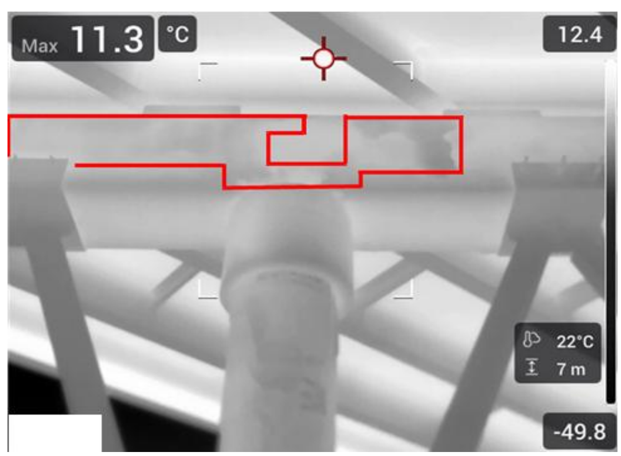
Thermal Sensitivity

Thermal sensitivity is expressed in noise equivalent temperature difference (NETD) and measures how small a temperature difference a camera can detect. A lower NETD value means the camera can distinguish finer temperature variations. A thermal sensitivity of 40 mK or lower is preferred.

Temperature Range within Frame

Reducing the thermal range of the image is critical in improving the accuracy and clarity. Most thermal cameras show the maximum and minimum temperatures within the frame. In the thermal image below, the temperature range varies widely between -49.8 to 12.4°C. It is likely capturing the ambient temperature of the sky in the background. Because the image covers such a wide temperature range, the temperature differences between the sound and delaminated concrete in the pier cap does not appear clearly.

Picture 1 – Photo taken with digital camera of pier cap with marked areas of delamination.



Picture 2 – Similar photo taken using a thermal camera with wide temperature range.

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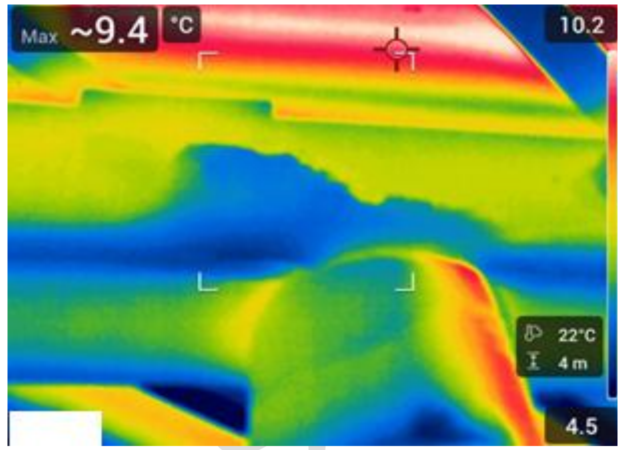
By comparison, the thermal image below of the same pier cap has a much smaller temperature range, between 4.5 to 10.2 °C. As the result, the temperature differences between the sound and delaminated concrete in the pier cap is much more visible.

Picture 3 – Photo taken with digital camera of pier cap with marked areas of delamination.

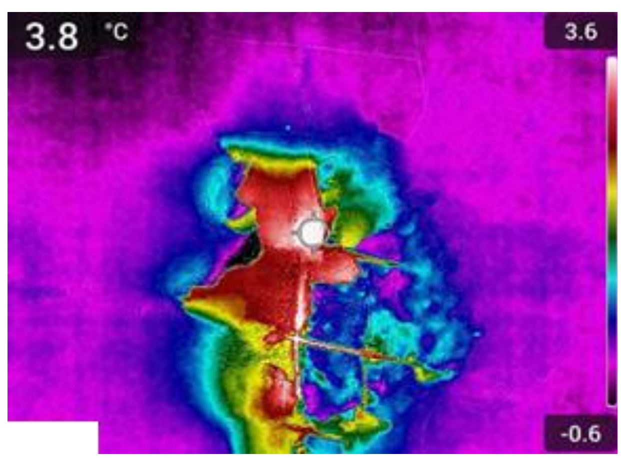


Picture 4 – Similar photo taken using a thermal camera with narrow temperature range.

Field of View

Thermal cameras typically have a narrower field of view compared to regular cameras, and not all thermal cameras have zoom capability. In Picture 5 and Picture 6, both images are taken from the same location without any zoom applied. The thermal image appears more 'zoomed in' due to the narrower field of view of the thermal camera. When taking thermal images, it is recommended to take a regular side-by-side photo and adjust the zoom of the regular camera to match that of the thermal image as closely as possible.

Picture 5 – Photo taken with digital camera (corresponding thermal image outlined in red)



Picture 6 – Photo taken using a thermal camera.

It is recommended the camera have a manual or automatic adjustable focus; for general inspections, the standard field of view (24°) should be used. However, for inspections completed from a distance, a narrower lens (14°) should be considered.

P1-11.2 Impact Echo and Pulse Velocity

The Ministry has used impact echo and pulse velocity techniques to evaluate grouted post-tensioned ducts to assess their condition and detect voids.

Impact echo involves generating a stress wave by applying a small impact to the concrete surface. The stress wave travels through the concrete and reflects off internal features such as cracks, voids, and embedded reinforcing steels. Only access to one side is required, as the reflected waves are captured by sensors placed on the surface of the concrete. The characteristics of the reflected waves, such as their amplitude, frequency, and time of arrival, are analyzed to identify defects within the concrete.

There are limitations to impact echo. The maximum element thickness is limited to approximately 60 cm (2 ft.). It requires the front and back surfaces of the element to be near parallel; irregular geometries can complicate the waveform and interpretation. Features such as overlapping ducts, ducts having an anchorage on the opposite side of the concrete surface, etc., can also affect the wave reflections and results.

Pulse velocity is often used alongside impact echo and is closed related in principle. In this method, a stress wave is transmitted through the concrete using a transducer at the transmitting end and received by another transducer at the receiving end positioned some distance away. (ACI 228.2-13). Best results are obtained with transducers located directly opposite of each other, requiring access from both sides. When only one side is accessible, the results may only be indicative of the near-surface concrete condition.

The travel time of the stress wave between the two points are used to calculate the wave velocity. Known velocity ranges are available for different materials, but it is best practice to calibrate the test using a sound, defect-free area of the same structure. This ensures that comparisons account for site-specific conditions. The wave velocity provides an indication of the concrete's consistency and potential presence of defects. This method is described in *ASTM C597 (Standard Test Method for Ultrasonic Pulse Velocity through Concrete)*.

P1-11.3 Engineering Laser Scanning

Engineering survey laser scanning is an application of light detection and ranging (LiDAR) technology used to gather accurate three-dimensional measurements of physical objects or surfaces. It is a non-contact method that emits laser pulses and measures their return time to create a point cloud - a dense collection of data points representing the surface geometry of the scanned object. From the point cloud, detailed surfaces and cross-sections can be generated for precise measurements and comparisons.

MTO has used LiDAR for various applications, including mapping out the geometry of large culverts and monitoring culvert distortions over time by conducting periodic scanning surveys and comparing the results to detect changes or movements within the structure.

P1-A1 Field Guidelines for Conducting Detailed Condition Surveys

This Appendix provides general information on how to prepare and conduct a detailed condition survey. Information in this section is to be used as a guide; requirements may vary with individual projects.

P1-A1.1 General

Prior to carrying out a detailed condition survey, considerable preparations are required to ensure field investigations are conducted properly.

In advance of the field investigations, pertinent features of the structure shall be identified, and requirements for the grid layout, sampling and data collection, equipment, staffing, and traffic control shall be determined.

P1-A1.2 Plans and Previous Inspections / Surveys

The existing structure plans and construction drawings should be reviewed for the following:

- Location and site topography.
- Unusual features in the design.
- Details of previous rehabilitations.
- Orientation and size of top reinforcement for cover-meter check.
- Locations of utility ducts.
- Locations of stressing cables and void tubes on post tensioned structures.
- Number of separate grounds that will be required for potential measurements (a separate ground is required for each discontinuous slab).

Previous inspection and survey reports should be reviewed for history of deterioration, details of previous repairs, and to determine appropriate locations for samples.

A copy of the latest OSIM inspection report should be obtained from the regional structural office.

P1-A1.3 Preliminary Site Visit

A preliminary site visit may be necessary to establish:

- Traffic control requirements.
- General condition of the structure to better estimate the duration of field work and crew size.
- The extent of deterioration, including the soffit condition of decks, and the need to arrange for a boat, bucket truck or other specialized access equipment.
- Any potentially unusual circumstances.

P1-A1.4 Traffic Control

Traffic control shall be according to the latest *Ontario Traffic Manual Book 7: Temporary Conditions*. The responsibility for the provision of traffic control may vary from region to region but shall be identified in the Service Provider's agreement. Timing windows, lane closure restrictions, and notification requirements shall be discussed and determined with the Regional Structural and Traffic Sections. A traffic control plan shall be developed prior to commencing field work.

P1-A1.5 Staffing

The inspection crew will typically consist of a supervising professional Engineer and two to four crew members. Additional personnel may be required for traffic control, on large structures, and where there are timing constraints for completing the fieldwork.

P1-A1.6 Sampling And Data Collection

The sampling and data collection requirements are contained in the Service Provider's scope of work. When a detailed condition survey is carried out by Regional Structural Section staff, the sampling and data collection requirements shall be determined using the guidelines set forth in Section P1-9 Requirements for Detailed Condition Survey. Data shall be collected with reference to a grid system.

P1-A1.7 Grid Layout

P1-A1.7.1 General

A grid layout shall be established using existing drawings prior to going to site. Grid lines (longitudinal, transverse, vertical, and horizontal) shall run parallel to their respective reference lines. Typically:

- A 1.5 m x 1.5 m grid is used on bridge decks.
- A 3.0 m x 3.0 m grid could be considered for bridge decks with an area greater than 500 m^2 and constructed after 1975.
- A minimum of 5 longitudinal lines are required on bridge decks.
- A 1.0 m x 1.0 m grid is used on other concrete components, but the size of this grid may vary depending on the size of the component.
- When a survey has been carried out previously, the orientation of the grid lines for the current survey shall match.

