中華民國自來水協會 106 年度研究計畫

水池滲漏修復工法之探討

The Research of Repairing Method of Reservoir Leakage

委託單位：中華民國自來水協會

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摘要

台灣水資源開發不易，自來水事業供水設備之水池滲漏，造成額外的成本損失及珍貴水資源浪費，滲漏嚴重時甚而危及附近居民之生命財產安全，其修復工作可說是供水設施維護當中相當重要之一環。

本研究以自來水公司供水設備之水池為研究對象，透過文獻回顧瞭解池狀結構滲漏型式及修復工法，蒐集台灣自來水公司共四個區處十二處水池之修復案例，並與水池修復廠商、臺北自來水事業處、專家學者、設計單位及顧問公司等進行訪談，俾找出不同類型之滲漏適合之修復工法與修復材料。

經研究發現，早期圓形水池設計構造簡單，以類似獨立基腳方式設計，容易在結構受外力錯動或材料老化後由接縫處開始滲漏。而以滲漏位置(如板、牆、裂縫等)將水池滲漏型式及修復工法進行分類，則顯示「位置」並非主要依據，而係裂縫大小、水池損壞程度、水池供水條件等才是決定工法適用性之依據。

經綜合彙整防水材料塗佈類、高(低)壓噴射灌漿(地質改良)類、裂縫(伸縮縫)修復類等類型修復工法之優、缺點及適用性，並訂定「水池滲漏修復工程之工法選擇及施工流程圖」及相關工法之參考單價，可供相關人員於執行修復作業時能迅速判斷原因及選擇合適工法，加速水池修復之效率，以降低水資源之浪費及提升供水穩定。

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第一章　前言

1.1 研究動機及計畫緣起

台灣水資源開發不易，自來水事業供水設備之水池當滲漏發生時，除造成額外的成本損失及珍貴水資源浪費，滲漏嚴重掏空附近地基更可能造成水池沉陷或崩壞，進而危及附近居民之生命財產安全，故水池滲漏之修復工作係供水設施維護當中相當重要之一環，因此有必要再進一步探討。

本研究主要以台灣自來水公司(以下簡稱台水公司)供水設備之水池為研究對象，以探討水池滲漏及其修復工法之相關議題。所欲探究問題主要有幾個面向，包括水池滲漏發生之原因及形式、修漏工法及其使用材料之適用性、以及相對限制條件下滲漏修復的策略與建議。

1.2 計畫目標及預期成果

本研究之成果，期使自來水事業從業人員於面對水池滲漏發生時，能針對成因及現場環境限制，提供對應可行之工法，儘速辦理修復，以降低對環境之影響及提高供水穩定。另研究內容亦可提供設計及施工人員參考，由不同之工程階段全面降低滲漏之發生。

1.3 預定進度

本計畫由民國 106 年 2 月 23 日中華民國自來水協會第 18 屆技術研究委員會第 7 次委員會議審查通過，執行期程為 106 年 3 月至 106

年 12 月，以期中報告為界，分為上下兩期執行，整理如表 1-1。

第一期 106 年 3 月至 106 年 7 月就研究重點進行文獻蒐集與探討，並研析台水公司 12 個修復水池案例，另進行廠商訪談。

第二期 106 年 8 月至 106 年 12 月，就前所蒐集案例實地調查，並進行專家學者座談會，與台北自來水事業處交流參訪，並持續蒐集國外有關水池修復資料等，俾提出水池修復之適合工法及材料。

計畫執行進度表詳表 1-1

表 1-1 計畫執行進度表

時程 / 工作項目	106年度									
	3月	4月	5月	6月	7月	8月	9月	10月	11月	12月
文獻探討	▬	▬	▬	▬						
蒐集水池修復案例		▬	▬	▬	▬					
廠商訪談				▬						
案例實地調查					▬	▬	▬	▬		
北水處交流參訪						▬				
專家學者座談會							▬			
資料整理分析						▬	▬	▬	▬	▬
期中、末報告					■					■
總進度(%)	5	10	20	35	50	60	70	80	90	100

