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Automated feasibility analysis of cathodic protection (CP) and electrochemical chloride extraction for reinforced concrete bridge structures in Pennsylvania

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Automated Feasibility Analysis of Cathodic Protection (CP) and Electrochemical Chloride Extraction for Reinforced Concrete Bridge Structures in Pennsylvania

by

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ABSTRACT:

Severe corrosion of the reinforcing steel that occurs from ingress of chloride ion of deicing salts is a major maintenance problem facing concrete bridges. The feasibility of the prospective corrosion maintenance of a bridge is a function of the severity of the corrosion as well as the properties of the existing structure and the considered treatment method. The work presented here is a feasibility study of two electrochemical restoration techniques, cathodic protection (CP) and electrochloride extraction (ECE), for Pennsylvania bridge structures. The first objective was to establish a set of criteria under which CP or ECE would be viable alternatives. The second objective was to develop an implementation plan with a web-oriented, multi-user computer program, AFACE. This application identifies those bridges most receptive to electrochemical treatment.

Key words: Corrosion maintenance, web-based, decision system, electro-chloride extraction, concrete bridge

CHAPTER I: Introduction

Corrosion resides in many parts of human's daily life. Most of the public know its importance and get their share by experiencing the effects of corrosion frequently. However there are also unpredictable parts of corrosion, significance of which is still remaining as a secondary issue even for the educated professionals. Without any precaution, the corrosion process continues until major problems begin to occur. Generally it happens to be too late for a last minute application to avoid the problematic effects of corrosion.

Among civil engineers, since it is required to design and manage the structures with the guidance of the specifications, corrosion may not be seen as a primary problem in the beginning. But on the other hand, new design procedures and especially the lately developed technology and the materials, may sometimes cause unique corrosion problems on the structure. Furthermore, the time has shown that aging of a structure without the required maintenance and/or precautions would cause fatal results due to corrosion before the end of the design life of the structure.

Severe corrosion of the reinforcing steel that occurs from ingress of chloride ion of deicing salts is a major maintenance problem facing concrete bridges. Although, there are numerous techniques to avoid this problem, not many options can be considered to treat the bridge after the problem arises. In other words there are a few techniques, which are incorporated into a rehabilitation program on an existing structure to mitigate or stop an ongoing deterioration or corrosion process. Some of these options are as follows:

- To demolish and reconstruct the structure.
- To apply an electrochemical technique (Cathodic Protection-CP or Electrochemical Chloride Extraction-ECE).
- To leave the structure as it is (do nothing option).

The criteria used to select one of these options are influenced by economical, technical, educational or even sometimes political restrictions. Several parameters such as inconsistency in the budgetary plan of the agency responsible with the maintenance of the structure, the knowledgebase of the decision maker, and other technical difficulties can be named as other important influences in this process. This means that a life cycle cost analysis just may not be enough for finalizing the decision process for all of the cases. Furthermore, some technical aspects may remain unknown or seem less important than they actually are. Without considering all of these issues, the ultimate selection may not be a feasible one.

If we look at the three possibilities above, it is obvious that more effort is required for the second option, which is "to apply an electrochemical technique" and subsequently, be able to answer the question "why?"

One of the reasons why no such analysis is available yet is, because the history of these techniques does not lie much in the past.

An important aspect of the management and maintenance of reinforced concrete structures which are subject to chloride induced corrosion and deterioration is first, the assessment of the present condition and, second, the rate at which continued deterioration can be expected to occur. The feasibility of the prospective corrosion maintenance of a bridge is a function of the severity of the corrosion as well as the cost the considered treatment method.

The work presented in this study is a feasibility study of two electrochemical restoration techniques, cathodic protection (CP) and electrochloride extraction (ECE), for Pennsylvania bridge structures. In here, the first objective was to establish a set of criteria under which CP or ECE would be viable alternatives. The second objective was to develop a feasibility assessment procedure implemented through a web-oriented, multi-user computer program, called the AFACE. This application is intended to identify those bridges that would be most receptive to an electrochemical treatment.

CHAPTER II: Background

2.1 Introduction

Corrosion is the "destructive" result of chemical reactions between a metal or metal alloy and its environment. Metal atoms in nature are present in chemical compounds. The same amounts of energy needed to extract metals from their minerals are emitted during the chemical reactions that produce corrosion. Corrosion returns the metals to their combined states in chemical compounds that are similar or even identical to the minerals from which the metals were extracted. Thus, corrosion has been called extractive metallurgy in reverse (Jones, 1996).

"Destructive" is specified purposely to exclude all sorts of chemical and electrochemical processes that are used industrially to react with metals and which are designed to improve the metal, not damage it. Thus these processes are not considered to be corrosion.

"Metal or metal alloys" are mentioned in the definition of corrosion, but any material can be damaged by its environment: plastics swell in solvents, concrete dissolves in sewage, wood ruts, and so on. These results are all very serious problems that occur by various mechanisms, but they are not included in this definition. Metals, whether they are attacked uniformly or pit or crack in corrosion, are all corroded by the same basic mechanisms, which are quite different from those of other materials.

The environment that corrodes a metal can be anything; air, water, and soil are common but everything from tomato juice to blood are environments are corrosive to metal. Corrosion is a natural process for metals that causes them to react with their environment to form more stable compounds. In a perfect world the right material would always be selected, equipment designs would have no flaws, no mistakes would be made in operation, and corrosion would still occur - but at an acceptable rate (Bradford, 1993).

An electrochemical reaction is defined as a chemical reaction involving the transfer of electrons or one that involves oxidation and reduction processes. During the corrosion process, there is a flow of electricity from certain areas on the metal surface to other areas through a solution (an electrolyte) capable of conducting electricity. Electrolytes conduct electricity due to the presence of ions, which are positively or negatively charged atoms or group of atoms in the solution. The term anode is used to describe the metal surface from which current leaves the metal to enter the solution and this is the area where metal dissolution or corrosion takes place. The term cathode is used to describe the metal surface where current leaves the solution and returns to the metal. There is no metal dissolution at the cathode. The circuit is completed through the metal itself or outside the solution through a conductor joining two pieces of metal (FHWA-SHRP Showcase, 1996).

Rather than resorting to a classification system, some of the more common forms of corrosion and terms associated with corrosion are defined below:

Uniform/General Corrosion: A form of attack that produced overall uniform wastage of the metal. Often associated with atmospheric corrosion and some high temperature oxidation or sulfidation attack.

Pitting Corrosion: A high-localized attack of the metal creating pits of varying depth, width, and number. Pitting may often lead to complete perforation of the metal with little or no general corrosion of the surface.

Crevice Corrosion: Similar to pitting corrosion in its localized nature but associated with crevices. Stainless steels and some nickel-base alloys are particularly susceptible to this form of corrosion.

Intergranular Attack: The preferential corrosion of grain boundaries in a metal caused by prior thermal treatments and related to specific alloy chemistries.

Dealloying: The selective removal of one element (usually the least noble) from an alloy by the corrosive environment. Also referred to as selective leaching or dezincification, denickelification, etc. designating the element removed.

Corrosion Fatigue: The initiation and extension of cracks by the combined action of an alternating stress and a corrosive environment often eliminates the fatigue limit of a ferrus alloy creating a finite life regardless of stress level.

Galvanic Corrosion: Accelerated corrosion of the least noble metal when coupled to one or more other metals. The more noble metals are protected from corrosion by this action.

Erosion Corrosion: Many forms of flow-assisted corrosion are often included in this term such as cavitation, impingement, and corrosion erosion. All of these types of attack are the result of accelerated corrosion due to flow of solids, liquids, and gases.

Stress Corrosion Cracking: The initiation and propagation of cracks by the combined action of a corrosive environment and a tensile stress. Generally, susceptibility to cracking increases with increasing temperature. Not every alloy cracks in every environment, however, the list of environment/alloy combinations produce stress corrosion cracking is continually increasing.

Hydrogen Damage: There are numerous forms of damage associated with hydrogen, which are contained under the collective term "hydrogen damage." For hydrogen embrittlement and hydrogen stress cracking, a tensile stress and hydrogen atoms are necessary to cause failure. However, contrary to stress corrosion cracking, susceptibility is greatest near room temperature. Other terms and forms are: hydrogen induced cracking, blistering, sulfide stress cracking, hydrogen stress corrosion cracking, hydrating, and hydrogen attack (Craig, 1990).

2.2 Corrosion in Concrete

2.2.1 Problem in US

The Strategic Highway Research Program (SHRP) recently estimated that the cost of damage to America's bridges due to corrosion currently stands at approximately $20 billion and is increasing at a rate of $500 million per year. SHRP also concluded that the structural deterioration found in these bridges is primarily the result of chloride-induced corrosion. There are approximately 600,000 highway structures in the US Federal System, approximately 2/3rd of which are in States that use de-icing salts during winter months and therefore are directly exposed to chloride salts on a regular basis. Of these, 200,000 have been rated as structurally deficient or functionally obsolete. Furthermore, over ¼th of all bridges (150,000) are over 50 years old. 50 years is the average design life of a bridge.

Corrosion instigated by ingress of chlorides has historically been a difficult phenomenon to deal with. Several solutions have been proposed over the years falling generally into two broad categories. The first solution is to physically remove and replace the contaminated concrete and then use barrier techniques, coatings, impregnation etc. to stop chlorides re-entering the concrete. The second repair option, cathodic protection (CP) is an electrochemical technique designed to overcome the tendency for steel to corrode in chloride-contaminated concrete. Both these solutions have had successes and failures and have been improved upon over the course of time.

ECE is another electrochemical treatment, which offers a third alternative repair method to the bridge engineer for addressing chloride induced corrosion damage to highway structures. It is anticipated that by employing ECE techniques, the service life of approximately 1,000 bridges per year may be extended. These structures would otherwise need to be replaced or repaired conventionally, incurring additional budget resources over their lifetime (Electrochemical Chloride Extraction Expert Task Group, 1999; FHWA-SHRP Showcase, 1996).

2.2.2 Description

In the past three decades, corrosion of steel in concrete has become a considerable durability problem in mild as well as in severe climatic conditions. Whereas in the past, concrete design issues were mainly the performance of the concrete itself, e.g. resistance of concrete to sulphate attack (typically in marine structures), at present, a common issue is the durability problem or the corrosion of steel in concrete. The increased incidence of durability problems involving steel corrosion in reinforced concrete structures is the result of several changes in the environmental conditions in which concrete is being increasingly used (Bentur et al., 1997).

It is now generally recognized that reinforced concrete structures exposed to chlorides, typically either from deicing salts in the case of Northern climates or sea water for marine structures (or both), experience corrosion induced deterioration and abbreviated service life compared to situations where chloride is absent. Thus, while embedded steel in concrete is normally passive and corrosion rate accordingly low, accumulation of chlorides at the steel depth in a critical amount compromises the protective film and, in the conjoint presence of moisture and oxygen, induces active corrosion. The resultant solid corrosion products accumulate in the concrete pore structure at the steel-concrete interface and induce tensile stresses in the concrete. Because concrete is relatively weak in tension, cracking and spalling ultimately flow. Depending upon the type of structure and its service function, the reduced concrete section or continued reinforcing steel corrosion, or both, eventually compromise load bearing capacity to the point where limit state (end of useful life) is reached (Hartt et al., 1998).

While the alkaline nature of the cement paste in concrete (pH = 12.0 to 13.0) facilitates formation and maintenance of a protective, passive film and low corrosion rate, carbonation or chloride intrusion can compromise this situation. In the presence of moisture and oxygen at cathodic sites, chloride intrusion cause corrosion rate to become unacceptably high. Passivity refers to the loss of chemical reactivity experienced by certain metals and alloys under particular environmental conditions. That is, certain metals and alloys become essentially inert and act as if they were noble metals like gold and platinum. Many common engineering and structural materials such as iron, nickel, chromium, titanium and alloys containing these metals, display this behavior. The passive film on a metal can be disrupted or prevented from forming by many agents, particularly halides. Thus the presence of chloride ions is known to destroy the passive film on iron and lead to accelerated corrosion in the presence of oxygen. Reduction of pH also leads to the breakdown of passivity on iron (FHWA-SHRP Showcase, 1996).

2.3 Electrochemical Methods

Corrosion deteriorates concrete bridges and structures by oxidizing the embedded steel reinforcing bars (rebars). The steel corrosion produces larger volume iron oxides and hydroxides, which cause expansion and cracking of the concrete overlay, which in turn lowers the strength of the concrete. Corrosion of the rebars may be stopped or reduced by using either cathodic protection (CP) or electrochemical chloride extraction (ECE). Both CP and ECE are similar in that a negative voltage is applied to the steel rebars. For this "polarization" to be effective, the steel rebars must all be in electrical contact (have electrical continuity). The negative potential (voltage) is applied to the rebars with a DC power supply, and an anode is attached on the surface of the concrete for the positive potential (as illustrated in Figure 2.1). If the anode is zinc, then the power supply may or may not be used since the zinc anode alone can provide some galvanic protection.

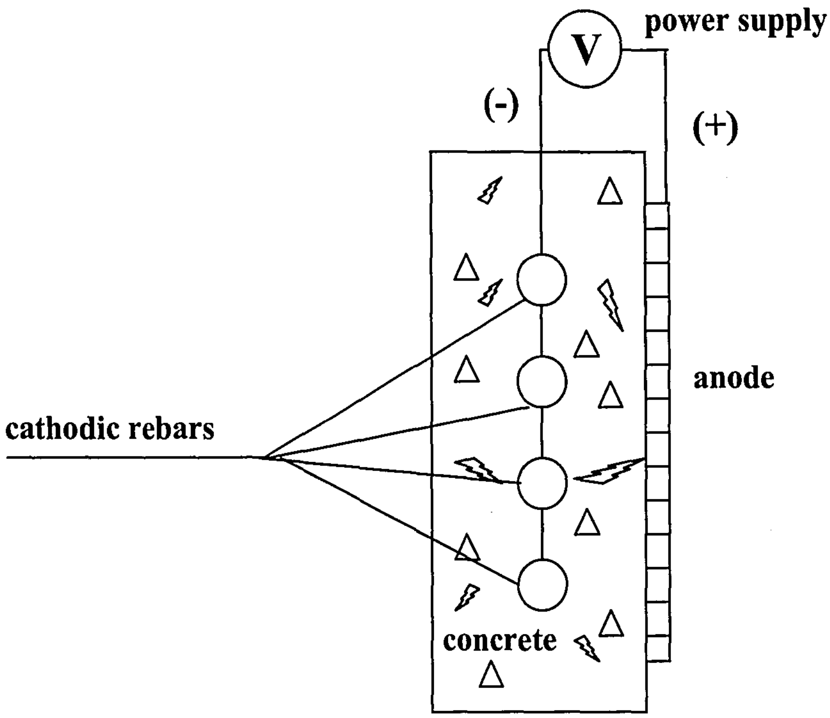

FIG. 2.1. In cathodic protection (CP) or electrochloride remediation (ECE), a negative voltage is applied to the steel rebars embedded in the concrete, and a positive voltage is applied to an anode at the surface. Electrical or ionic contact between the anode and the concrete must be maintained.

The three main benefits of this applied negative voltage are: a) there is a reduction of the rate of iron oxidation by reversing the electron flow, b) the formation of an alkaline atmosphere around the steel provides protective conditions, c) the negative voltage at the steel rebars causes electrostatic repulsion of chloride anions (electromigration). These benefits each are described in greater detail below:

a) Reduction of the rate of iron oxidation by reversing the electron flow:

The corrosion of iron is an electrochemical process. Each iron atom must loose two or three electrons in order for the iron atom to become oxidized. If a negative voltage is applied to the iron, then the electrons are forced back onto the iron, and the corrosion of iron is slowed or reversed. The chemical reactions are shown in Equations (2.1), (2.2), and (2.3).

Before applying negative potential: $Fe \rightarrow Fe^{+2} + 2e^-$ (2.1)

After applying negative potential: $Fe \leftrightarrow Fe^{+2} + 2e^-$ (2.2)

Applying a large negative potential: $Fe \leftarrow Fe^{+2} + 2e^-$ (2.3)

Although the electroplating of iron [shown in equation (2.3)] is not actually occurring in concrete, the applied negative voltage does stop or slow the corrosion.

b) The formation of a protective alkaline atmosphere around the steel:

Concrete is naturally alkaline with pH=12-13 (FHWA-SHRP Showcase, 1996). However, this alkalinity may be reduced by acid rainfall (sulfuric acid) or the carbonation (carbonic acid) (Broomfield, 2000). Any acidification of the concrete weakens it by dissolution, but an applied negative voltage can reverse this effect. The applied negative voltage forces excess electrons to the cathodic steel rebars. These electrons react with water to form hydroxyl anions. If oxygen is present, the water and oxygen are consumed to form the hydroxyl (OH^-), as shown in Equation (2.4). If no oxygen is available, then the water is broken into hydrogen and hydroxyls, as shown in Equation (2.5).

If oxygen is present: $H_2O + \frac{1}{2} O_2 + 2e^- \rightarrow 2\ OH^-$ (2.4)

If no oxygen is present: $H_2O + e^- \rightarrow OH^- + \frac{1}{2} H_2$ (2.5)

The presence of hydroxyl anions creates an alkaline atmosphere with a high pH. This alkaline atmosphere protects the steel from corroding because the oxides and hydroxides of iron are stable at high pH, and are insoluble (Figure 2.2). This region of stability (passivation) is illustrated in the Pourbaix diagram in Figure 2.3. The concrete environment exists around pH=13, between the two dashed lines, a and b, which show the limits for the stability of water.

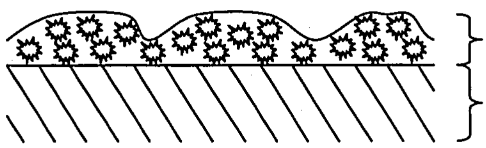

FIG. 2.2 At high pH (alkaline conditions) iron is naturally passive, with a stable oxide or hydroxide film forming over the surface.

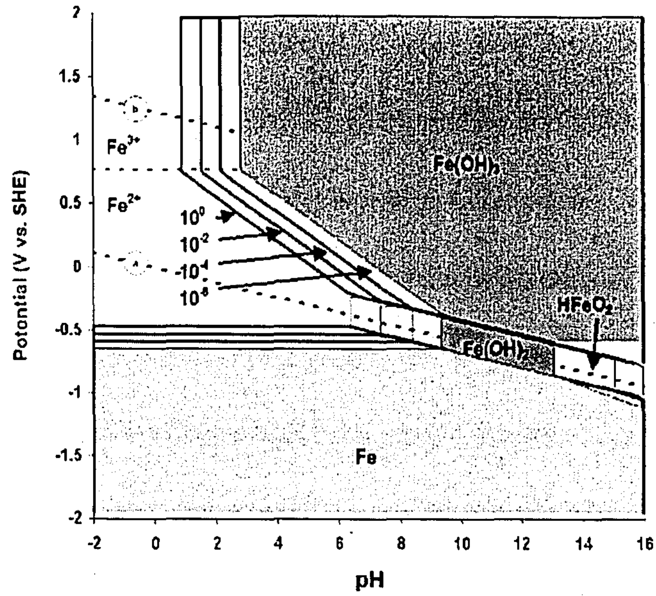

FIG. 2.3 The Porbaix diagram for iron-water equilibrium illustrates that at high pH (alkaline conditions) iron has a larger passive region (Pourbaix, 1974). The dashed lines show the limits for the stability of water.

Note that this increased alkalinity of the concrete would be detrimental if the concrete were already deteriorating due to alkali-silica reaction (ASR). In ASR, a poor choice of aggregate results in a reaction of silica with the alkaline solution in the concrete, and the formation of an alkali-silica gel. The alkali-silica gel absorbs moisture and swells and cracks the overlying concrete (FHWA-SHRP, 1996).

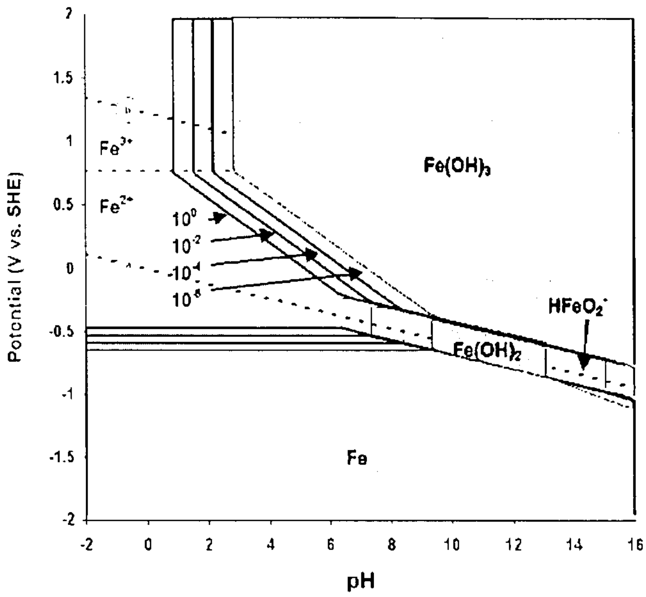

FIG. 2.3 The Porbaix diagram for iron-water equilibrium illustrates that at high pH (alkaline conditions) iron has a larger passive region (Pourbaix, 1974). The dashed lines show the limits for the stability of water.

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c) The electrostatic repulsion of chloride anions:

The third effect of the negative applied voltage on the steel rebars is the repulsion of the negatively charged chloride anions. This phenomenon is also termed electromigration. The chloride ions are detrimental since they accelerate corrosion by destabilizing the iron passivation layers. Repulsion of these chloride ions will reduce the corrosion rates. The American Concrete Institute (ACI) recommends 0.20% Cl^- by weight of concrete as the upper limit for chloride in concrete before chloride-induced corrosion becomes significant. Many highway agencies use a chloride content of 1.2 lb/yd^3 (0.7 kg/m^3) of concrete as the corrosion threshold limit (SHRP-S-347, 1993).

2.3.1 Types of Electrochemical Methods and Their Requirements

Cathodic protection (CP) and electrochemical chloride extraction (ECE) are similar processes, but the main difference between CP and ECE is the magnitude of the applied potential and the time duration of treatment: CP is a low current at a low voltage, continued for the lifetime of the structure, while ECE uses much higher currents and voltages, lasting for several weeks. Another difference is that CP uses a permanent or semi-permanent anode, while ECE uses a disposable steel mesh anode. Both CP an ECE require electrical connectivity of the steel rebars. Generally wire-wrapped bare steel rebars show electrical continuity. At broken sections, drilling and locating the rebars, checking for electrical continuity, and welding electrical connectors in locations where the electrical continuity is lost, may repair the electrical conductivity. Oregon DOT has written specification SP00532 (10-24-96), which describes the procedure for establishing, rebar continuity.

Epoxy coated rebars however show little if any electrical continuity because of electrical isolation by the epoxy layer. Because of the difficulty in restoring electrical continuity, CP would normally not be recommended for epoxy coated rebars. ECE would not be recommended for epoxy coated rebars because in addition to the electrical continuity problem, the high voltages could cause cathodic disbondment of the epoxy coating from the rebars.

For both CP and ECE, cracks or spalling of the concrete must be repaired before applying CP or ECE. Where rebars are exposed and new concrete is placed around them, the fresh concrete is more passivating to steel rebars than the older chloride-contaminated concrete. This difference in chloride content can cause galvanic corrosion of the older sections of the concrete. To minimize this effect, salt is sometimes added to the new concrete to make it as corrosive as the old (Covino et al, Dec. 1999). This may be a self-destructive solution, and instead it is recommended that small zinc anodes (e.g. Norcure's Galvashield XP) be attached to the rebars, prior to their encapsulation in new concrete. These anodes will prevent galvanic corrosion of the rebar, and are a better solution than adding corrosive salt to the new concrete.

A thermally sprayed aluminum alloy may be locally applied as a galvanic coating for cathodic protection of reinforcing steel in the area surrounding a concrete spall. The alloy consists of aluminum-zinc-indium (Al-20Zn-0.2In) wire. The coating was developed under a FHWA research program and is used to provide galvanic cathodic protection to reinforcing steel in salt-contaminated concrete bridge substructure. The coating may be applied to the soffit of bridge decks and/or bridge piers. Lose concrete is removed from the structure surface. The reinforcing steel and concrete surrounding the spall is cleaned with abrasive blasting. The wire alloy is then sprayed over the exposed rebar and surrounding concrete using arc spray equipment. The coating is typically applied to reach a nominal thickness of 12 mils (300 microns). Connection is made to the anode by spraying directly over the reinforcing steel. Galvanic cathodic protection uses a more reactive metal (anode) such as Al-Zn-In to create current flow. The estimated life of the Al-Zn-In anode is 10-15 years, after which it can be reapplied. The coating has a gray/silver color appearance, similar to concrete (Private Communication, Corrpro Co. Inc.).

2.3.2 Cathodic Protection (CP)

The cathodic protection concept is based on the capability of an applied current discharged by an anode to polarize the metal to be protected. The current flow forced from the externally placed anode polarizes the metal in the negative direction thereby reducing the rate of the oxidation reaction to a negligible value.

Cathodic protection controls the corrosion of steel in concrete by applying an external source of direct current to the reinforcing steel through the concrete. It provides an external energy to the steel surface to inhibit the development and progression of corrosion. Since corrosion is an electrochemical reaction by nature, by controlling the flow of the current, corrosion can be controlled.

There are two types of cathodic protection systems, a) impressed current systems, and b) galvanic anode systems. The impressed current system utilizes an external power source to provide the current discharged by the external anode onto the cathodically protected metal. The galvanic system utilizes a metal higher in electro-potential in relation to the metal being protected to produce the protective current (Hartt, 1998).

Cathodic protection of the steel rebars requires first that the steel rebars be in electrical contact (the cathode), second, an external anode must be in contact with the cement, and third a direct current power supply to drive the impressed current between the cathodic rebars and the anode. The power supply may be eliminated if a sprayed metal anode supplies the current by galvanic action. Many of the issues surrounding cathodic protection have been described in SHRP-S-337 (1993), "Cathodic Protection of Reinforced Concrete Bridge Elements: A State-of-the-Art Report", and also in FHWA-SHRP Showcase Report (1996). The two main categories for CP are for bridge decks, and for the bridge substructure. There are three main CP systems available for bridge decks.

1. Non-overlay slotted (impressed current)
2. Non-conductive overlay (impressed current)
3. Conductive overlay (impressed current)

These systems require rerouting of traffic, and reconstruction of the bridge deck. Details may be found in FHWA-SHRP (1996).

There are three systems available for the bridge substructures:

1. Surface applied (impressed current or galvanic)
2. Encapsulated (impressed current)
3. Non-encapsulated (impressed current or galvanic)

Again, details about these systems for the bridge substructure may be found in FHWA-SHRP (1996).

The very promising CP technique, which has been generating interest in recent years is the thermal spray-zinc anode (also known as arc-spray zinc), which has helped cut the cost of rehabilitating and protecting bridges according to Covino et al (1999). The thermally spray-zinc technique may be used either beneath the bridge decks (it is not durable enough for the bearing surface) or on the substructure. Since the anodes are not applied to the bearing surface, it would be feasible for traffic to use the bridge deck during the CP installation on the underside.

The thermally spray-zinc anodes may be used either with or without a power supply. The potential drop between the corroding zinc and the corroding steel is about half a volt. However, if the concrete resistance is very high, there will be very little current flow. If more protecting current is needed, an impressed current may be applied. The impressed current will lead to an increased consumption of the zinc anode and greater protection of the steel rebars. An increased current may also be accomplished by decreasing the concrete resistance by brush-applying a humectant onto the thermally spray-zinc anode to promote the retention of water at the zinc interface. Lithium bromide has shown the best performance for galvanic thermally spray-zinc CP, while lithium nitrate showed the best performance for impressed current thermally spray-zinc CP (Covino, 1999).

Lately, another thermally spray CP has been introduced by using titanium, which is known as an expensive material. A service life of 40 years has been estimated for the Ti anodes, versus 20 years for the Zn anode (Covino et al, 1999).

2.3.3 Electrochemical Chloride Extraction (ECE)

Initial research and development on Electrochemical Chloride Extraction (ECE) was completed in the US in the early 1970's. ECE was first commercially practiced in Europe in 1987 although it benefited from a parallel development in North America starting only a couple of years later. Rather than address the symptoms of chloride-induced corrosion, i.e., the spalls, cracks, and delaminations by conventional methods, a technique was devised that would remove the problem by extracting the offending chloride ions from the concrete matrix. The concept is based upon the forces experienced by negatively charged chloride ions within an electric field. When an externally applied current generates an electric field through a piece of reinforced concrete, the chloride ions migrate in accordance with the arrangement of the electrodes. By placing the positively charged electrode, the electrode to which the chloride ions will be attracted, on the outside of a structure one can transport the chlorides out of the concrete. At the same time, as the chloride ions are moving out of the concrete a concentration of negatively charged hydroxyl ions is being established at the reinforcing bar interface. This initiates the generation of a very passive oxide layer on the steel surface, which is additional protection generated by the process (Electrochemical Chloride Extraction Expert Task Group, 1999).

The ECE technology has been promoted to North America by Vector Corrosion Technologies, using the Norcure Chloride Removal System. For horizontal flat bridge decks, a titanium mesh anode was sandwiched between layers of felt and is spread across the deck. The felt and the bridge deck were immersed beneath 1-2 cm of water, and the voltage was applied between the titanium anode and the steel bar cathode. For vertical bridge piers, a steel mesh is applied to the surface of the concrete, to electrically connect the anode to the concrete (Manning and Pianca, 1993). A power supply applies high voltages (~40 V) and high currents for 4-8 weeks. The chlorides migrate away from the rebars, and into a wood pulp mat over the anode. The surface must be kept damp by spraying daily with water during the several week of the process. The current decreases as the concrete resistance increases. After 4-8 weeks, the wood pulp and the steel mesh are removed and discarded. The chloride anions are forced away from the steel rebars during this process, but is uncertain how long until they migrate back in sufficient concentration to cause corrosion. On the La Salle River Bridge (Starbuck, Manitoba/CDN) remediated in fall 1998, Vector estimated a 22 year service life extension.

The criteria for candidate structures have been identified by SHRP-S-347 (1993). The highlights of the criteria are the following:

- Chloride-induced corrosion
- No prestressed steel
- No alkali-reactive aggregate
- Minimum concrete damage
- No coatings or non-conductive overlays
- Minimum steel exposed at the surface
- Minimum conflict with flow of traffic
- Availability of AC power
- Good electrical continuity of steel
- Acceptable concrete resistance
- Simple geometry (e.g. large flat surfaces)

SHRP-S-347 estimates that the chloride removal has an effective lifetime of 5 to 10 years, and recommends that another technique be used if longer life is needed. Clemena in Road Savers (1996) estimates that "the beneficial effect may last for 12 to 15 years or even more."

