SUMMARY

Eugene J. Fasullo, Deputy Director of Engineering and Deputy Chief Engineer of The Port Authority Of New York And New Jersey gave the keynote address entitled "Infrastructure: The Battlefield Of Corrosion." His presentation offered the attendees examples of successful projects using new technology coupled with reasonable risks and support of management. His paper covers the cost of corrosion of infrastructure to the U.S.A. and the reasons for this serious problem. He covered the role of corrosion in the infrastructure arena, the causes of corrosion, prevention methods, and the main causes of rebar corrosion. In his paper he focuses on the major problems in transportation and offers some advanced technology for each segment. While many innovative technologies are available to help infrastructure managers, their acceptance requires a sharing of the financial and technical risks among designers, manufacturers, builders, and government agencies. In his conclusion he challenged the engineering societies, universities, scientists, and constructors to come up with innovative solutions that can benefit future generations.

Robert Baboian, Principal Fellow and Head of the Electrochemical and Corrosion Laboratory at Texas Instruments, Inc. presented a paper entitled "Synergistic Effects Of Acid Deposition And Road Salts On Corrosion". Mr Baboian stated that "the importance of corrosion in our modern, high-tech society can be measured by the magnitude of the direct and indirect problems that result from this degradation process." His paper covers the effect of acid deposition and road salts individually and synergistically. He tabulates in his paper the atmospheric corrosion rates of zinc and iron at various sites. He also compares the corrosion rate of auto bodies when bare steel is used versus galvanized steel. In his conclusion he advises to consider the "real world" environment in solving the most serious infrastructure problems to reach the most economic and safe solutions.

Thomas R. Menzies, Research Associate at the Transportation Research Board, National Research Council presented a paper entitled "National Cost Of Damage To Infrastructure From Highway Deicing." His paper addresses the impact of deicing salt on bridge decks, bridge components, highway components, and parking structures. In the summary of bridge deck costs, he stated that "during the next 10 years, the total cost of protecting newly-constructed decks and restoring currently sound decks that become damaged by salting will be roughly $125 million to $325 million per year." In the summary of other bridge components costs, he mentioned that their repair can be very difficult and expensive. The cost is estimated to be as high as deck costs so the range is between $125 million to $325 million per year. In the summary of impacts on other highway components, the cost is about $100 million per year. As for the parking structures the cost is estimated to be in

the range of $75 million to $175 million per year for the next 10 years.

With the increased use of atmospheric resistant steels, known as weathering steels, for infrastructure, the need for estimating the rate of corrosion penetration at the end of the service life arose. To address this topic Richard H. McCuen et al, Professor, Department of Civil Engineering, University of Maryland, College Park, Maryland presented a paper on "A New Approach To Power Model Regression." Two mathematical formula were given: The upper bound and the log-log fitting of power model. Indices for assessing models are also given. The proposed formula are backed up with data from an atmospheric exposure test. The paper concluded that Goodness-of-fit statistics obtained from the linear model based on logarithms do not reflect the prediction accuracy of the nonlinear model, which is the model used for design. Also, the correlation coefficient as traditionally calculated should only be applied to linear unbiased models, not the power model.

Computer simulation in corrosion control engineering is one of the new tools emerging. Directions for proper use and application is discussed in a paper entitled "A Review Of Computational Simulation Techniques" presented by V. Gensheimer De Giorgi et al, Research Engineer, Mechanics of Material Branch, Naval Research Laboratory, Washington, D.C. The paper outlines the necessary steps for the design of accurate computational simulation. An example is given for the simulation of an impressed current cathodic protection system for the surface of a ship. The paper concluded by emphasizing the need for complete detailed understanding of the corrosion process by the analyst as well as the computational simulation procedure used.