第二章　文獻回顧

2.1 概述

池狀結構物包括沈砂池、混和池、膠凝池、沈澱池、過濾池、配水池和送、配水抽水窨井等設備[1]。其構造上應具安全、耐久、耐震及水密性等，並充分考慮衛生要求。

台水公司之池狀結構以清水池及配水池為大宗，其中清水池為儲水之重要設備，為確保清水水質安全，並防止雨水及灰塵等及陽光照射滋生藻類，須為封閉之構造並具有水密性、耐震性及耐久性。清水池常用鋼筋混凝土(Reinforced concrete, RC)、預力混凝土、鋼板或玻璃纖維強化塑膠(Fiber Reinforced Polymer, FRP)等材料製造。其中 RC 造者為保持水密性需採用品質優良之混凝土，除因其施工接縫甚易漏水，施工時應特別慎重之外，為減少混凝土因乾燥收縮及溫度收縮而裂損，每 20~30m 左右應設置伸縮縫。必要時須加防水水泥砂漿粉刷，柏油防水塗刷或防水水泥噴漿，亦可添加防水劑於混凝土中以增加其水密性[2]。混凝土於養生期間之乾縮經常遠大於其後因溫度升降、濕度變化或其他因素而產生之膨脹收縮，施工時如能適當地設置施工縫並採跳段施工方式則能減少乾縮之影響一半以上，進而減低混凝土之龜裂，提高構造物之水密性[3]。

國內一般建築工程伸縮縫使用材料最大宗的為保麗龍板

(Expanded Polystyrene Styrofoam, EPS)，其他亦有摩利龍或發泡橡膠條等，而台水公司池狀結構伸縮縫則以止水帶、填充物、橡膠條，配合防水水泥或金屬蓋板等方式施作，然當伸縮縫經過長年累月之溫度變化，內填材料反覆的壓縮、拉伸，及材料本身的老化等，漸漸就會產生疲勞、位移，造成與混凝土界面的結合減弱，往往就會開始滲漏[4]。

由前述可知，為減少混凝土因乾燥收縮及溫度收縮而裂損，池狀結構設置伸縮縫有其必要性，然伸縮縫之老化與位移亦為滲漏之主要原因，因此滲漏之修復即成為無法避免之課題。

2.2 池狀結構滲漏型式

池狀結構之滲漏型式約可分為三大類，即接縫處、穿孔處與其他[5]，概述如下：

2.2.1 接縫處：為滲漏的主要發生型式，其中接縫又可分為數種：

1. **施工縫**：新舊混凝土澆置所產生的接縫，或為防止乾縮作用產生之裂縫位置無法預期，預先設置之隔縫(又稱引導性勾縫)。因巨大面積的混凝土結構物無法一次灌注完成，新舊混凝土交界面間即會出現施工縫，在接合處若處理不慎時，容易造成滲水現象。施工時若條件許可應盡量採用一次澆築，避免施工縫之產生。

2. **伸縮縫**：為避免混凝土因熱脹擠壓破碎所設置之接縫。現今施工為減少接縫，伸縮縫常與施工縫合併設置。

3. **轉折接頭處**：牆與版的續接處，或地梁與版的續接處等，施工時應注意地樑排筋不可與版分離，否則當底版受地下水浮力影響而產生拉裂情況，亦將造成滲漏。

4. **溫度變化龜裂**：混凝土凝固時因養護不夠乾縮所造成的裂縫，或因遇有天氣變化和化學反應，內部產生熱量而膨脹或外面受空氣冷卻而收縮，產生受溫度變化熱脹冷縮的應力，使構材產生裂縫漏水。

5. **地震或不均勻沉陷**：如建築物結構體不良，受外力(如地震)之劇烈振動而開裂，或結構體本身良好，因受基礎底部之差異沉陷，引起內部應力不平衡而發生龜裂，此種龜裂較為寬大往往可以明顯觀察到。

6. **鋼筋生鏽、移位**：鋼筋在混凝土內，因細微裂縫及混凝土表面受風化使水氣入侵，造成鋼筋生鏽膨脹，將原有之細微裂縫撐大，或於灌漿時過度夯實，使鋼筋移位與混凝土無緊密握裹，所產生之裂縫均會造成滲漏。

7. **蜂窩現象處**：混凝土搗振不實、缺少砂漿、模版接縫不嚴密或泌水造成砂漿沖刷流失等原因，造成蜂窩麻面而漏水。

2.2.2 穿孔處：結構物之穿孔處因四周界面處理不易，容易產生孔隙而漏水，施工時應採用過牆管並事先預留管孔，可避免事後敲除管孔造成較大之破壞面而產生滲漏。

2.2.3 其他：非屬結構體破壞所造成之滲漏，舉例如下：

1. **防水層破損、不足**：施工前，未對施工表面不平整部分做適當的處理，施工面不清潔以致刺破防水層、防水層厚度不足、疊接長度不夠或接著力不夠而產生剝離，或是後續施工不慎破壞防水層等等，皆會造成防水層失敗，產生滲漏。