2.4 Cost of CP and ECE

The table below is from the data recently compiled by Clemena (2000) from CP and ECE projects completed across North America. Table 2.1 illustrates the variability in costs for the different CP options and ECE. Clemena (Clemena, 2000) reports that after weighing the costs and the service lives for piers and abutments (substructures), the use of thermal spray zinc or titanium with impressed current produces the optimum solution.

TABLE 2.1. Information From Known Applications of Corrosion Control Methods for Concrete Bridges (Clemena, 2000)

Corrosion Control Option	Bridge Component	Anode	Amount of Area Involved (m^2)	Unit Cost ($\$/m^2$)	Unit Cost ($\$/ft^2$)	Projected Life (yr)
Impressed Current CP	Decks	Catalyzed Ti Mesh	740-38,500	57-97	5.3-9.0	60-90
	Piers/Abutments	Conductive Paints	1,040-7,700	82-151	7.6-14.0	12-15
		Thermal Sprayed Zn Coating	19-18,200	86-108	8.0-10.0	Up-27
		Thermal Sprayed Ti Coating	66-280	105	9.8	20-40
Galvanic CP	Piers/Abutments	Thermal Sprayed Zn Coating	480-981	86-108	8.0-10.0	< 10[a]
		Thermal Sprayed Al-Zn-In Coating	42-4,180	118-160	11.0-15.0	10-15[a]
		Zn/Hydrogel	24-8,750	26-171	2.4-15.9	10-12[b]
ECE Treatment	Decks	Catalyzed Ti Mesh	720-1,560	128-135	11.9-12.5	> 10
	Piers/Abutments	Steel/Catalyzed Ti Mesh	89-488	86-321	8.0-29.8	> 10

[a] At 12 mil. [b] At 10 mil.

2.5 Selection of the Right Treatment

After deciding on an electrochemical treatment, the question of selection of the most conducive treatment arises. If CP is selected then what would be the type of CP, or if ECE is selected then which anode and electrolyte should be used?

There are several factors that may effect these decisions. First, the properties of the bridge structure carry a lot of importance that has to be considered. Then the possible treatment types should be analyzed to determine whether they are applicable for this unique treatment. Every treatment is considered to be a unique application because of the unique properties of a given structure.

Following are some of the bridge properties that need to be factored into the analysis:

- Location (climatic condition) of the structure
- Overall condition of the structure
- Condition in terms of corrosion
- Materials (concrete type, reinforcement type, etc.) that has been used in the structure
- Access to the structure
- Traffic density on the structure
- Importance of the structure
- Age of the structure

Note that, this is not an exhaustive list and may be longer since every structure has its own special environment.

Compatibility analysis is the second main part in the issue of selecting the right treatment. Limitations of the electrochemical treatment methods effect the selection at advanced levels of the decision process. Some of these limitations are:

- Prestressed members
- Epoxy coated rebars
- Alkali-reactive aggregates
- High resistivity concrete patches (>10% of surface area)
- Epoxy injection in horizontal cracks
- Penetrating sealers
- Poor electrical continuity of the rebars

In addition to the list above, following should be added to the limitations for an ECE application:

- Low chloride level
- Lack of power source
- Pre-tensioned or post-tensioned members
- Unusual shaped members
- Presence of cracks

- Polymer impregnated concrete

After the consideration of the treatment limitations and structural properties, some tests must be done to confirm the preliminary assessment. The tests can be identified as (SHRP-Workshop: Assessment of the Physical Condition of Concrete Bridge Components):

Required tests:

- Visual survey (spalls & others)
- Delamination detection
- Bar cover survey
- Chloride content (surface and bar levels)

Supportive/corrective tests:

- Half-Cell corrosion detection
- Rate of Corrosion measurement

Conditional tests:

- Permeability (AASHTO T277), when: w/c ratio not known
- Resistivity (AASHTO T277), when: deterioration not started yet

2.6 Similar Studies

The FHWA demonstrated a handbook and a software, CORRODE, for the "SHRP Life-Cycle Cost Methodology for Treatment of Concrete Bridge Components". The handbook version is presented first through worked examples using the life cycle cost worksheet and nomograms to facilitate hand calculations. This helps the engineers to become familiar with the logic of the methodology.

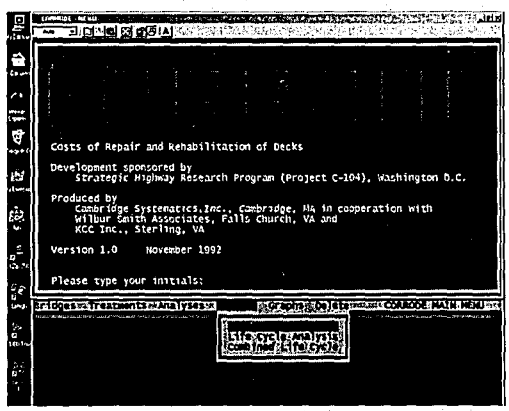

FIG. 2.4 The "Corrode" software.

Subsequently, the CORRODE software and its input and output features are demonstrated. The software was developed in early 90's and some of its features are considered outdated. Development of an enhanced version of the software, capable of duplicating all of the features of the handbook, such as worksheets and charts, is strongly recommended (Babei et al., 1996).

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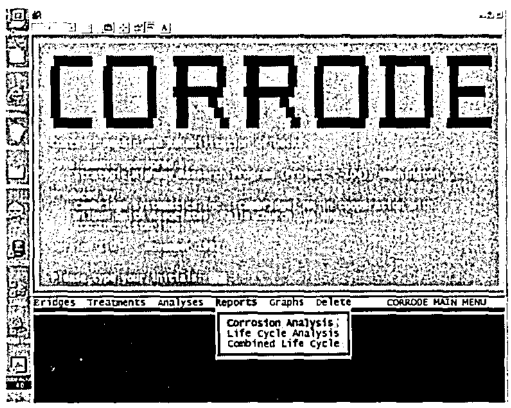

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LEO is a computer-assisted decision software based on a deterioration model, which takes into account carbonation and chloride induced corrosion (Petre-Lazar et al., 1998). It evaluates the in-time degradation and its effect on the engineering functions of the reinforced concrete structural elements. The predictions help the site inspector to diminish the maintenance costs through better planning and repair policy.

The error of the short-term predictions could be as low as 15 %, but is very sensitive to the quality of the input data. A probabilistic analysis should be performed in order to take in account the natural variability of the environment and material parameters (Petre-Lazar et al., 1998).

CHAPTER III: Methodology

3.1 Introduction

In this chapter, AFACE (Automated Feasibility Analysis of Cathodic Protection or Electrochloride Extraction for Reinforced Concrete Bridge Structures in Pennsylvania) procedure is discussed, including all of the tools used to construct it.

Besides many satisfactory applications of electrochemical methods, there always have been many others that were not successful. In most cases this was because of inadequate evaluation and choice of the method and its installation. The process developed here makes use of the available internet capabilities and databases, thus providing a useful tool for the engineers to make quick and educated decisions about electrochemical rehabilitation options.

3.2. Tools Used in Developing AFACE

3.2.1 BMS (Bridge Management System)

BMS is a management tool, which enables a systematic determination of the present and future needs for maintenance, rehabilitation and replacement of bridges in Pennsylvania. The system uses various scenarios, along with a prioritization, which provides guidance in the effective use of designated funds. The basic parts of the BMS are shown in Fig. 3.1.

*SIRS: Structure Inventory Records System

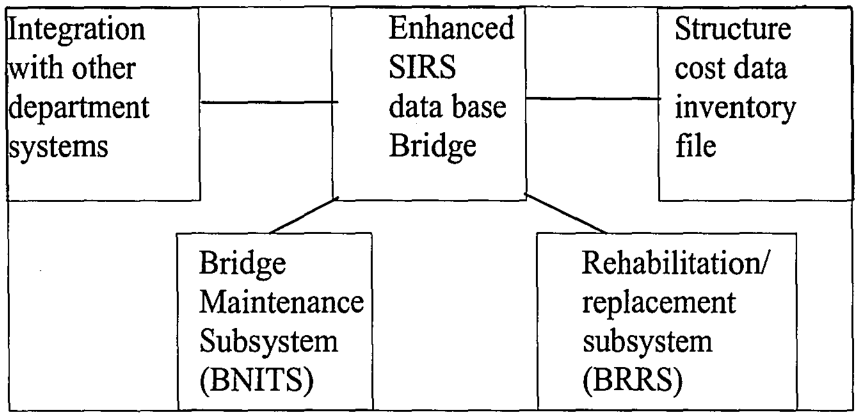


FIG. 3.1. Diagram of the basic parts of a BMS

Maintenance and rehabilitation/replacement subsystems are the important components where the decisions for maintenance and rehabilitation are made. There is a specific prioritization method, which includes deficiency point assignment and bridge importance factor assignment tools. These tools have been used in AFACE to establish compatibility with BMS of the Pennsylvania Department of Transportation's (PennDOT).

Tables 3.1, 3.2, and 3.3 summarize the contents of the prioritization tools used in BMS. A tabular representation of the development of the total deficiency rating for bridges is presented in Table 3.3. The deficiency points assigned in this table are combined to yield a Total Deficiency Rating (TDR).

TABLE 3.1. List of Deficiencies

Deficiency Category	**Description**	**Deficiency Category**	**Description**
LCD	Load capacity	BCD	Bridge condition
WD	Clear deck width	SPD	Condition for the superstructure
VCOD	Over clearance	SBD	Condition for the substructure
VCUD	Under clearance	BDD	Condition for the deck
RLD	Remaining life	WAD	Adequacy of the waterway
AAD	Approach roadway alignment		

TABLE 3.2. Functional classification factors

Functional classification	ϕ
Interstate	1.00
Arterial	0.95
Collector	0.85
Local	0.75

TABLE 3.3. Development of TDR for bridges

Deficiency Category	Maximum Deficiency Points	*Listing Conditions in Category*		
		(1), (2)	*(3)*	*(4)*
LCD	70	70	$\Sigma \leq 80$	$\Sigma\, \chi\phi \leq 100$
BDD	50	$\Sigma \leq 50$		
SPD	50			
SBD	50			
WD	15	15	15	
VCOD	15	15	15	
RLD	5	5	5	
VCUD	10	$\Sigma \leq 15$	15	
WAD	10			
AAD	10	10	10	
Maximum Totals	285	180	140	100

The summation of deficiency points is represented by the simple equation:

TDR = ϕ [LCD + WD + VCOD + VCUD + BCD + RLD + AAD + WAD]

Where, **BCD = SPD + SBD + BDD**

The last step in the determination of TDR is to apply the factor ϕ, which is dependent upon the functional classification of the highway carried by the bridge. The values of ϕ are given in Table 3.2 (Mcclure and Hoffman, 1990).

3.2.2 Pontis

Pontis is another bridge management system, first version of which has been developed in 1992. It uses "what if" method for bridge inventory analysis. One of the plug-ins in Pontis that has been developed by Federal Highway Administration (FHWA) is the prediction of the condition of concrete bridge decks at network level, when historical data are not available.

In the development of Pontis, corrosion of the reinforcing steel was recognized as one of the main causes of deterioration of concrete bridge decks in the U.S. The condition of bridge decks is predicted by taking into account the severity of the corrosive environment, permeability of the concrete, and the concrete cover thickness. Accordingly, bridge decks are divided into groups with 3 levels of deicing salt exposure, 3 levels of specified water-cement ratio, and 3 levels of specified bar cover depth.

National Cooperative Highway Research Program (NCHRP) Report 2972 gives empirical relations between the cumulative number of salt applications, water-cement ratio of concrete, and the depth of cover at which the reinforcing steel will be subject to corrosion in bridge decks, i.e., "Corrosion Threshold Cover Depth." The Pontis empirical relations between "No. of Salt Applications", and "Corrosion Threshold Bar Cover Depth" for an assigned water-cement ratio is given below. These equations are applied to concrete bridge decks to find the Corrosion Threshold Cover Depth (CD) for any given bridge deck age.

Water-Cement Ratio	**N = No. of Salt Applications** **CD = Corrosion Threshold Bar Cover Depth, in.**
0.60	$CD = (N / 6.93)^{0.2804}$
0.53	$CD = (N / 10.80)^{0.2741}$
0.52	$CD = (N / 11.60)^{0.2729}$
0.51	$CD = (N / 12.47)^{0.2720}$
0.50	$CD = (N / 13.40)^{0.2711}$
0.49	$CD = (N / 16.29)^{0.2731}$
0.48	$CD = (N / 20.73)^{0.2789}$
0.47	$CD = (N / 25.49)^{0.2824}$
0.46	$CD = (N / 31.73)^{0.2861}$
0.45	$CD = (N / 39.47)^{0.2901}$
0.44	$CD = (N / 51.10)^{0.2979}$
0.43	$CD = (N / 64.99)^{0.3038}$
0.42	$CD = (N / 83.00)^{0.3097}$
0.40	$CD = (N / 141.85)^{0.3293}$

In Pontis, 5 condition states are defined for bridge decks based on concrete deterioration; State I being the best condition and State IV being the worst condition:

Deterioration (by percent of area)	Pontis Condition State
0	I
> 0, but ≤ 2	II
> 2, but ≤ 10	III
> 10, but ≤ 25	IV
> 25	V

Symptoms of bar corrosion, such as spalls and delaminations play a major role in defining the amount of deterioration and condition state of bridge decks in Pontis.

The distribution of a network of bridge decks among the five Pontis condition states was possible by assuming a normal distribution for bar cover standard deviation, for which the average was assumed 0.35 in. (9 mm) and variance (standard deviation) was taken 0.15 in. (4 mm).

This methodology was applied to bridge decks of age up to 50 years, and the results were aggregated to produce an "Age Versus Condition" table for the bridge deck category of interest. Such "Age Versus Condition" tables, however, are applicable to corroding areas of the deck, whereas Pontis classification of condition applies to all deteriorating areas of the deck (Babaei et al., 1996).

3.3. Overview of AFACE

AFACE is the "Automated Feasibility Analysis of Cathodic Protection or Electrochloride Extraction for Reinforced Concrete Bridge Structures in Pennsylvania." AFACE 1.0 is the first version of the web-based program, which enables the usage of the AFACE procedure throughout the internet. Hypertext Markup Language (HTML) and JavaScript have been used to develop AFACE 1.0. Unlike HTML, JavaScript is not tag based and does require learning a programming language with a unique syntax in the way that VBScript does. HTML is used to define the structure, and to some extent, the layout and design of a Web page. JavaScript is used to specify actions. As in most Web application environments, both HTML and JavaScript are used together in files that are processed by any server to generate complete Web pages to be displayed in the users' browsers.

AFACE is divided into two major parts:

A) Determination of the State of Reinforcement Corrosion in the Structure and the Candidacy of the Structure for Electrochemical Treatment

- *BMS* Phase
- *REGION* Phase

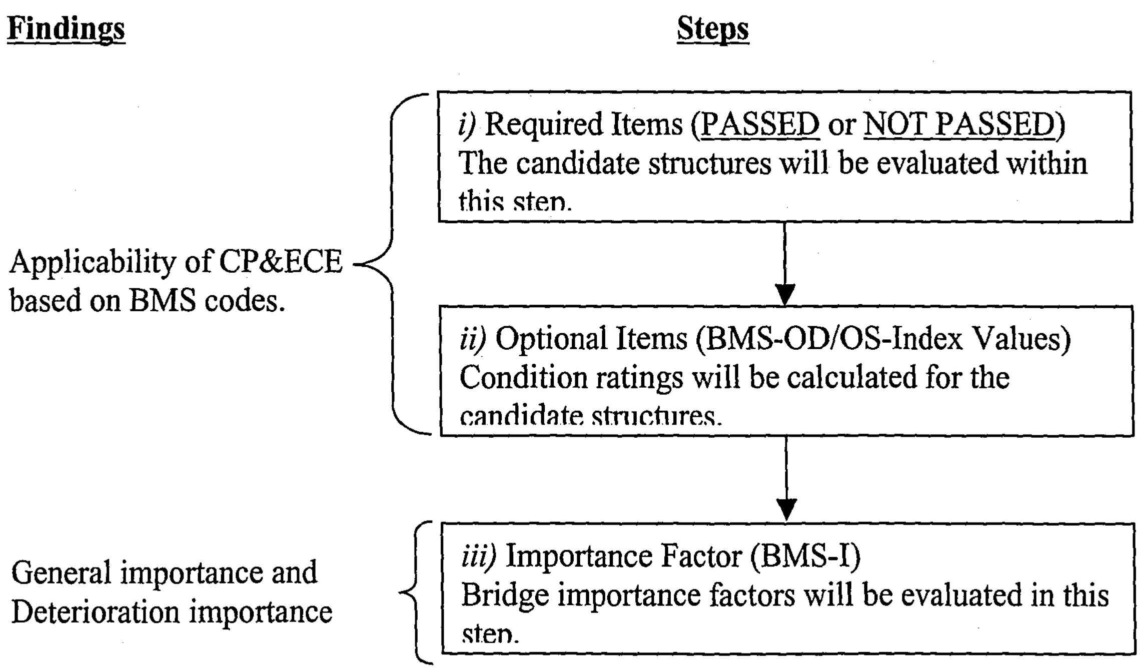
B) Selection of the Best Method Based on Compatibility of the Method with the Bridge Condition

- *Selection* Phase

In each phase there are questions asked to the user, answers to which form the decision path for the procedure. In the BMS phase, the answers to the questions may be collected from the bridge inventory data or they may be the best estimates made by the user. The required parameters are asked in the Region phase, and the evaluation criteria of CP and ECE are applied in the Selection phase.

3.3.1 BMS Phase

The purpose here is to identify the corroded concrete bridge structures and prioritize them depending on their condition ratings, and the importance of the structure. There are three steps in this phase:



The candidate structure will be expected to meet all the required conditions (Required items) that have been set. The evaluation questions are pulled out from the BMS menu and the answers are assigned points according to an evaluation criterion. For a given bridge, the checklist for required items are filled out according to the following guide (Table 3.4):

1. The assignments to a set of pre-selected BMS codes will be entered by the user.
2. Internally, each code will be awarded a "Yes" or "No" according to a set of evaluation criteria in the database.
3. Each group will be assigned "Yes" if at least one of the item answers is "Yes" in a group, and the evaluation will proceed to the next step, otherwise terminated.

Detailed information about the selected BMS codes and the associate evaluation criteria are given in the Appendix A.

TABLE 3.4. Checklist at the End of "Required Items" Step

Group	BMS Code	Description	User Response	Feasibility for ECE and CP	Proceed to the next step?
1	*A23	**Maintenance Code**	~Answer~	Yes / No	Yes / No
2	*C05	**Structure Type / FHWA**	~Answer~	Yes / No	
	*C09	**Bridge Deck Type**	~Answer~		
3	*E17	**Deck Condition Rating**	~Answer~	Yes / No	
	*E18	**Superstructure Condition Rating**	~Answer~		
	*E20	**Substructure Condition Rating**	~Answer~		
	*E21	**Channel & Channel Protection Condition Rating**	~Answer~		
	*E22	**Culvert Condition Rating**	~Answer~		
4	*E24	**Structural Condition Appraisal**	~Answer~	Yes /No	

In the next step where the optional items are evaluated, two very important index values are developed. These are, BMS-OD for deck and BMS-OS for substructure. These indices define part of the all compatibility of each structure's properties with CP and ECE. The checklist for optional items are filled out according to the following guide (Tables 3.5 and 3.6):

1. A set of BMS codes are entered and evaluated according to pre-selected criteria.
2. The answers are assigned a numeric value V_i (0 through 5), 0 being lowest priority and 5 highest. The values assigned for subcategories in each code group are added.
3. The sum of the assigned values constitutes the BMS-OD or BMS-OS index.

TABLE 3.5. Checklist for Deck at the End of "Optional Items" (BMS-OD) Step

Code	Name	Max Value (Vi)	Min Value (Vi)
*C05	**Structure Type / FHWA**	**5**	**4**
*C09	**Bridge Deck Type**	**5**	**0**
*C10	**Wearing Surface Type**	**5+5+5**	**4+4+0**
C21	**Type of Deck Reinforcement Bar Protection**	**5**	**0**
E23	**Estimated Remaining Service Life**	**5**	**0**
		Σ = 35	**Σ = 12**

TABLE 3.6. Checklist for substructure at the End of "BMS-OS" Step

Code	Name	Max Value (Vi)	Max Value (Vi)
*C05	**Structure Type / FHWA**	**5**	**4**
C39	**Pier Material and Configuration**	**5**	**4**
E23	**Estimated Remaining Service Life**	**5**	**0**
		Σ = 15	**Σ = 8**

The BMS phase also involves the determination of the "Maintenance deficiency points assignment", or later referred to as the "Importance Factor", BMS-I.

Table 3.7 lists the items evaluated for the development of the Importance Factor.

TABLE 3.7. Importance Factor by Extracting Maintenance Deficiency Points Assignment in BMS

Deficiency points	Component	Element	Deficiency point assignment
25	Bridge maintenance activity rank	Group AF	40
	(Note: AF =group A activity that is	A	25
	fatigue prone and controls the	B	20
	inventory rating)	C	15
		D	10
		E	5
25	Activity urgency factor	Code 0	25
		1	20
		2	15
		3	10
		4	5
		5	0
25	Bridge criticality		
	Part A: Interstate		5
	US numbered highway		4
	State highway		3
	County highway		2
	City, Borough St & Twp Rd		1
	Part B: PCN		5
	PCN/coal haul		5
	Agricultural access		3
	Industrial access		3
	Part C: ADT x detour length ≥ 30 000		15
	≥ 15 000 but < 30 000		10
	> 3 000 but < 15 000		5
	< 3 000		0
25	Bridge adequacy		
	Part A: Lowest condition rating < 3		15
	> 3 but < 4		10
	> 4 but < 5		5
	> 5		0
	Part B: Load capacity (inventory rating)		
	(H configuration) ≤ 12 t		10
	(H configuration) > 12 ≤ 20		7
	(M L 80 configuration) > 20 to ≤ 30		4
	(M L 80 configuration) > 30		0

In addition to the maintenance deficiency points, “functional classification factor” and “TDR, BDD, SBD” values have been pulled out from BMS (Tables 3.1, 3.2, 3.3).

Additionally, total deficiency, substructure deficiency and bridge deck deficiency ratings are also assigned as factors TDR, SBD’, and BDD’ respectively. These factors are used later in the *Selection Phase* of AFACE.

3.3.2 REGION Phase

The purpose here is to evaluate the bridges according to their corrosion condition. This phase has been added for primary corrosion condition assessment according to the following criteria:

1. Age of the bridge (function of i, ii and iii)
   - i) Year the bridge was built
   - ii) Reinforcement and/or deck protection
   - iii) Type and year of last major construction on the bridge
2. Severity of the environment (function of the frequency and quantity of deicing usage)
3. Water-cement ratio
4. Cover depth of the deck

More importantly, after defining the corrosion condition state of the bridge deck, the issue becomes assigning a suitable treatment method for that condition state. To do this, past successful applications are used as if they were the candidates in this evaluation phase. The range of the condition states of those bridges are defined as the required range of condition state parameters for either CP or ECE.

3.3.3 SELECTION Phase

The purpose here is to find the most appropriate electrochemical treatment for the bridge structure. The requirements for this phase are:

- *First*, the prospective bridge must have met all the conditions in the previous phases. (BMS and Region Phases)
- *Second*, the two main components –deck and the substructure- of a bridge are analyzed separately.
- *Third*, the replacement option is available but not compared with CP or ECE.

Figure 3.2 represents a brief flowchart of the selection phase:

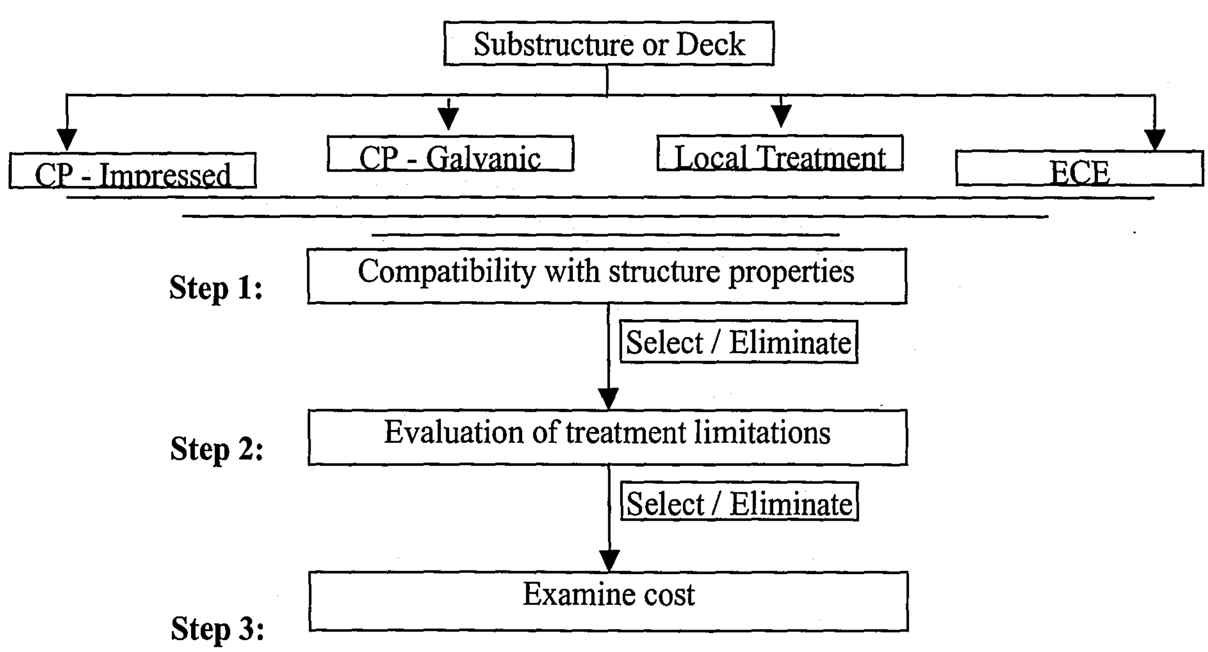


FIG. 3.2. Flowchart of the process in Selection Phase

To select a candidate treatment method and its associated components, first, the condition of the bridge has to be assessed. The limitations of a particular bridge and its environment should also be evaluated at the beginning of the decision process. The proposed evaluation procedure consists of three steps:

1. Assess the condition of bridge and its environment (BMS and Region information).
2. Compare the bridge requirements (step 1) with the requirements of the evaluated treatment methods (Table 3.8) and, proceed to a conclusion that rank the treatment methods.
3. Provide information about the approximate cost of each treatment method.

At this stage of work, the items in Table 3.8 are not exhausted. Additional bridge factors may be added for completeness in the next version of AFACE. For example, specific items, such as range of half-cell potential, salt contamination are also desired for the determination of the matching treatment components (i.e. anode type, magnitude of power).

TABLE 3.8. Comparison of System Requirements for Various Electrochemical Methods

BRIDGE FACTORS	TREATMENT REQUIREMENTS			
	Impressed Current CP	Galvanic CP	**ECE**	Local Treatment
External power source	Low consumption	Not needed	High consumption	Not needed
Concrete damage	Low	Low	Low	Any
Prestressed steel	Not Applicable	Applicable	Not Applicable	Applicable
Alkali reactive aggregates	Applicable	Applicable	Applicable	Applicable
Coatings or non-conductive overlays	Applicable	Applicable	Applicable	Applicable
Steel exposed at the surface	Low	Low	Very low	Any
Geometry of the component	Simple	Any	Very Simple	Any
Maintenance	High	Low	Low	Low
Monitoring	High	Low	Low	Medium

A simple example demonstrates the use of using the "selection" procedure. A bridge deck, suffering from severe corrosion attack needs to be treated. After the initial condition assessment it is concluded that the structure has the following properties:

- The structure is built with prestressed members
- Deck has been deteriorated %... (Low) by the surface area
- %... (Low) of exposed steel has been detected
- Maintenance and monitoring is possible based on pre-measured low traffic density
- Concrete resistivity is ... (Low)
- No signs of possible ASR has been observed

- External power will not be a problem
- No coatings were detected
- Electrical continuity is high

Based on these properties and the requirements given in Table 3.8, one of the methods was found to be suitable for the structure. The applicable method is the Impressed Current CP. The single eliminating reason in this particular case was the presence of prestressed steel. For a complete analysis, information from prior tiers of evaluation would be needed. These are:

- The Compatibility Factor ***(BMS-OD, BMS-OS)***
- The Importance Factor ***(BMS-I)***
- The Total Deficiency Rating ***(TDR)***
- Substructure/Deck Deficiency Rating ***(SBD', BDD')***
- Deck Condition-corrosion prediction- (Region Phase)
- Average Life of Treatment
- Treatment Time
- Recommendations based on past field applications

Following this evaluation, one can go further into the cost estimation of sub-components of each possible method. Now, selecting the right installation according to the severity of the bridge's condition should lead us to an approximate assignment of the final cost. To do this, detailed information about anodes and other components are needed.

CP systems can be divided into several components. These components consist of those parameters related to the selected CP system. As an example, the components and the percentage share of each component in the total cost of an "Impressed current CP with thermal spray zinc coating" was given by Holcomb and Cryer (1998) (Table 3.9).

TABLE 3.9. Approximate Cost Percentage Shares of Impressed Current CP (Holcomb and Cryer, 1998)

Component	*Percentage Share in the Total Cost of CP (%)*
• Quality control training and certification	0.4
• Reference cells and null probes	8.1
• Continuity	13.4
• Terminal plates	1.6
• Anode surface preparation	12.7
• Anode installation	50.6
• Electrical systems	13.2

Regarding the cost of CP for bridge decks, many of the installations are bid on a lump sum basis and therefore a cost breakdown by item is often not possible. However, unit cost information for a typical large titanium mesh / overlay system that was installed during 1997 – 1999 by Corrpro Co. Inc. is provided here as an example. The cost breakdown is listed in Table 3.10 (Private Communication, Corrpro Co. Inc.):

TABLE 3.10. Cost Breakdown of a Large Titanium Mesh / Overlay CP System that was Installed in 1997-1999 (Corrpro Companies Inc.)*

Item	Quantity	Unit	Unit Price	Cost	% Tot. Cost
Rectifier system	1	Lump sum	$205,504	$205,504	9.4%
Reference cells	226	Each	$226	$54,014	2.5%
Continuity bonds	70	Each	$76.26	$5,338	0.2%
Titanium anode mesh	414,718	Sq. ft.	$4.63	$1,920,144	87.9%

Total Cost:	$2,185,000
Avrg. Cost:	$5.26/sq. ft.

