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Investigating Available State-of-the-art Technology for Determining Needed Information for Bridge Rating Strategies

by

Afshin Karshenas, Ph.D.
FDH Infrastructure Services

Babak Naghavi, Ph.D., P.E., PH
Hardesty & Hanover

4101 Gourrier Avenue | Baton Rouge, Louisiana 70808
(225) 767-9131 | (225) 767-9108 fax | www.ltrc.lsu.edu

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Afshin Karshenas, Ph.D.
Babak Naghavi, Ph.D., P.E., PH

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Louisiana State University
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16. Abstract
In this report, nondestructive test (NDT) methods are evaluated in the context of providing input parameters to perform bridge load rating calculations for different bridge types. Relevant NDT methods are identified based on diverse technologies including mechanical impact, acoustic, electromagnetic, electrical and chemical, cuclear, and miscellaneous methods. The required parameters for successful bridge load rating of concrete precast slab (COPCSS), concrete slab (COSLAB), concrete prestress channel (COPSCH), prestressed girder bridges, and steel bridges are identified and the available NDT methods to provide these parameters are presented. These parameters are categorized in three basic groups that consist of as-built geometric parameters, as-built strength parameters, and as-inspected strength parameters. All the available NDT techniques that can be used to obtain each parameter have been presented. Finally, the NDT methods are rated by cost, ease of use, and reliability of data using a three-level rating system and the most cost effective, feasible, and reliable methods have been recommended.

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by

Afshin Karshenas, Ph.D,
Senior Research Scientist, FDH Infrastructure Services
6521 Meridien Dr., Raleigh, NC, 27616

and

Babak Naghavi, Ph.D., P.E., PH
Regional Manager, Hardesty & Hanover
3850 N. Causeway Blvd, Suite 1850
Metairie, LA 70002

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ABSTRACT

In this report, nondestructive test (NDT) methods are evaluated in the context of providing input parameters to perform bridge load rating calculations for different bridge types. Relevant NDT methods are identified based on diverse technologies including mechanical impact, acoustic, electromagnetic, electrical and chemical, cuclear, and miscellaneous methods. The required parameters for successful bridge load rating of concrete precast slab (COPCSS), concrete slab (COSLAB), concrete prestress channel (COPSCH), prestressed girder bridges, and steel bridges are identified and the available NDT methods to provide these parameters are presented. These parameters are categorized in three basic groups that consist of as-built geometric parameters, as-built strength parameters, and as-inspected strength parameters. All the available NDT techniques that can be used to obtain each parameter have been presented. Finally, the NDT methods are rated by cost, ease of use, and reliability of data using a three-level rating system and the most cost effective, feasible, and reliable methods have been recommended.

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IMPLEMENTATION STATEMENT

The comprehensive literature review of the practice-ready NDT methods presented in the report indicates that the required bridge rating parameters could adequately be collected and used for successful analyses of various types of bridges such as Concrete Precast Slab (COPCSS), Concrete Slab (COSLAB), Concrete Prestress Channel (COPSCH), prestressed girder bridges, and steel bridges.

Other parameters without NDT testing methods warrant further research by the industry. However, in practice, these parameters can be obtained from the *Manual of Bridge Evaluation*, the year the bridge was built, or based on standard practice and will likely not affect the rating significantly at the critical section (i.e., near the center of a span). This is common practice in load rating methodology and destructive testing would typically be performed only when ratings are less than desirable, and there is evidence that higher strength material may have been used.

Based on the findings of this report, the researchers recommend an implementation study to develop a methodology for bridges when such information and parameters are not available. Such implementation stategy will be based on the most reliable, cost effective, and practical or easy to use methods identified in the study. The results of the methodology should also be tested via the use of blinded-experiments on several bridges to ensure the accuracy of the results obtained.

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INTRODUCTION

According to the bridge load rating group of the Louisiana Department of Transportation and Development (DOTD), there are about 8,000 bridges on the state system and 5,000 off-system bridges owned by various entities in the state of Louisiana *[1]*. Title 23 of the US Code mandates sttates to inspect and evaluate all highway bridges for safety and serviceability *[1]*. To comply with this code, all bridges in the state should be evaluated and rated on a regular basis.

Louisiana DOTD has hundreds of bridges for which the as-built plans are missing or incomplete. The unavailability of the needed information will prevent the bridge rater from performing the calculation to decide whether to post such bridge or not. This study identifies the best available nondestructive testing (NDT) and the related costs for determining currently missing as-built information for these bridges.

A comprehensive literature review of the NDT methods is performed, and a summary of the available methods is presented. The required parameters for a successful bridge rating for each type of bridge of interest are presented. Based on the needed parameters established by the experienced bridge rating engineers at H&H, the most suitable technologies were selected for the measurement of the needed parameters.

OBJECTIVE

The purpose of this project is to search and report available technologies and their related costs to determine needed information for LADOTD to perform the load rating for bridges that are missing as-built information. Examples of missing information include items that fall under geometry, such as bridge length, width, and other member dimensions; and items related to the strength of the bridge materials, concrete and/or steel, as well as reinforcing bar locations. Rating strategies will be developed based on the needed parameters for load rating of each type of bridge, such as concrete precast slab (COPCSS), concrete slab (COSLAB), and concrete pre-stressed channel (COPSCH), and to a lesser extent, pre-stressed girder bridges and steel bridges. Timber bridges were not included in this research per the original scope of work.

SCOPE

To determine the needed information, this report primarily focuses on the practice-ready, nondestructive testing methods, with an emphasis on the established national and international standard methods. If there is no standard testing method to determine the required information, then applicable NDT methods in the development phase (experimental) are presented. Successful application of the experimental methods cannot be warranted, and it may be required to perform some limited destructive testing to verify the results of the NDT tests.

METHODOLOGY

Bridge load rating is an important indicator for infrastructure management authorities. To perform a successful bridge load rating, critical information is required for each type of bridge. Four key steps are typically followed to complete load rating analyses: (1) collect member properties, (2) calculate dead loads, (3) determine member capacity and applied loads, and (4) calculate rating factor.

The first step involves the collection of data. If this information is not readily available, then a load rating cannot be performed successfully. This set of parameters was assembled for this report using the extensive experience of the authors and a literature review regarding the required information, software, and methods required to perform a load rating.

When bridge material and geometry data are missing, nondestructive testing (NDT) methods offer the best means to safely and economically determine this information. To identify proper NDT methods for measuring the missing data for different types of bridges, the authors' extensive NDT experience was used to guide a thorough literature view of the available NDT methods from the civil engineering field as well as from related industries, such as aviation, chemical, nuclear, and electronic devices.

The deliverables for this research summarize the information required for a bridge load rating by bridge type and also present the technology available to gather missing information with an analysis of how this technology can be used to determine each parameter required for a bridge rating. The report concludes with a comprehensive and practical tabular presentation for each major bridge type and the required as-built information. These tables provide each required parameter and the NDT methods available to obtain that information. Each NDT method is rated based on cost, ease of use, and data reliability.

DISCUSSION OF RESULTS

Bridge Load Rating, Definition, and Procedure

A Chronological Review of the Bridge Load Rating Methods

Performing a load rating for a new or existing structure produces vital information regarding its capacity and loading threshold. While the concept of load rating has largely remained constant, the methodology used to determine a structure's rating factor has evolved concurrent with design procedures. The traditional rating analysis methods most commonly used are the allowable stress (ASR) and load factor (LFR) methods. However, as the design of new structures has shifted to load resistance factor design (LRFD), load ratings have also shifted to using a load and resistance factor rating (LRFR). These procedures are described in detail in AASHTO's *Manual for Bridge Evaluation [2]*. In addition to the hand calculation methods as laid out in the manual, numerous analysis software programs have been developed that assist in producing rating factors for structures. These programs can be very useful to arrive at rating factors with relative ease for complex structure types and loading sequences. The most well-known load rating program is AASHTOWare bridge, which has the capability of determining the rating factor of a structure for a variety of loading vehicles *[3]*.

Required Parameters for A Successful Bridge Load Rating

Each of the following subsections addresses the information needed for determining the strength capacity of the major system components of main bridge members, which is required for load rating. However, in order to do a complete load rating of the bridges, an accurate account of dead load is required. Therefore, collecting information on sidewalks, barriers, wearing surface, secondary members, utilities, etc., is also required. These elements do not typically require NDT testing and can be measured directly during a hands-on inspection.

Concrete Precast slab (COPCSS). Concrete precast slab bridges consist of shallow rectangular panels that are tied together transversely via concrete closure pours or post-tensioning. These panels behave as both the superstructure as well as the riding surface. The panels may be solid concrete for its full depth or have a series of voids throughout. They are generally reinforced with ASTM A709 or A615 grade 60 reinforcement and may be prestressed *[4]*.

To perform a load rating of this type of structure, the information in Table 1 is required:

Table 1
Required information for load rating of concrete precast slab bridge (COPCSS)

As-Built Geometric Parameters	As-Built Strength Parameters	As-Inspected Strength Parameters
• Span continuity • Number, length and spacing of beams • Slab width • Slab depth • Live loading zones • Bridge skew and radius (if curved) • Superimposed dead loads • Size of internal voids, if present	• Concrete compressive strength • Rebar/strand size • Number of reinforcement layers • Reinforcement location and orientation for each layer • Rebar yield strength	• Overall slab condition • Section loss to rebar (exposed and not exposed) • Concrete slab spalls • Rebar debonding

The as-inspected strength parameters are determined from visual and hands-on inspection techniques, which include sounding of concrete, measuring spalls, and measuring reinforcement diameter. Values such as concrete thickness, original diameter of reinforcement, and debondment length can be verified from the original contract or as-built plans where available.

Figure 1
Multi-span precast slab made continuous for live load over intermediate pier *[5]*

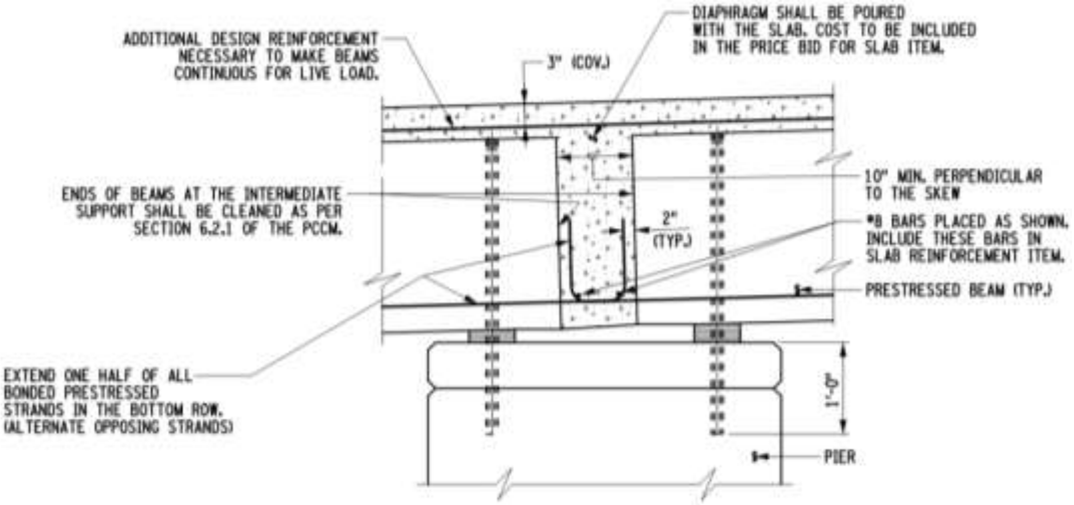


Figure 2
Multi-span precast slab made continuous for live load over intermediate pier *[6]*

Concrete Slab (COSLAB). Concrete slab bridges consist of a continuously poured element that acts as both the superstructure as well as the riding surface. These bridges are similar to precast slab bridges. However, it is less common that these bridges have any voids. They are generally reinforced with ASTM A709 or A615 grade 60 reinforcement and may be post-tensioned *[4]*.

To perform a load rating of this type of structure, the information in Table 2 is required:

Table 2
Required information for load rating of concrete slab bridge (COSLAB)

As-Built Geometric Parameters	As-Built Strength Parameters	As-Inspected Strength Parameters
• Span continuity • Number, length and spacing of beams • Slab width • Slab depth • Live loading zones • Bridge skew and radius (if curved) • Superimposed dead loads	• Concrete compressive strength • Rebar/strand size • Number of reinforcement layers • Reinforcement location and orientation for each layer • Rebar yield strength	• Overall slab condition • Section loss to rebar (exposed and not exposed) • Concrete slab spalls • Rebar debonding

The as-inspected strength parameters are determined from visual and hands-on inspection techniques, which include sounding of concrete, measuring spalls, and measuring reinforcement diameter. Values such as concrete thickness, original diameter of reinforcement, and debondment length can be verified from the original contract or as-built plans where available.

Concrete Prestressed Channel (COPSCH). Concrete prestressed channel bridges consist of a series of C-shaped beams where the web of the channel acts as the deck and riding surface. The flanges of the channels behave similar to rectangular concrete beams that contain prestressing strands to provide flexural strength to the structure.

To perform a load rating of this type of structure, the information in Table 3 is required:

Table 3
Required information for load rating of concrete prestressed channel bridge (COPSCH)

As-Built Geometric Parameters	As-Built Strength Parameters	As-Inspected Strength Parameters
• Span continuity • Number, length, and spacing of beams • Flange width and thickness • Web depth and thickness • Live loading zones • Identify if beams have a shear key • Identify if there is a deck slab and its connection to the beams • Identify if there are diaphragms • Bridge skew and radius (if curved) • Superimposed dead loads	• Concrete compressive strength • Rebar/strand size • Number of reinforcement layers • Rebar and strand location and orientation • Rebar and strand yield strength • Strand contour • Strand bond zone • Stirrup size, spacing, and location • Stirrup yield strength • Deck rebar size and location • Deck rebar yield strength	• Overall beam condition • Section loss to rebar, strands, and stirrups (exposed and not exposed) • Concrete spalls • Rebar and strand debonding

The as-inspected strength parameters are determined from visual and hands-on inspection techniques, which include sounding of concrete, measuring spalls, and measuring reinforcement diameter. Values such as concrete thickness, original diameter of reinforcement, and debondment length can be verified from the original contract or as-built plans where available.

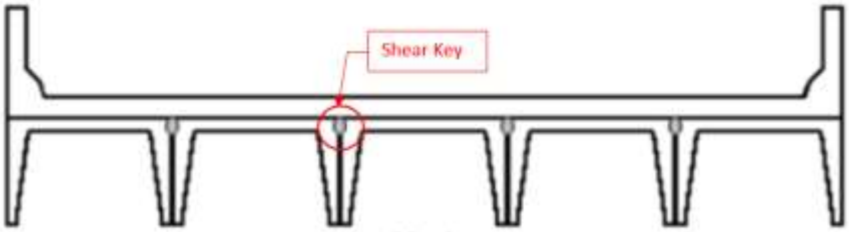


Figure 3
Typical cross section of prestressed concrete channel *[7]*

Figure 4
Concrete channel bridge with diaphragms *[8]*

The most common type of diaphragm used for this type of construction is a rectangular concrete beam. These diaphragms consist of reinforcement that is developed into the legs of the channel via inserts. The concrete for the diaphragm is placed from above through a hole in the web of the channel as shown in Figure 5.

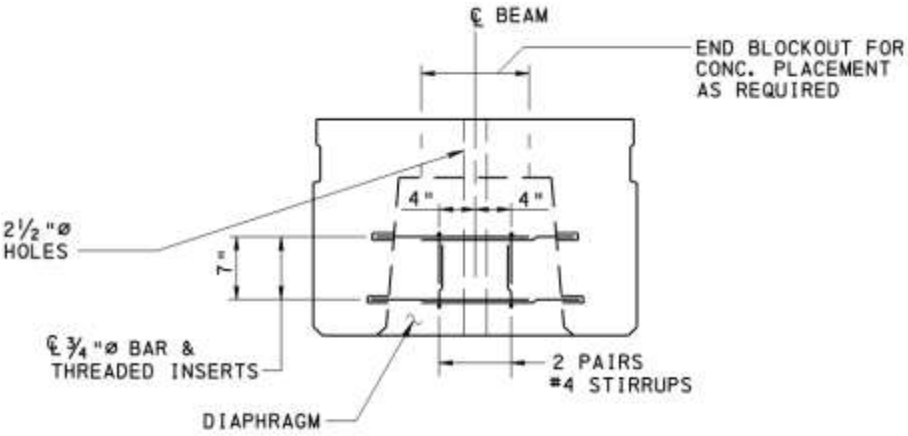


Figure 5
Concrete channel bridge typical connection to deck *[9]*

The typical methodology that is employed to create composite action between the beam and deck is extending reinforcement from the beam into the deck, as shown in Figure 6.

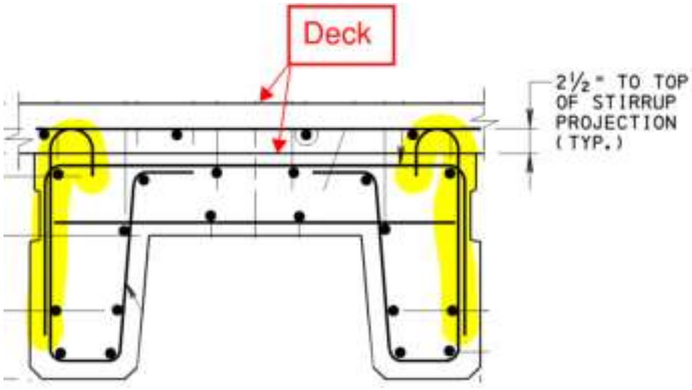


Figure 6
Concrete channel bridge typical connection to deck *[9]*

Prestressed girder bridges. Concrete prestressed girder bridges consist of multiple elements, such as box beams, T-beams, I-girders, etc., that usually act compositely with a deck slab.

To perform a load rating of this type of structure, the information in Table 4 is required:

Table 4
Required information for load rating of prestressed girder bridges

As-Built Geometric Parameters	As-Built Strength Parameters	As-Inspected Strength Parameters
• Span continuity • Girder type, dimensions, spacing, number, and length • Live loading zones • Identify if beams have a shear key (where applicable) • Identify if there is a deck slab and its connection to the beams • Identify if there are diaphragms • Bridge skew and radius (if curved) • Superimposed dead loads	• Concrete compressive strength • Rebar/strand size • Number of rebar layers • Rebar and strand location and orientation • Rebar and strand yield strength • Strand bond zone • Strand contour • Strand prestressing forces • Stirrup size, spacing, and location • Stirrup yield strength • Deck rebar size and location • Deck rebar yield strength	• Overall beam condition • Section loss to rebar, strands, and stirrups (exposed and not exposed) • Concrete spalls • Rebar and strand debonding

The as-inspected strength parameters are determined from visual and hands-on inspection techniques, which include sounding of concrete, measuring spalls, and measuring reinforcement diameter. Values such as concrete thickness, original diameter of reinforcement, and debonding length can be verified from the original contract or as-built plans where available.

Adjacent box beam bridges can be tied together transversely via grouting and/or post-tensioning, as shown in Figure 7, to ensure all beams are acting as a unit and differential deflection does not occur between adjacent members.

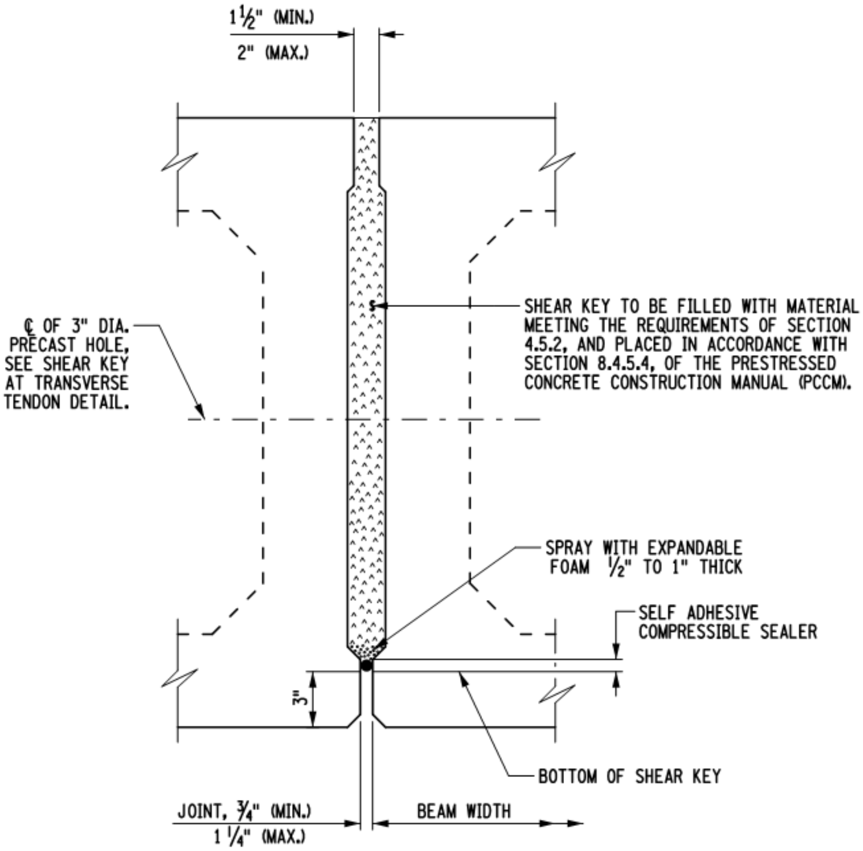


Figure 7
Concrete channel bridge typical connection to deck *[6]*

Steel Bridges. Steel bridges consist of a multitude of various types, such as multi girder, floor system (girder, floor beam, stringer), truss, arch, cable, open box beam, etc. The deck/riding surface for these systems can also vary from concrete slab, steel grid (open, filled, and partially filled), steel plate, orthotropic, etc.

To perform a load rating of this type of structure, the information in Table 5 is required:

Table 5
Required information for load rating of steel bridge primary system

As-Built Geometric Parameters	As-Built Strength Parameters	As-Inspected Strength Parameters
• Bridge type • Span continuity • Deck type • Girder type (if applicable) • Girder dimensions, length, spacing • Number of girders • Shear stud size and spacing • Live loading zones • Deck thickness and connection • Identify if there are diaphragms • Bridge skew, radius (if curved) • Superimposed dead loads	• Concrete compressive strength (if applicable) • Deck rebar size • Number of reinforcement layers • Deck rebar location and orientation • Deck rebar yield strength • Steel member yield strength	• Section loss and deformations to steel members in high stress areas • Spalled deck • Deck rebar section loss • Deck rebar debonding • Deck connection (if applicable)

Elements that make up steel bridges are assembled via connections and connector elements, which are required to transfer force from one member to another. These connections generally consist of bolts, rivets, welds, gusset plates, splice plates, or connector plates.

To perform a load rating of this type of structure, the information in Table 6 is also required:

Table 6
Required information for load rating of steel bridge connections

As-Built Geometric Parameters	As-Built Strength Parameters	As-Inspected Strength Parameters
• Number of bolts/rivets • Bolt/rivet size • Bolt/rivet center to center spacing and edge distance • Bolt/rivet group pattern and total length • Bolt thread length/stick through • Hole size and orientation of slot (if applicable) • Weld length • Identify connection type • Thickness of connected members • Number of connected piles	• Steel member yield strength • Bolt material type • Filler metal strength • Weld size • Surface condition of connected members	• Section loss and deformations to connected members and to bolts/rivets • Missing or loose bolts/rivets • Sheared bolts/rivets • Cracked welds • Cracked connected members • Detection of slip between connected members or stress deformations in steel • Gaps or pack rust between connected members

Nondestructive Testing Methods

According to the American Society of Nondestructive Testing (ASNT), “nondestructive testing (NDT) is the process of inspecting, testing, or evaluating materials, components or assemblies for discontinuities, or differences in characteristics without destroying the serviceability of the part or system” *[10]*.

According to ACI 301-99, the use of nondestructive testing is restricted as the sole basis for accepting or rejecting concrete, though they may be used to “evaluate” concrete when the standard-cured cylinder strengths fail to meet the specified strength criteria *[11]*. For using an in-place test method, sufficient correlation data between cored or existing cylinders and the measured in-situ parameters are required *[12]*. In-place testing does not eliminate the need for coring, but it can reduce the total amount of coring needed to evaluate a large volume of concrete. For existing construction, the relationship is usually established by performing in-place tests at selected locations in the structure and determining the strength of cores drilled from adjacent locations. Figure 8 is a schematic of a strength relationship in which the cylinder compressive strength is plotted as a function of an in-place test result. This relationship would be used to estimate the strength of concrete in a structure based on the value of the in-place test result obtained from testing the structure. The accuracy of the strength estimate depends on the degree of correlation between the strength of concrete and the quantity measured by the in-place test *[12]*.

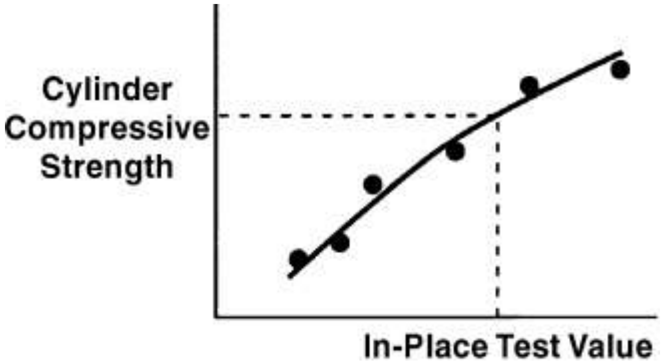


Figure 8
Schematic of relationship between cylinder compressive strength and in-place test value *[12]*

The nondestructive testing (NDT) methods for the inspection of concrete and steel bridges are summarized in the following sections. The following discussion divides the NDT techniques into six technology categories:

- Mechanical Impact
- Acoustic
- Electromagnetic
- Electrical/Chemical
- Nuclear
- Miscellaneous

Mechanical Impact

Static or dynamic stress fields are generated to identify mechanical peroperties of materials. The dynamic test provides information on the elastic behavior of the material (modulus) and the static test transcends the elastic phase and indicates the point of failure (strength) *[13]*.

Rebound Number (ASTM C 805). The operation of the rebound hammer (also called the Schmidt Hammer or Swiss Hammer) is illustrated in Figure 9. The device consists of the following main components: (1) outer body, (2) plunger, (3) hammer, and (4) spring. To perform the test, the plunger is extended from the body of the instrument and brought into contact with the concrete surface. When the plunger is extended, a latching mechanism locks the hammer to the upper end of the plunger. The body of the instrument is then pushed toward the concrete member. This action causes an extension of the spring connecting the hammer to the body (Figure 9(b)). When the body is pushed to its limit of travel, the latch is released, and the spring pulls the hammer toward the concrete member (Figure 9(c)). The hammer impacts the shoulder area of the plunger and rebounds (Figure 9(d)). The rebounding hammer moves the slide indicator, which records the rebound distance. The rebound distance is measured on a scale numbered from 10 to 100 and is recorded as the rebound number. This test method is applicable to assess the in-place uniformity of concrete, to delineate variations in concrete quality throughout a structure, and to estimate in-place strength if a correlation is developed between rebound numbers measured on the structure with the measured strengths of cores taken from corresponding locations (ASTM C 805) *[12, 14]*.

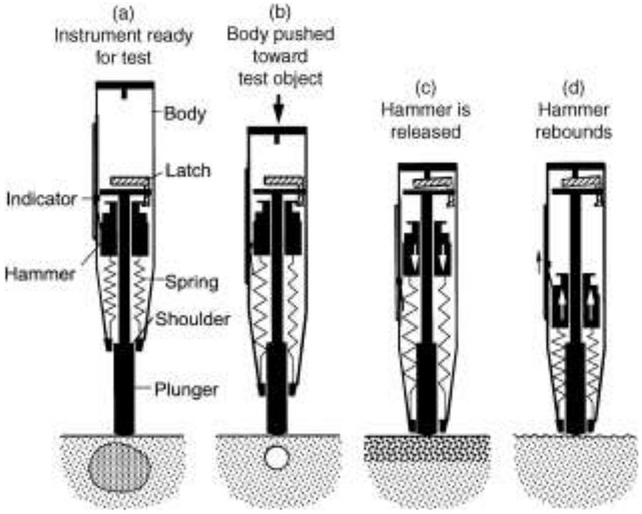


Figure 9
Schematic to illustrate operation of the rebound hammer ***[12]***

Penetration Resistance (ASTM C 803/C 803M). In the penetration-resistance technique, the depth of penetration of a probe or a pin forced into the hardened concrete is measured. The depth of penetration of the probe is an indicator of the concrete strength. Penetration tests are less affected by surface conditions than the rebound number method. The coarse aggregate, however, has a significant effect on the resulting penetration. For the gun-driven probe system, the type of coarse aggregate affects the strength relationship; for the spring-driven pin system, tests that impact coarse aggregate particles are disregarded. It is standardized by ASTM C803 / C803M-17, "Standard Test Method for Penetration Resistance of Hardened Concrete" *[12, 15]*.

Pullout Test for Existing Structures (ASTM C 900). The pullout test can be used to estimate the strength of concrete by measuring the force required to extract an insert embedded in fresh concrete or installed in hardened concrete. In existing construction, it is possible to perform pullout tests using post-installed inserts. There is a strong relationship between the compressive strength of concrete and pullout strength. The procedure for performing post-installed pullout tests in existing structures based on ASTM C900 is summarized in Figure 10. *[12, 16]*

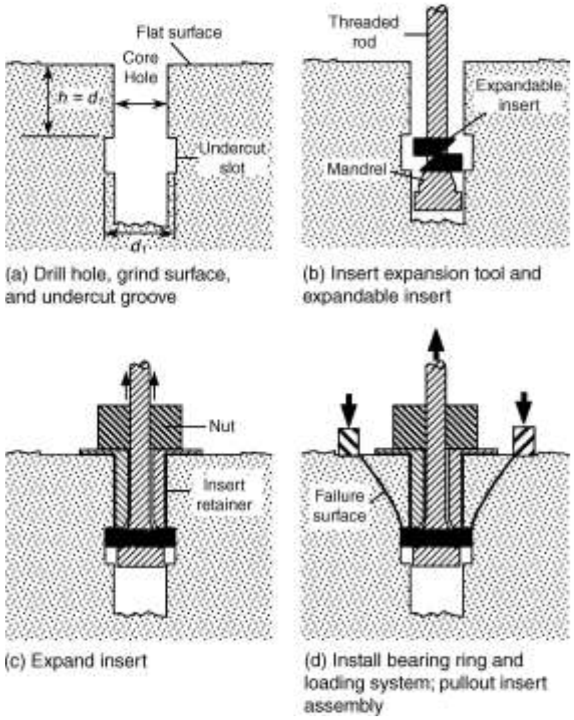


Figure 10
Technique for post-installed pullout test *[12]*

In a commercial test system, known as CAPO (for Cut And Pull Out), the insert is a coiled, split ring that is expanded with specially designed hardware. The CAPO system performs similarly to the cast-in-place system of the same geometry *[12, 17, 18]*.

Acoustic

In these methods, static or dynamic stress waves are produced using acoustic/mechanical impact to determine mechanical characteristics of materials. Changes in the behavior of the waves within materials provide information to detect reinforcing bars, voids, cracks, delaminations, and other interfaces or inclusions. Acoustic wave spectrum and the frequency range for different acoustic NDT methods are presented in Figure 11*[19]*.

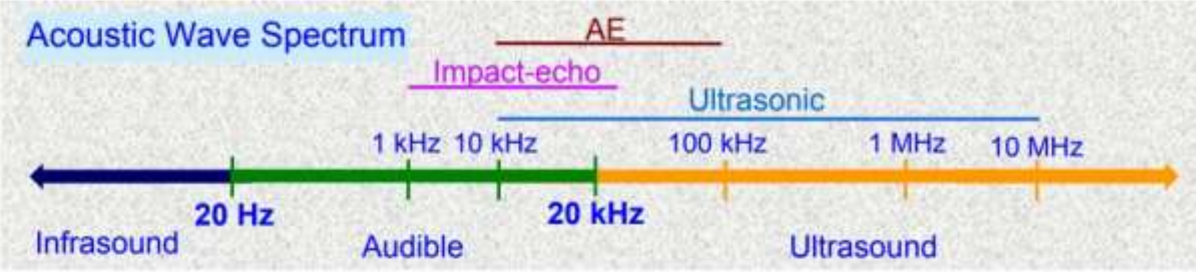


Figure 11
The frequency range for different acoustic NDT methods *[19]*

Figure 12 presents possible travel paths of stress waves generated by mechanical impact to sensors in forward scattering field *[20]*.

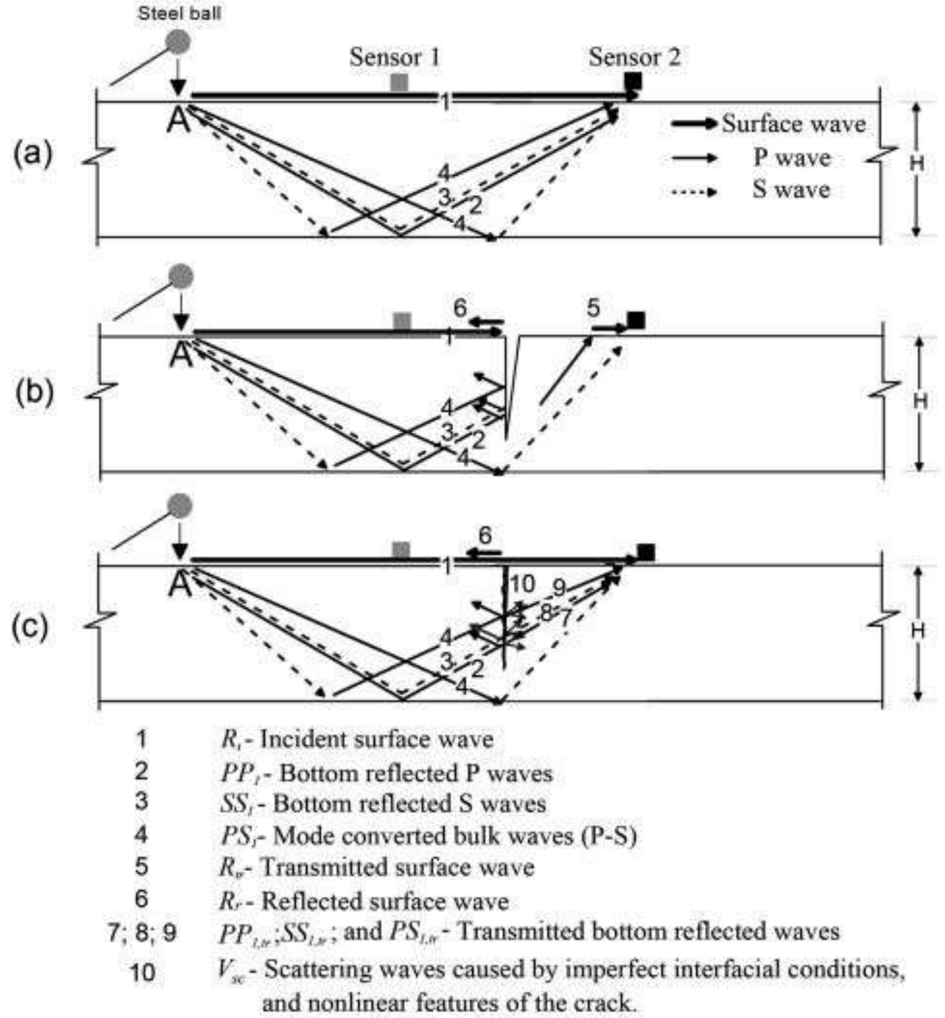


Figure 12
Possible travel paths of stress waves generated by mechanical impact to sensors in forward scattering field (a) before cracking, (b) after cracking with open crack, and (c) partially closed crack *[20]*

Ultrasonic Pulse Velocity. The time of travel for an ultrasonic pulse through concrete is used in this method to detect elastic properties, density, and uniformity of concrete based on ASTM C597-16 "Standard test method for pulse velocity through concrete" *[21]*. Ultrasonic pulse velocity (UPV) test method can be used to determine the extent of defects, including voids, honeycombing, cracks, and segregation. This method requires access to both sides of the member. Figure 13 presents the effects of defects on travel time of ultrasonic pulse and schematics of UPV test *[22]*.