2. **混凝土的水密性不夠**：混凝土凝結期間水泥燃燒不完全含有多量的氧化鈣，水化時產生游離態石灰質能溶解於水中，使得混凝土毛細擴大產生孔隙，並降低混凝土的水密度與強度，因而產生漏水現象。

3. **泌水現象**：混凝土在施工時須拌合相當的水量以利泵送，但實際上混凝土凝結過程之需水量不多，多餘的水份稱為「游離水」，其在混凝土中會尋找空隙設法向外逸散，造成毛細管通道進而發展成裂縫，成為滲漏的原因。

2.3 池狀結構滲漏修復工法

滲漏之修復依修復範圍原則上可分類為點狀、線狀及面狀修復，然池狀結構之滲漏往往為綜合性發生，不同位置之破壞情形需搭配不同之修復方式始可達到修復成效，以下列舉數種常見之修復工法[6]：

2.3.1 外覆防水層：以防水層將池狀構造物外側包裹起來，達到防止滲漏之功效。此種工法適用於量體較小且地上式之池狀結構。

2.3.2 內塗防水塗料：無法施作外側防水處理時，可採用內部防水之處理方式。

2.3.3 打 V 字型槽塗抹防水劑水泥砂漿：在壁體滲漏之出水點打鑿一 V 型槽，再塗抹或填補上添加防水劑之水泥砂漿。此種工法往往只能達到表面或局部之止水堵漏效果，無法達到深層的填埔和阻水，詳圖 2-1。

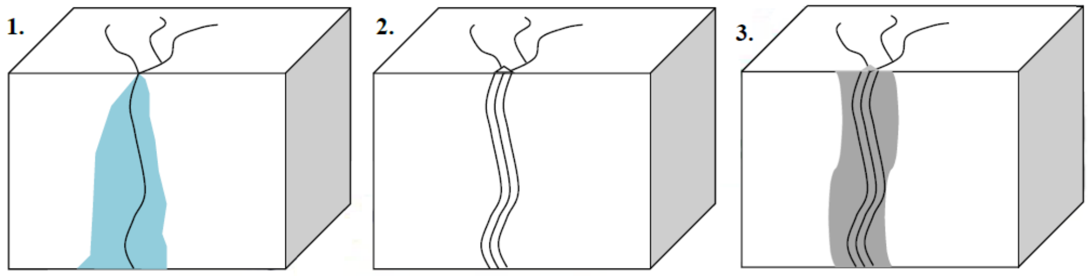


圖 2-1　V 槽填補工法示意圖

2.3.4 裂縫高壓灌漿止漏：於裂縫處旁做 45 度斜向鑽孔，使鑽孔與結構體內的裂縫相交於滲漏源上游，再利用高壓灌注機的高壓動力，將化學灌漿材料注入裂縫中，所灌注的漿液會沿著鑽孔於滲水源頭做止漏，將水流完全堵塞在結構體內部，並往下游繼續填滿於結構裂隙內，達到止水堵漏的目的，詳圖 2-2。

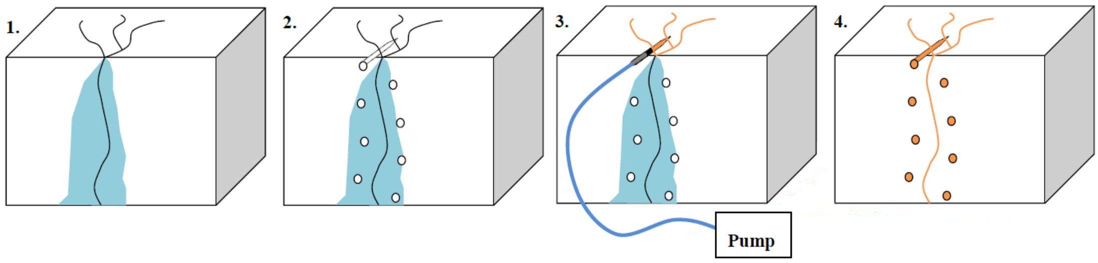


圖 2-2 高壓灌漿工法示意圖

2.3.5 穿越壁體外側隔幕灌漿：此工法乃是於滲漏處鑽孔至結構體內或穿越至外側，利用化學藥劑或水泥等，以適當的配比，拌合成黏滯度與凝結時間適當的漿液，經由鑽孔以高壓或低壓注入，於結構體內部或外側形成隔幕止水層，而達到防止滲漏的效果，詳圖 2-3。

