行政院及所屬各機關出國報告

(出國類別：出席國際會議)

出席 2002 年國際腐蝕學會第七屆印度分會年會及第二屆亞太區域國際會議報告

服務機關：交通部公路總局
出國人 職稱：副處長
姓名：黃三哲

出國地區：印度
出國期間：91 年 11 月 26 日至 91 年 12 月 2 日
報告日期：92 年 3 月

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行政院及所屬各機關出國報告提要

出國報告名稱：出席2002年國際腐蝕學會第七屆印度分會年會及第二屆亞太區域國際會議報告

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出國人員姓名/服務機關/單位/職稱/電話

黃三哲/交通部公路總局/第三區養護工程處/副處長/08-7862103

出國類別：●考察○進修○研究○實習○其他

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關鍵詞：國際腐蝕學會(NACE)及防蝕技術

內容摘要：

國際腐蝕協會印度分會年會和亞太地區國際年會同時舉行，會中發表之論文從各類環境下如高溫、海岸、太空及焊接等之基本腐蝕理論之探討、使用防蝕材料後影響結構物安全其設計規範之修正研議、監測腐蝕技術之開發及各種防蝕技術之實務運用乃至於防蝕工業之環境管理系統均有包含，內容非常豐富。

印度人民平均生活品質雖然並不優渥，但正用自己特有方式逐步進步成長，此次會議成功的結合學術界和產業界共同發表多篇論文並且舉行三場實務工作探討，讓業者與學者間能有經驗的交流，同時於會場展示業者產品，並評選研究生優良研究作品加以表揚，此種有助於產業技術提昇之國際會議模式值得我國借鏡。

目　　錄

壹 、前言

國際腐蝕協會〔National Association of Corrosion Engineers, International〕印度分會〔India Section〕第七屆年會和第二屆亞太區域國際腐蝕會議於２００２年１１月２８日至１１月３０日爲期三天在印度西南岸城市--果阿(Goa)之濱阿拉伯海岸海灘大飯店(Cidade de Goa)之會議中心舉行。

本會議主要係由印度學術界及產業界分三組於三天內分別對防蝕工作近年內研究成果及理論探討發表約１３０篇論文；舉凡基本防蝕原理乃至實際應用方法如塗裝、陰極防蝕、抑制氧化劑、焊接、管線及海岸防蝕等各方面均有論文發表，並分組對實際工作成果做技術性研討。於會議地點旁並設有產業界各種產品之展示場讓與會者能充分了解新進之各種防蝕方法及產品。

本局於２００２年5月獲該協會邀請並報奉公

路總局９１、１１、１９九十一路人考字第９１４６６４２號函准派第三區養護工程處副處長黃三哲前往參加會議。

貳、行程

本次會議於印度果阿省〔Goa〕面向阿拉伯海之 Vainguinim Beach 渡假大飯店會議中心舉行，並於公務完成後返台順道於新加坡參觀其都市景觀，茲將行程略述如后：

11 月 26 日　啓程搭機過境新加坡，抵達印度第二大城—孟買。

11 月 27 日　自孟買搭機前往會議地點果阿省之 Cidade de Goa 飯店辦理會議住宿報到。

11 月 28 日　上午會議註冊及開幕式並至展覽會場舉行開展儀式；下午分三個會場就陰極防蝕、公共設施腐蝕及基本防蝕理論三個主題共有 37 篇論文由學者及業界發表同時有一場陰極防蝕技術實務探討會，晚間舉行表揚酒會。

11 月 29 日　本日主題爲塗裝系統及就太空、高溫、微生物、工業、海岸及焊

接各方面腐蝕提出共 74 篇論文發表，並有場結構物防蝕之技術實務探討會。

11 月 30 日　本日主題係就管線腐蝕、局部腐蝕、合成物腐蝕及腐蝕抑制劑方面發表 36 篇論文，同時於上午有場關於管線、海上及船之塗裝技術實務探討會下午則為石油和瓦斯氣工業腐蝕之實務探討；並於 16 時至 18 時舉行閉幕儀式。

12 月 01 日　中午搭機前往孟買等候隔日回程班機前往新加坡。

12 月 02 日　順道休假於新加坡停留一日參觀聖陶沙地區及當地都市景觀。

12 月 03 日　搭機返回台灣。

參、會議紀要

本次會議係 NACE 印度分會年會和亞太區域年會一併舉行由 Trustee，P. F. ANTO 及主席 Prof. A. S. Khanna 主持開幕式並表揚對印度及亞太地區於防蝕方面有重大貢獻之學者，來自台灣成功大學蔡文達教授受獎表揚。會場除由產業界及學術界發表論文外並評選防蝕方面研究所優良碩士論文於閉幕式上接受表揚。所發表論文主題分述如后：

1、 Basic Corrosion
2、 Infrastructure Corrosion
3、 Cathodic Protection
4、 Coatings & Linings
5、 Advanced Coatings
6、 Aerospace Corrosion
7、 High Temperature Corrosion
8、 Microbiological Corrosion
9、 Coating Performance
10、 Corrosion in Industries
11、 Offshore Corrosion
12、 Pipeline Coatings
13、 Weld Corrosion
14、 Pipeline Corrosion
15、 Corrosion and Composites
16、 Surface Treatment
17、 Corrosion Inhibitors
18、 Localised Corrosion 以上各主題所發表之論文及作者詳附錄 A。

肆、會議心得報告

本次會議之論文多達 150 篇分別於三個會議廳發表，主要爲從腐蝕基本理論探討、結構物於各種環境下腐蝕現象之研究到防蝕技術之實務成果均包含內容非常豐富。

公共建築物如橋樑等腐蝕現象之研究和防蝕技術之開發，可預防公共危險之發生並可節省維護經費及延長結構物之壽命值得共同探討和重視。茲將主要論文之重要心得敘述如后：

一、鋼筋混泥土使用塗裝鋼筋(coated rebars)設計時應考慮事項

現今有愈來愈多的臨海 RC 建築物使用塗裝鋼筋以抵抗惡劣的腐蝕環境增長結構物之使用壽命，然而眾所周知塗裝鋼筋其束縛力(bond strength)必然較一般鋼筋爲小尤其在荷重狀態下更形突出。世界各國設計規範對此現象於設計過程中均有適當之修

正因素以爲設計時之參考遵行；印度之設計規範(IS)和台灣規範一樣尚無提及此類規定然而其學術界已對此問題實驗探討並提出思考之方向和建議。

所有塗裝鋼筋以環氧樹脂(epoxy coated)最爲常用，爲確保其塗裝品質可參考下列規範之試驗方法：

1、 ASTM A775/A775M-96 Standard Specification for Epoxy-coated Prefabricated Steel Reinforcing Bars
2、 ASTM A934/A934M-96 Fusion bonded epoxy coated carbon steel bars for the reinforcement of concrete – Specification for coated bars
3、 BS 7295:Pt. 1-1990 Epoxy coated steel for the reinforcement of concrete
4、 IS: 13620-1993 Fusion Bonded Epoxy Coated Reinforcing Bars - Specification Standard for Epoxy-Coated Reinforcing Steel Bars
5、 ISO 14654-1999
6、 Eurocode

以上規範主要係對於塗裝鋼筋或有此類鋼筋之混泥土試體規定應完成下列試驗：

1、 乾膜厚度試驗(Dry Film Thickness test)

2、 孔洞檢驗(Pin-hole detection test)

3、 黏著力試驗(Adhesion test)

4、 抗化學性試驗(Chemical resistance test)

5、 電壓試驗(Impressed voltage test)

6、 束縛力試驗(Bond strength to concrete test)

7、 抗損性試驗(Abrasion resistance test)

8、 衝擊試驗(Impact test)

9、 硬度試驗(Hardness test)

10、 噴鹽曝曬試驗(Salt spray chamber exposure test)

經過試體實驗得知，塗裝鋼筋由於表面較光滑其束縛力較一般鋼筋減少約 20%左右且同條件下混泥土產生 0.2mm 裂縫在使用一般鋼筋時之 85%荷重時即產生，尤其是用合成橡膠 polyurethane 塗裝於 60%荷重時就發生。於混泥土與鋼筋間應力之傳遞受束縛力之影響甚鉅對於環氧樹脂塗裝鋼筋 epoxy coated 而言各種結構試體研究就已有顯著成果茲述如后：

1、 保護層厚度和鋼材間距的加大將使得束縛力增加。

2、 使用 epoxy coated 鋼筋其橈度較一般鋼筋加大 20%。

3、 環氧樹脂鋼筋其彎鉤之錨定力較一般鋼筋減

少。

4、同條件下使用還氧樹脂鋼筋混泥土裂縫寬度和高度均較使用一般鋼筋爲大。

由於以上研究成果故在美國 ACI Building Code 如使用環氧樹脂鋼筋其延伸長度有建議修正係數：

- 使用環氧樹脂鋼筋保護層小於 3 倍鋼筋直徑或鋼筋間距小於 6 倍直徑其延伸長度修正係數爲一般鋼筋的 1.5 倍。
- 其他使用環氧樹脂鋼筋其延伸長度修正係數爲使用一般鋼筋的 1.2 倍。

故在規範之修正上應採用重新檢討用增加延伸長度修正係數來補足因使用環氧樹脂鋼筋而所造成之 20%束縛力的損失。

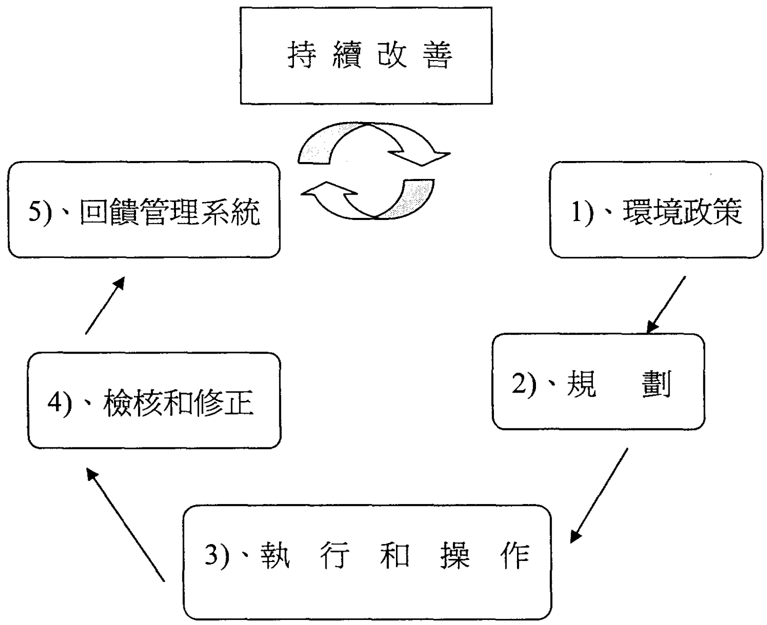
二、腐蝕和環境管理系統

經濟自由化致使工業高度發展，全球環境因而被工業所產生之有害物質污染並引起臭氧層破洞、溫室效應等現象；腐蝕是自然界一種無可避免的現象，

如何使防蝕工業與環境管理系統相結合是值得注視的一個重要課題。

1、 環境管理系統(EMS)