The spacing for longitudinal grid lines is measured perpendicular to the longitudinal reference line. The transverse grid line spacing is measured parallel to the longitudinal reference line.

The spacing for vertical grid lines is measured perpendicular to the vertical reference line. The horizontal grid line spacing is measured parallel to the vertical reference line.

Grid lines are usually placed 0.1 m from the edge of the component except on bridge decks where they are normally placed 0.25 to 0.5 m from the curb, barrier, or expansion joint end dams. On bridge decks with longitudinal or transverse construction joints, a grid line shall be placed 0.1 m on each side of the construction joint.

Grid sheets of bridge decks and components should be prepared prior to data collection. Each grid sheet shall include the grid lines and cover a convenient portion of the component. Copies of the grid sheets are used in the field to record data and plot defects in their appropriate location. Examples of grid layouts are provided in Appendix P1-A5 Example Grid Layouts for Detailed Condition Surveys.

P1-A1.7.2 Post-Tensioned Decks with Circular Voids

Based on experience, half-cell readings directly over voids are usually more negative than the adjacent area. When a half-cell survey is specified:

- Longitudinal grid lines shall be located at every void and midpoint between them. If the spacing of the voids is less than 1.5 m, spacing of the longitudinal grid lines does not have to be less than 0.75 m. Representative voids may be selected to reduce the total number of survey points.

- Additional longitudinal grid lines are spaced 0.25 m from curbs / barriers, and then spaced up to 1.5 m until the first void; and,

- Transverse grids are spaced at 1.5 m.

Where a large asphalt strip is removed to expose the concrete surface, a half-cell survey shall be conducted on the exposed surface using a grid of 0.5 m x 1.0 m with at least one grid line centered at the void; additional longitudinal grid lines shall be provided at cracks.

P1-A1.8 Equipment

The service provider is responsible for determining the appropriate tools and equipment to complete the required fieldwork. Some tools are required to meet certain specifications and thresholds including:

- Voltmeter and suitable lead wire as specified in the latest *ASTM C876 (Standard Test Method for Corrosion Potentials of Uncoated Reinforcing Steel in Concrete).*
- Copper-copper sulphate half-cell as specified in the latest ASTM C876.
- AC ohmmeter capable of measuring 0.1 to 1000 ohms and insensitive to AC and DC ground currents.
- Epoxy patching material from Ministry's *DSM List 9.65.73*.
- Asphalt patching material from Ministry's *DSM List 3.05.70*.
- Ministry approved, post-applied waterproofing.
- Cementitious proprietary patching material from the MTO's pre-qualified product list for filling core holes, and shall be mixed, handled, and cured according to *OPSS.PROV 1350*.

P1-A1.9 Forms

Standard forms required to carry out a detailed condition survey are provided in Appendix P1-A6 Standard Forms.

P1-A1.10 Field Procedures, Data Processing and Documentation

P1-A1.10.1 General

The data and sampling requirements for each component are specified in the consultant agreement. Field data shall be recorded on grid sheets in such a manner that the final drawings can be prepared.

P1-A1.10.2 Photographs

Colour photographs are required and shall be taken with a digital camera. General views of the structure should ideally be in a single photograph. Sawn sample photographs shall show the condition of the waterproofing membrane and the condition of the deck surface. A photograph is required at each expansion joint. Where extensive deterioration is evident, only typical areas need to be photographed; a photograph of each spalled area is not required.

P1-A1.10.3 Grid Layout

Grid points are marked on the surface of the bridge deck using chalk or crayon. The grid layout may be modified if the reference lines chosen from the drawings are not acceptable.

For areas where it is difficult to layout a grid system, reference rulers can be demarcated on the component at the appropriate locations. The data collected should be plotted on the field drawings as accurately as possible using the reference rulers.

P1-A1.10.4 Equipment Calibration

The 'Survey Equipment and Calibration' form (refer to Appendix P1-A6 Standard Forms) is used to document calibration data for equipment used to check concrete cover and measuring corrosion activity. A description of the equipment and the ambient temperatures are also documented.

P1-A1.10.5 Concrete Surface Deterioration Mapping

The description of defects shall be according to the OSIM. Common defects in waterproofing membranes are not covered in the OSIM and are described below:

- Inadequate thickness.
- Excessive thickness.
- Poor adhesion to the bridge deck or asphalt.
- Moisture beneath the waterproofing membrane.
- Penetration from aggregates in the bituminous overlay.
- Migration of the membrane into the bituminous overlay.
- Rotting of the fibreglass in some fibreglass-asphalt emulsion systems.
- Embrittlement in mastic waterproofing.

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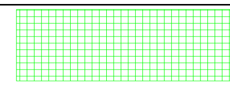
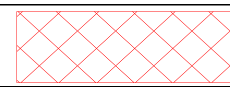
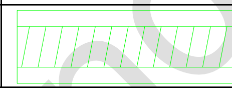
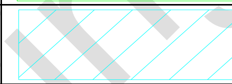
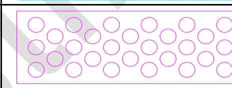
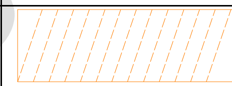
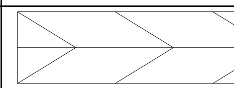
The size and location of defects shall be measured and recorded on the field grid sheets. Common defects and their classifications are summarized in Table 11. In general:

- The severity of scaling is visually assessed based on the depth of mortar loss.
- Stained (wet and/or with efflorescence) and unstained cracks in concrete surfaces are labelled separately.
- Cracks on concrete surfaces narrower than 0.3 mm (shrinkage cracks) need not be recorded. However, extensive shrinkage or pattern cracks shall be noted under "Remarks" on the detailed condition survey summary sheets.
- If measuring the depth of the medium and wide cracks is specified in the work order, the depth shall be measured using feeler gauges or fine wires. The crack surfaces should also be carefully assessed for degree of contamination and leakage.
- On asphalt covered decks, the general condition of the asphalt and cracks wider than 3 mm shall be mapped on the grid sheet. However, the quantity (e.g., linear metre) of asphalt cracks do not need to be recorded; and,
- Bottom-up surface defects (such as potholes, protrusions, pattern cracks, etc.) that may be indicative of deterioration in the concrete deck slab shall be recorded.

Defects on the deck soffit shall be recorded on a separate grid sheet with the same grid layout as the deck surface. The location of any void drains shall be noted. The sizes of defects are measured where accessible and are otherwise estimated. However, when a delamination survey is specified for the deck soffit, all areas of deterioration shall be measured.

Table 11 – Legend for Common Concrete and Asphalt Defects.

	Defect	Classification (If applicable)	Criteria (If applicable)	Suggested Legend
Concrete	Scaling		**Depth (mm)**	
		Light	0 to 5	
		Medium	6 to 10	
		Severe	10 to 20	
		Very Severe	> 20	
	Unstained Cracks		**Width (mm)**	
		Medium	0.3 to 1.0	M
		Wide	> 1.0	W
	Stained Cracks		**Width (mm)**	
		Medium	0.3 to 1.0	M

		Wide	> 1.0	W 
	Spalls	Patched	-	
		Unpatched	-	
	Surface Rust	-	-	
	Exposed Reinforcing Steel	-	-	
	Delamination	-	-	
	Honeycombed Areas	-	-	
	Wet Areas	-	-	
Asphalt	**Cracks (> 3 mm)**	Unsealed	-	C 
	Rutting	-	-	

P1-A1.10.6 Delamination Survey

Delaminations in concrete can be detected by striking the concrete surface and noting a change in the emitted sound. Several methods have been used, including using hammers, steel rods, chains, and more recently, electronic acoustical devices, radar, and thermography.

The chain drag method has been found to be the most suitable for detecting delaminations on the top surface of exposed bridge decks, sidewalks, and medians. The chain is moved from side to side in a swinging motion along the surface of the concrete. A change from the normal ringing to a dull sound normally indicates that a delaminated area has been encountered. A heavy chain (2.2 kg/m with 50 mm links) has proven to be the most suitable, especially in areas where there is interference from traffic noise. The chain drag is generally used in detecting delaminations on exposed horizontal concrete surfaces only.

For asphalt-covered decks, chain dragging can be useful as a ‘quick check’ to identify potentially debonded areas that might require further investigation. However, these areas do not need to be measured or recorded.

Hammers and steel rods are typically used to detect delaminations on vertical and overhead surfaces. If the striking object is highly resonant, the difference between sound and delaminated concrete may be difficult to distinguish. Care must be taken when interpreting the sounds produced.

Delaminated areas shall be marked directly on the surface of the components using red chalk. These areas are measured (size and location) and recorded on the appropriate grid sheets.

P1-A1.10.7 Corrosion Potential (Half-Cell) Survey

The corrosion potential survey is used to measure the corrosion activity of reinforcing steel at the time of the test and is carried out according to the requirements of latest *ASTM C876 (Standard Test Method for Corrosion Potentials of Uncoated Reinforcing Steel in Concrete)*. Corrosion activity shall be measured by comparing the potential of the reinforcing steel with the potential of a standard copper-copper sulphate reference cell.

Areas are typically characterised into three categories – low, uncertain, and high probability of corrosion as shown in Table 12.

Table 12 – Legend for Corrosion Potential Categories.

Category (Probability of corrosion activity)	Corrosion Potential (V)	Suggested Legend
Low	less negative than -0.20	
Uncertain	between -0.20 and -0.299	
	between -0.30 and -0.349	
High	Between -0.35 and -0.45	
	more negative than -0.45	

Corrosion potential readings shall be taken at all grid points and used to construct contour plots to graphically delineate areas where corrosion activity may be occurring.

Calibration procedures shall be completed prior to commencing the survey, including checking and recording the location and concrete cover to the ground, method of connecting to ground, total resistance and voltage drop to confirm electrical continuity, and the resistance of lead wire on the survey equipment and calibration form. At least five potential measurements shall be checked at the beginning and the end of the test, and each time a new ground is used. Duplicate readings should differ by no more than 0.02 V. Where greater differences are recorded, the test shall be repeated.