The next paper was by Fred H. Haynie, Consultant, formerly with Atmospheric Research and Exposure Assessment Laboratory, U.S. Environmental Protection Agency, Research Triangle Park, N.C."Evaluation Of An Atmospheric Corrosion Rate Monitor" introduces a tool to measure the rate of corrosion in the atmosphere based on the polarization resistance technique. An atmospheric corrosion rate monitor (ACRM) that could be attached to a point on a structure to measure corrosion rate as a function of time would be a valuable tool for the corrosion engineer to use. The results and responses of the new sensor sere compared with other methods of measuring corrosion such as the mass loss and the time of wetness.
The new sensor can measure the time of wetness in a few hours rather than days. In the conclusion, Mr Haynie mentioned that the experimental work can be turned into a valuable tool by changing some of the hardware and software to measure polarization resistance.

Pedro Albrecht, Professor, Department of Civil Engineering, University of Maryland, College Park, Maryland presented a

paper entitled "Corrosion Control Of Weathering Steel Bridges." The forms of corrosion of bare weathering steel bridges were enumerated, and their effects on bridge performance were discussed. Numerous examples are cited in the paper to drive the point home.
This paper is a detailed description of the types of weathering steels and includes a historical data of their applications and experience results. Mr Albrecht included a method for site analysis to determine the suitability of using weathering steel. Also included in the paper are design details for the enhancement of the material performance. Recommendations for construction, inspection, maintenance, and rehabilitation are added.

Jean-Jacques Hechler, Senior Research Officer and Program Manager at the Industrial Materials Research Institute,National Research Council of Canada, boucherville, Province of Quebec, Canada presented a paper entitled "Wetness Monitoring on the Exterior of Infrastructures." This paper describes the results of a comprehensive study on the effects of the design and orientation on the corrosion of metals on buildings using an existing ASTM time of wetness sensor. In the conclusion Mr Hechler stated that the ASTM sensor for measuring the time of wetness can provide more information besides its original intent. The nature of wetness, the speed of deposition, and drying are some of the important information provided. Thus, it is valuable in studies related to degradation, restoration & design of building material to withstand atmospheric deterioration, corrosion, and weathering.

Corrosion of steel reinforced concrete is the topic of the following paper:"Performance of Rehabilitated\Protected Concrete Bridge Decks" the title of the paper by Khossrow Babaei et al., which compares the results of three protective systems to determine their effectiveness. Latex modified concrete overlay, (LMC), low-Slump dense concrete overlay (LSDC), and a Cathodic protection (CP) were the three systems studied. The results showed that after an average of seven years of service, the LMC and LSDC showed various levels of post-overlay corrosion-induced deterioration. On the other hand, after about five years of service, the CP system showed satisfactory reinforcment of steel.

Electrochemical Impedance is an important technique to determine the rate of corrosion of metals. Advancement in computer science allowed the use of that technique in the field. The next paper, entitled "Utilization of Electrochemical Impedance Techniques to Estimate Corrosion Damage of Steel Infrastructures" was presented by Koji Hamma et al of Nippon Steel Corporation, Japan.
The paper introduces three new sensors: all are using AC impedance method for field application. The first sensor can be used for measuring the corrosion rate of marine steel

structures. The second sensor enables the estimate of corrosion damage of reinforcing bars in concrete. The third sensor can be used for detecting the deterioration of painted steel.

The impact of stray current corrosion can be serious if ignored. The next paper "Improved Rail Fastener Insulation For Stray Current Control" presented by Peter L. Todd of the Bay Area Rapid Transit, Oakland, California, describes the laboratory tests conducted on a prototype rail fastener and the actual field conditions. Effective electrical insulation limits current flow through as well as across the surface of the insulator. A contaminated environment can reduce the resistance of the current path leading to significant stray current corrosion.The conclusion reported that successful simulation of field conditions by the laboratory apparatus can be used as a practical tool for predicting the performance of new rail fasteners. One of the new rail fasteners can reduce the leakage current by a factor of 100,000 , which is very effective.

The integrity of gas and oil pipelines are very important. Corrosion of these pipelines can cause loss of life as well as loss of precious material. They are controlled by empirical and conservative regulations. However, they proved deficient in some cases. The next paper "A Theoretical Analysis For The Residual Strength Of Corroded Gas And Oil Transmission Pipelines" was prepared by Melvin F. Kanninen et al, Program Director, Engineering Mechanics at the Southwest Research Institute, San Antonio, Texas, and Carl H. Poplar, Professor, Department Of Engineering Mechanics, Ohio State University, Columbus, Ohio. This paper used a maximum hoop stress criterion in an axisymmetric approximation of the metal loss to provide a relation for the failure pressure for a pipe with axial direction metal loss. The paper suggests that if the shell bending theory approach is extended to the plane strain case, then it may be the circumferential dimension of the damage that actually governs the failures of corroded pipes. Similar models can be developed and used in addressing corrosion-related problems associated with other infrastructure components.