* Cost does not include corrosion-engineering services; concrete repair or concrete overlay installation.

Regarding the cost of CP for bridge substructure, Corrpro Companies Inc. again provided cost information for a thermally sprayed Al-Zn-In galvanic anode system on four bridge piers having a total surface area of 40,600 sq. ft. The cost breakdown is listed in Table 3.11:

TABLE 3.11. Cost Breakdown of a Thermally Sprayed Al-Zn-In Galvanic Anode CP System on Four Bridge Piers (Corrpro Companies Inc.)*

Item	**Quantity**	**Unit**	**Unit Price**	**Cost**	**% Tot. Cost**
Mobilization	1	Lump sum	$8,000	$8,000	1.7%
Surface preparation by abrasive blasting	40,600	Sq. ft.	$1.23	$49,938	10.5%
Install instrumentation for two test windows	2	Each	$4,000	$8,000	1.7%
Thermally sprayed galvanic coating	40,600	Sq. ft.	$9.11	$370,000	77.7%
Corrosion engineering (services/supervision)	1	Lump sum	$40,000	$40,000	8.4%

Total Cost:	$476,000
Avrg. Cost:	$11.72/sq. ft.

* Cost does not include access to the piers (scaffolding), enclosures or concrete repair.

Like CP, ECE system can also be divided into several components. ECE system components are often selected according to bridge and its environment properties. The Table 3.12 of ECE cost information for bridges treated during 1994-1999 as provided by the Vector Inc. (Private Communication, Vector Inc.) As observed, the cost was not itemized but rather reported as lump sum per application.

TABLE 3.12. ECE cost information between 1994 and 1999 (Vector Inc.)

Norcure™ North American References – Cost Breakdown of ECE Treatment							
Country	**Project**	**Year**	**Size**	**Member**	**Cost**	**Unit Cost**	**Comments**
CDN	Starbuck, MB; bridge deck	1997	2,905	Horizontal	$ 27,586	$ 9.50	Used traffic bearing system
USA	34th St. over I-395, Arlington, VA; bridge deck	1995	7,887	Horizontal	$ 69,220	$ 8.78	Reference cells also installed
CDN	St. Adolphe, MB; bridge deck	1998	11,997	Horizontal	$ 134,483	$ 11.21	
CDN	St. Adolphe, MB; bridge deck	1999	15,193	Horizontal	$ 134,483	$ 8.85	
USA	Stein Hwy, Seaford, DE; bridge deck	1997	16,678	Horizontal	$ 179,948	$ 10.79	ECE with lithium electrolyte – ASR
CDN	Hwy #16 & 11, Saskatchewan; bridge columns	1994	1,614	Vertical	$ 30,000	$ 18.59	
CDN	Hwy #6 & 11, Saskatchewan; bridge columns	1995	1,937	Vertical	$ 47,300	$ 24.42	
CDN	Winnipeg, MB; bridge substructure	1998	2,367	Vertical	$ 18,931	$ 8.00	
USA	Washington, DC; bridge substructure	1999	2,367	Vertical	$ 37,000	$ 15.63	
USA	I-394, Minneapolis, MN; bridge substructure	1997	2,421	Vertical	$ 67,610	$ 27.93	
CDN	QEW, Burlington, ON; bridge piers	1997	2,884	Vertical	$ 39,075	$ 13.55	
CDN	Hwy #1 & 6, Saskatchewan; bridge columns	1995	3,981	Vertical	$ 46,276	$ 11.62	
USA	Peoria, IL; bridge substructure	1998	4,971	Vertical	$ 115,620	$ 23.26	
USA	Council Bluffs, Iowa; bridge substructure	1998	4,982	Vertical	$ 148,650	$ 29.84	
USA	5th St. over I-64, Charlottesville, VA; pier bents	1995	5,251	Vertical	$ 55,840	$ 10.63	Price includes ref. cells & sealant
USA	Omaha, NE; bridge substructure	1999	15,064	Vertical	$ 306,325	$ 20.33	
USA	I-480, Omaha, NE; bridge substructure	1998	16,409	Vertical	$ 393,100	$ 23.96	
CDN	Burlington, ON; bridge substructure	1999	16,495	Vertical	$ 215,965	$ 13.09	

1) All costs quoted in USD, Canadian dollar amounts converted to USD using rate of 1.45

2) Prices don't include preliminary/related work such as patch repairs (unless otherwise noted)

CHAPTER IV: Results

4.1 Example Run

In this section, an example run will be executed and the process will be explained by the help of figures, which were obtained from the actual AFACE 1.0. Note that the answers of the example run will not be acquired from a real-life case. Instead, they will be hypothetical responses.

In the introduction pages of the procedure, the user is prepared to use AFACE 1.0. The necessary background information is given as the user clicks on the appropriate buttons. These introduction pages can be found in the Appendix F.

The steps of this example run is as follows:

a) Required Items (BMS Phase)
b) Optional Items (BMS Phase)
c) Importance Items (BMS Phase)
d) Region Phase
e) First Summary
f) Selection Phase

A) Required Items (BMS Phase):

The evaluation process begins with the "Phase-I BMS Required Items Step", as shown in Fig. 4.1. After the user reads the necessary instructions for this step one should easily begin answering the questions. At this stage, it would be convenient if the user has already pulled out the necessary information about the bridge from BMS inventory. There are nine questions to be answered within this step and the user can choose only one answer for each question. After the user makes a choice, he/she should continue with the next question by using the browser's scrollbar. The choices that have been made in this step for this example run are listed below on Table 4.1.

TABLE 4.1. User responses in the "Required Items Step" for the example run

Question	Response
Maintenance code	PennDOT has the maintenance responsibility
Structure type/FHWA	Concrete
Bridge deck type	Reinforced concrete
Deck condition rating	Fair
Superstructure condition rating	Satisfactory
Substructure condition rating	Satisfactory
Channel & channel protection condition rating	N/A
Culvert condition rating	N/A
Structural condition appraisal	Condition meeting minimum tolerable limits to be left in place as is

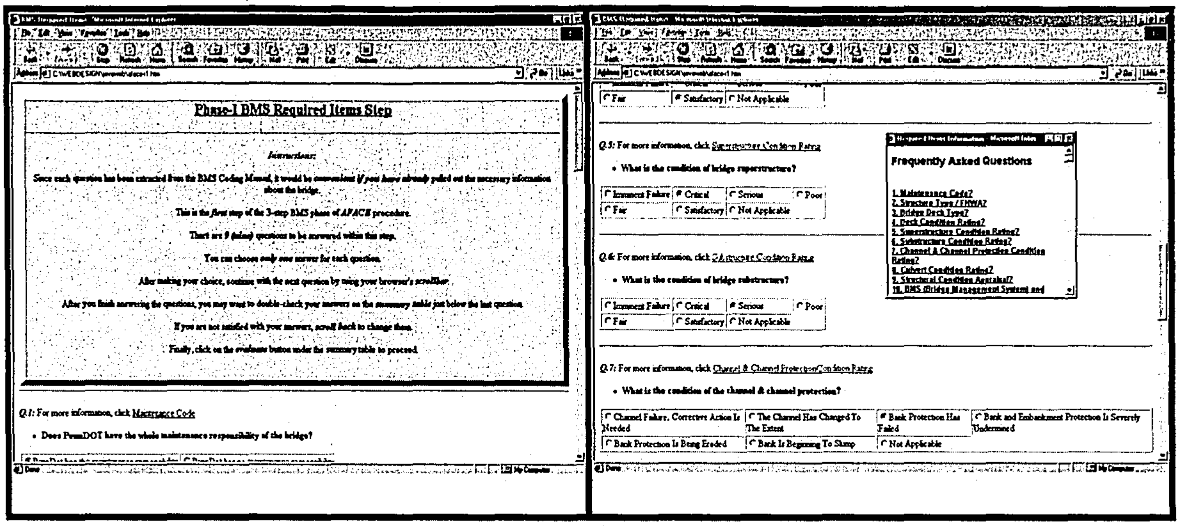


FIG. 4.1. Required Items Step (BMS Phase)

While answering the questions, user can easily access more information by clicking on the hyper linked phrases that have been placed behind each question. The action of clicking onto these phrases brings forth a help menu, which includes extended information about the current and several other related topics.

After the user finishes answering the questions, he/she may want to double-check his/her answers on the summary table just below the last question. This table is shown in Figure 4.2. If the user is not satisfied with his answers, he is able to scroll back to the question that he will be correcting and simply click on another answer.

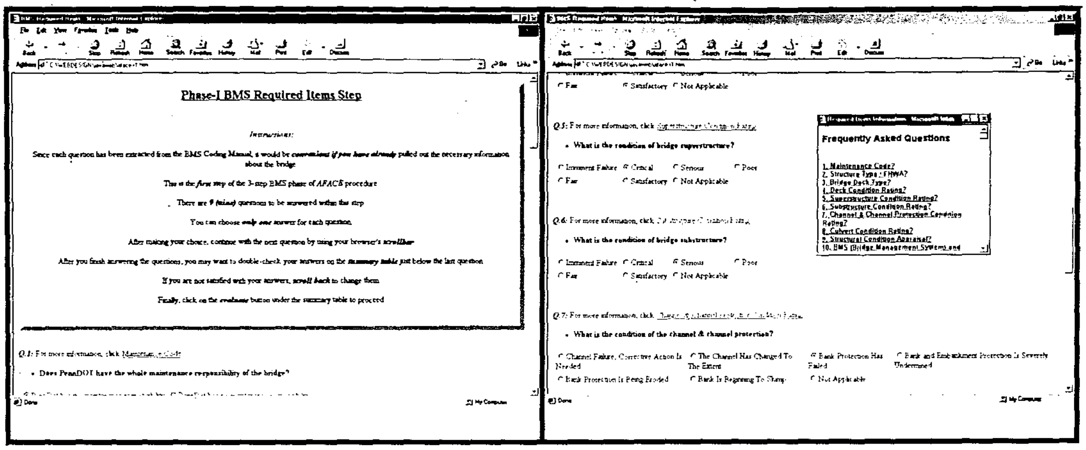


FIG. 4.1. Required Items Step (BMS Phase)

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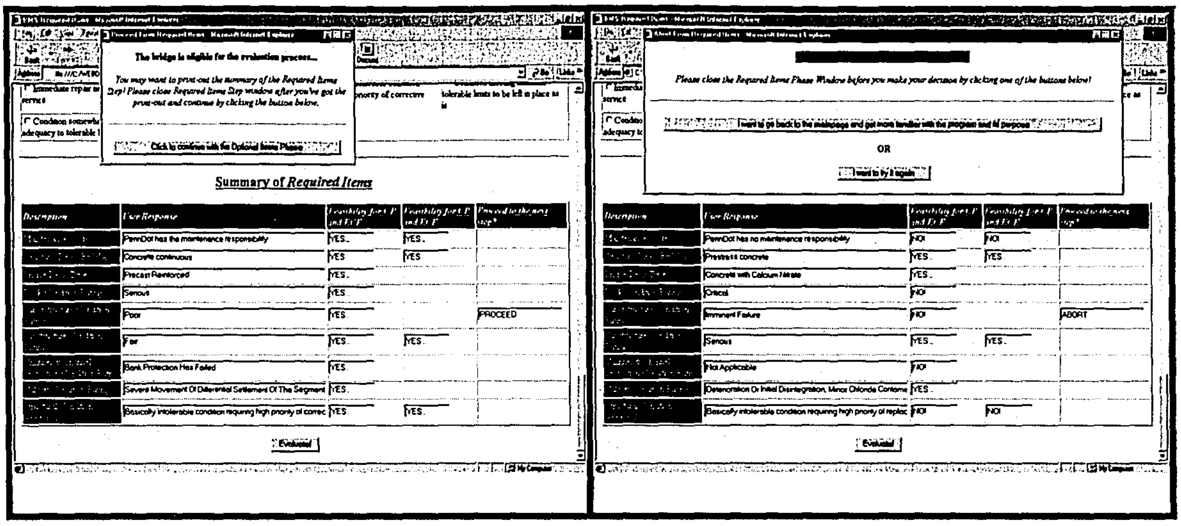

FIG. 4.2. Required Items Step (BMS Phase)

To finalize this first step of the 3-step BMS phase of AFACE procedure, the user should click on the "Evaluate" button, which is located under the summary table to proceed.

At this point, there are two events that might happen:

1) "ABORT" message appears on the summary table under the "Proceed to the next step?" column and a transition window pops up. "ABORT" message appears only when one of the answers under the "Feasibility" column is assigned a "No". The transition window prompts the user to either go back to front page or start AFACE again.

2) "PROCEED" message appears on the summary table under the "Proceed to the next step?" column and a transition window pops up. This window prompts the user to proceed to the next step.

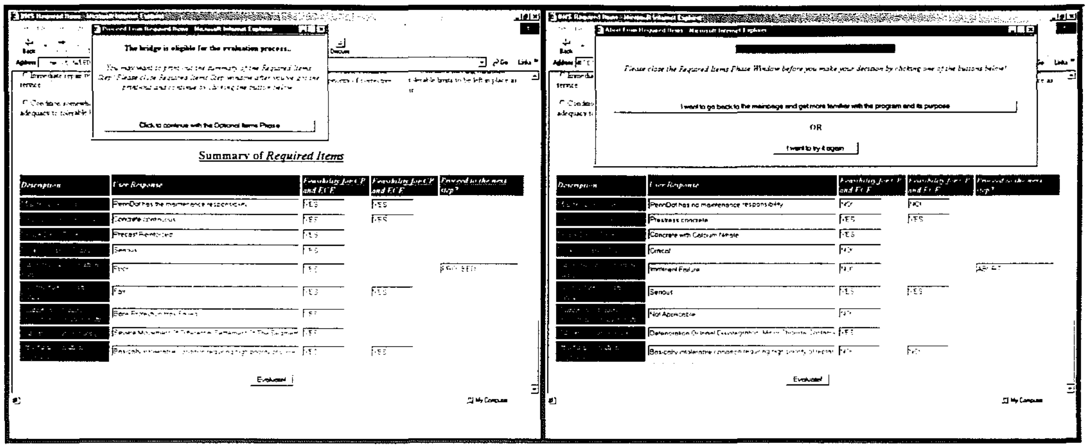

FIG. 4.2. Required Items Step (BMS Phase)

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2) "PROCEED" message appears on the summary table under the "Proceed to the next step?" column and a transition window pops up. This window prompts the user to proceed to the next step.

The purpose of the transition windows is to inform the user about the progress of the evaluation procedure and to supply a gateway to the next step of AFACE 1.0.

In the second event above, the user has no other choice but to continue. However in occurrence of the first event, the user has two possible choices. One is to go back to the main page and get more familiar with the program and its purpose, and the other is to try the first step of the 3-step BMS phase. Again, these choice windows are illustrated in Figure 4.2.

B) Optional Items (BMS Phase):

Second step of the 3-step BMS phase is similar to the previous step. There are two differences between the two steps. One of them is that there is no evaluate button here. Instead the user clicks onto the "Save" button to store the input information (internet cookies are used to accomplish this process).

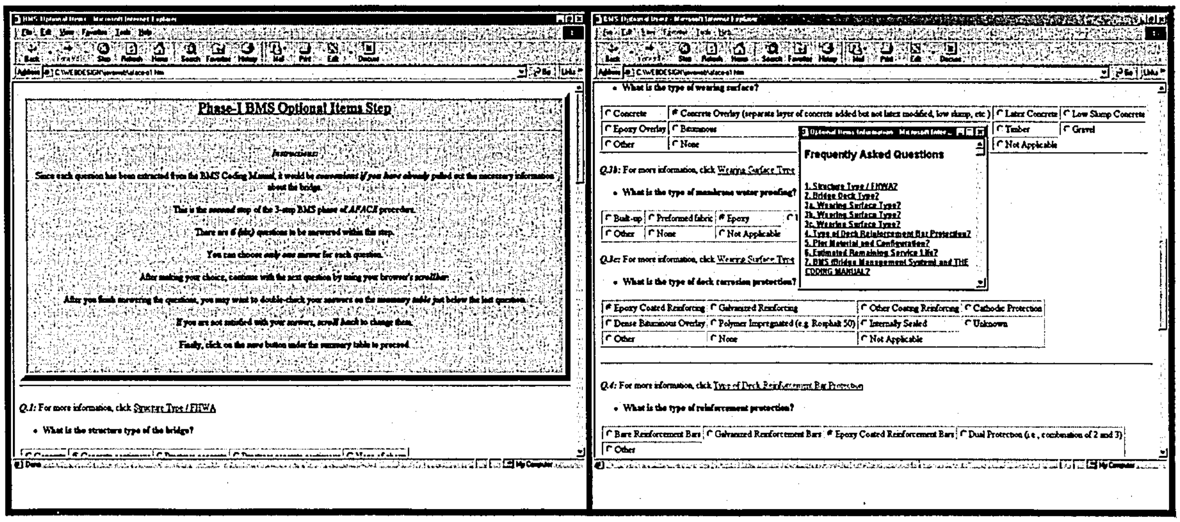

FIG. 4.3. Optional Items Step (BMS Phase)

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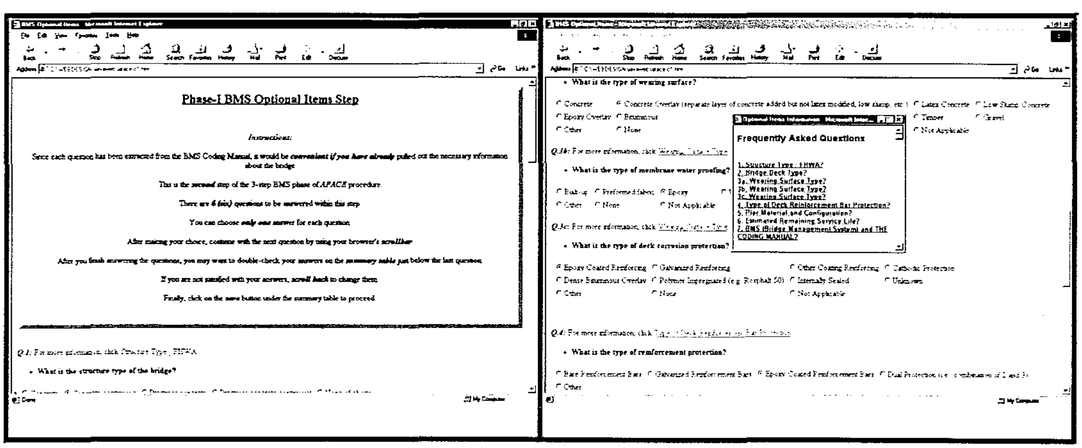

FIG. 4.3. Optional Items Step (BMS Phase)

The other difference is that the user is not given a choice and the evaluation procedure continues with the response of the user. Here, the response is meant to be a click on the "Continue" button that resides in the transition window, which comes forth after the click action on the "Save" button. These windows are illustrated in Figure 4.4. The choices that have been made in this step for the example run are listed below, in Table 4.2.

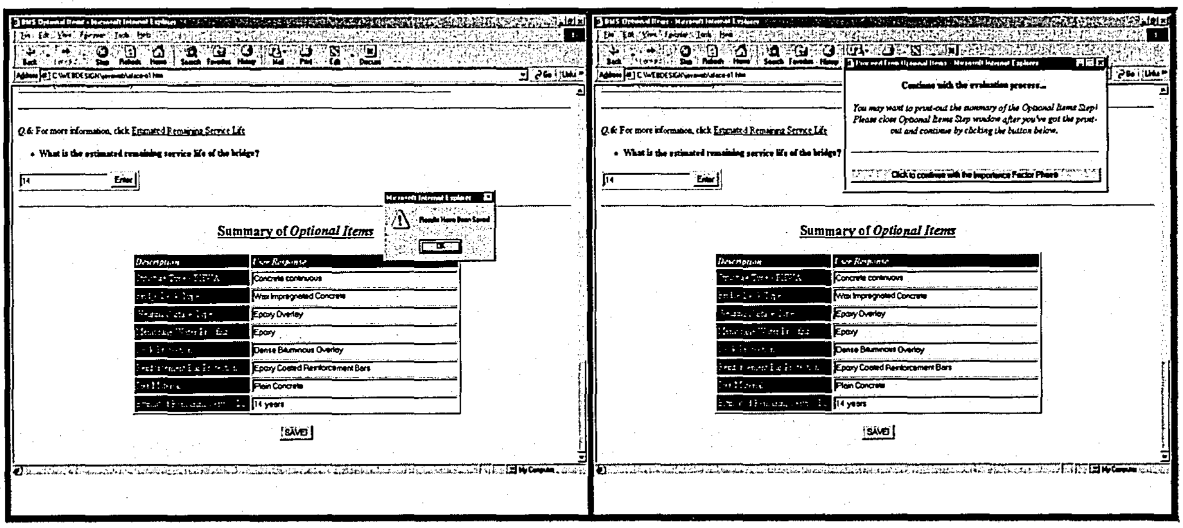

FIG. 4.4. Optional Items Step (BMS Phase)

TABLE 4.2. User responses in the "Optional Items Step" for the example run

Question	Response
Structure type/FHWA	Concrete
Bridge deck type	Reinforced concrete
Wearing surface type	Bituminous
Membrane water proofing	Pre-formed fabric
Deck protection	None
Reinforcement bar protection	Bare reinforcement
Pier material	Reinforced concrete
Estimated remaining service life	20

The other difference is that the user is not given a choice and the evaluation procedure continues with the response of the user. Here, the response is meant to be a click on the "Continue" button that resides in the transition window, which comes forth after the click action on the "Save" button. These windows are illustrated in Figure 4.4. The choices that have been made in this step for the example run are listed below, in Table 4.2.

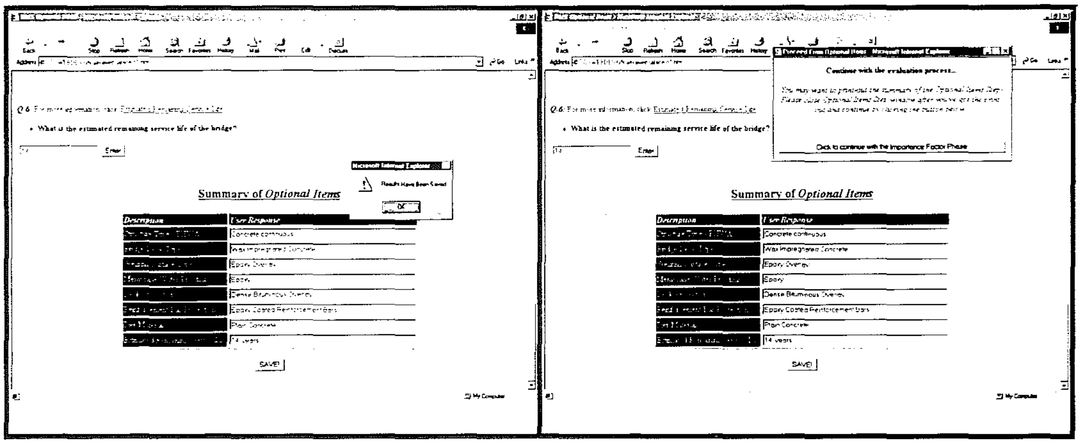

FIG. 4.4. Optional Items Step (BMS Phase)

TABLE 4.2. User responses in the "Optional Items Step" for the example run

Question	Response
Structure type/FHWA	Concrete
Bridge deck type	Reinforced concrete
Wearing surface type	Bituminous
Membrane water proofing	Pre-formed fabric
Deck protection	None
Reinforcement bar protection	Bare reinforcement
Pier material	Reinforced concrete
Estimated remaining service life	20

C) Importance Items (BMS Phase):

Third step of the 3-step BMS phase follows the same procedure as it is in the previous step. However, at the end of this step the user is asked to make a choice in the transition page. Figure 4.5 illustrates the introduction to the third step of the BMS Phase, called the Importance Factor and Deficiency Assignment.

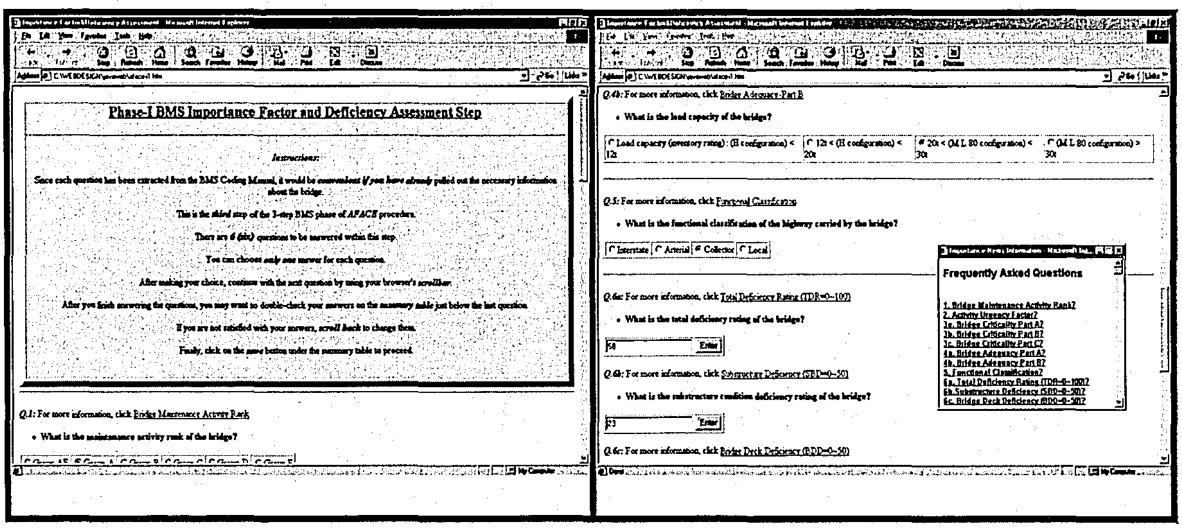

FIG. 4.5. Importance Factor and Deficiency Assessment Items Step (BMS Phase)

Since the region phase within the AFACE procedure was designed for only the decks of the bridge structures, it is unnecessary to let the user continue with the region phase after the BMS phase unless he is evaluating the bridge deck. So there are two options for the user, continue with the region phase (if it is bridge deck that one is evaluating) or continue with the first summary page (if it is the bridge substructure that one is

C) Importance Items (BMS Phase):

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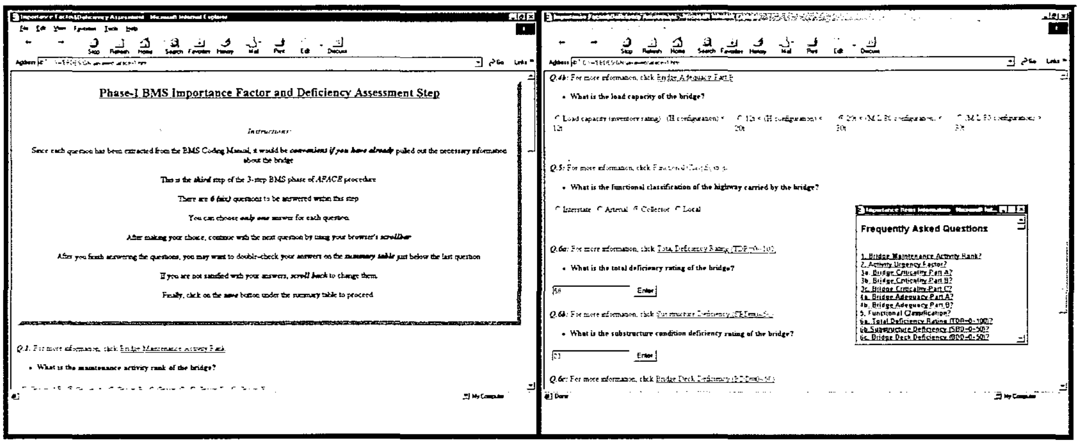

FIG. 4.5. Importance Factor and Deficiency Assessment Items Step (BMS Phase)

Since the region phase within the AFACE procedure was designed for only the decks of the bridge structures, it is unnecessary to let the user continue with the region phase after the BMS phase unless he is evaluating the bridge deck. So there are two options for the user, continue with the region phase (if it is bridge deck that one is evaluating) or continue with the first summary page (if it is the bridge substructure that one is evaluating). Figure 4.6 illustrates the evaluation step. The choices that have been made in this step for this example run are listed below on Table 4.3.

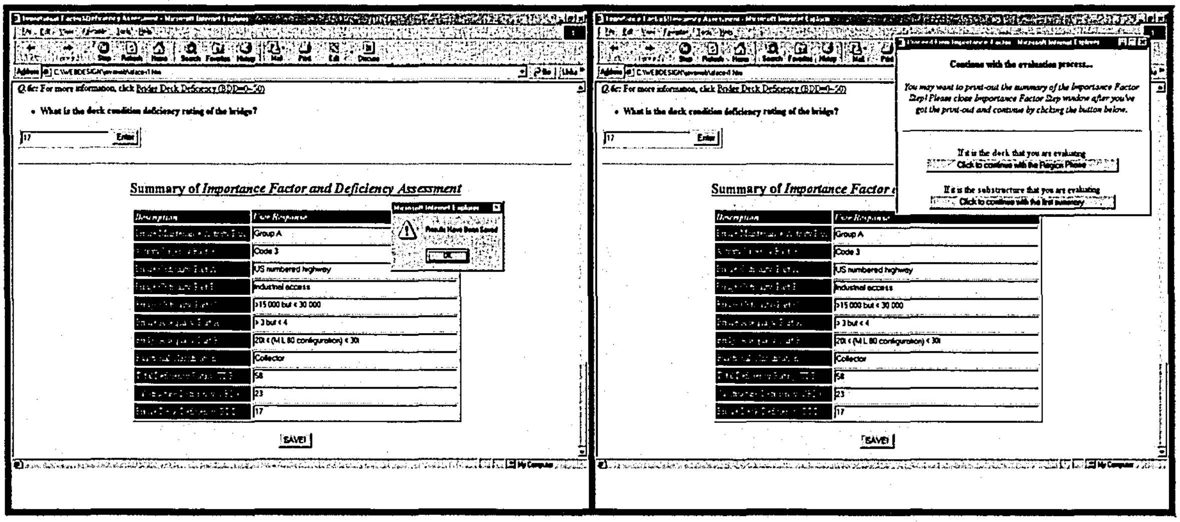

FIG. 4.6. Importance Factor and Deficiency Assessment Items Step (BMS Phase)

TABLE 4.3. User responses in the "Importance Items Step" for the example run

Question	Response
Bridge maintenance activity rank	Group C
Activity urgency factor	2
Bridge critically - Part A	State highway
Bridge critically - Part B	Agricultural access
Bridge critically - Part C	< 3,000
Bridge adequacy – Part A	> 3 but < 4
Bridge adequacy – Part B	20t < (M L 80 configuration) < 30t
Functional classification	Collector
Total deficiency rating	N/A
Substructure deficiency rating	N/A
Bridge deck deficiency rating	N/A

evaluating). Figure 4.6 illustrates the evaluation step. The choices that have been made in this step for this example run are listed below on Table 4.3.