Corrosion activity is a function of temperature and readings shall not be taken when the air and concrete temperature is lower than 5°C. The concrete temperature shall be measured in a shaded area of the structure.

The concrete should have sufficient moisture to be conductive but should not have standing water at the time of the corrosion potential survey. Pre-wetting of the grid points is recommended. The presence of contaminants may influence readings on exposed concrete decks. The surface of exposed concrete decks shall be removed by 2 mm at each grid point using chipping hammers or by grinding.

A positive ground connection shall be made directly to the reinforcing steel. The ground connection should be made with a self-tapping screw or compression clamp. When a compression clamp is used, all corrosive deposits should be removed at the reinforcing steel ground location. The use of adhesive tape for grounding the reinforcing steel is not acceptable.

A separate ground shall be used for each portion of the component that is not continuous. The reinforcing steel should be checked for electrical continuity by measuring the resistance (ohms) and voltage drop (mV) between the ground and another reinforcing steel bar which is as far as possible and diagonally opposite from the ground connection. The resistance should be measured one way, then the polarity of the leads should be reversed, and the resistance measurements should be repeated.

When the procedure above is followed, discontinuity of the reinforcing steel will be indicated by any one of the following:

- Any resistance reading more than 5 ohms or a negative number (after deducting the resistance of the test leads).
- Resistance readings that are unstable; or,
- Voltage drop readings greater than 3.0 mV.

If electrical continuity cannot be established on the first attempt, the ground connection should be checked. If the ground connection is secure and the resistance and voltage drop are still high, the continuity check shall be repeated using different reinforcing steel bars for ground connection and/or resistance checks. The survey should be subdivided into smaller areas on long bridge decks.

At grid points where corrosion potential readings are taken, a 15 mm diameter hole shall be drilled through the asphalt and any waterproofing material to make contact with the concrete. The drilling dust shall be removed from the holes by vacuum or air blasting before adding the wetting solution to take the reading.

Asphalt depths shall be measured in the holes drilled for corrosion potential tests. It is recognised that an exact measurement is not possible because of the difficulty in defining when contact is made between the drill bit and the deck surface. However, small errors are not significant in relation to the large number of readings taken.

On decks with a latex modified concrete overlay treatment, an additional set of corrosion potential readings should be obtained at 5 grid point locations via 15 mm diameter holes that have been drilled through the latex modified overlay into the original concrete substrate to verify that the readings are the same as those taken at the top of the overlay.

All drill holes shall be repaired by removing the wetting solution and caulking with bituthene caulking material for the full depth of the hole. Fine sand shall be sprinkled on the surface to prevent tracking.

P1-A1.10.7.1 Procedure for Concrete with Epoxy-Coated Steel

A standard half-cell survey cannot be carried out on decks with epoxy coated reinforcing steel because there is no electrical continuity between the coated bars. The condition of the reinforcing steel can be assessed by taking localized corrosion potential readings where reinforcing steel is exposed as part of the concrete coring operation. Only reinforcing steel in the top layer of the top mat should be tested.

Half-cell readings shall be taken at all locations where reinforcing steel is exposed by the coring operation. The connection to the reinforcing steel bar and location of the half-cell should be at the same bar. A smaller type of half-cell can be used for taking readings inside the core hole. The reading can be very unreliable when the half-cell location does not correspond to the same reinforcing steel bar as the ground connection.

All data, both measured and calculated, shall be recorded on the detailed condition survey summary sheet.

P1-A1.10.8 Ground Penetrating Radar Survey

The ground penetrating radar (GPR) survey is used to indicate the relative chloride ingress within the materials between the top upper reinforcing bars and the antenna. Through interpretation of data and core testing, corrosion risk can be assessed by comparing the amplitude losses across the deck.

ASTM D6087 (Standard Test Method for Evaluating Asphalt-Covered Concrete Bridge Decks Using Ground Penetrating Radar) describes several methods for obtaining relative chloride ingress results across a bridge deck, with the most popular and recommended technique by many practitioners being based on top rebar reflection amplitude [3] and variations in relative signal loss or attenuation over the deck surface. The main reason attributed to using top rebar reflection amplitudes as the basis for analysis is that steel reinforcement is considered a near-perfect reflector of electromagnetic waves [6] and no energy can pass through them. Further, the area of interest for chloride ingress is within the concrete cover layer over the top layer of reinforcement, and therefore looking at GPR attenuation in this region is of utmost importance.

Therefore, the field requirements contained within *ASTM D6087* are acceptable practices for collecting the data, in conjunction with the manufacturer's procedures. However, the methods described in Section P1-A1.10.8.1 GPR Post Processing shall be followed for data post-processing.

Prior to beginning the survey, the deck shall be dry, or damp without ponded water, and with all dirt, sand, and debris removed as this may affect the interpretation of the data.

After the deck has been cleaned of debris, the grid spacing shall be marked out on the deck in accordance with manufacturers recommendation or based on the experience of the practitioner. Typical grid lines are spaced at 0.5 m intervals.

Once the grid spacing has been marked out, the GPR equipment shall be calibrated. Calibration of GPR equipment is assumed to be slightly different for each type of equipment and shall therefore be based on the manufacturer's recommendation.

The requirements contained in Section P1-10.4 GPR Requirements shall always be required. Following the completion of data gathering, the information is then processed in the office. This is called "post processing".

P1-A1.10.8.1 GPR Post Processing

Post processing is the process of taking the raw data from the GPR survey and interpreting it. The following provides a typical workflow for completing post processing of the field collected data.

1. Perform Time Zero Correction
   a. Time zero correction is the process of shifting data to consistently establish a zero two-way travel time at or near the maximum peak of the direct coupling reflection to indicate the surface of the asphalt, concrete or concrete deck.

2. Top Rebar Reflection Picking
   a. Rebar reflection picking is the measurement of the highest amplitude from each hyperbolic rebar reflection characteristic imaged in each GPR profile, often at or very near to the minimum two-way travel time. Several options exist for this process:
      i. Manual rebar picking from the original GPR profile (it can be difficult to select individual rebars when they are closely spaced).
      ii. Manual rebar picking from migrated GPR profiles (requires an assumed velocity which optimally collapses hyperbolic rebar reflections to a point). Or,
      iii. Automated rebar picking algorithms*.

**Automated algorithms, if used, shall have proven effectiveness at not identifying false picks and/or other errors leading to inaccurate results. Automated results normally require manual review and editing.*

3. Amplitude Normalization
   a. Several available options exist in practice:
      i. Normalization based on percentiles of the maximum measurable amplitudes; or,
      ii. Normalization using the direct coupling amplitude.

4. Depth Correction
   a. The process and requirements of depth correction have been defined in Section P1-10.4.1.1 GPR Depth Correction Requirements.

5. Contour Plot of Depth Corrected Amplitudes
   a. Based on the requirements contained for the specific condition survey the following plots shall be developed:
      i. Corrosion risk.
      ii. Concrete cover.
      iii. Asphalt thickness.

P1-A1.10.8.2 GPR Requirements for Contour Plots

Once the process above (steps 1-4) has been followed, the GPR consultant should now have the appropriate data to generate plots for corrosion risk, concrete cover, and asphalt thickness. The areas of corrosion risk are typically characterised into three categories – low, uncertain (or transitioning), and high, as shown in Table 13. These categories are based on the signal attenuation which are further broken down into smaller subsections. As noted below, the ranges determined for the contour plot will be site specific. However, under no circumstances should any range be greater than 5 dB's, other than the final range for the low and high category.

Table 13 – Legend for Corrosion Risk Categories.

Category (Corrosion Risk)	Rebar Reflection Amplitudes (dBs)	Suggested Legend
Low	**	
Uncertain or Transitioning	**	
	**	
High	**	
	**	

***Ranges shall be determined by the GPR consultant performing the depth correction and any proprietary corrosion thresholds.*

An asphalt thickness plot based on GPR data differs from that of a traditional survey because the amount of data points generated is significantly greater. Plotting asphalt thickness in a grid pattern is not applicable; it shall be recorded on a contour plot, and the legend in Table 14 shall be used. The same is true for concrete cover, except the legend found in Appendix P1-A1.10.9 Concrete Cover Survey shall be used.

Table 14 – Legend for Asphalt Thickness.

Concrete Cover (mm)	Suggested Legend
More than 100 mm	
80 to 99 mm	
50 to 79 mm	
Less than 50 mm	

P1-A1.10.9 Concrete Cover Survey

The concrete cover over the outer layer of reinforcing steel can be measured using a cover-meter. The cover shall be measured at grid points or by taking an average of the bars on either side of the grid point.

The existing structure drawings shall be reviewed to determine orientation and sizes of top bars. The cover-meter shall be operated with the probe oriented parallel to the top bars.

If the structural drawings are not available and the orientation of the top bars is not known, the probe shall be rotated at several locations until a sharply defined minimum reading (maximum deflection) is obtained. This indicates the probe is directly above a bar, and the orientation of the bar coincides with the longitudinal axis of the probe.

On some instruments, the calibration tends to drift while in use. The instrument shall be checked periodically at core holes where bar depths are known or at an exposed bar (as per the survey equipment and calibration form). This procedure will also identify if there are magnetic particles in the concrete for which a correction factor must be derived.

- On asphalt-covered decks, cover shall be measured in areas where sawn samples have been removed.

- On exposed concrete decks, cover shall be measured on a 3.0 m x 3.0 m grid.

- On other concrete surfaces, the cover shall be measured at a maximum 1.0 m x 1.0 m grid for components less than 50 m^2 and on a 2.0 m x 2.0 m grid if the area of the component is greater than 50 m^2.

- The value recorded shall be the cover to the uppermost bar nearest to the intersection of the grid lines.

Reinforcing steel rebars are tied together to form a relatively rigid mat. As a result, any significant change in the cover readings at adjacent points should be viewed with caution and additional readings taken to confirm the results. Concrete cover shall be recorded on a contour plot, and the legend in Table 15 shall be used.