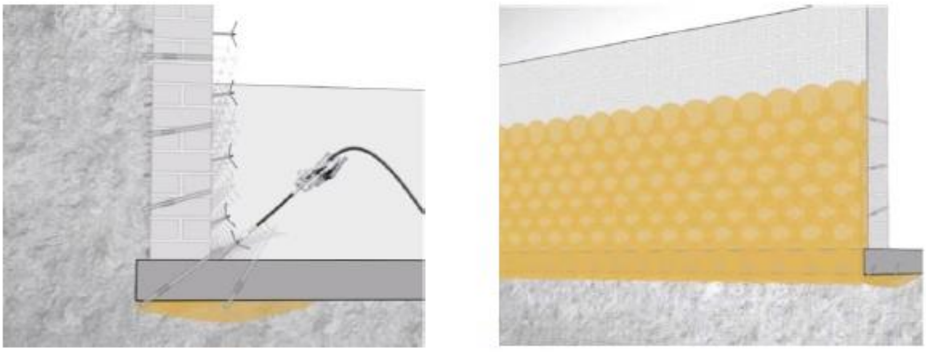


圖 2-3 隔幕灌漿工法示意圖

2.3.6 混凝土深層滲透塗封劑：又稱 CDPS(Concrete Deep Penetration Sealer)，它是由波特蘭水泥、矽砂和多種特殊的活性化學物質所組成的灰色粉末狀無機材料。其防水原理是 CDPS 特有的活性化學物質，利用水泥混凝土本身的化學特性及多孔性，以水做載體，借助滲透作用在混凝土毛細管中傳輸、並催化混凝土內的微粒和未完全水化的成份再次發生水化作用，而形成不溶性的枝蔓狀結晶，並與混凝土結合成為一體，進而使任何方向來的水或液體被堵塞，達到永久性的防水、防潮和保護鋼筋、增強混凝土結構強度的效果[7]，詳圖 2-4。