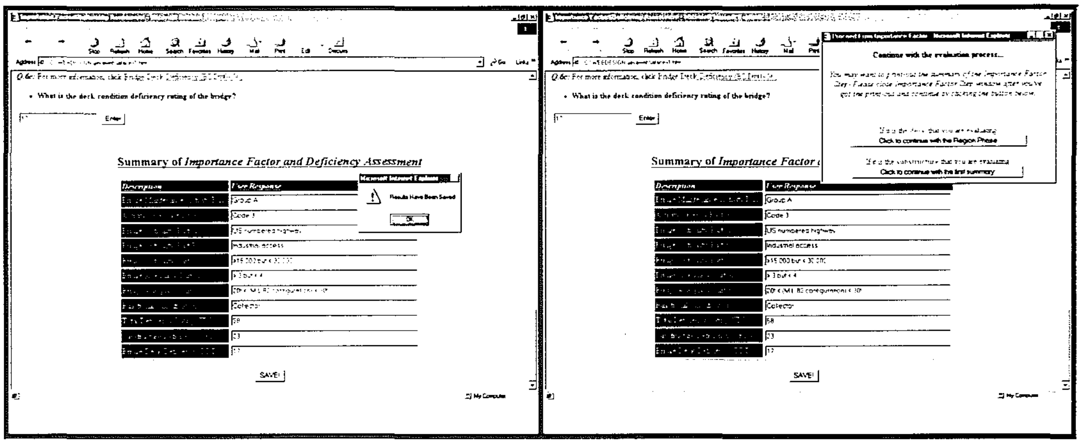

FIG. 4.6. Importance Factor and Deficiency Assessment Items Step (BMS Phase)

TABLE 4.3. User responses in the "Importance Items Step" for the example run

Question	Response
Bridge maintenance activity rank	Group C
Activity urgency factor	2
Bridge critically - Part A	State highway
Bridge critically - Part B	Agricultural access
Bridge critically - Part C	< 3,000
Bridge adequacy – Part A	> 3 but < 4
Bridge adequacy – Part B	20t < (M L 80 configuration) < 30t
Functional classification	Collector
Total deficiency rating	N/A
Substructure deficiency rating	N/A
Bridge deck deficiency rating	N/A

D) Region Phase:

As discussed earlier, this phase was designed for bridge decks. Assuming that the user may not supply all of the requested information within this phase, he is given the opportunity to input the estimated values for the corresponding answers. To make this decision easier, default values were already embedded in this phase, which are also accompanied by the help menu. Figures 4.7 and 4.8 illustrate the introduction and the results of the region phase, respectively.

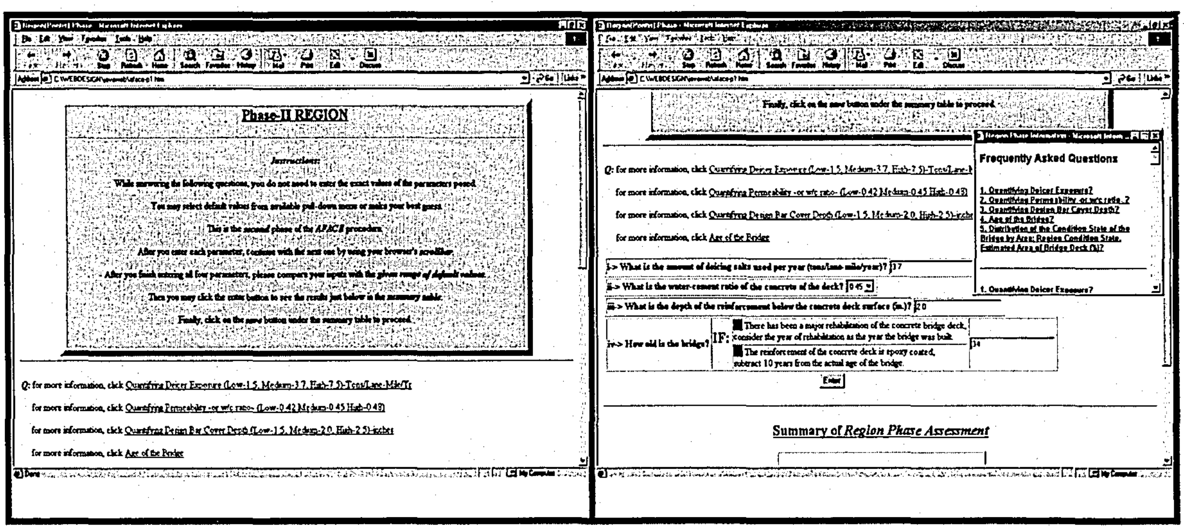

FIG. 4.7. Introduction and the Results of the Region Phase

The given range of default values can also be useful to select the inputs. Finally, the user may click the "Enter" button to see the results in a summary table and clicking on the "Save" button under the summary table would complete this phase. The program would

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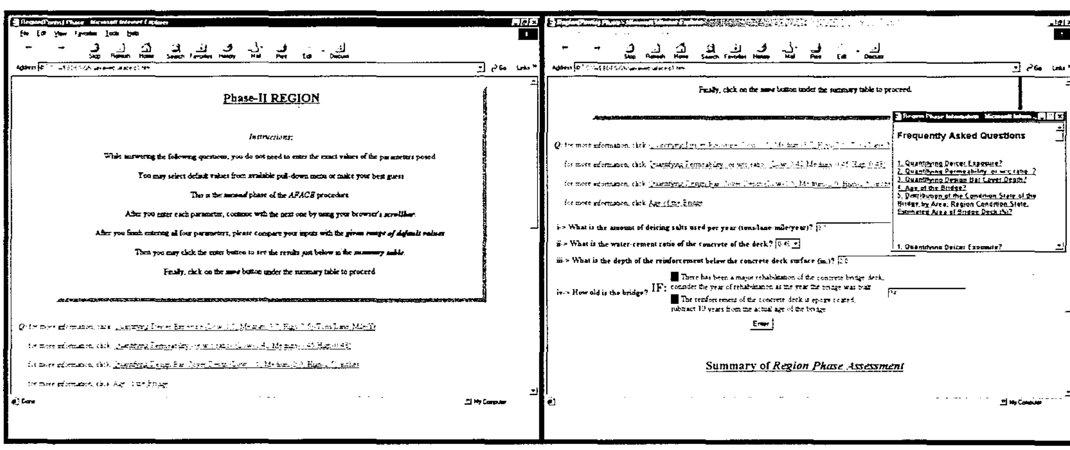


FIG. 4.7. Introduction and the Results of the Region Phase

The given range of default values can also be useful to select the inputs. Finally, the user may click the “Enter” button to see the results in a summary table and clicking on the “Save” button under the summary table would complete this phase. The program would then proceed to the first summary stage with the help of a transition page. The values that have been input in this phase for the example run are listed below on Table 4.4.

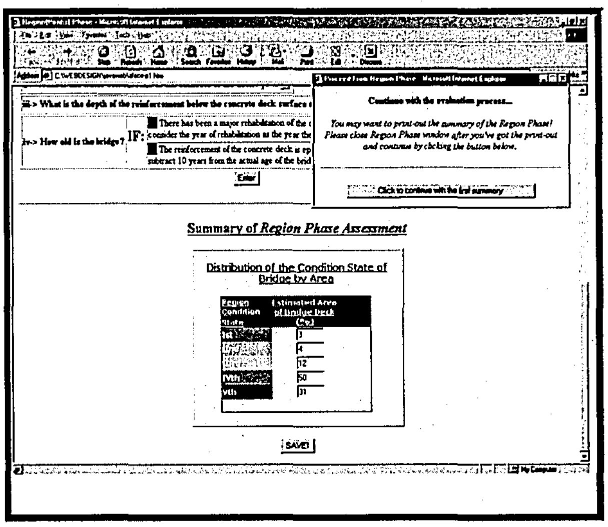
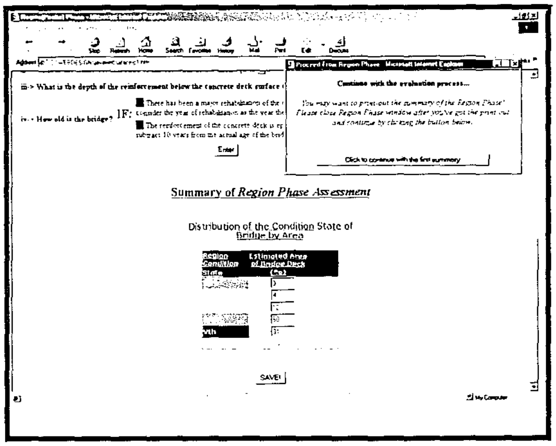


FIG. 4.8. Result and the Transition of the Region Phase

TABLE 4.4. User responses in the "Region Phase" for the example run

Question	Response
Quantifying deicer exposure	3.0 tons/lane-mile/year
Quantifying permeability -or w/c ratio-	0.45
Quantifying design bar cover depth	2.0 in
Age of the bridge	30 years

then proceed to the first summary stage with the help of a transition page. The values that have been input in this phase for the example run are listed below on Table 4.4.



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E) First Summary:

Two separate summary pages have been provided as "Aface-summary1.htm" and "Aface-summary2.htm" for decks and substructures, respectively. These are shown in Figures 4.9 and 4.10.

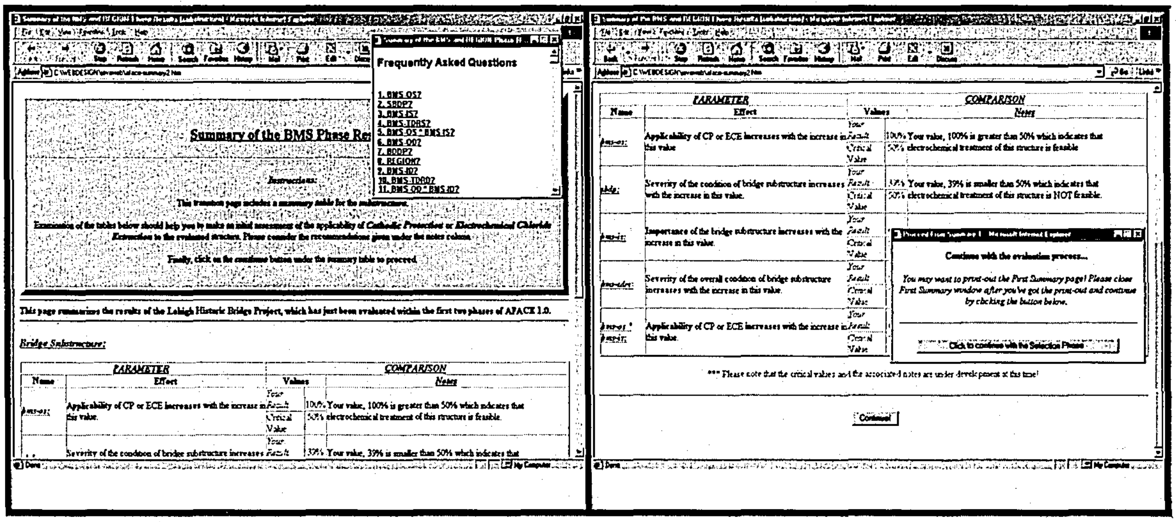

FIG. 4.9. Summary Page for Substructure

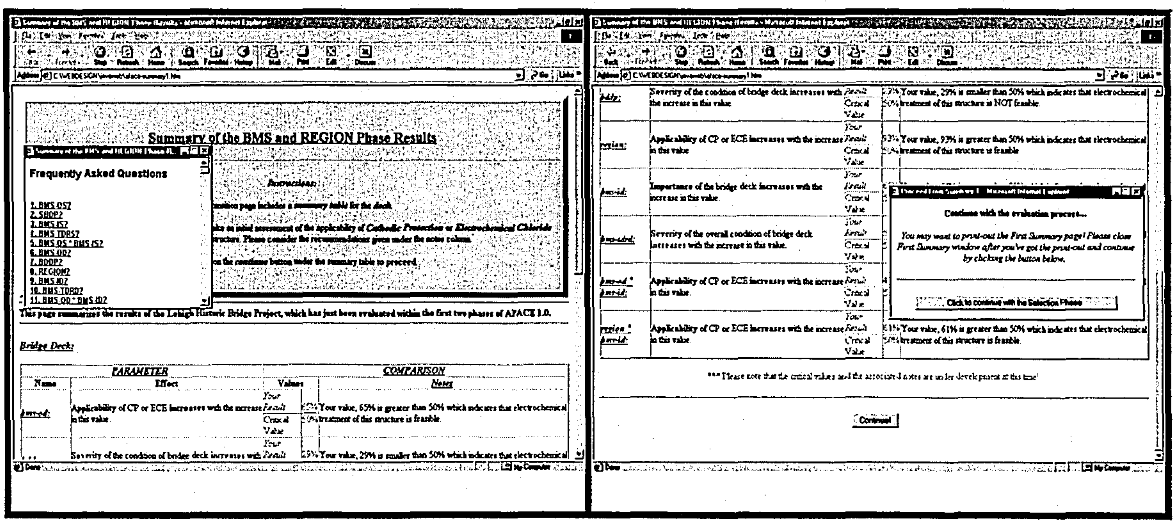

FIG. 4.10. Summary Page for Deck

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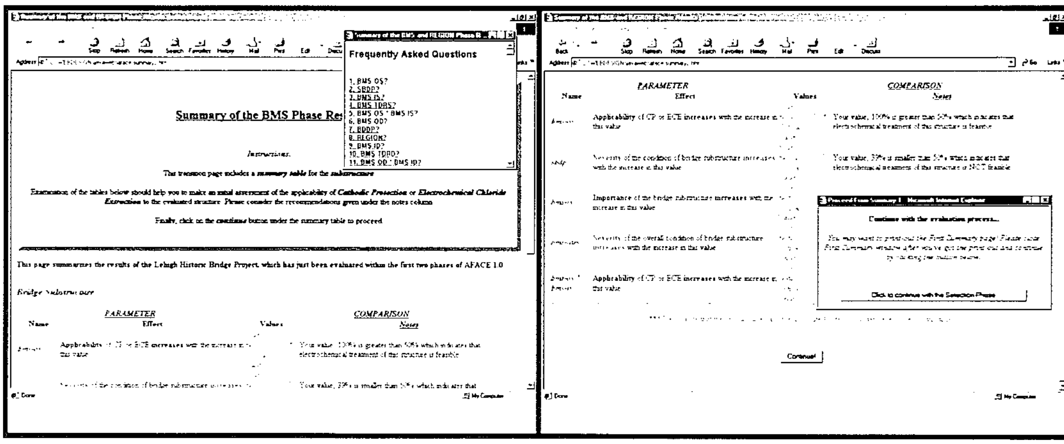

FIG. 4.9. Summary Page for Substructure

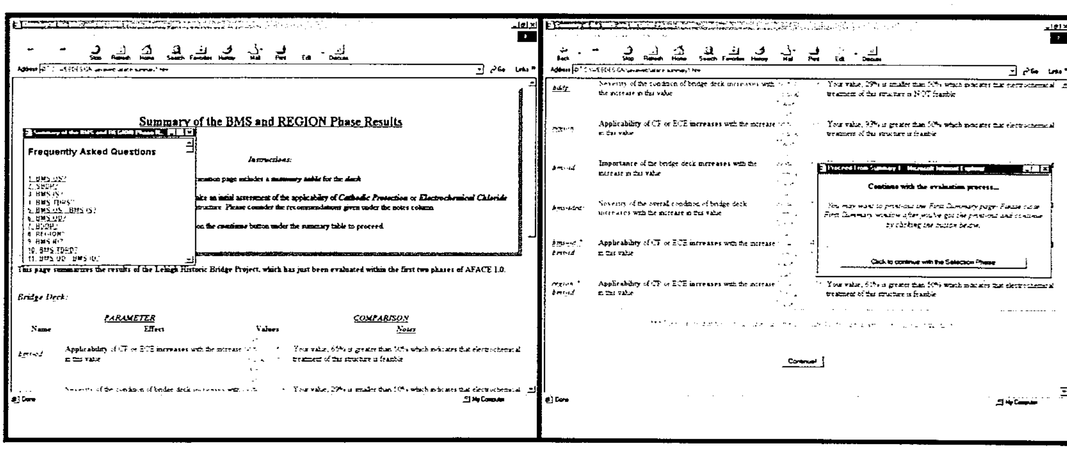

FIG. 4.10. Summary Page for Deck

The index numbers that have been calculated at the end of the first two phases of the AFACE procedure are presented in these summary pages. It is anticipated that the examination of the tables on the summary pages provides the user to make initial assessment of the applicability of cathodic protection and electrochemical chloride extraction to the evaluated structure. Additionally, the user should also make use of the recommendations given under the notes column in the tables.

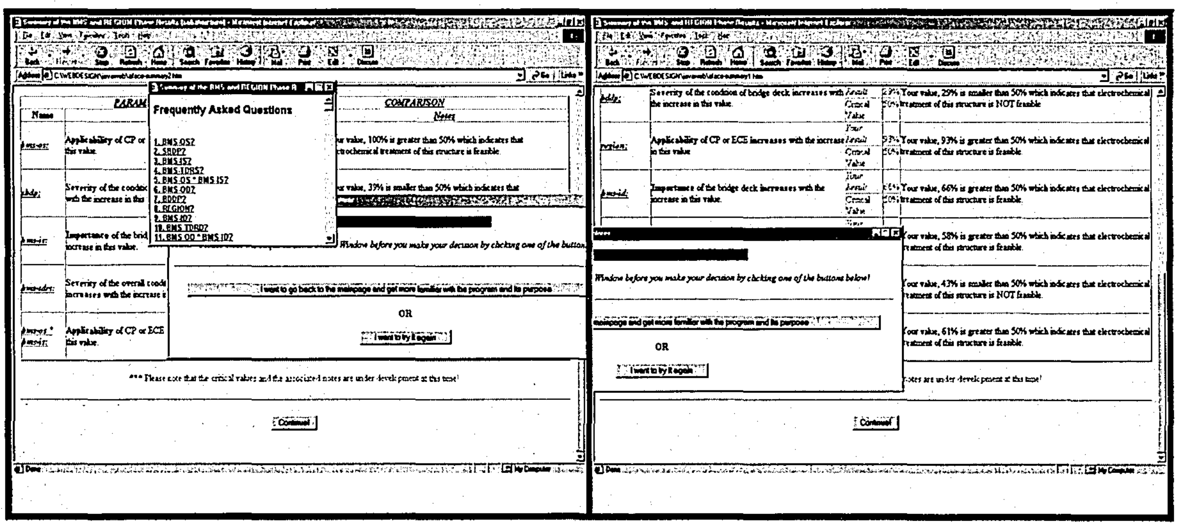

FIG. 4.11. Summary Pages for Deck (left) and for Substructure

These pages have been adjusted to respond in two ways after the user clicks on the "Continue" button under the summary tables to proceed. One way lets the evaluation

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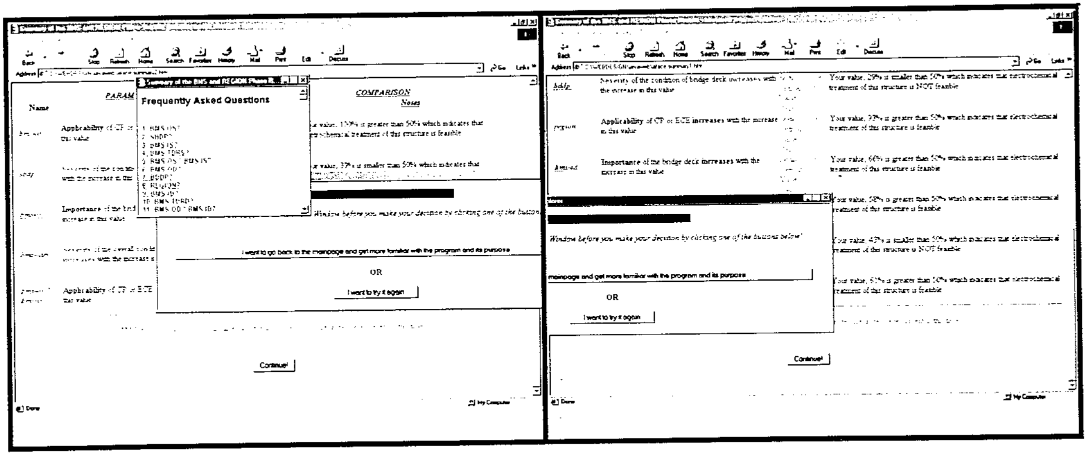

FIG. 4.11. Summary Pages for Deck (left) and for Substructure

These pages have been adjusted to respond in two ways after the user clicks on the "Continue" button under the summary tables to proceed. One way lets the evaluation process to continue with the selection phase unless any of the index numbers do not fall between unacceptable regions of the index values. The other way aborts the process if one of the indices fall within the unacceptable region for that particular value. In that case, a transition window prompts the user to go back to the beginning of AFACE or the front page, as shown in Figure 4.11. Acceptable and unacceptable regions (index numbers criteria that is formed by critical index values) are explained in detail in Appendix E. The results of the index number values for the example run are listed (for decks only) below in Table 4.5.

TABLE 4.5. Index number values of bridge deck for the example run

Index Name	**Value**
BMS-OD	74 %
BMS-OS	29 %
BMS-I	45 %
TDR	N/A
BDD	N/A
SBD	N/A
REGION	80 %
BMS-OD * BMS-I	33 %
REGION * BMS-I	36 %
BMS-OS * BMS-I	13 %

F) Selection Phase:

The last phase of AFACE 1.0 is the selection phase, which is similar to the steps in the BMS phase. Since this is the final (decision, selection) phase of the procedure, there are additional questions to be answered (Figure 4.12).

The user is now able to see the results of the whole evaluation procedure right after he/she clicks onto the "Evaluate" button and scrolls down the page until he/she reaches the results section.

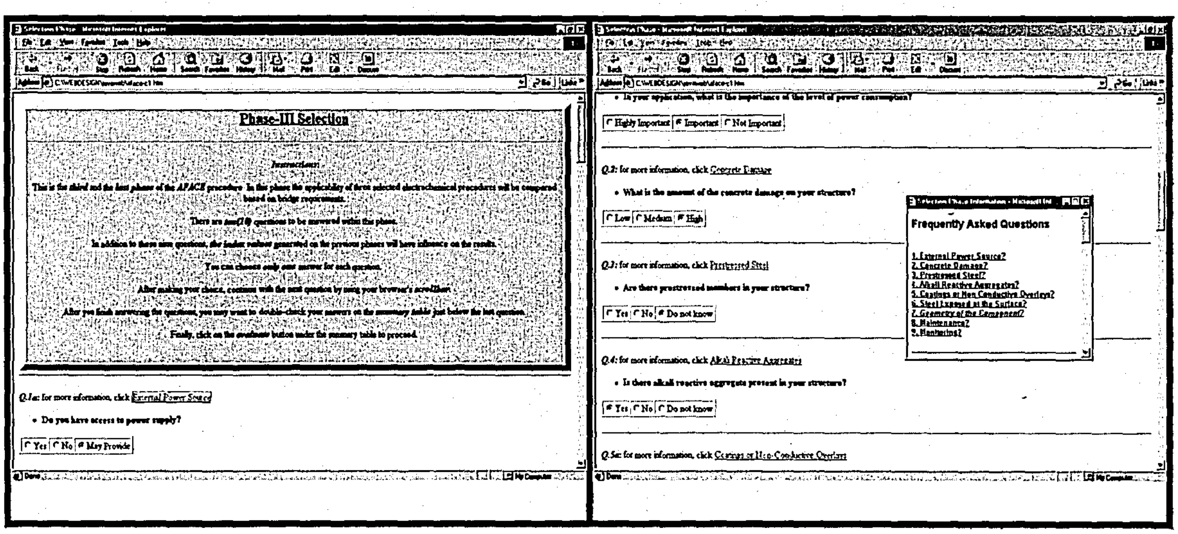

FIG. 4.12. Selection Phase

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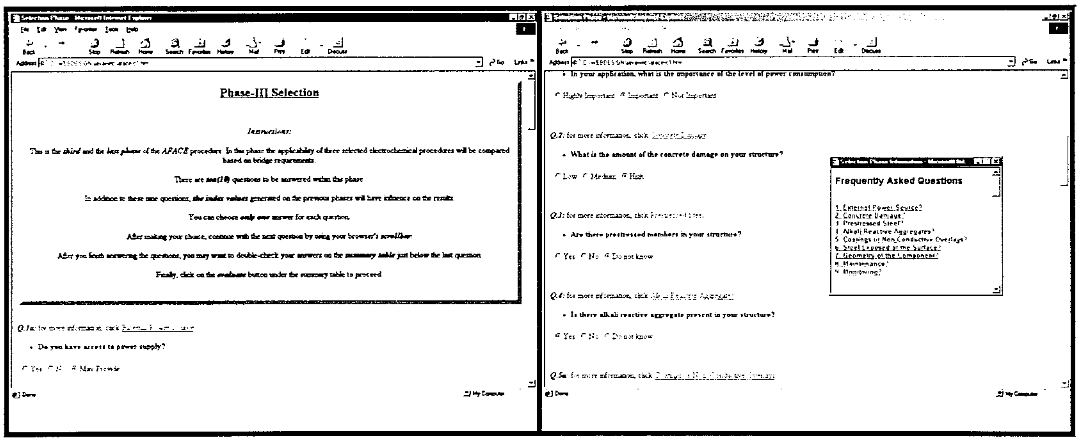

FIG. 4.12. Selection Phase

In the results section, the user will be introduced with a table, which includes four possible electrochemical treatment types and their probabilistic chances of applicability for the evaluated bridge structure.

Because this phase was prepared with highly differentiating questions, an explanation (or comparison) table was also embedded for the user's ability to understand the logic of the selection process and also to compare his/her choices with the requirements of all the treatment methods including the selected one. Clicking action on the hyper linked question summaries on the very left column of this table brings up the necessary information into the available boxes placed under each treatment and the user response columns.

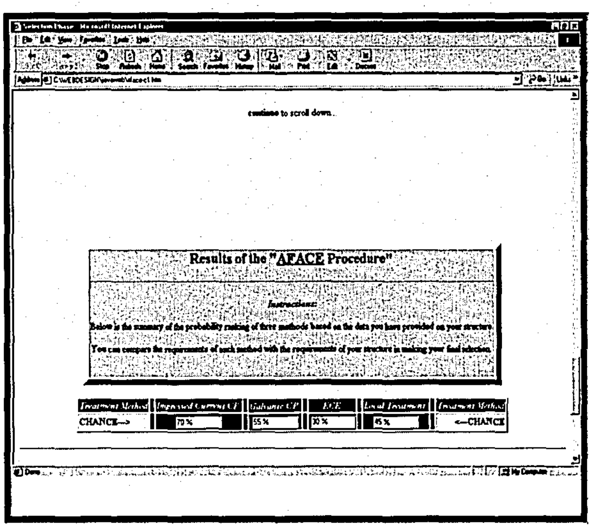

FIG. 4.13. Chance Table in the Page of Selection Phase

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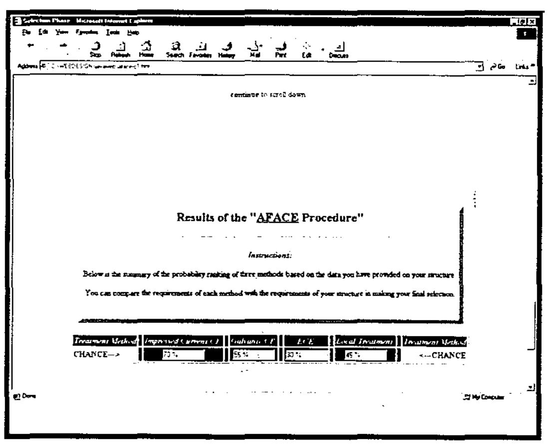

FIG. 4.13. Chance Table in the Page of Selection Phase

Figure 4.13 shows the final table where the probabilistic chance of each procedure is evaluated. Right below this table is the table, which shows the background information and requirements of the recommended method as well as the requirements posed by the user evaluated bridge (Figure 4.14).

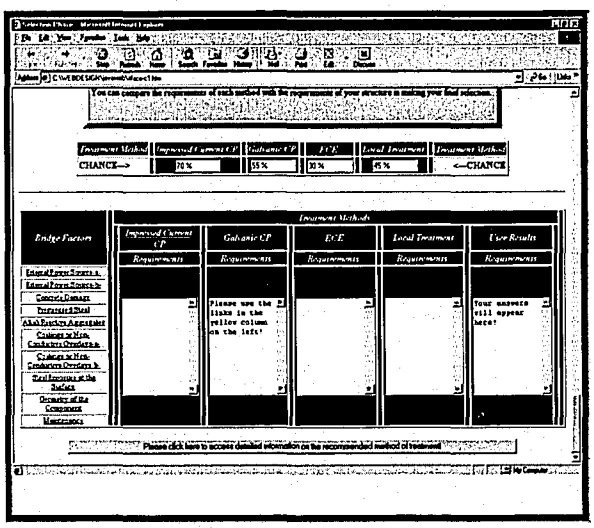

FIG. 4.14. Comparison Table in the Page of the Selection Phase

Lastly, the button under the comparison table helps the user to access detailed information about the selected treatment method.

4.2 Cost?

It should be noted that there is no life-cycle-cost-analysis work done within this procedure. An approach, which directs the procedure into a cost analysis, was also avoided. The reason for these was having insufficient information about the cost

Figure 4.13 shows the final table where the probabilistic chance of each procedure is evaluated. Right below this table is the table, which shows the background information and requirements of the recommended method as well as the requirements posed by the user evaluated bridge (Figure 4.14).