Table 15 – Legend for Concrete Cover.

Concrete Cover (mm)	Suggested Legend
Greater than 60 mm	
40 to 60 mm	
20 to 39 mm	
Less than 20 mm	

P1-A1.10.10 Expansion Joint Survey

Expansion joints shall be visually assessed for material and performance defects as described in the OSIM. The type and extent of the deterioration shall be recorded on the 'Detailed Condition Survey Summary Sheet – Expansion Joints' form (P1-A6 Standard Forms). Measurements to determine the joint dimensions, skew, and slope shall be taken and recorded on the summary form. A minimum of three measurements shall be taken for each expansion joint, equally distributed along its length as reasonably as possible.

The dimensions of each joint are required even when there is no armour or seal because new joints are usually installed as part of the rehabilitation. All joint gaps should be measured perpendicular to the line of the joint.

Where the joint has been paved over, the asphalt shall be removed at the curbs and at the centreline of the highway to measure the joint gap.

There may be exceptional circumstances, such as the use of sliding plates, where it is not possible to measure the joint gap. The engineer should be aware of this situation from the review of the plans and should make a note on the summary form.

Sketches of typical sections of the expansion joint in the curb or sidewalk area as well as the driving lane area are required. The sections shall show any steel angles, steel cover plates, dimensions of concrete end dams, and other pertinent information. Where Type 'C' strip seals are present, details of the retainer configuration and geometry shall be recorded.

The thickness of asphalt at the concrete end dams shall be measured at the curbs and at the centreline of the highway on the bridge deck. Asphalt shall be removed by coring or other suitable methods.

The quality of concrete in the deck, curbs, and ballast walls adjacent to the joint shall be noted.

P1-A1.10.11 Bridge Deck Drains

Deck drains shall be visually assessed for material and performance defects as described in the OSIM and the type and extent of deterioration shall be recorded on the 'Detailed Condition Survey Summary Sheet – Drainage' form (refer to Appendix P1-A6 Standard Forms).

The size of the drains shall be measured. The length and angle of inclination of the drains may be estimated. The deck soffit should be inspected for the presence of void drains on voided decks and asphalt drainage tubes on decks with transverse expansion joints.

Surface drainage of the deck shall be considered in terms of overall runoff from the structure with particular attention to historical evidence of ponding, vegetation growth and signs of leaking below the superstructure. Particular attention shall be paid to gutter lines and transitions onto the approach slab and beyond to approach drainage infrastructure. Locations of inadequate drainage shall be recorded.

P1-A1.10.12 Bearings

Bearings shall be visually assessed for material and performance defects as described in the OSIM and the type and extent of deterioration shall be recorded on the 'Detailed Condition Survey Summary Sheet – Bearings' form (refer to Appendix P1-A6 Standard Forms). Bearing contact surfaces shall be inspected for contact, smoothness, and uniformity, and bearing thickness shall be measured at a minimum of 4 quadrants to the nearest millimeter with dial indicators or inside calipers and recorded on the form. Any gaps or non-contact issues shall be reported, and their extent determined with feeler gauges.

P1-A1.10.13 Concrete Coring

In general, coring through the top mat of steel shall be avoided using a cover-meter. However, in areas of high corrosion potential with sound concrete, some cores should intentionally be taken through the steel to observe the condition of the rebar.

Cores shall not be taken through pre-stressing steel, utility ducts, embedded cathodic protection components (including cables), or in areas immediately below or above the bearings. The cores shall be long enough to carry out the required tests and shall extend below the top mat of reinforcing steel.

When cores are taken prior to non-destructive testing, excess water should be vacuumed frequently to prevent interference with measurements.

Where the concrete being cored is in poor condition and is broken into several fragments, the juxtaposition of the pieces shall be recorded, by either a sketch or identification of individual pieces, so that the core can be pieced together in the laboratory. Cracks in the concrete core caused by the coring operation should be identified as such.

The inside of the core hole shall be examined carefully for horizontal cracks and the condition of the concrete. The condition and orientation of any rebar located in the side of the hole shall also be recorded.

Each core shall be given a number that identifies the structure and the core's location in the structure. The location and the number (prefaced with "C") of the cores shall be noted directly on the grid sheets and the core log. It is a good practice to complete the dimensions and remarks section of the core log in the field; this reduces the possibility of errors in identifying cores. The location of the cores shall be given with respect to the grid lines.

The diameter of the cores shall be 100 mm. When coring a deck with an asphalt wearing surface which has a poor bond between the concrete and asphalt, it is advisable to remove the asphalt from the core bit before drilling the deck slab so that the asphalt is not broken inside the bit. Where asphalt thickness is more than 100 mm, it is sometimes necessary, in order to retrieve the concrete core, to remove a 150 mm diameter core from the asphalt prior to taking the 100 mm diameter core in the concrete.

P1-A1.10.14 Repairs to Core Holes and Expose Rebars

Prior to repairing a core hole, the sides of the hole shall be cleaned, and any water removed. The cut ends of epoxy coated bars, or any damage areas of the coating shall be cleaned and repaired with an approved epoxy patching material.

The core holes shall be repaired using a cementitious proprietary patching material from the MTO's pre-qualified product list for filling core holes, and shall be mixed, handled, and cured according to *OPSS.PROV 1350*. The hole shall be filled level with the concrete surface. On decks that have a waterproofing membrane, a layer of post-applied waterproofing material shall be cut to fit the core hole and adhered to the concrete surface. Cold mix asphalt shall then be compacted to a level slightly above the bituminous surface.

P1-A1.10.15 Asphalt Sawn Samples

Sawn samples are removed from asphalt covered decks to assess the condition of the concrete deck, the presence and condition of waterproofing materials, and to check the cover to reinforcing steel. The size of the sawn samples shall be a minimum of 250 mm x 250 mm. The sample shall be removed by dry sawing to determine if and how much moisture is present beneath the asphalt. Prior to saw cutting, the depth of asphalt shall be established from adjacent half-cell survey drill holes (allowance should be made for partial penetration of the drill into the concrete surface). The depth of saw cutting shall be such that there will be no damage to the concrete surface and reinforcing steel.

The number of sawn samples required is specified in Table 10. Sawn samples provide considerably more information on the degree and type of surface deterioration than cores. All sawn samples shall be concentrated in areas with deterioration or prone to deterioration. They can be especially useful in investigating the condition of the deck slab at cracks in the asphalt, above the areas of deterioration in the soffit, in deteriorated areas identified by GPR (if available), and in areas of high corrosion potential on decks with uncoated reinforcing steel. At least one sample shall be removed from the area adjacent to the curb.

The condition of the concrete and waterproofing are of greater significance than the condition of the asphalt. Consequently, photographs shall be taken to clearly show the condition of the concrete surface. This may involve cleaning the concrete surface of asphalt residue. Care should be taken during asphalt removal to ensure that the concrete surface is not damaged by the breakers used for removal.

The 'Asphalt Sawn Sample Log' form (P1-A6 Standard Forms) shall be completed in the field. The location shall be given with respect to the grid lines. The concrete cover to the top reinforcing steel layer in each removal area shall be measured using a cover meter. The depth of asphalt and waterproofing shall also be recorded. The concrete in the sample area shall be sounded for delaminations using both the hammer and chain technique.

Sawn sample areas shall be repaired by compacting cold mix asphalt to slightly above the level of the asphalt surface. On decks which have been waterproofed or are protected by cathodic protection, a piece of Ministry-approved post-applied bituthene waterproofing material shall be cut to fit the removed area and mastic shall be used to affix the membrane to the deck surface. Where the saw blade has accidentally cut into the concrete or asphalt surface, the resulting groove shall be sealed with bituthene caulking material.

P1-A1.10.16 Removal of Large Asphalt Strips

On decks where removal of a large asphalt strip is warranted, the location of the strip shall be selected to coincide with:

- Soffit deteriorations.
- Suspected top surface deteriorations such as low concrete cover, high corrosion potential areas (more negative than -0.35 V), etc.; or,

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- Centred over a void for post-tensioned decks with circular voids.

The large asphalt strip removal area shall be repaired by placing hot-applied rubberised waterproofing, protection board, and hot-applied asphalt.

P1-A2 Coring Requirements for Exposed Concrete Decks

The number of cores on bridge decks with an exposed concrete wearing surface are tabulated in Table 16 and Table 17.

Table 16 – Number of Concrete Cores for First-time Survey of Exposed Bridge Decks.

Deck Area (m^2)	Basic	Extra	Minimum	Maximum
< 500	6	1 per 50 m^2**	6	10
> 500	1 per 200 m^2*	1 per 100 m^2**	10	20

** Based on area of bridge deck.*
*** Based on area of high corrosion potential (more negative than -0.35V).*

Table 17 – Number of Concrete Cores for Updated Survey of Exposed Bridge Decks.

Deck Area (m^2)	Basic	Extra	Minimum	Maximum
< 500	3	1 per 100 m^2**	3	7
> 500	1 per 500 m^2*	1 per 200 m^2**	3	10

** Based on area of bridge deck*
*** Based on area of high corrosion potential (more negative than -0.35V).*

P1-A3 The Report

P1-A3.1 Introduction

The purpose of the report is to document the condition of the structure so the results of the condition survey can be used to select the method of rehabilitation and to prepare the contract documents. The primary requirement is for the report to be clear and concise.

As the Ministry employs various service providers to carry out condition surveys, it is necessary that a standard format be used for the report. This format is also to be followed for reports produced in-house. To facilitate the use of a standard format, forms have been developed for recording the data. This enables specific information to be located quickly and reduces the length of the text.

P1-A3.2 Contents

The material in the report shall be presented in the following order:

- Table of Contents
- Structure Identification Sheet
- Key Plan
- Summary of Significant Findings
- Detailed Condition Survey Summary Sheets
- Survey Equipment and Calibration Procedures
- Core Photographs and Sketches
- Core Logs
- Sawn Asphalt Sample Photographs
- Sawn Asphalt Sample Log
- Site Photographs
- Drawings

P1-A3.3 Standard Forms

Data is recorded on the following standard forms in Section P1-A6 Standard Forms.