Underground pipelines constitute a significant segment of the infrastructure. Replacement of such pipes is costly and produces a lot of inconveniences when streets have to be closed for construction. New technology was developed to reconstruct small diameter pipes without excavation. The next paper "The NUPIPE Reconstruction Technology" presented by James B. Hinte of NUPIPE, Inc, Memphis, TN. describes the procedure and necessary equipment to insert a PVC pipe inside existing, deteriorated underground pipes without excavation. The new PVC pipe provides structural support and isolates the effluent from the corroded pipe. The new technology can also be used for lining non-metallic pipes such as concrete. In

conclusion it was stated that the new technology reestablishes the structural integrity of deteriorated systems with a continuous, corrosion resistant pipe that will extend the useful life of the system.

Tools to predict accurately the life expectancy of structures are very valuable. One of the major problems in reinforced concrete infrastructure is the corrosion of steel rebar due to chloride penetration into the concrete. The next paper "Estimating The Life Cycle Of Reinforced Concrete Decks And Marine Piles Using Laboratory Diffusion And Corrosion Data" prepared by Neal S. Berke et al of W.R.Grace & Co, Cambridge, MA. presents the results of a laboratory study showing that chloride ingress into concrete follows Fick's Diffusion equation for properly cured concrete. Several models were presented. One model showed reducing water-to-cement ratio and increasing concrete cover over the steel to reduce the chloride ingress. Another model demonstrated the use of microsilica in the concrete mixture, resulting in drastic reduction of chloride penetration. A third model showed that calcium nitrite initially reduces resistivity and increases rapid chloride permeability values in concrete with silica fume. However, it has no adverse affect on actual concrete permeability and improves the durability of concrete in corrosive environments.

Cyclic conditions are known to cause high corrosion rates. One of these is the tidal zone in marine structures. Thus, it is important to identify the mechanism of corrosion in this zone. The next paper "Investigation Of Rebar Corrosion In Partially Submerged Concrete" was prepared by Miki Funahashi, et al, of Corrpro Companies,Inc.
The paper discusses the results of potentials, total corrosion current, and macro cell corrosion current of steel in concrete in three zones, namely submerged, tidal, and atmospheric. The paper concluded that in chloride contaminated concrete, the rebar was found to be anodic in the submerged zone and cathodic in the atmospheric zone. Moisture content influenced the corrosion rate of a drier concrete and visa versa.

Reinforced concrete and prestressed structures are used widely in infrastructure. Thus, inspection techniques are very important to determine accurately their conditions. The next paper "Recent Developments In Inspection Techniques For Corrosion Damaged Concrete Structures prepared by Gareth John, et al, of CAPCIS Ltd, Manchester, UK and P.A. Gaydecki of UMIST, Manchester, UK. Introduces prototype ultrasonic procedures to determine the condition of prestressed, pretentioned tendons in concrete. The paper also describes the application of electrochemical impedance for estimating the rate of corrosion of reinforcing steel using surface-mounted sensors. The system features iso-potential contour maps of the surveyed surface and corresponding iso-corrosion rate contour maps of the same area. The results of the corrosion rate

survey were in general agreement with the corresponding half-cell survey. As for the ultrasonic procedure, the paper describes a computerized system capable of determining the necessary level of signal and frequency. The paper points out that this technique must be used in addition to other inspection procedures and not as a sole criterion for structural integrity.

