SUMMARY OF NONDESTRUCTIVE METHODS FOR CONCRETE STRUCTURES

Techniques being utilized, researched & under development at Inspection & Testing Services, Inc.

Method and Principle	***Applications***	**Advantages**	***Limitations***
Visual Inspection – Observe, classify and document the appearance of distress on exposed surface of the structure	Map patterns of distress such as cracking, spalling, scaling, erosion, or construction defects		

STRESS WAVE METHODS FOR STRUCTURES			
Method and Principle	***Applications***	**Advantages**	***Limitations***
Ultrasonic pulse velocity (through or direct transmission) – Measure the travel time of a pulse of ultrasonic waves over a known path length	Determine the relative *condition* of concrete based on measured pulse velocity	Portable equipment is available; relatively easy to use.	Require access to two sides of members; does not provide information on depth of defect
Ultrasonic-echo – Transducer emits short pulse of ultrasonic waves which is reflected by opposite side of member or an internal defect; arrival of reflected pulse is recorded by an adjacent receiver, and round-trip travel time is determined	Locate delaminations and voids in relatively thin elements	Access to only one face is needed; provides information on depth of defect	Applicable to limited member thickness; not commercially available; experienced operator is required.
Impact-echo – Receiver adjacent to impact point monitors arrival of stress waves as they undergo multiple reflections between surface and opposite side of plate-like member or from internal defects. Frequency analysis permits determination of distance to reflector if wave speed is known	Locate variety of defects within concrete elements such as delaminations, voids, honeycombing, or measure element thickness.	Access to only one face is needed; equipment is commercially available; capable of locating a variety of defect; does not require coupling materials.	Experienced operator is required; current instrumentation limited to testing members less than 2 m thick.
Spectral analysis of surface waves – Impact is used to generate a surface wave and two receivers monitor the surface motion; signal analysis allows determination of wave speed as a function of wavelength; inversion process determines elastic constants of layers.	Determine the stiffness profile of a pavement system. Also used to determine depth of deteriorated concrete.	Capable of determining the elastic properties of layered systems, such as pavements, interlayered good and poor quality concrete.	Experienced operator is required; involves complex signal processing

SURFACE REFLECTION MEHODS FOR DEEP FOUNDATIONS			
Method and Principle	***Applications***	**Advantages**	***Limitations***
Sonic-echo – Hammer impact on surface and receiver monitors reflected stress wave. Time-domain analysis used to determine travel time.	Determine the length of deep foundations (piles and piers); determine the location of cracks or constrictions (neck-in)	No pre-placed tubes. Portable equipment. Rapid.	Confuses necking and bulging. Does not measure diameter. Unable to determine defects in shafts > 30 m or with L/d >30
Impulse-response (Mobility) – Test is similar to sonic echo method except that signal analysis involves frequency-domain analysis of the received signal and the impact force history	Determine the length of deep foundation (piles and piers), location of cracks and constrictions (neck-in). Provides information on low-strain dynamic stiffness of the shaft/ soil system	No pre-placed tubes. Stiffness measurements. Portable equipment. Rapid.	Results interpretation is delicate. Limitations on geometry of pile to be tested, as for sonic-echo.
Impedance logging – Test is similar to sonic echo or impulse-response, but the use of more complex signal analysis (time and frequency domain) allows reconstructing the approximate shape of the deep foundation.	Determine the approximate 2-dimensional shape of the deep foundation.	As for mobility test, plus effective shape of shaft derived from analysis.	Requires very good test data for accurate analysis. Full analysis can not yet be completed on site at time of test.

DIRECT TRANSMISSION MEHODS FOR DEEP FOUNDATIONS			
Method and Principle	***Applications***	**Advantages**	***Limitations***
Crosshole sonic logging – Analogous to the ultrasonic0pulse velocity test, but transducers are positioned within tubes cast into the deep foundation or holes drilled after construction.	Determine the location of low quality concrete along the length of the shaft and between transducers. With drilled holes permits direct determination of shaft length.	Relatively fast. Detection of defects between tubes is much more accurate than in surface reflection tests. Performance is not limited by depth.	Pre-placed tubes or coring required. May not detect defects at edge of shaft.
Parallel seismic – Receiver is placed in hole adjacent to the foundation. Foundation is struck with a hammer and signal from receiver is recorded. Test is repeated with receiver at increasing depth.	Determine the foundation depth and determine whether it is of uniform quality.	Relatively fast. Foundations under existing structures can be tested. Not affected by soil damping as much as surface reflection methods.	Cost of bore hole adjacent to each foundation. Signal stops at first major anomaly. Can bypass edge defects.