環境管理系統是爲保護全球環境的一種方法，ISO 14001規範五個主要項目指導原則以確環境保護的改善工作能有效率的完成。五個主要項目之流程表如下：



2、 腐蝕管制系統

腐蝕雖是一種無可避免的自然現象，但可依照不同

之環境選擇適當的方法有效管制和避免繼續惡化。腐蝕管制系統有：

1〉 腐蝕抑制劑系統

2〉 塗裝油漆系統

3〉 陰極、陽極防蝕系統

4〉 選擇金屬或非金屬材料

5〉 其他方法

3、 塗裝防蝕工業之環境管理系統

利用前述環境管理系統流程於塗裝系統工業之執行方法敘述如后：

1)環境政策

用簡潔明確的條文訂定環境政策以達成防止環境污染並且符合所有法規的限制和要求。

2)規劃

● 定義影響環境各因素及其標準

環境管理系統主要係減少廢棄物產生並使成本和風險降低，經常考慮的影響因素有空氣、水、土壤、原料和自然資源等。一般這些因素可利用專家經驗法則或數據準則之方法訂定

改善標準之依據。

- 訂定符合法規或需求之管理程序
- 依據環境政策制定達成之項目及目標
- 訂定環境管理計畫(environmental management programmers EMPs) 依據制定之項目及目標設立完成之步驟。

3)執行和操作

以下各項爲考慮重點：

- 執行組織結構和責任之區分
- 環境影響因素課程之教育及員工能力之培訓
- 溝通 適當溝通能讓所有員工了解環境管理系統 EMS 之重要性而能全體合作達成目標。
- 文件記錄管制 有關環境管理系統之手冊、執行過程、訓練及督導改正過程等均須要有文件記錄和電腦存檔。
- 操作管制 塗裝工業因有原料會產生鉛及其他有毒氣體，使人們會產生對人體健康有害之疑慮，所以在操作過程管制應利用設備除去此種有害健康物質的產生。

● 緊急應變機制　建立緊急應變機制可讓任何現場發生之意外損害減至最低的程度。

4)檢核和修正行動

企業組織須建立查核制度以檢查環境管理系統是否確依目標執行，如無法達成原設目標或環境已破壞改變應予以提出檢討並修正各個流程之行動。

5)回饋管理系統

定期檢討評估現行之環境管理系統的適用性和效率性是必須的，其目的在於能加以改善使其臻於完善達成企業環境改善之政策。

因此環境管理系統必須企業不斷的依據環境需求訂定政策、計劃、執行、管制、檢討、修正行動及回饋管理技術的改良且持續改善執行才能達到環境改善之效率。

三、由腐蝕監測預估預力樑橋之服務生命週期

混凝土橋梁有其設計之服務年限然而由於因爲養護不當、超載及不利的環境因素造成橋樑使用年限

之縮短。這些因素中以混凝土中鋼材腐蝕引起之問題影響最大，尤其是預力樑因使用鋼索其斷面遠較鋼筋爲小且承受較大之應力故受腐蝕之影響更形嚴重；如何藉由現場腐蝕率之監測來預估預力樑橋尚可使用之年限成爲一值得探討的課題。

1、 腐蝕反應

腐蝕是一種電化學反應現象，鋼材埋設於混凝土中以防止腐蝕但由於氯離子的侵入和碳化現象使鋼材的表面形成陰極和陽極再加上濕氣和氧氣就產生腐蝕，其陰、陽極之反應如圖 1。

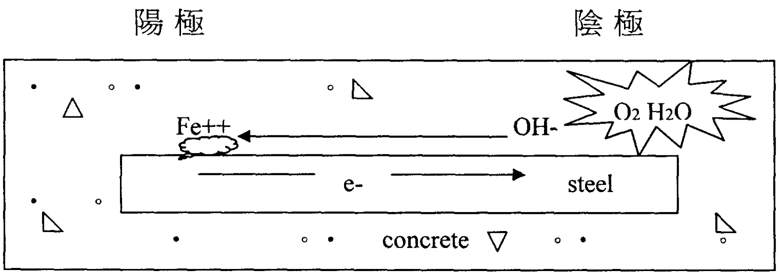


圖 1 Corrosion Cell on steel in concrete

陽極反應　$Fe^{++} \rightarrow Fe + 2e^-$

陰極反應　$4e^- + 2H_2O + O_2 \rightarrow 4OH^-$

這種電化學反應最後生成鐵銹。

$Fe^{++} + 2OH^- \rightarrow Fe(OH)_2$

$4Fe(OH)_2 + O_2 \rightarrow 2Fe_2O_3H_2O$(鐵銹)$+2H_2O$

鐵銹產生後其體積變成原來的三倍在混凝土內就產生張力而使混凝土龜裂，此現象使水氣、氯離子及不利的腐蝕因子更容易滲透至混凝土內而加速鋼材之腐蝕；鋼材斷面因腐蝕而減小造成承受應力之能力減低，如此周而復始將使鋼材混凝土結構物終至破壞。故監測鋼材混凝土之腐蝕行爲是需要的除可預估鋼材混凝土尙可之使用年限外更可爲提供適當修復方法之依據。

2、 腐蝕監測技術

各種不同腐蝕監測技術提供各類監測結果如 Half Cell Potential Technique 僅能得知腐蝕性質之資訊而於此討論之線性極化技術(Linear Polarization Technique)可求得腐蝕率計算鋼材直徑之損失進而預估結構體之再使用年限和據此決定適合的保護及修復系統。

此技術主要原理爲利用外加電流去量測於陰極和陽極間腐蝕電位的改變求得極化電阻(Rp)和腐蝕

電流(Icorr)，依據 Stern and Geary 研究〔附錄 B〕其相關方程式爲：

Icorr=B/Rp(v)

Icorr=腐蝕電流(corrosion current)

Rp=極化電阻(polarization resistance)

B=常數，腐蝕系統 B=26mv

電位的改變和外加電流有直接比例關係而腐蝕率即利用電位差和電流曲線斜率求得。

以上所述原理在實驗室可直接外加電流於鋼材但於橋樑結構物現場並無法直接外加電流於如此龐大之鋼材故發展出護環法(guard ring method)，利用感應器控制於混凝土表面外加電流能量測到固定區段之鋼材變化狀況測得其腐蝕率。

有關腐蝕監測系統應用於實際例之探討請參閱附錄 B。

伍、結論與建議

一、結論

1、印度屬於大陸國家面積約 330 萬平方公里，人口約 9 億多佔世界第二位，由於宗教信仰關係街道常見聖牛漫步及婦孺成群沿街向停紅綠燈過客乞討不僅阻礙交通亦造成髒亂。

2、印度南部溫度日間約 30 度以上晚間溫差達 10 度以上，街上充斥大部分爲無冷氣設備之計程車和三輪馬達無門街車一般人民生活條件較差，貧富差距相當懸殊，於第二大城_孟買住宿於五星級飯店卻座落在貧民窟附近，出飯店區域沿途糞便滿路肩，衛生條件差距更形突出足以讓所有觀光客的感官有巨大的衝擊。

3、印度平均生活條件雖然落後些然卻用自己方法逐步改善，其資訊科技發展相當進步；在此次會議產業界和學術界對腐蝕現象及防蝕工

業技術的發展作實質研討使理論和實務能進一步結合。

4、會議對由各類腐蝕發生原因探討、對結構物影響的管控乃至於結構設計規範因防蝕材料之使用均提出實際有用之方法和建議方案，並對防蝕材料工業對環境影響之管控提出環境管理系統(EMS)的應用以使環境能受到有效的保護，此次會議實是豐富論文發表之年會。

二、建議

1、本次會議為腐蝕協會 NACE 印度分會和亞太區域年會合併舉行屬國際會議，我國防蝕學會和 NACE 臺灣分會係屬不同組織應予結合舉辦國際型會議吸引外國產、學界參與提升國際地位並使國內學術界與產業界能共同研發有效防蝕技術。

2、我國橋樑設計規範大部分源自美國，關於使用防蝕塗裝材料如 EPOXY COATED BARS 對設

計條件影響其均有相關規範規定，我國規範尚未提及應即早研擬探討納入修正規範才能避免對結構物之安全造成影響。

3、 我國許多橋樑在沿海地區興建其內部鋼材之腐蝕狀況應探討有效監測系統以量測鋼材的實際腐蝕率進而能提出適當之修復方式。

4、 各種防蝕工業應重視生產過程對環境的保護行動，企業界應能確切實施環境管理系統(EMS)並不斷的檢討回饋改善該管理系統以達到共同維護環境的目標。

5、 順道參觀新加坡城市景觀，其在橋樑護欄處興建花台種植花草，或道路兩旁有混凝土結構物之前均利用各種方式種植綠色植物美化，使整個城市綠意盎然，值得我國於道路景觀改善時借鏡。

附錄 A

論文主題及作者一覽表

TECHNICAL SESSIONS

DAY - 1

Thursday, November 28, 2002

Time : 13.30 - 16.00

HALL "A"

Cathodic Protection

V. G. Kulkarni - Chairman

Rehabilitation & Cathodic Protection of Old Pipeline.
Rajendra Kumar & Pawan Kumar Bansal, Indian Oil Corporation Ltd. Ajmer, Rajasthan

Cathodic Protection of Underground Pipelines.
A. K. Garg, N T P C, Noida

Performance of Zinc-Nickel Alloy Coatings as Anodes for Impressed Current Cathodic Protection of Steel
Y. Barakat, M. A. Shoieb, I. M. Ghavad and N. Gomea , (CMRDI), Cairo, Egypt

Health survey findings for India's first cross-country pipeline incorporating Cathodic Protection system
I. B. Borbora and D. Saram, CEPL

High performance Al-Zn alloy Composite sacrificial anodes
S. M. A. Shibli, V. S. Gireesh, George Sony and R. Manu, University of Kerala, Trivandrum, Kerala

Condition Monitoring Through CIPL on – off and DCVG Survey for GREP Pipeline
Ayush Gupta and S. D. Sharma, GAIL, Agra

Supervisory Control and Data Acquisition of Cathodic Protection (CP) Systems, Today and Tomorrow
J. R. Anjaria, Cimcon Software India Pvt. Ltd.