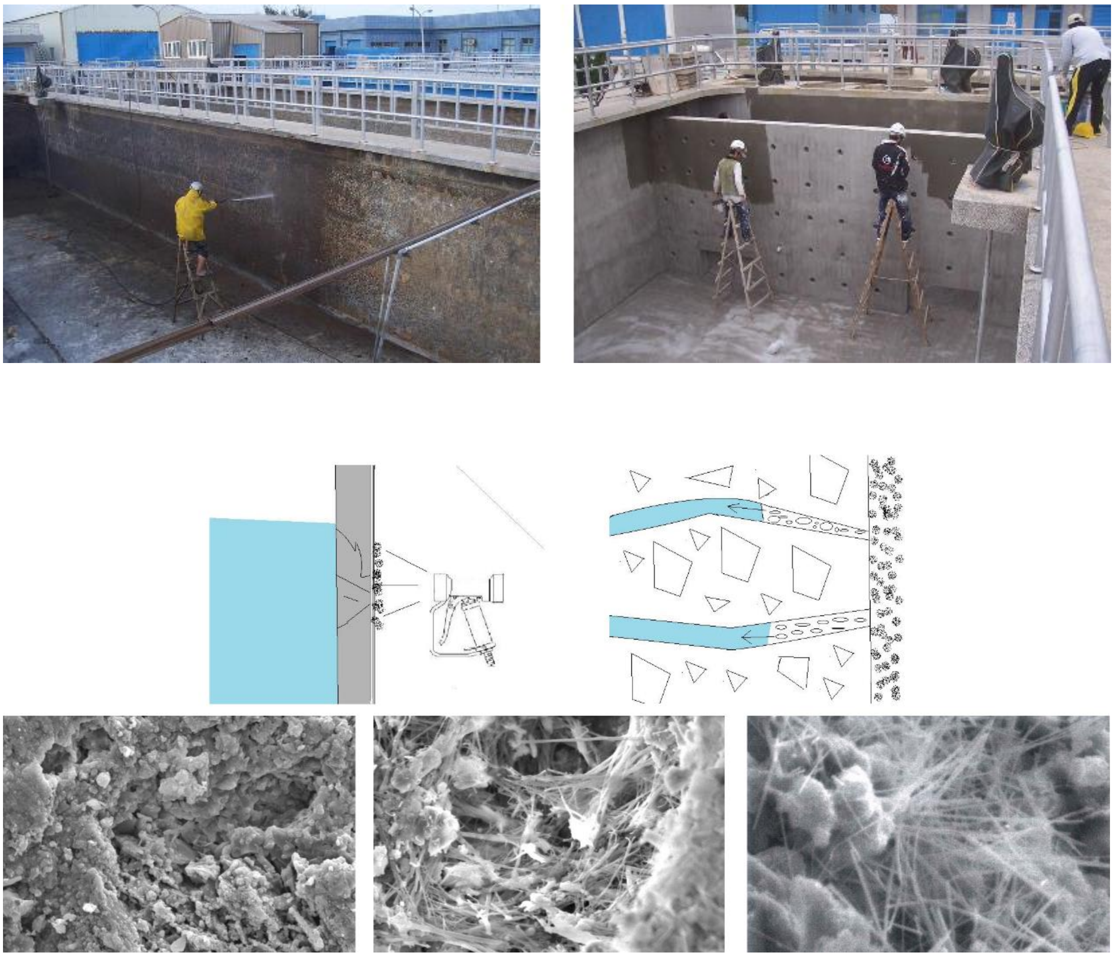


圖 2-4 CDPS 施工及內部結晶示意圖

2.3.7 橡膠壓條(配合不鏽鋼壓版)：利用橡膠容許膨脹、收縮、可彎曲且具有良好耐久性之物理特性，以一定間距之螺栓固定於伸縮縫或錯動之裂縫間，頂部視需要加封不鏽鋼壓版，其施工快速、維護便利，且完工後允許結構物之微小變型，除水池伸縮縫外亦適用於混凝土管道、管槽裂縫之修復[8]，詳圖 2-5~2-7。

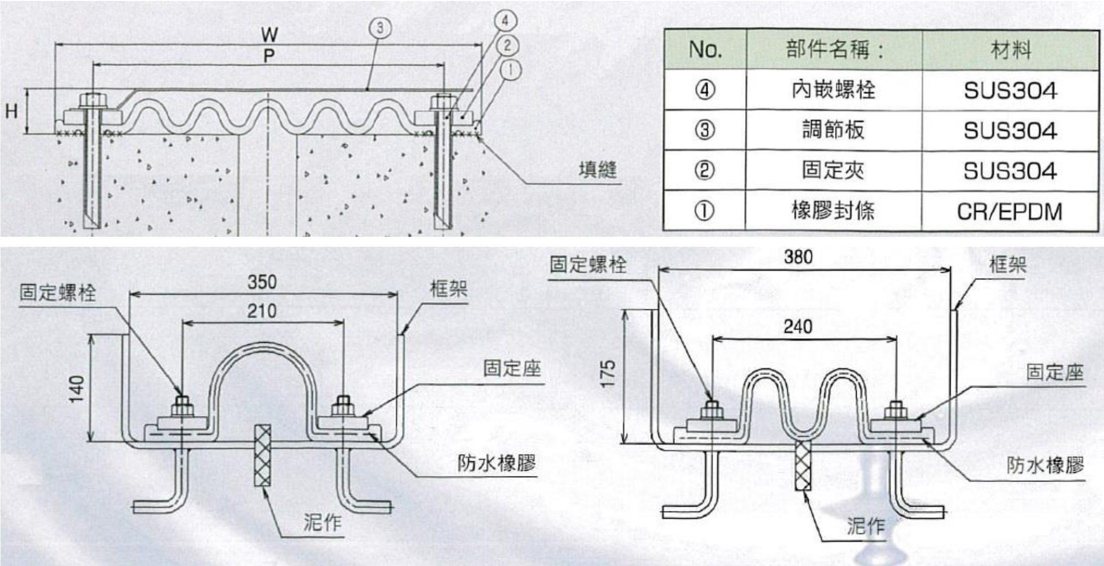


圖 2-5 橡膠壓條構造示意圖

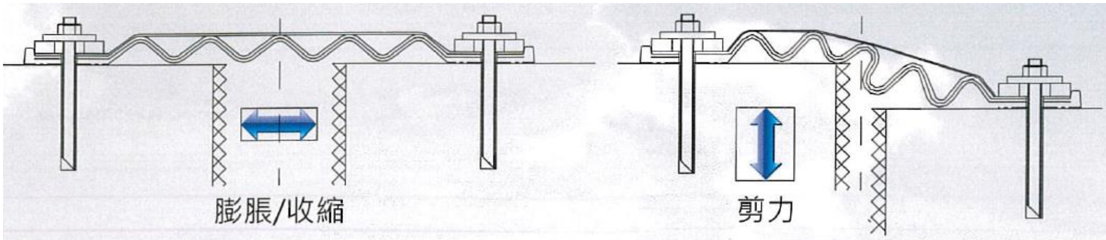


圖 2-6 橡膠壓條變形示意圖

圖 2-7 橡膠壓條完工示意圖

第三章　研究方法與過程

3.1 研究方法

本研究結合了文獻蒐集、實地調查台水公司近年水池滲漏原因及修復工法、訪談及座談會等多方面，就水池滲漏修復工法及使用之材料，探討其適用性與優缺點，進而針對不同滲漏方式及相對限制條件下，提出修復之策略與建議工法。