- Structure Identification Sheet
- Survey Equipment and Calibration Procedures
- Detailed Condition Survey Summary Sheets
- Asphalt Covered Bridge Deck
  - Exposed Concrete Component
  - Expansion Joint
  - Drainage
  - Bearing
- Concrete Core Log
- Sawn Asphalt Sample Log

P1-A3.3.1 Guide to Completing the Standard Forms

The following guide has been prepared to clarify the information to be shown on the standard forms.

P1-A3.3.1.1 Structure Identification Sheet

- The structure number and other identifying information can be obtained from the regional structural section or the Bridge Management System (BMS).
- Annual Average Daily Traffic (AADT) is available from the regional traffic section or the MTO iCorridor website.
- All members of the survey team shall be listed.
- The sheet shall be stamped by the professional engineer responsible for the work.

P1-A3.3.1.2 Detailed Condition Survey Summary Sheets

- Where the deck geometry is complex, the deck area should be taken from the design drawings.
- The dimensions of concrete components shall be reported to the nearest 0.01 m.
- Areas for the different corrosion potential ranges are calculated statistically. The method involves counting the number of readings in each range and dividing by the total number of readings. On short span decks (< 25 m length) with expansion joints, the readings along the expansion joint should not be included in the statistical calculation.
- Areas of deterioration are transcribed from grid sheets and measured using a computer aided design and drafting software. When a grid layout is not required, areas of deterioration are measured in the field.
- Where a structure has been widened, the test results for the old and newer portions of the structure shall be tabulated separately.

P1-A3.4 Text

The intent of the text is to summarize and explain significant deterioration or unusual findings. In this respect, it can be compared to an executive summary. It is not necessary to describe the test methods or field procedures since these are specified in the consultant agreement and in this manual. The text should provide a concise discussion of the relevant findings from the condition survey and explain relationships and/or inconsistencies/anomalies in the field observations, test results, or data. For example:

- Summarize significant deteriorations with references to forms and photographs.
- Summarize results from the original structure and widening portion(s) separately.

- Highlight unusual defects, inconsistent data, or unexpected results.
- Discuss overlaps between deck top and soffit deteriorations.
- Discuss correlations between observed deteriorations and field measurements such as corrosion potential, concrete cover, and chloride content.
- Discuss relationships between deteriorations and observed structural deficiencies (e.g., excessive cracking at a location with observed settlement, etc.).
- Discuss correlations between material properties and observed deteriorations such as scaling and concrete air void systems test results.
- Discuss correlation between measurements and test results and specified values from original construction such as concrete compressive strength, concrete cover, waterproofing thickness, etc.
- Describe how the acid soluble chloride content is adjusted for background chlorides and whether the acid soluble chloride content (adjusted) is above the threshold value at reinforcing steel level.
- Ensure photographs in the report are captioned with their location and a brief description.

P1-A3.4.1 Ground Penetrating Radar Requirements

When a GPR survey is specified as part of the detailed condition survey, a more thorough overview shall be provided. The following additional information shall be included at a minimum:

- Equipment model and associated specifications (e.g., centre frequency, spatial resolution, etc.).
- Description of calibration technique.
- Discussion on the following topics:
    - Method used for time zero correction.
    - Method for rebar picking.
    - Method for amplitude normalization; and,
    - Method for depth correction, and references of any applicable research papers and/or manuals.
- Discuss the relationship between the GPR survey and the inspection findings.

P1-A3.5 Drawings - Detailed Condition Survey

P1-A3.5.1 General Requirements for All Drawings

The drawings are prepared using a CAD software by transcribing the data from the field grid sheets. The following requirements apply to all concrete components:

- The scale shall be 1:100, except where another scale may be more suitable.

- Show grid lines on all drawings.
- Show the locations of all grounds and continuity checks for black reinforcing steel on the corrosion potential survey drawings; and,
- Include a legend on each drawing; standard legends are provided in P1-A1.10 Field Procedures, Data Processing and Documentation.

P1-A3.5.2 Exposed Concrete Components, Excluding Decks

In addition to the requirements listed under P1-A3.5.1 General Requirements for All Drawings, the following shall be included on drawings for exposed concrete components, excluding decks:

- Show the locations of wall drains if present; and,
- Show concrete core locations and numbers on all drawings. Highlight cores containing defects.

Separate plans are required for exposed concrete components to show:

- A drawing showing concrete surface deterioration and delamination mapping as defined in Sections P1-9.2 Surface Deterioration Mapping and P1-9.3 Delamination Mapping.

- A drawing showing concrete cover measurements at grid points and contour lines and shaded areas for 20 mm, 40 mm, and 60 mm covers; and,

- If applicable, a plan showing corrosion potential measurement at grid points and the 0.20V, 0.35V, and 0.45V contour lines with shaded areas between contour lines. For components with epoxy coated reinforcing steel, the half-cell potentials are recorded only at core locations with exposed top bars.

P1-A3.5.3 Bridge Decks

In addition to the requirements listed under P1-A3.5.1 General Requirements for All Drawings, the following shall be included on all drawings for bridges decks:

- Show concrete core and asphalt sawn sample locations and numbers on all drawings. Highlight those containing defects.

- Show the locations of deck drains.

- Show the centreline of piers (if applicable) and deck features such as sidewalks, curbs, medians, and joints on all drawings.

Separate plans are required for bridge decks to show the following:

- A drawing showing concrete surface deterioration and delamination mapping, as defined in Sections P1-9.2 Surface Deterioration Mapping and P1-9.3 Delamination Mapping, on the top surface of the curbs, sidewalks, medians, and inside faces of concrete barrier/parapet walls, where present. The inside face of concrete barrier/parapet walls may be shown on a separate drawing:

- For asphalt-covered decks, also show asphalt defects and the thickness of asphalt at core and sawn sample locations.

- For exposed concrete decks, also show surface deterioration and delamination mapping on the deck surface.

- A drawing showing surface deterioration and delamination on deck soffit with the location of longitudinal beams.

- A drawing showing corrosion potential measurement at grid points and the 0.20V, 0.35V, and 0.45V contour lines with shaded areas between contour lines. For decks with epoxy coated reinforcing steel, the half-cell potentials are recorded only at core locations with exposed top bars.

- When a GPR survey is specified, a drawing showing the corrosion risk with the appropriate contour lines. Similar shading shall be used to that of corrosion potential. However, the ranges shall be modified based on project specific information. Similar drawings shall also be provided for concrete cover and asphalt thickness when specified as part of a GPR survey.

P1-A4 Review of the Report

The contents of the report should conform to the requirements described in Appendix P1-A3 The Report. Additional guidance is provided in this Section to help review the report and identify inconsistencies in the data. The following is not intended to be a comprehensive list of quality control procedures for preparation of the report.

P1-A4.1 General

- Check that dimensions and areas are in general agreement with Contract Drawings.
- Check the overall assessment of the condition and bond of waterproofing is consistent with the core and sawn sample logs.
- Compare concrete cover, asphalt, and waterproofing thicknesses at grid points with measurements from nearby cores and sawn samples for consistency.

P1-A4.2 Concrete Cover

- Check that cover measurements do not vary significantly at adjacent grid points. If so, it may indicate that the cover has not been measured to the uppermost bar.
- Compare measurements with specified cover from construction drawings.

P1-A4.3 Corrosion Potential

- Check that the ambient temperature is not less than 5°C on the day(s) the corrosion potential readings are taken.
- Check that readings increase or decrease uniformly between adjacent grid points.
- Check that areas of high corrosion activity generally coincide with delaminations and spalls.
- Check that the chloride content is typically lower in areas of low corrosion activity and higher in areas of high corrosion activity. Chloride content is likely above threshold at rebar level in areas of high corrosion potential.

P1-A4.4 Cores and Sawn Samples (Asphalt Covered Deck)

- Check that cores are distributed in both 'high risk' and 'low risk' areas as defined in Section P1-9.7.1 Number of Cores on Asphalt-Covered Bridge Decks.
- Check that asphalt sawn samples are located within areas of suspected deterioration (e.g., high corrosion potential areas, cracks, or wet spots on the underside).
- If defective cores and samples are concentrated in one or few areas, it is more indicative of localized issues at those locations. Whereas, if defective cores and samples appear

randomly distributed, it is more indicative of the condition of the entire bridge deck / component.

- If a GPR survey has been carried out, check that the cores were located within areas of high signal attenuation.

- If there are a larger number of delaminated and spalled cores and sawn samples in an area of high corrosion potential versus the other areas, verify that the corrosion potential survey is reliable.