HALL "B"

Infrastructure Corrosion-1

P. K. Sikdar - Chairman

Corrosion of Infrastructure – A Stainless Perspective
Nitin Gulve, Sun Flag Iron & Steel Co. Ltd., Mumbai

30 years performance of fusion bonded epoxy coating on reinforced steel bars in RCC structures
P. Subramaniam, Inf. Consultant, Chennai & R. Radhakrishnan, PSL Corrosion Control Service, Mumbai

Performance of Bridge Deck Slabs Reinforced with Glass Fibre Reinforced Plastic (GFRP) bars
Dr. M. S. M. Ali (CRRI), S. K. Sharma (CRRI), Bichittar Singh (DCE,DU), Dr. V. V. L. K. Rao (CRRI), and Prof. D. Goldar (DCE,DU), Central Road Research Institute, New Delhi

Repair and Rehabilitaition of Berthing Structures
Prof. M. R. Pranesh & Prof. R. Sundaravadivelu, Dept. of Ocean Eng., I I T Madras, Chennai

A Novel Organic Based Corrosion Inhibiting Admixture for Marine National Highway Bridges
M. Vishnudevan, K. Thangavel and T. M. Balasubramanyan, Central Electrochemical Research Institute, Karaikudi

Design Considerations for Concrete Structures Reinforced with Coated Rebars
Dr. V.V.L. Kanta Rao, Dr. M.S.M. Ali, S.K. Sharma and M.V.B. Rao , Central Road Research Institute, New Delhi

Coatings & Linings for Anti Corrosion & Erosion of Concrete Structures
Hemant M. Kapadia, Univest Chemicals Pvt. Ltd., Mumbai – 400 004, India.

New Flexiblize, Highly Crosslinked 100% Solid Epoxy Lining for Steel and Concrete Repair and Protection
Raymond J. Jaworowski, A Wesley Langeland, Pankaj Jain and N. Varia, Wearresist Technologies Pvt. Ltd., 749/9 GIDC Makarpura, Baroda: 390 010

HALL "C"

Basic Corrosion-1

Prof. S. N. Malhotra - Chairman

Evaluation of Nitric acid passivation on 316L SS and its Effect on Hydroxyapatite Coatings – An Electrochemical approach - S. Kannan, A. Balamurugan and S. Rajeswari University of Madras, Chennai

Corrosion Behaviour of 18 Ni 250 Grade Maraging Steel in Acid Medium
Jagannath Nayak, P. Saravanan, H. V. Sudhaker & K. R. Hebbar, Dept. of Metallurgical & Materials Eng. KREC, Surathkal

Corrosion Behaviour of Different Zinc Electroplated and Passivated Steel
Urvesh. Vala, I. B. Dave & K. B. Pai , M. S. University of Baroda, Vadodara

Studies on Anodized Oxide Film of Al-Li & Al-Cu as an Aerospace Material
I. B. Dave, U. V. Vala and K. B. Pai , Ghandhy College of Eng. Tech & M. S. University of Baroda, Vadodara

Electro – Plating: A Novel Route for Corrosion Control
Dr. Dilip R. Peshwe & Dr. S. U. Pathak, VRCE, Nagpur

Corrosion Behaviour of Electroless Ni-P Coatings as a Function of Plating Bath pH
S. Parasuraman, Prof. S. K. Seshadri and M. Palaniappa, Indian Institute of Technology Madras, Chennai

Corrosion Resistant Electrodiposited Zinc Coating from Zinc Dross
M.N.Singh, D.K.Basu, A. K.Bhattamishra and S.K.Narang, NML, Jamshedpur

Compatibility studies on Stainless Steel-304, and Carbon Steel in Permanganic acid and organic acid mixture
Puspalata Rajesh, Dr. S. V. Narasimhan, P S. Kumar, S. Suresh, Sinu Chandran, H. Subramanian, and S. Velmurugan, Water and Steam Chemistry Laboratory, BARC Facilities, Kalpakkam

TECHNICAL SESSIONS

DAY - 1

Thursday, November 28, 2002

Time : 16.00 - 18.30

HALL "A"	HALL "B"	HALL "C"
Cathodic Protection	**Infrastructure Corrosion-2**	**Basic Corrosion-2**
Technical Workshop -1 Cathodic Protection	**Nirmaljit Singh** - Chairman	**M. K. Totlani** - Chairman
A M Uplenchwar - Chairman **Anand Kulkarni** - Coordinator **Panel members:** R P Nagar V P Sharma, Sandeep Mittal, Ranjit Chowdhury, Bhattcharya.	Advantage Against Corrosion by Flyash Admixed Reinforced Concrete Prof. P. K. Sikdar & Satander Kumar, Central Road Research Institute, New Delhi Development of Improved Corrosion Resistant Thermo-Mechanically Treated Re-Enforcement Bars Dr. A. Bhattacharyya, B. K. Panigrahi, S. Srikanth, B. D. Tripathy, R&D Centre for Iron & Steel, SAIL, Ranchi Reinforcement Corrosion in contaminated concrete : Role of Chemistry and micro structure of rebars D.D.N.Singh and Rita Ghosh, Corrosion Protection Division, NML, Jamshedpur Restoration of Corrosion Damaged Structures M. S. Venkatesh, Fosroc Chemicals (India) Pvt. Ltd. Bangalore Chloride Induced Corrosion of Reinforcement in R. C. Concrete beams Under Stressed Condition S. Shanmugam, Dr. A. Sethurathnam, Coimbatore Institute of Technology, Coimbatore Effect of Loading and Unloading on Corrosion behaviour of RCC J. C. Roy, P. K. Mitra and S. Paul, Jadavpur University, Calcutta Service Life Prediction of Prestressed Concrete Bridges through On-Site Corrosion Measurements V.V.L.K. Rao, S.S. Gaharwar, Dr. Ram Kumar, M.V. Bhaskara Rao, Central Road Research Institute, New Delhi	Elecrochemical Interferometry of Carbon Steel in Seawater with Low Concentration of RA-41 Corrosion Inhibitor K. Habib, Material Science Lab., Dept. of Advanced Systems, KISR, Kuwait Corrosion and Environmental Management Sundar Kataria and Dr. B. M. Reddy ICS, Mumbai Controlling Corrosion by Modifying the Environment Dr. Dilip R. Peshwe, Yogini Kalambhe, Dr. S. U. Pathak VRCE, Nagpur Bioglass coated stainless steel as implant material D. K. Pattanayak, A. S. Karakoti, A. S. Khanna, T. R. Rama Mohan, I I T Bombay Corrosion Behavior of Age-hardenable Aluminium-Chromium Alloys J. Datta, S. Datta and M. K. Banerjee, Dept. of Chemistry, B.E. College (D.U.), Howrah Electrochemical noise analysis of open circuit potential fluctuation of some Al alloys in non deaerated 3.5% NaCl aqueous solution R. C. Barik, R. Khandagle, S. N. Malhotra, R. Raman, I I T Bombay Corrosion characteristics of nitrogen containing steel alloys R. S. Chaudhary, N. K.Handa, H. Kumar and S. Chaudhary, Dept. of Chemistry, M D University, Rohtak

TECHNICAL SESSIONS

DAY - 2

Friday, November 29, 2002

Time : 9.00 - 13.00

HALL "A"

Coating & Linings

Matthew Brown - Chairman

Advances in Accelerated Testing for High Performance Coatings
Mike Mitchell, International Coatings Ltd, Gateshead, NE10 OJY

Pipe coating adhesive technology comes to India
Jamie Cox, DuPont, Canada

"Purecoat" a new Arcspray method of to give coatings with improved hot and wet corrosion properties
T. P. Lester, Metallisation Ltd., Peartree Lane, Dudhey, England

Proven maintenance coating for corrosion control in offshore oil industries
P. S. Khanolkar, Goodlass Nerolac Paints, Mumbai

Maintenance painting water jetting as a surface preparation
Jakov Radjenovic- Bobo -Hempel Coatings (Singapore) PTE.Ltd

Development of Galvannealed Steel: An Ideal Coated Product for the Automobiles
Santanu Chakrabarti, R. Chattopadhyay, G. Jha, Avtar Singh and H. C Kharkar, Tata Steel, Jamshedpur

Moisture Cured Urethanes & their Relevance to Industry where long Maintenance Free Periods on Steel, Concrete, Wood are Envisaged
Venkateswarlu and Dr. B. G. K. Murthy, Solvosol Paints Pvt. Ltd., Hyderabad.

Advanced Coating Systems

Mike Mitchell - Chairman

Long Term Corrosion Using Heavy-Duty Glassflake Filled Coatings.
Graham Greenwood-Sole, Corrocoat Ltd., Forster Street, Leeds, England

High Performance Glass Flake Coatings For Aggressive Environts.
Dr. B. P. Mallik, Asian Paints (India) Ltd. Mumbai, Sree Kumar and Prof. A.S.Khanna. IIT Bomaby

Formulating Novel Aqueous Epoxy Rein Systems For Metal Primer Applications
Dr. L.D. McManus, Air Products Chemicals, Manchester

HALL "B"

Aerospace Corrosion

AVM (Retd.) G. K. Kwatra- Chairman

Laser Radiation as a Tool for Manufacturing and Repair of Aerospace and Power Plant Components
Dr. E. W. Kreutz, Lehrstuhl fur Lasertechnik, RWTH Aachen, Steinbachstr, Germany

Studies on Material and Corrosion Characteristics of Aluminium Alloy Skin and Low Alloy Steel Screw of IL-76 Aircraft
D. D. N. Singh, S. R. Singh, S. K. Das, B. R. Kumar, S. Bhattacharjee and B. A. Lakra, NML, Jamshedpur

Fracture Mechanics Based Methods for Evaluating the SCC behaviour of Aerospace Aluminium Alloy
K. Sree Kumar, V. M. J. Sharma, G. Venkata Narayana, V. Diwakar, Vikram Sarabhai Space Centre, Trivandrum

Effect of Parameters in the formation of Three dimensional components by Laser Forming
Sujata Mahapatra, A S Khanna and A Gasser, Indian Institute of Technology Bombay

Corrosion Behaviour of Al-Mg-Si Alloys in Different Media – Some Observations
A. K. Bhattamishra, D. K. Basu, M. N. Singh P. K. De , K. Lal, S. Das and S. K. Narang, N M L, Jamshedpur

Corrosion Related Failures - Case study on typical Aircrafts Components
S.R. Mukunde, Sucy Oommen, K.M. Varghese, M.S. Nadgir, HAL (Aircrafts Division) , Nasik.

Technical Workshop - 2
Corrosion Protection of Structures

R. K. Jha - Chairman

Rajan Bahri - Coordinator

Panel members:

P. Subramaniam,

Nitin Gulve,

Dr. V. V. L. Kantarao,

Prof. A.S. Khanna,

P. Kamat

HALL "C"

High Temperature Corrosion

Dr. E. W. Kreutz - Chairman

Effects of Environmental Degradation In Ferritic Steels During High Temperature Fatigue
Dr. S.L. Mannan and K. Bhanu Sankar Rao, MDG, IGCAR, Kalpakkam

High Temperature Oxidation and Rupture Of Acid Gas Line In Sulphur Recovery Unit,
H. R. Sharath, Krishna Hegde, Vijay G Joshi, Mangalore Refinery & Petrochemicals Limited, Mangalore

Hot corrosion of Superalloys Inconel 718 and Superni 601
Pallavi Pharkya & Manisha, Dr.M.K.Bhargava, Dr.C.P. Sharma and Dr.A.K.Bhargava, Malaviya Regional Engineering College, Jaipur

Use of Nano powders (TiO_2, SiO_2, Al_2O_3) to protect scale formation on cold rolled steel
S.Dhabal , T.B.Ghosh, Department of Physics, IIT, Kharagpur

Microbiological Corrosion

B. N. Bankapur - Chairman

Experience of Microbiologically Induced corrosion in recycled treated effluent in a Petroleum refinery,
C. Sreeraj, Sudhir Pai M, M. Vinayakumar, Mangalore Refinery & Petrochemicals Limited, Mangalore

Application of Chlorine Dioxide as an ideal Biocide than Cl_2 for effective control of micro-organism and biological growth in presence of ammonia in circulating cooling water of Urea cooling tower- An experience at GNFC
Dr. R. K. Sharma & L. R. Patel, GNFC Ltd., Bharuch.