3.2 案例調查

本報告蒐集台水公司共四個區處十二座水池之修復案例，包含啟用年份、形狀、容量、水位高、破壞位置(方式)、破壞原因、修復時間、修復方式、施工流程、檢驗方式、施工注意事項、修復成效及施工照片等資料，並於報告第四章彙整提出水池修復參考流程。表 3-1 呈現本報告蒐集之水池基本資料。

表 3-1 台水公司十二座水池基本資料

區處別	位置	容量(M^3)
四區處(埔里所)	南投縣魚池鄉	3,000
四區處(沙鹿所)	台中市沙鹿區	40,000
四區處(鯉魚潭廠)	台中市后里區	50,000
七區處(拷潭廠)	高雄市大寮區	10,000
七區處(牡丹廠)	屏東縣牡丹鄉	10,000
七區處(東港所)	屏東縣枋寮鄉	6,500
九區處(工務課)	花蓮縣(支亞千)	5,000
	花蓮縣(豐濱)	200
	花蓮縣(富源)	100
	花蓮縣(松浦)	300
十一區處(員林所)	彰化縣員林市	6,500
十一區處(鹿港所)	彰化縣鹿港鎮	1,700

3.2.1 魚池 3,000 噸配水池

1. 基本資料，詳表 3-2

表 3-2 魚池 3,000 噸配水池修復基本資料

水池名稱	魚池 3,000 噸配水池
啟用年份	89 年 12 月
形狀	圓形
容量(M^3)	3,000
水位高(M)	4
破壞位置(方式)	池底滲漏
破壞原因	地震
修復時間	104 年 8 月
修復方式	整池 FRP 及無毒環氧樹脂塗佈
施工流程	池水放乾→表面處理→FRP 鋪設→無毒環氧樹脂塗佈→施工完成
檢驗方式	觀察地面潮濕、水位試水
施工注意事項	注意塗佈面乾燥及整潔
修復成效	至今地面均無潮濕現象，成效良好