P1-A5 Example Grid Layouts for Detailed Condition Surveys

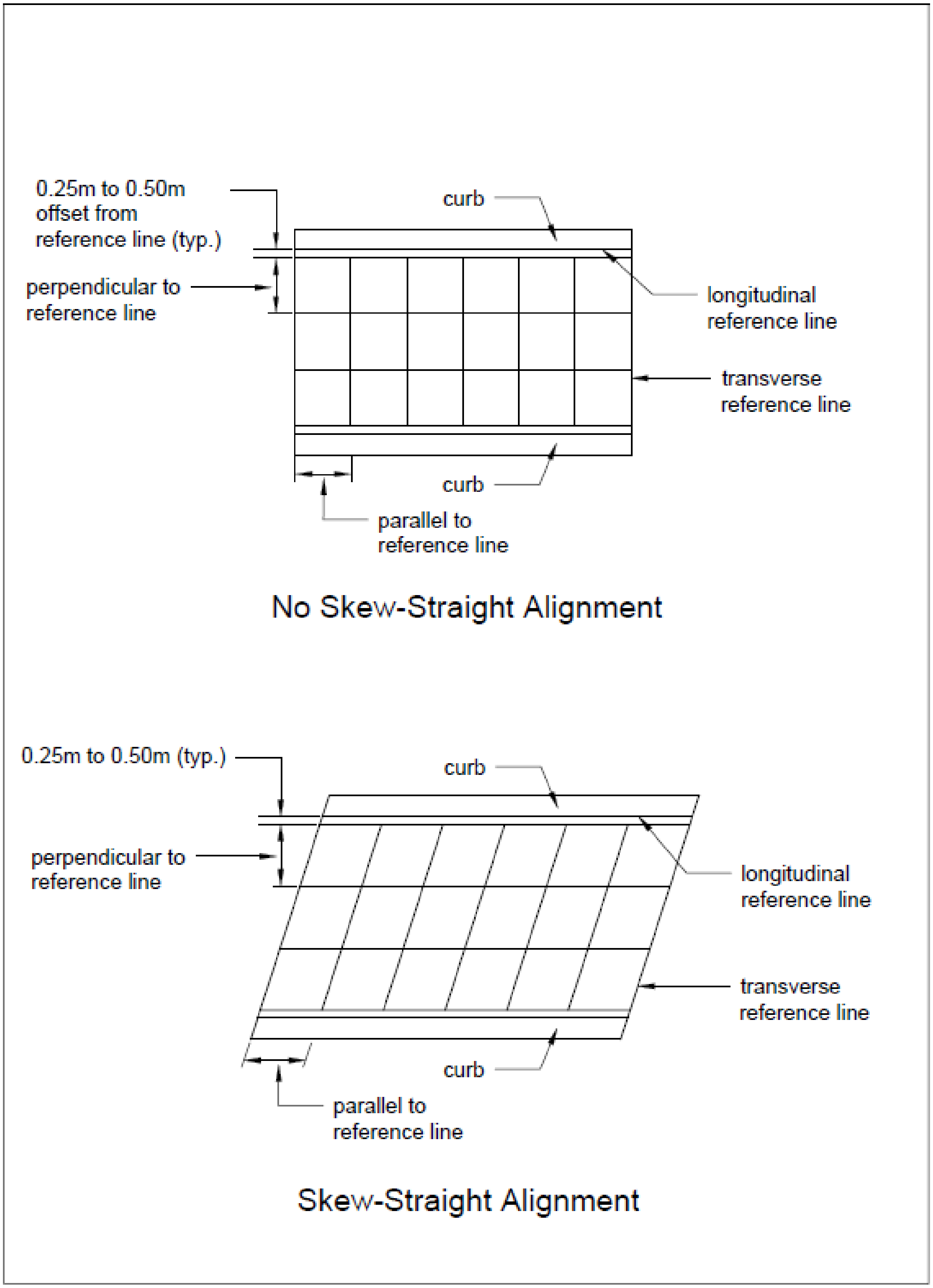

Figure 1 – Typical grid layout for bridge decks.

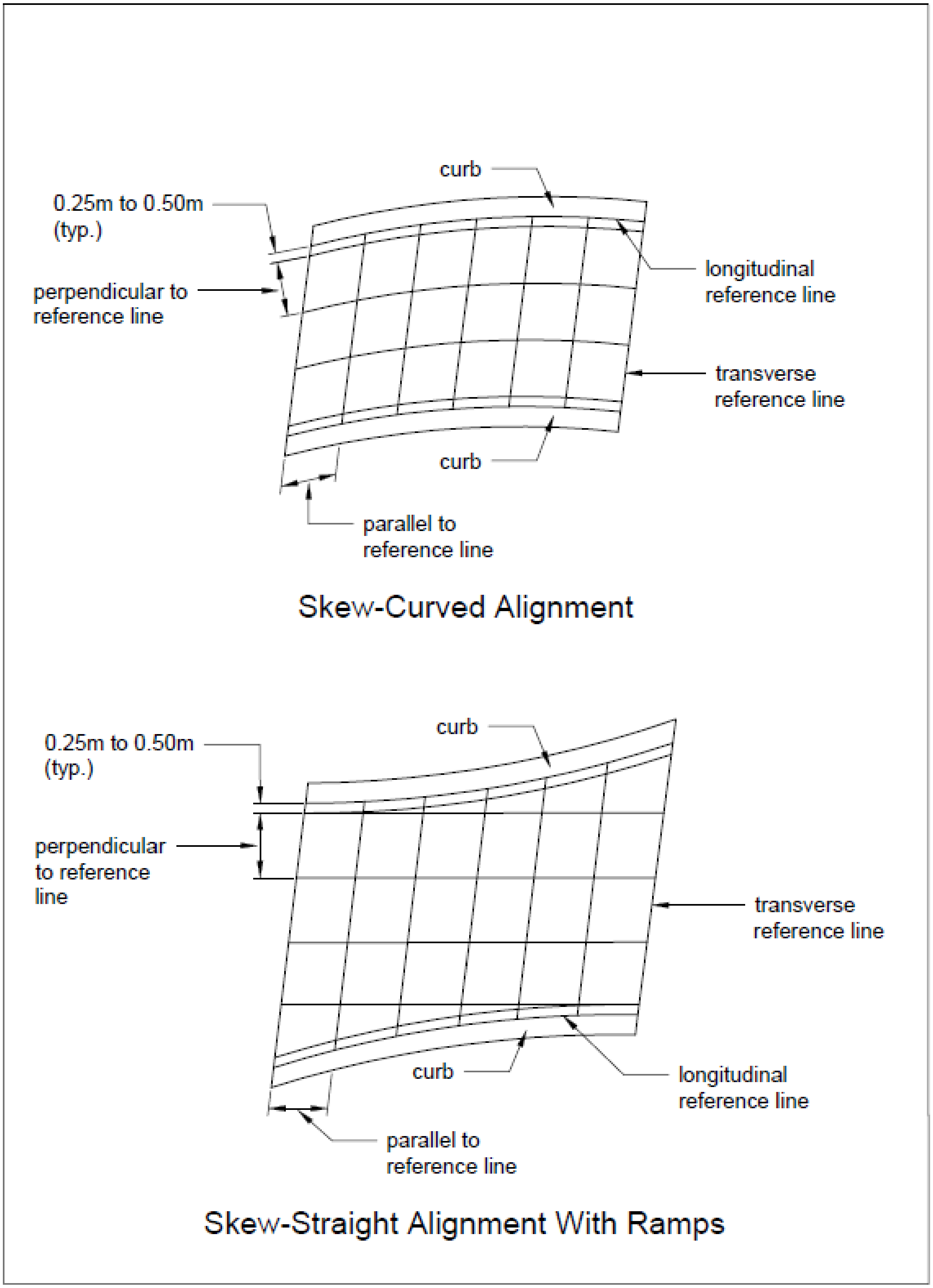

Figure 2 – Typical grid layout for bridge decks.

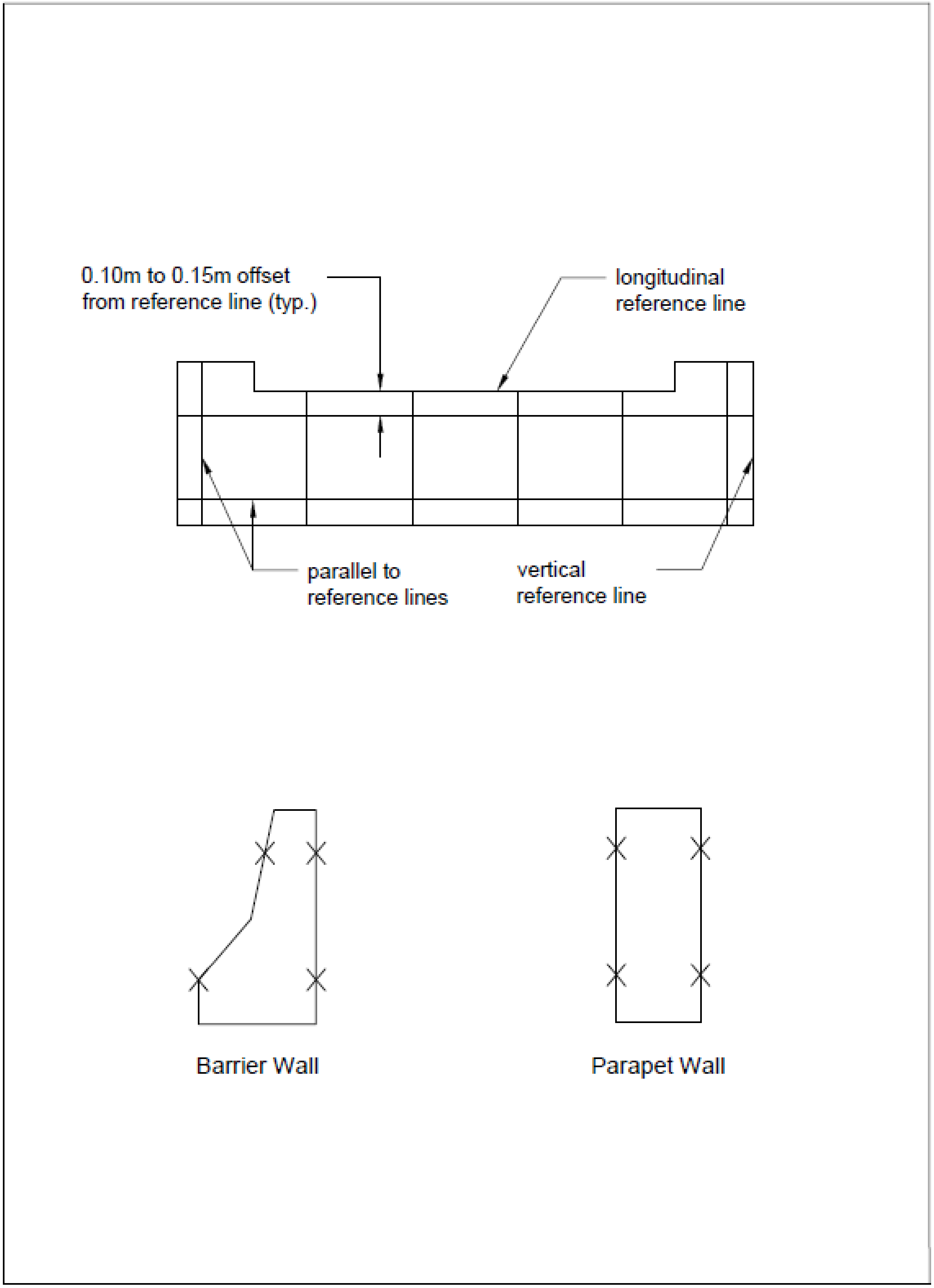

Figure 3 – Typical grid layouts for parapet & barrier walls.