Corrosion and Control of Cu-Ni and Cu-Zn alloys-Economic and scientific aspects
Waheed A Badawy , University of Cairo Giza, Egypt

Evaluation of copper corrosion in Simulated body fluids
S. Ramesh, S. Kannan and S. Rajeswari University of Madras, Chennai

TECHNICAL SESSIONS

DAY - 2

Friday, November 29, 2002

Time : 14.00 - 18.00

HALL "A"

Corrosion Behaviour of Automobile Part (Carburetor) in Marine Environment and Developing New Protective Coatings
R. Elansezhian, V. Soundararajan, M. Natesan, S. Palraj, Pondicherry Engineering College, Pondicherry

Studies on epoxy acrylate high performance paint
Sharif Ahmad, S. M. Ashraf, M. Alam, Abul Hasnat MRL, Jamia Millia Islamia, New Delhi

Performance Evaluation of Epoxy Novolac and High Build Epoxy Coating
Dhananjay Dhage, G. S. Mahpatra, A. S. Khanna, Mukul Gupta and S.B. Das, R. E. C Durgapur

Film-galvanisation – A New Concept in corrosion Resistance
R. K. Bhatia, John Galt Zinga Technologies

Prevention of Microbial Corrosion of mild Steel with Novel Antibacterial Polymeric Coating
Dr. R. S. Dubey, R. J. College, University of Bombay, Mumbai

Coating Performance

T. S. Lamba - Chairman

Bridgeing the Gap in Coating Performance
Matthew Brown, Sigma Coatings, Singapore

Best practice anti corrosion systems for floating production storage and offloading vessels (FPSOs)
James Kavanagh, AkzoNobel (Asai Pacific Region)

Dehumidification Enables Quality Coatings – Case Studies
Jagdeep Singh, Technical Drying Services (Asia) Pvt. Ltd, New Delhi

Effective Corrosion Control of Steel through Conducting Polymer Coating
T. K. Rout, G. Jha, A. K. Singh, N. Bandyopadhyay & O. N. Mohanty, R & D Division, Tata Steel, Jamshedpur

Plural Component Painting Application Equipments.
Denzil D'costa, Graco Fluid Handling Equipments

HALL "B"

Corrosion in Industries

Rajendra Prasad - Chairman

Comparative Corrosion Performance of materials used in handling Paper machine White Water
Dr. A. K. Singh and G. Singh, Dept. of Paper Technology, I I T, Roorkee, Saharanpur

Corrosion Deposit Control in Boiler Fire Side
Deepak Phulwar, Vasu Chemicals, Mumbai

SO_2 Induced Corrosion in Sugar Factories
Narendra Mohan, A. Bajpai and S. K. Gupta, National Sugar Institute, Kanpur

Significance of Cooling Water Management in Captive Power Plants
R Sethuraman, R Annapurna and Y Kalpana, BHEL Corporate R&D, Hyderabad

Corrosion of Aluminium Industrial Products
A. K. Saha, Bharat Aluminium Company Ltd., Balco, Korba

Electro chemical Evaluation of corrosion inhibitors for Monel - 400 in Process Cooling Waters(PCW)"
M. S. Eswaran, Sumathi Suresh and S.Rangarajan, Water and Steam Chemistry Laboratory, BARC Facilities, Kalpakkam

Studies on Titanium-its Alloy and Stainless Steels for Phosphoric Acid Plant
S. R. Raval, U. V. Vala and K. B. Pai, M. S. University of Baroda, Surat

Case study of High Temperature Sulphide Corrosion in Stabilizer Reboiler of LPG recovery unit
Mr. M. Y. Bhave, Indian Oil Corp Ltd, Guwahati refinery, Guwahati.

Corrosion in Industries (Rehabilitation & Monitoring)

R. Shah - Chairman

Corrosion in Refinery Industries
S. Ghatak Chaudhuri, Indian Oil Corporation Ltd., New Delhi

HALL "C"

Recent Advances in Detection, Identification and Monitoring of Microbiologically influenced Corrosion of Metallic Materials in Marine Environment
Dr. R. S. Dubey, R. J. College, University of Bombay, Mumbai

Biocidal Action of Triazole additives on Mild Steel in Natural Aqueous Environment
S. Ramesh S. Rajeswari and S. Maruthamuthu University of Madras, (CECRI),Chennai,

Microbiologically Influenceed corrosion of Stainless Steel
R. S. Dubey & S. N. Upadhyay, Dept. of Chemistry, BHU, Varanasi

Biofilm development and corrosion of steel in a polluted environment with emphasis on water quality
Jothi Basu, S. Selvarajan, P. Sriyutha Murthy, D. Magesh Peter,S.L. Sasikala, A. Palavesam, R. Venkatesan and M. Ravindran, N I O Tech., Chennai,Institute for coastal area studies, Nagercoil.

Offshore Corrosion

Bob Phang - Chairman

Investigation of Causes of Tubing failure of an oil well in Indian Offshore
A. G. Sarkar, Sangeeta R. Prasad, S. S. Bhat, Asis Isor, A. Bhardwaj, and G. R. Sanjiva, IEOT, ONGC, Panvel

Control of Sulphate Reducing Bacteria in Water Injection and Well Fluid Lines in Western Offshore
Sandeep Narain, A. K. Shukla, V P S Bagga, S. C. Maheshwari, N. V. Subramanayam, M. K. Bhatta Pipeline Division, ONGC, MRBC, Mumbai

H_2S generation & its mitigation in well fluid lines located in Western Offshore - A Case Study
P. V. Mali, Sandeep Narain, P. S. Sagar and Anil Johri, ONGC, IOGPT, Panvel

Health Monitoring of the Pipelines of Mumbai Offshore Field
M. K. Bhatta, N. V. Subramanayam, S. C. Maheshwari, V P S Bagga, Sandeep Narain, A. K. Shukla, Pipeline Division, ONGC, MRBC, Mumbai

TECHNICAL SESSIONS

DAY - 2

Friday, November 29, 2002

Time : 16.00 - 18.00

HALL "A"

ISO 9001, Quality Management System, Corrosion Coating System Industry
Sundar Kataria and Dr. B. M. Reddy, International Certifications Services, Mumbai

Surface tolerant coatings a new era in high performance coatings
J. B. Jain, Grand Polycoats Company Pvt. Ltd., Vadodara

Pipeline Coatings

A. K. Purwah - Chairman

Online Coating and Refurbishment
Rainer Kuprion & Christopher P Dorsey, Goldschmidt TIB GmbH, Germany

Dual Powder Fusion Bonded Epoxies: Ten years later
Kuruvila Varughese, DuPont, USA

Girth Weld Joint Coatings for On-shore Buried Pipeline in India,
Robin John, Tyco Adhesives – Raychem Corrosion Department, England

Advanced High Density Polyethylene (HDPE) System for Steel Pipe Coating
Suhas Savant, Reliance Industries Ltd, Mumbai

Selection of Coating materials for underground Pipelines for high temperature services
T.K. Roy, S.T.P Ltd, Calcutta

HALL "B"

Naphthanic Acid Corrosion Failure in Refineries
B. S. Negi, Indian Oil Corporation Ltd., New Delhi

Rehabilitation Parallel – plumbing in-Plant Pipelines
Dr. Anil Bhardwaj, I. R. Kapoor, G. R. Sanjiva and A. K. Sonawane, IEOT, ONGC, Panvel

Monitoring Plant Using 'Plant Integrity Assurance Manuals'
U Anand, Amish B Jani, Reliance Petroleum Ltd, Jamnagar

Corrosion Monitoring & Auditing
Ramesh Kumar, Indian Oil Corporation Ltd., New Delhi

Health Monitoring of Industrial Structures
A. R. Santhakumar, Anna University, Chennai

Failure of Equipment with Exotic Materials – Analysis in Petrochemical Complex at NCPL
Amit P Dave, Narmada Chematur Petrochemicals Ltd., Narmadanagar, Bharuch

Corrosion monitoring in process Industries
By M.K. Rastogi & K.R. Soni, IOCL, Haldia Refinery

Corrosion/erosion problems in fluidized catalytic cracking unit of Haldia Refinery
By: DP Ghosh & K R Soni, IOCL, Haldia Refinery

HALL "C"

Live Prediction of Fishing Trawler Wharf after Rehabilitation
Prof. R. Sundaravadivelu & Prof. M. R. Pranesh, Dept of Ocean Engineering, I I T, Madras, Chennai

Long terms preservation of ships
CDR S C Mittal, Naval Dockward, Mumbai.

Marine Corrosion in Goa
V. M. Gaitonde, V. S. Dempo & Co.