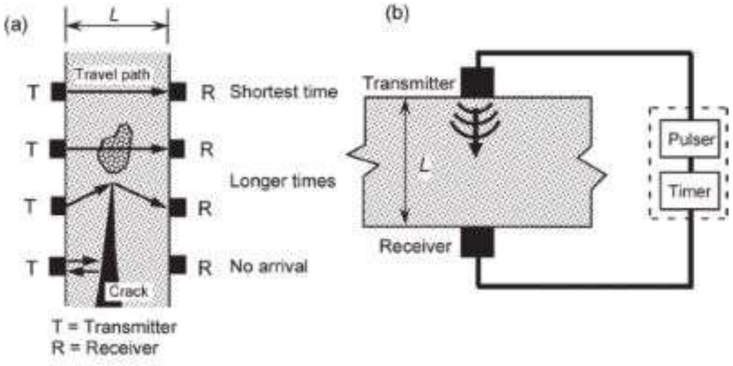


Figure 13
(a) Effects of defects on travel time of ultrasonic pulse, and (b) schematic of through-transmission test system *[22]*

The ultrasonic pulse velocity is proportional to the square root of the elastic modulus, which may provide a means of estimating strength of concrete, even though there is no direct physical relationship between these two properties *[22]*. Because elastic modulus and strength are not linearly related, pulse velocity is inherently a less-sensitive indicator of concrete strength as strength increases. The amount and type of aggregate has a strong influence on the pulse velocity versus strength relationship, and the in-place pulse velocity is affected by moisture content and the presence of steel reinforcement *[12, 21]*.

Ultrasonic Pulse Echo. Ultrasonic pulse-echo techniques can be used to determine the integrity of materials by accessing only one surface of the concrete structure under investigation. The principle of the echo tests is shown in Figure 14. This method measures the change in acoustic impedance at various interfaces, voids, reinforcing bars, cracks, delaminations, and other interfaces *[13]*.

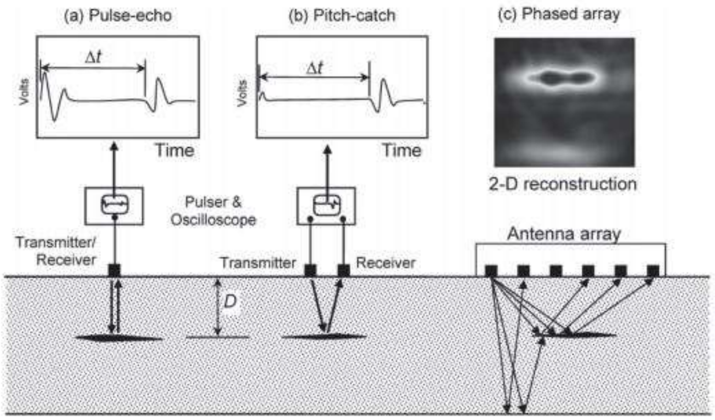


Figure 14
Schematic of ultrasonic-echo methods: (a) pulse-echo method, (b) pitch-catch method, and (c) multiple pitch-catch using transducer array *[22]*

ASTM E797 provides guidelines for measuring the thickness of materials using the contact pulse-echo method. This practice is applicable to any material in which ultrasonic waves will propagate at a constant velocity throughout the part, and from which back reflections can be obtained and resolved. Ultrasonic thickness measurements are used extensively on basic shapes and products of many materials, on precision machined parts, and to determine wall thinning in process equipment caused by corrosion and erosion. In addition, ultrasonic testing can be used to inspect welds, bolts, and rivets of steel members *[23]*.

According to FHWA Technical Advisory 5140.31, ultrasonic testing (UT) can be used to determine the remaining section thicknesses in gusset plates that have areas that cannot be seen *[24]*. Ultrasonic thickness measuring devices (also known as D-meters) are attainable, inexpensive, and easy to use *[25]*.

Impact-echo. In the impact-echo method, a mechanical impact is used to produce stress waves in material. The location and extent of the defect can be determined by identifying the dominant frequencies associated with reflections of the stress waves. The principle of the impact-echo technique is illustrated in Figure 15 *[22]*. The impact-echo technique can be used for determining the thickness and flaws in plate-like structural members, such as slabs and bridge decks with or without overlays. The use of the impact-echo method for determination of the thickness of concrete plate elements was standardized in ASTM C1383 *[26]*.

The impact-echo technique has been used for detecting flaws in beams, columns, and hollow cylindrical structural members; assessing the quality of bond in overlays; measuring crack depth; and void detection in grouted ducts of post-tensioned bridge beams.

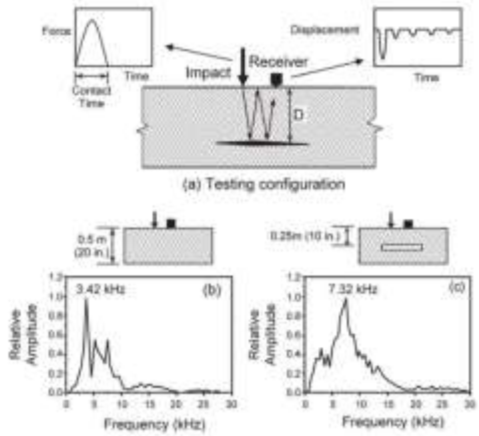


Figure 15
(a) Schematic of impact-echo method, (b) amplitude spectrum for test of solid slab, and (c) amplitude spectrum for test over void in slab *[22]*

Spectral Analysis of Surface Wave (SASW). In this method, R-waves are generated using a series of mechanical impacts with variable excitation frequencies. The general test configuration is illustrated in Figure 16. Two accelerometers are used to capture the R-wave frequencies that propagate along the surface. This data is used to infer the stiffness of the underlying layers *[22]*. Measured changes in the elastic properties of concrete slabs by SASW are used for the preliminary assessment of material stiffness, condition, and layer thickness *[13]*.

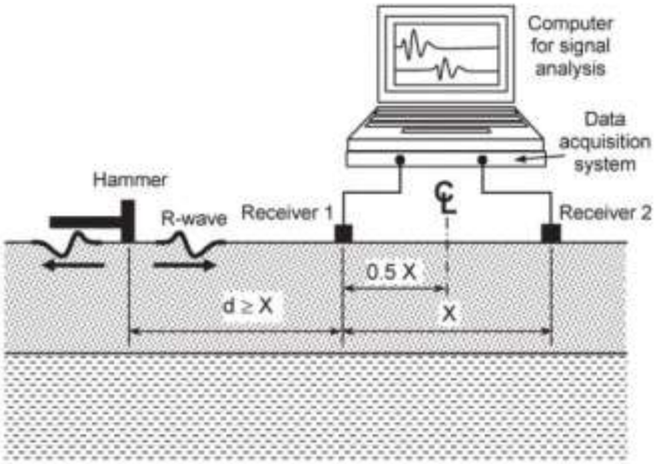


Figure 16
Schematic of spectral analysis of surface wave (SASW) method *[22]*

An ultrasonic transducer can be used to produce excitations on a concrete surface. This method is called ultrasonic surface wave (USW) and can be used to obtain the concrete modulus profile *[27]*. Data from a USW test is typically presented as the concrete modulus distribution. Figure 17 presents an example contour map of concrete modulus distribution obtained from USW testing *[28]*.

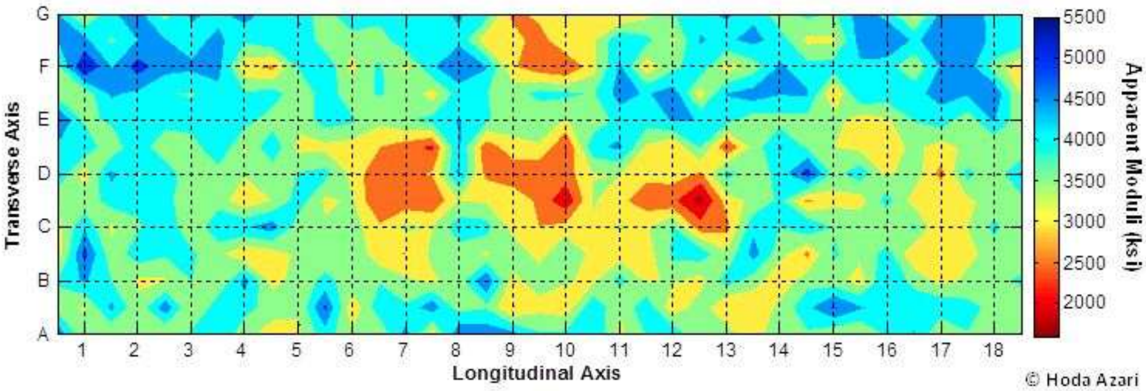


Figure 17
Contour map of concrete modulus distribution from USW testing *[28]*

Impulse Response. The impulse response method uses a low-strain impact typically by a 3-lb (1.5 kg) instrumented hammer with a plastic tip to send stress waves through the tested element *[22]*.

The frequency spectra from the impact hammer sensor and the response at the nearby transducer (displacement, geophone, or accelerometer) are obtained, as shown in Figure 18. The ratio of the displacement and impact spectra represents a flexibility spectrum, and the ratio of the velocity and impact spectra is termed mobility spectrum. ASTM C1740 standardized the impulse response method to evaluate the condition of concrete plates *[29]*.

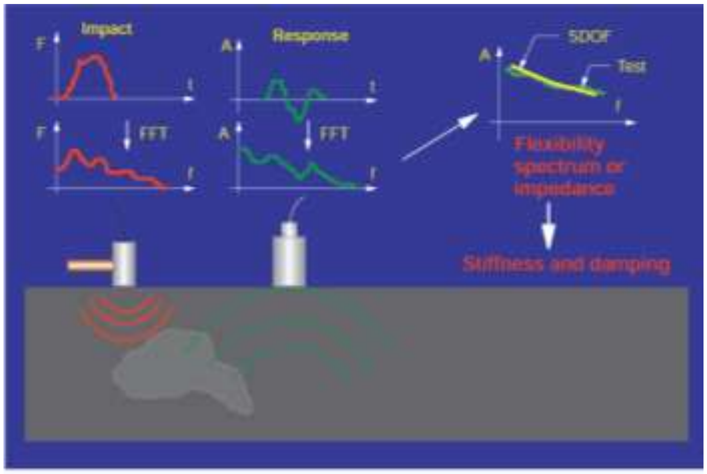


Figure 18
Principle of impulse response testing *[30]*

Acoustic Emission (AE). According to ASTM E 1316 “Standard Terminology for Nondestructive Examinations,” acoustic emission is defined as “the class of phenomena whereby transient elastic waves are generated by the rapid release of energy from localized sources within a material.” *[31]*. ASTM E3100 standardized the acoustic emission examination of concrete structures. The acoustic emission method can be used to detect and monitor internal cracks growing in the concrete, assess crack growth rate as a function of different load or environmental conditions, or to detect concrete micro-cracking due to significant rebar corrosion *[32]*. Acoustic emission is a continuous real-time structural monitoring method. Figure 19 presents a schematic illustration of the principle of the acoustic emission process.

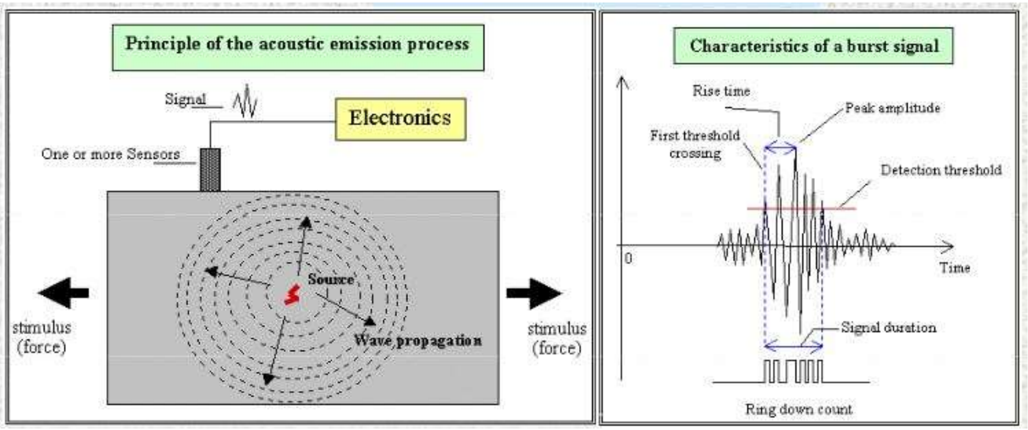


Figure 19
Schematic illustrating the principle of the AE process, and the characteristics of typical burst signals recorded from the sensor *[19]*

Ultrasonic Phased Arrays / Ultrasonic Phase Spectroscopy. In this method, a transducer assembly with multiple elements arranged in a strip (linear array), a ring (annular array), a circular matrix (circular array), or a more complex shape is used for mapping components at appropriate angles, and the inspection of components with complex geometries. This method can be used in weld inspection, bond testing, thickness profiling, and in-service crack detection *[13]*. Figure 20 presents a schematic view of a phased array probe arangement *[33]*.

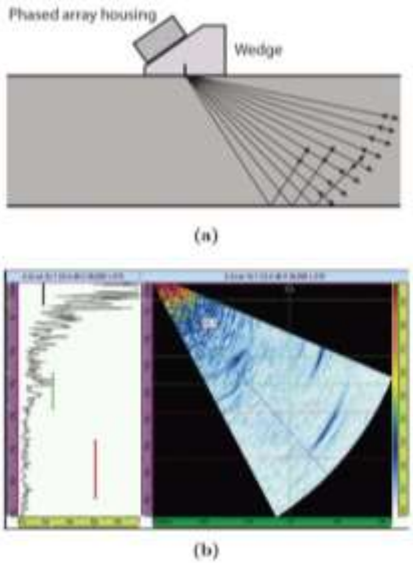


Figure 20
Schematic of (a) a PA probe arrangement and (b) an example of data display in sectorial scan presentation. By sweeping the ultrasonic beam, a weld volume can be inspected *[33]*

Standard Practice for Measuring Delaminations in Concrete Bridge Decks by sounding. Methods described in ASTM D4580 / D4580M - 12(2018) may be used in determining the general condition of concrete bridge decks by sounding to determine any delamination in the concrete. It is not intended that the procedures described in this standard practice to be used on bridge decks that have been overlaid with bituminous mixtures. The following three procedures are covered in this practice *[34]*.

- Electro-mechanical sounding device: This procedure uses an electric-powered tapping device, sonic receiver, and recorder mounted on a cart. The cart is pushed across the bridge deck, and delaminations are recorded on the recorder *[34]*.
- Chain drag: This procedure consists of dragging a chain over the bridge deck surface. The detection of delaminations is accomplished by the operator noting dull or hollow sounds. Tapping the bridge deck surface with a steel rod or hammer may be substituted for the chain drag *[34]*.
- Rotary percussion: This procedure consists of rolling a dual-wheel, multi-toothed apparatus attached to an extension pole over the bridge deck surface. The percussive force caused by the tapping wheels will create either a dull or hollow sound, indicating any delamination *[34]*.

Hardness. The hardness test measures the material's resistance to plastic deformation. There usually is an indentation made on the surface of the material. If the hardness test is made without indentation by using eddy currents or ultrasonic, it can be considered truly nondestructive *[35]*. ASTM A1038 defines the procedure for performing a portable hardness test by the ultrasonic contact impedance method *[36]*. As it is shown in ASTM A370, there is a correlation between the hardness number and the tensile strength of steel *[37]*. According to a survey performed by Thiel et al. (2001), the Arizona Department of Transportation used in-situ hardness testing for material confirmation *[38]*.

Electromagnetic

In these methods, electromagnetic waves are produced (no net electrical current passing through the element) and transmitted or reflected waves are used to identify inclusions and voids within materials *[13]*.

Ground Penetrating RADAR (GPR). In Radio Detection and Ranging (RADAR), the reflection of the emitted electromagnetic waves, which are radio- or micro-waves, is used to detect objects in different medium.

Ground Penetrating RADAR (GPR) is a radar system developed for detecting buried objects in the ground or concrete. The working principle of GPR is presented in Figure 21, where an electromagnetic pulse is emitted via a transmitter antenna, and the reflected waves at the surface and interior layer boundaries of an object are recorded via the receiver antenna *[39]*.

ASTM D6087 - 08(2015)e1 “Standard Test Method for Evaluating Asphalt-Covered Concrete Bridge Decks Using Ground Penetrating Radar” describes the process for evaluation of concrete bridge deck with RADAR *[40]*.

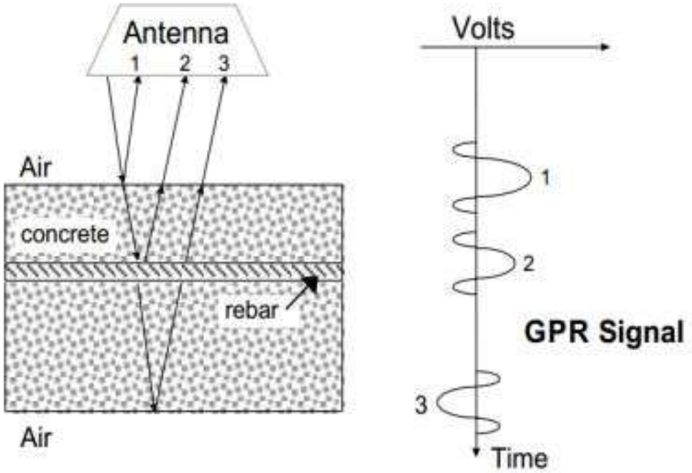


Figure 21
GPR signal for concrete bridge deck *[41]*

Light Detection and Ranging (LiDAR). According to FHWA (2016), “Light Detection and Ranging (LiDAR) is a remote sensing method that uses pulsed laser light to examine terrain and generate precise, three dimensional (3D) information regarding surface shape and characteristics. *[42]* LiDAR estimates a distance from the device to a target point by measuring the time of flight or phase shift of the reflected laser beam , and can be used for long-range and large-area scanning *[43]*. Figure 22 shows the two working principles of LiDAR. The red solid line and blue dotted line denote the paths of the reference and reflected laser beam, respectively. BS, D, T, and φ refer to a beam splitter, distance to the target, time of flight of the reflected laser pulse, and phase difference between two laser beams, respectively *[44]*.

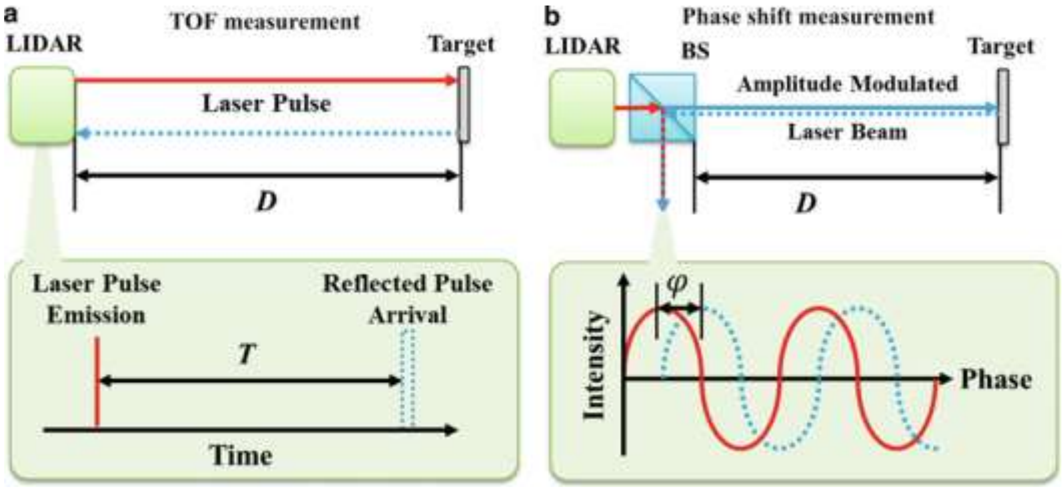


Figure 22
Schematic diagram of LiDAR measurement working principle: (a) time of flight measurement and (b) phase shift measurement *[44]*

ASTM standard E2938 helps evaluate the measurement performance of 3D imaging systems for the selection of a suitable instrument that has an acceptable range and error *[45]*.

The three platforms for collecting LiDAR data are drone, helicopter or fixed wing airplane, vehicle (truck or van), and tripod. The vertical accuracies of LiDAR measurements based on the platform are shown in Table 7.

Table 7
Vertical accuracies of LiDAR data acquisition methods *[42]*

Method	Network Accuracy (RMS)[1]
Fixed Wing Aerial LiDAR/Photogrammetry	3 in. – 6 in.
Low Altitude Helicopter LiDAR/Photogrammetry	1 in. - 2 in.
Mobile LiDAR	1/2 in. - 1 in.
Tripod-Mounted Static LiDAR	1/4 in.- 1/2 in.

[1] Root Mean Square

Magnetic Flux Leakage. Discontinuities in a material cause distortions in the flux lines of a magnetized member. In the Magnetic Flux Leakage method, the Hall Effect sensor, an electronic device, is used to identify these discontinuities. Magnetic Flux Leakage can reveal both internal and external flaws in the material *[38]*. A standard test method has been developed for the inspection of steel wire rope (ASTM E1571 - 11(2016)e1) and steel tubular products (ASTM E570 - 15e1) based on the magnetic flux leakage method *[46, 47]*.

Eddy Current Array. Eddy current array allows for a fast examination of carbon steel welds for surface-breaking cracks located on the surface closest to the sensor. ASTM E3052 describes the standard methods for the detection of surface cracks in the carbon steel welds using the eddy current array method *[48]*.

The principle of the eddy current flow detection is based on the flow of an electrical current through a wire coil. If the coil is placed near an electrical conductive material, the electromagnetic field permeates the material and causes the flow of an electrical current within the material. These currents flow circularly and parallel to the surface. Due to the fact that they diminish quickly with increasing depth, they are called eddy currents. Since the flowing of the electrical current causes an electromagnetic field, another electromagnetic field is brought into existence. The second electromagnetic field in this consideration, is called secondary field in contrast to the exciting field, which is also called the primary field. These electromagnetic fields are counteracting, forming a resulting electromagnetic field, which is detected and measured by a second coil rendering a measuring voltage *[49]*. Defect inspection is based on the fact that these measured voltages differ in cases of sound and defective material *[49]*. A schematic illustration of the principle of the flow detection by the eddy current method is shown in Figure 23.

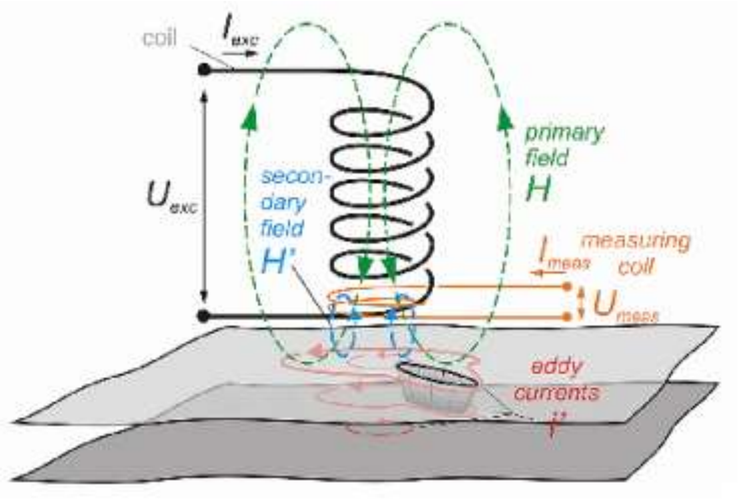
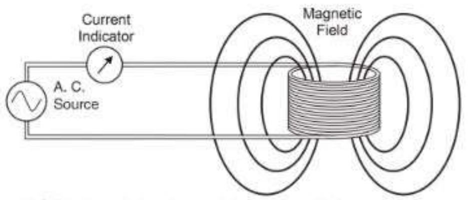
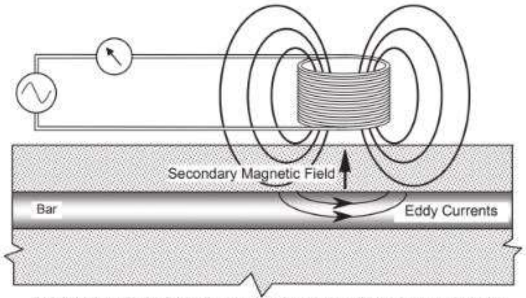


Figure 23
Principle of eddy current technology *[49]*

Eddy currents can also be used to determine the concrete cover over reinforcing steel. BS standard 1881-204:1998, "Recommendations on the Use of Electromagnetic Covermeters," provides guidance on the usage of covermeters as illustrated in Figure 24 *[50]*.



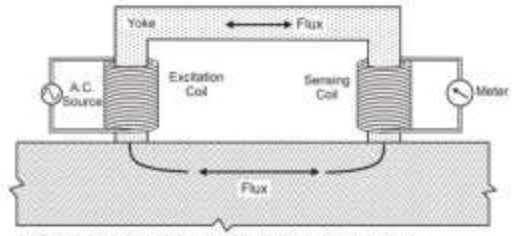
(a) Coil in air results in a characteristic current amplitude.



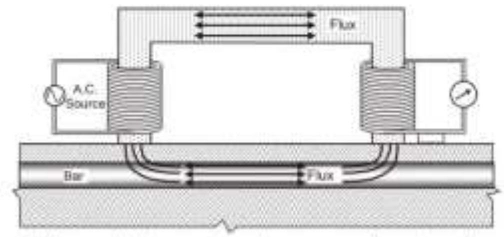
(b) Interaction with reinforcing bar causes changes in coil impedance and current amplitude.

Figure 24
Cover meter based on eddy current *[22]*

Magnetic Reluctance. The resistance to magnetic flux is called reluctance. Figure 25 shows the working principle of a covermeter based on the changes in the reluctance of a magnetic circuit. The reluctance of the magnetic circuit depends strongly on the distance between the bar and the poles of the yoke and the size of the bar. An increase in a concrete cover increases the reluctance and reduces the current in the sensing coil. If the reluctance was plotted as a function of the cover for each bar size, it could be used to measure the cover *[22]*.



(a) Small current induced in sensing coil when no bar is present.



(b) Presence of bar increases flux and increases current in sensing coil

Figure 25
Cover meter based on principle of magnetic reluctance *[22]*

Magnetic Particle. The magnetic particle method of nondestructive testing indicates the presence of surface and near-surface discontinuities in materials that can be magnetized (ferromagnetic). This method can be used for production examination of parts/components or structures and for field applications where portability of equipment and accessibility to the area to be examined are factors (ASTM E709) *[51]*. ASTM E1444 establishes minimum requirements for magnetic particle testing used for the detection of surface or slightly subsurface discontinuities in ferromagnetic material *[52]*. Guide ASTM E709 can be used in conjunction with this practice as a tutorial.

The area of a member to be examined can be magnetized by applying a current to the member. Fine iron powder flakes are applied to the magnetized area. The iron powder accumulates along flux lines and at locations where discontinuities in the material prevent the smooth flow of current. This method can be used to identify surface flaws but does not locate internal flaws *[38]*.

Infrared Thermography (passive and active). Infrared (IR) thermography methods are non-contact temperature mesurement methods that are used to visualize and quantify damage by detecting changes in heat transfer characteristics near the defect using an IR camera *[44]*. In the passive IR method, the natural sunlight and the ambient temperature are used as the heat source. Clark et al. detected delamination in a concrete slab of a bridge by detecting regions with abnormal temperature in comparison with the rest of the areas by using sunlight as a passive heat source *[53]*.

In active thermography methods, a controlled heat source, such as a halogen lamp, and an acoustic transducer are used *[54]*. Recently, a high-power laser has been used as a heat source for active thermography *[55]*. ASTM D4788-03(2013) standardized the test method for detecting delamination in bridge decks using infrared thermography *[56]*.

Electrical/Chemical

In these methods, a net alternating or direct current passes through the element. Electrical or electrochemical instrumentation is used to identify changes in the chemical state of the material based on a reference cell *[13]*.

Half-cell Potential. In half-cell potential, the voltage (i.e., potential difference) between the steel reinforcement and a standard reference electrode is measured to indicate the likelihood of reinforcement corrosion. The half-cell potential method is used to determine the likelihood of corrosion activity. The standard test method is given in ASTM C876 and is illustrated in Figure 26. It is often necessary to use other data, such as chloride contents, depth of carbonation, delamination survey findings, rate of corrosion results, and environmental exposure conditions, in addition to corrosion potential measurements, to formulate conclusions concerning corrosion activity of embedded steel and its probable effect on the service life of a structure *[22, 57]*.

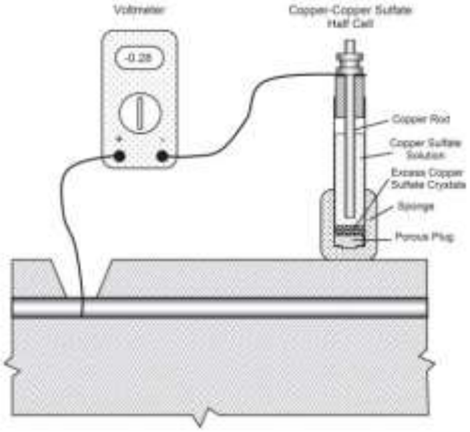


Figure 26
Half-cell potential method *[22]*

Electrical Resistivity. In this method, concrete is part of an electrical circuit where the amount of current that will flow for a given voltage is a measure of the concrete resistivity. The corrosion rate of the concrete is a function of electrical resistivity *[13]*. The electrical resistivity can be used for predicting the degradation process of concrete structures *[58]*. Electrical resistivity has been used as a measure of concrete to resist chloride ingress, and the process is described in ASTM C1202 - 18 “Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration” *[59]*. Figure 27 presents a schematic view of the four-point Wenner probe for determining the resistivity of field concrete.

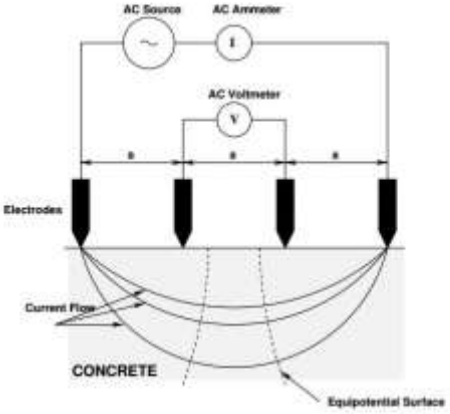


Figure 27
Four-probe method for measuring concrete resistivity *[19]*

Nuclear

Neutron sources can be used to measure the amount of moisture in concrete and to determine the elemental composition of concrete. All nuclear test methods require test personnel to have specialized safety training and licensing. The application of nuclear tests is limited due to safety considerations of generating sufficiently high-energy neutrons to pass through large concrete elements *[19, 60]*.

Direct Transmission Techniques. Direct transmission techniques can be used to detect reinforcement in concrete structures and the in-place density both in fresh and hardened concrete (ASTM C1040/C1040M) *[22]*. In Figure 28, the working principle of the direct transmission techniques is illustrated. As it is shown, the radiation source is placed on one side and the detector is placed on the opposite side of the concrete element. As the radiation passes through the concrete, a portion is scattered by free electrons, and another portion is absorbed by atoms. The amount of the scattering depends on the density of the concrete, and the amount of absorption depends on chemical composition *[22]*.

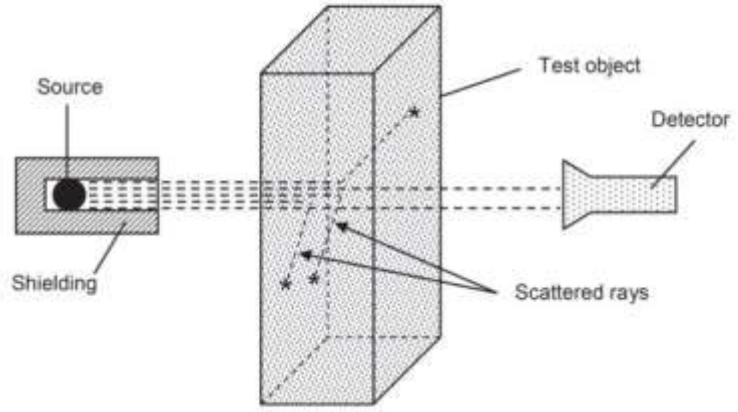


Figure 28
Direct transmission radiometry with source and detector external to test object *[22]*

Backscatter Radiometry for Density. The procedure for using the backscatter method to measure the density of hardened concrete is illustrated in Figure 29.

Backscatter technique is best suited for measurement of the density of the surface zone of a concrete element. A good example of this method is monitoring the density of bridge deck overlays *[22]*.

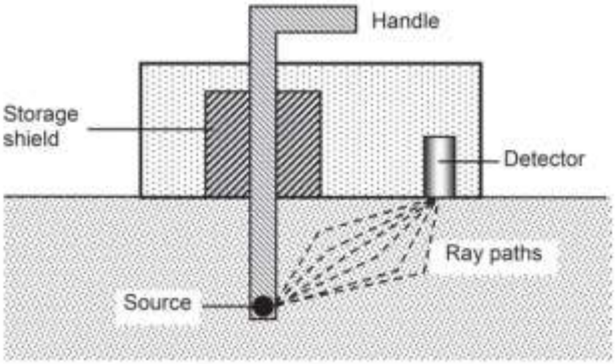


Figure 29
Schematic of backscatter nuclear density gauge *[22]*

Radiography. In the radiography method, electromagnetic radiation is used to determine the location and extent of imperfections. This method can be used to detect cracks, voids, honeycombs, ducts, and the location of reinforcing steel. Moreover, radiographic method is used to inspect the quality of butt welds in the fabrication of steel plates for bridge girders, as indications of cracks and discontinuities in the welds will show up as darker areas on the high contrast image *[61]*. ASTM E390 describes the standard method for radiographic inspection of the steel fusion welds *[62]*. According to Ocel, radiography appears to be a viable tool to determine section loss and its magnitude (area and depth) in multilayered gusset plate connections *[25]*.