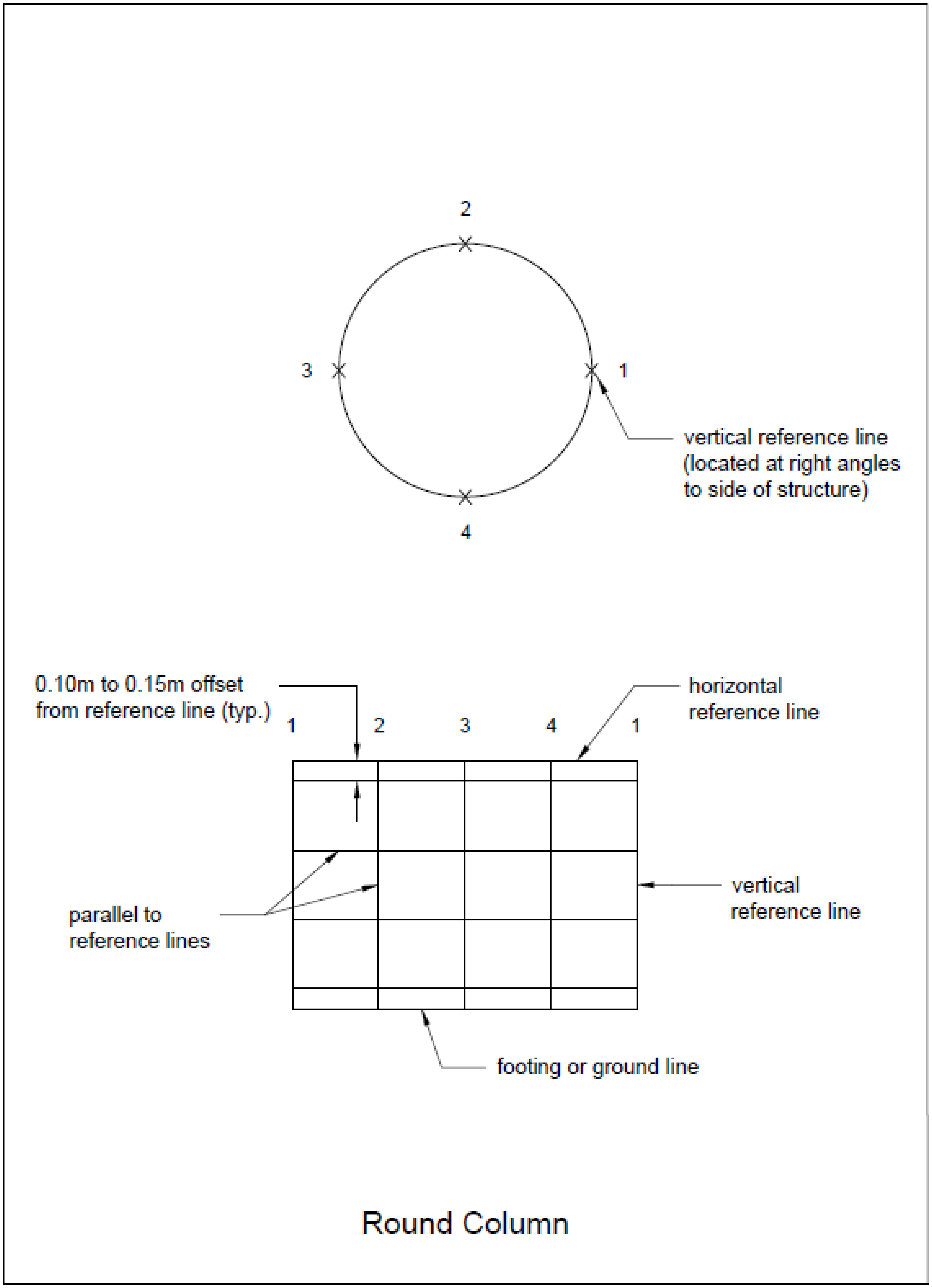

Figure 4 – Typical grid layouts for piers.

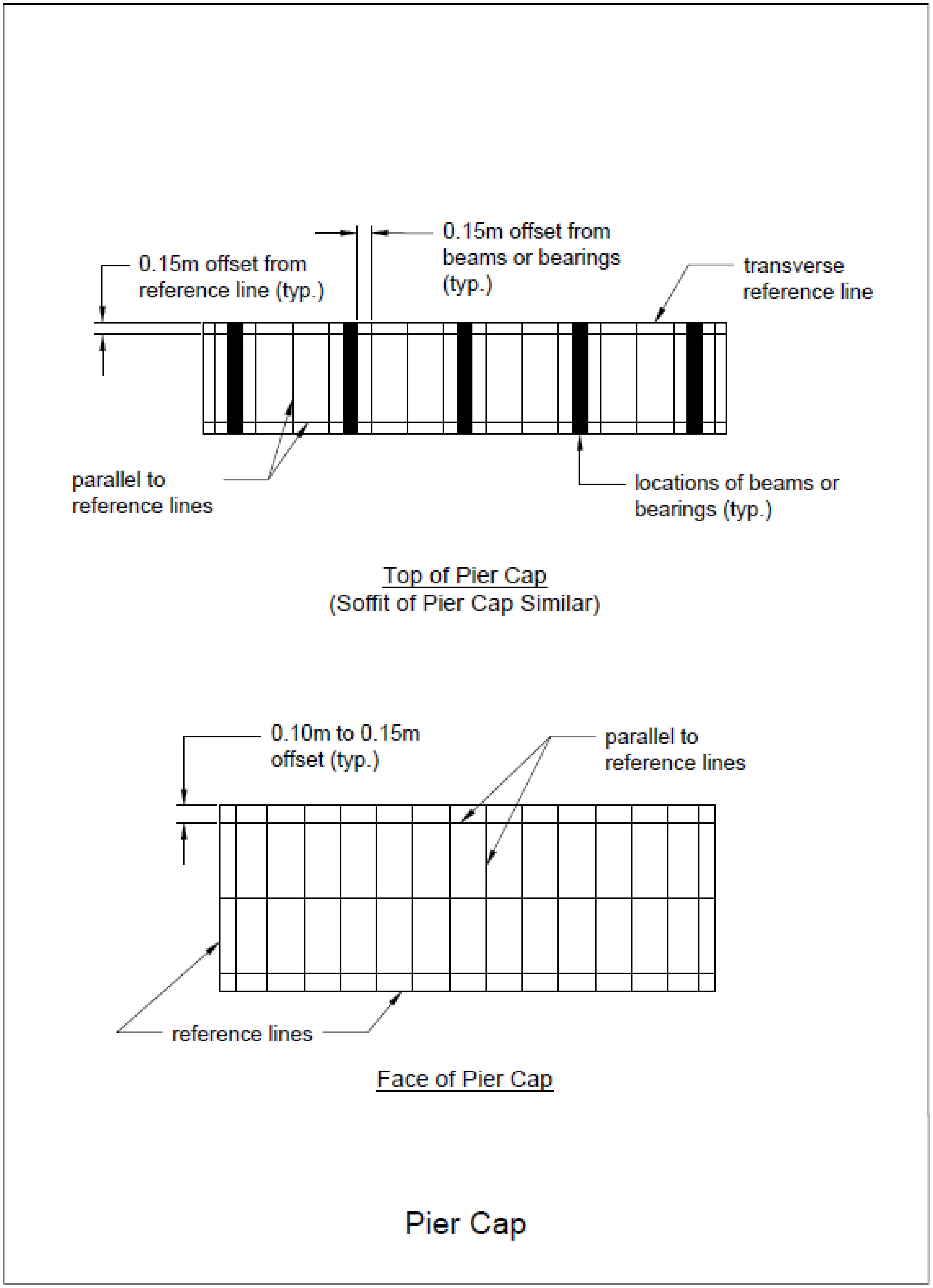

Figure 5 – Typical grid layouts for piers.