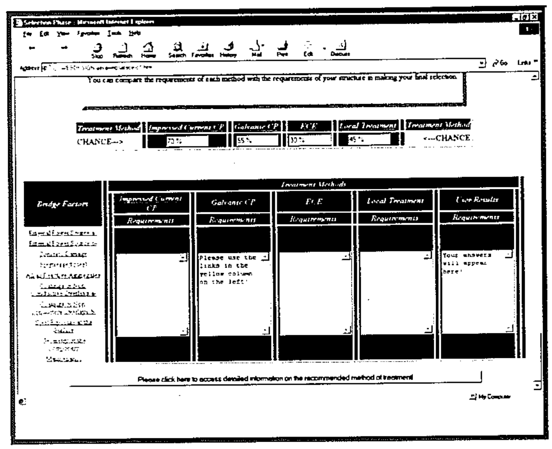

FIG. 4.14. Comparison Table in the Page of the Selection Phase

Lastly, the button under the comparison table helps the user to access detailed information about the selected treatment method.

4.2 Cost?

It should be noted that there is no life-cycle-cost-analysis work done within this procedure. An approach, which directs the procedure into a cost analysis, was also avoided. The reason for these was having insufficient information about the cost breakdown of each method. Furthermore primary connections and the criteria to develop a proper cost analysis step were also missing.

Instead, mentioning about general cost of each treatment method and giving sufficient information from the historical data in the selection phase seemed sufficient for AFACE procedure.

4.3 Summary of Indices and Flowchart of the AFACE Procedure

All of the indices developed in each step are summarized in a table. The usage and the name of the indices and their minimum and maximum values are also explained. The units of the indices are converted into percentages to provide the compatibility within each other. The summary of all of the indices is given in Table 4.6.

In the flowchart of the procedure the steps of AFACE are illustrated in the order of process flow. Complete flowchart of the AFACE procedure is given in Figure 4.15.

TABLE 4.6. The Indices Generated and Used in AFACE

Phase	Step	Usage	Index Name	Min-max values	Unit
BMS	Required Items	Desired Conditions	BMS-R	N/A	%
	Optional Items	Compatibility Factor of CP and ECE for Deck	BMS-OD	0 < BMS-OD < 100	%
		Compatibility Factor of CP and ECE for Substructure	BMS-OS	0 < BMS-OS < 100	%
	Maintenance Deficiency Points Assignment	Importance Factor	BMS-I	0 < BMS-I < 100	%
	Total Deficiency Rating	Condition Factor for the Whole Structure	TDR	0 < TDR < 100	%
	Substructure Deficiency	Condition Factor for Substructure	SBD’	0 < SBD’ < 100	%
	Bridge Deck Deficiency	Condition Factor for Deck	BDD’	0 < BDD’ < 100	%
REGION	Pontis Condition State	Condition Factor for Deck	P-III+P-IV+P-V	0 < P-i < 100	%
Selection	N/A	N/A	N/A	N/A	N/A

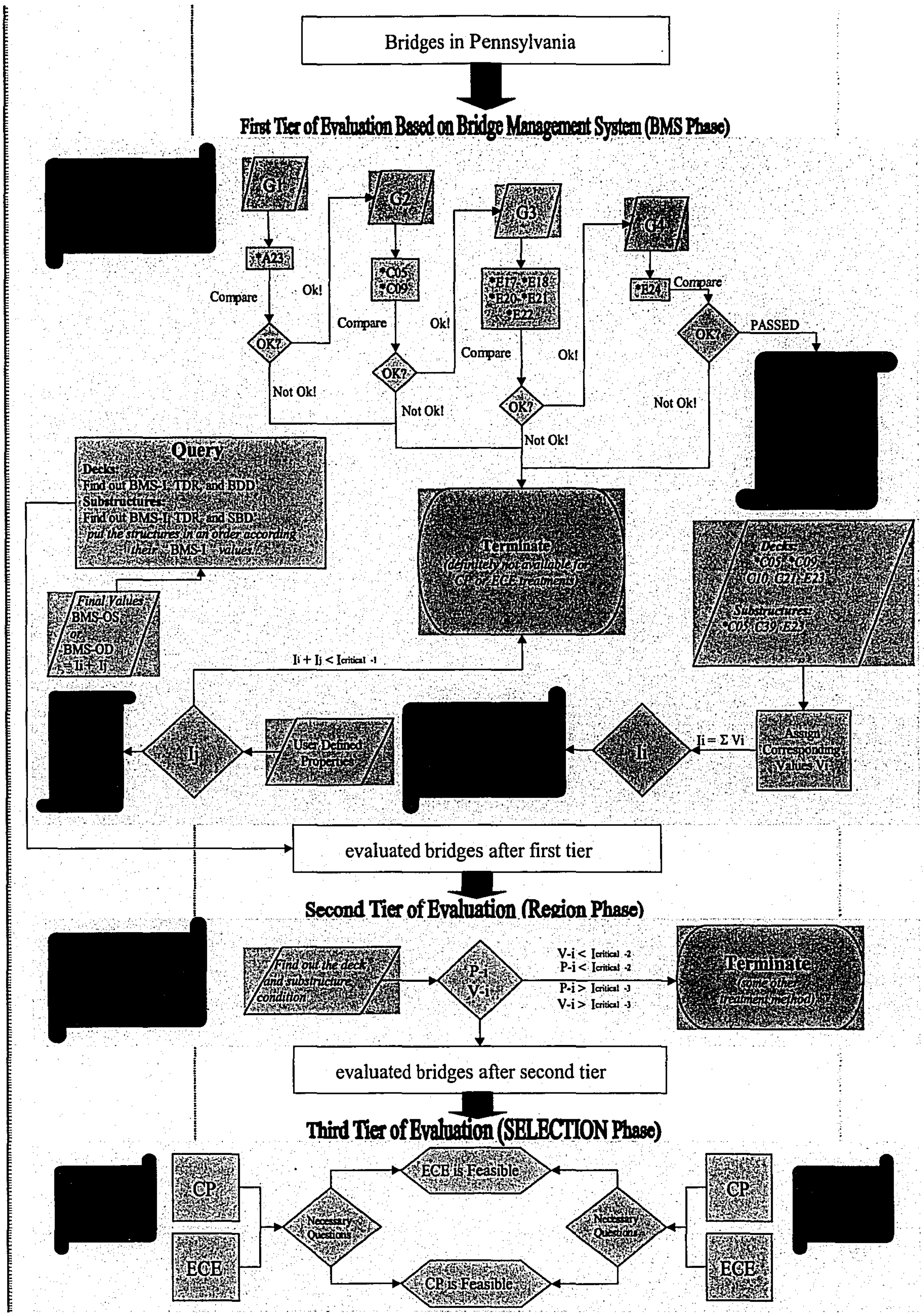

FIG. 4.15. The complete flowchart of the AFACE procedure

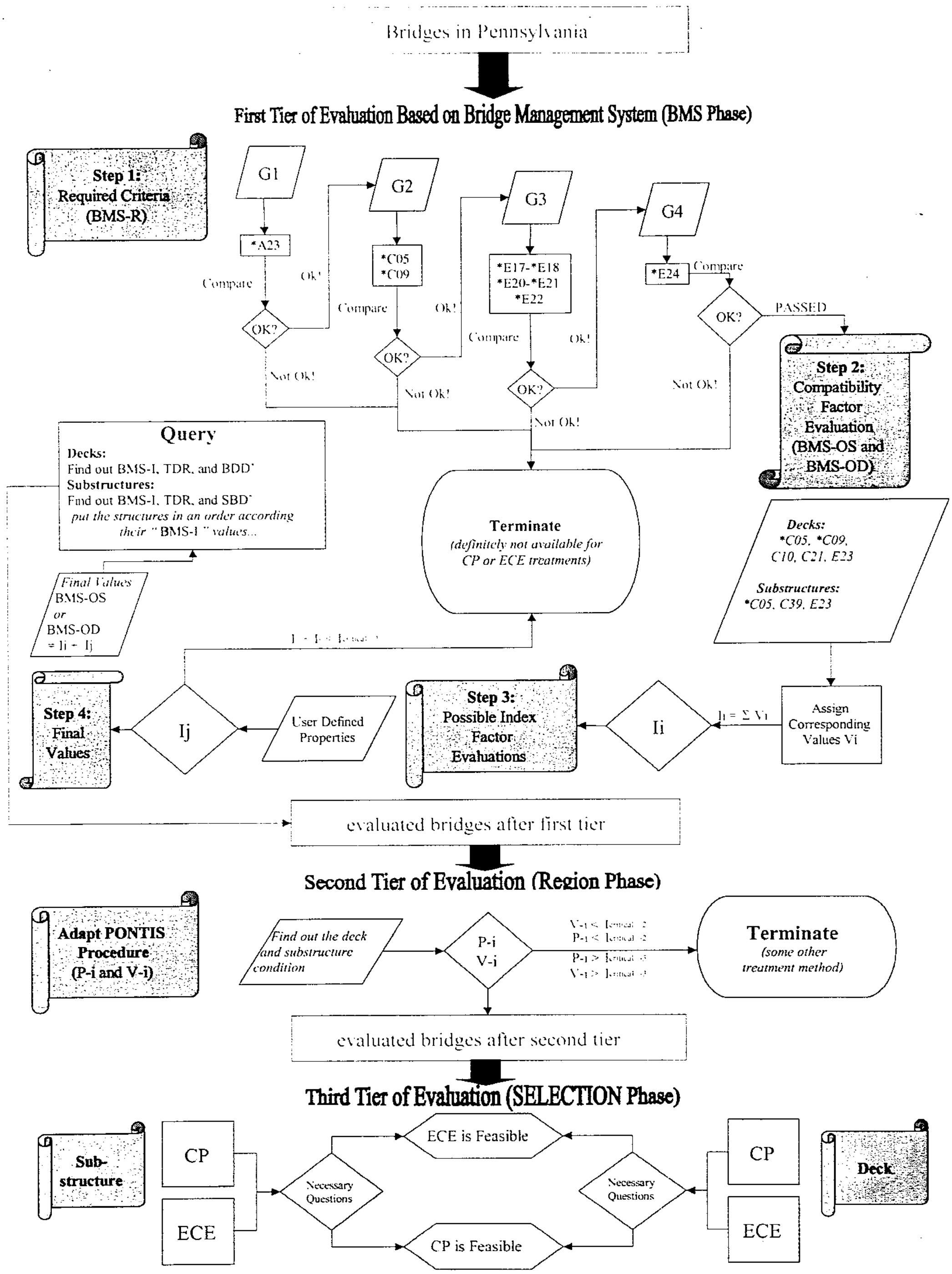

FIG. 4.15. The complete flowchart of the AFACE procedure

CHAPTER V: Conclusion

5.1 Conclusions

A new decision making tool, AFACE was developed to determine the feasibility of electrochemical treatment methods for bridge rehabilitation. AFACE is designed as a web-based internet accessible system. It makes use of existing systems such as Bridge Management System (BMS) and PONTIS to evaluate the suitability of any given bridge deck or substructure for an electrochemical treatment. In the final phase of the analysis, AFACE uses treatment requirements and bridge properties and its environment to rank the suitability of given electrochemical treatments (CP, ECE, Local Treatment).

The system is perceived as an instructional tool as well as a pre-feasibility analysis tool. It is anticipated that the users will be well versed about the available electrochemical treatment technologies and will be able to make educated selecting when they are familiar with AFACE.

5.2 Recommendations

More information is needed on following issues:

- Applicable cost components for all CP systems.
- The cost components for ECE systems.
- An estimate of ECE treatment service life.
- Approximate cost percentage shares of the components of the various ECE and CP applications. (Similar to Table 3.8)

Since some of the components' percentage shares are dependent on the severity of the condition of bridge and other selections made (i.e. anode selection, surface preparation etc.), information about the properties of the bridge and the environment corresponding to those applications are also desired.

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APPENDIX:

A-Pre-Selected BMS Codes:

a. Codes in the Required Items Step:

<table>
<tr><th>Group</th><th>Code</th><th>Description</th><th>User Response</th><th>Feasibility for ECE and CP</th><th>Proceed the next step?</th></tr>
<tr><td>1</td><td>*A23</td><td>Maintenance Code</td><td>~Answer ~</td><td>Yes / No</td><td rowspan="10">Yes
No</td></tr>
<tr><td rowspan="2">2</td><td>*C05</td><td>Structure Type / FHWA</td><td>~Answer ~</td><td rowspan="2">Yes / No</td></tr>
<tr><td>*C09</td><td>Bridge Deck Type</td><td>~Answer ~</td></tr>
<tr><td rowspan="6">3</td><td>*E17</td><td>Deck Condition Rating</td><td>~Answer ~</td><td rowspan="6">Yes / No</td></tr>
<tr><td>*E18</td><td>Superstructure Condition Rating</td><td>~Answer ~</td></tr>
<tr><td>*E20</td><td>Substructure Condition Rating</td><td>~Answer ~</td></tr>
<tr><td>*E21</td><td>Channel & Channel Protection Condition Rating</td><td>~Answer ~</td></tr>
<tr><td>*E22</td><td>Culvert Condition Rating</td><td>~Answer ~</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td>4</td><td>*E24</td><td>Structural Condition Appraisal</td><td>~Answer ~</td><td>Yes /No</td></tr>
</table>

Checklist will be filled out according to the guide below:

1. For a given bridge, each data in BMS for corresponding item will be evaluated according to the pre-selected criteria given below.
2. Each group will be awarded as "Yes" if at least one of the items' answer in that group is suitable.
3. "Yes" will be assigned to a candidate bridge if all the groups get confirmation with "Yes".
4. Proceed with the next step.

APPENDIX:

A-Pre-Selected BMS Codes:

a. Codes in the Required Items Step:

Group	Code	Description	User Response	Feasibility for ECE and CP	Proceed the next step?
1	*A23	**Maintenance Code**	~Answer ~	Yes / No	Yes No
2	*C05	**Structure Type / FHWA**	~Answer ~	Yes / No	
	*C09	**Bridge Deck Type**	~Answer ~		
3	*E17	**Deck Condition Rating**	~Answer ~	Yes / No	
	*E18	**Superstructure Condition Rating**	~Answer ~		
	*E20	**Substructure Condition Rating**	~Answer ~		
	*E21	**Channel & Channel Protection Condition Rating**	~Answer ~		
	*E22	**Culvert Condition Rating**	~Answer ~		
4	*E24	**Structural Condition Appraisal**	~Answer ~	Yes /No	

Checklist will be filled out according to the guide below:

1. For a given bridge, each data in BMS for corresponding item will be evaluated according to the pre-selected criteria given below.
2. Each group will be awarded as "Yes" if at least one of the items' answer in that group is suitable.
3. "Yes" will be assigned to a candidate bridge if all the groups get confirmation with "Yes".
4. Proceed with the next step.

APPENDIX:

A-Pre-Selected BMS Codes:

a. Codes in the Required Items Step:

Group	Code	Description	User Response	Feasibility for ECE and CP	Proceed the next step?
1	*A23	**Maintenance Code**	~Answer ~	Yes / No	Yes No
2	*C05	**Structure Type / FHWA**	~Answer ~	Yes / No	
	*C09	**Bridge Deck Type**	~Answer ~		
3	*E17	**Deck Condition Rating**	~Answer ~	Yes / No	
	*E18	**Superstructure Condition Rating**	~Answer ~		
	*E20	**Substructure Condition Rating**	~Answer ~		
	*E21	**Channel & Channel Protection Condition Rating**	~Answer ~		
	*E22	**Culvert Condition Rating**	~Answer ~		
4	*E24	**Structural Condition Appraisal**	~Answer ~	Yes /No	

Checklist will be filled out according to the guide below:

1. For a given bridge, each data in BMS for corresponding item will be evaluated according to the pre-selected criteria given below.
2. Each group will be awarded as "Yes" if at least one of the items' answer in that group is suitable.
3. "Yes" will be assigned to a candidate bridge if all the groups get confirmation with "Yes".
4. Proceed with the next step.

Group 1: Consists of only one item.

- Maintenance Code (BMS 3-digit)

*A23	Maintenance Code

Attention:

- For mixed responsibility the decision will be made later.

Answer that awards "Yes": 1
Answers that award "No": rest of the answers

1. {0-1-all}: PennDOT has the maintenance responsibility.

Group 2: Consists of two items.

- Structure Type / FHWA (BMS 3-digit)
- Bridge Deck Type (BMS 3-digit)

*C05	Structure Type / FHWA

Answers that award "Yes": 1, 2, 3, and 4
Answers that award "No": rest of the answers

1 {1-all}: Concrete
2 {2-all}: Concrete continuous
3 {5-all}: Prestress concrete
4 {6-all}: Prestress concrete continuous

*C09	Bridge Deck Type

Answers that award "Yes": 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17 and 18
Answers that award "No": rest of the answers

1 {08}: Prestressed Planks
2 {09}: Precast Reinforced Concrete Planks/Slabs
3 {10}: Reinforced Concrete

Group 1: Consists of only one item.

- Maintenance Code (BMS 3-digit)

*A23	**Maintenance Code**

Attention:

- For mixed responsibility the decision will be made later.

Answer that awards "Yes": 1
Answers that award "No": rest of the answers

1. {0-1-all}: PennDOT has the maintenance responsibility.

Group 2: Consists of two items.

- Structure Type / FHWA (BMS 3-digit)
- Bridge Deck Type (BMS 3-digit)

*C05	**Structure Type / FHWA**

Answers that award "Yes": 1, 2, 3, and 4
Answers that award "No": rest of the answers

1 {1-all}: Concrete
2 {2-all}: Concrete continuous
3 {5-all}: Prestress concrete
4 {6-all}: Prestress concrete continuous

*C09	**Bridge Deck Type**

Answers that award "Yes": 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17 and 18
Answers that award "No": rest of the answers

1 {08}: Prestressed Planks
2 {09}: Precast Reinforced Concrete Planks/Slabs
3 {10}: Reinforced Concrete

4 {11}: Special Mix Concrete
5 {12}: Polymer Impregnated Concrete
6 {13}: Wax Impregnated Concrete
7 {14}: Wire Reinforced Concrete
8 {15}: Concrete with Cathodic Protection
9 {16}: Concrete Filled Metal
10 {21}: Post-tensioned Precast Concrete
11 {22}: Post-tensioned CIP Concrete
12 {23}: Lightweight Reinforced Concrete
13 {24}: Prestressed Concrete Planks
14 {25}: Isotropic Concrete
15 {26}: Orthotropic Concrete
16 {27}: Concrete with Calcium Nitrate
17 {28}: Concrete with Flyash and Cement
18 {29}: Concrete with Type K Cement

Group 3: Consists of five items.

- Deck Condition Rating (BMS 1-digit)
- Superstructure Condition Rating (BMS 1-digit)
- Substructure Condition Rating (BMS 1-digit)
- Channel & Channel Protection Condition Rating (BMS 1-digit)
- Culvert Condition Rating (BMS 1-digit)

*E17	**Deck Condition Rating**

Answers that award "Yes": 3, 4 and 5
Answers that award "No": 1, 2, 6 and 7

1 {1}: "Imminent" Failure
2 {2}: Critical
3 {3}: Serious
4 {4}: Poor
5 {5}: Fair
6 {6}: Satisfactory
7 {N}: Not Applicable

*E18	**Superstructure Condition Rating**

Answers that award "Yes": 3, 4 and 5

4 {11}: Special Mix Concrete
5 {12}: Polymer Impregnated Concrete
6 {13}: Wax Impregnated Concrete
7 {14}: Wire Reinforced Concrete
8 {15}: Concrete with Cathodic Protection
9 {16}: Concrete Filled Metal
10 {21}: Post-tensioned Precast Concrete
11 {22}: Post-tensioned CIP Concrete
12 {23}: Lightweight Reinforced Concrete
13 {24}: Prestressed Concrete Planks
14 {25}: Isotropic Concrete
15 {26}: Orthotropic Concrete
16 {27}: Concrete with Calcium Nitrate
17 {28}: Concrete with Flyash and Cement
18 {29}: Concrete with Type K Cement

Group 3: Consists of five items.

- Deck Condition Rating (BMS 1-digit)
- Superstructure Condition Rating (BMS 1-digit)
- Substructure Condition Rating (BMS 1-digit)
- Channel & Channel Protection Condition Rating (BMS 1-digit)
- Culvert Condition Rating (BMS 1-digit)

*E17	**Deck Condition Rating**

Answers that award "Yes": 3, 4 and 5
Answers that award "No": 1, 2, 6 and 7

1 {1}: "Imminent" Failure
2 {2}: Critical
3 {3}: Serious
4 {4}: Poor
5 {5}: Fair
6 {6}: Satisfactory
7 {N}: Not Applicable

*E18	**Superstructure Condition Rating**

Answers that award "Yes": 3, 4 and 5

Answers that award "No": 1, 2, 6 and 7

1 {1}: "Imminent" Failure
2 {2}: Critical
3 {3}: Serious
4 {4}: Poor
5 {5}: Fair
6 {6}: Satisfactory
7 {N}: Not Applicable

*E20	**Substructure Condition Rating**

Answers that award "Yes": 3, 4 and 5
Answers that award "No": 1, 2, 6 and 7

1 {1}: "Imminent" Failure
2 {2}: Critical
3 {3}: Serious
4 {4}: Poor
5 {5}: Fair
6 {6}: Satisfactory
7 {N}: Not Applicable

*E21	**Channel & Channel Protection Condition Rating**

Answers that award "Yes": 1, 2, 3, 4, 5 and 6
Answers that award "No": 7

1 {1}: Channel Failure, Corrective Action Is Needed
2 {2}: The Channel Has Changed To The Extent
3 {3}: Bank Protection Has Failed
4 {4}: Bank and Embankment Protection Is Severely Undermined
5 {5}: Bank Protection Is Being Eroded
6 {6}: Bank Is Beginning To Slump
7 {N}: Not Applicable

*E22	**Culvert Condition Rating**

Answers that award "No": 1, 2, 6 and 7

1 {1}: "Imminent" Failure
2 {2}: Critical
3 {3}: Serious
4 {4}: Poor
5 {5}: Fair
6 {6}: Satisfactory
7 {N}: Not Applicable

*E20	**Substructure Condition Rating**

Answers that award "Yes": 3, 4 and 5
Answers that award "No": 1, 2, 6 and 7

1 {1}: "Imminent" Failure
2 {2}: Critical
3 {3}: Serious
4 {4}: Poor
5 {5}: Fair
6 {6}: Satisfactory
7 {N}: Not Applicable

*E21	**Channel & Channel Protection Condition Rating**

Answers that award "Yes": 1, 2, 3, 4, 5 and 6
Answers that award "No": 7

1 {1}: Channel Failure, Corrective Action Is Needed
2 {2}: The Channel Has Changed To The Extent
3 {3}: Bank Protection Has Failed
4 {4}: Bank and Embankment Protection Is Severely Undermined
5 {5}: Bank Protection Is Being Eroded
6 {6}: Bank Is Beginning To Slump
7 {N}: Not Applicable

*E22	**Culvert Condition Rating**

Answers that award "Yes": 1, 2, 3, 4, 5 and 6
Answer that awards "No": 7

1 {1}: Corrective Action May Put Back In Light Service
2 {2}: Integral Wing Walls Collapsed, Severe Settlement Of Roadway Due To Loss Of Fill
3 {3}: Severe Movement Of Differential Settlement Of The Segments, Or Loss Of Fill
4 {4}: Large Spalls, Heavy Scaling, Wide Cracks, Considerable Efflorescence, Or Opened Construction Joint Permitting Loss Of Backfill
5 {5}: Moderate To Major Deterioration Or Disintegration, Extensive Cracking And Leaching, Or Spalls On Concrete Walls And Slabs
6 {6}: Deterioration Or Initial Disintegration, Minor Chloride Contamination, Cracking With Some Leaching, Or Spalls On Concrete Walls And Slabs
7 {N}: Not Applicable

Group 4: Consists of only one item.

- Structural Condition Appraisal (BMS 1-digit)

*E24	**Structural Condition Appraisal**

Answers that award "Yes": 3, 4 and 5
Answers that award "No": 1, 2 and 6

1 {1}: Immediate repair necessary to put back in service
2 {2}: Basically intolerable condition requiring high priority of replacement
3 {3}: Basically intolerable condition requiring high priority of corrective action
4 {4}: Condition meeting minimum tolerable limits to be left in place as is
5 {5}: Condition somewhat better than minimum adequacy to tolerable being left in place as is
6 {N}: Not Applicable

Answers that award "Yes": 1, 2, 3, 4, 5 and 6
Answer that awards "No": 7

1 {1}: Corrective Action May Put Back In Light Service
2 {2}: Integral Wing Walls Collapsed, Severe Settlement Of Roadway Due To Loss Of Fill
3 {3}: Severe Movement Of Differential Settlement Of The Segments, Or Loss Of Fill
4 {4}: Large Spalls, Heavy Scaling, Wide Cracks, Considerable Efflorescence, Or Opened Construction Joint Permitting Loss Of Backfill
5 {5}: Moderate To Major Deterioration Or Disintegration, Extensive Cracking And Leaching, Or Spalls On Concrete Walls And Slabs
6 {6}: Deterioration Or Initial Disintegration, Minor Chloride Contamination, Cracking With Some Leaching, Or Spalls On Concrete Walls And Slabs
7 {N}: Not Applicable

Group 4: Consists of only one item.

- Structural Condition Appraisal (BMS 1-digit)

*E24	**Structural Condition Appraisal**

Answers that award "Yes": 3, 4 and 5
Answers that award "No": 1, 2 and 6

1 {1}: Immediate repair necessary to put back in service
2 {2}: Basically intolerable condition requiring high priority of replacement
3 {3}: Basically intolerable condition requiring high priority of corrective action
4 {4}: Condition meeting minimum tolerable limits to be left in place as is
5 {5}: Condition somewhat better than minimum adequacy to tolerable being left in place as is
6 {N}: Not Applicable

b. Codes in the Optional Items Step:

DECK			
Code	Name	Max Value (Vi)	Min Value (Vi)
*C05	**Structure Type / FHWA**	**5**	**4**
*C09	**Bridge Deck Type**	**5**	**0**
*C10	**Wearing Surface Type**	**5+5+5**	**4+4+0**
C21	**Type of Deck Reinforcement Bar Protection**	**5**	**0**
E23	**Estimated Remaining Service Life**	**5**	**0**
	Σ	**35**	**12**

SUBSTRUCTURE			
Code	Name	Max Value (Vi)	Min Value (Vi)
*C05	**Structure Type / FHWA**	**5**	**4**
C39	**Pier Material and Configuration**	**5**	**4**
E23	**Estimated Remaining Service Life**	**5**	**0**
	Σ	**15**	**8**

For a given bridge, each data in BMS for corresponding item will be evaluated according to the pre-selected criteria (by assigning corresponding points) given below.

b. **Codes in the Optional Items Step:**

DECK			
Code	Name	Max Value (Vi)	Min Value (Vi)
*C05	**Structure Type / FHWA**	**5**	**4**
*C09	**Bridge Deck Type**	**5**	**0**
*C10	**Wearing Surface Type**	**5+5+5**	**4+4+0**
C21	**Type of Deck Reinforcement Bar Protection**	**5**	**0**
E23	**Estimated Remaining Service Life**	**5**	**0**
	Σ	**35**	**12**

SUBSTRUCTURE			
Code	Name	Max Value (Vi)	Min Value (Vi)
*C05	**Structure Type / FHWA**	**5**	**4**
C39	**Pier Material and Configuration**	**5**	**4**
E23	**Estimated Remaining Service Life**	**5**	**0**
	Σ	**15**	**8**

For a given bridge, each data in BMS for corresponding item will be evaluated according to the pre-selected criteria (by assigning corresponding points) given below.