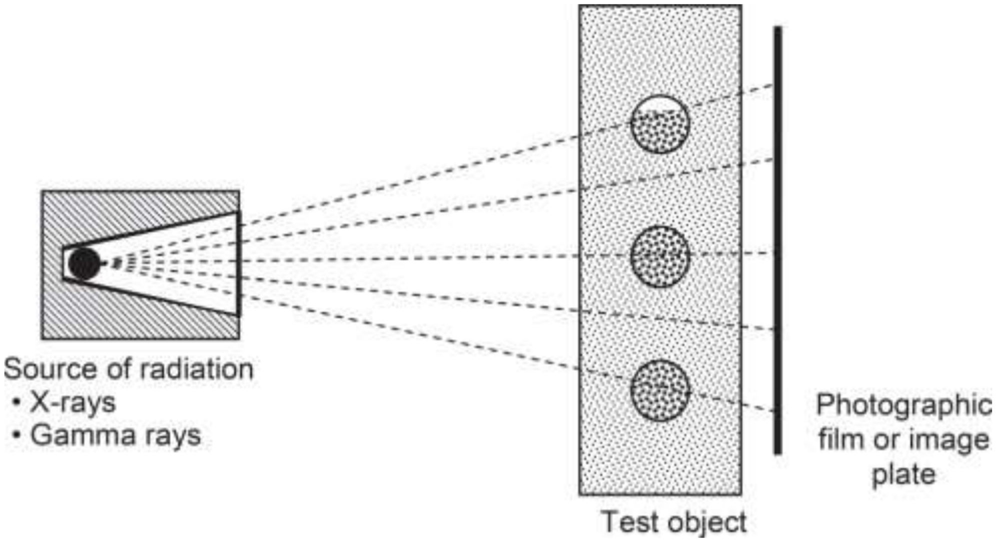


Figure 30
Schematic of radiographic method *[22]*

Miscellaneous

Liquid Penetrant Testing. Penetrant testing is a nondestructive testing method for detecting discontinuities that are open to the surface, such as cracks, seams, laps, cold shuts, shrinkage, laminations, through leaks, or lack of fusion. This is applicable to in-process, final, and maintenance examinations. It can be effectively used in the examination of nonporous, metallic materials, ferrous and nonferrous metals, and of nonmetallic materials, such as nonporous glazed or fully densified ceramics, as well as certain nonporous plastics, and glass (ASTM E1417).

ASTM E165 covers procedures for penetrant examination of materials and ASTM E1417 establishes the minimum requirements for conducting liquid penetrant examination of nonporous metal, and nonmetal components. Liquid penetrant testing can be used to verify and measure existing surface cracks on a steel bridge member. The surface to be examined is first cleaned, and a dye is applied to the member. A developer is administered, which reveals the cracks on the exterior of the member *[38, 63, 64]*.

Visual Inspection and Direct Measurement. Many parameters required for load rating can be obtained by visual observation of the structure and by measuring the visible components. This technique would include photographic documentation of visible components and documentation of measurements, either photographically or in writing.

NDT Methods Organized by Type of Testing

Table 8 organizes this content by the type of testing required for bridge load ratings. This table provides the standard by which the test is performed, the type of technology, an average cost range to obtain the testing in the field and whether lane closure is required for the test. .

Table 8
NDT methods organized by type of testing required for bridge load rating

NDT Method	Standard	Technology	Cost Range	Lane Closure
Determining Concrete Properties				
Ultrasonic pulse echo	ASTM E797	Acoustic	$1,700	Y
Impact-echo	ASTM C1383	Acoustic	$2,500+	Y
Spectral analysis of surface wave	---	Acoustic	$3,500	Y
Impulse response	ASTM C1740	Acoustic	$2,500	Y
Acoustic emission	ASTM E3100	Acoustic	$2,500	N
Electro-mechanical sounding device	ASTM D4580	Acoustic	$2,500	Y
Chain drag	ASTM D4580	Acoustic	$100 - $200	Y
Rotary percussion	ASTM D4580	Acoustic	$100 - $150	Y
Ground penetrating RADAR	ASTM D6087	Electro-magnetic	$2,500+	N
Cover meter (eddy currents)	BS 1881-204	Electro-magnetic	$2,500	Y
Cover meter (magnetic reluctance)	BS 1881-204	Electro-magnetic	$2,500	Y
Half-cell potential	ASTM C876	Electrical/ Chemical	$5,000	Y
Electrical resistivity	ASTM C1202	Electrical/ Chemical	$1,250	Y
Infrared thermography (passive & active)	ASTM D4788	Electro-magnetic	$5,000+ varies	N
Light detection and ranging (LiDAR)	ASTM E2938	Electro-magnetic	$5,000+ varies	N
Determining Concrete Density				
Direct Transmission	ASTM C1040	Nuclear	$750	Y
Backscatter Radiometry	ASTM D6938	Nuclear	$750	Y
Radiography	ASTM E1472	Electro-magnetic	$2,500	Y
Determining Concrete Strength				
Rebound Number	ASTM C805	Mechanical Impact	$300-$1,500	Y
Penetration Resistance	ASTM C803	Mechanical Impact	$2,500	Y
Pullout Test	ASTM C900	Mechanical Impact	$1,250	Y
Ultrasonic Pulse Velocity	ASTM C597	Acoustic	$1,250	Y
Determining Metals Properties				
Ultrasonic Pulse Echo	ASTM E797	Acoustic	$1,250	N
Ultrasonic phased array/phase spectroscopy	ASTM E2700	Acoustic	$2,500	N
Radiography	ASTM E390	Electro-magnetic	$2,500	N
Magnetic Flux Leakage	ASTM E570 ASTM E1571	Electro-magnetic	$2,500	N
Eddy Current Array	ASTM E3052	Electro-magnetic	$2,500	N
Magnetic Particle	ASTM E709	Electro-magnetic	$2,500	N
Liquid Penetrant Testing	ASTM E165 ASTM E1417	Miscellaneous	$750	N
Hardness	ASTM A1038	Acoustic	$1,500	N

Load Rating of Bridges Without As-Built Plan

It is difficult to perform load rating for bridges without as-built plans or with insufficient structural details available. Currently, to evaluate bridges within this category, the potential solutions involve destructive evaluation to characterize the materials and components, proof load testing, or engineering judgment-based characterization *[65]*. In the following section, available nondestructive methods for the evolution of the required parameters for performing load rating of concrete bridges without as-built plans are summarized, and the strengths and shortcomings for each one of these methods are explained. If no standard for nondestructive testing method for measurement of any of the parameters exists, then experimental methods for evaluation of those parameters are discussed.

Evaluation methods for the required parameters for the load rating of bridge structures are presented below. These parameters are organized in accordance with the format laid out in Section 1 as required parameters for a successful bridge load rating. The applicability of these methods are presented for each bridge type in the following section.

As-built Geometric Parameters

Bridge Type, Deck Type and Span Continuity. Span continuity can be evaluated by the visual inspection methods or by 3D laser scanning technique (LiDAR) for identifying the expansion joint locations and types. For a bridge with a continuous span, ground penetrating radar (GPR), covermeter, and radiography may be used to evaluate the reinforcement details at the connections.

Number, Length, Width, Type, and Spacing of Members. Direct measurement and the 3D laser scanning technique, like LiDAR, can be utilized to measure a bridge's span length and slab width accurately. The advantage of the LiDAR 3D scanning is that all disciplines within any given agency can collaboratively develop a unified set of information requirements that will guide data collection so that it satisfies everyone's operational needs. Such a set will include, at minimum, products to support transportation planning, right-of-way acquisition, environmental assessments and historic preservation, 3D design for roadway and structures, construction workflows, traffic operations, signing and striping, highway safety, maintenance activities, and multi-modal operations *[42]*. Figure 31 shows a detailed scan of a truss steel bridge.

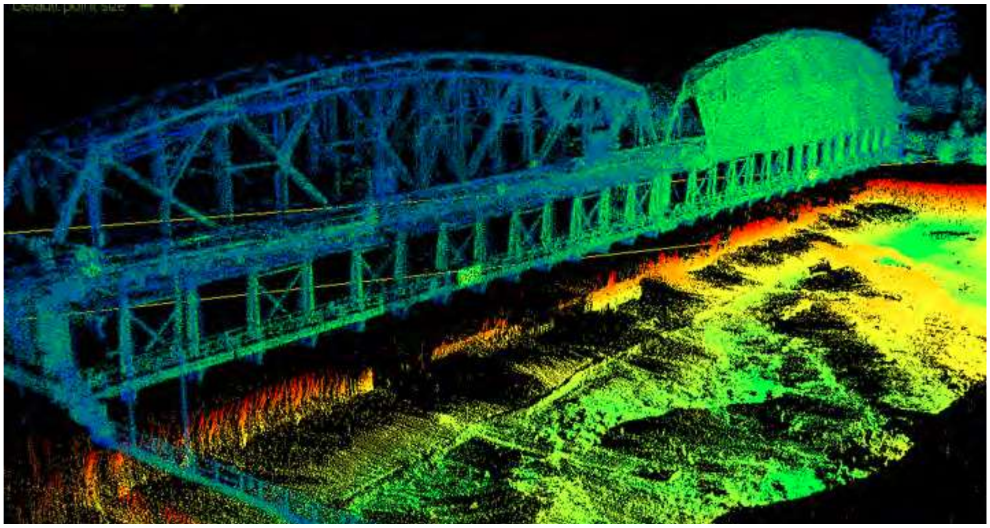


Figure 31
LiDAR helps to capture and collect vast datasets quickly, accurately, and safely *[42]*

Slab Depth. Impact-echo, per the standard method outlined in ASTM C1383 “Standard Test Method for Measuring the P-Wave Speed and the Thickness of Concrete Plates Using the Impact-Echo Method,” enables accurate detection of a concrete slab depth.

Live Loading Zones. LiDAR can be used to build a 3D model of an entire bridge structure, which will be used to extract the required geometries.

Presence of a Shear Key. The presence of a shear key can evaluated by visual inspection methods or by LiDAR of the entire bridge structure. For a bridge with a shear key, impact echo, GPR, covermeter, and radiography may be used to evaluate the geometry and reinforcement details of the shear key.

Presence of a Deck Slab and Its Connection to the Beams. The presence of a deck slab can be evaluated by the visual inspection methods or by LiDAR of the entire bridge structure. The connection of the deck to the beams can be evaluated using ultrasonic pulse echo. GPR, covermeter, and radiography may be used to evaluate the reinforcement details at the connection.

Presence of a Diaphragm. A diaphragm can be evaluated by visual inspection methods or by LiDAR of the entire bridge structure.

Bridge Skew and Radius (if curved). LiDAR can be used to build a 3D model of an entire bridge structure, which will be used to extract the required geometries, such as bridge skew and radius for curved bridges.

Superimposed Dead Loads. Impact-echo can be used to evaluate dimensions of the concrete and asphalt pavement elements, and direct transmission and backscatter radiometry (ASTM C1040) are suitable methods for evaluation of the density of the concrete and asphalt elements for the prediction of their weight.

Size of Internal Voids. GPR can can be used for detecting internal voids cast into a pre-cast concrete slab. Impact-echo can also be used to detect these internal voids.

As-built Strength parameters

Concrete Compressive Strength. Rebound number, penetration resistance, pullout test, and ultrasonic pulse velocity are the standard methods for the evaluation of the in-situ strength of concrete. To calibrate and verify the results, testing cores according to ACI 214.4, "Guide for Obtaining Cores and Interpreting Compressive Strength Results," can be used *[66]*.

Rebar, Strand, and Stirrup Size. Covermeter is a suitable method for evaluating size of rebar and strand. Subedi used a covermeter and a Schmidt hammer for estimating the rebar sizes, locations, and the compressive strength of concrete, respectively, for the load rating of a flat slab bridge without as-built plans *[67]*. Figures 32 and 33 show the simple NDT instruments and the field measurement procedures used in the project. Subedi suggested a procedure for the load rating of the flat slab bridges by combination of nondestructive testing and finite element analysis (FEA). The outline of the methods used in this research by Subedi can be summarized as follows:

- Measuring dimensions of the existing slab bridge, such as span, width and thickness of the deck.

- Collecting size, clear cover, and spacing information of the main reinforcement by using Profoscope (covermeter) and estimating compressive strength of concrete in the existing bridge using the Schmidt rebound hammer test.

- Determining the yield strength of steel with reference to the *Ohio Manual of Bridge Inspection* (based on historical data).

- Developing a three-dimensional FEA model.

- Performing FEA under self-weight and truck loads at different positions to find out the most critical loading scenario.

- Determining the maximum truck load that would produce the maximum allowable deflection at the critical point defined by AASHTO Section 2.5.2.6.2.
- Calculating the rating factor in terms of tonnage for a particular vehicle *[67]*.

Figure 32
NDT instruments (a) Profoscope (cover meter) used by Subedi for estimating reinforcement size and location, and (b) Schmidt hammer (rebound hammer) used for estimating concrete strength *[67]*

Figure 33
Field data collection

Reinforcement Layers: Number, Location, and Orientation. GPR, covermeter, and radiography can be used for detecting the reinforcement details in a bridge slab. Figure 34 represents an image of a bridge deck scan by radar, which shows the reinforcement details and the concrete slab thickness *[68]*.

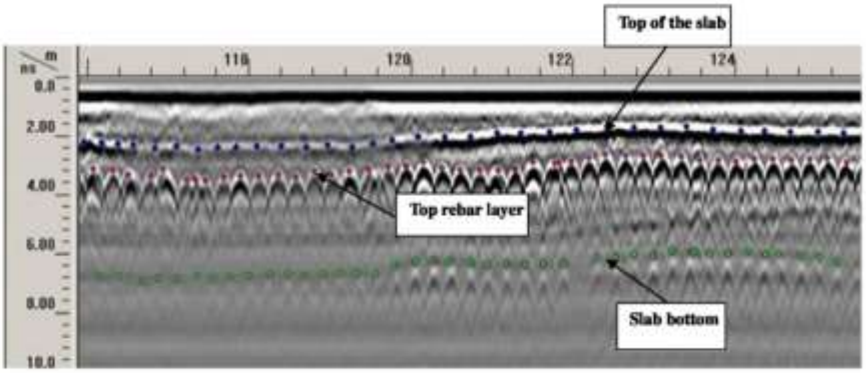


Figure 34
GPR profile of a bridge deck in Queens, NY. Blue dots represent top of the slab; red dots, top reinforcing bar layer; and green dots, slab bottom *[68]*

A radiographic image of reinforcing can be very detailed, enabling reinforcing bar size, depth, spacing, and configuration to be established *[69]*.

An indirect method for the detection and mapping of the reinforcement in concrete bridges is presented by researchers at the University of Delaware, which is based on the measurement of the strain or displacement of the bridge under a known loading condition in conjunction with the basic mechanics principles. To verify this procedure, diagnostic load tests were performed on a bridge. The estimated steel areas are reasonable, though they are not exactly the same as the real area due to the assumptions in the model and the errors in the field test. Generally speaking, the estimated steel areas by virtue of the strains measurement are less than the actual steel area. The estimated steel areas by virtue of the displacement data are larger than the actual area *[70]*.

Rebar, Strand, and Stirrup Yield Strength. There are currently no nondestructive testing methods for determining the yield strength of reinforcing steel and prestressing strands in existing concrete. This is an opportunity for further research and development.

An alternative to NDT for yield strength is to perform destructive testing by removing a small sample of rebar and testing it in a lab to determine its physical properties. Another option is to use the AASHTO *Manual for Bridge Evaluation* guidance on identifying reinforcement characteristics when structural details are unknown *[2]*. Table 9 provides a synthesis of this guidance through a list of the type of reinforcing steel and bridge construction’s date with corresponding yield strength of reinforcing steel *[65]*.

Table 9
Yield Strengths of unknown reinforcing steel *[65, 71]*

Type of Reinforcing Steel	**Yield Strength f_y (MPa)**
Unknown steel constructed prior to 1954	230
Structural grade, Grade 250	250
Billet or intermediate grade, Grade 280, or unknown steel constructed during or after 1954	280
Rail or hard grade, Grande 350	350
High-yield steel grad, Grade 420	420

Strand Contour. Ground penetrating radar (GPR), covermeter, and radiography can be used for detecting the contour of prestressing strand in an existing structure.

Strand Bond Zone. There are currently no nondestructive testing methods for determining the bond zone for prestressing strands. This is an opportunity for further research and development.

Strand Prestressing Forces. There are currently no nondestructive testing methods for determining the prestressing forces for prestressing strands in existing concrete. This is an opportunity for further research and development.

Steel Member Yield Strength. There are currently no nondestructive methods for determining steel member yield strength. Coupons could possibly be taken from less critical areas, with members either replaced or repaired by welding. Alternatively, design drawing research or knowledge of construction vintage and material sources may enable assumption of yield strength.

As-inspected Strength Parameters

Overall Condition. Visual inspection and sounding methods, according to ASTM D4580, are the primary methods for evaluation of the overall slab condition in concrete structures. Infrared (IR) thermography and ground penetrating radar (GPR) can be used to detect delamination in the deck. Also, impact-echo has been used successfully to detect delamination in bridge decks.

Section Loss to Rebar, Strands and Stirrups (exposed and not exposed). Half-cell potential can predict the presence of areas with potential corrosion damage in concrete structures. GPR detects corrosion-induced bridge deck deterioration at an early stage and is very effective, especially in combination with IR *[72]*.

Concrete Spalls. Visual inspection is typically used to identify concrete spalls. Laflamme et al. attempted to automatically detect cracks from LiDAR point clouds data *[73]*.

Rebar and Strand Debonding. Visual inspection is the primary methods for evaluation of the rebar and strand debondment. Acoustic emission methods can also be used to determine debonding.

System Identification Methods of Load Rating

The process of building a structural model from response data is called system identification of the structural integrity of the bridge. System identification can be performed using a variety of response data, such as modal and time history response. For modal response, the frequencies and mode shapes of the structure are obtained either from ambient vibration data or from the results of harmonic excitation. A time history response is the response (i.e., displacements or acceleration) of one or more points on the structure as a function of time due to a known loading function. For either type of response data, the results are used to determine structural parameters. The combination of destructive tests, numerical simulations, and NDT methods is becoming a very efficient way to obtain information about material parameters and the behavior of structural components under different type of loads *[74]*.

Bagheri et al. developed a method for load rating of bridges without structural properties and plans based on nondestructive test methods and system identification. In the proposed approach, a series of finite element analyses were conducted to describe the modal properties of a large population of bridges with different geometric characteristics. Results and geometric inputs were then used to develop an artificial neural network model that predicts the flexural rigidity of a bridge based on the measured modal frequencies derived from vibration testing. Due to the uncertainty in internal geometry of concrete, nondestructive approaches are presented to obtain the cross-section dimensions of bridge as well as the elastic modulus and compressive strength of concrete. Next, the cross-sectional area of the internal reinforcing steel is estimated through a quasi-static load test coupled with an optimization approach. These structural and material properties are then used to determine load effects and ultimately the bridge’s capacity.

Result of the validation test shows that the proposed nondestructive approach can be used to satisfactorily determine the load rating factor of the test bridge and can ultimately be used for load rating of concrete slab bridges without structural information. The frameworks of the proposed method is shown in Figure 35.

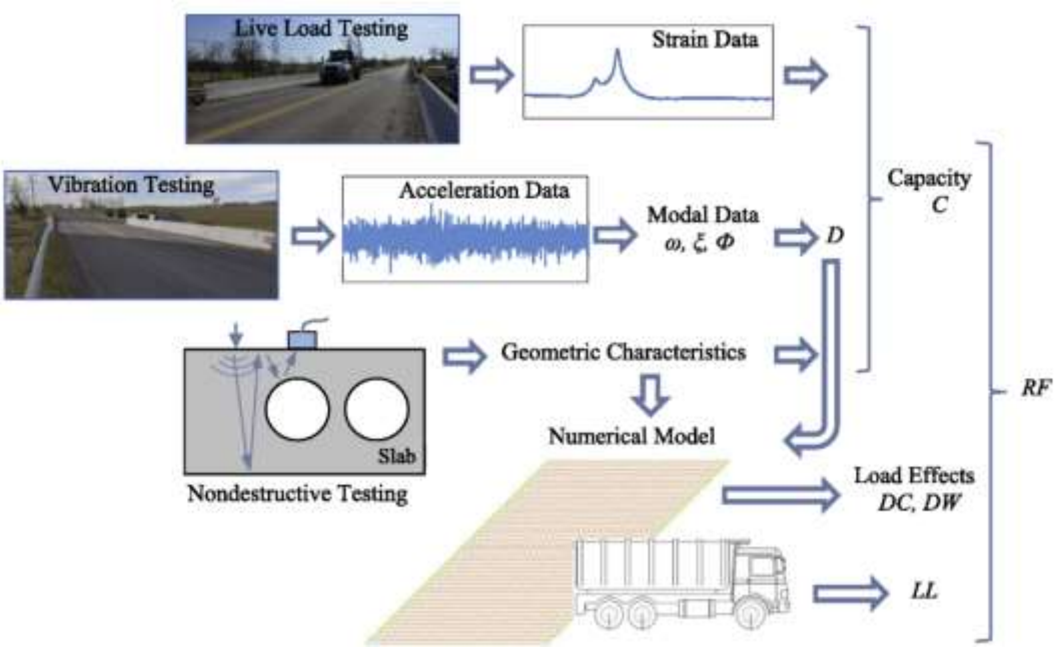


Figure 35
Framework for proposed approach for load rating of bridges without as-built information *[65]*

CONCLUSIONS

Commercially Available NDT Methods by Bridge Type

The following pages contain tables that provide the available NDT methods for each parameter listed in the Discussion section tables as being required to calculate load ratings. These tables are organized by the following bridge types:

- Concrete Precast Slab bridges (COPCSS) and Concrete Slab Bridge (COSLAB)
- Required information for the load rating of a Concrete Prestressed Channel bridge (COPSCH)
- Required information for the load rating of prestressed girder bridges
- Required information for the load rating of steel bridges
- Required information for the load rating of steel bridge connections

Under each bridge type the results are organized into the following categories of information:

- As-built geometric parameters
- As-built strength parameters
- As-inspected strength parameters

These NDT methods are rated by cost, ease of use, and reliability of data. A three-level rating system is provided and explained in Table 10.

Table 9
Explanation of rating system

Cost	
◔	Low cost for technology Low cost for labor to collect data
◑	Low to medium cost for technology Low to medium cost for labor to collect data
◕	Medium to high cost for technology Medium to high cost for labor to collect data
Ease of Use	
◔	Equipment is easy to use with minimal training
◑	Equipment can only be used by experienced technician
◕	Equipment requires special training and/or certification
Data Reliability	
◔	Easy to verify data; widely used technology with long history of success
◑	Results can vary; established technology with long history of use
◕	Results are open to interpretation; newer technology with limited history in practice

Table 10
COPCSS and COSLAB
As-built geometric parameters

Required Information for Load Rating	Cost	Ease of Use	Data Reliability
Span Continuity			
Visual inspection	◔	◔	◔
LiDAR to identify expansion joints	◕	◑	◔
GPR for the reinforcement details at connections	◕	◑	◑
Cover meter for the reinforcement details at connections	◑	◑	◑
Radiography for the reinforcement details at connections	◑	◕	◕
Number, Length, and Spacing of Beams			
Direct measurement	◔	◔	◔
LiDAR	◕	◑	◔
Slab Width			
Direct measurement	◔	◔	◔
LiDAR	◕	◑	◔
Slab Depth			
Impact echo	◑	◑	◑
Live Loading Zones			
Visual inspection and direct measurement	◔	◔	◔
LiDAR	◕	◑	◔
Bridge Skew and Radius (if curved)			
LiDAR	◕	◑	◔

Table 11
COPCSS and COSLAB
As-built geometric parameters (continued)

Required Information for Load Rating	**Cost**	**Ease of Use**	**Data Reliability**
Superimposed Dead Loads			
Visual inspection and direct measurement	◔	◔	◔
Impact echo for thickness	◑	◑	◑
Direct transmission for density of materials	◕	◕	◑
Backscatter radiometry for density of materials	◕	◔	◑
LiDAR for geometry	◕	◑	◔
Size of Internal Voids (if present)			
GPR	◕	◑	◑
Impact echo for thickness	◑	◑	◑

Table 12
COPCSS and COSLAB
As-built strength parameters

Required Information for Load Rating	Cost	Ease of Use	Data Reliability
Concrete Compressive Strength (if applicable)			
Testing cores	◑	◑	◔
Rebound number	◔	◑	◕
Penetration resistance	◑	◑	◑
Pullout test	◑	◑	◑
Ultrasonic pulse velocity	◑	◑	◑
Rebar/Strand Size			
Cover meter	◑	◑	◑
Number of Reinforcement Layers			
GPR	◕	◑	◑
Cover meter	◑	◑	◑
Reinforcement Location and Orientation for Each Layer			
GPR	◕	◑	◑
Cover meter	◑	◑	◑
Radiography to identify beam reinforcement details (requires access to both sides of beam flanges and webs)	◑	◕	◕
Rebar Yield Strength			
Hardness can be correlated to yield strength, but no current NDT method exists to measure directly	—	—	—

Table 14
COPCSS and COSLAB
As-inspected strength parameters

Required Information for Load Rating	Cost	Ease of Use	Data Reliability
Overall Slab Condition			
Visual inspection	◔	◔	◔
Electromechanical sounding device, chain drag and rotary percussion for delamination in decks	◔	◑	◕
Infrared thermography for delamination in decks	◕	◕	◔
GPR for delamination in decks	◕	◑	◑
Impact echo for delamination in decks as well as cracking in concrete structures	◑	◑	◑
Impulse response	◑	◑	◑
Section Loss to Rebar (exposed and not exposed)			
Half-cell potential	◑	◑	◕
GPR	◕	◑	◑
IR thermography for delamination in decks	◕	◕	◔
Concrete Slab Spalls			
Visual inspection	◔	◔	◔
LiDAR	◕	◑	◔
Rebar Debonding			
Visual inspection	◔	◔	◔
Acoustic emissions can detect the presence of debonding, but may not be able to define the extent	◑	◑	◕

Table 13
COPSCH
As-built geometric parameters

Required Information for Load Rating	Cost	Ease of Use	Data Reliability
Span Continuity			
Visual inspection	◔	◔	◔
LiDAR to identify expansion joints	◕	◑	◔
GPR for the reinforcement details at connections	◕	◑	◑
Cover meter for the reinforcement details at connections	◑	◑	◑
Radiography for the reinforcement details at connections	◑	◕	◕
Number, Length, and Spacing of Beams			
Direct measurement	◔	◔	◔
LiDAR	◕	◑	◔
Flange Width and Thickness			
Direct measurement for width	◔	◔	◔
Impact echo for thickness	◑	◑	◑
LiDAR for width	◕	◑	◔
Web Depth and Thickness			
Direct measurement for width	◔	◔	◔
Impact echo for thickness	◑	◑	◑
LiDAR for width	◕	◑	◔
Live Loading Zones			
Visual inspection and direct measurement	◔	◔	◔
LiDAR	◕	◑	◔

Table 14
COPSCH
As-built geometric parameters (continued)

Required Information for Load Rating	Cost	Ease of Use	Data Reliability
Identify If Beams Have A Shear Key			
Visual inspection and direct measurement	◔	◔	◔
LiDAR	◕	◑	◔
Impact echo to identify thickness	◑	◑	◑
Identify If There is a Deck Slab and its Connection to the Beams			
Visual inspection and direct measurement	◔	◔	◔
LiDAR	◕	◑	◔
Ultrasonic-echo methods	◑	◑	◑
Cover meter	◑	◑	◑
GPR to identify reinforcement details at the beam	◕	◑	◑
Radiography to identify beam reinforcement details (requires access to both sides of members)	◑	◕	◕
Identify if There Are Diaphragms			
Visual inspection and direct measurement	◔	◔	◔
LiDAR	◕	◑	◔
Bridge Skew and Radius (if curved)			
LiDAR	◕	◑	◔
Superimposed Dead Loads			
Visual inspection and direct measurement	◔	◔	◔
Impact echo for thickness	◑	◑	◑
Direct transmission for density of materials	◕	◕	◑
Backscatter radiometry for density of materials	◕	◔	◑
LiDAR for geometry	◕	◑	◔

Table 15
COPSCH
As-built strength parameters

Required Information for Load Rating	Cost	Ease of Use	Data Reliability
Concrete Compressive Strength			
Testing cores	◑	◑	◔
Rebound number	◔	◑	◕
Penetration resistance	◑	◑	◑
Pullout test	◑	◑	◑
Ultrasonic pulse velocity	◑	◑	◑
Rebar/Strand Size			
Cover meter	◑	◑	◑
Number of Reinforcement Layers			
GPR	◕	◑	◑
Cover meter	◑	◑	◑
Rebar and Strand Location and Orientation			
GPR	◕	◑	◑
Cover meter	◑	◑	◑
Radiography to identify beam reinforcement details (requires access to both sides of members)	◑	◕	◕
Rebar and Strand Yield Strength			
Hardness can be correlated to yield strength, but no current NDT method exists to measure directly	—	—	—

Table 16
COPSCH
As-built strength parameters (continued)

Required Information for Load Rating	Cost	Ease of Use	Data Reliability
Strand Contour			
GPR	◕	◑	◑
Cover meter	◑	◑	◑
Radiography to identify beam reinforcement details (requires access to both sides of members)	◑	◕	◕
Strand Bond Zone			
No NDT method is currently available	—	—	—
Stirrup Size, Spacing, and Location			
GPR	◕	◑	◑
Cover meter	◑	◑	◑
Radiography to identify beam reinforcement details (requires access to both sides of members)	◑	◕	◕
Stirrup Yield Strength			
Hardness can be correlated to yield strength, but no current NDT method exists to measure directly	—	—	—
Deck Rebar Size and Location			
GPR	◕	◑	◑
Cover meter	◑	◑	◑
Radiography to identify beam reinforcement details (requires access to both sides of members)	◑	◕	◕
Deck Rebar Yield Strength			
Hardness can be correlated to yield strength, but no current NDT method exists to measure directly	—	—	—

Table 17
COPSCH
As-inspected strength parameters

Required Information for Load Rating	Cost	Ease of Use	Data Reliability
Overall Beam Condition			
Visual inspection	◔	◔	◔
Electromechanical sounding device, chain drag and rotary percussion for delamination in decks	◔	◑	◕
IR thermography for delamination in decks	◕	◕	◔
GPR for delamination in decks	◕	◑	◑
Impact echo for delamination in decks as well as cracking in concrete structures	◑	◑	◑
Impulse response	◑	◑	◑
Section Loss to Rebar, Strands and Stirrups			
Half-cell potential	◑	◑	◕
GPR	◕	◑	◑
IR thermography for delamination in decks	◕	◕	◔
Concrete Spalls			
Visual inspection	◔	◔	◔
LiDAR	◕	◑	◔
Rebar and Strand Debonding			
Visual inspection	◔	◔	◔
Acoustic emissions can detect the presence of debonding, but may not be able to define the extent	◑	◑	◕

Table 18
Prestressed girder bridges
As-built geometric parameters

Required Information for Load Rating	Cost	Ease of Use	Data Reliability
Span Continuity			
Visual inspection	◔	◔	◔
LiDAR to identify expansion joints	◕	◑	◔
GPR for the reinforcement details at connections	◕	◑	◑
Cover meter for the reinforcement details at connections	◑	◑	◑
Radiography for the reinforcement details at connections	◑	◕	◕
Girder Type, Dimensions, Spacing, Number, and Length			
Direct measurement	◔	◔	◔
LiDAR	◕	◑	◔
Live Loading Zones			
Visual inspection and direct measurement	◔	◔	◔
LiDAR	◕	◑	◔
Identify if Beams Have a Shear Key (If Applicable)			
Visual inspection and direct measurement	◔	◔	◔
LiDAR	◕	◑	◔
Impact echo for thickness	◑	◑	◑

Table 19
Prestressed girder bridges
As-built geometric parameters (continued)

Required Information for Load Rating	Cost	Ease of Use	Data Reliability
Identify if There is a Deck Slab and its Connection to the Beams			
Visual inspection and direct measurement	◔	◔	◔
LiDAR	◕	◑	◔
Ultrasonic-echo methods	◑	◑	◑
Cover meter	◑	◑	◑
GPR to identify reinforcement details at the beam	◕	◑	◑
Radiography to identify beam reinforcement details (requires access to both sides of members)	◑	◕	◕
Identify if There are Diaphragms			
Visual inspection and direct measurement	◔	◔	◔
LiDAR	◕	◑	◔
Bridge Skew and Radius (if curved)			
LiDAR	◕	◑	◔
Superimposed Dead Loads			
Visual inspection and Direct measurement	◔	◔	◔
Impact echo for thickness	◑	◑	◑
Direct transmission for density of materials	◕	◕	◑
Backscatter radiometry for density of materials	◕	◔	◑
LiDAR for geometry	◕	◑	◔

Table 20
Prestressed girder bridges
As-built strength parameters

Required Information for Load Rating	Cost	Ease of Use	Data Reliability
Concrete Compressive Strength			
Testing cores	◑	◑	◔
Rebound number	◔	◑	◕
Penetration resistance	◑	◑	◑
Pullout test	◑	◑	◑
Ultrasonic pulse velocity	◑	◑	◑
Rebar/Strand Size			
Cover meter	◑	◑	◑
Number of Reinforcement Layers			
GPR	◕	◑	◑
Cover meter	◑	◑	◑
Rebar and Strand Location and Orientation			
GPR	◕	◑	◑
Cover meter	◑	◑	◑
Radiography to identify beam reinforcement details (requires access to both sides of members)	◑	◕	◕
Rebar and Strand Yield Strength			
Hardness can be correlated to yield strength, but no current NDT method exists to measure directly	—	—	—
Strand Bond Zone			
No NDT method is currently available	—	—	—

Table 21
Prestressed girder bridges
As-built strength parameters (continued)

Required Information for Load Rating	Cost	Ease of Use	Data Reliability
Strand Contour			
GPR	◕	◑	◑
Cover meter	◑	◑	◑
Radiography to identify beam reinforcement details (requires access to both sides of members)	◑	◕	◕
Strand Prestressing Forces			
No NDT method is currently available	—	—	—
Stirrup Size, Spacing, and Location			
GPR	◕	◑	◑
Cover meter	◑	◑	◑
Radiography to identify beam reinforcement details (requires access to both sides of members)	◑	◕	◕
Stirrup Yield Strength			
Hardness can be correlated to yield strength, but no current NDT method exists to measure directly	—	—	—
Deck Rebar Size and Location			
GPR	◕	◑	◑
Cover meter	◑	◑	◑
Radiography to identify beam reinforcement details (requires access to both sides of members)	◑	◕	◕
Deck Rebar Yield Strength			
Hardness can be correlated to yield strength, but no current NDT method exists to measure directly	—	—	—

Table 22
Prestressed girder bridges

As-Inspected Strength Parameters

Required Information for Load Rating	Cost	Ease of Use	Data Reliability
Overall Beam Condition			
Visual inspection	◔	◔	◔
Electromechanical sounding device, chain drag and rotary percussion for delamination in decks	◔	◑	◕
IR thermography for delamination in decks	◕	◕	◔
GPR for delamination in decks	◕	◑	◑
Impact echo for delamination in decks as well as cracking in concrete structures	◑	◑	◑
Impulse response	◑	◑	◑
Section Loss to Rebar, Strands, and Stirrups			
Half-cell potential	◑	◑	◕
GPR	◕	◑	◑
IR thermography for delamination in decks	◕	◕	◔
Concrete Spalls			
Visual inspection	◔	◔	◔
LiDAR	◕	◑	◔
Rebar and Strand Debonding			
Visual inspection	◔	◔	◔
Acoustic emissions can detect the presence of debonding but may not be able to define the extent	◑	◑	◕

Table 23
Steel bridges
As-built geometric parameters

Required Information for Load Rating	Cost	Ease of Use	Data Reliability
Bridge Type			
Visual inspection	◔	◔	◔
LiDAR	◕	◑	◔
Span Continuity			
Visual inspection	◔	◔	◔
LiDAR	◕	◑	◔
Deck Type			
Visual inspection	◔	◔	◔
LiDAR	◕	◑	◔
Girder Type (if applicable)			
Visual inspection	◔	◔	◔
LiDAR	◕	◑	◔
Girder Dimensions, Length, and Spacing			
Visual inspection and direct measurement	◔	◔	◔
LiDAR	◕	◑	◔
Number of Girders			
Visual inspection	◔	◔	◔
LiDAR	◕	◑	◔
Shear Stud Size and Spacing			
GPR for connection	◕	◑	◑