Summary of Non Destructive Methods for Concrete Structures

NUCLEAR METHODS			
Method and Principle	***Applications***	**Advantages**	***Limitations***
Direct transmission radiometry – Measure the intensity of high energy electromagnetic radiation after passing through concrete	Determine in-place density of hardened concrete. Locate reinforcing steel or voids	Portable equipment available for determination of in-place density. Minimal operator skill is required.	Operators must be licensed. Available equipment limited to path lengths less than 12". Requires access to inside of members or opposite faces.
Backscatter radiometry – Measure the intensity of high-energy electromagnetic radiation that is backscattered (reflected) by the near surface region of a concrete member.	Determine in-place density of fresh or hardened concrete.	Requires access only to surface of test object and is suitable for fresh or hardened concrete.	Operators must be licensed. Precision of density measurements is lower than direct transmission. Measurement is affected by near surface material and sensitive to chemical composition.
Radiography – The intensity of high-energy electromagnetic radiation which passes through a member is recorded on photographic film	Locate reinforcing and prestressing steel, conduits, pipes, voids, and honeycombing	Provides view of the internal structure of the test object	Operators must be licensed and highly skilled. X-ray equipment is bulky and expensive. Difficult to identify cracks perpendicular to radiation beam. Gamma-ray penetration limited to 20" of concrete.
Gamma-gamma logging – see direct transmission and backscatter radiometry	Locate regions of low density along length of foundation.		

MAGNETIC AND ELECTRICAL METHODS			
Method and Principle	***Applications***	**Advantages**	***Limitations***
Covermeter – A low frequency alternating magnetic field is applied on the surface of the structure; the presence of embedded reinforcement alters this field, and measurement of this change provides information on the reinforcement	Locate embedded reinforcement, measure depth of cover, and estimate diameter of reinforcement	Able to locate reinforcing bars and other embedded objects. Equipment is lightweight, portable, and easy to use. Cover depth can be estimated.	Accuracy of estimated cover depth affected by bar size and bar spacing. Bar diameters difficult to estimate with precision. Cannot identify presence of second layer of reinforcement. Ability to discern an individual bar is affected by the meter design, cover depth, and bar spacing. Meters based on magnetic reluctance can detect only ferromagnetic objects. Maximum penetration is limited and depends on meter design.
Half-cell potential – Measure the potential difference (voltage) between the steel reinforcement and a standard reference electrode; the measured voltage provides an indication of the likelihood that corrosion is occurring in the reinforcement.	Identify region or regions in a reinforced concrete structure where there is a high probability that corrosion is occurring at the time of the measurement	Lightweight portable equipment. Provides indication of likelihood of corrosion activity at time of testing.	Requires a connection to embedded reinforcement, and reinforcement must be electrically connected. Not applicable to epoxy-coated bars. Concrete has to be moist. No indication of corrosion arte. Testing and interpretation must be done by experienced personnel.

MAGNETIC AND ELECTRICAL METHODS			
Method and Principle	**Applications**	**Aadvantages**	**Limitations**
Polarization methods – Measure the current required to change by a fixed amount the potential difference between the reinforcement and a standard reference electrode; the measured current and voltage allow determination of the polarization resistance, which is related to the rate of corrosion.	Determine the instantaneous corrosion rate of the reinforcement located below the test point	Lightweight portable equipment for linear polarization. Provides indication of corrosion rate at time of testing.	Requires a connection to embedded reinforcement, and reinforcement must be electrically connected. Not applicable to epoxy-coated or galvanized bars. No standard for interpreting test results. Cover depth has to be less than 4". Concrete surface has to be smooth, uncracked, free of impermeable coating, and free of visible moisture. Testing and interpretation must be done by experienced personnel.