Structure Type / FHWA (BMS 3-digit)

Code	Name	Value (Vi)
*C05	**Structure Type / FHWA**	**V1**
Digit\#	Property	↓
1\1	Concrete	**5**
1\2	Concrete continuous	**5**
1\5	Prestress concrete	**4**
1\6	Prestress concrete continuous	**4**

Structure Type / FHWA (BMS 3-digit)

Code	Name	Value (Vi)
*C05	**Structure Type / FHWA**	**V1**
Digit\#	Property	↓
1\1	Concrete	**5**
1\2	Concrete continuous	**5**
1\5	Prestress concrete	**4**
1\6	Prestress concrete continuous	**4**

Bridge Deck Type (BMS 3-digit)

Code	Name	Value (Vi)
*C09	**Bridge Deck Type**	V6
Digit\#	Property	↓
1,2\08	Prestressed Planks	4
1,2\09	Precast Reinforced Concrete Planks/Slabs	5
1,2\10	Reinforced Concrete	5
1,2\11	Special Mix Concrete	5
1,2\12	Polymer Impregnated Concrete	0
1,2\13	Wax Impregnated Concrete	0
1,2\14	Wire Reinforced Concrete	5
1,2\15	Concrete with Cathodic Protection	0
1,2\16	Concrete Filled Metal	5
1,2\21	Post-tensioned Precast Concrete	4
1,2\22	Post-tensioned CIP Concrete	4
1,2\23	Lightweight Reinforced Concrete	5
1,2\24	Prestressed Concrete Planks	4
1,2\25	Isotropic Concrete	5
1,2\26	Orthotropic Concrete	5
1,2\27	Concrete with Calcium Nitrate	5
1,2\28	Concrete with Flyash and Cement	5
1,2\29	Concrete with Type K Cement	5
1,2\99	Other	0

Bridge Deck Type (BMS 3-digit)

Code	Name	Value (Vi)
*C09	**Bridge Deck Type**	**V6**
Digit\#	Property	↓
1,2\08	Prestressed Planks	**4**
1,2\09	Precast Reinforced Concrete Planks/Slabs	**5**
1,2\10	Reinforced Concrete	**5**
1,2\11	Special Mix Concrete	**5**
1,2\12	Polymer Impregnated Concrete	**0**
1,2\13	Wax Impregnated Concrete	**0**
1,2\14	Wire Reinforced Concrete	**5**
1,2\15	Concrete with Cathodic Protection	**0**
1,2\16	Concrete Filled Metal	**5**
1,2\21	Post-tensioned Precast Concrete	**4**
1,2\22	Post-tensioned CIP Concrete	**4**
1,2\23	Lightweight Reinforced Concrete	**5**
1,2\24	Prestressed Concrete Planks	**4**
1,2\25	Isotropic Concrete	**5**
1,2\26	Orthotropic Concrete	**5**
1,2\27	Concrete with Calcium Nitrate	**5**
1,2\28	Concrete with Flyash and Cement	**5**
1,2\29	Concrete with Type K Cement	**5**
1,2\99	Other	**0**

Wearing Surface Type (BMS 3-digit)

Code	Name	Value (Vi)
*C10	**Wearing Surface Type**	V3
Digit\#	Property	↓
First Digit	Type of Wearing Surface	
1\1	Concrete	5
1\2	Concrete Overlay (separate layer of concrete added but not latex modified, low slump, etc.)	5
1\3	Latex Concrete	4
1\4	Low Slump Concrete	5
1\5	Epoxy Overlay	4
1\6	Bituminous	4
1\7	Timber	0
1\8	Gravel	0
1\9	Other	5
1\0	None	5
1\0	Not Applicable	5
Second Digit	***Type of membrane Water-Proofing***	
2\1	Built-up	5
2\2	Preformed fabric	5
2\3	Epoxy	4
2\8	Unknown	4
2\9	Other	4
2\0	None	5
2\0	Not Applicable	5

Code	Name	Value (Vi)
*C10	**Wearing Surface Type**	**V3**
Digit\#	Property	↓
First Digit	Type of Wearing Surface	
1\1	Concrete	**5**
1\2	Concrete Overlay (separate layer of concrete added but not latex modified, low slump, etc.)	**5**
1\3	Latex Concrete	**4**
1\4	Low Slump Concrete	**5**
1\5	Epoxy Overlay	**4**
1\6	Bituminous	**4**
1\7	Timber	**0**
1\8	Gravel	**0**
1\9	Other	**5**
1\0	None	**5**
1\0	Not Applicable	**5**
Second Digit	***Type of membrane Water-Proofing***	
2\1	Built-up	**5**
2\2	Preformed fabric	**5**
2\3	Epoxy	**4**
2\8	Unknown	**4**
2\9	Other	**4**
2\0	None	**5**
2\0	Not Applicable	**5**

Third Digit	*Deck Corrosion Protection*	
3\1	Epoxy Coated Reinforcing	0
3\2	Galvanized Reinforcing	5
3\3	Other Coating Reinforcing	0
3\4	Cathodic Protection	0
3\5	Dense Bituminous Overlay (e.g. Rosphalt 50)	4
3\6	Polymer Impregnated	0
3\7	Internally Sealed	0
3\8	Unknown	4
3\9	Other	4
3\0	None	5
3\0	Not Applicable	5

Third Digit	*Deck Corrosion Protection*	
3\1	Epoxy Coated Reinforcing	0
3\2	Galvanized Reinforcing	5
3\3	Other Coating Reinforcing	0
3\4	Cathodic Protection	0
3\5	Dense Bituminous Overlay (e.g. Rosphalt 50)	4
3\6	Polymer Impregnated	0
3\7	Internally Sealed	0
3\8	Unknown	4
3\9	Other	4
3\0	None	5
3\0	Not Applicable	5

Type of Deck Reinforcement Bar Protection (BMS 3-digit)

Code	Name	Value (Vi)
C21	**Type of Deck Reinforcement Bar Protection**	**V8**
Digit\#	Property	↓
1\1	Bare Reinforcement Bars	**5**
1\2	Galvanized Reinforcement Bars	**5**
1\3	Epoxy Coated Reinforcement Bars	**0**
1\4	Dual Protection (i.e., combination of 2 and 3)	**0**
1\9	Other	**0**

Pier Material and Configuration (BMS 2-digit)

Code	Name	Value (Vi)
C39	**Pier Material and Configuration**	**V9**
Digit\#	Property	↓
1\3	Reinforced Concrete	**5**
1\4	Plain Concrete	**5**
1\5	Prestressed Concrete	**4**
1\8	Concrete Unknown, can not determine type	**5**
1\9	Other	**5**

Estimated Remaining Service Life (BMS 2-digit)

Code	Name	Year (Y)	Value (Vi)
E23	**Estimated Remaining Service Life**	**Y<5, Y≥20**	**0**
		5≤Y<10, 15≤Y<20	**3**
		10≤Y<15	**5**

Type of Deck Reinforcement Bar Protection (BMS 3-digit)

Code	Name	Value (Vi)
C21	**Type of Deck Reinforcement Bar Protection**	**V8**
Digit\#	Property	↓
1\1	Bare Reinforcement Bars	**5**
1\2	Galvanized Reinforcement Bars	**5**
1\3	Epoxy Coated Reinforcement Bars	**0**
1\4	Dual Protection (i.e., combination of 2 and 3)	**0**
1\9	Other	**0**

Pier Material and Configuration (BMS 2-digit)

Code	Name	Value (Vi)
C39	**Pier Material and Configuration**	**V9**
Digit\#	Property	↓
1\3	Reinforced Concrete	**5**
1\4	Plain Concrete	**5**
1\5	Prestressed Concrete	**4**
1\8	Concrete Unknown, can not determine type	**5**
1\9	Other	**5**

Estimated Remaining Service Life (BMS 2-digit)

Code	Name	Year (Y)	Value (Vi)
E23	**Estimated Remaining Service Life**	**$Y < 5$, $Y \geq 20$**	**0**
		$5 \leq Y < 10$, $15 \leq Y < 20$	**3**
		$10 \leq Y < 15$	**5**

B-Region Phase Parameters:

- *Quantifying Deicer Exposure*

Bridge deck corrosive environment is primarily linked to deicing salt exposure. Deicing salt exposure was quantified in terms of tons of salt applied per lane-mile (or lane-kilometer) per year. Three ranges of deicing salt exposure representing low (1.5 tons/lane-mile/year), medium (3.7 tons/lane-mile/year), and high (7.5 tons/lane-mile/year) were identified as the default values, based on information on the deicing salt usage in the U.S.

- *Quantifying Permeability -or w/c ratio-*

Permeability of conventional concrete is traditionally represented by the concrete's water-cement ratio. Bridge decks typically incorporate conventional concrete. In the past three decades, the specified water-cement ratio of bridge deck concrete has gradually been decreased from a maximum of 0.50 to a maximum of 0.45 to comply with the American Association of State Highway and Transportation Officials (AASHTO) specifications. Three ranges of specified water-cement ratio representing low (0.42), medium (0.45) and high (0.48) permeability concrete were identified as the default values. However, the following values can also be selected: 0.40, 0.43, 0.44, 0.46, 0.47, 0.49, 0.50, 0.51, 0.52, 0.53, and 0.60.

- *Quantifying Design Bar Cover Depth*

For bridge deck slabs, current AASHTO bridge design code requires a minimum of 2 in. (51 mm) cover depth in mild climates and 2.5 in. (64 mm) in severe climates. The current code was generally implemented by the States in early 1980's. Prior to 1980's, it was not unusual to design bridge decks with cover depths as low as 1.5 in. (38 mm). In accordance with the past and current design practices, three design bar cover depths were identified and assigned as the default values (low = 1.5 in., medium = 2.0 in., high = 2.5 in.), which represent almost all of the bridge decks designed in the U.S. since 1950's.

- *Age of the Bridge*

Since corrosion-induced deterioration typically lags about 3 years behind the reinforcing steel corrosion, the "Age Versus Condition" table can be adjusted to represent deteriorating areas, instead of corroding areas. This is done by subtracting 3 years from the bridge deck age and using the adjusted age in the methodology to determine the percentage of bridge decks in each Region condition state. Following this concept, bridge decks with ages up to 3 years will have 100 percent of the decks in Condition State I.

Early research in the United States indicated that reinforcing bars that were epoxy coated would perform well in salt contaminated concrete, indefinitely. Presently, the general opinion is that although bridge deck performance with epoxy-coated bars has been satisfactory, this corrosion control alternative may not provide the totally maintenance free service life that was forecast earlier.

Sufficient information in the literature is not available to precisely project the extended corrosion-free life as a result of the use of epoxy-coated bars. Agencies need to determine the extended life based on their own experience with the performance of bridge decks with epoxy-coated bars. A default value of 10 years is suggested for the extended corrosion-free life in the absence of any information. Accordingly, the following procedure is suggested to develop "Age Versus Condition" tables for bridge decks with epoxy-coated bars:

The "Age Versus Condition" tables developed for decks with uncoated reinforcing steel may be used for decks with epoxy-coated bars, provided the extended corrosion-free life is subtracted from the age of bridge decks. For example if the age of bridge decks with epoxy-coated bars is 18 years, and if the default value for the extended corrosion-free life from epoxy coating is used (i.e., 10 years), the Region condition state information for that bridge deck age can be obtained from the corresponding table for uncoated bars assuming a bridge deck age of 8 years (18-10=8 years).

Also any major rehabilitation on the concrete bridge deck must be considered in order to under rate the condition state of the concrete deck.

C-Index Numbers in Summary Pages:

- *For Bridge Deck*

BMS-OD
Expansion: Bridge Management System Optional Items Step Deck Compatibility Index
Source and the Contributing Factors: BMS Phase Optional Items Step is the source. Factors included in this index number are; Structure Type / FHWA, Bridge Deck Type, Wearing Surface Type, Type of Deck Reinforcement Bar Protection, Estimated Remaining Service Life.

BDDP
Expansion: Factored Deck Deficiency Points Index
Source and the Contributing Factors: BMS Phase Importance Factor and Deficiency Assessment Step is the source. Factors included in this index number are: Functional Classification, Bridge Deck Deficiency (BDD=0~50).

REGION
Expansion: Region Phase Deck Condition Index
Source and the Contributing Factors: Region Phase is the source. Factors included in this index number are; Quantifying Deicer Exposure (Low-1.5, Medium-3.7, High-7.5)-Tons/Lane-Mile/Yr, Quantifying Permeability -or w/c ratio- (Low-0.42 Medium-0.45 High-0.48), Quantifying Design Bar Cover Depth (Low-1.5, Medium-2.0, High-2.5)-inches, Age of the Bridge.

BMS-ID
Expansion: Bridge Management System Deck Importance Factor Index
Source and the Contributing Factors: BMS Phase Importance Factor and Deficiency Assessment Step is the source. Factors included in this index number are; Bridge Maintenance Activity Rank, Activity Urgency Factor, Bridge Criticality-Part A, Bridge Criticality-Part B, Bridge Criticality-Part C, Bridge Adequacy-Part A, Bridge Adequacy-Part B.

BMS-TDRD
Expansion: Bridge Management System Total Deficiency Rating (Deck)
Source and the Contributing Factors: BMS Phase Importance Factor and Deficiency Assessment Step is the source. Factor included in this index number is: Total Deficiency Rating (TDR=0~100).

BMS-OD * BMS-ID
Expansion: BMS-OD/BMS-ID Combined Index
Source and the Contributing Factors: Product of BMS-OD and BMS-ID indices.

REGION * BMS-ID
Expansion: REGION/BMS-ID Combined Index
Source and the Contributing Factors: Product of REGION and BMS-ID indices.

- *For Bridge Substructure*

BMS-OS
Expansion: Bridge Management System Optional Items Step Substructure Compatibility Index
Source and the Contributing Factors: BMS Phase Optional Items Step is the source. Factors included in this index number are: Structure Type / FHWA, Pier Material and Configuration, Estimated Remaining Service Life.

SBDP
Expansion: Factored Substructure Deficiency Points Index
Source and the Contributing Factors: BMS Phase Importance Factor and Deficiency Assessment Step is the source. Factors included in this index number are: Functional Classification, Substructure Deficiency (SBD=0~50).

BMS-IS
Expansion: Bridge Management System Substructure Importance Factor Index
Source and the Contributing Factors: BMS Phase Importance Factor and Deficiency Assessment Step is the source. Factors included in this index number are; Bridge Maintenance Activity Rank, Activity Urgency Factor, Bridge Criticality-Part A, Bridge Criticality-Part B, Bridge Criticality-Part C, Bridge Adequacy-Part A, Bridge Adequacy-Part B.

BMS-TDRS
Expansion: Bridge Management System Total Deficiency Rating (Substructure)
Source and the Contributing Factors: BMS Phase Importance Factor and Deficiency Assessment Step is the source. Factor included in this index number is: Total Deficiency Rating (TDR=0~100).

BMS-OS * BMS-IS
Expansion: BMS-OS/BMS-IS Combined Index
Source and the Contributing Factors: Product of BMS-OS and BMS-IS indices.

NOTES ABOUT THE *ECE* REAL TIME CASES:

Step 1:
Answer for Question 1→ "PennDOT has the maintenance responsibility" for all ECE Case Studies.

Step 3:
Answer for Question 1→ "Group C" for all ECE Case Studies.
Answer for Question 2→ "2" for ECE Case Study #16.
Answer for Question 3b→ "Agricultural" or "Industrial" for all ECE Case Studies.

ECE Case Study # / Date	1 / 1989, 1997, 1999
Member	PIERS
Location	Burlington, ON - CDN

Section 1 – BMS Required		**Section 2 – BMS Optional**		**Section 3 – BMS Importance**		**Section 4 – BMS Region**	
Q	***Answers***	***Q***	***Answers***	***Q***	***Answers***	***Q***	***Answers***
1	PennDOT has the …	**1**	Concrete	**1**	Group C	**I**	8.0
2	Concrete	**2**	Reinforced concrete	**2**	4	**II**	0.45
3	Reinforced concrete	**3a**	Bituminous	**3a**	Interstate	**III**	2.5
4	Satisfactory	**3b**	Pre-formed fabric	**3b**	Agricultural or industrial	**IV**	50
5	Fair	**3c**	Polymer impregnated	**3c**	> 30,000		
6	Poor	**4**	Bare reinforcement	**4a**	3 - 4		
7	N/a	**5**	Reinforced concrete	**4b**	> 30		
8	N/a	**6**	25	**5**	Interstate		
9	Meets min. limits			**6a**	N/a		
				6b	N/a		
				6c	N/a		

Result:	**Result:**		**Result:**		**Result:**	
PASSED	BMSOD	52	BMS-I	53	P-I	0
			TDR	N/a	P-II	0
	BMSOS	29	BDD	N/a	P-III	0
			SBD	N/a	P-IV	1
					P-V	98

REGION	99
BMS-OD * BMS-I	28
REGION * BMS-I	52
BMS-OS * BMS-I	15

ECE Case Study # / Date	2 / 1990
Member	PIERS
Location	Toronto, ON - CDN

Section 1 – BMS Required		**Section 2 – BMS Optional**		**Section 3 – BMS Importance**		**Section 4 – BMS Region**	
Q	***Answers***	***Q***	***Answers***	***Q***	***Answers***	***Q***	***Answers***
1	PennDOT has the…	**1**	Concrete continuous	**1**	Group C	**I**	4.0
2	Concrete continuous	**2**	Reinforced concrete	**2**	3	**II**	0.45
3	Reinforced concrete	**3a**	Concrete	**3a**	County	**III**	2.0
4	Satisfactory	**3b**	None	**3b**	Agricultural or industrial	**IV**	20
5	Satisfactory	**3c**	Polymer impregnated	**3c**	3,000 – 15,000		
6	Fair	**4**	Bare reinforcement	**4a**	3 – 4		
7	N/a	**5**	Reinforced concrete	**4b**	> 30		
8	N/a	**6**	20	**5**	Collector		
9	Meets min. limits			**6a**	N/a		
				6b	N/a		
				6c	N/a		

Result:	**Result:**		**Result:**		**Result:**	
PASSED	BMSOD	57	BMS-I	45	P-I	12
			TDR	N/a	P-II	17
	BMSOS	29	BDD	N/a	P-III	41
			SBD	N/a	P-IV	29
					P-V	1

REGION	71
BMS-OD * BMS-I	26
REGION * BMS-I	32
BMS-OS * BMS-I	13

ECE Case Study # / Date	3 / 1991
Member	RETAINING WALL (ABUTMENT)
Location	Route 90; Winnipeg, MB - CDN

Section 1 – BMS Required		**Section 2 – BMS Optional**		**Section 3 – BMS Importance**		**Section 4 – BMS Region**	
Q	***Answers***	***Q***	***Answers***	***Q***	***Answers***	***Q***	***Answers***
1	PennDOT has the…	**1**	Concrete	**1**	Group C	**I**	4.0
2	Concrete	**2**	Concrete w/ CP	**2**	3	**II**	0.42
3	Concrete w/ CP	**3a**	Concrete	**3a**	City	**III**	2.0
4	Poor	**3b**	None	**3b**	Agricultural or industrial	**IV**	15
5	Fair	**3c**	Concrete w/ CP	**3c**	15,000 – 30,000		
6	Fair	**4**	Bare reinforcement	**4a**	3 – 4		
7	N/a	**5**	Reinforced concrete	**4b**	> 30		
8	N/a	**6**	30	**5**	Arterial		
9	High priority corrective			**6a**	N/a		
				6b	N/a		
				6c	N/a		

Result:	**Result:**		**Result:**		**Result:**	
PASSED	BMSOD	35	BMS-I	49	P-I	41
			TDR	N/a	P-II	39
	BMSOS	29	BDD	N/a	P-III	19
			SBD	N/a	P-IV	0
					P-V	1

REGION	20
BMS-OD * BMS-I	17
REGION * BMS-I	10
BMS-OS * BMS-I	14

ECE Case Study # / Date	4 / 1994
Member	PIERS
Location	Hwy 11&16; Saskatoon, SK - CDN

Section 1 – BMS Required		**Section 2 – BMS Optional**		**Section 3 – BMS Importance**		**Section 4 – BMS Region**	
Q	***Answers***	***Q***	***Answers***	***Q***	***Answers***	***Q***	***Answers***
1	PennDOT has the…	**1**	Concrete continuous	**1**	Group C	**I**	4.0
2	Concrete continuous	**2**	Reinforced concrete	**2**	2	**II**	0.42
3	Reinforced concrete	**3a**	Bituminous	**3a**	Interstate	**III**	2.0
4	Fair	**3b**	Pre-formed fabric	**3b**	Agricultural or industrial	**IV**	25
5	Satisfactory	**3c**	Dense bituminous	**3c**	15,000 – 30,000		
6	Satisfactory	**4**	Bare reinforcement	**4a**	4 – 5		
7	N/a	**5**	Reinforced concrete	**4b**	> 30		
8	N/a	**6**	25	**5**	Interstate		
9	Better than min.			**6a**	N/a		
				6b	N/a		
				6c	N/a		

Result:	**Result:**		**Result:**		**Result:**	
PASSED	BMSOD	70	BMS-I	53	P-I	22
			TDR	N/a	P-II	30
	BMSOS	29	BDD	N/a	P-III	41
			SBD	N/a	P-IV	7
					P-V	1

REGION	49
BMS-OD * BMS-I	37
REGION * BMS-I	26
BMS-OS * BMS-I	15

ECE Case Study # / Date	5 / 1995
Member	PIERS
Location	Morinville, AB - CDN

Section 1 – BMS Required		Section 2 – BMS Optional		Section 3 – BMS Importance		Section 4 – BMS Region	
Q	***Answers***	***Q***	***Answers***	***Q***	***Answers***	***Q***	***Answers***
1	PennDOT has the…	**1**	Concrete continuous	**1**	Group C	**I**	2.0
2	Concrete continuous	**2**	Reinforced concrete	**2**	2	**II**	0.42
3	Reinforced concrete	**3a**	Bituminous	**3a**	State	**III**	2.0
4	Satisfactory	**3b**	Built-up	**3b**	Agricultural or industrial	**IV**	25
5	Fair	**3c**	None	**3c**	3,000 – 15,000		
6	Satisfactory	**4**	Bare reinforcement	**4a**	4 – 5		
7	N/a	**5**	Reinforced concrete	**4b**	> 30		
8	N/a	**6**	25	**5**	Arterial		
9	Better than min.			**6a**	N/a		
				6b	N/a		
				6c	N/a		

Result:	**Result:**		**Result:**		**Result:**	
PASSED	BMSOD	74	BMS-I	46	P-I	44
			TDR	N/a	P-II	39
	BMSOS	29	BDD	N/a	P-III	16
			SBD	N/a	P-IV	0
					P-V	1

REGION	17
BMS-OD * BMS-I	34
REGION * BMS-I	8
BMS-OS * BMS-I	13

ECE Case Study # / Date	6 / 1995
Member	DECK
Location	Arlington, VA - CDN

Section 1 – BMS Required		**Section 2 – BMS Optional**		**Section 3 – BMS Importance**		**Section 4 – BMS Region**	
Q	***Answers***	***Q***	***Answers***	***Q***	***Answers***	***Q***	***Answers***
1	PennDOT has the…	**1**	Concrete	**1**	Group C	**I**	1.0
2	Concrete	**2**	Reinforced concrete	**2**	3	**II**	0.45
3	Reinforced concrete	**3a**	Concrete	**3a**	City	**III**	1.5
4	Fair	**3b**	None	**3b**	Agricultural or industrial	**IV**	30
5	Fair	**3c**	None	**3c**	< 3,000		
6	Fair	**4**	Bare reinforcement	**4a**	4 – 5		
7	N/a	**5**	Reinforced concrete	**4b**	20 – 30		
8	N/a	**6**	25	**5**	Local		
9	Better than min.			**6a**	N/a		
				6b	N/a		
				6c	N/a		

Result:	**Result:**		**Result:**		**Result:**	
PASSED	BMSOD	78	BMS-I	38	P-I	6
			TDR	N/a	P-II	8
	BMSOS	29	BDD	N/a	P-III	24
			SBD	N/a	P-IV	56
					P-V	7

REGION	87
BMS-OD * BMS-I	30
REGION * BMS-I	33
BMS-OS * BMS-I	11

ECE Case Study # / Date	7 / 1995
Member	PIERS
Location	Hwy. 1&6; Regina, SK - CDN

Section 1 – BMS Required		Section 2 – BMS Optional		Section 3 – BMS Importance		Section 4 – BMS Region	
Q	*Answers*	*Q*	*Answers*	*Q*	*Answers*	*Q*	*Answers*
1	PennDOT has the…	**1**	Concrete continuous	**1**	Group C	**I**	4.0
2	Concrete continuous	**2**	Reinforced concrete	**2**	3	**II**	0.45
3	Reinforced concrete	**3a**	Bituminous	**3a**	Interstate	**III**	2.0
4	Fair	**3b**	Built-up	**3b**	Agricultural or industrial	**IV**	30
5	Fair	**3c**	Dense bituminous	**3c**	15,000 – 30,000		
6	Fair	**4**	Bare reinforcement	**4a**	4 – 5		
7	N/a	**5**	Reinforced concrete	**4b**	> 30		
8	N/a	**6**	20	**5**	Interstate		
9	Better than min.			**6a**	N/a		
				6b	N/a		
				6c	N/a		

Result:		**Result:**		**Result:**		**Result:**	
PASSED		BMSOD	70	BMS-I	48	P-I	4
				TDR	N/a	P-II	5
		BMSOS	29	BDD	N/a	P-III	15
				SBD	N/a	P-IV	55
						P-V	21

REGION	91
BMS-OD * BMS-I	34
REGION * BMS-I	44
BMS-OS * BMS-I	14

ECE Case Study # / Date	8 / 1995
Member	PIERS
Location	Charlottesville, VA - USA

Section 1 – BMS Required		**Section 2 – BMS Optional**		**Section 3 – BMS Importance**		**Section 4 – BMS Region**	
Q	***Answers***	***Q***	***Answers***	***Q***	***Answers***	***Q***	***Answers***
1	PennDOT has the…	**1**	Concrete	**1**	Group C	**I**	2.0
2	Concrete	**2**	Reinforced concrete	**2**	3	**II**	0.45
3	Reinforced concrete	**3a**	Epoxy overlay	**3a**	City	**III**	2.0
4	Fair	**3b**	Epoxy	**3b**	Agricultural or industrial	**IV**	20
5	Satisfactory	**3c**	None	**3c**	3,000 – 15,000		
6	Satisfactory	**4**	Bare reinforcement	**4a**	4 – 5		
7	N/a	**5**	Reinforced concrete	**4b**	> 30		
8	N/a	**6**	20	**5**	Local		
9	Better than min.			**6a**	N/a		
				6b	N/a		
				6c	N/a		

Result:	**Result:**		**Result:**		**Result:**	
PASSED	BMSOD	70	BMS-I	39	P-I	30
			TDR	N/a	P-II	36
	BMSOS	29	BDD	N/a	P-III	31
			SBD	N/a	P-IV	2
					P-V	1

REGION	34
BMS-OD * BMS-I	27
REGION * BMS-I	13
BMS-OS * BMS-I	11

ECE Case Study # / Date	9 / 1995
Member	PIERS
Location	Hwy. 6&11; Regina, SK - CDN

Section 1 – BMS Required		**Section 2 – BMS Optional**		**Section 3 – BMS Importance**		**Section 4 – BMS Region**	
Q	***Answers***	***Q***	***Answers***	***Q***	***Answers***	***Q***	***Answers***
1	PennDot has the…	**1**	Concrete continuous	**1**	Group C	**I**	4.0
2	Concrete continuous	**2**	Concrete w/ CP	**2**	2	**II**	0.45
3	Concrete w/ CP	**3a**	Bituminous	**3a**	Interstate	**III**	2.0
4	Fair	**3b**	Built-up	**3b**	Agricultural or industrial	**IV**	25
5	Fair	**3c**	Concrete w/ CP	**3c**	15,000 – 30,000		
6	Fair	**4**	Bare reinforcement	**4a**	4 – 5		
7	N/a	**5**	Reinforced concrete	**4b**	> 30		
8	N/a	**6**	25	**5**	Interstate		
9	Better than min.			**6a**	N/a		
				6b	N/a		
				6c	N/a		
Result:		**Result:**		**Result:**		**Result:**	
PASSED		BMSOD	30	BMS-I	53	P-I	7
				TDR	N/a	P-II	9
		BMSOS	29	BDD	N/a	P-III	28
				SBD	N/a	P-IV	51
						P-V	4

REGION	83
BMS-OD * BMS-I	16
REGION * BMS-I	44
BMS-OS * BMS-I	15

ECE Case Study # / Date	10 / 1997
Member	DECK
Location	Seaford, DE - US

Section 1 – BMS Required		**Section 2 – BMS Optional**		**Section 3 – BMS Importance**		**Section 4 – BMS Region**	
Q	***Answers***	***Q***	***Answers***	***Q***	***Answers***	***Q***	***Answers***
1	PennDot has the…	**1**	Concrete	**1**	Group C	**I**	1.0
2	Concrete	**2**	Reinforced concrete	**2**	3	**II**	0.50
3	Reinforced concrete	**3a**	Bituminous	**3a**	State	**III**	1.5
4	Poor	**3b**	None	**3b**	Agricultural or industrial	**IV**	55
5	Satisfactory	**3c**	Dense bituminous	**3c**	< 3,000		
6	Satisfactory	**4**	Bare reinforcement	**4a**	4 – 5		
7	N/a	**5**	Plain concrete	**4b**	20 – 30		
8	N/a	**6**	30	**5**	Arterial		
9	High priority corrective			**6a**	N/a		
				6b	N/a		
				6c	N/a		

Result:	**Result:**		**Result:**		**Result:**	
PASSED	BMSOD	70	BMS-I	40	P-I	0
			TDR	N/a	P-II	0
	BMSOS	29	BDD	N/a	P-III	0
			SBD	N/a	P-IV	0
					P-V	100

REGION	100
BMS-OD * BMS-I	28
REGION * BMS-I	40
BMS-OS * BMS-I	12

ECE Case Study # / Date	11 / 1997
Member	DRAINAGE CHAMBERS
Location	Toronto, ON - CDN

Section 1 – BMS Required		**Section 2 – BMS Optional**		**Section 3 – BMS Importance**		**Section 4 – BMS Region**	
Q	***Answers***	***Q***	***Answers***	***Q***	***Answers***	***Q***	***Answers***
1	PennDOT has the…	**1**	Prestress concrete cont.	**1**	Group C	**I**	4.0
2	Prestress concrete cont.	**2**	Post-tensioned CIP	**2**	3	**II**	0.45
3	Post-tensioned CIP	**3a**	Bituminous	**3a**	City	**III**	3.0
4	Fair	**3b**	Built-up	**3b**	Agricultural or industrial	**IV**	30
5	Satisfactory	**3c**	Polymer impregnation	**3c**	< 3,000		
6	Satisfactory	**4**	Bare reinforcement	**4a**	4 – 5		
7	N/a	**5**	Reinforced concrete	**4b**	> 30		
8	N/a	**6**	25	**5**	Local		
9	Meets min. limits			**6a**	N/a		
				6b	N/a		
				6c	N/a		

Result:	**Result:**		**Result:**		**Result:**	
PASSED	BMSOD	43	BMS-I	34	P-I	76
			TDR	N/a	P-II	22
	BMSOS	14	BDD	N/a	P-III	1
			SBD	N/a	P-IV	0
					P-V	1

REGION	2
BMS-OD * BMS-I	15
REGION * BMS-I	1
BMS-OS * BMS-I	5

ECE Case Study # / Date	12 / 1997
Member	DECK
Location	Starbuck, MB - CDN

Section 1 – BMS Required		**Section 2 – BMS Optional**		**Section 3 – BMS Importance**		**Section 4 – BMS Region**	
Q	***Answers***	***Q***	***Answers***	***Q***	***Answers***	***Q***	***Answers***
1	PennDOT has the…	**1**	Concrete	**1**	Group C	**I**	1.0
2	Concrete	**2**	Reinforced concrete	**2**	1	**II**	0.45
3	Reinforced concrete	**3a**	Concrete	**3a**	City	**III**	2.0
4	Poor	**3b**	None	**3b**	Agricultural or industrial	**IV**	30
5	Fair	**3c**	None	**3c**	< 3,000		
6	Satisfactory	**4**	Bare reinforcement	**4a**	4 – 5		
7	N/a	**5**	Reinforced concrete	**4b**	12 – 20		
8	N/a	**6**	20	**5**	Local		
9	Meets min. limits			**6a**	N/a		
				6b	N/a		
				6c	N/a		

Result:	**Result:**		**Result:**		**Result:**	
PASSED	BMSOD	78	BMS-I	51	P-I	37
			TDR	N/a	P-II	39
	BMSOS	29	BDD	N/a	P-III	23
			SBD	N/a	P-IV	1
					P-V	1

REGION	25
BMS-OD * BMS-I	40
REGION * BMS-I	13
BMS-OS * BMS-I	15

ECE Case Study # / Date	13 / 1997
Member	PIERS
Location	I-394; Minneapolis, MN - USA

Section 1 – BMS Required		**Section 2 – BMS Optional**		**Section 3 – BMS Importance**		**Section 4 – BMS Region**	
Q	***Answers***	***Q***	***Answers***	***Q***	***Answers***	***Q***	***Answers***
1	PennDOT has the…	**1**	Prestressed concrete	**1**	Group C	**I**	6.0
2	Prestressed concrete	**2**	Reinforced concrete	**2**	3	**II**	0.45
3	Reinforced concrete	**3a**	Concrete	**3a**	Interstate	**III**	2.0
4	Fair	**3b**	None	**3b**	Agricultural or industrial	**IV**	30
5	Fair	**3c**	None	**3c**	> 30,000		
6	Poor	4	Bare reinforcement	**4a**	3 – 4		
7	N/a	**5**	Other – glass & carbon fiber wraps afterward	**4b**	> 30		
8	N/a	**6**	20	**5**	Interstate		
9	High priority of corrective			**6a**	N/a		
				6b	N/a		
				6c	N/a		