2. 施工照片，詳圖 3-1

1.FRP(玻璃纖維強化塑膠)材料

2.池底 FRP 鋪設及塗佈

3.池牆 FRP 鋪設及塗佈

4.施工完成

圖 3-1 魚池 3,000 噸配水池修復施工照片

3.2.2 沙鹿 40,000 噸配水池

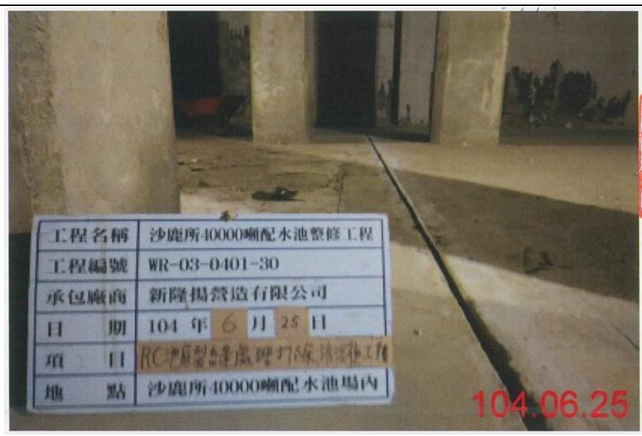
1. 基本資料，詳表 3-3

表 3-3 沙鹿 40,000 噸配水池修復基本資料

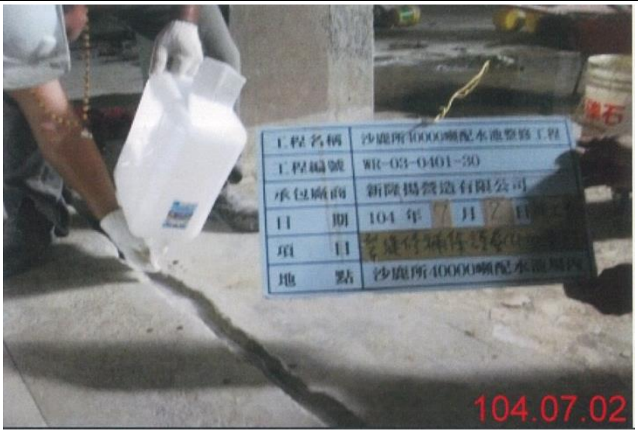
水池名稱	沙鹿所 40,000 噸配水池
啟用年份	83 年 6 月
形狀	矩形
容量(M^3)	40,000
水位高(M)	2.5~5
破壞位置(方式)	底板、池牆伸縮縫錯動
破壞原因	地震
修復時間	104 年 1 月
修復方式	伸縮縫填縫料拆除重做
施工流程	池水放乾→舊有填縫料清除→環氧樹脂+彈性填縫劑→FRP 鋪設→彈性橡膠+不鏽鋼板→施工完成
檢驗方式	水位試水、週邊排水溝水量觀測
施工注意事項	1. 伸縮縫需確保清潔、乾燥狀態再行施工。 2. 局限空間作業相關氣體偵測、強制進排氣、照明設備需落實。
修復成效	至今仍維持修復後水準，成效良好

2. 施工照片，詳圖 3-2

1.原有填縫材清除



2.伸縮縫清潔處理



3.環氧樹脂灌注修補

4.彈性填縫劑填補

5.彈性填縫劑填補完成

6.保護層鋪設 FRP

7.FRP 施作完成

8.軟性橡膠+不銹鋼板施工

 9.施工完成	

圖 3-2 沙鹿 40,000 噸配水池修復施工照片

3.2.3 拷潭 10,000 噸清水池

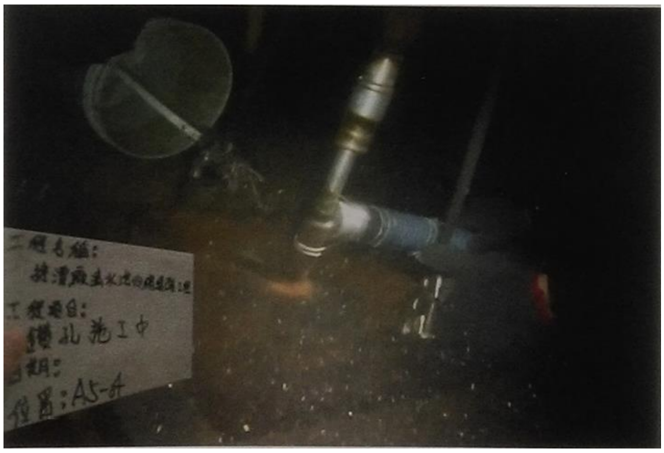
1. 基本資料，詳表 3-4

表 3-4 拷潭 10,000 噸清水池修復基本資料

水池名稱	拷潭廠清水池
啟用年份	61 年 6 月
形狀	矩形
容量(M^3)	10,000
水位高(M)	2.75
破壞位置(方式)	伸縮縫滲漏(早期以柏油及蔗板做為填縫劑)
破壞原因	1. 蔗板自然腐化及柏油硬化龜裂脫落 2. 地震產生不均勻沉陷 3. RC 結構風化造成龜裂
修復時間	104 年 5 月
修復方式	低壓噴射地質改良 (地下式池體因開挖不便無法以一般方式修復)
施工流程	由池體內部以鑽桿貫穿池牆，利用鑽桿前端之壓力噴嘴低壓噴射，使水泥漿隨漏水向外流動並固結後止漏。
檢驗方式	利用排水孔觀測及曼寧公式推算漏水量
施工注意事項	1. 水中作業需注意缺氧及漏電危險 2. 施工中品質之控制重點在壓力觀測
修復成效	至今利用排水孔觀測仍維持修復後水準，成效良好