Summary of Non Destructive Methods for Concrete Structures

PENETRABILITY METHODS			
Method and Principle	**Applications**	**Advantages**	**Limitations**
Penetrability methods – Measure the flow of a fluid (air or water) into concrete under prescribed test conditions; the flow rate depends on the penetrability characteristics of the concrete.	Compare alternative concrete mixtures. Primary research tools, but have the potential to be used for assessing adequacy of curing process.	ISAT Simple and inexpensive to perform. Portable equipment. Sensitive to changes in concrete quality. Totally nondestructive. Considerable experience has been gained in its use.	Unreliable for concrete with a high sorptivity surface layer. Measures absorption of outer surface concrete only and is affected by surface coatings. Difficult to seal circular cap at the concrete surface. Sensitive to concrete moisture condition.
		Figg Water-Absorption Test Not affected by coatings and surface concrete layer. Inexpensive and simple to use.	Intrusive because drilling is necessary. Drilling may affect concrete under test. Sensitive to aggregate characteristics. Sensitive to concrete moisture condition.
		Covercrete-Absorption Test Gives an integrated measure of the entire cover zone.	Intrusive because drilling is necessary. Drilling may affect concrete under test. Sensitive to concrete moisture condition.
		CLAM (Water Permeability) Measures flow under constant pressure conditions.	Provides a permeability index, not coefficient of permeability. Sensitive to concrete moisture condition. Concrete surface is damaged. Long test time required
		Steinert Method(Water Permeability) Measures unidirectional flow. Easier to interpret than CLAM.	Provides a permeability index, not coefficient of permeability. Sensitive to concrete moisture condition. Concrete surface is damaged. Long test time required

		Figg Air-permeability Testwell Laboratories, Inc. Inexpensive and simple to use. Not influenced by surface layer or coatings. Less sensitive to moisture condition than water test.	Sensitive to aggregate characteristics. Intrusive because drilling is required. Drilling may affect concrete under test. Provides a permeability index, not coefficient of permeability.
		Schonlin Test(Air Permeability) Nondestructive. Less sensitive to moisture condition than water tests. Includes concrete moisture conditioning procedure.	Provides a permeability index, not coefficient of permeability. Measure outer surface concrete only and is affected by surface coatings.
		Surface Airflow Test Nondestructive. Less sensitive to moisture condition than water tests. Includes concrete moisture conditioning procedure.	Provides a permeability index, not coefficient of permeability. Measure outer surface concrete only and is affected by surface coatings.

INFRARED THERMOGRAPHY			
Method and Principle	***Applications***	**Advantages**	***Limitations***
Infrared thermography – The presence of flaws within the concrete affects the heat conduction properties of the concrete and the presence of defects are indicated by differences in surface temperatures when the test object is exposed to correct ambient conditions	Locate delaminations in pavements and bridge decks. Also widely used for detecting moist insulation in buildings.	A global technique that covers much greater areas than other test methods, and is therefore cost effective. Results provide an indication of the percentage of deteriorated area in the survey region.	Expensive equipment. Requires proper environmental conditions for testing. The depth and thickness of a subsurface anomaly cannot be measured. Variations in test response occure with varying environmental conditions (temprature gradient, shaded or direct sunlight, cloud cover, and surface water). As the depth of the anomaly increases, it becomes more difficult to detect. Trained individual needed to assure that acquired data are meaningful and correctly interpreted.

GROUND PENETRATING RADAR			
Method and Principle	***Applications***	**Advantages**	***Limitations***
Radar - Analogous to ultrasonic-echo methods except that electromagnetic waves are used instead of stress waves. Interface between materials with different dielectric properties results in reflection of a portion of incident electromagnetic pulse.	Locate metal embedments, voids beneath pavements, and regions of high moisture contents; determine thickness of members	Non-contact antennas permit fast speed scanning. Very sensitive to presence of embedded metal objects. Ability to penetrate across concrete-air interfaces. Sensitive to the prsence of moisture.	Region irradiated by the antenna is limited to cone-shaped volume directly below antenna. Congested can prevent penetration beyond the reinforcement. Cracks and delaminations are not easy to detect unless moisture is also present in the cracks or region of the delaminaton. Pulses from high resolution antennae have limited depth of penetration(400 to 750mm). The behavior of electromagnetic pulses propagating through reinforced concrete structures is not completely known. Experienced operator required to operate equipment and interpret results. Large amounts. Large amounts of data obtained during scans.