Internal corrosion of piping systems in buildings and factories is a major concern. Equipment to indicate the condition of the internal surfaces without dismantling the pipe would be very valuable. The next paper "An Automatic Pipe Corrosion Inspection System" prepared by Mitsuru Shimizu, et al of Obayashi Corporation, Tokyo, Japan, and Masahiro Hamada, et al of Osaka Gas Company, Osaka, Japan describes in detail a new robotics computerized system to perform accurate inspection of the internal surface of the pipe. It utilizes ultrasonic waves and the state-of-the-art in electronics technology to complete the inspection automatically. The robot, which carries the ultrasonic device, moves on the outside of the pipe and transfers the data collected to a computer. The computer analyzes the data and calculates the pipe thickness distribution, the minimum thickness, the percent of metal loss, and the rate of corrosion of the metal. From this information the remaining life expectancy of the pipe is estimated based on proper theory. This new inspection technique is conducted while the pipe is operational, which is a real advantage in minimizing the down time for any operation without compromising the safety of a building in case of sprinkler pipes. The data collected gives a clear cross-section of the pipe on a 360 degree basis, not a one-spot measurement. The results of the new system were verified and deemed successful.

Sewer pipes are an important segment of the infrastructure. Reinforced concrete pipe is used frequently for this application. The next paper "Prediction And Control Of Sulfide Induced Corrosion In Concrete Sewer Infrastructure And Rehabilitation Techniques" presented by Jey K. Jeyapalan, Engineer Consultant, Redmond, Wa.describes the chemical behavior of sulfides and the conditions necessary for hydrogen sulfide corrosion to occur. It also gives a formula to calculate the corrosion rate based on the amount of generated sulfuric acid and the alkalinity of concrete.The paper recommends steps to control corrosion and rehabilitation methods for existing pipes with this problem. In the summary, recommendations are made for more research on the various physico-chemical phenomena involved in concrete corrosion due to sulfide buildup. Advice is also offered to the design engineers to consider the impact of that problem during the design phase.

Oil refineries use frequently reinforced concrete structures. The environment of these refineries is very corrosive. The

next paper "Corrosion Related Deterioration Of Reinforced Concrete Structures At Oil Refineries In The Persian Gulf Region" prepared by Vladimir Novokshchenov, Consultant, Gibsonia, Pennsylvania includes several case histories of corrosion failures of reinforced concrete structures in an aggressive environment. The single most important cause of rebar corrosion was found to be the presence of chloride ions at the level of the reinforcement. Contaminated aggregates and sea water were used during the mixing of concrete. The conditions were aggravated by the flow of sea water in the concrete system and the moisture condensate contaminated with salt-laden dust. The paper reported the recommended methods for rehabilitation in each situation, which could be used as a guide in similar cases.

One of the most important problems in infrastructure is the corrosion of steel in concrete. Chlorides were identified as the major cause of this problem. Chemical inhibitors are one of the methods generally used for corrosion control. The next paper "Impregnation Of Concrete With Corrosion Inhibitors" was prepared by Neal S. Berke et al of W.R. Grace & Co, Cambridge, Massachusetts, and Richard E. Weyers et al of Virginia Polytechnic and State University, Blacksburg, Virginia reports the results of impregnating chloride contaminated concrete with liquid calcium nitrite an effective corrosion inhibitor. Two different procedures were used: One involved heating a bridge deck to above-boiling point of water, then slowly cooling it to ambient temperature, and impregnating liquid calcium nitrite. The second involved placing calcium nitrite rich latex modified grout in predrilled holes and calcium nitrite rich latex modified concrete to replace removed delaminated concrete. Polarization resistance was used to determined the rate of corrosion of steel. Potential measurements were also collected before and after the process. The preliminary results of the two procedures indicate the successful arrest of corrosion. However, more time is needed to determine the effectiveness over a long period as well as a feasibility study to determine the cost for large structures.

Bridges are a vital element of the infrastructure. Bridge management strategies are based on life cycle cost analyses of viable alternatives. The next paper "Predicting Service Life Of Concrete Bridge Decks Subject To Reinforcement Corrosion" was prepared by Philip D. Cady Professor at Penn State University, University park, Pennsylvania, and Richard E. Weyers, Professor at Virginia Polytechnic Institute and State University, Blacksburg, Virginia and presents a mathematical model to predict the service life of a bridge deck. Two main factors control the model. The first is the time for the concrete ion concentration to reach the corrosion threshold level at the reinforcement locations. The second is the time necessary for the corrosion reaction to produce loss of serviceability. The two factors are controlled by the chloride

diffusion through concrete and the rate of corrosion of the reinforcement steel. The paper concluded that the model proved that the actual bridge deck life is influenced by specific site elements such as climate, traffic, and policies.