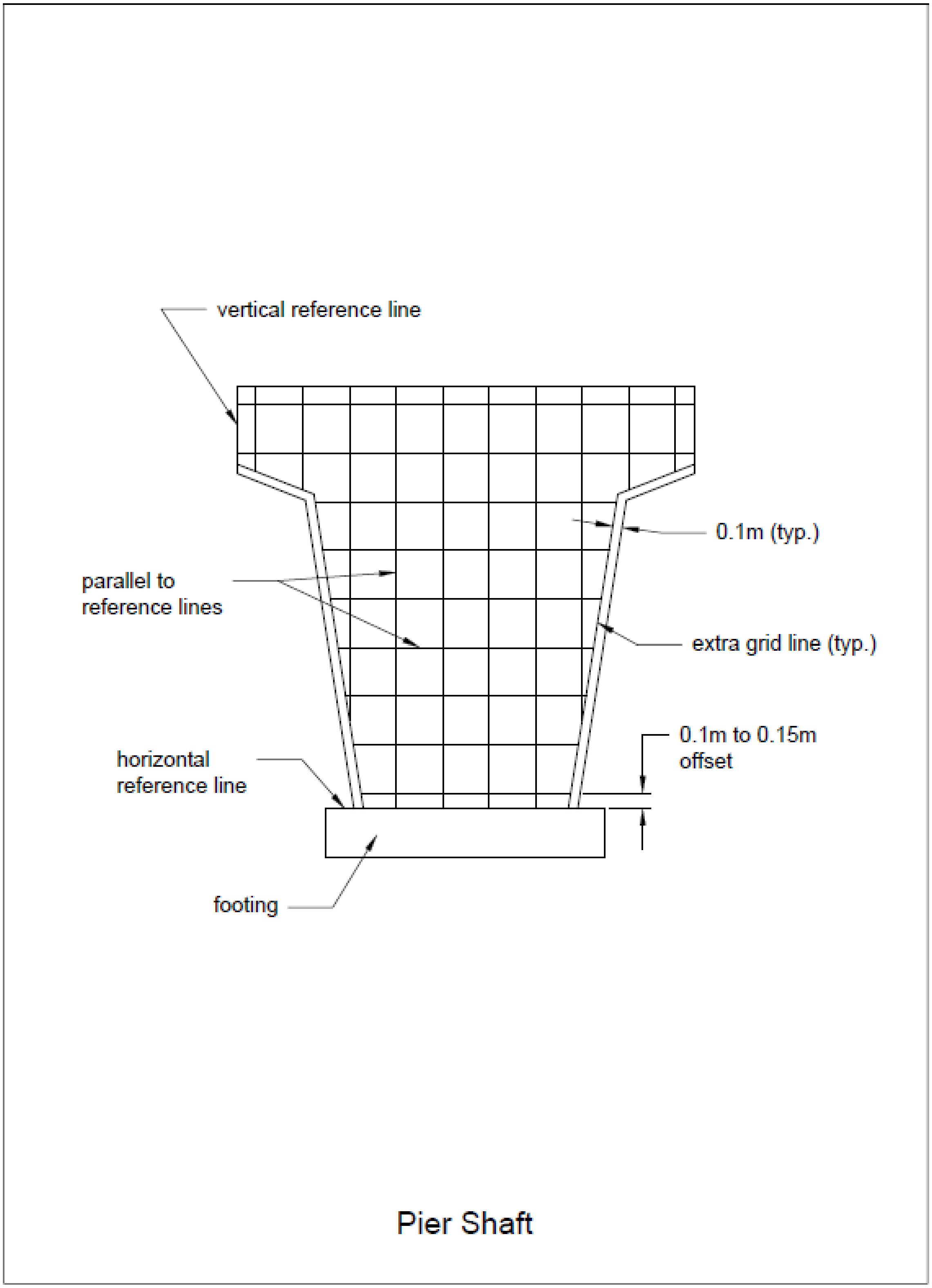

Figure 6 – Typical grid layout for pier shaft.

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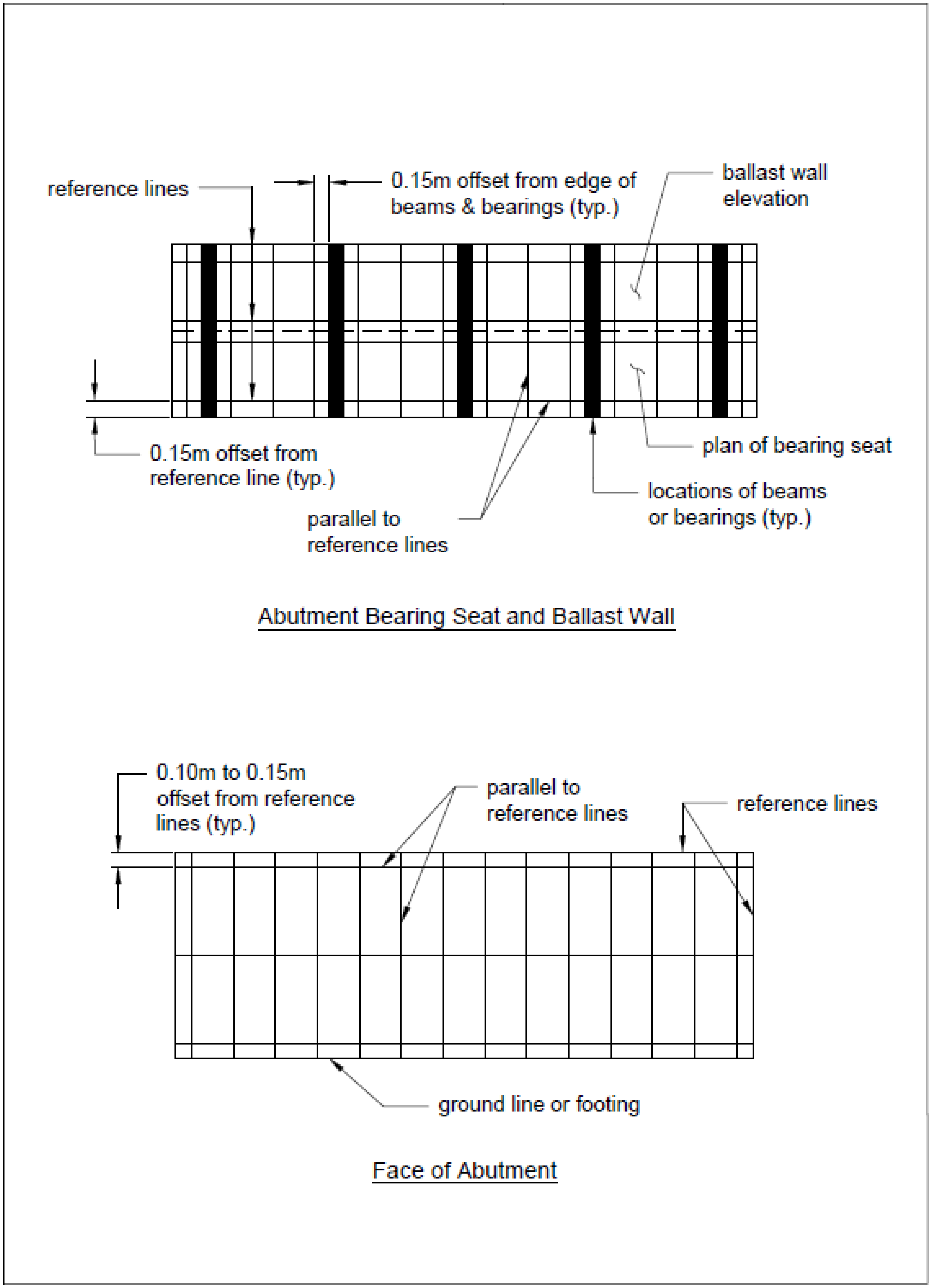

Figure 7 – Typical grid layouts for abutments.

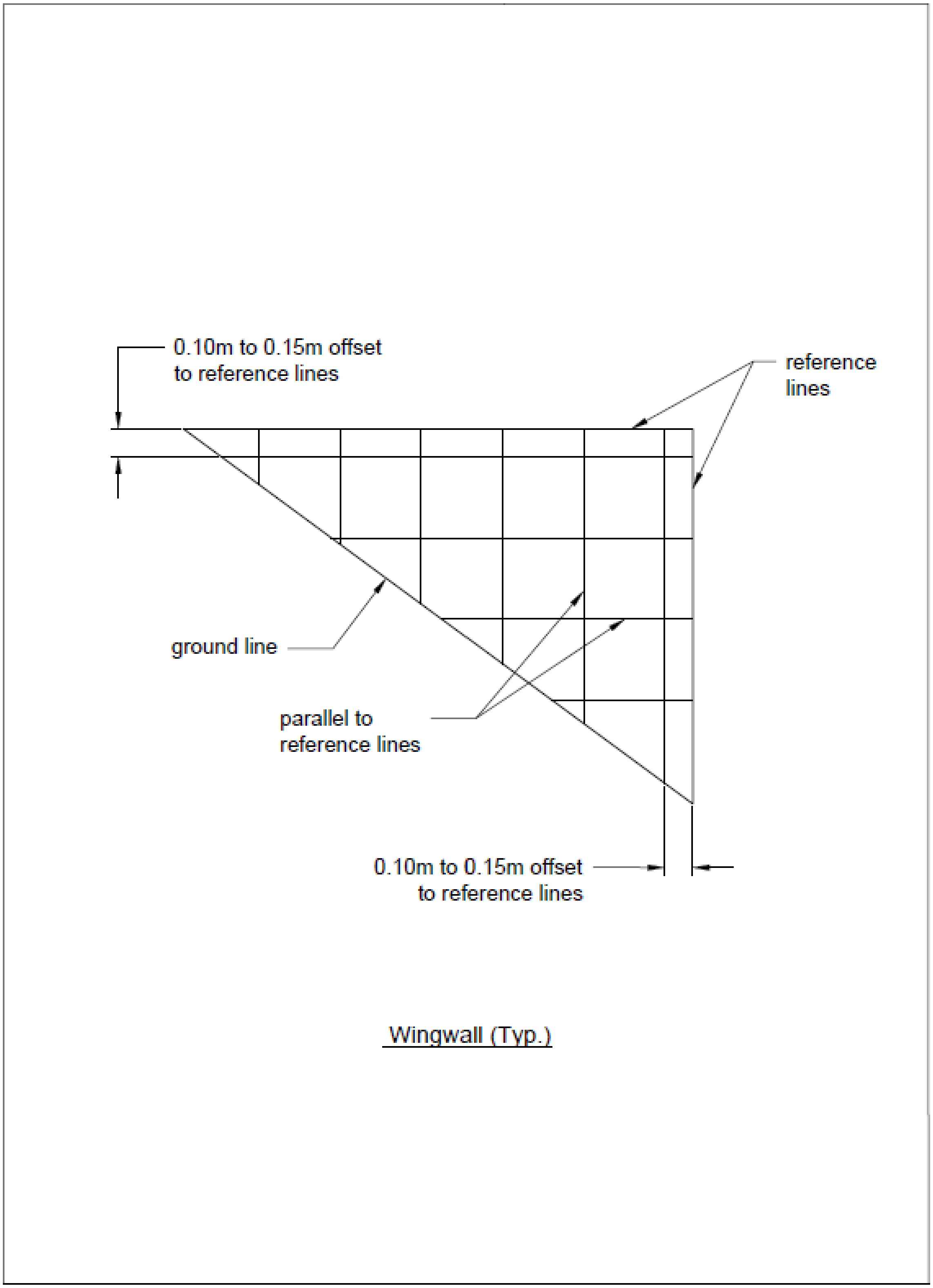

Figure 8 – Typical gird layout for wingwalls.

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P1-A6 Standard Forms