Table 24
Steel bridges
As-built geometric parameters (continued)

Required Information for Load Rating	Cost	Ease of Use	Data Reliability
Live Loading Zones			
Visual inspection and direct measurement	◔	◔	◔
LiDAR	◕	◑	◔
Deck Thickness and Connection			
Impact echo for thickness	◑	◑	◑
Radiography for connection	◑	◕	◕
GPR for connection	◕	◑	◑
Identify if There Are Diaphragms			
Visual inspection and direct measurement	◔	◔	◔
LiDAR	◕	◑	◔
Bridge Skew and Radius (if curved)			
LiDAR	◕	◑	◔
Superimposed Dead Loads			
Visual inspection and Direct measurement	◔	◔	◔
Impact echo for thickness	◑	◑	◑
Direct transmission for density of materials	◕	◕	◑
Backscatter radiometry for density of materials	◕	◔	◑
LiDAR for geometry	◕	◑	◔

Table 25
Steel bridges
As-built strength parameters

Required Information for Load Rating	Cost	Ease of Use	Data Reliability
Concrete Compressive Strength (if applicable)			
Testing cores	◑	◑	◔
Rebound number	◔	◑	◕
Penetration resistance	◑	◑	◑
Pullout test	◑	◑	◑
Ultrasonic pulse velocity	◑	◑	◑
Deck Rebar Size			
Cover meter	◑	◑	◑
Number of Reinforcement Layers			
GPR	◕	◑	◑
Cover meter	◑	◑	◑
Deck Rebar Size and Location			
GPR	◕	◑	◑
Cover meter	◑	◑	◑
Radiography to identify slab reinforcement details (requires access to both sides of deck)	◑	◕	◕
Deck Rebar Yield Strength			
Hardness can be correlated to yield strength, but no current NDT method exists to measure directly	—	—	—
Steel Member Yield Strength			
Hardness can be correlated to yield strength, but no current NDT method exists to measure directly	—	—	—

Table 26
Steel bridges
As-inspected strength parameters

Required Information for Load Rating	Cost	Ease of Use	Data Reliability
Section Loss and Deformations in High Stress Areas			
Ultrasonic test	◑	◑	◑
Radiography	◑	◕	◕
Spalled Deck			
Radiography	◑	◕	◕
Deck Rebar Section Loss			
Half-cell potential	◑	◑	◕
GPR	◕	◑	◑
IR thermography for delamination in decks	◕	◕	◔
Deck Rebar Debonding			
Visual inspection	◔	◔	◔
Acoustic emissions can detect the presence of debonding, but may not be able to define the extent	◑	◑	◕
Deck Connection (if applicable)			
Radiography	◑	◕	◕
GPR	◕	◑	◑

Table 27
Steel bridge connections
As-built geometric parameters

Required Information for Load Rating	Cost	Ease of Use	Data Reliability
Number of Bolts/Rivets			
Visual inspection and direct measurement	◔	◔	◔
LiDAR	◕	◑	◔
Bolt/Rivet Size			
Visual inspection and direct measurement	◔	◔	◔
Ultrasonic test for length	◑	◑	◑
Bolt/Rivet Center to Center Spacing and Edge Distance			
Visual inspection and direct measurement	◔	◔	◔
LiDAR	◕	◑	◔
Bolt/Rivet Group Pattern and Total Length			
Visual inspection and direct measurement	◔	◔	◔
Ultrasonic test for length	◑	◑	◑
LiDAR	◕	◑	◔
Bolt Thread Length/ Stick Through			
Visual inspection and direct measurement	◔	◔	◔
Ultrasonic test for length	◑	◑	◑
Hole Size and Orientation of Slot (if applicable)			
Radiography	◑	◕	◕
Weld Length			
Direct measurement	◔	◔	◔
Identify Connection Type			
Visual inspection	◔	◔	◔

Table 28
Steel bridge connections
As-built geometric parameters (continued)

Required Information for Load Rating	Cost	Ease of Use	Data Reliability
Thickness of Connected Members			
Radiography	◑	◕	◕
Ultrasonic test for length	◑	◑	◑
Number of Connected Plies			
Visual inspection	◔	◔	◔
Radiography	◑	◕	◕

Table 29
Steel bridge connections
As-built strength parameters

Required Information for Load Rating	Cost	Ease of Use	Data Reliability
Steel Member Yield Strength			
Hardness can be correlated to yield strength, but no current NDT method exists to measure directly	—	—	—
Bolt Material Type			
Hardness	◔	◑	◕
Filler Metal Strength			
Hardness can be correlated to yield strength, but no current NDT method exists to measure directly	—	—	—
Weld Size			
Ultrasonic test	◑	◑	◑
Surface Condition of Connected Members			
Visual inspection	◔	◔	◔

Table 30
Steel bridge connections
As-inspected strength parameters

Required Information for Load Rating	Cost	Ease of Use	Data Reliability
Section Loss and Deformations to Connected Members			
Ultrasonic test	◑	◑	◑
Radiography	◑	◕	◕
Missing or Loose Bolts/Rivets			
Visual inspection	◔	◔	◔
Sheared Bolts/Rivets			
Visual inspection	◔	◔	◔
Radiography	◑	◕	◕
Ultrasonic	◑	◑	◑
Cracked Welds			
Welds crack detection based on Eddy Current Array	◑	◑	◑
Ultrasonic weld inspection	◑	◑	◑
Cracked Connected Members			
Liquid Penetrant Testing	◔	◑	◑
Magnetic Particle	◑	◑	◑
Detection of Slip and/or Stress Deformations in Steel			
Visual inspection	◔	◔	◔
Radiography	◑	◕	◕
Gaps or Pack Rust Between Connected Members			
Ultrasonic for rust detection	◑	◑	◑
Radiography	◑	◕	◕

RECOMMENDATIONS

Nondestructive testing methods were evaluated to obtain various required parameters for performing bridge load rating of different types of bridges. The required parameters are categorized into three categories: As-Built Geometric parameters, As-Built Strength parameters, and As-Inspected Strength parameters. Five different types of bridges including Concrete Precast Slab (COPCSS), Concrete Slab (COSLAB), Concrete Prestress Channel (COPSCH), Prestressed girder bridges and steel bridges have been studied in this work. The following recommendations are made from this study.

1. Based on the findings above, availability of the equipment/service, and common practice, the recommended methods of identifying the major load rating parameters are:

   As-built geometric: Direct measurement, GPR, Impact Echo, Ultrasonic Echo, Cover meters and Radiography

   As-built strength: Core testing, Rebound, Penetration Resistance, GPR, Covermeters, and Radiography

   As-inspected strength: Visual Inspection, Impact Echo, Impulse Response, Half Cell, and Radiography

2. The following parameters currently do not have nondestructive testing methods available and warrant further research by the industry:

   Yield strength of steel embedded in concrete,

   Prestressing forces of strand embedded in concrete,

   Extent of debondment of reinforcing steel that is not visible, and

   Bond zone of prestressing steel embedded in concrete.

ACRONYMS, ABBREVIATIONS, AND SYMBOLS

3D	Three Dimensional
AASHTO	American Association of State Highway and Transportation Officials
ACI	American Concrete Institute
AE	Acoustic Emission
ASNT	American Society of Nondestructive Testing
ASR	Allowable Stress
cm	centimeter(s)
COPCSS	Concrete Precast Slab
COPSCH	Concrete Prestressed Channel
COSLAB	Concrete Slab
DOTD	Louisiana Department of Transportation and Development
FEA	Finite Element Analysis
FHWA	Federal Highway Administration
ft.	foot (feet)
GPR	Ground Penetrating RADAR
in.	inch(es)
IR	InfraRed
LFR	Load Factor
LiDAR	Light Detection And Ranging
LRFD	Load and Resistence Factor Design
LRFR	Load and Resistence Factor Rating
LTRC	Louisiana Transportation Research Center
lb.	pound(s)
m	meter(s)
NDT	Nondestructive Testing
PA	Phased Array
RADAR	RAdio Detection And Ranging
SASW	Spectral Analysis of Surface Wave
US	United States
USW	Ultrasonic Surface Wave

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APPENDICES

Appendix A: Representative Mechanical Impact Equipment

Rebound Number

proceq

schmidt
CONCRETE TEST HAMMERS

Swiss Precision since 1954

CONCRETE TEST HAMMERS

The concrete test hammers are the most widely used portable NDT measuring instruments for a rapid assessment of the condition of a concrete structure. Proceq's Schmidt Hammer portfolio is the most comprehensive available.

The concrete test hammer was developed by Ernst O. Schmidt and introduced by Proceq at the beginning of the 1950's. Since then, Proceq has continuously developed its Schmidt Family to cover the entire range of compressive strength classes.

Rebound Hammer Standards

The SilverSchmidt is fully compliant with ASTM C805, EN 12504-2 and EN 13791. The Chinese standard been applied in SilverSchmidt for the procedure to determine the rebound number.

The Original Schmidt is fully compliant with all major standards.

Each rebound hammer is built for a different purpose in order to meet the specific needs of the customer. The following table gives an overview of the specifications and applications for each instrument.

	Concrete Compressive Strength Range					
	1 - 5 MPa 145 - 725 psi	5 - 10 MPa 725 - 1,450 psi	10 - 30 MPa 1,450 - 4,351 psi	30 - 70 MPa 4,351 - 10,153 psi	70 - 100 MPa 10,153 - 14,504 psi	> 100 MPa > 14,504 psi
	Fresh Concrete Very Low Strength Concrete		**Normal Concrete**		**High Strength Concrete**	**Ultra High Performance Concrete**
SilverSchmidt 			SilverSchmidt ST/PC Type N			Only with user defined custom curves
			SilverSchmidt ST/PC Type L			
		SilverSchmidt PC Type L with Mushroom Plunger				
		Only with user defined custom curves				
Original Schmidt 			Original Schmidt Type N/ND/NR			
			Original Schmidt Type L/LD/LR			
Schmidt OS-120 	Schmidt OS-120PT	Only with user defined custom curves				

Type N	Standard impact energy. Minimum thickness of test object: 100 mm (3.9") and should be firmly fixed in the structure.
Type L	Low impact energy. Suitable for brittle objects or structures less than 100 mm (3.9") thick.

ST Model: Standard model. Hammerlink software provided for performing firmware upgrades and selecting statistics presets only. Useful memory limited to the last 20 series.
PC Model: Full Hammerlink software functionality. Extended memory usage. Download to PC. User defined custom curves.

SilverSchmidt

ST/PC Type N/L: The world's most advance rebound hammer, with unmatched dispersion characteristics, durability and measuring range.

Independent validation testing by BAM Germany has shown that the SilverSchmidt's **patented measuring** principle has less dispersion than the classical hammers over the entire range.

Its **inherent impact angle** independence removes one possible source of user error completely. Automatic evaluation according to pre-defined statistical criteria and software analysis tools, greatly enhance the uniformity assessment application.

All major standards recommend to create mixtures specific curves. Such **user defined correlation curves** can be downloaded via the powerful Hammerlink software (PC version only) onto the hammer. This, together with on board correction for form factor and carbonation allows the best possible assessment of compressive strength.

In combination with the SilverSchmidt PC Type L hammer, the **mushroom plunger** extends the lower measuring range down to approximately 5 MPa (725 psi). This, coupled with the SilverSchmidt's inherent angle independency makes it the perfect tool for applications such as determining when to remove formwork in tunnel linings.

Original Schmidt / Digi-Schmidt

Type N/L: The benchmark against which all rebound hammers are compared and the basis of every international rebound hammer standard. Available with different impact energies allowing customers to test a wide variety of materials and types of structure.

Type NR/LR: Ever popular version with impact values recorded as a bar chart on registration paper for ease of control. Greatly simplifies the calculation of the rebound value and in checking the uniformity of the object under test. One roll of paper can record up to 4'000 impacts.

Type ND/LD (Digi-Schmidt): The world's first digital rebound hammer with data storage, impact angle correction and direct display of compressive strength. The Digi-Schmidt allows correction for form factor and carbonation. It comes with a number of pre-programmed correlation curves, allowing the user to select the most suitable for the mixture under test. All data and parameters may be transferred to a PC for further evaluation with the ProVista software.

Schmidt OS-120

Type PT: Equipped with a larger plunger surface, it is especially designed to test on softer material such as light weight concrete, gypsum boards and on fresh concrete. It is often used to determine the right time to remove formwork.

Type PM: Designed to test the mortar joints in brickwork. It has a specially developed plunger whose shape ensures the impacts are applied to the surface of the joint. Based on the rebound values the mortar quality can be classified.

Applications

The Schmidt concrete test hammers can be applied on all concrete structures such as **bridges, buildings, retaining walls, barrages** and many more. But they are also the perfect instruments to test in **tunnels** (e.g. the formwork stripping strength which is the concrete compressive strength f_c to be achieved before removal of the formwork).

Spotlight: Tunnel Testing (1/2)

	Test Surfaces and Compressive Strength f_c Range		
	1	**2**	**3**
	On all vertical and horizontal surfaces (including overhead)	On arched tunnel linings	On vertical front face and on vertical side of arched Tunnel linings
Tunnel Types	**BDB*, CC***	**BDB***	**BDB***

Original Schmidt **Digi-Schmidt**	> 10 MPa (>1'450 psi)	N/A	N/A
SilverSchmidt	> 10 MPa (>1'450 psi)	> 10 MPa (>1'450 psi)	N/A
SilverSchmidt with Mushroom plunger	5 to 10 MPa (725 to 1'450 psi)	5 to 10 MPa (725 to 1'450 psi)	N/A
Schmidt OS-120PT Pendulum Hammer	1 to 5 MPa (145 to 725 psi) *On intermediate walls, If designer approved it.*	N/A	1 to 10 MPa (145 to 1'450 psi)

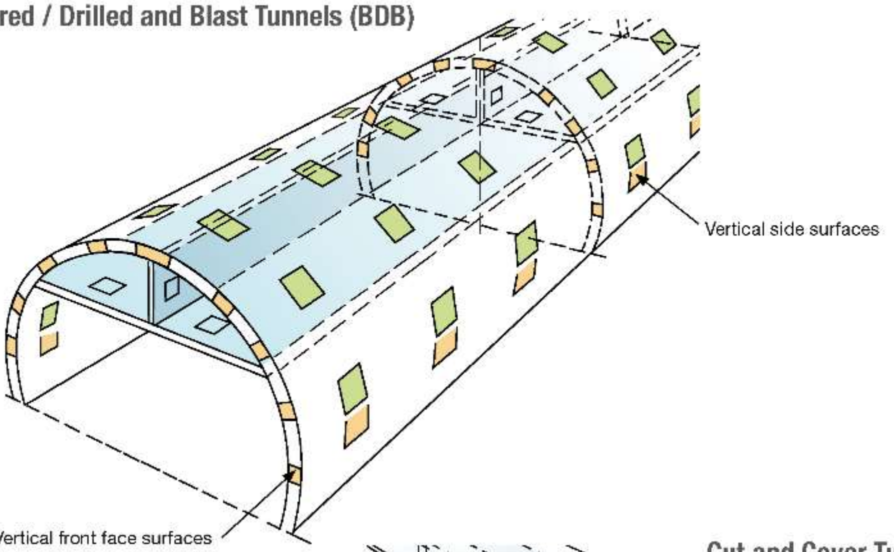
Information about the Austrian Guideline "Innenschalenbeton" (Inner Concrete Linings of Tunnels)	Article 9.4.4 mentions the P-Type Pendulum Hammer to test on top of intermediate roofs. But as this particular Pendulum Hammer type is not produced anymore, we recommend using the Original-, Digi- or SilverSchmidt instead.	Article 3.5.3.1 mentions the Schmidt OS-120PT Pendulum Hammer and the SilverSchmidt to test the formwork stripping strength. The article also states that tests must be conducted on the top of the front face and on the vertical side surfaces which is only applicable for the PT Pendulum Hammer while the SilverSchmidt can be used over the entire arch without the need to correct the impact direction. Article 3.1.2 mentions for fc = 2 to 3 MPa (290 to 435 psi).

***BDB Tunnels:** Bored / Drilled and Blast Tunnels (Arch lining)

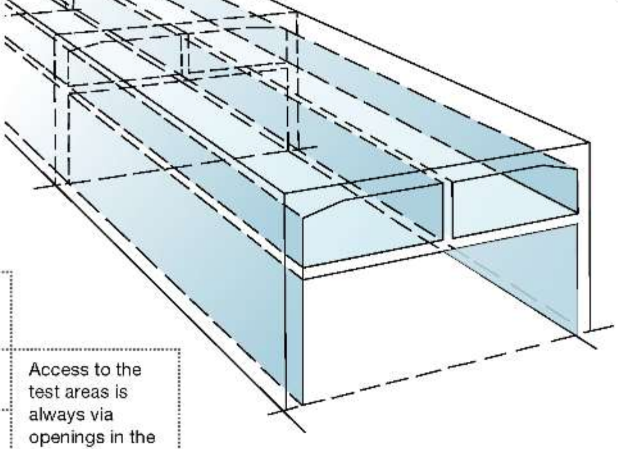
***CC Tunnels:** Cut and Cover Tunnels (Rectangular Cross Section)

Spotlight: Tunnel Testing (2/2)

Bored / Drilled and Blast Tunnels (BDB)



Cut and Cover Tunnels (CC)



1	**On all vertical and horizontal surfaces (including overhead)**	
2	**On arched tunnel linings**	Access to the test areas is always via openings in the formwork
3	**On vertical front face and on vertical side of arched tunnel linings**	

Penetration Resistance

The Windsor HP Probe System

For in-place strength testing *of normal and high-performance concrete.*

Applications:

Form Removal

Structural Analysis

Light weight concrete strength determination

Standard concrete strength determination

High strength concrete strength determination

High precision strength determination

Features and Benefits

- New electronic measuring system enhances accuracy and efficiency.
- Measurement up to 17000 psi (110 MPa).
- Memory for data storage and uploading to PC.
- Safe: no accidental discharge and no recoil.
- Fast and economical use.
- Determines the developing strength of concrete; improves safety, ensures quality and reduces costs.
- Monitors the strength for rehabilitation as concrete ages.
- Conforms to ASTM C-803, ACI 347-78, BS 1881 #207, ANSI A. 10-3.

www.ndtjames.com

NDT JAMES INSTRUMENTS INC. 5

The Windsor HP Probe System

Safe and User Friendly

The Windsor HP System does not require great skill to use and consistent results can be obtained by construction site supervisory staff or field technicians. In fact, among its users are contractors, engineers, architects, testing laboratories, ready mix concrete producers, owners, managers and government authorities. This system has widespread use in testing concrete in-situ, on conventionally placed, sprayed or precast concrete; on horizontal or vertical slabs; on floors or overhead; on fresh or mature concrete.

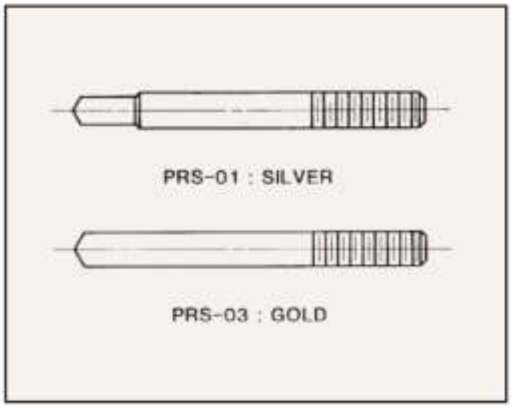
The system is safe to use. The driver cannot be discharged unless it is fully depressed with some force against the actuating template which rests against the surface being examined.

Probes

There are two power settings available, low and standard power. The low power is used where concrete strength is less than 3000 psi (19.4 MPa). Standard power is for any strengths above that.

The newly designed silver probes can be used for high performance concrete with strength up to 17000 psi (110 MPa). The probes are made of a high strength alloy, specially heat treated and annealed to achieve a hardness of Rockwell C 48. Special machining of each probe eliminates stress concentrations.

The gold probe has a 56% greater cross-sectional area than the silver; it is recommended for light weight concrete — less than 125 lbs/cu. ft. (2003 Kg/m^3) in density. The silver probe is used with concrete having a density greater than 125 lbs/cu. ft. (2003 Kg/m^3).



Procedure

A. Actuating

Load the driver with a power load and probe suited for the type of concrete being examined. Place the driver firmly on the actuating template and fire. The locating template is then used to locate the probes at the corners of a fixed triangle. Normally, three measurements are required for consistent and statistically reliable results.

B. Measuring

The electronic measuring device is menu driven and programmed for selection according to the following parameters.

- Aggregate hardness
- Light weight, normal, or HP concrete
- American or Metric units

The three individual tests are automatically averaged and displayed on the LCD in accordance with ASTM procedure. This data together with time and date of the test are stored in the memory for subsequent uploading to a PC. An extractor is supplied to facilitate probe removal after the test.

The Standard Windsor Probe System includes a depth gauge and "Strength Chart" for determining the concrete strength.

This is an economical alternative for many concrete test environments.

Manual Depth Gauge

Front and Side View

The Windsor HP Probe System

Technical Specifications

The Windsor HP Probe System.

Standard measuring gauge

Technical

The Windsor HP Probe System is designed to evaluate the compressive strength of concrete in place. It is non-destructive and can be used with equal effectiveness on fresh and mature concrete. Equally accurate results are obtained on horizontal or vertical surfaces provided that the probe is perpendicular or at right angles to the test surface.

A hardened steel alloy probe is propelled at high speed by an exactly measured explosive charge into the concrete and its penetration measured. Each power load is guaranteed to have an energy level to give an exit muzzle velocity tolerance within ±3%. The compressive strength of the concrete is directly related to the resistance to penetration of the crushed aggregate and cement matrix: this is determined by the distance required to absorb the specific amount of kinetic energy of the probe. The compressive strength of the concrete is empirically related to the penetration that varies with the hardness of the aggregate. This relationship is recognized by determining the Moh's scale of hardness of the aggregate and applying a correction factor to the penetration.

The combined contributions of both the aggregate and the cement paste to concrete strength are examined by the test. The accuracy of the inferred strengths has been examined in many independent tests and trials. The Windsor HP results correlate well with the concrete strength determinations obtained by conventional means.

For most accurate test results ASTM recommends that a correlation be developed for the particular mix design being tested. Exact duplication of cylinder test results should not be expected. The probes measure the strength of the actual concrete in a structure rather than that of a sample compacted and cured under strict and somewhat artificial conditions which do not necessarily represent those of the structure itself.

The Windsor Probe test has been approved by federal, state and municipal agencies as well as a number of foreign countries. It conforms to the following tests, specifications and practices:

ASTM C803	ACI 347
ANSI A.10-3	BS 1881 #207

Sales Numbers & Specifications

Z-WP-1000 PSI	Complete Windsor HP System with readings in PSI
Z-WP-1000 MPA	Complete Windsor HP System with readings in MPA
Z-WP-534	Complete Windsor Probe Standard System
Z-WP-500	Driver Unit
Z-WP-700 PSI	Electronic Measuring Kit with readings in PSI
Z-WP-700 MPA	Electronic Measuring Kit with readings in MPA
U-PRS-01	Box of 75 Silver Probes and 75 Power Loads
U-PRS-03	Box of 75 Gold Probes and 75 Powder Loads

NDT *JAMES INSTRUMENTS INC.*
NON DESTRUCTIVE TESTING SYSTEMS
3727 North Kedzie Avenue,
Chicago, Illinois 60618
1-800-426-6500 (773) 463-6565
FAX (773) 463-0009
e-mail: info@ndtjames.com
http://www.ndtjames.com

GI

CAPO-TEST

Purpose

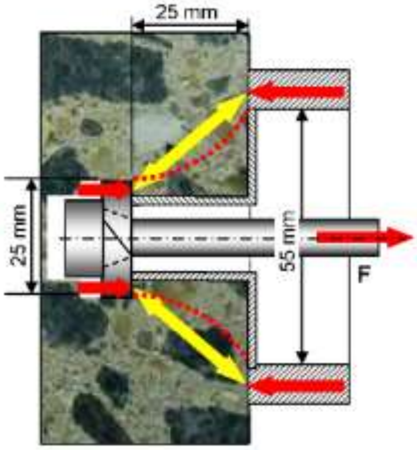
The **CAPO-TEST** permits performing pullout tests on existing structures without the need of pre-installed inserts. **CAPO-TEST** provides a pullout test system similar to the **LOK-TEST** system (pg. 84) for accurate on-site estimates of compressive strength. Procedures for performing post-installed pullout tests, such as **CAPO-TEST**, are included in ASTM C900 and EN 12504-3.

Typical applications of the **CAPO-TEST** include the following:

- Quality assurance testing of the finished structure
- Verification of in-place strength if strength of standard-cured specimens fails to meet acceptance criteria
- Estimating strength of concrete in existing structures
- Evaluation of fire-damaged structures

Principle

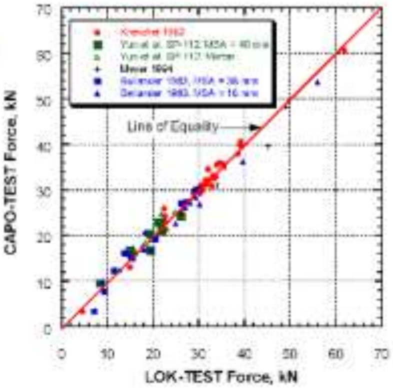
When selecting the location for a **CAPO-TEST**, ensure that reinforcing bars are not within the failure region. The surface at the test location is ground using a planing tool and a 18.4 mm hole is made perpendicular to the surface using a diamond-studded core bit. A recess (slot) is routed in the hole to a diameter of 25 mm and at a depth of 25 mm. A split ring is expanded in the recess and pulled out using a pull machine reacting against a 55 mm diameter counter pressure ring. As in the **LOK-TEST**, the concrete in the strut between the expanded ring and the counter pressure ring is in compression. Hence, the ultimate pullout force **F** is related directly to compressive strength.



The test is performed until the conic frustum between the expanded ring and the inner diameter of the counter pressure is dislodged. Thus there is minor surface damage, which should be repaired for aesthetic reasons or to avoid potential durability problems.

Correlation and Accuracy of Estimated Strength

Several investigations have shown that the pullout strength measured by the **CAPO-TEST** is essentially the same as the pullout strength measured by **LOK-TEST**. This equality is illustrated in the graph to the right, which includes data from four independent studies. The maximum aggregate size varied from sand up to 40 mm. Thus the general correlations for the **LOK-TEST** shown on page 85 are also valid for the **CAPO-TEST**.



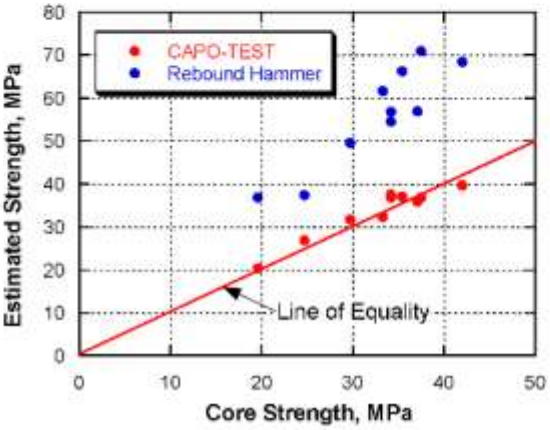
Based on testing experiences and laboratory studies, it has been found that the accuracy of the compressive strength estimated by the **CAPO-TEST** using the general correlations shown on page 85 is similar to results obtained with the **LOK-TEST**. For normal density concrete, the coefficient of variation of individual **CAPO-TEST** results is about 8 %.

GI CAPO-TEST

Comparison with Core Strength

An investigation on 10 bridges compared the strength of cores with strengths estimated on the basis of the **CAPO-TEST** and the rebound hammer test (ASTM C805, EN 12504-2). As shown in the following figure, strengths estimated by the **CAPO-TEST** were on average within 6 % of the core strength. This study confirms the inherent reliability of pullout testing for estimating in-place compressive strength.

Reference: Moczko, A., "Comparison Between Compressive Strength Tests From Cores, CAPO-TEST and Schmidt Hammer," Wroclaw Technical University, Poland, 2002.



Example Applications

Routing recess for the expandable ring in preparation for **CAPO-TEST** *to evaluate surface strength of an industrial floor slab*

View of valid **CAPO-TEST** *of a slab. Note the well-formed failure ring on the surface of the slab.*

CAPO-TEST *being performed in parking garage to evaluate in-place strength of suspect concrete*

CAPO-TEST

CAPO-TEST Equipment and Ordering Numbers

Inserts and Resizing Tool

C-112 CAPO *expandable inserts*

C-111 Resizing Tool
For resizing C-112 insert 2 to 3 times

CAPO-TEST Kits

The **CAPO-TEST** kit includes C-101 Preparation Kit, the C-102 DSV-Kit, and a C-104 pull machine kit with the 0 to 100 kN digital gauge.

C-101 CAPO-TEST Preparation Kit

This kit is used to drill the center hole and to cut the recess to accommodate the expandable insert. The kit also contains the unit for expanding the **CAPO-TEST** insert and other miscellaneous tools for conducting the test.

Item	Order #
Counter pressure	C-142
Expansion unit	C-101-1
Water pump	C-150
Recess router unit	C-101-2
Distance piece, 25 mm	C-136
Bottle w. CAPO-Oil	C-143
Diamond drill unit	C-101-3
Electric drill	C-101-4
Wrench, 14 mm	C-151
Wrench, 19 mm	C-155

Item	Order #
Screwdriver	C-149
Tweezers	C-148
Plastic hose	C-157
Marking chalk	C-160
Pliers	C-147
Allen key, 4 mm	C-156
Wrench, 46 mm	C-147-1
Wrench, adjustable	C-147-2
Vernier caliper	C-135
Attaché case	C-160

C-102 DSV-Kit

The kit includes the diamond planer, the suction plate, a vacuum pump, and the necessary tools for planing the surface so that it is flat before drilling the center hole and routing the recess. The diamond planer, the diamond core drill unit, and the recess router are positioned in the recess of the suction plate for proper alignment and dimensional control.

Item	Order #
Diamond planer	C-102-1
Vacuum pump w. hose	C-102-4
Centering brass tap	C-102-5
Suction plate	C-102-2

Item	Order #
Clamping pliers, 2	C-102-3
Small screwdriver	C-158
Wrench, 17 mm	C-154
Plastic hose	C-147
Attaché case	C-161

C-104 CAPO Pull Machine Kit

The hydraulic pull machine has a calibrated 0 to100 kN precision electronic gauge with memory for storage of test results (peak-value, time and date of testing). The peak-value is shown after a test has been terminated. The internal resolution of the gauge is 0.01 kN, but the pull force is displayed to the nearest 0.1 kN. The same pull machine can be used for the **BOND TEST** and the **LOK-TEST**.

Item	Order #
Hydraulic pull machine with electronic gauge	L-11-1
AMIGAS printing software	L-13
Cable for printer	L-14
Oil refilling cup	L-24
Oil refilling bottle	L-26
Large screwdriver	C-149
Small screwdriver	C-157
Calibration table	L-32
Manual	L-33
Attaché Case	C-104-1

Note: The calibration of the pull machines needs to be verified at least once a year, or sooner, if serviced or damaged. The L-30 Load Verification Unit shown on page 87 is available for this purpose.

Appendix B: Representative Acoustic Equipment

Ultrasonic Pulse Velocity

UTEST
MATERIAL TESTING EQUIPMENT

CONCRETE

Protection and Repair of Concrete Structures (NDT)

NON-DESTRUCTIVE CONCRETE TESTING in STRUCTURES

Product Code

UTC-3050	Pundit Lab+ Ultrasonic Pulse Velocity Tester (Proceq)
UTC-3055	S-Wave Transducers, 250 kHz, for UTC-3050 (Proceq)
UTC-3060	Pundit PL-200 Ultrasonic Pulse Velocity Tester (Proceq)
UTC-3065	Pundit PL-200PE Ultrasonic Pulse Velocity Tester (Proceq)

Standards

EN 12504-4; ASTM C 597-02; BS 1881 Part 203; ISO1920-7:2004; IS13311; CECS21

Pundit Lab+

Pundit PL200-PE

The measurement of pulse velocity can be used for the determination of the uniformity of concrete, the presence of cracks or voids, changes in properties with time and in the determination of dynamic physical properties. EN 12504:4 gives guidance on testing fresh concrete, hardened concrete and concrete in structures. It specifies a method for the determination of the velocity of propagation of pulses of ultrasonic longitudinal waves in concrete.

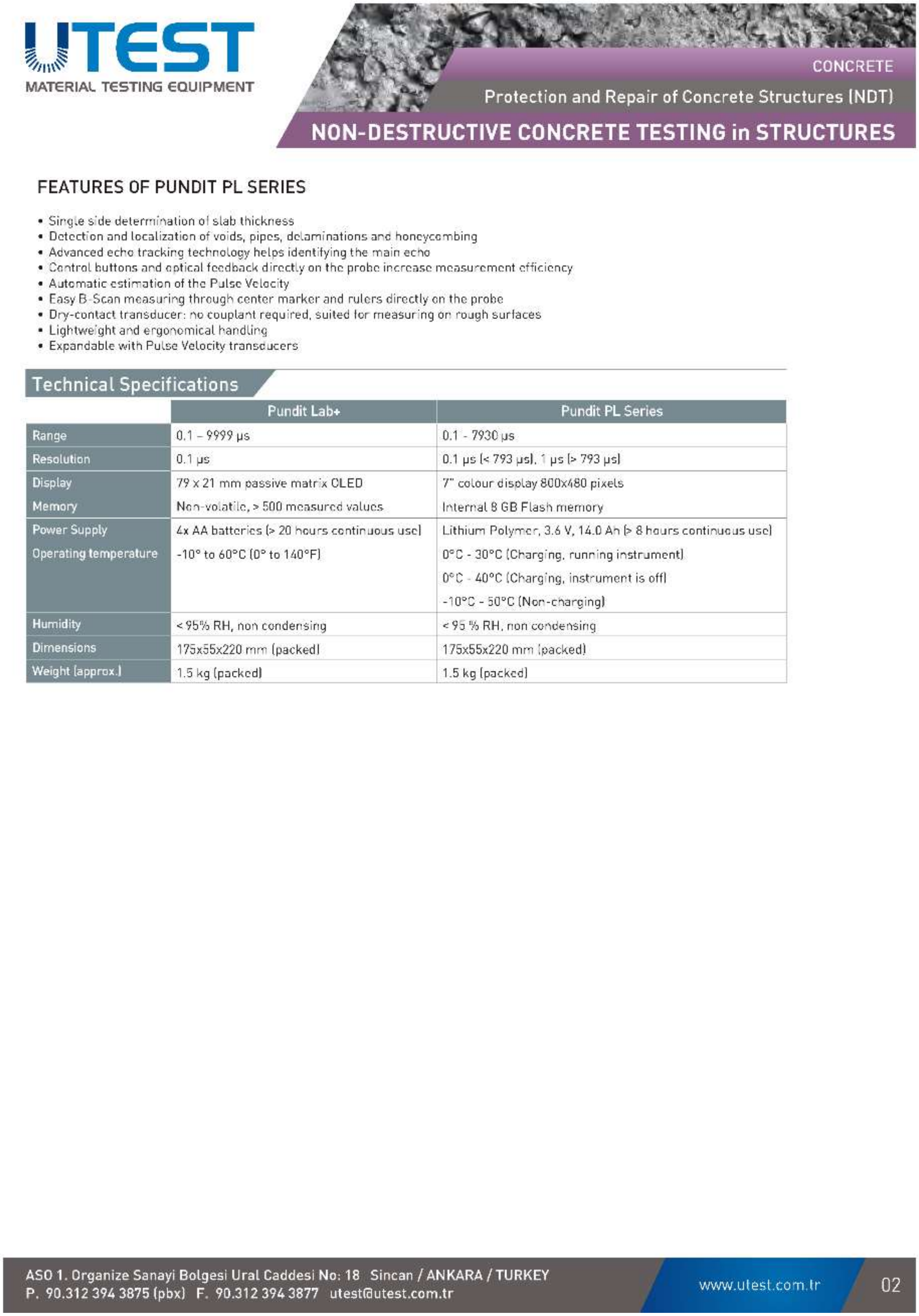
UTC-3050 is an ultrasonic pulse velocity test instrument which is used to examine the quality of concrete. It features online data acquisition, waveform analysis and full remote control of all transmission parameters. Along with the traditional transit time and pulse velocity measurement, UTC-3050 offers path length measurement, perpendicular crack depth measurement and surface velocity measurement. Optimized pulse shaping gives greater transmission range at lower voltage levels. This, coupled with automated combination of the transmitter voltage and the receiver gain, ensures an optimum received signal level, guaranteeing accurate and stable measurements. An integrated waveform display allows manual triggering of the received waveform. Pundit Lab+ offers other features such as the possibility to estimate compressive strength by Sonreb Method in combination with a rebound hammer value.