Result:	**Result:**		**Result:**		**Result:**	
PASSED	BMSOD	74	BMS-I	58	P-I	1
			TDR	N/a	P-II	0
	BMSOS	14	BDD	N/a	P-III	1
			SBD	N/a	P-IV	4
					P-V	94

REGION	99
BMS-OD * BMS-I	43
REGION * BMS-I	57
BMS-OS * BMS-I	8

ECE Case Study # / Date	14 / 1998
Member	PIERS
Location	Council Bluffs, IA - USA

Section 1 – BMS Required		**Section 2 – BMS Optional**		**Section 3 – BMS Importance**		**Section 4 – BMS Region**	
Q	***Answers***	***Q***	***Answers***	***Q***	***Answers***	***Q***	***Answers***
1	PennDOT has the…	**1**	Pre-stress concrete cont.	**1**	Group C	**I**	3.0
2	Pre-stress concrete cont.	**2**	Reinforced concrete	**2**	3	**II**	0.45
3	Reinforced concrete	**3a**	Low slump overlay	**3a**	County	**III**	2.0
4	Fair	**3b**	None	**3b**	Agricultural or industrial	**IV**	35
5	Serious	**3c**	None	**3c**	3,000 – 15,000		
6	Fair	**4**	Bare reinforcement	**4a**	4 – 5		
7	N/a	**5**	Reinforced concrete	**4b**	20 – 30		
8	N/a	**6**	20	**5**	Arterial		
9	Meets min. limits			**6a**	N/a		
				6b	N/a		
				6c	N/a		
<u>Result:</u>		**<u>Result:</u>**		**<u>Result:</u>**		**<u>Result:</u>**	
PASSED		BMSOD	74	BMS-I	44	P-I	6
				TDR	N/a	P-II	7
		BMSOS	14	BDD	N/a	P-III	23
				SBD	N/a	P-IV	56
						P-V	8

REGION	87
BMS-OD * BMS-I	33
REGION * BMS-I	38
BMS-OS * BMS-I	6

ECE Case Study # / Date	15 / 1998
Member	PIERS
Location	Peoria, IL – USA

Section 1 – BMS Required		Section 2 – BMS Optional		Section 3 – BMS Importance		Section 4 – BMS Region	
Q	***Answers***	***Q***	***Answers***	***Q***	***Answers***	***Q***	***Answers***
1	PennDOT has the…	**1**	Concrete	**1**	Group C	**I**	6.0
2	Concrete	**2**	Reinforced concrete	**2**	2	**II**	0.45
3	Reinforced concrete	**3a**	Concrete overlay	**3a**	State	**III**	2.5
4	Fair	**3b**	None	**3b**	Agricultural or industrial	**IV**	30
5	Fair	**3c**	None	**3c**	3,000 – 15,000		
6	Fair	**4**	Bare reinforcement	**4a**	4 – 5		
7	N/a	**5**	Reinforced concrete	**4b**	> 30		
8	N/a	**6**	15	**5**	Collector		
9	Better than min.			**6a**	N/a		
				6b	N/a		
				6c	N/a		
Result:		**Result:**		**Result:**		**Result:**	
PASSED		BMSOD	91	BMS-I	46	P-I	16
				TDR	N/a	P-II	23
		BMSOS	71	BDD	N/a	P-III	44
				SBD	N/a	P-IV	17
						P-V	1

REGION	62
BMS-OD * BMS-I	42
REGION * BMS-I	29
BMS-OS * BMS-I	33

ECE Case Study # / Date	16 / 1998
Member	DECK
Location	St. Adolphe, MB – CDN

Section 1 – BMS Required		Section 2 – BMS Optional		Section 3 – BMS Importance		Section 4 – BMS Region	
Q	***Answers***	***Q***	***Answers***	***Q***	***Answers***	***Q***	***Answers***
1	PennDOT has the…	**1**	Concrete	**1**	Group C	**I**	3.0
2	Concrete	**2**	Reinforced concrete	**2**	2	**II**	0.45
3	Reinforced concrete	**3a**	Bituminous	**3a**	State	**III**	2.0
4	Fair	**3b**	Pre-formed fabric	**3b**	Agricultural or industrial	**IV**	30
5	Satisfactory	**3c**	None	**3c**	< 3,000		
6	Satisfactory	**4**	Bare reinforcement	**4a**	4 – 5		
7	N/a	**5**	Reinforced concrete	**4b**	20 – 30		
8	N/a	**6**	20	**5**	Collector		
9	Meets the min. limits			**6a**	N/a		
				6b	N/a		
				6c	N/a		
Result:		**Result:**		**Result:**		**Result:**	
PASSED		BMSOD	74	BMS-I	45	P-I	8
				TDR	N/a	P-II	12
		BMSOS	29	BDD	N/a	P-III	33
				SBD	N/a	P-IV	45
						P-V	2

REGION	80
BMS-OD * BMS-I	33
REGION * BMS-I	36
BMS-OS * BMS-I	13

ECE Case Study # / Date	17 / 1998
Member	PIERS
Location	Pembina Hwy.; Winnipeg, MB - CDN

Section 1 – BMS Required		**Section 2 – BMS Optional**		**Section 3 – BMS Importance**		**Section 4 – BMS Region**	
Q	***Answers***	***Q***	***Answers***	***Q***	***Answers***	***Q***	***Answers***
1	PennDOT has the…	**1**	Concrete	**1**	Group C	**I**	4.0
2	Concrete	**2**	Reinforced concrete	**2**	3	**II**	0.45
3	Reinforced concrete	**3a**	Bituminous	**3a**	Interstate	**III**	2.0
4	Satisfactory	**3b**	Built-up	**3b**	Agricultural or industrial	**IV**	30
5	Satisfactory	**3c**	None	**3c**	3,000 – 15,000		
6	Fair	**4**	Bare reinforcement	**4a**	3 – 4		
7	N/a	**5**	Reinforced concrete	**4b**	> 30		
8	N/a	**6**	20	**5**	Interstate		
9	Meets the min. limits			**6a**	N/a		
				6b	N/a		
				6c	N/a		

Result:		**Result:**		**Result:**		**Result:**	
PASSED		BMSOD	74	BMS-I	48	P-I	4
				TDR	N/a	P-II	5
		BMSOS	29	BDD	N/a	P-III	15
				SBD	N/a	P-IV	55
						P-V	21

REGION	91
BMS-OD * BMS-I	36
REGION * BMS-I	44
BMS-OS * BMS-I	14

ECE Case Study # / Date	18 / 1998, 1999
Member	HAMMERHEAD PIERS
Location	I-480; Omaha, NE - CDN

Section 1 – BMS Required		**Section 2 – BMS Optional**		**Section 3 – BMS Importance**		**Section 4 – BMS Region**	
Q	***Answers***	***Q***	***Answers***	***Q***	***Answers***	***Q***	***Answers***
1	PennDOT has the…	**1**	Concrete continuous	**1**	Group C	**I**	3.0
2	Concrete continuous	**2**	Concrete filled metal	**2**	4	**II**	0.45
3	Concrete filled metal	**3a**	Latex overlay	**3a**	Interstate	**III**	2.0
4	Critical	**3b**	None	**3b**	Agricultural or industrial	**IV**	30
5	Fair	**3c**	None	**3c**	> 30,000		
6	Serious	**4**	Bare reinforcement	**4a**	< 3		
7	N/a	**5**	Reinforced concrete	**4b**	> 30		
8	N/a	**6**	40	**5**	Interstate		
9	High priority for rplmnt.			**6a**	N/a		
				6b	N/a		
				6c	N/a		

<u>Result:</u>	**<u>Result:</u>**		**<u>Result:</u>**		**<u>Result:</u>**	
PASSED	BMSOD	74	BMS-I	58	P-I	8
			TDR	N/a	P-II	12
	BMSOS	29	BDD	N/a	P-III	33
			SBD	N/a	P-IV	45
					P-V	2

REGION	80
BMS-OD * BMS-I	43
REGION * BMS-I	46
BMS-OS * BMS-I	17

ECE Case Study # / Date	19 / 1999
Member	PIER
Location	Minot, ND - CDN

Section 1 – BMS Required

Q	*Answers*
1	PennDOT has the…
2	Concrete
3	Reinforced concrete
4	Fair
5	Poor
6	Fair
7	N/a
8	N/a
9	Better than min.

Result:

PASSED

Section 2 – BMS Optional

Q	*Answers*
1	Concrete
2	Reinforced concrete
3a	Concrete
3b	None
3c	None
4	Bare reinforcement
5	Reinforced concrete
6	15

Result:

BMSOD	91
BMSOS	71

Section 3 – BMS Importance

Q	*Answers*
1	Group C
2	3
3a	City
3b	Agricultural or industrial
3c	<3,000
4a	4 – 5
4b	12 – 20
5	Local
6a	N/a
6b	N/a
6c	N/a

Result:

BMS-I	41
TDR	N/a
BDD	N/a
SBD	N/a

Section 4 – BMS Region

Q	*Answers*
I	2.0
II	0.50
III	2.0
IV	70

Result:

P-I	0
P-II	0
P-III	0
P-IV	0
P-V	100

REGION	100
BMS-OD * BMS-I	37
REGION * BMS-I	41
BMS-OS * BMS-I	29

ECE Case Study # / Date	20 / 1999
Member	RETAINING WALL (ABUTMENT)
Location	Washington DC - USA

Section 1 – BMS Required		Section 2 – BMS Optional		Section 3 – BMS Importance		Section 4 – BMS Region	
Q	***Answers***	***Q***	***Answers***	***Q***	***Answers***	***Q***	***Answers***
1	PennDOT has the…	**1**	Concrete	**1**	Group C	**I**	1.0
2	Concrete	**2**	Reinforced concrete	**2**	5	**II**	0.48
3	Reinforced concrete	**3a**	Bituminous	**3a**	City	**III**	1.5
4	Serious	**3b**	None	**3b**	Agricultural or industrial	**IV**	60
5	Poor	**3c**	None	**3c**	< 3,000		
6	Critical	**4**	Bare reinforcement	**4a**	< 3		
7	N/a	**5**	Reinforced concrete	**4b**	< 12		
8	N/a	**6**	40	**5**	Local		
9	High priority for rplmnt.			**6a**	N/a		
				6b	N/a		
				6c	N/a		

Result:	**Result:**		**Result:**		**Result:**	
PASSED	BMSOD	74	BMS-I	44	P-I	0
			TDR	N/a	P-II	0
	BMSOS	29	BDD	N/a	P-III	0
			SBD	N/a	P-IV	0
					P-V	100

REGION	100
BMS-OD * BMS-I	33
REGION * BMS-I	44
BMS-OS * BMS-I	13

ECE Case Study # / Date	21 / 1999						
Member	PIERS						
Location	Jackson, MI - USA						
Section 1 – BMS Required		**Section 2 – BMS Optional**		**Section 3 – BMS Importance**		**Section 4 – BMS Region**	
Q	***Answers***	***Q***	***Answers***	***Q***	***Answers***	***Q***	***Answers***
1	PennDOT has the…	**1**	Concrete	**1**	Group C	**I**	7.0
2	Concrete	**2**	Reinforced concrete	**2**	2	**II**	0.45
3	Reinforced concrete	**3a**	Concrete	**3a**	State	**III**	2.0
4	Fair	**3b**	None	**3b**	Agricultural or industrial	**IV**	35
5	Fair	**3c**	None	**3c**	> 30,000		
6	Fair	**4**	Bare reinforcement	**4a**	3 – 4		
7	N/a	**5**	Reinforced concrete	**4b**	> 30		
8	N/a	**6**	20	**5**	Interstate		
9	Meets min. limits			**6a**	N/a		
				6b	N/a		
				6c	N/a		

Result:	**Result:**		**Result:**		**Result:**	
PASSED	BMSOD	78	BMS-I	61	P-I	0
			TDR	N/a	P-II	0
	BMSOS	29	BDD	N/a	P-III	0
			SBD	N/a	P-IV	0
					P-V	100

REGION	100
BMS-OD * BMS-I	48
REGION * BMS-I	61
BMS-OS * BMS-I	18

ECE Case Study # / Date	22 / 2000
Member	ABUTMENTS, WING-WALLS, RETAINING WALLS
Location	North Bay, ON - CDN

Section 1 – BMS Required		**Section 2 – BMS Optional**		**Section 3 – BMS Importance**		**Section 4 – BMS Region**	
Q	***Answers***	***Q***	***Answers***	***Q***	***Answers***	***Q***	***Answers***
1	PennDOT has the…	**1**	Concrete	**1**	Group C	**I**	3.0
2	Concrete	**2**	Reinforced concrete	**2**	3	**II**	0.40
3	Reinforced concrete	**3a**	Bituminous	**3a**	Interstate	**III**	2.0
4	Poor	**3b**	Built-up	**3b**	Agricultural or industrial	**IV**	20
5	Fair	**3c**	None	**3c**	15,000 – 30,000		
6	Fair	**4**	Bare reinforcement	**4a**	3 – 4		
7	N/a	**5**	Reinforced concrete	**4b**	20 – 30		
8	N/a	**6**	40	**5**	Interstate		
9	High priority of corrective			**6a**	N/a		
				6b	N/a		
				6c	N/a		

<u>Result:</u>	**<u>Result:</u>**		**<u>Result:</u>**		**<u>Result:</u>**	
PASSED	BMSOD	74	BMS-I	57	P-I	55
			TDR	N/a	P-II	36
	BMSOS	29	BDD	N/a	P-III	8
			SBD	N/a	P-IV	0
					P-V	1

REGION	9
BMS-OD * BMS-I	42
REGION * BMS-I	5
BMS-OS * BMS-I	17

ECE Case Study #	Struc.Type	BMS-OD	BMS-OS	BMS-I	R-I	R-II	R-III	R-IV	R-V	REGION	BMS-OD*BMSI	REGION*BMS-I	BMS-OS*BMS-I
1	subst.	52	29	53	0	0	0	0	0	99	28	52	15
2	subst.	57	29	45	12	17	41	29	1	71	26	32	13
3	subst.	35	29	49	41	39	19	0	1	20	17	10	14
4	subst.	70	29	53	22	30	41	7	1	49	37	26	15
5	subst.	74	29	46	44	39	16	0	1	17	34	8	13
6	*deck*	78	29	38	6	8	24	56	7	87	30	33	11
7	subst.	70	29	48	4	5	15	55	21	91	34	44	14
8	subst.	70	29	39	30	36	31	2	1	34	27	13	11
9	subst.	30	29	53	7	9	28	51	4	83	16	44	15
10	*deck*	70	29	40	0	0	0	0	100	100	28	40	12
11	subst.	43	14	34	76	22	1	0	1	2	15	1	5
12	*deck*	78	29	51	37	39	23	1	1	25	40	13	15
13	subst.	74	14	58	1	0	1	4	94	99	43	57	8
14	subst.	74	14	44	6	7	23	56	8	87	33	38	6
15	subst.	91	71	46	16	23	44	17	1	62	42	29	33
16	*deck*	74	29	45	8	12	33	45	2	80	33	36	13
17	subst.	74	29	48	4	5	15	55	21	91	36	44	14
18	subst.	74	29	58	8	12	33	45	2	80	43	46	17
19	subst.	91	71	41	0	0	0	0	100	100	37	41	29
20	subst.	74	29	44	0	0	0	0	100	100	33	44	13
21	subst.	78	29	61	0	0	0	0	100	100	48	61	18
22	subst.	74	29	57	55	36	8	0	1	9	42	5	17
ECE Case Study #	**Struc.Type**	**BMS-OD**	**BMS-OS**	**BMS-I**	**R-I**	**R-II**	**R-III**	**R-IV**	**R-V**	**REGION**	**BMS-OD*BMSI**	**REGION*BMS-I**	**BMS-OS*BMS-I**

	BMS-OD	BMS-OS	BMS-I	R-I	R-II	R-III	R-IV	R-V	REGION	BMS-OD*BMSI	REGION*BMS-I	BMS-OS*BMS-I
All-Min.	N/A	N/A	**34**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
All-Max.	N/A	N/A	**61**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
All-avrg.	N/A	N/A	**48**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Deck-Min.	**70**	N/A	**38**	**0**	**0**	**0**	**0**	**1**	**25**	**28**	**13**	N/A
Deck-Max.	**78**	N/A	**51**	**37**	**39**	**33**	**56**	**100**	**100**	**40**	**40**	N/A
Deck-avrg.	**75**	N/A	**44**	**13**	**15**	**20**	**26**	**28**	**73**	**33**	**31**	N/A
Subst.-Min.	N/A	**14**	**34**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	**5**
Subst.-Max.	N/A	**71**	**61**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	**33**
Subst.-avrg.	N/A	**31**	**49**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	**15**

BMS-OD	BMS-OS	BMS-I	R-I	R-II	R-III	R-IV	R-V	REGION	BMS-OD*BMSI	REGION*BMS-I	BMS-OS*BMS-I

NOTES ABOUT THE *LOCAL TREATMENT* REAL TIME CASES:

Step 1:
Answer for Question 1→ "PennDOT has the maintenance responsibility" for all Local Treatment Case Studies.

Step 3:
Answer for Question 1→ "Group C" for all Local Treatment Case Studies.
Answer for Question 3b→ "Agricultural" or "Industrial" for all Local Treatment Case Studies.

Local Trt. Case Study # / Date	1 / 2000
Member	DECK
Location	British Columbia Ministry of Transportation & Highways; Revierstoke - CDN

Section 1 – BMS Required		**Section 2 – BMS Optional**		**Section 3 – BMS Importance**		**Section 4 – BMS Region**	
Q	***Answers***	***Q***	***Answers***	***Q***	***Answers***	***Q***	***Answers***
1	PennDOT has the…	**1**	Concrete	**1**	Group C	**I**	7.5
2	Concrete	**2**	Reinforced concrete	**2**	5	**II**	0.48
3	Reinforced concrete	**3a**	Concrete	**3a**	State	**III**	2.5
4	Serious	**3b**	None	**3b**	PCN	**IV**	20
5	Serious	**3c**	None	**3c**	15,000 – 30,000		
6	Fair	**4**	Dual protection	**4a**	< 3		
7	N/a	**5**	Reinforced concrete	**4b**	> 30		
8	N/a	**6**	25	**5**	Arterial		
9	High priority of corrective			**6a**	N/a		
				6b	N/a		
				6c	N/a		

<u>**Result:**</u>	<u>**Result:**</u>		<u>**Result:**</u>		<u>**Result:**</u>	
PASSED	BMSOD	57	BMS-I	48	P-I	8
			TDR	N/a	P-II	11
	BMSOS	29	BDD	N/a	P-III	31
			SBD	N/a	P-IV	48
					P-V	3

REGION	82
BMS-OD * BMS-I	27
REGION * BMS-I	39
BMS-OS * BMS-I	14

Local Trt. Case Study # / Date	2 / 2000
Member	BRIDGE WIDENING
Location	British Columbia Ministry of Transportation & Highways; Vancouver - CDN

Section 1 – BMS Required		**Section 2 – BMS Optional**		**Section 3 – BMS Importance**		**Section 4 – BMS Region**	
Q	***Answers***	***Q***	***Answers***	***Q***	***Answers***	***Q***	***Answers***
1	PennDOT has the…	**1**	Concrete	**1**	Group C	**I**	3.7
2	Concrete	**2**	Reinforced concrete	**2**	1	**II**	0.42
3	Reinforced concrete	**3a**	Bituminous	**3a**	Interstate	**III**	2.5
4	Satisfactory	**3b**	Other	**3b**	PCN	**IV**	30
5	Satisfactory	**3c**	Dense bituminous	**3c**	> 30,000		
6	Satisfactory	**4**	Bare reinforcement	**4a**	> 5		
7	N/a	**5**	Reinforced concrete	**4b**	> 30		
8	N/a	**6**	25	**5**	Interstate		
9	Better than min.			**6a**	N/a		
				6b	N/a		
				6c	N/a		
Result:		**Result:**		**Result:**		**Result:**	
PASSED		BMSOD	65	BMS-I	60	P-I	61
				TDR	N/a	P-II	33
		BMSOS	29	BDD	N/a	P-III	5
				SBD	N/a	P-IV	0
						P-V	1

REGION	6
BMS-OD * BMS-I	39
REGION * BMS-I	4
BMS-OS * BMS-I	17

Local Trt. Case Study # / Date	3 / 2000
Member	PRECAST CHANNELS
Location	Red Deer - CDN

Section 1 – BMS Required		**Section 2 – BMS Optional**		**Section 3 – BMS Importance**		**Section 4 – BMS Region**	
Q	***Answers***	***Q***	***Answers***	***Q***	***Answers***	***Q***	***Answers***
1	PennDOT has the…	**1**	Concrete	**1**	Group C	**I**	1.5
2	Concrete	**2**	Pre-cast reinforced	**2**	4	**II**	0.42
3	Pre-cast reinforced	**3a**	Bituminous	**3a**	City	**III**	1.5
4	Fair	**3b**	Built-up	**3b**	Industrial	**IV**	20
5	Serious	**3c**	Dense bituminous	**3c**	< 3,000		
6	Satisfactory	**4**	Bare reinforcement	**4a**	> 5		
7	N/a	**5**	Reinforced concrete	**4b**	12 – 20		
8	N/a	**6**	25	**5**	Local		
9	High priority of corrective			**6a**	N/a		
				6b	N/a		
				6c	N/a		

Result:	**Result:**		**Result:**		**Result:**	
PASSED	BMSOD	70	BMS-I	31	P-I	17
			TDR	N/a	P-II	24
	BMSOS	29	BDD	N/a	P-III	44
			SBD	N/a	P-IV	14
					P-V	1

REGION	59
BMS-OD * BMS-I	22
REGION * BMS-I	18
BMS-OS * BMS-I	9

Local Trt. Case Study # / Date	4 / 2000
Member	SUBSTRUCTURE
Location	Winnipeg - CDN

Section 1 – BMS Required		**Section 2 – BMS Optional**		**Section 3 – BMS Importance**		**Section 4 – BMS Region**	
Q	***Answers***	***Q***	***Answers***	***Q***	***Answers***	***Q***	***Answers***
1	PennDOT has the…	**1**	Pre-stress concrete	**1**	Group C	**I**	3.7
2	Pre-stress concrete	**2**	Special mix. concrete	**2**	4	**II**	0.42
3	Special mix. concrete	**3a**	Epoxy overlay	**3a**	State	**III**	2.0
4	Satisfactory	**3b**	Epoxy	**3b**	Industrial	**IV**	25
5	Fair	**3c**	None	**3c**	> 30,000		
6	Poor	**4**	Bare reinforcement	**4a**	3 – 4		
7	N/a	**5**	Reinforced concrete	**4b**	> 30		
8	N/a	**6**	20	**5**	Arterial		
9	Meets min. limits			**6a**	N/a		
				6b	N/a		
				6c	N/a		
Result:		**Result:**		**Result:**		**Result:**	
PASSED		BMSOD	65	BMS-I	51	P-I	24
				TDR	N/a	P-II	32
		BMSOS	14	BDD	N/a	P-III	38
				SBD	N/a	P-IV	5
						P-V	1

REGION	44
BMS-OD * BMS-I	33
REGION * BMS-I	22
BMS-OS * BMS-I	7

Local Trt. Case Study # / Date	5 / 1999
Member	BEAM ENDS
Location	Concordia Bridge

Section 1 – BMS Required		Section 2 – BMS Optional		Section 3 – BMS Importance		Section 4 – BMS Region	
Q	***Answers***	***Q***	***Answers***	***Q***	***Answers***	***Q***	***Answers***
1	PennDOT has the…	**1**	Pre-stress concrete	**1**	Group C	**I**	3.7
2	Pre-stress concrete	**2**	Special mix. concrete	**2**	4	**II**	0.42
3	Special mix. concrete	**3a**	Epoxy overlay	**3a**	State	**III**	2.0
4	Satisfactory	**3b**	Epoxy	**3b**	Industrial	**IV**	25
5	Fair	**3c**	None	**3c**	> 30,000		
6	Poor	**4**	Bare reinforcement	**4a**	3 – 4		
7	N/a	**5**	Prestressed concrete	**4b**	> 30		
8	N/a	**6**	20	**5**	Arterial		
9	Meets min. limits			**6a**	N/a		
				6b	N/a		
				6c	N/a		

Result:	**Result:**		**Result:**		**Result:**	
PASSED	BMSOD	65	BMS-I	51	P-I	24
			TDR	N/a	P-II	32
	BMSOS	0	BDD	N/a	P-III	38
			SBD	N/a	P-IV	5
					P-V	1

REGION	44
BMS-OD * BMS-I	33
REGION * BMS-I	22
BMS-OS * BMS-I	0

Local Trt. Case Study # / Date	6 / 1999, 2000
Member	DECK
Location	Winnipeg - CDN

Section 1 – BMS Required		**Section 2 – BMS Optional**		**Section 3 – BMS Importance**		**Section 4 – BMS Region**	
Q	***Answers***	***Q***	***Answers***	***Q***	***Answers***	***Q***	***Answers***
1	PennDOT has the…	**1**	Pre-stress concrete con.	**1**	Group C	**I**	3.7
2	Pre-stress concrete cont.	**2**	Post-tensioned pre-cast	**2**	4	**II**	0.45
3	Post-tensioned pre-cast crt.	**3a**	Low slump concrete	**3a**	County	**III**	2.5
4	Critical	**3b**	None	**3b**	PCN	**IV**	25
5	Fair	**3c**	None	**3c**	> 30,000		
6	Satisfactory	**4**	Bare reinforcement	**4a**	4 – 5		
7	N/a	**5**	Reinforced concrete	**4b**	20 – 30		
8	N/a	**6**	20	**5**	Collector		
9	High priority of corrective			**6a**	N/a		
				6b	N/a		
				6c	N/a		

Result:	**Result:**		**Result:**		**Result:**	
PASSED	BMSOD	70	BMS-I	51	P-I	43
			TDR	N/a	P-II	39
	BMSOS	14	BDD	N/a	P-III	16
			SBD	N/a	P-IV	0
					P-V	1

REGION	17
BMS-OD * BMS-I	36
REGION * BMS-I	9
BMS-OS * BMS-I	7

Local Trt. Case Study # / Date	7 / 2000
Member	DECK
Location	Brandon - CDN

Section 1 – BMS Required		**Section 2 – BMS Optional**		**Section 3 – BMS Importance**		**Section 4 – BMS Region**	
Q	***Answers***	***Q***	***Answers***	***Q***	***Answers***	***Q***	***Answers***
1	PennDOT has the…	**1**	Concrete	**1**	Group C	**I**	3.7
2	Concrete	**2**	Reinforced concrete	**2**	4	**II**	0.48
3	Reinforced concrete	**3a**	Bituminous	**3a**	State	**III**	2.5
4	Critical	**3b**	Built-up	**3b**	Agricultural	**IV**	50
5	Poor	**3c**	None	**3c**	3,000 – 15,000		
6	Poor	**4**	Bare-reinforcement	**4a**	4 – 5		
7	N/a	**5**	Plain concrete	**4b**	12 – 20		
8	N/a	**6**	10	**5**	Local		
9	High priority of corrective			**6a**	N/a		
				6b	N/a		
				6c	N/a		
Result:		**Result:**		**Result:**		**Result:**	
PASSED		BMSOD	96	BMS-I	43	P-I	3
				TDR	N/a	P-II	3
		BMSOS	100	BDD	N/a	P-III	8
				SBD	N/a	P-IV	39
						P-V	48

REGION	95
BMS-OD * BMS-I	41
REGION * BMS-I	41
BMS-OS * BMS-I	43

Local Trt. Case Study # / Date	8 / 2000
Member	DECK
Location	St. Francis, MB - CDN

Section 1 – BMS Required		**Section 2 – BMS Optional**		**Section 3 – BMS Importance**		**Section 4 – BMS Region**	
Q	***Answers***	***Q***	***Answers***	***Q***	***Answers***	***Q***	***Answers***
1	PennDOT has the…	**1**	Concrete continuous	**1**	Group C	**I**	3.7
2	Concrete continuous	**2**	Reinforced concrete	**2**	3	**II**	0.45
3	Reinforced concrete	**3a**	Bituminous	**3a**	US numbered hghway	**III**	2.0
4	Fair	**3b**	Built-up	**3b**	Agricultural	**IV**	30
5	Satisfactory	**3c**	Dense bituminous	**3c**	3,000 – 15,000		
6	Satisfactory	**4**	Bare reinforcement	**4a**	3 – 4		
7	N/a	**5**	Reinforced concrete	**4b**	> 30		
8	N/a	**6**	30	**5**	Interstate		
9	Better than min.			**6a**	N/a		
				6b	N/a		
				6c	N/a		

Result:	**Result:**		**Result:**		**Result:**	
PASSED	BMSOD	70	BMS-I	47	P-I	5
			TDR	N/a	P-II	6
	BMSOS	29	BDD	N/a	P-III	20
			SBD	N/a	P-IV	57
					P-V	11

REGION	88
BMS-OD * BMS-I	33
REGION * BMS-I	41
BMS-OS * BMS-I	14

Local Trt. Case Study # / Date	9 / 1999
Member	DECK
Location	Omaha, NB – CDN

Section 1 – BMS Required		**Section 2 – BMS Optional**		**Section 3 – BMS Importance**		**Section 4 – BMS Region**	
Q	***Answers***	***Q***	***Answers***	***Q***	***Answers***	***Q***	***Answers***
1	PennDOT has the…	**1**	Pre-stress concrete	**1**	Group C	**I**	3.7
2	Pre-stress concrete	**2**	Pre-stressed concr. Planks	**2**	5	**II**	0.48
3	Pre-stressed concr. Planks	**3a**	Concrete	**3a**	State	**III**	2.0
4	Serious	**3b**	None	**3b**	Industrial	**IV**	25
5	Fair	**3c**	N/a	**3c**	3,000 – 15,000		
6	Poor	**4**	Bare reinforcement	**4a**	< 3		
7	N/a	**5**	Reinforced concrete	**4b**	20 – 30		
8	N/a	**6**	20	**5**	Collector		
9	High priority of corrective			**6a**	N/a		
				6b	N/a		
				6c	N/a		

Result:	**Result:**		**Result:**		**Result:**	
PASSED	BMSOD	70	BMS-I	45	P-I	1
			TDR	N/a	P-II	1
	BMSOS	14	BDD	N/a	P-III	4
			SBD	N/a	P-IV	19
					P-V	75