Weld Corrosion

S. L. Kataria - Chairman

Corrosion Problems in Weldments of Austenitic Stainless Steels and Their Mitigation
Dr. H. S. Khatak & H. Sheikh, IGCAR, Kalpakkam, Tamil Nadu

The Electrochemical Behavior of Ti-6Al-4V Alloy after Electron Beam Welding (EBW)
Kung-Cheng Li, C. A. Huang and T. T. Wang, Dept. Mechanical Engg. Chang Gung University, Taoyuan, Taiwan

Pitting Corrosion Characteristics across the thickness of duplex stainless steel weld clad on carbon steel
R. Dalvi, S. G. Sardesai, R. Raman, Dept. of Metallurgical Eng. and Materials Service, I I T Bombay

Repassivation studies by rapid scratch technique on super duplex stainless steel welds in nondeaerated 3.5% NaCl solution
Ramesh P, R. Khandagale, R. Dalve, Depashree Nage, R. Raman, I I T Bombay

Effect of deformation on sensitization-desensitization behavior of stainless steels
Raghuvir Singh, A. Kumar, P.K. Dey, and I. Chattoraj, N M L, Jamshedpur

TECHNICAL SESSIONS

DAY - 3

Saturday, November 30, 2002

Time : 9.00 - 13.00

HALL "A"

Pipeline Corrosion

K. M. Bansal - Chairman

Multiflow Dynamic loop – an excellent tool to simulate pipeline corrosion
A. S. Khanna, I I T, Bombay

Internal Health Assessment of Pipeline with Flow parameters
K. K. Jha & P. R. Thatte, Indian Oil Corporation Ltd., Pipeline Division, Noida

Internal Corrosion and its Control in the long Sub-sea Gas Condensate Pipelines Containing H_2S and CO_2
B. P. Babu & D. K. Mukherjee, MRBC, ONGC, Mumbai

Cross Country Petroleum Pipelines Need to Consider Corrosion Allowance in Design
V. C. Sati, Indian Oil Corporation Ltd., Pipeline Division, Noida

Re-Certification of Pipeline Using "Risk Based Inspection (RBI System)
Sundar Kataria and Haridasan Thekkethil, ICS, Mumbai

Protection of VCM Pipeline and Supports
Dr. R. Sundaravadivelu and R. Jayakumar, Dept of Ocean Eng., IIT Madras, & DCW Ltd, Sahupuram

Monitoring of Internal and external corrosion of underground Gas Pipeline : A Gail Perspective
By J.P.N.Agrawal, Sr Manager (E), Gail, Dibiyapur

Technical Workshop - 3

Coating - Pipeline, Offshore & Ships

S. P. Rao - Chairman

B. Ramakrishnan - Coordinator

Panel members:

Matthew Brown,

G. B. Palankar,

Suraj Kumar,

T. S. Lamba

HALL "B"

Corrosion and Composites

G. S. Vishwanathan - Chairman

Composite Material An – alternative to metallic alloys for Oil & Gas application
G. S. Viswanath, Strategic Engineering Pvt. Ltd., Chennai

Composite Material – wear degradation mechanisms
Prof. A. N. Tiwari, IIT Bombay

A Study on the Synergistic Effect of Fluoride and Suphate Ions on the Kinetics of Corrosio of 16-HCR-TMT (Cu-Mo)-500 Reinforcement Bars in 3.5% Sodium Chloride Solution
K C Roy, D. K. Mondal and A M Popli, CA & CE Group, RDCIS, SAIL, Ranchi

Corrosion and Wear Resistance of Nickel – Alumina Composite
R. K. Yadava & Virendra Singh, Malaviya Regional Engineering College, Jaipur

Computer simulation of the corrosion properties of advanced materials like ZA-27 metal matrix composites reinforced with quartz particulates
P V Krupakara, Department of Chemistry, R V College of engineering, Mysore Road, Bangalore

Surface Treatment

S. J. William - Chairman

Laser Surface Treatment of Thermal Barrier Coatings
Christian Coddet, LERMPSUTBM, France

Fire Protection of Steel Structures – An Art
Jayanta K. Saha, & Dr. S.R. Mediratta, Institute for Steel Development & Growth, Kolkata

Effect of Application Process on Corrosion Protection Performance of Zinc & Aluminium Thermal Spray Coatings in Marine Steel Structures
Cdr P K Sharma, Lt Cdr N Kumar and Prof A S Khanna, Naval Dockyard, Sena Bhavan, Delhi

Corrosion Control in Bimetallic Joints Using Primary Coats on Fasteners, Secondary Coats on Joints and Comparative Performance Evalua-

HALL "C"

Corrosion Inhibitors - 1

R. Rajamani - Chairman

The Investigation of the MCI Effectiveness on Randolph Street Bridge
Ashish Gandhi, Cortec Corporation, St. Paul, MN, USA

Application of Advanced Cooling Water Treatment to Achieve Multi prone Benefits
Dr. M. M. Pandya, N. N. Patel, B. V. Ankleshwaria, Research Centre, GSF&C Ltd., Vadodara

A Study of Adsorption Properties of Mercaptans on Mild Steel in Binary Acid Mixture(12% HCl + 3% HF)
Dr. S Vishwanatham, Indian School of Mines, Dhanbad

Synthesis and application of nano size for effective inhibition of mild steel corrosion in aqueous media
B. Jabeera, S. M. A. Shibli and T. S. Anirudhan, University of Kerala, Trivandrum, Kerala

New technique for determining antiscalant efficiency in Industrial Cooling water
R. S. Chaudhary and H. Kumar, Dept. of Chemistry, MD University, Rohtak

Inhibition of corrosion of brass alloys in acid medium
A. Lalitha, S. Ramesh and S. Rajeswari, University of Madras, Chennai

Corrosion Inhibition of Mild Steel by Some Organic Derivatives in 3.4% Sodium Chloride Solution
Sibasis Acharya, Indian Institute of Science, Bangalore

Corrosion Inhibitors - 2

A. K. Sonawane - Chairman

Evaluation of a Non - Organo Phosponate Organic Polymer as a Threshold Inhibitor for Power Plants
V. Saravanan, Tellabs Chemicals, Mumbai

Inhibitive Effect of Thiourea on E-34 Micro Alloyed Steels in 1N H_2SO_4
S.K. Asiful Hossain, P. K. Mitra, S. Paul Jadavpur University, Calcutta

TECHNICAL SESSIONS

DAY - 3

Saturday, November 28, 2002

Time : 14.00 - 16.00

HALL "A"

Technical Workshop - 4
Corrosion in Oil & Gas Industry

C. R. Prasad - Chairman
Kapil Garg - Coordinator

Panel members:
K. M. Bansal,
A. K. Sonawane,
Rajendra Kumar,
A. K. Fotedar,
R. C. Gaurh,
Kadam Singh

HALL "B"

tion after Salt Spray Test
A Basu, D B Pedram, KB Wagh & L D Singh, Defence R & D Org., R & D Establishment Engineers, Dighi, Pune

Evaluation of Corrosion Behaviour of Galvannealed Sheet for Auto Body Application
Dr. N Bandyopadhyay, G. Jha, A. K. Singh, T.K.Rout, A. J. Khan, O. N. Mohanty, R & D Div. Tata Steel, Jamshedpur

Fertilizers Induced Corrosion on Mild Steel and its Control by Suitable Surface Treatment
I. B. Singh & A. H. Yegneswaran, Regional Research Laboratory, (CSIR), Bhopal

On solid state reactions of multilayer film of Al / Cu / Fe
S. Dhabal , T. B. Ghosh Department of Physics, IIT , Kharagpur

Localized Corrosion

Bhalekar - Chairman

Quest for Aluminum Alloys with Improved Stress Corrosion Cracking Resistance
U. K. Chatterjee and K. S. Ghosh, Indian Institute of Technology, Kharagpur

Electrochemical analysis of crevice corrosion behavior of 304 stainless steel in scale forming ground water media
D. Gopi, S. Ramesh and S. Rajeswari, University of Madras, Chennai

Development of micro electrochemical Ecorr noise probing system to study degradation or enhancement of loacalised corrosion resistance of passive materials
R. Raman, R. Khandagale, R. Dalvi, I I T, Bombay

Pitting corrosion in annular plate projection of crude oil storage tanks & it's preventive maintenance – A case study for IOCL Vadinar,
S. S. Gurjar, & H. Baindail, Indian Oil Corporations Ltd., Jamnagar (Gujarat)

Corrosion Behaviour of Sol-Gel Hydroxyapatite and Titaniumdioxide Coatings on Surgical Grade 316L SS in Simulated body fluids
A. Balamurugan, S. Kannan, and S. Rajeswari, University of Madras, Chennai

HALL "C"

Studies on Improvement of Quality of Motor Gasoline through Additives
Hamid Ali and N. Sardar, M. A. Quraishi, Dept. of Petroleum Studies/IPS, Aligarh Muslim University, Aligarh

Studies on Corrosion Additives for Quality Fuel - Kerosene
Najam Sardar and Hamid Ali, M. A. Quraishi Dept. of Petroleum Studies/IPS, Aligarh Muslim University, Aligarh

附錄 B

CASE STUDY

V.V.L.Kanta Rao, S.S.Gaharwar, Ram Kumar, M.V. B. Rao

Scientists, Bridge & Instrumentation Engineering
Central Road Research Institute, New Delhi-110020, INDIA

Service Life Prediction of Prestressed Concrete Bridges Through On-Site Corrosion Monitoring

1.0 Introduction

Concrete bridges, which are properly designed and built, are supposed to function satisfactorily throughout their design life. However, during their service life span, they suffer from various distresses on account of inadequate maintenance, ignorance, overuse and adverse service environment. These distresses seriously affect the performance of the bridges. Sometimes the service life period of such bridges gets reduced significantly [1,8]. Among the other distresses, it is the corrosion of steel embedded in concrete, which poses the most critical problem to the durability and safety of such distressed bridges. Corrosion of tendons in prestressed concrete bridges, may be more serious than corrosion in reinforced concrete structures, since the prestressing tendons have a relatively small cross sectional area and they are in highly stressed condition [6]. Even a slight reduction in the cross sectional area due to corrosion may lead to significant weakening or even the collapse of the structure. Hence, distressed bridges require timely assessment of their structural condition and evolution of suitable rehabilitation measures as per the requirement. Before planning a rehabilitation scheme, it is a prerequisite to have an idea about the life expectancy of the bridge. Approximate estimate of life expectancy is valuable where damage is related to the time dependent deterioration processes like corrosion of reinforcement.

Service life of corroded prestressed concrete bridges can be predicted on the basis of on-site corrosion rate measurements [5,8]. Out of the various available methods for corrosion rate measurements, it is the linear polarisation measurement technique, which has potential for the laboratory as well as field applications [2,3,4,7]. The present paper describes the salient features of this technique along with its limitations. It also presents a case study of service life prediction through corrosion monitoring of a post tensioned concrete bridge whose ducts' grouting was found contaminated by chlorides.

2.0 Corrosion reactions

Corrosion is an electrochemical process. For reinforced and prestressed concrete structures, it is initiated due to the formation of anode and cathode on the steel surface causing a current to flow between anode and cathode. Electrodes' formation on steel surface may be attributed to the local differences in the metal composition, applied stresses, grain boundaries and the environmental conditions in the vicinity of steel in concrete.

Although the steel embedded in concrete is protected from corrosion due to the formation of a passive oxide film on its surface in the highly alkaline environment, it can be depassivated due to the chloride ingress or carbonation phenomena. As a result, the anodic and cathodic sites are formed on the steel surface. In the presence of moisture (which serves as an electrolyte medium) and oxygen (which remains in dissolved state in the moisture of concrete or enters the concrete through its pores), corrosion reactions are initiated at anodic and cathodic sites [1,6] as shown in Fig.1.

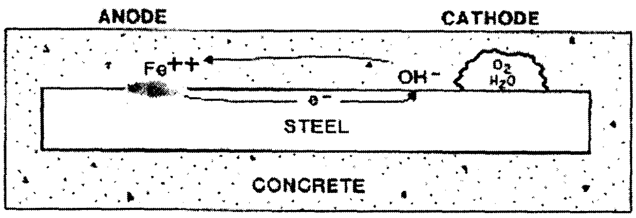


Fig.1. Corrosion Cell on Steel in Concrete [1]

Anodic reaction

$Fe \rightarrow Fe^{++} + 2e^-$ (i)

Cathodic reaction

$4e^- + 2H_2O + O_2 \rightarrow 4\,OH^-$ (ii)

The reactions' products further react with each other to form the rust.