The Pundit PL-200 is a best-in-class Ultrasonic pulse velocity (UPV) test instrument to examine the quality of concrete and other materials such as rock, wood and ceramics.

The Pundit PL-200PE employs state-of-the-art pulse echo technology to extend the ultrasonic application to objects where access is restricted to a single side.

FEATURES OF PUNDIT LAB+

- Integrated wave form display
- Remote control; A USB connection and the Pundit Link application allow full remote control of all features of the ultrasonic test equipment
- Full remote control of the instrument with a third party software
- Direct data logging on the PC
- Runs on battery supply, mains supply via AC adaptor and can also be powered from a PC via the USB connection.
- Supports a wide range of transducers from 24 kHz up to 500 kHz, making it suitable not only for concrete and rock, but also for other materials such as graphite, ceramics, woods, etc.
- Exponential transducers for rough surfaces and shear wave transducers for estimation of dynamic modulus of elasticity complete the portfolio.
- Integrated amplifier gain stage
- Real time stamp
- Direct estimation of compressive strength
- Combined ultrasonic pulse velocity / rebound value estimate of compressive strength (SONREB)
- Data review list on the instrument



UTEST
MATERIAL TESTING EQUIPMENT

CONCRETE

Protection and Repair of Concrete Structures (NDT)

NON-DESTRUCTIVE CONCRETE TESTING in STRUCTURES

FEATURES OF PUNDIT PL SERIES

- Single side determination of slab thickness
- Detection and localization of voids, pipes, delaminations and honeycombing
- Advanced echo tracking technology helps identifying the main echo
- Control buttons and optical feedback directly on the probe increase measurement efficiency
- Automatic estimation of the Pulse Velocity
- Easy B-Scan measuring through center marker and rulers directly on the probe
- Dry-contact transducer: no couplant required, suited for measuring on rough surfaces
- Lightweight and ergonomical handling
- Expandable with Pulse Velocity transducers

Technical Specifications

	Pundit Lab+	Pundit PL Series
Range	0.1 – 9999 µs	0.1 - 7930 µs
Resolution	0.1 µs	0.1 µs (< 793 µs), 1 µs (> 793 µs)
Display	79 x 21 mm passive matrix OLED	7" colour display 800x480 pixels
Memory	Non-volatile, > 500 measured values	Internal 8 GB Flash memory
Power Supply	4x AA batteries (> 20 hours continuous use)	Lithium Polymer, 3.6 V, 14.0 Ah (> 8 hours continuous use)
Operating temperature	-10° to 60°C (0° to 140°F)	0°C - 30°C (Charging, running instrument) 0°C - 40°C (Charging, instrument is off) -10°C - 50°C (Non-charging)
Humidity	< 95% RH, non condensing	< 95 % RH, non condensing
Dimensions	175x55x220 mm (packed)	175x55x220 mm (packed)
Weight (approx.)	1.5 kg (packed)	1.5 kg (packed)

ASO 1. Organize Sanayi Bolgesi Ural Caddesi No: 18 Sincan / ANKARA / TURKEY
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www.utest.com.tr 02

Ultrasonic Pulse Echo

General Purpose Thickness Gauge **PocketMIKE™**

With a thickness gauge in one hand and
your ultrasonic transducer in the other,
did you ever wish you had an extra hand?

Introducing the StressTel PocketMIKE™ general purpose thickness gauge. The PocketMIKE™ 's integrated product design combines the instrument and transducer into a single package not much larger than a traditional cabled probe allowing for true single hand operation.

The PocketMIKE™ thickness gauge is packaged in a machined stainless steel housing environmentally sealed to IP67.

Four button operation and Automatic On-Block Probe Zero further support StressTel's goal of providing very capable yet simple to use instruments.

The high contrast backlit display can be mechanically and electronically rotated for ease of reading in any orientation.

Single hand operation
Waterproof to IP67/IEC529

It's That Simple!

STRESSTEL
part of GE Inspection Technologies

PocketMIKE™ SPECIFICATIONS

Kit Includes

Instrument
Wrist Lanyard
One 1.5V AA Alkaline Battery
Hard Shell Carry Case
Integrated Transducer
Couplant
Operating Manual
Certificate of Calibration

1 Power Key
2 Increase value within CAL or SETUP
3 Decrease value within CAL or SETUP
4 SETUP key to change operating modes
5 Initiates CAL function
6 Backlight Status indicator
7 Coupling indicator
8 Thickness Mode indicator
9 Velocity Mode indicator
10 CAL Mode indicator
11 Metric or Imperial Units
12 Battery Control

Special Features

Integrated Transducer, 5 MHz
True Single Hand Operation
Machined Stainless Steel Housing
Environmentally Sealed to IP67/IEC529
Automatic On-Block Probe Zero
Automatic Timed Shutoff
Auto Backlight Mode
Known Thickness Calibration
Known Velocity Calibration
4 Button Sealed Membrane Keypad
User Selectable Measurement Units
Exchangeable Probes

* Material and application dependent
Specifications subject to change without notice

Physical Size

100 mm High (4 inches)
35 mm Nominal Diameter (1.38 inches)
12 mm (0.5 inch) Probe Diameter

Weight

200 grams with Battery

Power Source

One 1.5V AA Alkaline Battery

Measuring Range*

1.0 mm to 250 mm
(0.040 inches to 9.999 inches)

Displayed Resolution

0,01 up to 99,99 mm, 0,1 above
(0.001 up to 9.999 inches, 0.01 above)

Operating Temperature

-10° C to +50° C
(14° F to 122° F)

Probe Surface Temperature

-10° C to +100° C
(14° F to 212° F)

GEInspectionTechnologies.com

GE Inspection Technologies, LP
50 Industrial Park Road
Lewistown, PA, USA 17044
phone +1-717 242-0327
fax +1-717 242-2606

GE Inspection Technologies Systems GmbH
Robert-Bosch-Straße 3
D-50354 Hürth, Germany
phone +49 2233-601-0
fax +49 2233-601-402

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We reserve the right to technical modifications without prior notice.

Impact-Echo and Spectral Analysis of Surface Wave

GI DOCter

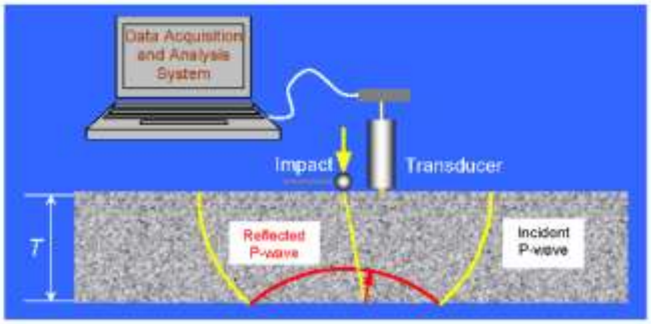
Purpose

The use of traditional stress wave methods, such as ultrasonic through transmission (pg. 123), to identify the presence of anomalies in structures requires access to both faces of a member. Furthermore, it is not possible to determine the depth to anomalies. These drawbacks are eliminated by using the impact-echo method, which requires access to only one surface. The impact-echo method is based on monitoring the periodic arrival of reflected stress waves and is able to obtain information on the depth of the internal reflecting interface or the thickness of a solid member.

The **DOCter** is a versatile, portable system based on the impact-echo method, and can be used for the following applications:

- Measure the thickness of pavements, asphalt overlays, slabs-on-ground and walls
- Detect the presence and depth of voids and honeycombing
- Detect voids below slabs-on-ground
- Evaluate the quality of grout injection in post-tensioning cable ducts
- Integrity of a membrane below an asphalt overlay protecting structural concrete
- Delamination surveys of bridge decks, piers, cooling towers and chimneystacks
- Detect debonding of overlays and patches
- Detect ASR damage and freezing-and-thawing damage
- Measure the depth of surface-opening cracks
- Estimate early-age strength development (with proper correlation)

Principle



A short-duration stress pulse is introduced into the member by mechanical impact. This impact generated three types of stress waves that propagate away from the impact point. A surface wave (R-wave) travels along the top surface, and a P-wave and an S-wave travel into the member. In impact-echo testing, the P-wave is used to obtain information about the member.

When the P-wave reaches the back side of the member, it is reflected and travels back to the surface where the impact was generated. A sensitive displacement transducer next to the impact point picks up the disturbance due to the arrival of the P-wave. The P-wave is then reflected back into the member and the cycle begins again. Thus the P-wave undergoes multiple reflections between the two surfaces. The recorded waveform of surface displacement has a periodic pattern that is related to the thickness of the member and the wave speed.

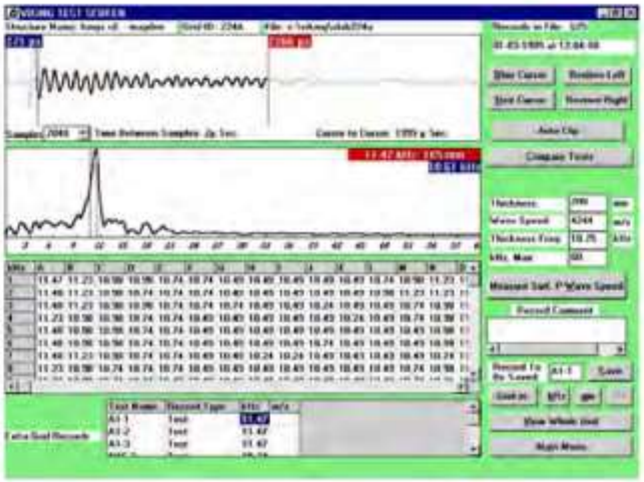
The displacement waveform is transformed into the frequency domain to produce an **amplitude spectrum**, which shows the predominant frequencies in the waveform. The frequency of P-wave arrival is determined as the frequency with a high peak in the amplitude spectrum. The thickness (T) of the member is related to this thickness frequency (f) and wave speed (C_p) by this simple approximate equation (see also pg. 51):

$$T = \frac{C_p}{2f}$$

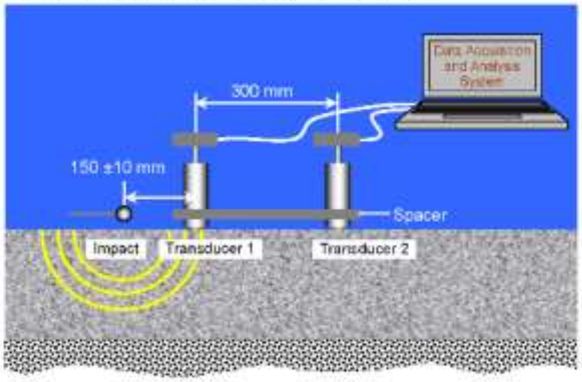
The same principle applies to reflection from an internal defect (delamination or void). Thus, the impact-echo method is able to determine the location of internal defects as well as measure the thickness of a solid member.

Example

The upper plot in this example shows the surface displacement waveform obtained from a test of a solid concrete slab. The figure below the waveform is the amplitude spectrum obtained by transforming the waveform into the frequency domain. The peak at 11.47 kHz is the thickness frequency. For a wave speed of 4240 m/s, this frequency corresponds to a thickness of 4240/(2×11,470) = 0.185 m, or 185 mm.



Thickness Measurement by ASTM C1383



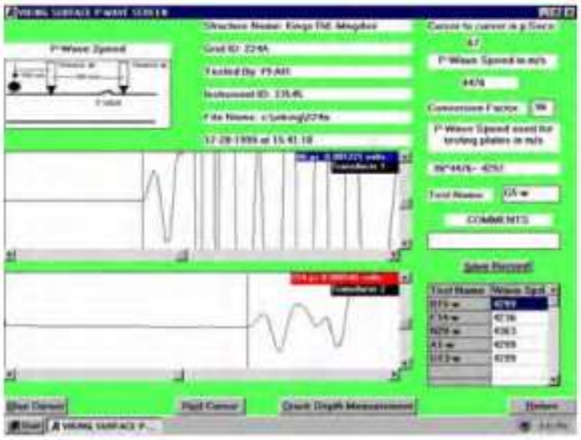
Accurate measurement of thickness requires knowledge of the in-place P-wave speed. ASTM C1383, "Test Method for Measuring the P-Wave Speed and the Thickness of Concrete Plates Using the Impact-Echo Method," permits two methods for obtaining the P-wave speed. One method is by determining the thickness frequency and then measuring the actual plate thickness at that point. The equation on page 50 is used to solve for C_p, i.e., $C_p = 2\,f\,T$.

Alternatively, C_p may be determined by measuring the time for the P-wave to travel between two transducers with a known separation. With the **LONGSHIP** two-transducer assembly, the transducers are placed 300 mm apart and the impactor is about 150 mm from one of the transducers one the line passing through the transducers. The distance L (300 mm) between the transducers, is divided by time difference Δt between arrival of the P-wave at the second and first transducers. In the figure shown on the next page, Δt was measured to be 67 µs, and the P-wave speed is 0.300 / 0.000067 = 4480 m/s. If the wave speed is determined by the surface measurement method, the resulting value is multiplied by 0.96 when it used to calculate thickness. Thus the correct equation for thickness calculation is:

$$T = \frac{0.96\,C_p}{2f}$$

The explanation for this 0.96 factor can be found in the following reference:

Gibson, A. and Popovics, J.A., 2005, "Lamb Wave Basis for Impact-Echo Method Analysis," *J. of Engineering Mechanics* (ASCE), Vol. 131, No. 4, April, pp. 438-443.



Measurement of P-wave Speed

The figure to the right is an example of the measurement of P-wave speed by using two transducers a known distance apart. The time of arrival of the P-wave at each transducer is determined as the point when the signal for each transducer rises above the background value. The **Viking** software allows the user to place cursors at the points corresponding to the P-wave arrivals, and calculates the value of C_p. In this case, the calculated speed is 4480 m/s, and 96 % of this value is 4300 m/s.

Detection of Internal Defects

The P-wave generated by impact will reflect at interfaces within the concrete where there is a change in **acoustic impedance**, which is defined as the product of the density and wave speed of a material. The following lists the reflection coefficients of a P-wave travelling through concrete and incident normal to an interface with air, water, soil, or steel:

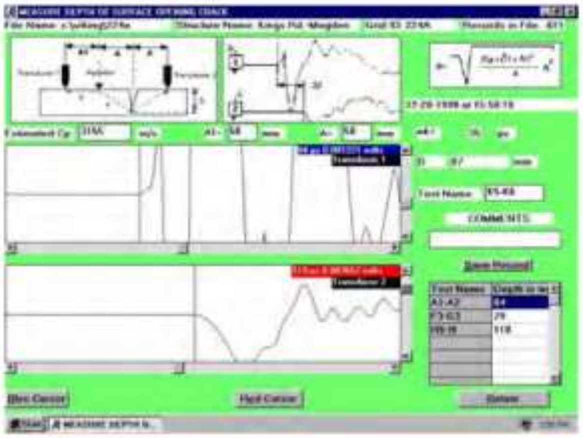
Interface	Reflection Coefficient
Concrete-air	-1.0
Concrete-water	-0.65 to -0.75
Concrete-soil	-0.3 to -0.9
Concrete-steel	0.65 to 0.75

A negative reflection coefficient means that the stress changes sign when the stress wave is reflected; for example, a compressive stress would be reflected as a tensile stress. Steel is "acoustically harder" than concrete and the stress does not change sign when reflected at a concrete-steel interface.

It is seen that at a concrete-air interface, there is complete reflection of the P-wave. This makes the impact-echo method inherently powerful for detecting air interfaces, such as those due to delaminations, cavities, and honeycombed concrete. If the area of the reflecting interface is large, the impact-echo response will be similar to that of a solid plate except that the thickness frequency will be shifted to the higher value corresponding to the depth of the interface. If the defect is just large enough to be detectable, the amplitude spectrum will show two peaks: a high frequency peak corresponds to reflection from the interface and the low frequency peak corresponds to the portion of the P-wave that travels around the defect and reflects from the opposite surface of the plate. By positioning the cursor at the frequency associated with the flaw, the flaw depth is shown by the **Viking** software. The frequency associated with the portion of the P-wave that travels around the defect will be shifted to a lower frequency value than the solid plate thickness frequency. This is because the wave has to travel a longer distance as it diffracts around the flaw. The frequency shift is a good indicator of the presence of a flaw if it is known that the plate thickness is constant.

DOCter

Depth of Surface-Opening Cracks



The **DOCter** can also be used to measure the depth of surface-opening cracks, using a time domain analysis. The **LONGSHIP** transducers are placed on opposite sides of the crack (as shown in the sketch to the right) and impact is generated on the line passing through the transducers. When the P-wave reaches the tip of the crack, the crack tip acts as a P-wave source, a process called **diffraction**. The diffracted P-wave is detected by the transducer on the opposite side of the crack from the impact. By measuring the time interval between the arrival of the direct P-wave at the first transducer and the arrival of the diffracted wave at the second transducer, the depth of the crack can be calculated. The example shown is from testing a fire-damaged structure, and a crack depth of 87 mm was estimated for a time difference of 35 μs and a P-wave speed of 3155 m/s.

Accuracy

For P-wave speed determined by calculation from a test at a point of known thickness, the error in thickness measured by the **DOCter** system is estimated to be within ± 2 %. This assumes that the same P-wave speed is applicable at all test points.

In the case of thickness measurement based on measuring the P-wave speed from surface measurements, the error in thickness dues to systematic errors associated with the digital nature of the measurements is about ± 3 %. This assumes that the P-wave speed is uniform with depth.

The depth of surface-opening cracks can be estimated within ± 4 %.

Testing Examples

Detection of delaminations and honeycomb in sewer pipe

Measurement of P-wave speed by surface method

Testing for quality of grout injection in cable ducts located by ground penetrating radar

GI DOCter

DOCter Ordering Numbers

The **DOCter** comes in two versions: the **DOC-700** for flaw detection and thickness measurement, and the **DOC-4000** for flaw detection, thickness measurement, crack depth measurement, and P-wave speed measurement. The **Spider** multiple impactor unit can be purchased as an option to increase the operating range of the systems.

DOC-700

The **DOC-700** system is a one-channel system for thickness measurement and flaw detection. The P-wave speed is determined by testing over a solid portion of a plate with known thickness. The system includes a laptop computer, a data acquisition module, one Mark IV transducer with impactors, and software. The hardware components and computer are delivered in attaché cases (not shown).

Item	Order #
Laptop computer	DOC-10
Data acquisition module with USB cable	DOC-20
Viking software, CD-ROM Data	DOC-30
Mark IV transducer	DOC-40
Star support with 5, 8 and 12 mm impactors	DOC-60
Impactors on spring rods, 5, 8, and 12 mm	DOC-70
Protection caps for transducer tips, 4 pcs	DOC-80
Single cable	DOC-90
Attaché case for Mark IV transducer	DOC-120
Attaché case for laptop computer	DOC-140
Manual for **Viking** software	DOC-150
Operation manual for DOC-700 system	DOC-160
Testing case studies	DOC-170

DOCter

DOC-4000

The **DOC-4000** system is a two-channel system that complies with the surface method for P-wave speed measurement given in ASTM C1383. Besides thickness determination and flaw detection, the **DOC-4000** can be used to estimate the depth of surface-opening cracks.

Item	Order #
Laptop computer	DOC-10
Data acquisition module with USB cable	DOC-20
Viking software, CD-ROM Data	DOC-30
Viking **LONGSHIP** with long handle and two Mark IV handheld transducers	DOC-50
Star support with 5, 8 and 12 mm impactors	DOC-60
Impactors on spring rods, 5, 8, and 12 mm	DOC-70
Short handle for crack depth measurement	DOC-80
Protection caps for transducer tips, 8 pcs	DOC-90
Double cable	DOC-100
Attaché case for **LONGSHIP**	DOC-130
Attaché case for laptop computer	DOC-140
Manual for **Viking** software	DOC-150
Operation manual for DOC-4000 system	DOC-160
Testing case studies	DOC-170

Spider, Order # DOC-210

The optional **Spider** contains 8 spherical impactors, with diameters ranging from 2 mm to 15 mm. The frequency content covered by the **Spider** impactors is approximately 1.2 kHz to 100 kHz on a hard concrete surface. The **Spider** is placed adjacent to the Mark IV transducer as shown in the photo.

Impulse Response

STRUCTURAL | PAVEMENT | TUNNEL SYSTEMS

Slab Impulse Response » ASTM C1740 | ACI 228.2R

The Slab Impulse Response (SIR) method is excellent for evaluating the condition of slab subgrade and tunnel lining support.

The Slab Impulse Response (SIR) system is designed to identify subgrade voids below slabs-on-grade less than two feet thick. In addition, the Slab IR test method can be used on other concrete structures to quickly locate areas with delaminations or voids in the concrete, if the damage is relatively shallow. Slab IR can be performed on reinforced and non-reinforced concrete slabs as well as asphalt or asphalt-overlay slabs.

The Slab IR method is often used in conjunction with GPR for subgrade void detection and mapping. Collecting Slab IR data at multiple, densely spaced locations can improve the conclusions by mapping relative areas of higher and lower mobility. Relatively low mobility (velocity/force) and flexibility (displacement/force) qualitatively indicates that such an area appears to be more solidly supported than an area with relatively high mobility and flexibility.

Features:

- System is compact, durable, and easily transported allowing for up to 600 tests per day
- Real-time waveform display while testing
- Short learning curve for data acquisition and basic processing
- 2-D maps are easily generated from data by exporting the tables from WinSIR into Excel
- English or Metric units can be used

» **Applicable On:**

- Concrete Slabs and Retaining Walls
- Pavements
- Pond or Pool Bottoms
- Runways
- Spillways
- Tunnel Liners

» **Test For:**

- Delaminations in Decks
- Voids below slabs/tunnel linings
- Soft, weak subgrade support

Model	Advantages
SIR-1 Model	Complete system for testing of slabs-on-ground
SIR-2 Model	Allows the user to test slabs and to expand testing to tunnels, inclined spillways, etc.

Freedom Data PC or NDE 360 Required Sold Separately

Slab Impulse Response » ASTM C1740 | ACI 228.2R

Method

Conventional SIR testing requires access to the top of the slab. The vertical geophone receiver is mounted to the surface of the slab adjacent to the impact location and generally 3-4 inches away. Once the slab top is impacted with an impulse hammer, the response of the slab is monitored by the geophone. The hammer input and the receiver output are recorded by an Olson Instruments Freedom Data PC or NDE 360 equipped with the Slab Impulse Response System. In easy access areas, 400-600 Slab IR tests can be performed in an 8 hour workday. Once all of the data is collected, it can be processed with the WinSIR software provided, imported into a spreadsheet program, and then contour mapped.

Data Collection

The user-friendly WinSIR software is written and tested at Olson Instruments' corporate office in Colorado. We do not outsource any tech support questions and, should you require software support, we welcome your questions and comments.

Available Models

The Slab Impulse Response system is available in two different models which can be run from Olson's Freedom Data PC or NDE 360 Platforms:

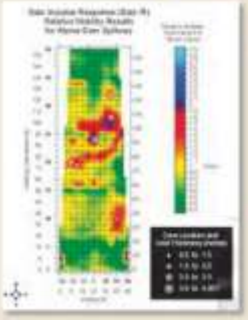
1. Slab Impulse Response - 1 (SIR-1)
2. Slab Impulse Response - 2 (SIR-2)

The **SIR-1 Model** includes a vertical geophone transducer for flat slabs, an instrumented hammer, cables, and the acquisition/processing software. This system can be easily used to test slabs-on-grade and then create 2-D contour maps by importing the results table into programs like Excel. These renderings are often a valuable resource for isolating and repairing voids below slabs-on-grade.

The **SIR-2 Model** includes the addition of an omni-directional velocity transducer to perform tests on walls and ceilings of concrete beams and tunnels.

Determine areas of void/poor subgrade support and flawed concrete conditions with Slab Impulse Response

Data Example » 1



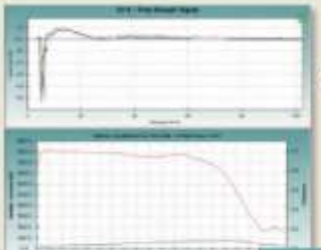
Subgrade support condition evaluation parameters:

- Mean mobility (in/sec/lbf)
- Shape of the mobility plot at frequencies above the initial straight-line portion of the curve (between 100 to 800 Hz in this investigation)
- Initial slope of the mobility plot gives the low-strain flexibility (in/lbf) of the spillway-subgrade system

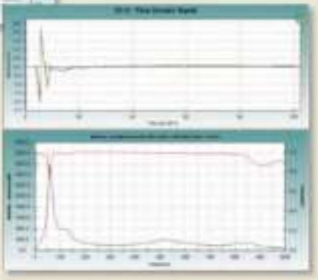
Interpretation Pitfalls

- Slab thickness
- Local reinforcement
- Local joints/seams

Data Example » 2



Good subgrade support – low, smooth mobility.



Poor subgrade support – high amplitude, low frequency mobility peak

Introduction to Acoustic Emission Sensors

AE sensors are used in a wide range of fields, including the inspection of manufactured products, monitoring the safety of structures, and the development of new materials.

What is AE ?

Acoustic Emission (AE) is the sound emitted as an elastic wave by a solid when it is deformed or struck. The use of AE sensors to detect these elastic waves and to non-destructively test on materials is called the AE method.

Quite some time before failure occurs, tiny deformations and minute cracks will appear and spread in materials. By picking up the trends in AE, the AE method can detect and predict flaws and failures in materials and structures.

Typical non-destructive testing methods

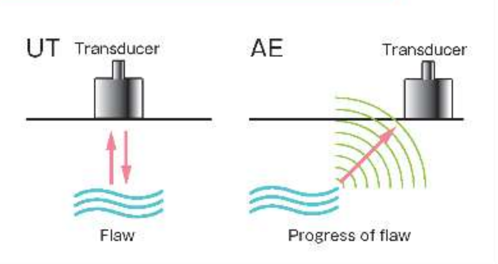
①Ultrasonic Testing (UT)
②Radiographic Testing (RT)
③Eddy Current Testing (ET)
④Acoustic Emission Testing (AET)

Features of the AE method

The AE method is used to detect frequencies in the ultrasonic range (several tens of kHz to several MHz). Although AE resembles ultrasonic testing, the AE method is different from other non-destructive testing methods in that it detects the dynamic energy that the flaws in the material themselves emit. The AE method offers the following advantages.

- Can observe the progress of plastic deformation and microscopic collapse in real time.
- Can locate a flaw by using several AE sensors.
- Can diagnose facilities while they are in operation.

A comparison of UT and AE methods



The principle behind the operation of the AE sensor

Except for special cases, PZT (lead zirconate titanate) is used as the detection element in AE sensors. Other materials, such as lead niobate and lithium niobate are available; however, their sensitivity is far lower than that of PZT and their applications are limited to special environments such as high temperatures.

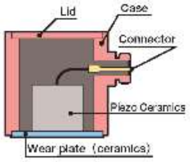
PZT and other piezoelectric materials generate an electrical charge when subjected to a force. AE waves propagating along a metal or other surface are transmitted to the PZT inside the AE sensor, and the deformation of the PZT is converted into an electric signal.

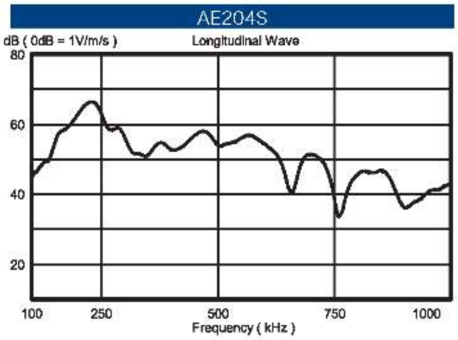
The structure and features of AE sensors

AE sensors are broadly classified into two types: resonance models (narrow-band) that are highly sensitive at a specific frequency, and wide bandwidth models that possess a constant sensitivity across a wide band of frequencies. The choice of model depends on the goal of the application.

Resonance model

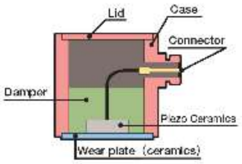
The mechanical resonance of the detector element is used to obtain high sensitivity. Generally, these types of sensors have resonant frequencies in the range of 30 kHz to 1 MHz. AE sensors having a piezoelectric accelerometer design are used if lower resonance characteristics are required.

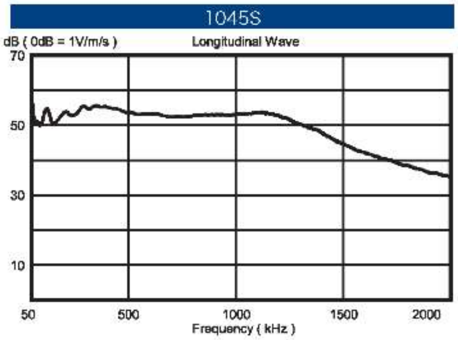




Wide bandwidth model

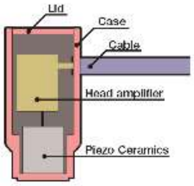
A damper is bonded on top of the detector element to suppress the resonance.

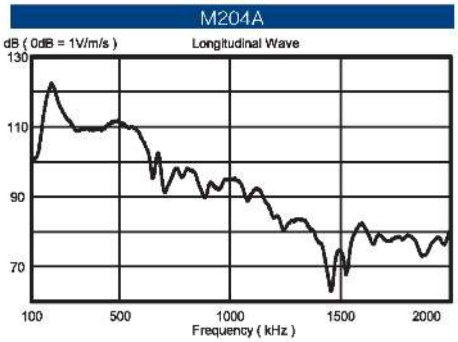




R-CAST TYPE

This design incorporates a head amplifier and a special pre-amplifier to yield high sensitivity with low noise levels. Compared with other models, the sensitivity (S/N ratio) is at least twice as high.





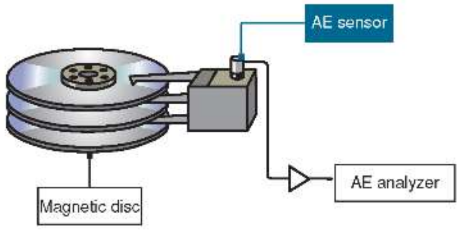
The application of AE sensors

AE sensors can pick up warning signals from manufactured products that human senses cannot detect. AE sensors have a wide range of applications, from quality control inspections of manufactured goods, to safety inspections of large structures.

Product testing

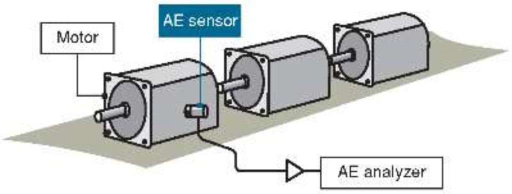
■Detecting event of "head touch" in magnetic discs

AE sensors are used in the quality control management of magnetic discs. The sensors can detect the sounds of tiny prominences on a rapidly spinning magnetic disc striking the magnetic head.



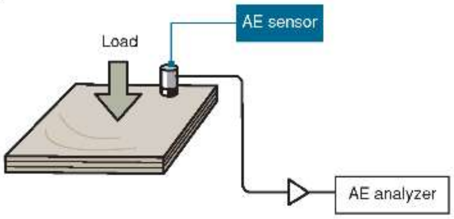
■Detection of abnormal sounds in small electric motors

The passing or failure of the product can be decided based on the level of abnormal sounds coming from motors and fans.



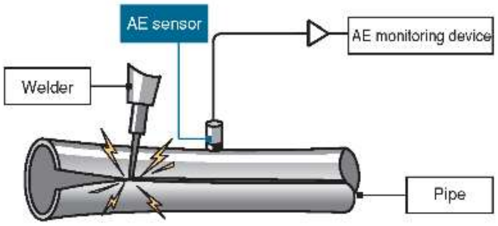
■Inspection of the bonding of laminated boards

An AE sensor can tell by the acoustic emissions generated when a load is applied to a laminated board whether there is poor bonding between laminations or not.



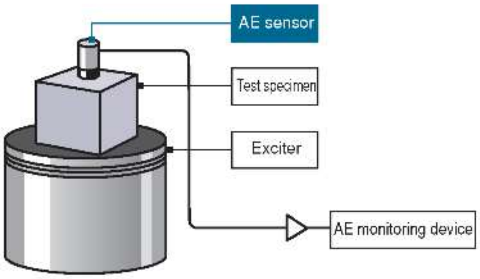
■Detection of sub-standard pipe welds

When pipes, etc., are improperly welded, the substandard welding can be detected by the AE that are generated.



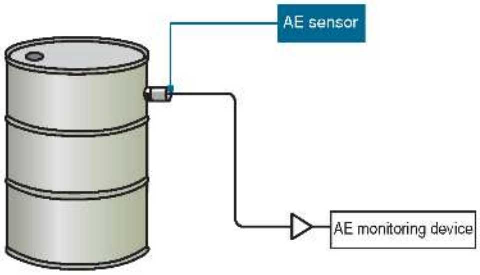
■Detection of foreign bodies in manufactured products

Can detect the sounds of solder scraps and other waste striking the walls inside manufactured goods.



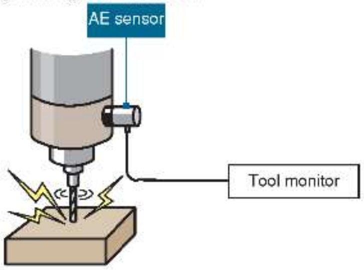
■Detection of tiny hole in drum cans

The passing or failure of the drum can be decided by leak detection when air is pumped into the drum.



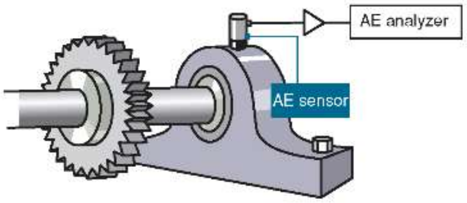
Tool monitoring

Detects the instant that the whetstone touches the work. This is useful in the improvement of product quality by controlling the speed of the whetstone and detecting damage to the tool.



Facility diagnosis

AE sensors are used in the facility diagnosis of rotating machinery.
They are particularly effective in the diagnosis of machinery rotating at slow speeds.

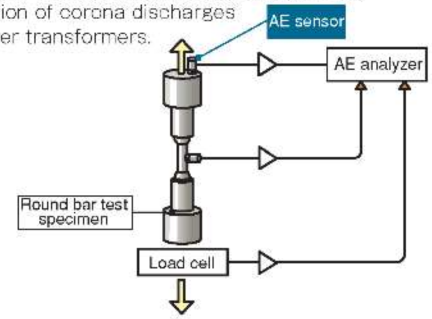


Safety monitoring in civil engineering projects

Detection of the sounds that occur before landslides, or signal the occurrence of cracks in tunnels and other underground spaces.