REGION	98
BMS-OD * BMS-I	32
REGION * BMS-I	44
BMS-OS * BMS-I	6

Local Trt. Case Study # / Date	10 / 1999
Member	SUBSTRUCTURE
Location	Omaha, NB - CDN

Section 1 – BMS Required		**Section 2 – BMS Optional**		**Section 3 – BMS Importance**		**Section 4 – BMS Region**	
Q	***Answers***	***Q***	***Answers***	***Q***	***Answers***	***Q***	***Answers***
1	PennDOT has the…	**1**	Concrete continuous	**1**	Group C	**I**	7.5
2	Concrete continuous	**2**	Concrete filled metal	**2**	3	**II**	0.48
3	Concrete filled metal	**3a**	Latex concrete	**3a**	Interstate	**III**	2.0
4	Serious	**3b**	Unknown	**3b**	PCN	**IV**	30
5	Fair	**3c**	Unknown	**3c**	> 30,000		
6	Poor	**4**	Bare reinforcement	**4a**	3 – 4		
7	N/a	**5**	Reinforced concrete	**4b**	> 30		
8	N/a	**6**	40	**5**	Interstate		
9	High priority of corrective			**6a**	N/a		
				6b	N/a		
				6c	N/a		
Result:		**Result:**		**Result:**		**Result:**	
PASSED		BMSOD	65	BMS-I	60	P-I	0
				TDR	N/a	P-II	0
		BMSOS	29	BDD	N/a	P-III	0
				SBD	N/a	P-IV	0
						P-V	100

REGION	100
BMS-OD * BMS-I	39
REGION * BMS-I	60
BMS-OS * BMS-I	17

Local Trt. Case Study # / Date	11 / 1999
Member	DECK
Location	Missouri - USA

Section 1 – BMS Required		Section 2 – BMS Optional		Section 3 – BMS Importance		Section 4 – BMS Region	
Q	***Answers***	***Q***	***Answers***	***Q***	***Answers***	***Q***	***Answers***
1	PennDOT has the…	**1**	Concrete	**1**	Group C	**I**	7.5
2	None of above	**2**	Reinforced concrete	**2**	4	**II**	0.48
3	Reinforced concrete	**3a**	Concrete	**3a**	City	**III**	2.0
4	Poor	**3b**	Unknown	**3b**	PCN	**IV**	25
5	Poor	**3c**	None	**3c**	3,000 – 15,000		
6	Fair	**4**	Bare reinforcement	**4a**	3 – 4		
7	N/a	**5**	Reinforced concrete	**4b**	20 – 30		
8	N/a	**6**	20	**5**	Collector		
9	High priority of corrective			**6a**	N/a		
				6b	N/a		
				6c	N/a		

<u>Result:</u>	**<u>Result:</u>**		**<u>Result:</u>**		**<u>Result:</u>**	
PASSED	BMSOD	74	BMS-I	45	P-I	0
			TDR	N/a	P-II	0
	BMSOS	29	BDD	N/a	P-III	0
			SBD	N/a	P-IV	0
					P-V	100

REGION	100
BMS-OD * BMS-I	33
REGION * BMS-I	45
BMS-OS * BMS-I	13

Local Trt. Case Study # / Date		12 / 1998, 1999, 2000					
Member		SUBSTRUCTURE					
Location		Council Bluffs, IA – USA					
Section 1 – BMS Required		**Section 2 – BMS Optional**		**Section 3 – BMS Importance**		**Section 4 – BMS Region**	
Q	***Answers***	***Q***	***Answers***	***Q***	***Answers***	***Q***	***Answers***
1	PennDOT has the…	1	Pre-stress concrete cont.	1	Group C	**I**	3.7
2	Pre-stress concrete cont.	**2**	Reinforced concrete	**2**	5	**II**	0.48
3	Reinforced concrete	**3a**	Low slump concrete	**3a**	State	**III**	2.0
4	Fair	**3b**	None	**3b**	Agricultural	**IV**	35
5	Critical	**3c**	None	**3c**	3,000 – 15,000		
6	Serious	**4**	Bare reinforcement	**4a**	< 3		
7	N/a	**5**	Reinforced concrete	**4b**	20 – 30		
8	N/a	**6**	40	**5**	Arterial		
9	High priority of corrective			**6a**	N/a		
				6b	N/a		
				6c	N/a		

Result:	**Result:**		**Result:**		**Result:**	
PASSED	BMSOD	74	BMS-I	45	P-I	0
			TDR	N/a	P-II	0
	BMSOS	14	BDD	N/a	P-III	0
			SBD	N/a	P-IV	0
					P-V	100

REGION	100
BMS-OD * BMS-I	33
REGION * BMS-I	45
BMS-OS * BMS-I	6

Local Trt. Case Study # / Date	13 / 1999
Member	PARAPET WALLS
Location	Reinfrew, ON - CDN

Section 1 – BMS Required		**Section 2 – BMS Optional**		**Section 3 – BMS Importance**		**Section 4 – BMS Region**	
Q	***Answers***	***Q***	***Answers***	***Q***	***Answers***	***Q***	***Answers***
1	PennDOT has the…	**1**	Concrete	**1**	Group C	**I**	7.5
2	Concrete	**2**	Reinforced concrete	**2**	3	**II**	0.42
3	Reinforced concrete	**3a**	Bituminous	**3a**	Interstate	**III**	1.5
4	Satisfactory	**3b**	Other	**3b**	PCN	**IV**	35
5	Satisfactory	**3c**	Polymer impregnated	**3c**	> 30,000		
6	Satisfactory	**4**	Bare reinforcement	**4a**	3 – 4		
7	N/a	**5**	Reinforced concrete	**4b**	> 30		
8	N/a	**6**	20	**5**	Interstate		
9	High priority of corrective			**6a**	N/a		
				6b	N/a		
				6c	N/a		
<u>Result:</u>		**<u>Result:</u>**		**<u>Result:</u>**		**<u>Result:</u>**	
PASSED		BMSOD	48	BMS-I	60	P-I	0
				TDR	N/a	P-II	0
		BMSOS	29	BDD	N/a	P-III	0
				SBD	N/a	P-IV	0
						P-V	100

REGION	100
BMS-OD * BMS-I	29
REGION * BMS-I	60
BMS-OS * BMS-I	17

Local Trt. Case Study # / Date	14 / 2000
Member	DECK
Location	Jackson County, MI - USA

Section 1 – BMS Required		Section 2 – BMS Optional		Section 3 – BMS Importance		Section 4 – BMS Region	
Q	***Answers***	***Q***	***Answers***	***Q***	***Answers***	***Q***	***Answers***
1	PennDOT has the…	**1**	Concrete	**1**	Group C	**I**	7.5
2	Concrete	**2**	Concrete w/ flyash	**2**	4	**II**	0.45
3	Concrete w/ flyash	**3a**	Concrete	**3a**	Interstate	**III**	2.5
4	Poor	**3b**	Unknown	**3b**	PCN	**IV**	40
5	Fair	**3c**	Unknown	**3c**	> 30,000		
6	Fair	**4**	Other	**4a**	3 – 4		
7	N/a	**5**	Reinforced concrete	**4b**	> 30		
8	N/a	**6**	20	**5**	Interstate		
9	High priority of corrective			**6a**	N/a		
				6b	N/a		
				6c	N/a		

<u>Result:</u>	**<u>Result:</u>**		**<u>Result:</u>**		**<u>Result:</u>**	
PASSED	BMSOD	48	BMS-I	55	P-I	3
			TDR	N/a	P-II	3
	BMSOS	29	BDD	N/a	P-III	11
			SBD	N/a	P-IV	48
					P-V	35

REGION	94
BMS-OD * BMS-I	26
REGION * BMS-I	52
BMS-OS * BMS-I	16

Local Trt. Case Study # / Date	15 / 1999						
Member	DECK						
Location	Quebec City - CDN						
Section 1 – BMS Required		**Section 2 – BMS Optional**		**Section 3 – BMS Importance**		**Section 4 – BMS Region**	
Q	***Answers***	***Q***	***Answers***	***Q***	***Answers***	***Q***	***Answers***
1	PennDOT has the…	**1**	Concrete continuous	**1**	Group C	**I**	7.5
2	Concrete continuous	**2**	Post-tensioned CIP concr.	**2**	5	**II**	0.48
3	Post-tensioned CIP concr.	**3a**	Concrete	**3a**	State	**III**	2.5
4	Imminent failure	**3b**	None	**3b**	PCN	**IV**	35
5	Fair	**3c**	None	**3c**	15,000 – 30,000		
6	Satisfactory	**4**	Galvanized reinfrcmnt.	**4a**	3 – 4		
7	N/a	**5**	Reinforced concrete	**4b**	> 30		
8	N/a	**6**	20	**5**	Arterial		
9	High priority of rplmnt.			**6a**	N/a		
				6b	N/a		
				6c	N/a		
Result:		**Result:**		**Result:**		**Result:**	
PASSED		BMSOD	74	BMS-I	43	P-I	0
				TDR	N/a	P-II	0
		BMSOS	29	BDD	N/a	P-III	0
				SBD	N/a	P-IV	0
						P-V	100

REGION	100
BMS-OD * BMS-I	32
REGION * BMS-I	43
BMS-OS * BMS-I	12

Local Trt. Case Study # / Date	16 / 2000						
Member	DECK						
Location	Florida Keys, FL – USA						
Section 1 – BMS Required		**Section 2 – BMS Optional**		**Section 3 – BMS Importance**		**Section 4 – BMS Region**	
Q	***Answers***	***Q***	**Answers**	***Q***	***Answers***	***Q***	***Answers***
1	PennDOT has the…	**1**	Pre-stress concrete cont	**1**	Group C	**I**	1.5
2	Pre-stress concrete cont.	**2**	Post-tensioned CIP concr.	**2**	3	**II**	0.40
3	Post-tensioned CIP concr.	**3a**	Concrete	**3a**	US numbered highway	**III**	2.5
4	Satisfactory	**3b**	None	**3b**	PCN	**IV**	10
5	Satisfactory	**3c**	Epoxy coated reinf.	**3c**	15,000 – 30,000		
6	Poor	**4**	Epoxy coated reinf.	**4a**	4 – 5		
7	N/a	**5**	Pre-stressed concrete	**4b**	> 30		
8	N/a	**6**	40	**5**	Arterial		
9	High priority of rplmnt.			**6a**	N/a		
				6b	N/a		
				6c	N/a		

Result:	**Result:**		**Result:**		**Result:**	
PASSED	BMSOD	26	BMS-I	49	P-I	98
			TDR	N/a	P-II	1
	BMSOS	0	BDD	N/a	P-III	0
			SBD	N/a	P-IV	0
					P-V	1

REGION	1
BMS-OD * BMS-I	13
REGION * BMS-I	0
BMS-OS * BMS-I	0

Local Trt. Case Study # / Date	17 / 2000
Member	SUBSTRUCTURE
Location	Hamburg, NY - USA

Section 1 – BMS Required		**Section 2 – BMS Optional**		**Section 3 – BMS Importance**		**Section 4 – BMS Region**	
Q	***Answers***	***Q***	***Answers***	***Q***	***Answers***	***Q***	***Answers***
1	PennDOT has the…	**1**	Concrete	**1**	Group C	**I**	7.5
2	None of above	**2**	Concrete filled metal	**2**	4	**II**	0.45
3	Concrete filled metal	**3a**	Concrete	**3a**	State	**III**	2.0
4	Fair	**3b**	Unknown	**3b**	PCN	**IV**	30
5	Satisfactory	**3c**	Unknown	**3c**	15,000 – 30,000		
6	Poor	**4**	Bare reinforcement	**4a**	3 – 4		
7	N/a	**5**	Reinforced concrete	**4b**	> 30		
8	N/a	**6**	25	**5**	Arterial		
9	High priority of corrective			**6a**	N/a		
				6b	N/a		
				6c	N/a		

Result:	**Result:**		**Result:**		**Result:**	
PASSED	BMSOD	70	BMS-I	48	P-I	0
			TDR	N/a	P-II	0
	BMSOS	29	BDD	N/a	P-III	0
			SBD	N/a	P-IV	0
					P-V	100

REGION	100
BMS-OD * BMS-I	34
REGION * BMS-I	48
BMS-OS * BMS-I	14

Local Trt. Case Study # / Date	18 / 2000
Member	CANTILEVER
Location	Pough Keepsie, NY – USA

Section 1 – BMS Required		**Section 2 – BMS Optional**		**Section 3 – BMS Importance**		**Section 4 – BMS Region**	
Q	***Answers***	***Q***	***Answers***	***Q***	***Answers***	***Q***	***Answers***
1	PennDOT has the…	**1**	Concrete	**1**	Group C	**I**	7.5
2	Concrete	**2**	Reinforced concrete	**2**	2	**II**	0.48
3	Reinforced concrete	**3a**	Bituminous	**3a**	State	**III**	1.5
4	Fair	**3b**	Unknown	**3b**	PCN	**IV**	45
5	Fair	**3c**	Polymer impregnated	**3c**	15,000 – 30,000		
6	Fair	**4**	Bare reinforcement	**4a**	4 – 5		
7	N/a	**5**	Reinforced concrete	**4b**	> 30		
8	N/a	**6**	25	**5**	Arterial		
9	Better than min.			**6a**	N/a		
				6b	N/a		
				6c	N/a		

Result:	**Result:**		**Result:**		**Result:**	
PASSED	BMSOD	48	BMS-I	53	P-I	0
			TDR	N/a	P-II	0
	BMSOS	29	BDD	N/a	P-III	0
			SBD	N/a	P-IV	0
					P-V	100

REGION	100
BMS-OD * BMS-I	25
REGION * BMS-I	53
BMS-OS * BMS-I	15

Local Trt. Case Study # / Date	19 / 2000						
Member	DECK						
Location	Stamford, CN - USA						
Section 1 – BMS Required		**Section 2 – BMS Optional**		**Section 3 – BMS Importance**		**Section 4 – BMS Region**	
Q	***Answers***	***Q***	***Answers***	***Q***	***Answers***	***Q***	***Answers***
1	PennDOT has the…	**1**	Concrete	**1**	Group C	**I**	1.5
2	Concrete	**2**	Reinforced concrete	**2**	2	**II**	0.48
3	Reinforced concrete	**3a**	Concrete	**3a**	State	**III**	2.5
4	Serious	**3b**	Unknown	**3b**	Agricultural	**IV**	40
5	Satisfactory	**3c**	Unknown	**3c**	< 3,000		
6	Satisfactory	**4**	Bare reinforcement	**4a**	4 – 5		
7	N/a	**5**	Unknown	**4b**	12 – 20		
8	N/a	**6**	5	**5**	Local		
9	High priority of corrective			**6a**	N/a		
				6b	N/a		
				6c	N/a		
Result:		**Result:**		**Result:**		**Result:**	
PASSED		BMSOD	83	BMS-I	48	P-I	36
				TDR	N/a	P-II	38
		BMSOS	71	BDD	N/a	P-III	24
				SBD	N/a	P-IV	1
						P-V	1

REGION	26
BMS-OD * BMS-I	40
REGION * BMS-I	12
BMS-OS * BMS-I	34

Local Trt Case #	Struc.Type	BMS-OD	BMS-OS	BMS-I	R-I	R-II	R-III	R-IV	R-V	REGION	BMS-OD*BMSI	REGION*BMS-I	BMS-OS*BMS-I
1	deck	57	29	48	8	11	31	48	3	82	27	39	14
2	deck	65	29	60	61	33	5	0	1	6	39	4	17
3	subst.	70	29	31	17	24	44	14	1	59	22	18	9
4	subst.	65	14	51	24	32	38	5	1	44	33	22	7
5	deck	65	0	51	24	32	38	5	1	44	33	22	0
6	deck	70	14	51	43	39	16	0	1	17	36	9	7
7	deck	96	100	43	3	3	8	39	48	95	41	41	43
8	deck	70	29	47	5	6	20	57	11	88	33	41	14
9	deck	70	14	45	1	1	4	19	75	98	32	44	6
10	subst.	65	29	60	0	0	0	0	100	100	39	60	17
11	deck	74	29	45	0	0	0	0	100	100	33	45	13
12	subst.	74	14	45	0	0	0	0	100	100	33	45	6
13	subst.	48	29	60	0	0	0	0	100	100	29	60	17
14	deck	48	29	55	3	3	11	48	35	94	26	52	16
15	deck	74	29	43	0	0	0	0	100	100	32	43	12
16	deck	26	0	49	98	1	0	0	1	1	13	0	0
17	subst.	70	29	48	0	0	0	0	100	100	34	48	14
18	deck	48	29	53	0	0	0	0	100	100	25	53	15
19	deck	83	71	48	36	38	24	1	1	26	40	12	34
Local Trt Case #	Struc.Type	BMS-OD	BMS-OS	BMS-I	R-I	R-II	R-III	R-IV	R-V	REGION	BMS-OD*BMSI	REGION*BMS-I	BMS-OS*BMS-I

	BMS-OD	BMS-OS	BMS-I	R-I	R-II	R-III	R-IV	R-V	REGION	BMS-OD*BMSI	REGION*BMS-I	BMS-OS*BMS-I
All-Min.	N/A	N/A	**31**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
All-Max.	N/A	N/A	**60**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
All-avrg.	N/A	N/A	**49**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Deck-Min.	**26**	N/A	**43**	**0**	**0**	**0**	**0**	**1**	**1**	**13**	**0**	N/A
Deck-Max.	**96**	N/A	**60**	**98**	**39**	**38**	**57**	**100**	**100**	**41**	**53**	N/A
Deck-avrg.	**65**	N/A	**49**	**22**	**13**	**12**	**17**	**37**	**65**	**32**	**31**	N/A
Subst.-Min.	N/A	**14**	**31**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	**6**
Subst.-Max.	N/A	**29**	**60**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	**17**
Subst.-avrg.	N/A	**24**	**49**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	**12**
	BMS-OD	BMS-OS	BMS-I	R-I	R-II	R-III	R-IV	R-V	REGION	BMS-OD*BMSI	REGION*BMS-I	BMS-OS*BMS-I

D-Evaluation Phase Items:

Point Assignment to the Treatment Requirements Evaluation Questions

Question	Answers	Assigned Points			
		Impr. CP	**Gal. CP**	**ECE**	**Local Treat.**
Do you have access to power supply?	Yes	1	1	1	1
	No	0	1	0	1
	May Provide	1	1	0	1
In your application, what is the importance of the level of power	Highly Important	0	1	0	1
	Important	1	1	0	1
	Not Important	1	1	1	1
What is the amount of the concrete damage on your structure?	Low	1	1	1	1
	Medium	0	1	0	1
	High	0	0	0	1
Are there prestressed members in your structure?	Yes	0	1	0	1
	No	1	1	1	1
	Do Not Know	1	1	0	1
Is there alkali reactive aggregate present in your structure?	Yes	0	1	0	1
	No	1	1	1	1
	Do Not Know	0	1	0	1
Are there coatings or non-conductive overlays on your structure?	Yes	0	0	0	1
	No	1	1	1	1
	Not Applicable	1	1	1	1
What is the condition rating of coatings or non-conductive overlays?	Good	0	1	0	1
	Average	1	1	0	1
	Poor	1	1	1	1
	Not Applicable	1	1	1	1
How much steel is exposed on the surface of the concrete structure?	Low	1	1	1	1
	Medium	1	1	0	1
	High	0	0	0	1
What is the geometry of your structure?	Very Simple	1	1	1	1
	Simple	1	1	1	1
	Complex	0	1	0	1
	Any	0	1	0	1
What is the level of frequency by which you can handle maintenance	Low	0	0	1	0
	Medium	0	1	1	1
	High	1	1	1	1

Point Assignment to the Index Values Acquired from BMS and REGION Phases

Index Name AND Critical Value	Values %	Assigned Points			
		Impr. CP	Gal. CP	ECE	Local Treat.
BMS-OS *> 13%*	% < 31	0	1	0	1
	% ≥ 31	1	1	1	1
SBDP *> N/A%*	N/A	0	0	0	0
BMS-IS or BMS-ID *> 40%*	% < 51	1	1	1	1
	% ≥ 51	1	1	0	1
BMS-TDRS or BMS-TDRD *> N/A%*	N/A	0	0	0	0
BMS-OS * BMS-IS *> 8%*	N/A	0	0	0	0
BMS-OD *> 45%*	% < 60	0	1	0	1
	61 ≤ % < 70	1	1	0	1
	% ≥ 71	1	1	1	1
BDDP *> N/A%*	N/A	0	0	0	0
REGION *> 60%*	% < 90	1	1	1	1
	90 ≤ % < 95	1	1	0	1
	% ≥ 95	0	0	0	1
BMS-OD * BMS-ID *> 27%*	N/A	0	0	0	0
REGION * BMS-ID *> 30%*	N/A	0	0	0	0

E-Logic (background calculations):

BMS Phase – Required Items Step:

There is an evaluation within this step, however no calculations were done.

BMS Phase – Optional Items Step:

Each answer within each question has already been assigned appropriate values. Within this step these values are added and converted into a percentage value to end up with the index numbers, BMS-OD and BMS-OS.

BMS Phase – Importance Factor and Deficiency Assessment Items Step:

Each answer within each question has already been assigned appropriate values. Within this step these values are added and converted into a percentage value to end up with the index numbers, BMS-I, TDR, BDD and SBD.

REGION Phase (for decks only):

After the user inputs the necessary parameters into the program, the values of the five condition states appear as an initial result. However the index number, REGION, is calculated by adding the condition states III, IV and V together. There is no need to convert the sum into a percentage value because the condition states themselves are already calculated as percentages.

First Summary:

Decks:

Additional indices, BMS-OD * BMS-I and REGION * BMS-I are calculated here by multiplying the two of the indices and factoring it by 1/100.

Within this step indices are compared with the critical index values and the program proceeds with the *Selection Phase* only if the user indices meet the requirements.

The critical values are given on the second table in Appendix D.

Substructures:

Additional index, BMS-OS * BMS-I IS calculated here by multiplying the two of the indices and factoring it by 1/100.

Within this step indices are compared with the critical index values and the program proceeds with the *Selection Phase* only if the user indices meet the requirements.

The critical values are given on the second table in Appendix D.

Selection Phase:

Each answer within each question has already been assigned appropriate weighing points which forms the *first decision matrix*. (See the "*Point Assignment to the Treatment Requirements Evaluation Questions*" table in Appendix D)

Some indices that have been calculated in *BMS Phase* also have the contribution in the *Selection Phase*. Similarly, those indices have already been assigned appropriate weighing points which forms the *second decision matrix*. (See the "*Point Assignment to the Index Values Acquired from BMS and REGION Phases*" table in Appendix D)

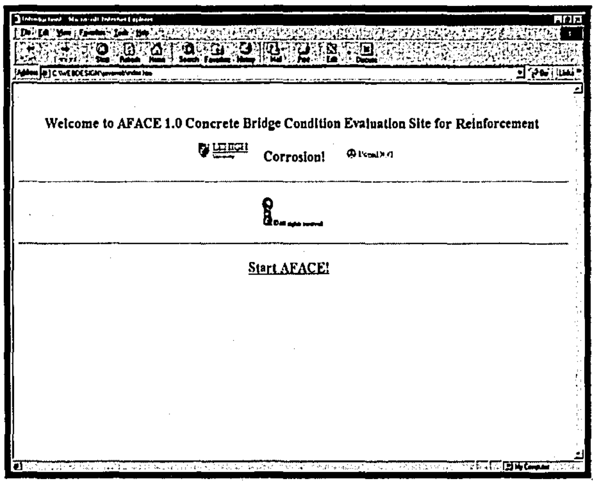
Finally in this step, these values are added and converted into a percentage value to end up with the probabilistic chance percentages for each treatment method. This is accomplished by using the following two equations:

- Unit chance % = 100/ {(# of questions in Selection Phase) + (# of contributing indices acquired from BMS phase)}

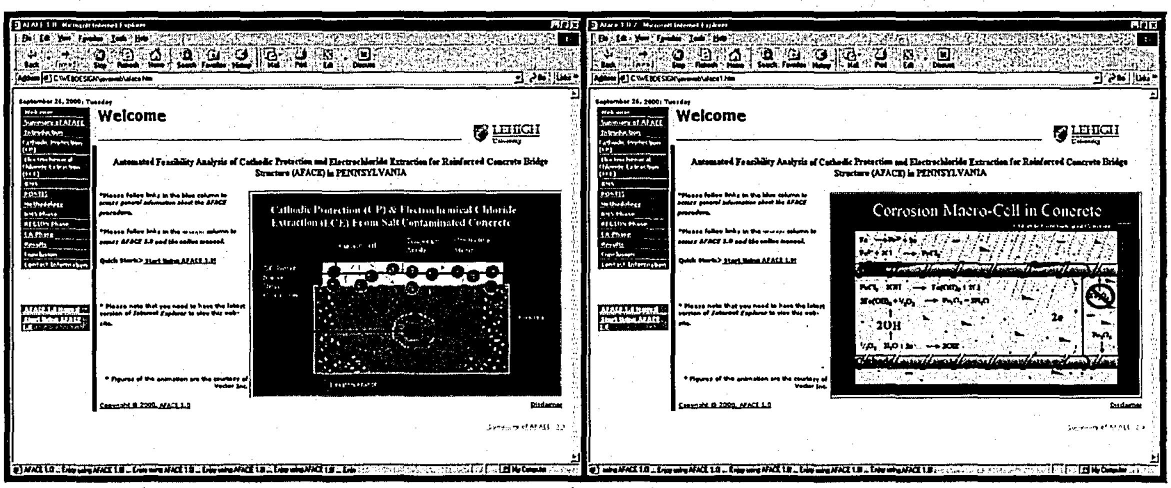
- Chance % $(\text{method})_i = \Sigma(\text{Assigned points})_i$ * Unit chance %

Higher the chance percentage, more applicable will be that treatment method.

F-Introduction Pages of AFACE 1.0:

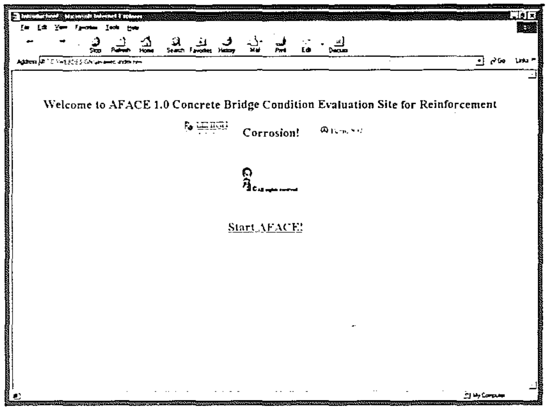


Entrance page of the AFACE 1.0



Introduction pages of the AFACE 1.0

F-Introduction Pages of AFACE 1.0:



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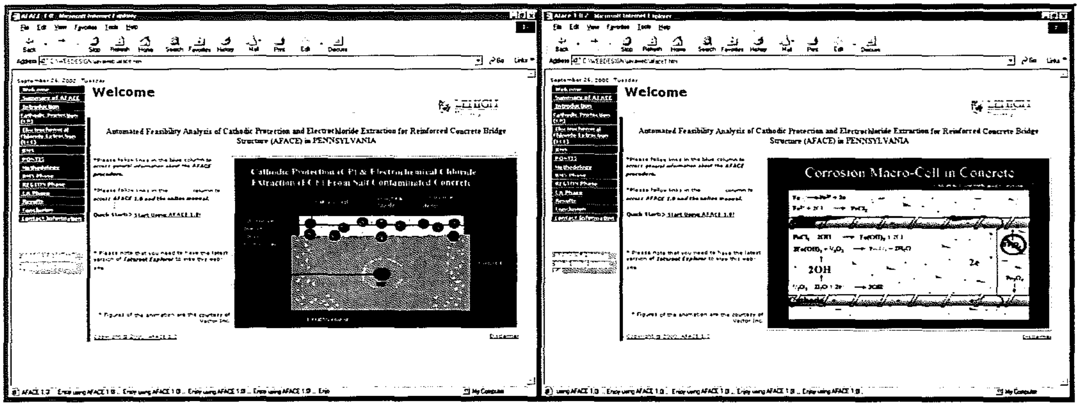
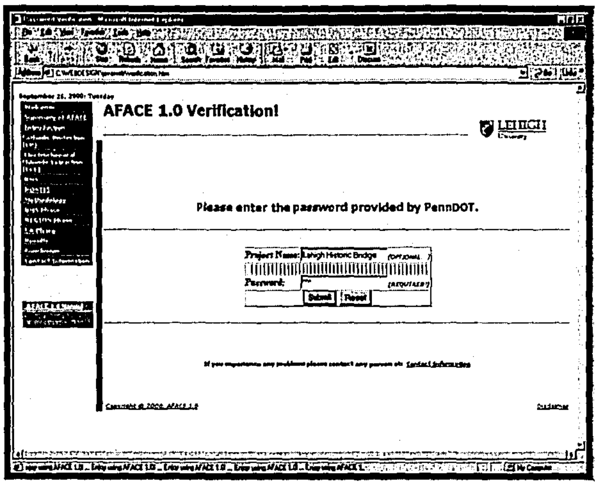
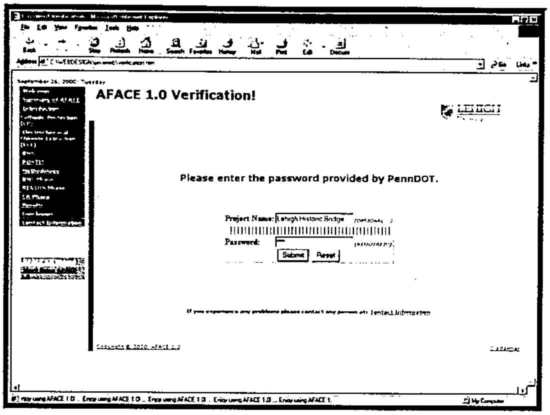


Introduction pages of the AFACE 1.0



Password verification page



Password verification page

VITA:

Mehmet Gokhan Yalcin was born in Ankara/TURKIYE on August 17th, 1976. He attended Ataturk Anatolian High School (A.A.A.L.) between years 1987 and 1994. After he graduated from A.A.A.L., he achieved to be within 1% of the general university entrance examination examinees and succeeded to enter Istanbul Technical University (I.T.U.), Civil Engineering Department to pursue his Bachelor's degree in 1994. Right after he got his B.S. degree from I.T.U. in 1998, he continued his education by proceeding with Master of Science at Lehigh University, Bethlehem/Pennsylvania in the same year.

END OF

TITLE