$Fe^{++} + 2OH^- \rightarrow Fe(OH)_2$ (iii)

$4Fe(OH)_2 + O_2$ ® $2Fe_2O_3\ H_2O$ (rust) $+ 2H_2O$ (iv)

At anode, steel is consumed through rust formation resulting in a decrease in its cross sectional area. Volume of rust is three times the volume of the steel consumed. Hence, it induces additional tensile stresses in concrete. Concrete, being weak in tension, develops cracks and through these cracks more amount of deleterious agents seek entry into the concrete to reach the steel surface. As the corrosion progresses, concrete develops more cracks leading to delamination and reduction in the load carrying capacity of the structure culminating in its collapse. Effect of corrosion on prestressing steel is even more severe due to the low surface area of the prestressing wires / strands and the high tension to which the prestressing steel is subjected to prior to concreting. Further, prestressing steel is prone to brittle failure, which takes place suddenly without giving a prior warning. It is therefore necessary to periodically monitor the concrete structures to assess the quantum of the corrosion activity. It would not only be useful for assessing the condition of the structure with respect to reinforcement corrosion leading to its service life estimation, but also for planning and implementing suitable rehabilitative measures.

3.0 Linear polarisation technique

Various techniques are used to monitor the reinforcement corrosion in concrete at site. Reliable corrosion rate measurements can be used to predict the service life of the structure and to decide the protection system or repair system that have to be applied. By taking measurements before and after rehabilitation, the extension in service life can be quantified. While some techniques, such as Half Cell Potential technique, give only the qualitative information about corrosion, the linear polarisation technique determines the corrosion rate quantitatively, from which the loss of steel diameter can be calculated and the remaining life of the structure can be estimated.

This technique is also known as the polarisation resistance technique. In this technique, the corrosion current (I_{corr}) is measured by applying a small perturbing current from a 'Counter Electrode', and the change in the halfcell potential of the specimen is measured. The polarisation resistance (R_p) is the ratio of change in potential to the corrosion current (I_{corr}) by the Stern and Geary equation [2,3].

$I_{corr} = B/R_p$ (v)

where, I_{corr} = Corrosion current

R_p = Polarization resistance

B = Constant, for corroding systems, B = 26 mV

It was observed by Stern and Geary that if the polarisation is within ± 20 mV, the potential change is directly proportional to the applied current. Slope of the voltage vs. current curve at zero applied current is inversely proportional to the corrosion rate [2,4].

The corrosion potential is the equilibrium potential between anode and cathode. However, if an external current is applied to a corroding system, the potential of the system shifts from corrosion potential and this phenomenon is called the polarisation.

The above technique has been extensively used for measurement of corrosion rates of steel in reinforced concrete members in laboratory. However, in field applications, the area of the steel reinforcement affected by the applied current cannot be determined due to the heavy steel reinforcement. Hence, the technique has been modified by placing a sensor controlled guard ring on the concrete surface so as to confine the applied current and define the area of steel reinforcement more precisely. This technique is known as the guard ring method.

Based on the above technique, several field instruments have been developed by the researchers. One such instrument is 'GECOR 6' as shown in Fig. 2. It consists of the following three main components [2,7].

- Corrosion Rate Meter
- Sensor 'A' (disk shaped)
- Sensor 'B' (rod shaped)

A calibration unit is also provided with the Sensor 'A'. Sensor 'A' is fitted with copper-copper sulphate electrodes, and stainless steel counter electrode (through which the external current is applied). The instrument measures corrosion rate (in micro-amps per sq. cm) and corrosion potential. Sensor 'B' is fitted with copper-copper sulphate electrode, stainless steel counter electrode and capacitance based relative humidity probe and solid state temperature probe. It measures concrete resistivity, relative humidity and ambient temperature. Based on the numerous laboratory and field investigations, corrosion activity has been correlated with the corrosion current [2,4,6,7] as given below.

Icorr < 0.1 $\mu A/cm^2$ Passive Condition

Icorr 0.1 to 0.5 $\mu A/cm^2$ Low to moderate corrosion

Icorr 0.5 to 1.0 $\mu A/cm^2$ Moderate to high corrosion

Icorr > 1.0 $\mu A/cm^2$ High corrosion

Fig. 2.1. Corrosion Rate Measuring Meter GECOR 6 [2,7]

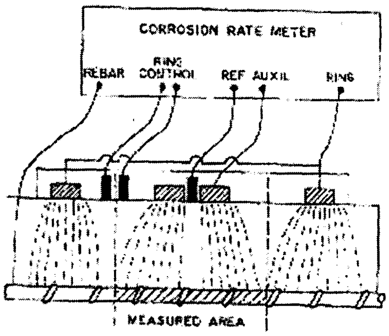


Fig. 2.2. Corrosion Rate Measurements using GECOR 6 [2,7]

4.0 Potentials and limitations of linear polarisation (LP) technique

LP technique can determine the corrosion rate at the time of measurement, which can be used to estimate the quantity of steel being lost due to corrosion using the Faraday's law. However, it can not predict the past and the future corrosion rate. This is due to the fact that corrosion rate depends on environment factors such as relative humidity and temperature. Hence, the remaining life prediction of a structure based on the LP technique without incorporating environmental effects can not be very accurate.

This technique assumes that the corrosion of steel takes place uniformly along the steel surface (general corrosion). However, in highly chloride contaminated concrete, corrosion of steel may occur through pitting or crevice mechanisms in which a continuous decrease in the cross section of steel at a few points takes place, while the rest of surface remains un-affected. This can not be detected by the LP corrosion rate measuring devices. Although the appearance of hysterisis loop between the forward and reverse scans is considered to represent the presence of pitting corrosion, however the investigations so far in this direction have been inconclusive [2,7].

Scan rate (i.e. the rate at which the polarisation of steel is done) may also affect the amount of current produced at all the values of the potential. Scan rate is selected by the user on the basis of experience and if not chosen properly, it may adversely affect the test results.

LP technique can be useful in identifying the probable cause of corrosion (i.e. whether chloride ingress or carbonation) according to the measured corrosion rates. Generally, the corrosion rate associated with carbonation rarely exceed 0.5 $\mu A/cm^2$, while the chloride induced corrosion can produce corrosion rates of more than 1.0 $\mu A/cm^2$.

5.0 Case study

Service life concept is closely related to the concepts of performance, durability and degradation. Performance is a function of time and is related to degradation and durability of concrete. Service life period of concrete structures can be defined as the time period during which the degradation reaches to an acceptable limit state [5,8]. For corrosion of steel reinforcement, service life period consists of initiation and propagation periods. During the initiation period, steel depassivates and corrosion starts. During the propagation period, corrosion reaches the acceptable limit state, i.e. the diameter of the steel bar gets reduced up to the critical bar diameter. Service life period of a concrete structure affected by corrosion can be estimated through corrosion rate measurements.

Andrade et al [3] reported a case study of corrosion rate measurements on a post tensioned concrete bridge in Spain. These corrosion rates were utilised for the remaining life estimation of the bridge.

5.1 Bridge description

The bridge is located somewhere in Spain. It was built between summer 1991 and June 1992. It has a composite section with a metallic girder, the deck being post tensioned. Total length of the bridge is 316 m. It consists of five spans of 40 m, 68 m, 100 m, 68 m and 40 m, respectively. The deck is about 30 m wide and 25 cm thick, with a constant section all along [3]. The section of the bridge is shown in Fig.3.

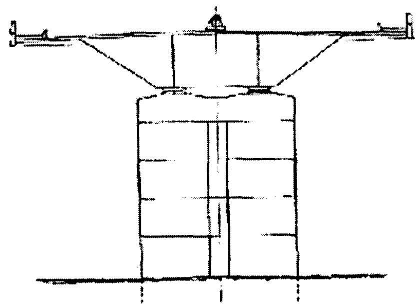


Fig. 3. Cross Section of the Bridge [3]

5.2 Damage observed

In Spain, the codal provisions restrict the chloride contents in mixing water up to 250 ppm for prestressing steel [3]. However, due to an unexpected sudden salinization of a well, whose water was used for the construction of the bridge, the deck concrete and prestressing grouting paste were contaminated with chlorides in quantities ranging between 1000 - 2000 ppm [3]. The salinization occurred due to the long dry climatic period experienced during the previous years by different regions of Spain. This dry period induced the increasing chloride contents in the tap water, mainly in coastal areas, where seawater permeated into the underground and contaminated the water table.

Presence of increased chlorides in the mixing water was noticed while concreting the last span. Immediately a visual inspection was carried out. Several perforations were made to reach up to the reinforcement and the prestressing tendons and some rusting spots were detected, conforming the initiation of localised corrosion.

Keeping in view the corrosion of reinforcement / prestressing tendons, the following decisions were taken.

i) To strengthen the deck by means of an additional top layer of heavily reinforced concrete.

ii) To introduce three additional non-adherent cables running along the interior of the girder. These cables were to be stressed in three phases - one, immediately; and the other two, in accordance to the gradual section loss of reinforcement / prestressing wires, induced by corrosion.

iii) To submit the bridge for continuous corrosion monitoring, in order to take decision regarding additional prestressing.

5.3 Corrosion monitoring

5.3.1 Testing zones

The deck was divided in to different zones. These zones were selected on the basis of, i) the concreting phases, ii) the stress concentrations, iii) the presence of joints.

Overall thirty testing points were finally selected. Out of which 12 were located on the joints between the spans. In these zones, perforations were made in order to reach up to the duct for direct visual inspection. These holes were kept permanently open in order to facilitate the electrical contact with the reinforcements.

5.3.2 Measurements

Initial visual inspection was made on the normal reinforcements, on the ducts and in the tendons (once the duct was broken). This inspection was carried out at an age between 1-6 months after concreting.

For corrosion monitoring, the electrochemical measurements were made when the bridge was about one year old. Further, in one of the inspection point, the measurements of the cross section loss were also undertaken. For this purpose, two prestressing wires of a prestressing tendon were cut and the pit depths were measured using the optical microscopy.

Third type of measurement was the periodic monitoring of the corrosion rates. It was measured by the linear polarisation technique using the equipment, GECOR 6. This equipment is able to make a sensorised confinement of the electrical current applied to the steel reinforcement, which is assured by a guard ring as shown in Fig.2.

The electrical contact was made directly with the normal reinforcements / prestressing duct, as it was ensured that all the bars, ducts and tendons were electrically connected. Assuming a generalised corrosion, the attack penetration (i.e. corrosion penetration depth) can be calculated according to the Faraday's law, using the following expression [3,6].

$x = 0.0115\ I_{corr}\ t$ (vi)

where,

x = attack penetration in mm

t = time from steel depassivation

I_{corr} = averaged value of corrosion intensity in mA/cm_2

However, in the present case, the attack is localised and therefore the residual bar diameter (§) can be estimated from the nominal diameter ($§_0$) as per Fig. 4.

$§ = §_0 - \alpha x$ (vii)

where,

α= a constant. In the present case, α= 10; which was selected on the basis of the microscopic observations of the pit depth.