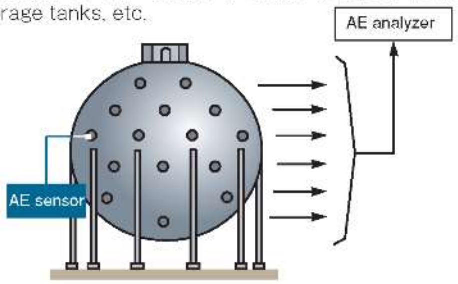
Material testing / other applications

Tensile testing and fracture toughness testing.
Detection of quenching in superconductivity.
Detection of corona discharges
in power transformers.



Diagnosis of the integrity of large structures

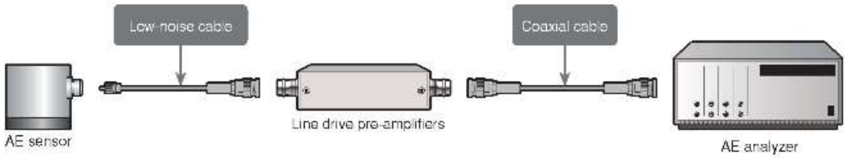
Monitoring for cracks in pressure vessels, bridge piers, rolling mill stands, etc.
Detection of the sound of leaks in pipes, valves, storage tanks, etc.



Examples of measuring system

The following two system combinations are available depending on the type of acoustic emission sensor.

●Amplifier not built-in type

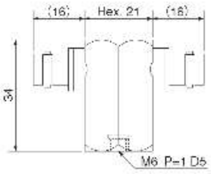


A preamplifier is used to amplify acoustic emission (AE) signals, which are very faint in nature. At the same time, filters are used to eliminate unnecessary signals.
A low-noise cable is required to connect a sensor to a preamplifier.

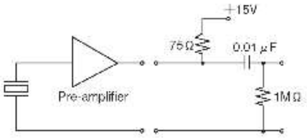
■AE preamplifier A20S-BB

Gain	20±2dB
Frequency range	20~2000kHz
Output impedance	75Ω
Maximum output voltage	1V_{P-P}
Power consumption	≦15mA
Temperature range	−20~+80℃
Power requirement	15V (load 75Ω)
IN/OUT connector	BNC
Weight	70gm

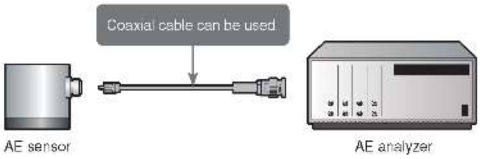
Size mm



Power supply



●Amplifier built-in type



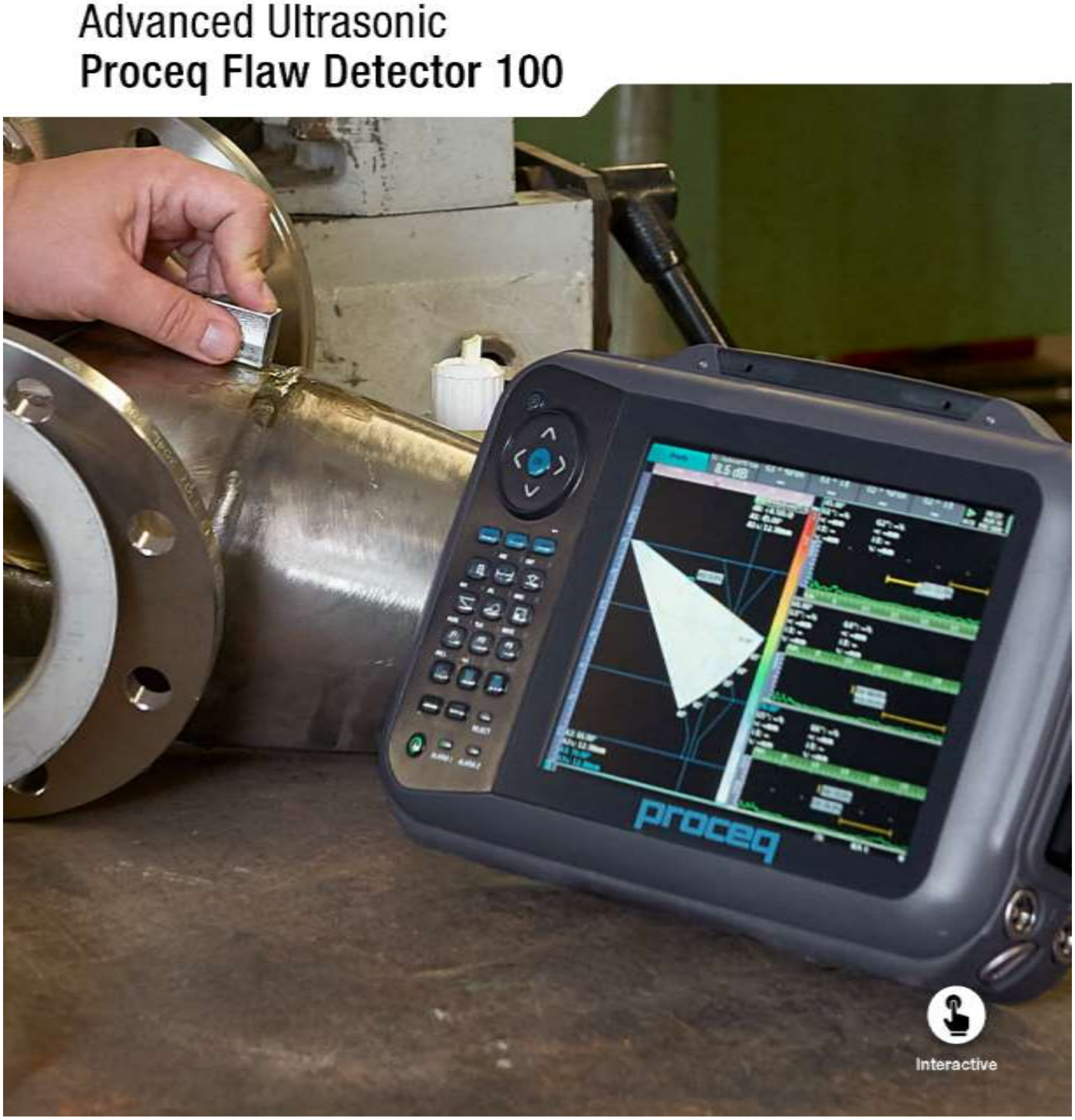
An ordinary coaxial cable can be used for AE sensor with built-in amplifier. In such cases, users should identify the operating conditions specified for the sensor drive power source that comes from the AE analyzer before use.

■Specification of amplifier inside the sensor

Gain	40dB	20dB
Power requirement	28V (load 50Ω)	15V (load 75Ω)
Applied model	SA40 type sensor	1045SWA

FUJI CERAMICS CORPORATION

Ultrasonic Phased Array / Phase Spectroscopy



Advanced Ultrasonic
Proceq Flaw Detector 100

High Performance
Adapted to your Requirements

Affordable high tech

- An essential tool for inspection, investigation and technique development
- Recognise more with a high pulser voltage
- Broad system bandwidth from 200 kHz to 20 mHz
- Including true top view and DGS flaw sizing technique
- All models have twin axis encoding

Excellent software and reporting

- Wizards and option specific help for fast configurations
- 3D scan plans assist in creating inspection procedures and analyzing the results
- Save and re-use settings
- Seamless connectivity between instrument and PC software
- Lateral wave removal functionality for TOFD

Rugged and compact

- Lightweight for single hand operation
- Robust IP 66 housing
- Protected connections: 2x USB, 1x Ethernet

Upgrade anytime, anywhere on-site

UT → TOFD

UT → PA 16:16

UT → PA 16:64

\+ Special upgrade: Export raw data in CSV format

proceq 2 Proceq Flaw Detector 100

Unmatched User Experience

Click wheel for fast navigation

Grouped options for easy setup, measurement and analysis

Shortcut keys for easy access to common options

Context sensitive help and workflow based tabs provide an intuitive user interface

Customizable screen with selectable layouts

Proceq FD Link Software for Preparation and Reporting

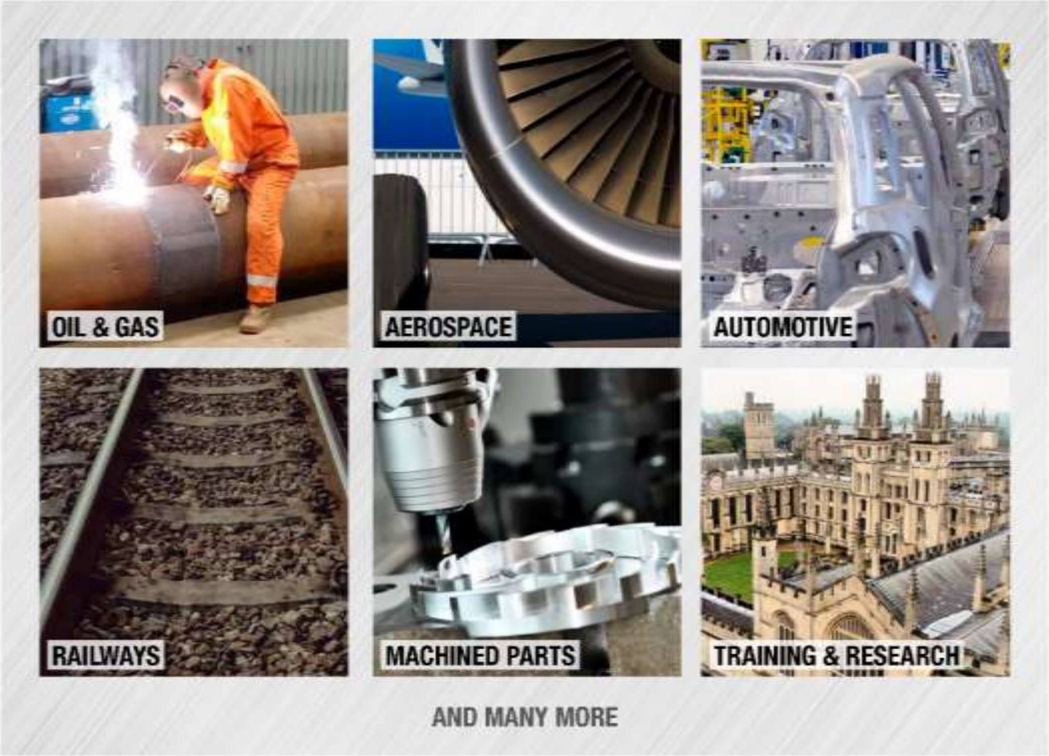
- ✓ Create acquisition layout and new sheets / customize layouts
- ✓ Review data / add cursors / extraction box / extract views
- ✓ Add free hand measurements and create images for reports
- ✓ Show defect position with the 3D toolset and add annotations
- ✓ Produce, open and review a PDF report
- ✓ Export data from amplitude Top / C-Scan as a .csv file

Applications and Industries

Proceq's advanced ultrasonic flaw detector offers technicians an extremely comprehensive measurement solution. All popular flaw sizing techniques such as DGS/AVG, DAC, TGC and AWS are included. Thanks to the A, B, C, True Top and End scans imaging capabilities, users can address many applications:

- General component inspection
- Pipeline welds
- Complex geometries
- Forgings and castings
- Aircraft composites delamination
- Corrosion mapping inspection
- On-site thickness profiling

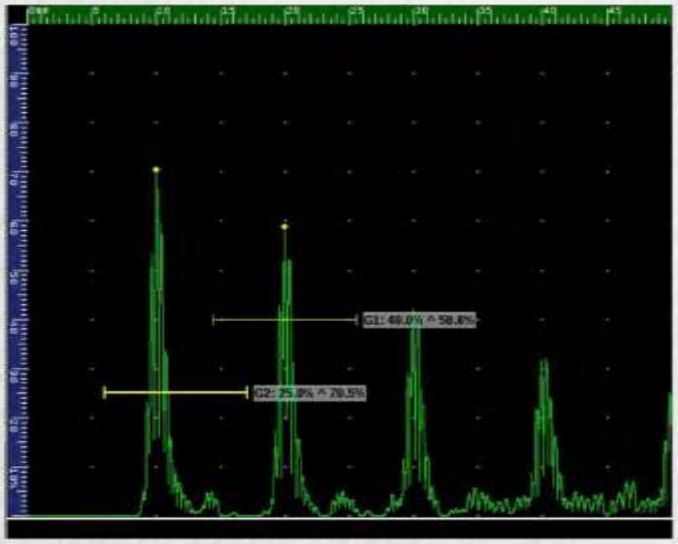
For efficient weld inspection, Proceq is offering both focused and unfocused PA scans.

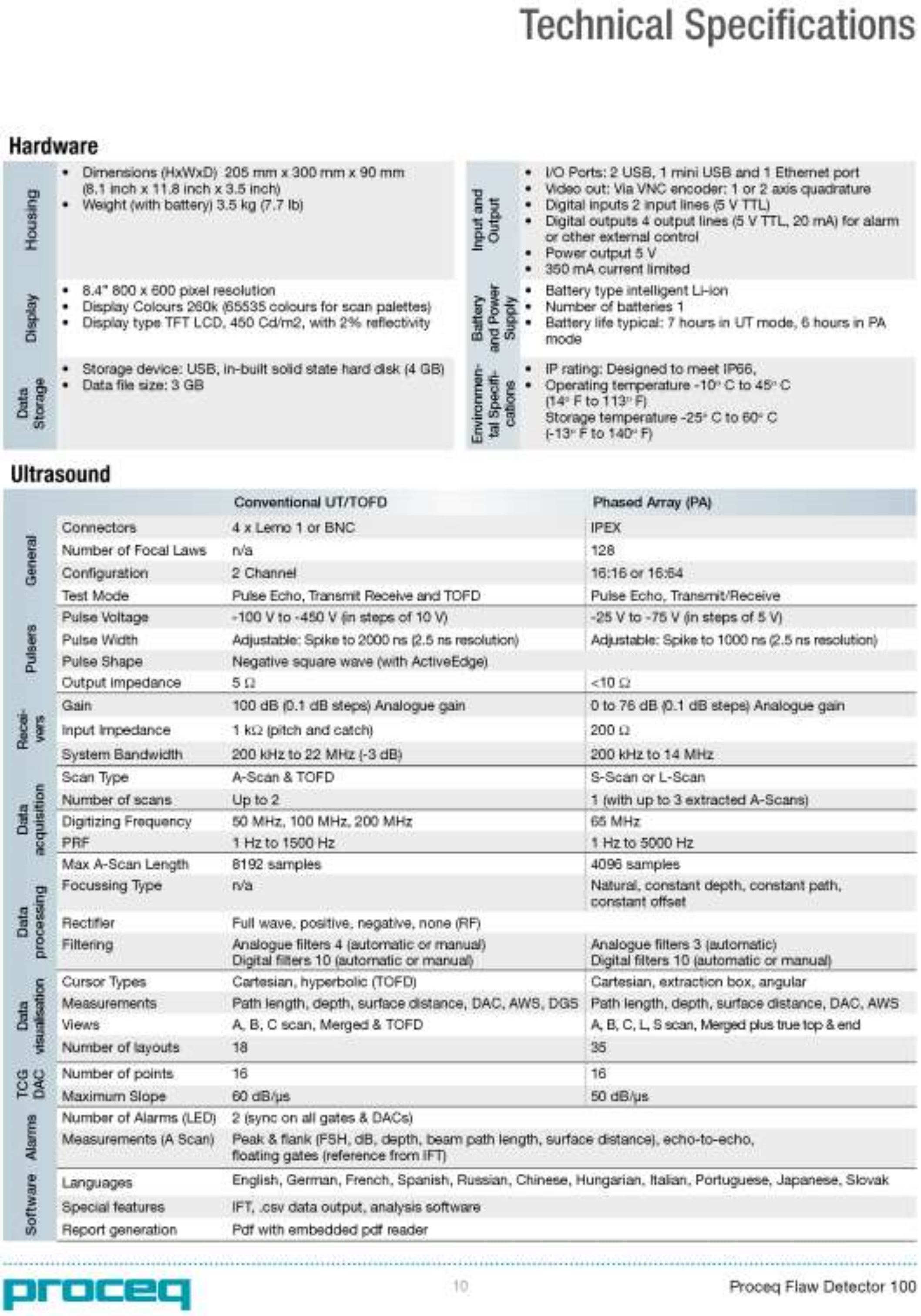


Ultrasonic Test Modes
Conventional UT

A, B and C scan data displays with a choice of multiple layouts enable a broad range of inspection applications:

- General component testing
- Corrosion mapping
- Thickness measurements
- Immersion testing (incl. IFT)
- Inclusion detection in steel bars and billets
- ISO 17640:2010 weld testing
- AWS D1.1 weld inspection
- DGS inspection using popular probes (MWB, SWB, MB and WB series)





Technical Specifications

Hardware

Housing

- Dimensions (HxWxD) 205 mm x 300 mm x 90 mm (8.1 inch x 11.8 inch x 3.5 inch)
- Weight (with battery) 3.5 kg (7.7 lb)

Display

- 8.4" 800 x 600 pixel resolution
- Display Colours 260k (65535 colours for scan palettes)
- Display type TFT LCD, 450 Cd/m2, with 2% reflectivity

Data Storage

- Storage device: USB, in-built solid state hard disk (4 GB)
- Data file size: 3 GB

Input and Output

- I/O Ports: 2 USB, 1 mini USB and 1 Ethernet port
- Video out: Via VNC encoder: 1 or 2 axis quadrature
- Digital inputs 2 input lines (5 V TTL)
- Digital outputs 4 output lines (5 V TTL, 20 mA) for alarm or other external control
- Power output 5 V
- 350 mA current limited

Battery and Power Supply

- Battery type intelligent Li-ion
- Number of batteries 1
- Battery life typical: 7 hours in UT mode, 6 hours in PA mode

Environmental Specifications

- IP rating: Designed to meet IP66,
- Operating temperature -10° C to 45° C (14° F to 113° F)
  Storage temperature -25° C to 60° C (-13° F to 140° F)

Ultrasound

		Conventional UT/TOFD	Phased Array (PA)
General	Connectors	4 x Lemo 1 or BNC	IPEX
	Number of Focal Laws	n/a	128
	Configuration	2 Channel	16:16 or 16:64
	Test Mode	Pulse Echo, Transmit Receive and TOFD	Pulse Echo, Transmit/Receive
Pulsers	Pulse Voltage	-100 V to -450 V (in steps of 10 V)	-25 V to -75 V (in steps of 5 V)
	Pulse Width	Adjustable: Spike to 2000 ns (2.5 ns resolution)	Adjustable: Spike to 1000 ns (2.5 ns resolution)
	Pulse Shape	Negative square wave (with ActiveEdge)	
	Output impedance	5 Ω	<10 Ω
Receivers	Gain	100 dB (0.1 dB steps) Analogue gain	0 to 76 dB (0.1 dB steps) Analogue gain
	Input Impedance	1 kΩ (pitch and catch)	200 Ω
	System Bandwidth	200 kHz to 22 MHz (-3 dB)	200 kHz to 14 MHz
Data acquisition	Scan Type	A-Scan & TOFD	S-Scan or L-Scan
	Number of scans	Up to 2	1 (with up to 3 extracted A-Scans)
	Digitizing Frequency	50 MHz, 100 MHz, 200 MHz	65 MHz
	PRF	1 Hz to 1500 Hz	1 Hz to 5000 Hz
Data processing	Max A-Scan Length	8192 samples	4096 samples
	Focussing Type	n/a	Natural, constant depth, constant path, constant offset
	Rectifier	Full wave, positive, negative, none (RF)	
	Filtering	Analogue filters 4 (automatic or manual) Digital filters 10 (automatic or manual)	Analogue filters 3 (automatic) Digital filters 10 (automatic or manual)
Data visualisation	Cursor Types	Cartesian, hyperbolic (TOFD)	Cartesian, extraction box, angular
	Measurements	Path length, depth, surface distance, DAC, AWS, DGS	Path length, depth, surface distance, DAC, AWS
	Views	A, B, C scan, Merged & TOFD	A, B, C, L, S scan, Merged plus true top & end
	Number of layouts	18	35
TCG DAC	Number of points	16	16
	Maximum Slope	60 dB/µs	50 dB/µs
Alarms	Number of Alarms (LED)	2 (sync on all gates & DACs)	
	Measurements (A Scan)	Peak & flank (FSH, dB, depth, beam path length, surface distance), echo-to-echo, floating gates (reference from IFT)	
Software	Languages	English, German, French, Spanish, Russian, Chinese, Hungarian, Italian, Portuguese, Japanese, Slovak	
	Special features	IFT, .csv data output, analysis software	
	Report generation	Pdf with embedded pdf reader	

proceq

10

Proceq Flaw Detector 100

New Product Announcement

Bulletin 276B

Albion

Dramatically increase your productivity and accuracy with the new DDT delamination detection tool!

The new DDT non-destructive rotary-percussion testing tool quickly and accurately identifies concrete delamination, membrane debonding or just about any "void" under a hard surface.

Documented field test results* showed an efficiency increased by over 500% using the ***DDT***—and there was improved accuracy. It's safer to use, helps avoid repetitive motion injuries, reduces wrist strain, and prevents accidents caused by excessive climbing up and down ladders.

The ***DDT*** adapts to most medium and heavy duty broom sticks and paint poles (available upon request) and accepts standard 3/4" crayon and paint markers for on-the-spot marking of delaminated areas.

Delamination Detection Tool shown with attached crayon for on-the-spot marking of delaminated areas.

It can be used on concrete slabs, columns, walls, beams, tile surfaces and masonry. The ***DDT is*** ideal for inspecting parking garages, bridge decks, support structures, balconies and tunnels, just to name a few.

Don't settle for anything less than the best.

For more information, visit us at our website at ***www.AlbionEng.com***. Our full line of products come with an Albion warranty and our commitment to professional quality tools.

*Published report available on our website

To order the DDT ask for part number 875-1

(additional extension poles available upon request)

Albion
DISPENSING SOLUTIONS

ALBION Engineering Co.
1250 N. Church St.
Moorestown, NJ 08057
(856) 235-6688

FAX TOLL-FREE: 800-841-7132

E-MAIL: service@albioneng.com
www.albioneng.com

Hardness

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Solutions since 1954

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Smart Portable Wireless
Leeb Hardness Solution

Equotip® Leeb D
Complete Portfolio

Equotip® Live

- Wireless
- Real-time Data Sharing
- Cloud Backup

Equotip® 550

- Expandable
- Heavy Duty

Equotip® Piccolo / Bambino 2

- Integrated


equotip® live
The global industry standard reinvented
776
56.4
5
Available on the App Store
Measure
New generation wireless impact device and mobile app
Sync and share
Quick and easy data review and sharing
Find out more (Page 4)
Find out more (Page 9)

Equotip® Live Leeb D Impact Device

Mounting ring
For easy and secure carrying

Loading grip
Innovative loading grip for safe operation

Multi-color LED ring
With status indication

On/Off button
And additional functions

USB connector
For charging and firmware updates

Functional materials
Slip proofed rubber and IP 54 sealed housing

Removable Bluetooth 4.0 low energy module
Built for Internet of Things (IoT)

Exchangeable support ring
Compatible with existing Proceq accessories

AAA battery compartment
Single use or rechargeable

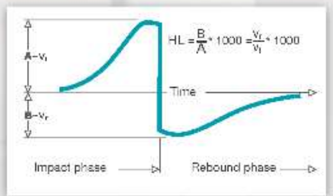
Easy to remove for faster check-in and shipping

- Following Proceq's known high quality standards and ensuring an accuracy of ± 4 HL
- Ultra portable wireless device perfect for confined spaces on-site
- Multiple users can share same impact device / Use multiple impact devices with the same app

The Leeb Measuring Principle

Invented by Proceq

Leeb hardness principle is based on the dynamic (rebound) method. An impact body with a hard metal test tip is propelled by spring force against the surface of the test piece. Surface deformation takes place when the impact body hits the test surface, which results in loss of kinetic energy. This energy loss is detected by a comparison of velocities v_i and v_r when the impact body is at a precise distance from the surface for both the impact and rebound phase of the test, respectively.



Velocities are measured using a permanent magnet in the impact body that generates an induction voltage in the coil which is precisely positioned in the impact device. The detected voltage is proportional to the velocity of the impact body. Signal processing is then providing the hardness reading.

Measuring Range		Scales	Units	Range
	Steel and cast steel	Vickers	HV	81-955
		Brinell	HB	81-654
		Rockwell	HRB	38-100
			HRC	20-68
			HS	30-99
		Shore	σ1	275-2194
		Rm N/mm²	σ2	616-1480
			σ3	449-847
	Cold work tool steel	Vickers	HV	80-900
		Rockwell	HRC	21-67
	Stainless steel	Vickers	HV	85-802
		Brinell	HB	85-655
		Rockwell	HRB	46-102
			HRC	20-62
	Cast Iron lamellar graphite GG	Brinell	HB	90-664
		Vickers	HV	90-698
		Rockwell	HRC	21-59
	Cast iron, nodular graphite GGG	Brinell	HB	95-686
		Vickers	HV	96-724
		Rockwell	HRC	21-60
	Cast aluminium alloys	Brinell	HB	19-164
		Vickers	HV	22-193
		Rockwell	HRB	24-85
	Copper/zinc alloys (brass)	Brinell	HB	40-173
		Rockwell	HRB	14-95
	CuAl/CuSn-alloys (bronze)	Brinell	HB	60-290
	Wrought copper alloys, low alloyed	Brinell	HB	45-315
	» Other combinations possible through custom conversions			

Test Piece Requirements	**Surface preparation**	Roughness grade class ISO 1302		N7
		Max. roughness depth R_t (µm / µinch)		10 / 400
		Average roughness R_a (µm / µinch)		2 / 80
	Minimum sample mass	Of compact shape (kg / lbs)		5 / 11
		On solid support (kg / lbs)		2 / 4.5
		Coupled on plate (kg / lbs)		0.05 / 0.2
	Minimum sample thickness	Uncoupled (mm / inch)		25 / 0.98
		Coupled (mm / inch)		3 / 0.12
		Surface layer thickness (mm / inch)		0.8 / 0.03
	Indentation size on test surface	With 300 HV, 30 HRC	Diameter (mm / inch)	0.54 / 0.021
			Depth (µm / µinch)	24 / 960
		With 600 HV, 55 HRC	Diameter (mm / inch)	0.45 / 0.017
			Depth (µm / µinch)	17 / 680
		With 800 HV, 63 HRC	Diameter (mm / inch)	0.35 / 0.013
			Depth (µm / µinch)	10 / 400

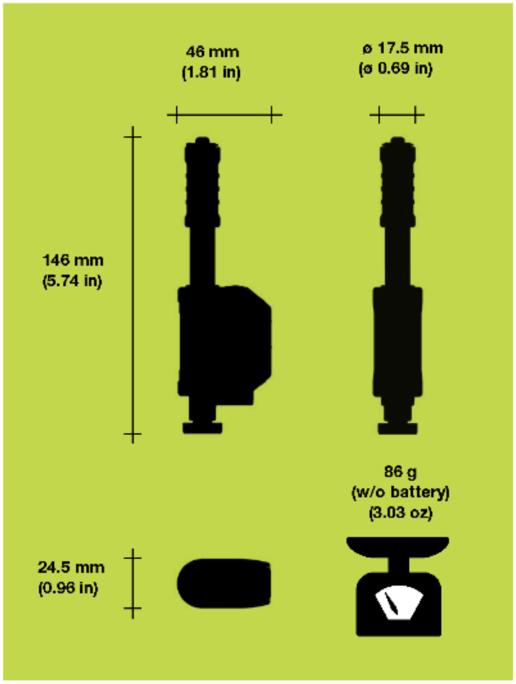
Technical Specifications
Full Standard Compliance and Traceability

Measuring

Measuring range	100 - 1000 HLD
Measuring accuracy	± 4 HL (0.5 % at 800 HL)
Measuring resolution	1 HL / HV / HB 0.1 HRC / HRB / HS 1 N/mm^2 Rm
Impact direction	Automatic compensation (± 5°)
Storage temperature	-20 to 60° C (-4 to 140° F)
Operating temperature	-10 to 50° C (14 to 122° F)
Charging temperature	0 to 40° C (32 to 104° F)
Humidity	90% max.
IP rating	IP 54

General

Battery type	1x rechargeable AAA NiMH 1000 mAh
Operating hours	> 20 h continuously measuring (1 impact/5 sec)
Communication	USB 2.0, Bluetooth 4.0 Low Energy
Connector	Micro-USB B



Full Traceability

In combination with the Equotip Leeb test blocks, hardness testing with the Equotip Live solution is fully traceable.

Standards

ASTM	A956 / A370
ISO	16859
DIN	50156 (withdrawn)
GB/T	17394
JB/T	9378

Conversion Standard

ASTM	E140

Guidelines

- ASME CRTD-91
- DGZfP Guideline MC 1
- VDI / VDE Guideline 2616 Paper 1
- Nordtest Technical Reports 421-1, 424-2, 424-3

Appendix C: Representative Electromagnetic Equipment

Ground Penetrating RADAR (GPR)

STRUCTURESCAN PRO FEATURES

Locate Targets in Concrete

The StructureScan Pro locates rebar, post tension cables, PVC and metal conduits, and voids.

Premium Mobility

The rugged handcart-based system is lightweight and simple to transport. GPR is a safe technology, with no site hazards or need to close off work areas as with radiography (X-Ray).

Fully Customizable System

The StructureScan Pro offers two antenna options; 1600 MHz or 2600 MHz. Designed to fit your needs, the StructureScan Pro is adaptable to expand survey capabilities with antenna upgrades, such as; compact survey areas, bridge, and utility applications.

TYPICAL USES

- Scan for Rebar, Post Tension, Conduits, and Non-metallic Objects
- Concrete Slab Scanning
- Locate Voids
- Concrete Scanning and Imaging
- Condition Assessment
- Structure Inspection

FCC, RSS-220 and CE Certified

STRUCTURESCAN PRO FLEXIBILITY

Utility Mapping and Locating

Locate the depth and position of metallic and non-metallic pipes in real time using our 400 MHz or 350 HS antennas and cart options.

Bridge Inspection

Determine the condition of bridge decks, parking structures, or balconies with the addition of a larger cart and software options.

Geophysical Survey Systems, Inc.
40 Simon Street • Nashua, NH 03060-3075 USA • www.geophysical.com

StructureScan™ Pro

The StructureScan™ Pro is GSSI's premium concrete scanning system, offering users modularity within one scanning system. The StructureScan Pro system provides a non-destructive means to accurately inspect concrete and structures, measure slab thickness, and locate voids.

The Pro Advantage

Despite the proven importance of identifying metal targets and electrical lines before cutting into concrete, every day there are stories about mishaps that happen when the necessary reconnaissance is not done. Using the StructureScan Pro is an accurate and efficient means to locate rebar, post-tension cables, or conduits in concrete prior to concrete cutting or any other destructive procedures. Users can quickly and easily locate embedments in real-time, or construct 3D X-Ray like images in advanced modes. Additional features include Focus Mode, Zoom Data, Depth Calibration, and Target Markers for enhanced data visualization.

MAX DEPTH 46 cm (18 inches)	**ANTENNA FREQUENCY** 1600 or 2600 MHz
WEIGHT 9.07 kg (20 pounds)	**STORAGE CAPACITY** 32 GB
OPTIONAL SOFTWARE RADAN 7, RADAN 7 StructureScan Module	**ACCESSORIES** Palm Antenna, SIR 4000 Stand, SIR 4000 Carry Harness

See our website for more information and detailed specifications: www.geophysical.com

Light Detection and Ranging (LiDAR)

Snoopy A-Series

Ready-to-Fly & Ready-to-Scan UAV Package

Specifications

- System Accuracy -- 3.1cm +/- Accuracy @ 50m

- Dimensions / Weight:
    - 3.5 inches tall
    - 11.75 inches long
    - 4.375 inches wide
    - Weight: 2.51kg
- INS Snoopy L1/L2
    - L1/L2 GPS+GLONASS (or Beidou)
    - SBAS
    - Single Antenna
- Power Consumption: 25 Watts
- Voltage Input: 10-30VDC
- Internal storage for several days
- Virtually unlimited removable storage
- Quick release mount
- Velodyne HDL-32E
    - 700,000 points/sec
    - 32 individual lasers
    - 40 degree Vertical FOV
    - 360 degree Horizontal FOV
    - +/- 2 cm accuracy
    - 100 m range

Software

- Generate trajectory in any coordinates
- LAS/LAZ/E57 and other file format outputs
- Point cloud filtering
- Control point adjustment tool
- Coordinate measurement update tool

LiDAR USA

a Fagerman Technologies company

Snoopy A-Series

HiWay Mapper HD Package + UAV Package

"Everything you need to take your company to the next level"

Specifications

- System Accuracy -- 3.1cm +/- Accuracy @ 50m
- Dimensions / Weight:
    - 3.5 inches tall
    - 11.75 inches long
    - 4.375 inches wide
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    - 32 individual lasers
    - 40 degree Vertical FOV
    - 360 degree Horizontal FOV
    - +/- 2 cm accuracy
    - 100 m range

Software

- Generate trajectory in any coordinates
- LAS/LAZ/E57 and other file format outputs
- Point cloud filtering
- Control point adjustment tool
- Coordinate measurement update tool

Weighing in at only 2.5kg, Snoopy A-Series is a smaller, evolved version of our Snoopy. This unit is also configurable but is designed to be an extremely accurate solution for multi-vehicle mounting. The A-Series is light-weight and easy to use. With just a click of a button on your smartphone you can scan over the edge of a boat, the front of a motorcycle, the belly of a drone, the back of a sedan, the side of a train, on top of a back-pack... Well, you get the picture! You can scan anywhere with this little guy.

LiDAR USA

a Fagerman Technologies company

Snoopy A-Series

Weighing in at only 2.5kg, Snoopy A-Series is a smaller, evolved version of our Snoopy. This unit is also configurable but is designed to be an extremely accurate solution for multi-vehicle mounting. The A-Series is light-weight and easy to use. With just a click of a button on your smartphone you can scan over the edge of a boat, the front of a motorcycle, the belly of a drone, the back of a sedan, the side of a train, on top of a back-pack... Well, you get the picture! You can scan anywhere with this little guy.