Steel Piles are used in the support of many infrastructures. The steel piles are usually driven in a variety of soils. Thus, it is important to have a method to measure the rate of corrosion of piles in situ. The next paper "Measuring The Underground Corrosion of Steel Piling At Turcot Yard, Montreal, Canada - A 14 Year Study" was prepared by Edward Escalante, Metallurgist, National Institute of Standards & Technology, Gaithersburg, Maryland.
This paper gives the results of using electrochemical polarization to measure the rate of corrosion of H steel piles in both disturbed and non disturbed soils. These results were compared with the actual physical measurements of metal loss. The paper concluded that the electrochemical polarization technique is useful even though it overestimates the rate of corrosion. The same technique showed that the corrosion current decreased over the-14-year-period of the test.

Steel reinforced concrete is an important component in infrastructure. Thus, it is essential to understand the causes, the forms, and identify the available techniques to assess the deterioration of concrete. The next paper "Assessing The Role Of Steel Corrosion In The Deterioration Of Concrete In The National Infrastructure: A Review Of The Causes Of Corrosion And Current Diagnostic Techniques" was prepared by Bernard H. Hertlein, Project Scientist, STS Consultants, Ashville, North Carolina explained the different elements of concrete and their sources. It also mentioned that the corrosion products of steel occupy 8 to 10 times its original volume. Thus causing the concrete to crack and expose the steel to air, water, and contaminants leading to increase of the corrosion rate. The paper described the forms of concrete deterioration and its impact on corrosion of imbedded steel. The test methods were subdivided into destructive such as coring, sampling, and drilling and non-destructive such as rebound hammer, ultrasonic pulse velocity, ground-penetrating radar, and half-cell potential. The monitoring systems mentioned included strain gages, acoustic emission, and tell-tale plates.

Epoxy-coated rebars are used to control their corrosion. However, coatings could compromise the bond between concrete and the reinforcement. The next paper "Bond Loss Between Epoxy And Alkyd Coated Reinforcement Rebars And Concrete" prepared by L. Maldonado et al, Research Scientist, Centro de Investigacion Y de Estudios Avanzados, Yucatan, Mexico describes the tests performed to determine the bond strength between epoxy coated rebars and concrete. The study showed that there is considerable loss of bond strength. The bond

losses varied with the different type of coating. On the other hand, they increased linearly with thickness in all cases. In the case of epoxy coating, it was found that the bond losses were independent of the bar size.

Cathodic protection has been used successfully to protect the steel rebar in concrete from corrosion. The next paper "Repair Of Corrosion Damaged Reinforced Concrete Wharves Using Cathodic Protection In The Middle East" was prepared by Gareth John, Technical Development Manager of CAPCIS Ltd, Manchester, UK, and Bill Leppard, Technical Director of Sir Alexander Gibb & Partners, Reading, UK, and Brian Wyatt, Cathodic Protection Manager of Tarmack Global, Tarmack Structural Repairs, Wolverhamptor, UK.
This paper describes the steps taken to investigate the cause of corrosion of the reinforced concrete. Regardless of the tightness of specifications and construction, the high chloride induced environment was the main reason determined. Impressed current cathodic protection system was carefully designed using a mixed metal oxide coated titanium mesh as an anode. Gunite (sprayed concrete) was used as an overlay since the protected structure was made of beams and the site conditions were difficult to select another method. Graphite and silver/silver chloride reference electrodes were embedded in concrete below the anode mesh for potential measurement. The final criteria used to control the system include achieving at least 100 mv depolarization after 5 hours, or at least 120 mv depolarization after 25 hours, or an instantaneous off potential of more negative than 750 mv measured against surface mounted Ag/Agcl/Kcl, or an instantaneous off potential of more negative than 600 mv measured against embedded Ag/Agcl/Kcl.

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