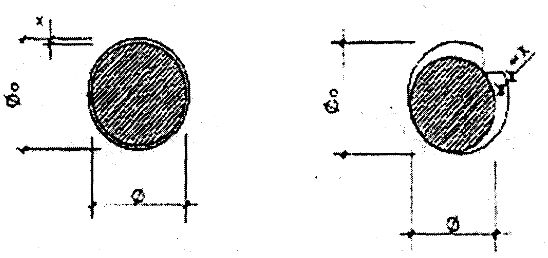


Fig. 4. Residual Reinforcing Bar Section for Homogeneous (left) and Localised (right) Attack [3]

5.4 Results

5.4.1 Visual inspection and pit depth determination

Non-Destructive Evaluation (NDE) of normal reinforcements, ducts and tendons inside the ducts, was carried out. It was found that localised attack was developed, forming small pits on the steel surface. Corrosion was similar in all metallic elements. Chloride contents in deck concrete and grout, were 0.083 % (by mass of concrete) and 0.05 % (by mass of grout) respectively. The pit depth was measured from the cross section of one of the wires, which were cut for microscopic observation as shown in Fig. 4. When the structure was 1 year old, the pit depths were found within the range between 30 and 130 mm (equivalent to the corrosion current intensity of 2.7 to 11.8 mA/cm²). These values were around 10 times the measured corrosion rate which confirmed the 'α' value of 10 as introduced in equation (vii).

5.4.2 Corrosion rate measurements

Corrosion rates were measured at 30 points. Table 1 gives the Icorr values measured from November 1992 to June 1994 [3]. It can be observed that the I_{corr} varies with time. This is shown in Fig. 5 for the points S5 and J1.

Table 1. Values of I_{corr} (mA/cm²) in Different Testing Points

Date	24-11-92	3-3-93	27-5-93	19-7-93	5-10-93	31-1-94	14-6-94
S1	0.12	0.19	0.24	0.11	0.242	0.085	0.2
S2	0.09	0.57	0.13	0.33	0.09	1.137	0.085
S3	0.05	0.46	0.29	0.3	0.28	0.058	0.08
S4	0.1	0.08	0.19	0.17	0.075	0.1	0.15
J1	0.09	0.01	0.02	0.12	0.067	0.028	0.2
J2	0.12	-	-	0.12	0.09	0.037	0.07
J3	0.25	-	-	-	-	-	-
J4	0.2	0.13	0.01	-	0.016	0.001	0.3
S5	0.11	0.41	0.42	0.18	0.42	0.219	0.23
S6	0.27	0.27	0.47	0.29	0.226	0.139	0.13
S7	0.47	0.54	-	-	0.019	0.169	-
S8	0.24	0.005	1.37	0.41	0.08	0.143	0.2
S9	0.06	0.29	1.69	0.5	0.09	0.231	0.2
S10	0.17	0.27	1.67	0.4	0.209	0.186	0.19
J5	-	0.11	0.26	0.2	0.04	0.046	0.2
J6	0.24	0.01	0.11	0.06	0.13	0.103	0.1
S11	0.22	0.44	-	0.14	0.186	0.193	0.25
S12	0.18	0.36	-	0.87	1.06	0.26	0.1
S13	0.15	0.14	-	0.32	0.03	0.413	0.03
S14	0.2	0.1	0.14	0.11	0.018	0.022	0.12
S15	0.15	0.17	0.11	0.16	0.17	0.15	0.08
S16	0.28	0.33	-	-	-	-	-
J7	0.18	-	-	-	-	-	-

J8	0.15	0.04	-	0.1	0.014	0.026	0.11
J9	-	0.03	-	0.37	0.611	0.056	0.02
J10	0.37	0.41	-	0.99	0.23	0.06	0.22
S17	-	0.26	-	0.33	0.039	0.088	0.06
S18	-	0.39	-	0.1	0.08	0.045	0.02
J11	-	-	-	0.32	0.02	0.031	0.05
J12	-	-	-	-	0.02	0.017	0.01

Fig. 6 shows the average Icorr values, that have been calculated for each section or joint [3]. It is clear that the testing points of the section S5 to S10 and those in the joints J9 and J10, present the highest values. For concreting the Icorr (in mA/cm2), the corrosion penetration depth (in mm) also known as attack penetration. Icorr values are multiplied by the pit concentration factor (a). For the present case, a = 10.

5.5 Discussions

The obtained Icorr values were utilised for two purposes. The first one concerns the residual life of the structure. For this purpose, Icorr was converted into the bar cross section loss in order to calculate the time to failure of the prestressing wires. The second one relates to the variation of the Icorr values with time, either due to the climatic influences, or due to a possible decrease in the chloride activity.

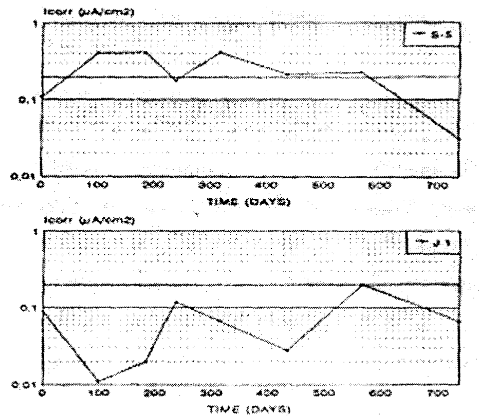


Fig. 5: Evolution of Icorr with Time [3]

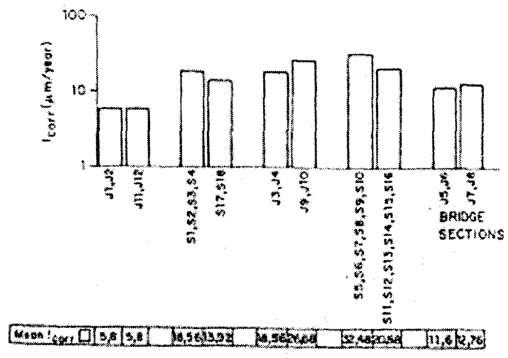


Fig. 6: Average Icorr in Different Testing Points [3]

5.5.1 Residual life of the prestressing wires

In a separate study, the critical crack length (KISCC) of the prestressing wires was characterised [3]. It resulted to correspond to the expression.

ac (mm) = 3.95 - 9 x 10^{-4} xP (Kg) (ix)

Considering the permissible prestressing wire force of 2000 Kg, the critical crack length for spontaneous failure works out to be as 2.15 mm. Therefore, this value was considered as the critical local attack penetration beyond which the prestressing wires break due to stress concentration.

Taking the case of Pier 2 (as shown in Table 2), the attack penetrations of 37.2 mm/year (which corresponds to the failure of 5 % of the tendons in pier 2) and of 15.1 mm/year (which corresponds to the failure of 63 % of the tendons in the same pier), Fig. 7 illustrates the calculation for residual life estimation, showing that the critical crack length would be reached at the point having maximum Icorr , in a period ranging between 57-142 years.

Fig. 7. Example of Rate of Attack Penetration (diameter loss)
for the Testing Points of Pier 2 [3]

Table2: Residual Life Period Calculations [3]

	Pier 1	Pier 2	Pier 3	Pier 4
mean I_{corr} ($\mu A/cm^2$)	0.1403	0.2041	0.2147	0.0903
standard deviation (σ)	0.0536	0.0726	0.1221	0.0431
μ - σ (63% of values) ($\mu A/cm^2$)	0.0867	0.1315	0.0926	0.0472
μ + 1.64 σ= characteristic Icorr ($\mu A/cm^2$)	0.2282	0.3231	0.4149	0.1609
pit concentration value (μm/year)	26.24	37.15	47.71	18.51
period to reach a crack of 2.15 mm	82-215	57-142	45-201	116-396

5.5.2 Icorr Variability

Icorr variability could be noticed due to the following factors.

1) the climatic changes or the active - passive periods typical of pit evaluation;

2) the differences in the position or localisation of the testing points.

It had been observed in outdoor conditions [3] that seasonal changes induced a variability co-efficient of about 1. This means that if the Icorr is measured for a continuous year, the values may vary from very low one to a value of the double of the mean calculated by integration w.r. to time. Hence, each testing point can be characterised by this averaged or 'Representative' Icorr , which represents the behaviour in time domain without considering any decay as it was not noticed during the 3 years of testing.

The dispersion of Icorr values while considering the several testing points, has to be treated differently with respect to the structural performance. In the case of the present bridge, the structural calculations indicate that the limit state of the bridge is reached when 55-65 % of the tendons of any of the four bridge piers would fail. As a result, first the averaging among the testing points has to be made pier by pier of all the four piers. Then, a guassian calculation on the representative Icorr of each pier has to be made in order to establish the mean value, the standard deviation and the characteristic Icorr (failure of 5 % of the tendons) and for the Icorr obtained from the mean, m, minus the standard deviation, ó, (failure of 63 % of the tendons). The periods so calculated, give the time for introducing the foreseen additional prestressing. Table 2 shows the values of all these parameters calculated for the four piers of the bridge, and time to reach a crack depth of 2.15 mm.The critical period is that of pier 3, which has the shortest expected life.

5.6 Conclusions

1. Linear Polarisation technique controlled by a guard ring, is a reliable method for field corrosion rate monitoring of steel reinforcement / prestressing wires.
2. The bridge was affected by corrosion due to accidental chloride ingress.
3. Residual life of the prestressing wires can be estimated through corrosion rate measurements.
4. Icorr varies with time due to climatic changes (humidity and temperature) and due to differences in the position or localisation of the testing points.
5. Frequency of additional prestressing can also be determined by corrosion measurements.

6.0 Acknowledgements

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References

1. Hime, W., and Drlim, B., "Some Chemical and Physical Aspects of Phenomena associated with Chloride Induced Corrosion", Corrosion, Concrete and Chlorides, SP-102, American Concrete Institute, Detroit, 1987, pp. 1-12.
2. J.P. Broomfield, J. Rodriguez, L.M. Ortega and A.M. Garcia,' Corrosion Rate Measurements by a Linear Polarisation Device', SP-151, ACI,' Concrete Bridges in Aggressive Environments', 1994, pp. 163-181.

3. C.Andrade, J. Sarria and C. Alonso, 'Corrosion Rate Field Monitoring of Post Tensioned Tendons in Contact with Chlorides', 'Durability of Building Materials and Components' (Volume Two), E & FN Spon Editors, 1996, pp. 959-967.
4. S. Feliu, J.A. Gonzalez, S. Feliu Jr., and M.C. Andrade, 'Confinement of the Electrical Signal for In-Situ Measurement of Polarisation Resistance in Reinforced Concrete, ACI Materials Journal, September - October 1990, pp. 457-460.
5. S.S. Gaharwar, B, Bhattacharjee, W. Buschmeyer and G. Iva~~nyi, 'Implications of Wetting and Drying in Service Life Prediction of Concrete Structures', State of the art Report, Essen University, Essen (Germany) Publication, December 2000.
6. P. Schibl, 'Corrosion of Steel in Concrete', RILEM Report, Champman & Hall Publishers, 1988.