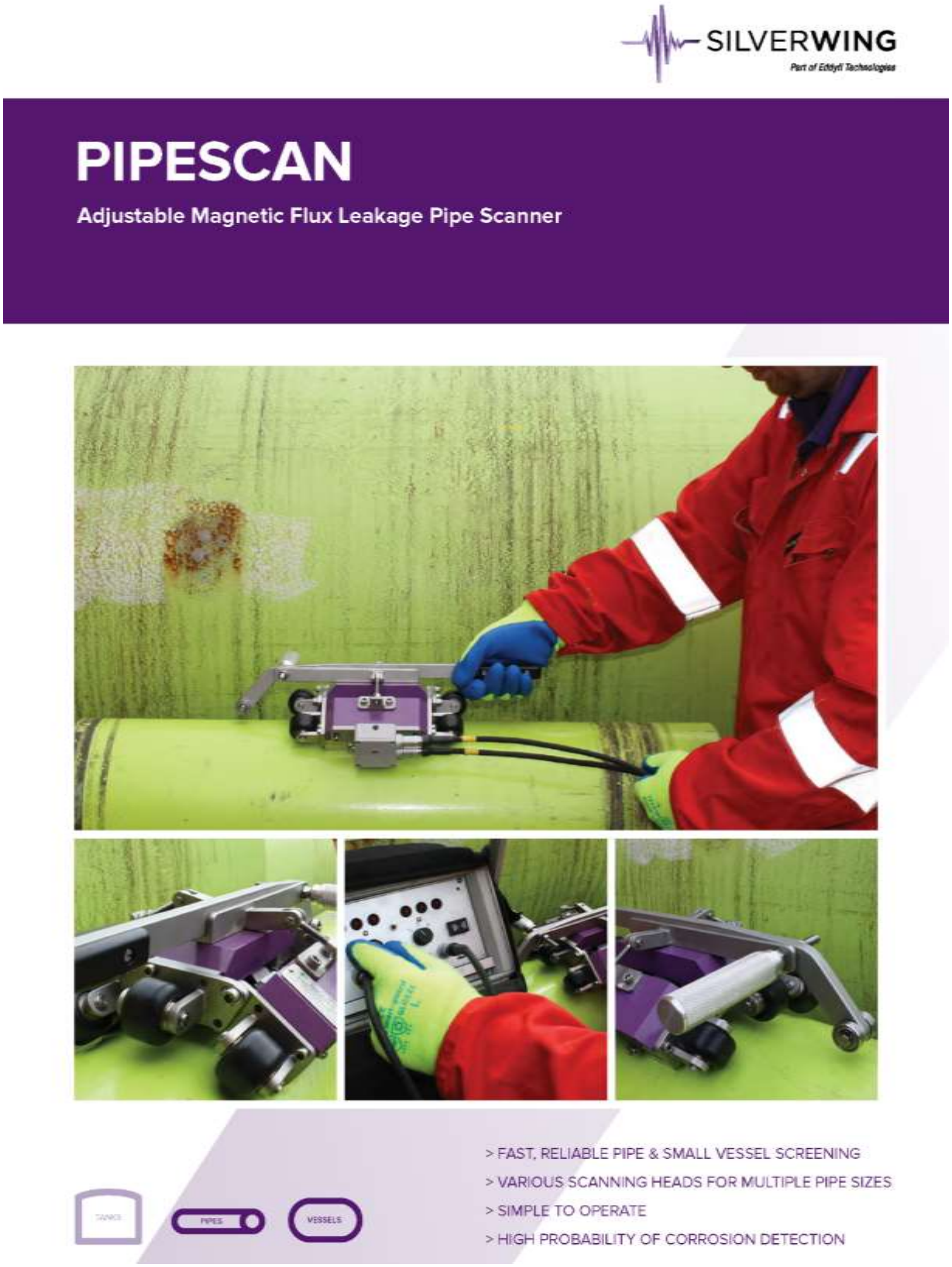
Specifications

- System Accuracy – 3.1cm +/- Accuracy @ 50m
- Dimensions / Weight:
  - 3.5 inches tall
  - 11.75 inches long
  - 4.375 inches wide
  - Weight: 2.51kg
- INS Snoopy L1/L2
  - L1/L2 GPS+GLONASS (or Beidou)
  - SBAS
  - Single Antenna
- Power Consumption: 25 Watts
- Voltage Input: 10-30VDC
- Internal storage for several days
- Virtually unlimited removable storage
- Quick release mount
- Velodyne HDL-32E
  - 700,000 points/sec
  - 32 individual lasers
  - 40 degree Vertical FOV
  - 360 degree Horizontal FOV
  - +/- 2 cm accuracy
  - 100 m range

Software

- Generate trajectory in any coordinates
- LAS/LAZ/E57 and other file format outputs
- Point cloud filtering
- Control point adjustment tool
- Coordinate measurement update tool

LiDAR USA
a Fagerman Technologies company



SILVERWING
Part of Eddyfi Technologies

PIPESCAN

Adjustable Magnetic Flux Leakage Pipe Scanner

- > FAST, RELIABLE PIPE & SMALL VESSEL SCREENING
- > VARIOUS SCANNING HEADS FOR MULTIPLE PIPE SIZES
- > SIMPLE TO OPERATE
- > HIGH PROBABILITY OF CORROSION DETECTION

PIPESCAN
MANUAL MAGNETIC FLUX LEAKAGE PIPE SCANNER

Pipescan is an easy to use, cost effective, portable, magnetic flux leakage inspection system for the rapid screening and detection of random internal corrosion in pipe runs and small diameter vessels.

The latest magnetic material coupled with unique mechanical designs enables coverage of all pipe diameters from 48 mm to 2.4 metres with a limited number of scanning heads.

IN-SERVICE INSPECTION

Magnetic flux leakage inspection is not affected by product flowing through the pipe so surveys can be carried out both on-line and off-line and at surface temperatures up to 90 C. Use of Pipescan, with its high probability of detection to locate the corrosion, coupled with ultrasonic prove up, provides a cost effective accurate system for the determination of plant integrity.

KEY FEATURES

- > Flexible heads fit a range of pipe & vessel sizes
- > Rapid screening of complete pipe work with higher probability of detection than UT spot readings
- > Use in conjunction with UT follow up for quantifying any indications
- > Simple to operate with minimum training to semi skilled operator
- > Separate battery operated lightweight MFL control module
- > Proven MFL technology
- > Field proven durability & reliability

MFL CONTROL MODULE

The easy to use Pipescan system consists of a scanning head and a rechargeable battery powered portable control module which provides up to 8 hours of operation. The same control module can be utilised with the Handscan MFL floor scanner.

The control module features audible and visual alarms to alert the operator to the presence of corrosion during a scan.

The alarm sensitivity is adjustable, allowing the operator to calibrate the Pipescan to detect corrosion above the defined reporting level, but ignore low level, non-relevant corrosion signals.

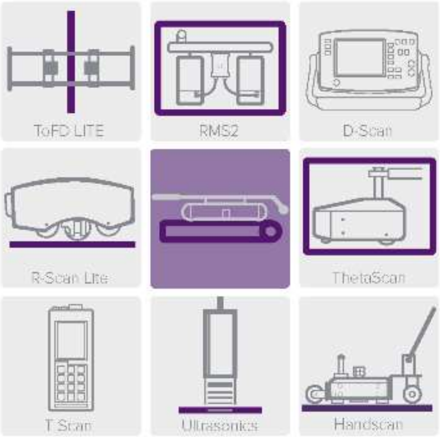
FIXED	
MODEL	**PIPE DIAMETER (OD)**
PS 100 B	48 - 54 mm
PS 100 F	63 - 75 mm
PS 100 C	75 - 90 mm

ADJUSTABLE	
MODEL	**PIPE DIAMETER (OD)**
PS 500	100 - 200 mm
PS 200	150 - 300 mm
PS 1200	300 - 2400 mm

CIRCUMFERENTIAL	
MODEL	**PIPE DIAMETER (OD)**
PS 300	300 - 2400 mm
PS 400	150 - 300 mm

THE SILVERWING SYSTEM

Silverwing produce a full range of equipment for corrosion inspection of storage tanks, including floor plate, wall and roof structures. The product range includes MFL mapping and manual systems, ultrasonic crawlers for thickness measurement, and vacuum boxes for weld inspection. By supplying a complete range we can offer unrivalled support, and ensure the highest quality inspection in the most efficient way. All our products are field proven by our in house teams and used by the most respected global inspection companies. For a complete overview contact our technical sales team.



For more information on Silverwing Systems please visit our web site: www.silverwingndt.com

HOW IT WORKS

The operator first connects the sensor cable between the scanning head and control module. Switch on the control module, set the required wall thickness and adjust the alarm sensitivity using a reference pipe with known artificial defects. Then simply set up the scanning head on the pipe to be inspected, push the scanning head and monitor the control module for the audible and visual alarm.

Any areas identified by the Pipescan system can then be marked on the pipe for further analysis by a secondary inspection technique, normally ultrasonic and for detailed corrosion mapping we recommend the RMS2 or Thetascan systems.

TECHNICAL SPECIFICATION

Principle of operation	Magnetic Flux Leakage
Detection	Up to 16 Hall Effect sensors (Model Dependant)
Pipe diameters	48 mm (2") to 2.4 metre (94") - Outside Diameter
Method of propulsion	Hand Push Speed 0.5 m/sec (20"/sec)
Profile	Clearance under / between pipework min 120 mm (4.7")
Maximum wall thickness	15 mm (5/8")
Test through coatings	Yes if non magnetic
Maximum coating thickness	6 mm
Sensitivity	Adjustable
Max sensitivity	30% pitting in 6 mm (1/4") wall pipe
	40% pitting in 12 mm (1/2") wall pipe
	50% pitting in 16 mm (5/8") wall pipe
Connecting cable	5 metre standard length
Power requirements	12v battery operation
Test time	8 hour continuous working
Transit case	Meets IATA requirements for transporting magnetizable material
Operating weight	18 Kg - combined weight of scanning head and electronics module

Centres of Excellence

Canada: +1 418 780 1565
UK: +44 (0) 1792 798711

Sales Offices

South Africa: +27 21 557 5740
Abu Dhabi: +971 2 505 6622
Dubai: +971 4 360 6751
France: +33 4 28 36 0100
USA: +1 281 542 3292

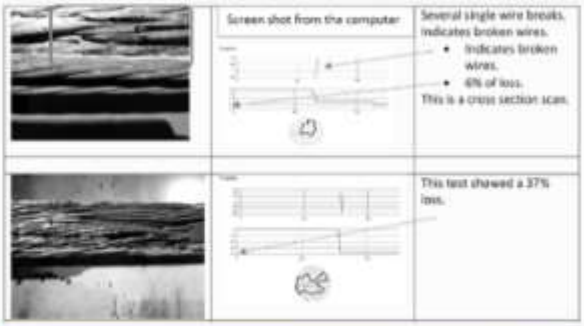
SILVERWING
Part of Eddyfi Technologies

www.silverwingndt.com
sales@silverwingndt.com

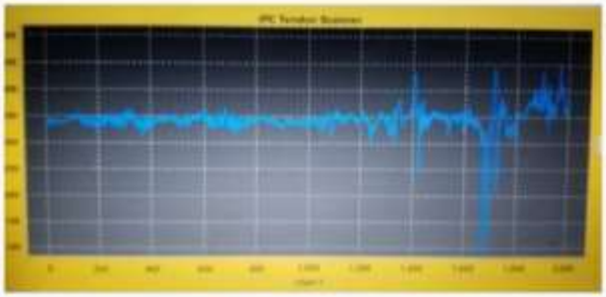
www.eddyfi.com
sales@eddyfi.com

CableScan® MFL (Magnetic Flux)

Robotic cable stay bridge inspection service. CableScan MFL is a magnetic flux leakage robotic inspection unit that can locate and quantify loss of metallic area inside an HDPE cable.



	Screen shot from the computer	Several single wire breaks. Indicates broken wires. • Indicates broken wires. • 6% of loss. This is a cross section scan.
		This test showed a 37% loss.

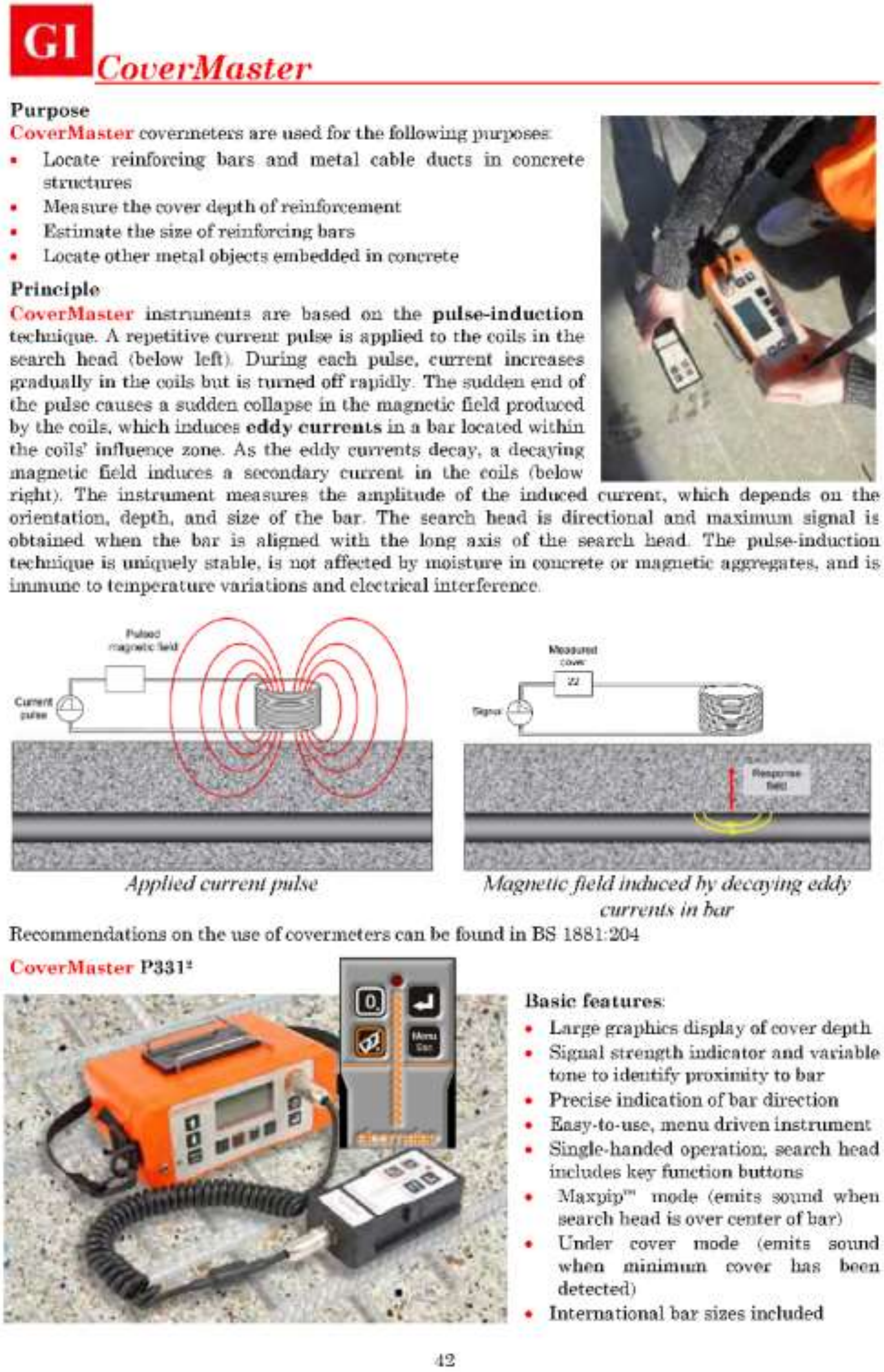


Steel Bridge Cables

Through the use of IPC's new patented and proprietary testing equipment and procedures, our inspectors can perform Cable Condition Assessments of bridge cables identifying loss of section and broken wires within cables. Our inspectors do not need cranes or bucket trucks. In addition, they do not require lane closures. CableScan® is a self-propelled robotic inspection system that attaches to the cable and travels along the full length of the cable transmitting data to the inspector's laptop.

In most cases, CableScan® can identify corrosion, loss of section and broken wires on site as well as cracks, holes and other anomaly's on a cable. IPC delivers a comprehensive report identifying individual cable conditions as well as overall condition assessments of the cable system for the bridge. In addition, IPC can take high definition video of the entire Cable Stay and locate length and depth of a crack as well as position on the structure. With each inspection cycle a comparative analysis of any anomalies over time can help with early repairs and more efficient asset management.

Cover meter (Eddy Current Array)



GI CoverMaster

Purpose

CoverMaster covermeters are used for the following purposes:

- Locate reinforcing bars and metal cable ducts in concrete structures
- Measure the cover depth of reinforcement
- Estimate the size of reinforcing bars
- Locate other metal objects embedded in concrete

Principle

CoverMaster instruments are based on the **pulse-induction** technique. A repetitive current pulse is applied to the coils in the search head (below left). During each pulse, current increases gradually in the coils but is turned off rapidly. The sudden end of the pulse causes a sudden collapse in the magnetic field produced by the coils, which induces **eddy currents** in a bar located within the coils' influence zone. As the eddy currents decay, a decaying magnetic field induces a secondary current in the coils (below right). The instrument measures the amplitude of the induced current, which depends on the orientation, depth, and size of the bar. The search head is directional and maximum signal is obtained when the bar is aligned with the long axis of the search head. The pulse-induction technique is uniquely stable, is not affected by moisture in concrete or magnetic aggregates, and is immune to temperature variations and electrical interference.

Applied current pulse

Magnetic field induced by decaying eddy currents in bar

Recommendations on the use of covermeters can be found in BS 1881:204

CoverMaster P331[2]

Basic features:

- Large graphics display of cover depth
- Signal strength indicator and variable tone to identify proximity to bar
- Precise indication of bar direction
- Easy-to-use, menu driven instrument
- Single-handed operation; search head includes key function buttons
- Maxpip™ mode (emits sound when search head is over center of bar)
- Under cover mode (emits sound when minimum cover has been detected)
- International bar sizes included

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CoverMaster

Basic Features (continued)

- Quick release battery pack and charger
- Can be used with different search heads (See below)
- Includes standard search head, cable, carrying case, and instruction manual
- Rechargeable battery pack

Optional Search Heads

In addition to a choice of four search heads, the CoverMaster P331^{2} can also be used with half-cell probes to measure the half-cell potential (see pg. 94). A borehole probe is also available for locating a second layer of reinforcement or deeply embedded tendon ducts. The borehole probe can be switched from the "forward looking" to the "side looking" mode.

Standard

For general purpose use; maximum cover 70 to 95 mm

Narrow Pitch

For resolving closely-spaced bars; maximum cover 60 to 80 mm

Deep Scan

Maximum cover 160 to 180 mm

Dual Search Head

For high strength and stainless steel

Borehole Probe

For measurement of second layer of reinforcement and tendon ducts

Half-Cell Potential Kit

Cu/CuSO$_4$ or Ag/AgCl

Sample Display

CoverMaster P331^{2} Models

Model B includes the basic features listed on previous page.

Model BH includes all of the features of Model B with the additional of capability to make half-cell potential readings

Model SH includes all the features of Model BH plus the following:

- Automatic bar sizing (auto size mode for quick estimate or orthogonal method for greater accuracy)
- Orthogonal mode bar diameter determination
- Min-Max cover limits (enter minimum and/or maximum cover to check with specifications)
- Data storage (up to 1000 individual cover measurements in linear sequence)
- Up to 10 linear batches can be stored
- Software to upload stored data to PC

Model TH includes all the features of Model SH plus the following:

- Data storage up to 240,000 points
- Linear and grid data storage (data stored in 2-D format, up to 1000 grids)
- User defined 2-D testing grid (up to 255 rows by 255 columns)
- Graphics plot and threshold plot

Model THD includes all the features of Model TH plus a stainless steel measurement probe.

CoverMaster P331^{+} Feature Comparison

Description	**Model**				
	B	**BH**	**SH**	**TH**	**THD**
Rebar location, orientation and depth of cover	•	•	•	•	•
Cover thickness reading in mm and inches	•	•	•	•	•
Graphics display with backlight	•	•	•	•	•
Multiple language menu structure	•	•	•	•	•
Signal strength display	•	•	•	•	•
Interchangeable heads with LED and keypad	•	•	•	•	•
User selectable bar range sizes and numbers	•	•	•	•	•
Measurement sound modes:	•	•	•	•	•
Locate *(tone increases as head approaches rebar)*	•	•	•	•	•
Under Cover *(tone only sounds for low cover)*	•	•	•	•	•
Maxpip™ *(tone only as head passes rebar center)*	•	•	•	•	•
Half-cell potential capability		•	•	•	•
Auto size mode for bar diameter determination			•	•	•
Orthogonal mode for bar diameter determination			•	•	•
RS232 output to printer or PC			•	•	•
EDTS Excel Link Software			•	•	•
CoverMaster® Software			•	•	•
Statistics			•	•	•
Minimum and maximum cover limits			•	•	•
Date and time			•	•	•
Memory			•	•	•
Graphics plot				•	•
Threshold plot				•	•
Stainless steel probe					•
Rugged waterproof case (IP65)	•	•	•	•	•
Adjustable beep volume and earphone socket	•	•	•	•	•

	Bar Diameter Ranges
Metric	5 to 50 mm in 21 values
U.S. Bar Numbers	#2 to #18 in 16 values
ASTM/Canadian	10 to 55M in 8 values
Japanese	6 to 57 mm in 17 values

Magnetic Particle

Magnetic Particle Inspection » Equipment » Y-1 MV Kit

Y-1 MV Kit

AC Electromagnetic Yoke Kit for Non-Fluorescent Magnetic Particle Inspections

The Y-1 MV Kit includes an ergonomic, light-weight electromagnetic AC yoke and visible magnetic powers for finding surface indications during magnetic particle testing.

This versatile kit is great for job sites, field testing, spot inspections, in-service inspections and weld inspection.

Kit comes with a Y-1 yoke, #1 Gray and #8A Red magnetic powders, a paint marker and hand cleaner towels in a convenient carrying case.

MAGNAFLUX

Product Data Sheet

Y-1 Yoke

AC Electromagnetic Yoke

The Y-1 is an AC electromagnetic yoke and the new generation of light weight, ergonomically designed yokes that improve job performance and productivity by reducing operator arm and wrist fatigue when testing in tight, confined and overhead areas. Provides a portable means of creating AC magnetic fields for the detection of surface indications during magnetic particle testing.

Lightweight, less than five pounds, and ergonomic with a molded grip and trigger on/off switch, the Y-1 has impact and chemical-resistant construction. Includes a robust strain-relieved ten-foot cord and carrying grommet for convenience in field use.

The Y-1 is also available as a test kit (Y-1 MV Kit), complete with a Y-1 yoke, #1 Gray and #8A Red magnetic powders, a paint marker and hand cleaner towels in a convenient carrying case.

FEATURES

- Ergonomic, light-weight design
- Soft-grip, angled body for better positioning
- Exceeds ASTM lifting specifications
- Steel shields for leg protection
- Durable rugged construction
- Oil and abrasion resistant power cord
- Individual serial number for each yoke

SPECIFICATION COMPLIANCE

- ASME BPVC
- ASTM E709
- ASTM E1444
- ASTM E3024

APPLICATIONS

Defect location: Surface

Ideal for:

- Field testing
- Difficult to reach areas
- Spot inspections
- In-service inspections
- Weld inspection

Defect examples:

- Seams
- Tears
- Shrink cracks
- Grinding cracks
- Quenching cracks
- Fatigue cracks

MAGNAFLUX

Product Data Sheet

PRODUCT PROPERTIES

Weight	4.6 lb / 2.1 kg
Leg Span	0–11 in / 0–28 cm
Cord Length	10 ft / 3 m
Duty Cycle	50%, max on time is 90 seconds
Electrical Requirements	115V – 60 Hz: 3.7 A 230V – 50/60 Hz: 2.6 A

USE RECOMMENDATIONS

NDT Method	Magnetic Particle Testing
Recommended Accessories	Yoke Test Weight PN 624115 Yoke Light PN 623745

PART NUMBERS

Y-1, 115V	623502
Y-1, 230V	623503
Y-1 MV Kit, 115V	623529
Y-1 MV Kit, 230V	623530

Revised: January 2019

magnaflux.com

MAGNAFLUX

Product Data Sheet

#1 Gray

Non-fluorescent Magnetic Particles

#1 Gray provides strong contrast on most metal surfaces during dry method mag particle testing in visible light. It is ready-to-use for visible light flaw detection of surface and slightly subsurface discontinuities in ferrous metals. It can be used in a powder blower or shaken from a bottle during magnetization, and blown off while current is still being applied. On material with a high magnetic retentivity, indications can still be formed after the current has been turned off.

FEATURES

- Sharp, color-contrast indications on high reflective surfaces
- Ready-to-use
- Good particle buildup for quick detection
- Highly refined for optimal particle shape and size combination
- Minimal dust build-up
- Does not require a black light or darkened inspection area

SPECIFICATION COMPLIANCE

- AMS 3040
- ASTM E709
- ASTM E1444
- ASME
- MIL-STD-271
- MIL-STD-2132
- NAVSEA 250-1500-1
- NAVSEA T9074-AS-GIB-010/271
- ISO 9934

PRODUCT PROPERTIES

Appearance	Fine, dry powder
Color in Visible Light	White-gray
Odor	Odorless
Mean Particle Size*	80 microns
SAE Sensitivity**	> 8

* As determined by industry-typical method for measuring particle size

** Representative of the number of indications on a tool steel ring as defined in ASTM E1444.

USE RECOMMENDATIONS

NDT Method	Magnetic Particle Testing, Nonfluorescent / Visible, Dry Method
Required Equipment	Magnetizing device, powder dispenser
Temperature Range†	NA to 750°F / NA to 399°C

† Particle integrity and mobility may decline beyond these temperature limits.

APPLICATIONS

Defect location: Surface and slightly subsurface

Ideal for:

- Light, medium, dark surfaces
- Detecting medium, large and course discontinuities
- Weld testing
- Forgings
- Castings
- Field testing
- Spot inspections
- In-service inspections
- Large parts
- Dark surfaces
- Extreme temperatures
- Rough/textured surfaces

Defect examples:

- Inclusions
- Seams
- Shrink cracks
- Tears
- Laps
- Flakes
- Welding defects
- Grinding cracks
- Quenching cracks
- Fatigue cracks

INSTRUCTIONS FOR USE

Use #1 Gray with appropriate magnetization procedure and equipment. For best results, all components, parts, or areas to be tested should be clean and dry prior to testing to provide an optimal test surface.

Apply a fine layer of #1 Gray to test area with a powder dispensing device, such as a powder spray bulb or powder blower. As the current is being applied, dust the powder over the part. If there is excessive powder background, gently blow the excess powder off while the magnetic current is flowing.

REMOVAL

All components, parts, or inspection areas must be properly demagnetized before cleaning to ensure easy particle removal. Remove particles with air blower or brush.

STORAGE

Store unused product in the original container. Keep container closed when not in use. Protect from sunlight. Store in a well-ventilated area away from magnetizing equipment. Cool, dry storage location is preferred. Refer to Safety Data Sheet for additional storage instructions.

PACKAGING

10 lb / 4.53 kg pail	01-1716-69
45 lb / 20.4 kg pail	01-1716-87

HEALTH AND SAFETY

Review all relevant health and safety information before using this product. For complete health and safety information, refer to the product Safety Data Sheet, which is available at www.magnaflux.com.

MAGNAFLUX Product Data Sheet

#8A Red

Non-fluorescent Magnetic Particles

#8A Red provides strong contrast on most metal surfaces during dry method mag particle testing in visible light. It is ready-to-use for visible light flaw detection of surface and slightly subsurface discontinuities in ferrous metals. It can be used in a powder blower or shaken from a bottle during magnetization, and blown off while current is still being applied. On material with a high magnetic retentivity, indications can still be formed after the current has been turned off.

FEATURES

- Sharp, color-contrast indications on high reflective surfaces
- Ready-to-use
- Good particle buildup for quick detection
- Highly refined for optimal particle shape and size combination
- Minimal dust build-up
- Does not require a black light or darkened inspection area

SPECIFICATION COMPLIANCE

- AMS 3040
- ASTM E709
- ASTM E1444
- ASME
- MIL-STD-271
- MIL-STD-2132
- NAVSEA 250-1500-1
- NAVSEA T9074-AS-GIB-010/271
- ISO 9934

PRODUCT PROPERTIES

Appearance	Fine, dry powder
Color in Visible Light	Rust red
Odor	Odorless
Mean Particle Size*	80 microns
SAE Sensitivity**	> 8

* As determined by industry-typical method for measuring particle size

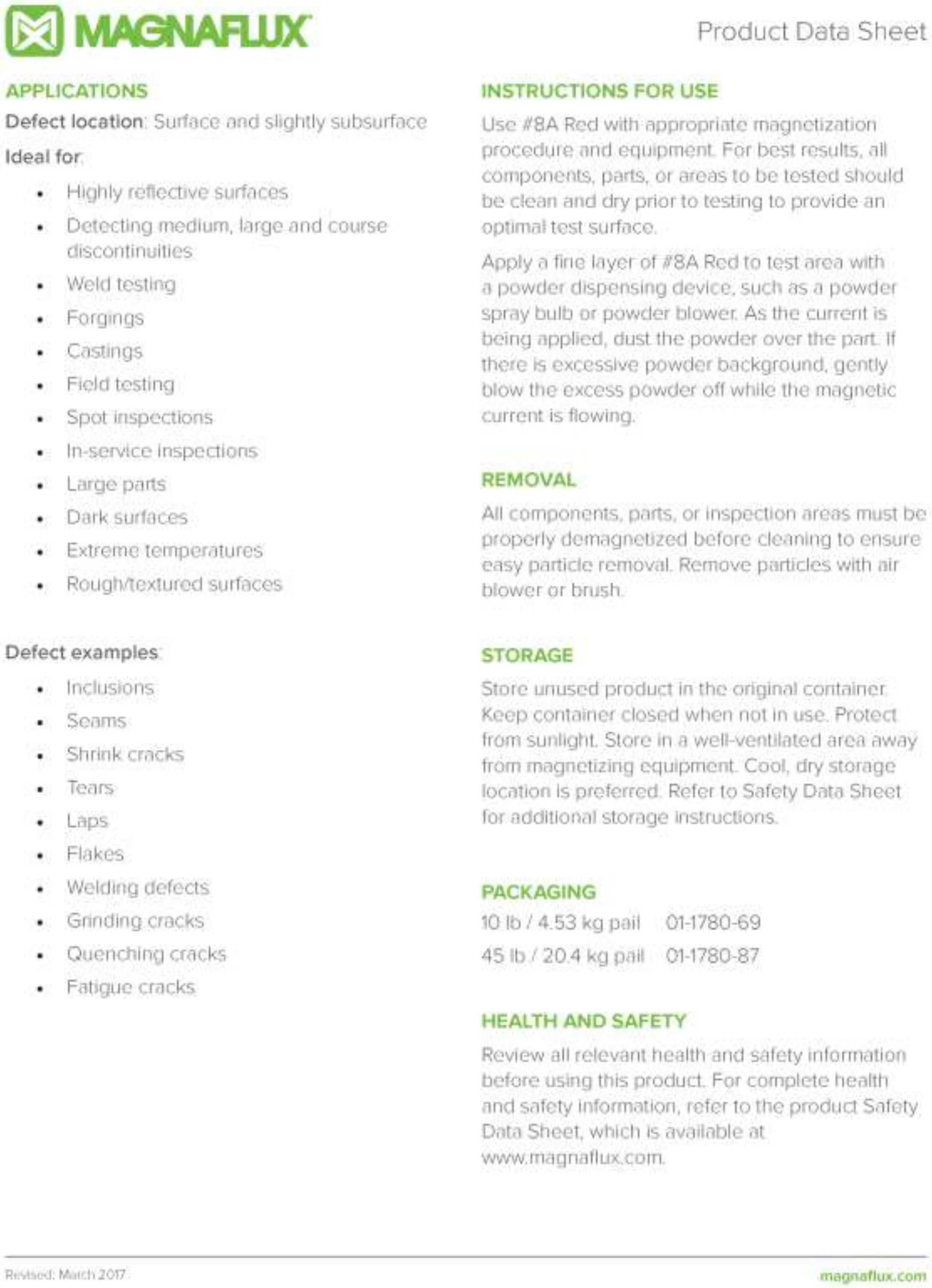
** Representative of the number of indications on a tool steel ring as defined in ASTM E1444.

USE RECOMMENDATIONS

NDT Method	Magnetic Particle Testing, Nonfluorescent / Visible, Dry Method
Required Equipment	Magnetizing device, powder dispenser
Temperature Range[1]	NA to 600°F / NA to 316°C

[1] Particle integrity and mobility may decline beyond these temperature limits.

Revised: March 2017



Product Data Sheet

APPLICATIONS

Defect location: Surface and slightly subsurface

Ideal for:

- Highly reflective surfaces
- Detecting medium, large and course discontinuities
- Weld testing
- Forgings
- Castings
- Field testing
- Spot inspections
- In-service inspections
- Large parts
- Dark surfaces
- Extreme temperatures
- Rough/textured surfaces

Defect examples:

- Inclusions
- Seams
- Shrink cracks
- Tears
- Laps
- Flakes
- Welding defects
- Grinding cracks
- Quenching cracks
- Fatigue cracks

INSTRUCTIONS FOR USE

Use #8A Red with appropriate magnetization procedure and equipment. For best results, all components, parts, or areas to be tested should be clean and dry prior to testing to provide an optimal test surface.

Apply a fine layer of #8A Red to test area with a powder dispensing device, such as a powder spray bulb or powder blower. As the current is being applied, dust the powder over the part. If there is excessive powder background, gently blow the excess powder off while the magnetic current is flowing.

REMOVAL

All components, parts, or inspection areas must be properly demagnetized before cleaning to ensure easy particle removal. Remove particles with air blower or brush.

STORAGE

Store unused product in the original container. Keep container closed when not in use. Protect from sunlight. Store in a well-ventilated area away from magnetizing equipment. Cool, dry storage location is preferred. Refer to Safety Data Sheet for additional storage instructions.

PACKAGING

10 lb / 4.53 kg pail	01-1780-69
45 lb / 20.4 kg pail	01-1780-87

HEALTH AND SAFETY

Review all relevant health and safety information before using this product. For complete health and safety information, refer to the product Safety Data Sheet, which is available at www.magnaflux.com.

Revised: March 2017

magnaflux.com

LWIR SCIENCE-GRADE CAMERA

FLIR A655sc™

With its uncooled, high-resolution detector and cutting-edge functionality, the FLIR A655sc helps researchers and scientists accurately quantify thermal patterns, leakage, dissipation, and other heat related factors in equipment, products, and processes in real-time.

www.flir.com/science

SUPERIOR IMAGE QUALITY & SENSITIVITY

Record crisp thermal images, even at high speeds

- Produce clearly detailed 640 x 480 thermal images using the maintenance free vanadium oxide (VoX) microbolometer
- Detect temperature differences as small as 50 mK
- Record 14-bit, full-frame data at up to 50 Hz, or 200 Hz with windowing

EASY, FLEXIBLE DATA COLLECTION

True plug and play connectivity simplifies data monitoring and sharing

- Fast image transfer over GigE Vision, using low-cost standard cables up to 100 meters
- Integrate with FLIR ResearchIR or third-party software seamlessly over Gigabit Ethernet connections
- Control the camera with GenICam protocol support

ADVANCED SOFTWARE COMPATIBILITY

Get more out of your data with advanced analysis tools

- Control and capture data directly intoFLIR ResearchIR Max or MathWorks® MATLAB
- Stream data directly to a PC running software for live viewing, recording, analysis, and sharing
- Integrate with your proprietary software through optional Software Developers Kit (SDK)

Motorcycle brake heating.

Thermal quality control on domestic appliances.

IMAGING SPECIFICATIONS

System Overview	FLIR A655sc
Detector Type	Uncooled Microbolometer
Spectral Range	7.5 – 14.0 µm
Resolution	640 x 480
Detector Pitch	17 µm
NETD	<30 mK
Imaging	
Time Constant	<8 ms
Frame Rate (Full Window)	50 Hz
Subwindow mode	User-Selected, 640 x 240 or 640 x 120 (Gigabit Ethernet Only)
Maximum Frame Rate (@Min. Window)	200 Hz (640 x 120)
Dynamic Range	16-bit
Digital Data Streaming	Gigabit Ethernet (50/100/200 Hz) USB (25 Hz)
Command and Control	Gigabit Ethernet, USB
Measurement	
Standard Temperature Range	–40°C to 150°C (–40°F to 302°F) 100°C to 650°C (212°F to 1,202°F)
Optional Temperature Range	Up to 2,000°C (3,632°F)
Accuracy	±2°C or ±2% of Reading
Optics	
Camera f/#	f/1.0
Available Lenses	6.5 mm (80°), 13.1 mm (45°), 24.5 mm (25°), 41.3 mm (15°), 88.9 mm (7°)
Focus	Automatic or Manual (Motorized)
Close up / Microscopes	Close up 25 µm, 50 µm, 100 µm
Image Presentation	
Digital Data	Via PC Using ResearchIR Software

General	
Operating Temperature Range	–15°C to 50°C (5°F to 122°F)
Storage Temperature Range	–40°C to 70°C (–40°F to 158°F)
Encapsulation	IP 30 (IEC 60529)
Bump / Vibration	25 g (IEC 60068-2-29) / 2 g (IEC 60068-2-6)
Power	12/24 VDC, 24 W Absolute Max
Weight	0.9 kg (1.98 lb)
Size	216 x 73 x 75 mm (8.5 x 2.9 x 3.0 in)
Mounting	1/4"-20 (on three sides), 2 x M4 (on three sides)

Power Connector: 2-pole pickable screw terminal
Allowed Voltage Range: 10-30 VDC

Gigabit Ethernet Port: RJ 45 connector, 1000 Mb

USB mini-B connector

Hardware reset

Power indicator

Digital I/O Connector: 6-pole screw terminal
Digital Out: 2 outputs, opto-isolated 10-30 V supply, max 100 mA
Digital In: 2 inputs, opto-isolated 10-30 V

CORPORATE HEADQUARTERS
FLIR Systems, Inc.
27700 SW Parkway Ave.
Wilsonville, OR 97070
PH: +1 877.773.3547

SANTA BARBARA
FLIR Systems, Inc.
6769 Hollister Ave
Goleta, CA 93117
PH: +1 805.690.6600

CANADA
FLIR Systems, Ltd.
920 Sheldon Court
Burlington, ON L7L 5K6
Canada
PH: +1 800.613.0507

LATIN AMERICA
FLIR Systems Brasil
Av. Antonio Bardella,
320 Sorocaba, SP 18085-852
Brasil
PH: +55 15 3238 7080

CHINA
FLIR Systems Co., Ltd
Rm 1613-16, Tower II
Grand Central Plaza
138 Shatin Rural Committee Rd.
Shatin, New Territories
Hong Kong
PH: +852 2792 8955955

EUROPE
FLIR Systems, Inc.
Luxemburgstraat 2
2321 Meer
Belgium
PH: +32 (0) 3665 5100

www.flir.com
NASDAQ: FLIR

17-1665 [illegible] Datasheet

The World's Sixth Sense®

Appendix D: Representative Electrical/Chemical Equipment

Half-Cell Potential

canin+

CORROSION ANALYZING INSTRUMENT

Extended Range of Applications

- Measurement of corrosion potential
- Measurement of electrical resistivity of reinforced concrete components

Compliance with Industry Standards

- Data collection and processing of test results comply with major industry standards ASTM C876-91,BS 1881 Part 201, SIA 2006, DGZfP B3, UNI 10174

Features

- Immediate presentation of test area and reading directly on the instrument display
- Optional wheel electrode for increased testing speed and productivity
- Optional Four-point Wenner probe for concrete resistance measurements
- Total memory for more than 200'000 readings

Standard half cell rod electrode

Wheel electrode with moistening wheel for continuous wetting up to a length of 200m (650ft). Linear distance recorder with travel direction detection. Automatic measurement at pre-selected intervals.

Four-point Wenner probe

In Switzerland, the Institute for Building Materials, Materials Chemistry and Corrosion of the ETH Zurich (Swiss Federal Institute of Technology) has been especially closely involved with potential field measurement. This institute initiated CANIN$^+$ and has provided scientific support.

Hoskin Scientific Ltd www.hoskin.ca

Vancouver: 604-872-7894 Burlington: 905-333-5510 Montreal: 514-735-5267 canin$^+$

Applications

The CANIN$^+$ instrument provides two methods for investigating and assessing the corrosion of steel in concrete.

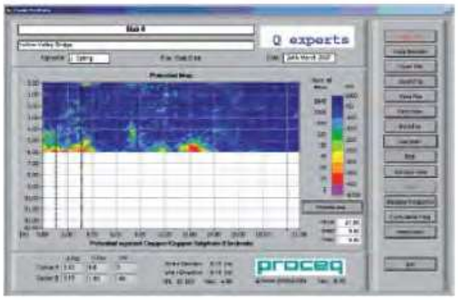
Corrosion Potential Application

Firstly, accurate **field** potential measurements aid in detecting corrosion in rebars. Corrosion of steel in concrete is an electrochemical process. A potential **field** can be measured on the concrete surface by the use of an electrode, known as a half-cell, and a high-impedance voltmeter. The CANIN$^+$ Corrosion Analyzing Instrument highlights corrosion activity before rust becomes visible. This early detection can be key in preventing an unanticipated structural failure.

CANIN$^+$ is ideally suited for assessment of corrosion potentials on large areas of 8,000 m² (83,000 sq.ft.) or multiple thereof, depending on the individual selectable grid size. 235,000 values can be stored by the intelligent memory. Up to 240 measurement values are displayed at a time in easy-to read grey-scale and a menu-driven approach facilitates simple operation using just nine keys.
Interpretation of the collected readings is facilitated by the use of the CANIN ProVista software.

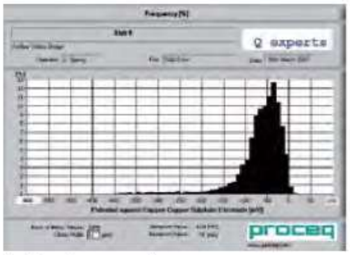
CANIN ProVista PC Software

The Windows based software CANIN ProVista, developed by Proceq SA, makes it possible to download, present and edit data measured by the CANIN$^+$ half-cell instrument in a fast and easy way using an IBM-compatible PC. The program generates a potential map, a relative frequency and a cumulative frequency diagram and provides a chipping graph. This statistical presentation is the basis for an **efficient** interpretation of the half-cell potentials by the corrosion engineer.

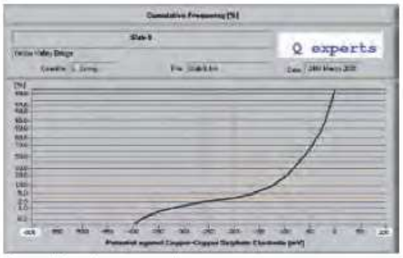


Potential Map

Single **files** can be opened and processed separately.
By rotating or mirroring in intervals of 90° the single potential maps can be combined to form a complete graph representing the total investigated surface area.

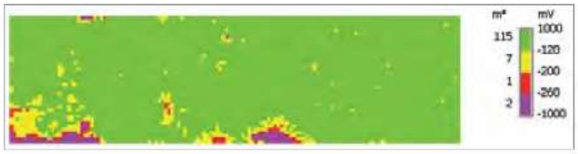


Relative frequency diagram



Cumulative frequency diagram

canin+



Chipping graph

Based on the user **defined** threshold potentials that represent certain conditions of the structure, up to four characteristic potential intervals can be chosen. The corresponding partial areas are marked with different colours in the presentation as a "Chipping graph".

Concrete Resistivity Application

Secondly, the instrument can measure the resistivity of the concrete. A lower concrete resistivity indicates a greater chance of corrosion of the reinforcement and also a greater corrosion rate. The resisitivity of concrete can vary extensively depending on the local conditions and environmental **influences.** The combination of resisitivity and potential measurement improves the information about the corrosion condition of the rebars.

- The concrete resistivity is measured by the four-point Wenner probe.
- All information is indicated on a large clear display.
- The instrument can also store up to 5,800 resistivity values and the data can be transferred to a PC for further analysis.

```
#100020
ϱ = 23kΩcm / n = 7
Min/Max = 14/38kΩcm
Position          Memory
   G7               38
Actual           Current
   39             100 %
      kΩcm

Position with ↑↓←→
Store with STORE
Menu by MENU
```

Technical Information CANIN

Potential Measurement

Measurement range:	±999 mV
Resolution:	1 mV
Memory:	non-volatile memory for up to 235'000 measurements stored in up to 71 object **files**
Software:	CANIN ProVista software for downloading data and evaluation on PC
Battery Operation:	Six LR 6 batteries, 1.5 V for up to 60 hours (or 30 hours with activated backlight)

Resistance Measurement

Measurement range:	0 to 99 k_ cm
Resolution:	1 k_ cm
Memory:	non-volatile memory for up to 5'800 measurements stored in up to 24 object **files**
Data Transfer:	by Windows Hyperterminal
Battery Operation:	Six LR 6 batteries, 1.5 V for up to 40 hours (or 20 hours with activated backlight)

General

Impedance:	10 M¯
Temperature range:	0° to 60° C
Display:	128 x 128 pixel graphic LCD with backlight
Data Output:	RS 232 interface, USB with adapter
Case Dimensions:	580 x 480 x 210 mm (22.8" x 18.9" x 8.3")
Weight:	Net. 10.6 kg (23.5 lbs); Shipping 14kg (31.1 lbs) (for article No. 330 00 204)

canin$^+$

Technical Information CANIN ProVista Software

SYSTEM REQUIREMENTS: Windows 2000, Windows XP, Windows Vista

SCALE OF LENGTH / UNIT LENGTH: Selectable grid with metric or imperial units. (Note: XY-grid settings must be equal)

EDITING: Individual readings can be deleted or changed

INSERTING: Separately measured objects can be merged to a complete potential map. If required, objects can be rotated and mirrored.

ANNOTATIONS: Comments about **specific** points on the concrete structure can be placed directly in the potential map.

BITMAPS: All graphics can be exported as **bmp-files** into external software for the generation of reports.

Ordering Information

Article No.	Description
330 00 201	**CANIN$^+$ Configuration with Rod Electrode** **Basic equipment,** Indicating device CANIN$^+$, carrying strap, protection sleeve for indicating device, transfer cable, USB-serial adapter, operating instructions, carrying case CANIN$^+$ **Rod electrode accessories** Rod electrode with spare parts, electrode cable 1.5 m (4.9 ft.), cable coil 25 m (82 ft.), CANIN ProVista PC software on memory stick, bottle with copper sulfate 250 g
330 00 202	**CANIN$^+$ Configuration with Rod and Wheel Electrodes** **Basic equipment** (see item 330 00 201), Rod electrode accessories (see item 330 00 201) Wheel Electrode accessories, one-wheel electrode system, tool kit to wheel electrode system, bottle with citric acid 250 g
330 00 203	**CANIN$^+$ with Wenner Probe** **Basic equipment** (see item 330 00 201), Wenner Probe accessories, Wenner resistance probe with spare rubber foam pads, cable to Wenner probe, control plate to Wenner probe
330 00 204	**CANIN$^+$ Combined Configuration with Rod and Wheel Electrodes and Wenner Probe** **Basic equipment** (see item 330 00 201), Rod electrode accessories (see item 330 00 201) Wheel Electrode accessories (see item 330 00 202), Wenner Probe accessories (see item 330 00 203)
Accessories	
330 00 956	One-wheel electrode system
380 02 520	Wenner probe with cable, spare rubber foam pads and control plate
390 00 542	USB-serial Adapter

Electrical Resistivity

resipod

The world's most accurate concrete surface resistivity meter

Surface resistivity measurement provides extremely useful information about the state of a concrete structure. Not only has it been proven to be directly linked to the likelihood of corrosion and the corrosion rate, recent studies have shown that there is a direct correlation between resistivity and chloride diffusion rate. The versatility of the method can be seen in these example applications:

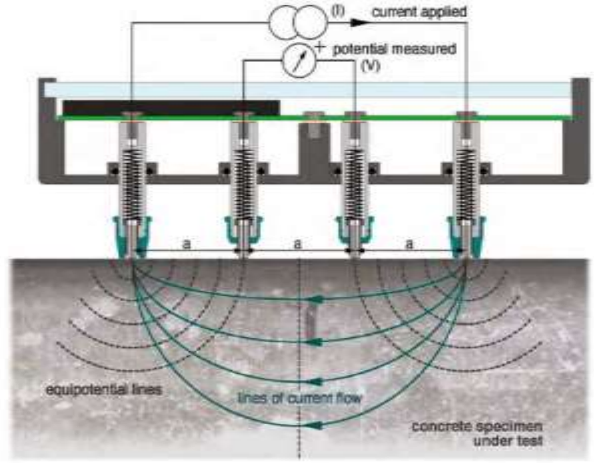
- Estimation of the likelihood of corrosion
- Indication of corrosion rate
- Correlation to chloride permeability
- On site assessment of curing efficiency
- Determination of zonal requirements for cathodic protection systems
- Identification of wet and dry areas in a concrete structure
- Indication of variations in the water/cement ratios within a concrete structure
- Identification of areas within a structure most susceptible to chloride penetration
- Correlation to water permeability of rock

Resipod is a fully integrated 4-point Wenner probe, designed to measure the electrical resistivity of concrete in a completely non-destructive test. It is the most accurate instrument available, extremely fast and stable and packaged in a robust, waterproof housing designed to operate in a demanding site environment.

proceq

resipod

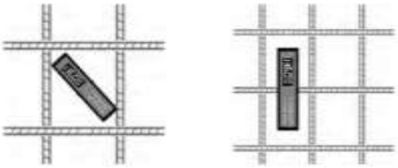
The measurement principle



Operating on the principle of the Wenner probe, the Resipod is designed to measure the electrical resistivity of concrete or rock. A current is applied to the two outer probes, and the potential difference is measured between the two inner probes. The current is carried by ions in the pore liquid. The calculated resistivity depends on the spacing of the probes.

Resistivity $\rho = 2\pi aV/I$ [kΩcm]

Resipod Models and Probe Spacing



A wider probe spacing provides a more consistent reading when measuring on an inhomogeneous material like concrete. However, if the spacing is too wide, there is more danger of the measurement being affected by the reinforcement steel. The industry standard 50 mm probe spacing has long been seen as a good compromise.

The 38mm (1.5") model is designed specifically to comply with the AASHTO T 358 standard for "Surface Resistivity Indication of Concrete's Ability to Resist Chloride Ion Penetration".

The Surface Resistivity (SR) test is a much quicker and easier test for estimating concrete permeability. It is a proven and mature test method which can replace the more laborious rapid chloride permeability test.

proceq

resipod

Unmatched Features

Despite being extremely simple to use, Resipod provides a variety of features that are unique in a concrete surface resistivity instrument.

- Fully integrated surface resistivity instrument
- Wide measuring range (0 to ca. 1000 kΩcm)
- Fast and accurate delivery of measuring results
- Highest resolution available for a surface resistivity instrument
- Meets the AASHTO T 358 standard (38mm, 1.5" probe spacing)
- Current flow indication and poor contact indication
- Hold, save and delete function, with onboard memory
- USB connection and dedicated PC software
- Designed to float (waterproof according to IP67)
- Allows variable probe spacing to be set
- Allows replacement of standard tips with accessories

Resipod Display

The display of the Resipod shows all necessary information while acquiring data on site.

1. Measured resistivity
2. Battery status
3. Range indication
4. Current indication
   20%, 40%, 60%, 80%, 100%
5. Indication of scaled reading

Indication of poor connection

A good connection between the instrument and the concrete surface is the most important factor for obtaining a reliable measurement. Resipod automatically detects a poor connection and alerts the user.

No contact inner probes

Overflow

"Open Line" indication

ResipodLink Software

The collected measurement values can then be analyzed comfortably with the Resipod Link PC tool.

proceq

Technical Information Resipod

Range	0.1 – ca. 1000 kΩcm (depending on probe spacing)
Resolution (nominal current 200µA)	±0.2 kΩcm or ±1% (whichever is greater)
Resolution (nominal current 50µA)	±0.3 kΩcm or ±2% (whichever is greater)
Resolution (nominal current <50µA)	±2 kΩcm or ±5% (whichever is greater)
Frequency	40 Hz
Memory	Non volatile, ca. 500 measured values
Power Supply	>50 hours autonomy
Charger connection	USB type B, (5V, 100mA)
Dimensions	197 x 53 x 69.7 mm (7.8 x 2.1 x 2.7 inch)
Weight	318 g (11.2 oz)
Operating temperature	0° to 50°C (32° to 122°F)
Storage temperature	-10° to 70°C (14° to 158°F)
IP Classification	IP67

Technical Information Resipod Link software

System requirements: Windows XP, Windows Vista, Windows 7, USB-Connector
An internet connection is necessary for soft- and firmware (using PqUpgrade) updates if available.

Ordering Information

Units	**Description**
381 10 000	Resipod, 50mm probe spacing, test strip, foam contact pads, charger with USB-cable, software, carrying strap, documentation and case.
381 20 000	Resipod, 38mm (1.5") probe spacing, test strip, foam contact pads, charger with USB-cable, software, carrying strap, documentation and case.
Parts and Accessories	
381 01 050	Extension cable set
381 01 043S	Set of replacement foam contact pads (20 pieces)
381 01 038	Test strip
381 01 014	USB cover
391 80 110	Carrying strap
341 80 112	USB charger, global

Service and Warranty Information

Proceq is committed to providing complete support for the Resipod testing instrument by means of our global service and support facilities. Furthermore, each instrument is backed by the standard Proceq 2-year warranty and extended warranty options.

Standard warranty
Electronic portion of the instrument: 24 months
Mechanical portion of the instrument: 6 months

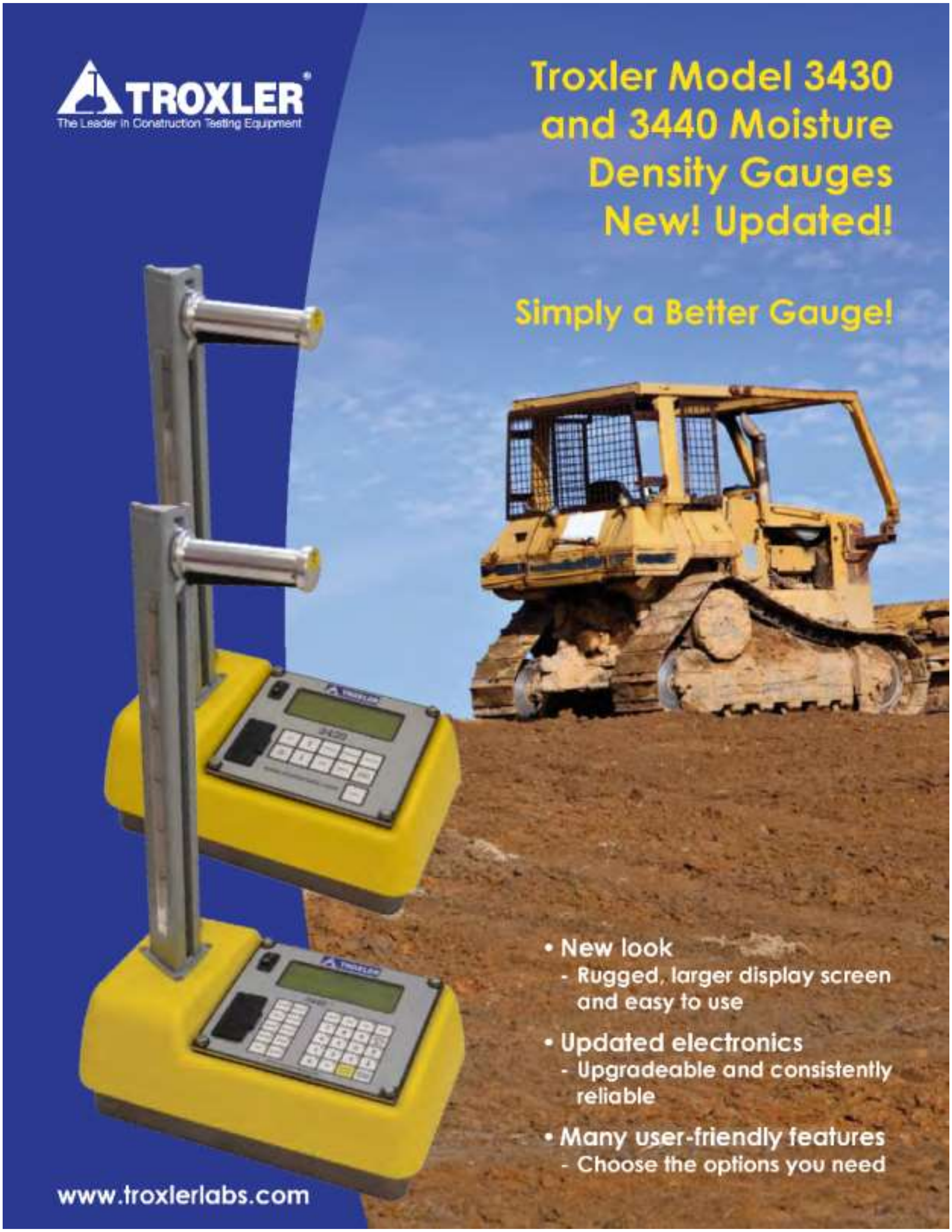
Extended warranty
When acquiring a Resipod, max. 3 additional warranty years can be purchased (for the electronic portion of the instrument). The additional warranty must be requested at time of purchase or within 90 days of purchase.

Head Office

Proceq SA
Ringstrasse 2
CH-8603 Schwerzenbach
Switzerland
Phone: +41 (0)43 355 38 00
Fax: +41 (0)43 355 38 12
info@proceq.com
www.proceq.com

Appendix E: Representative Nuclear Equipment

Direct Transmission and Backscatter Radiometry



TROXLER®

The Leader in Construction Testing Equipment

Troxler Model 3430 and 3440 Moisture Density Gauges New! Updated!

Simply a Better Gauge!

- New look
  - Rugged, larger display screen and easy to use
- Updated electronics
  - Upgradeable and consistently reliable
- Many user-friendly features
  - Choose the options you need

www.troxlerlabs.com

3430

The Troxler nuclear moisture density gauges are used by many contractors, engineers and highway departments for compaction control of soil, aggregate, concrete and full depth asphalt. The gauges meet or exceed the ASTM standards D6938, D2950 and C1040. The operator selects the density mode, backscatter or direct transmission, based on the material type and the thickness of the layer being measured. The Model 3430 is the simplest and most economical gauge offered by Troxler. The Model 3440 adds a larger keypad and more available features that are needed for some construction projects. Both models are customizable to meet your testing needs.

The Model 3430 is a simple gauge for users who don't need many "extras". The enhanced platform allows for many updates and advantages such as:

- Updated electronics
- NiMH batteries with fast recharge
- Larger backlit display screen - 8mm characters
- Optional user-friendly features that can be added:
  - External beeper
  - Alkaline battery backup feature
  - Remote start keypad on the handle
  - Data storage
  - USB port for data transfer
  - Spanish and French language options

Troxler also offers the enhanced platform for the Model 3440. Customers can now add the features desired in order to customize the gauge to their testing needs. This model also offers updated electronics, batteries and display screen.

Standard features include:
- Automatic Depth function
- USB Port
- Data Storage
- Alkaline Battery Backup

Optional Features include:
- External beeper
- Remote Keypad
- Backlit keypad
- Spanish and French language options
- GPS locations for measurements

Both models offer:
- Density measurement capability in backscatter or direct transmission mode and moisture measurement in backscatter mode to allow quick, non-destructive testing of soil, asphalt and concrete materials
- Direct Readout of test results (wet density, dry density, moisture, % moisture, % voids and % compaction)
- Multiple count time options (15 sec., 1 min., 4 min.)
- Moisture, Density and Trench Offsets
- User friendly software menus and keypads
- 18 month warranty

3440

Moisture Measurement

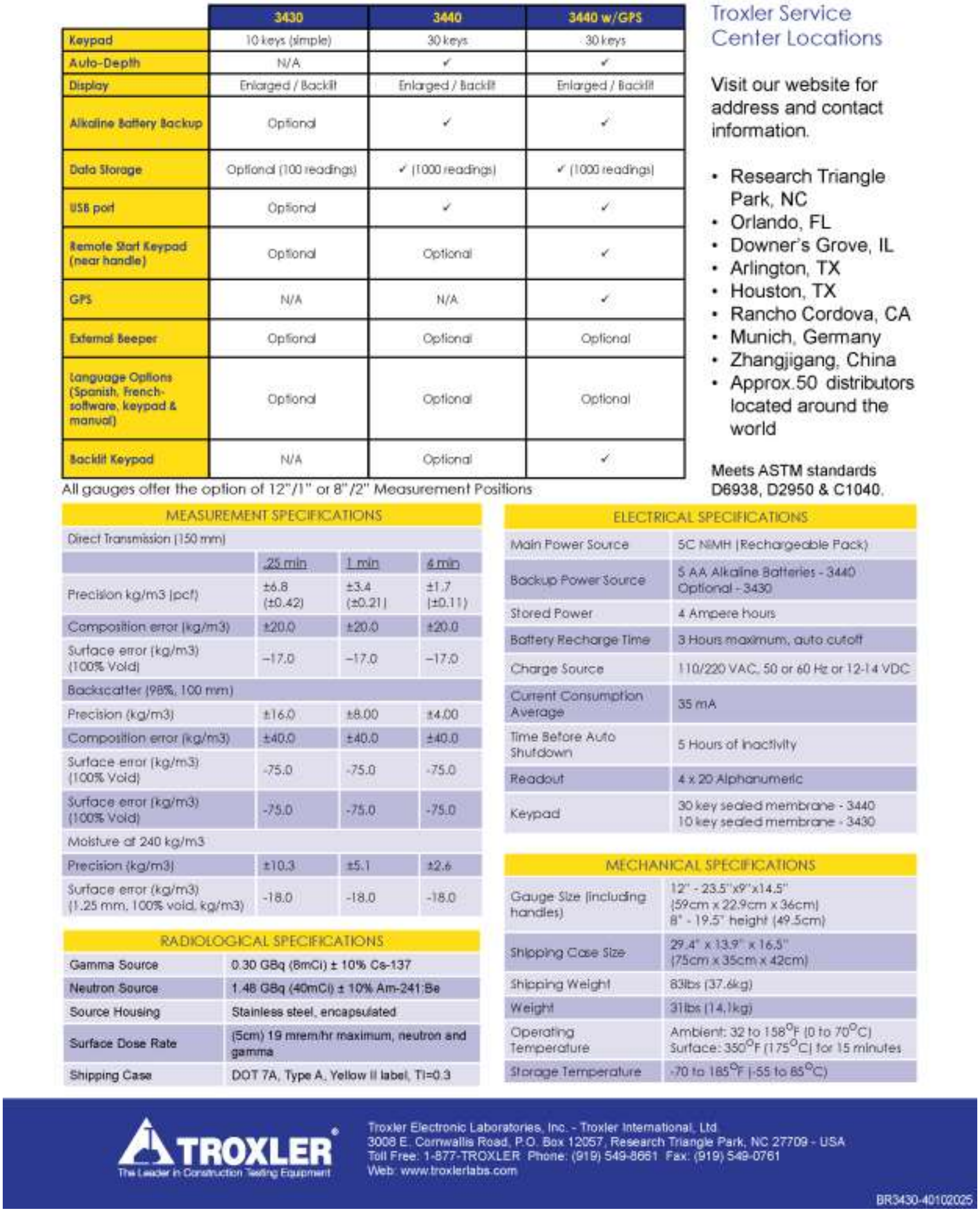
Moisture content is measured in a nondestructive test mode. Moisture is determined through the detection of thermalized neutrons ("fast" neutrons which have been slowed by the hydrogen present in the material, normally in the form of water).

Backscatter Measurement

The backscatter mode is a rapid and nondestructive means of testing materials that are approximately 4 in (10 cm) in depth. The gamma source remains inside the gauge and the gamma rays that are scattered back toward the detectors are counted, determining the density count for the material. This mode of testing is usually used on asphalt and concrete.

Direct Transmission Measurement

In the direct transmission position the source rod extends through the base of the gauge into a predrilled hole up to 12 in. (30 cm) deep in the material being tested. The gamma rays are transmitted from the density source, through the test material and are counted by detectors located within the gauge.



	3430	3440	3440 w/GPS
Keypad	10 keys (simple)	30 keys	30 keys
Auto-Depth	N/A	✓	✓
Display	Enlarged / Backlit	Enlarged / Backlit	Enlarged / Backlit
Alkaline Battery Backup	Optional	✓	✓
Data Storage	Optional (100 readings)	✓ (1000 readings)	✓ (1000 readings)
USB port	Optional	✓	✓
Remote Start Keypad (near handle)	Optional	Optional	✓
GPS	N/A	N/A	✓
External Beeper	Optional	Optional	Optional
Language Options (Spanish, French-software, keypad & manual)	Optional	Optional	Optional
Backlit Keypad	N/A	Optional	✓

All gauges offer the option of 12"/1" or 8"/2" Measurement Positions

Troxler Service Center Locations

Visit our website for address and contact information.

- Research Triangle Park, NC
- Orlando, FL
- Downer's Grove, IL
- Arlington, TX
- Houston, TX
- Rancho Cordova, CA
- Munich, Germany
- Zhangjigang, China
- Approx.50 distributors located around the world

Meets ASTM standards D6938, D2950 & C1040.

MEASUREMENT SPECIFICATIONS

Direct Transmission (150 mm)			
	.25 min	1 min	4 min
Precision kg/m3 (pcf)	±6.8 (±0.42)	±3.4 (±0.21)	±1.7 (±0.11)
Composition error (kg/m3)	±20.0	±20.0	±20.0
Surface error (kg/m3) (100% Void)	–17.0	–17.0	–17.0
Backscatter (98%, 100 mm)			
Precision (kg/m3)	±16.0	±8.00	±4.00
Composition error (kg/m3)	±40.0	±40.0	±40.0
Surface error (kg/m3) (100% Void)	-75.0	-75.0	-75.0
Surface error (kg/m3) (100% Void)	-75.0	-75.0	-75.0
Moisture at 240 kg/m3			
Precision (kg/m3)	±10.3	±5.1	±2.6
Surface error (kg/m3) (1.25 mm, 100% void, kg/m3)	-18.0	-18.0	-18.0

RADIOLOGICAL SPECIFICATIONS

Gamma Source	0.30 GBq (8mCi) ± 10% Cs-137
Neutron Source	1.48 GBq (40mCi) ± 10% Am-241:Be
Source Housing	Stainless steel, encapsulated
Surface Dose Rate	(5cm) 19 mrem/hr maximum, neutron and gamma
Shipping Case	DOT 7A, Type A, Yellow II label, TI=0.3

ELECTRICAL SPECIFICATIONS

Main Power Source	5C NiMH (Rechargeable Pack)
Backup Power Source	5 AA Alkaline Batteries - 3440 Optional - 3430
Stored Power	4 Ampere hours
Battery Recharge Time	3 Hours maximum, auto cutoff
Charge Source	110/220 VAC, 50 or 60 Hz or 12-14 VDC
Current Consumption Average	35 mA
Time Before Auto Shutdown	5 Hours of inactivity
Readout	4 x 20 Alphanumeric
Keypad	30 key sealed membrane - 3440 10 key sealed membrane - 3430

MECHANICAL SPECIFICATIONS

Gauge Size (including handles)	12" - 23.5"x9"x14.5" (59cm x 22.9cm x 36cm) 8" - 19.5" height (49.5cm)
Shipping Case Size	29.4" x 13.9" x 16.5" (75cm x 35cm x 42cm)
Shipping Weight	83lbs (37.6kg)
Weight	31lbs (14.1kg)
Operating Temperature	Ambient: 32 to 158°F (0 to 70°C) Surface: 350°F (175°C) for 15 minutes
Storage Temperature	-70 to 185°F (-55 to 85°C)

TROXLER®
The Leader in Construction Testing Equipment

Troxler Electronic Laboratories, Inc. - Troxler International, Ltd.
3008 E. Cornwallis Road, P.O. Box 12057, Research Triangle Park, NC 27709 - USA
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Web: www.troxlerlabs.com

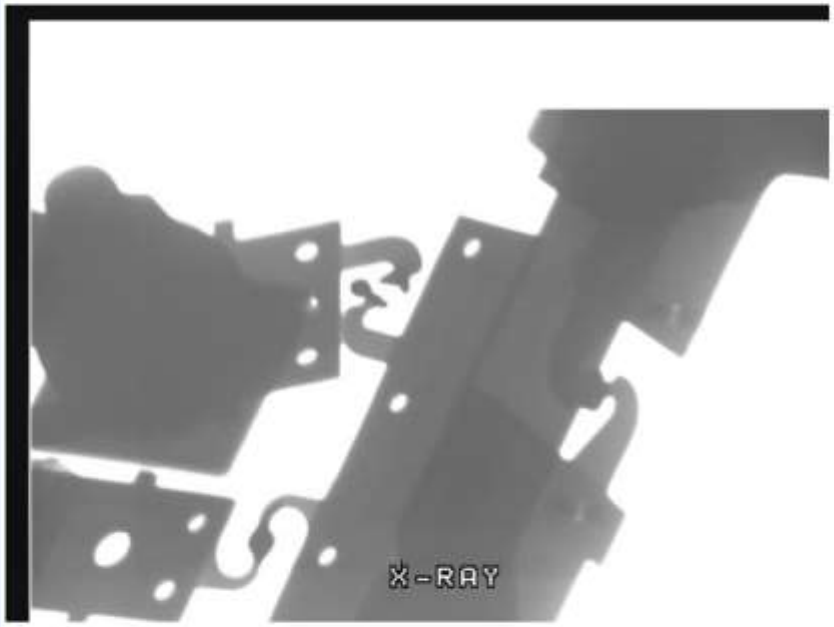
BR3430-40102025

Radiography

Gamma Ray:
With Magna Chek's Gamma Ray unit, we increase penetration capabilities up to 3.5 inches of steel. Gamma ray units do not require power because of the Iridium isotope, which makes them ideal for inspecting remote items such as pipelines, bridges, etc.

Mobile NDT Units:
Can't come to us? Then Magna Chek will come to you. Our units can be equipped with 200 or 300 kilovolt X-Ray machines or Gamma ray units – whatever your spec requires. On site development, interpretation and reporting are standard with Magna Chek. These units are available for on-site inspection of power generating turbines, boilers, pressure vessels, bridges, crane assemblies and much more.

Radiography



Radiography Applications:
- 200 and 300 Kilovolt Units Applications:
- Aircraft Structures and Components
- Welded Assemblies
- Pressure Vessels and Piping
- Electronic Circuitry
- Bridge Girders
- Similar Materials
- Gamma Ray Applications:
- Pipelines
- Bridge and Building Fabrications
- Pressure Vessels
- Large Forgings and Castings
- Armored Vehicle Components

Appendix F: Representative Miscellaneous Equipment

Liquid Penetrant

SPECIALTY CHEMICAL MANUFACTURERS FOR INDUSTRY, BIOSECURITY & AVIATION

NON DESTRUCTIVE TESTING
Penetrant Testing

APPROVED AEROSOL TYPE II VISIBLE TESTING OF MANUFACTURED ITEM

Sherwin Incorporated's DUBL-CHEK Dye Penetrants meet ASME and similar nuclear, aerospace and military specifications. Certification is available and forwarded on request. Sherwin NDT products are used around the world including such places as; Eifel Tower, Boeing Airframe, French & US Nuclear Facilities.

- Globally approved to nuclear, aeronautical and civil specifications.
- QPL approved under AMS 2644
- Simple 3 steps process
- Suitable for all metals, as well as plastics and ceramics

ADDITIONAL PRODUCTS:
Callington and Sherwin supply full range of NDT consumables. Contact your local agent for further details.

Callington

SPECIALTY CHEMICAL
MANUFACTURERS
FOR BIOSECURITY,
AVIATION & INDUSTRY

NATA

ASSDA MEMBER

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