7. Instruction Manual of GECOR6, James Instruments, U.S.A., 2002.

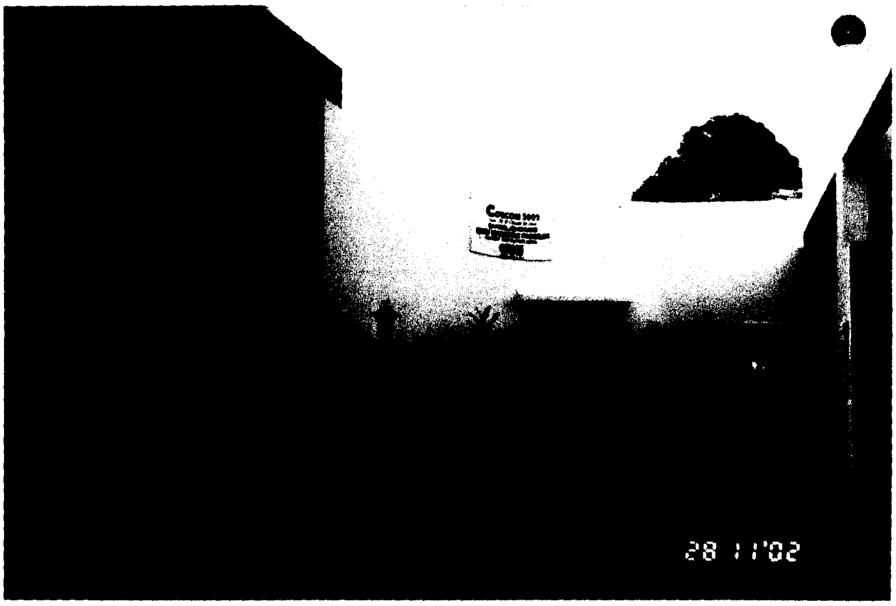
8. Charles J. Hookham,' Service Life Prediction of Concrete Structures - Case Histories and Research Needs', Concrete International, November 1992, pp. 50-53.

附錄 C

出席會議期間紀錄照片

孟買城市之輪街車

Goa 果阿街景



年會會場(一)

年會會場(二)

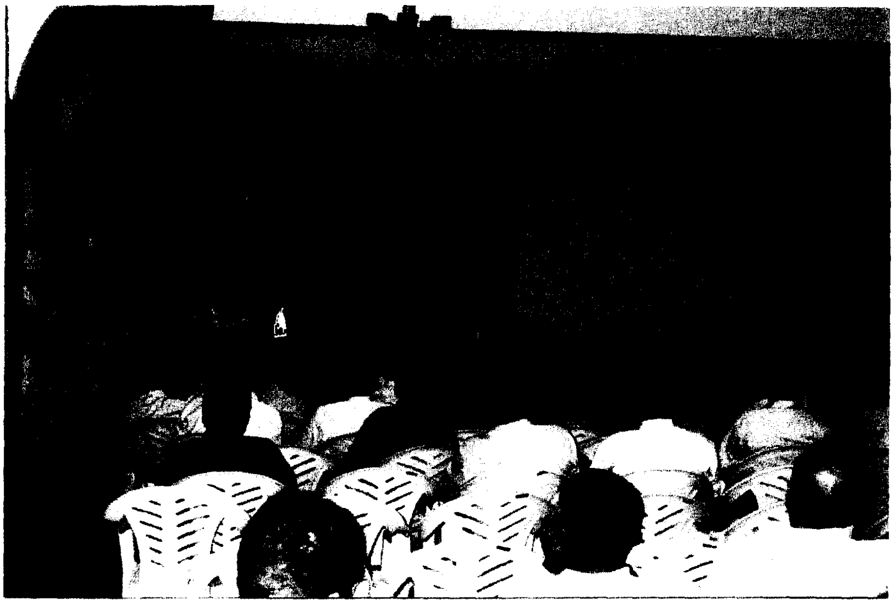
年會會場(三)

年會開幕式(一)

年會開幕式(二)

展覽場開幕式

展覽場



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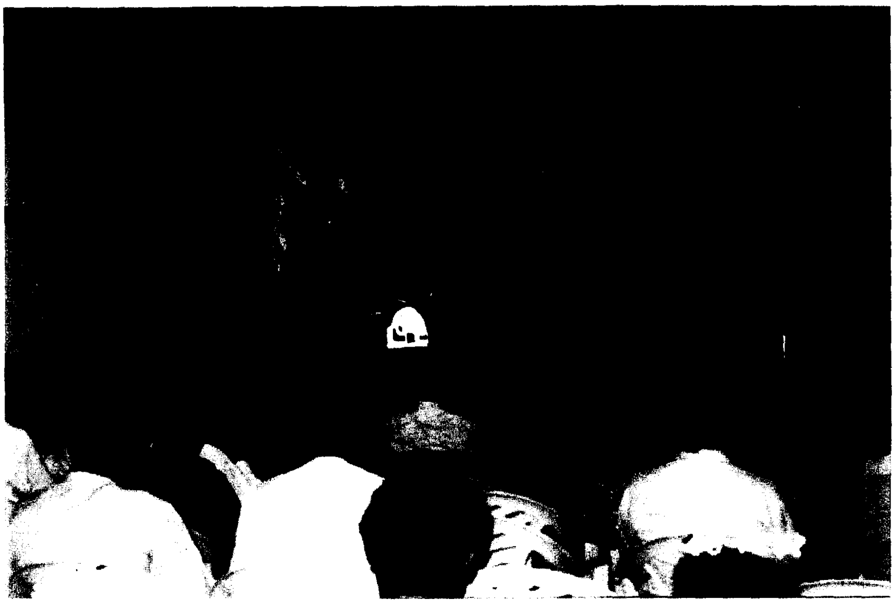

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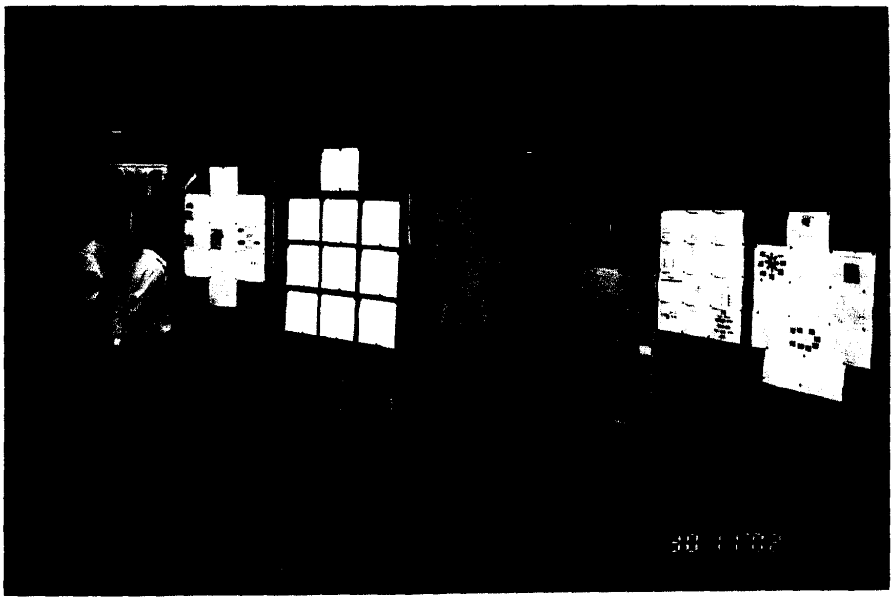

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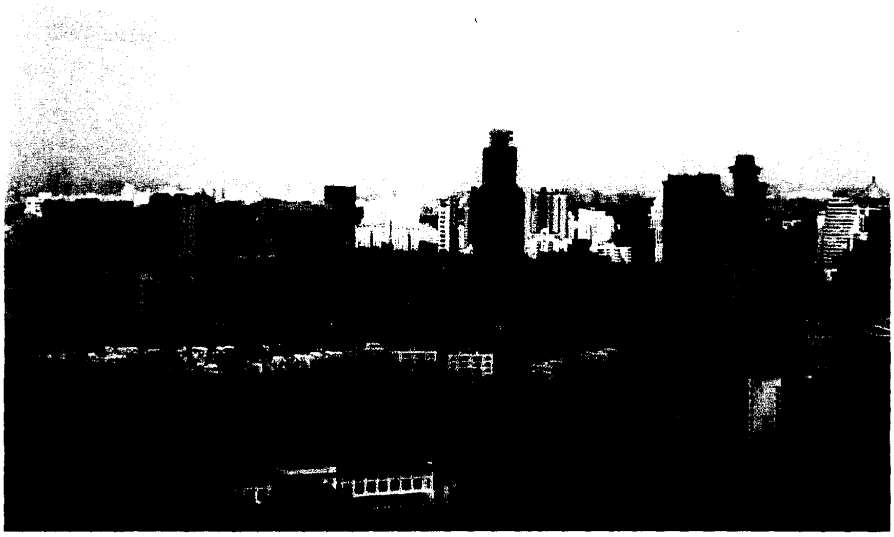
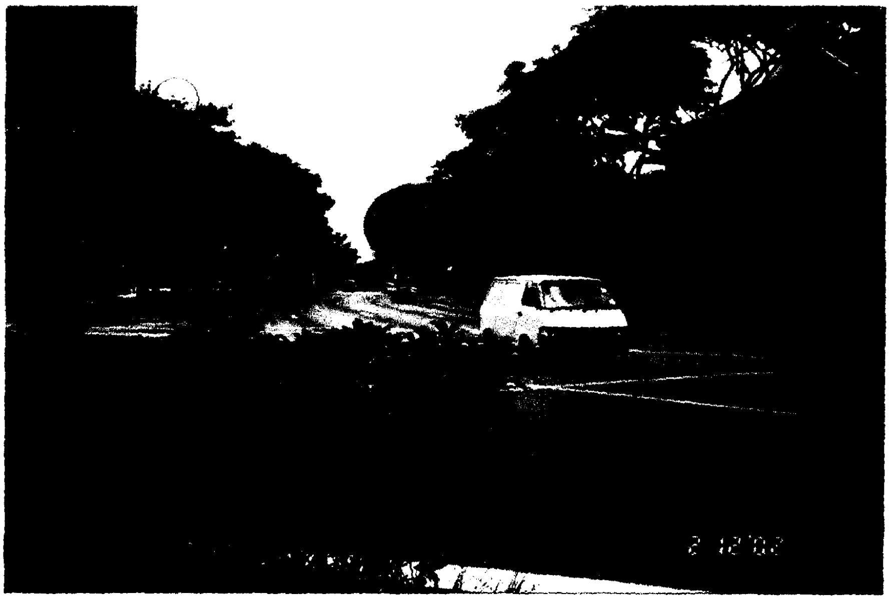


新加坡城市景觀(一)

新加坡城市景觀(二)

新加坡城市景觀(三)



新加坡城市景觀(四)