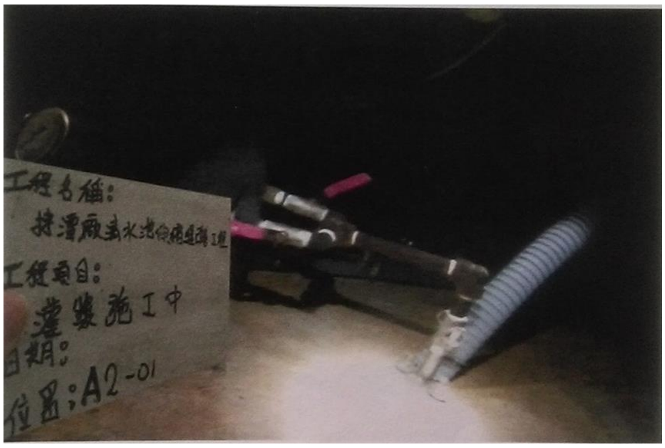
2. 施工照片，詳圖 3-3

1.確認鑽孔位置



2.池底板鑽孔

3.鑽孔完成



4.池底板低壓灌漿

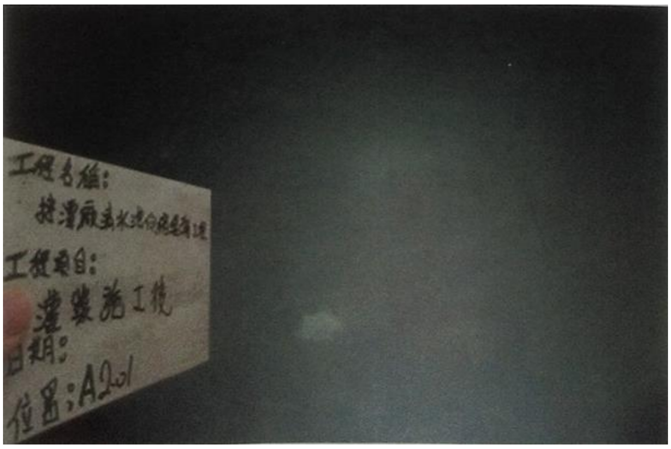
 5.低壓灌漿完成	

圖 3-3 拷潭 10,000 噸清水池修復施工照片

3.2.4 牡丹 10,000 噸清水池

1. 基本資料，詳表 3-5

表 3-5 牡丹 10,000 噸清水池修復基本資料

水池名稱	牡丹廠清水池
啟用年份	85 年
形狀	梯形
容量(M^3)	10,000
水位高(M)	2.5~3.4
破壞位置(方式)	伸縮縫滲漏、池體龜裂
破壞原因	材料老化
修復時間	102 年 5 月
修復方式	1. 伸縮縫填縫料拆除重做 2. RC 結構裂縫修補
檢驗方式	觀察地面潮濕、水位試水
施工流程	舊有伸縮縫止漏條拆除→新鋪設止漏材料→橡膠止漏條填充→表面防水水泥強化→施工完成
施工注意事項	不斷水施工
修復成效	修復後成效良好，惟近期有發現新滲水現象

2. 施工照片，詳圖 3-4

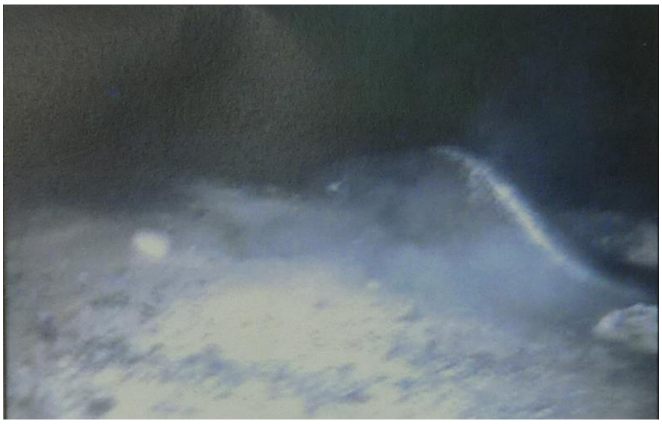
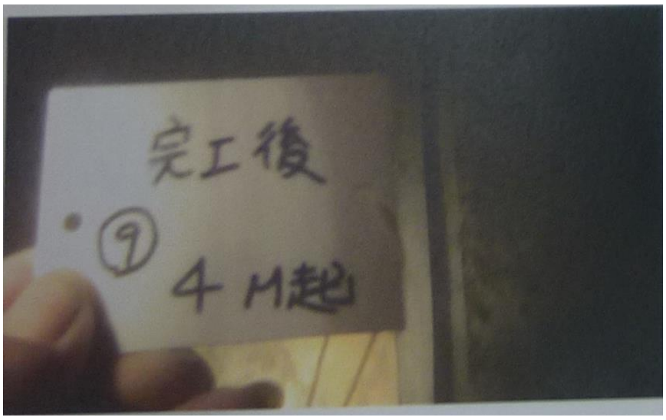
 1.舊有伸縮縫現況	 2.舊有伸縮縫拆除
 3.伸縮縫拆除後清理	 4.橡膠止漏條填充

圖 3-4 牡丹 10,000 噸清水池修復施工照片

3.2.5 東港 6,500 噸配水池

1. 基本資料，詳表 3-6

表 3-6 東港 6,500 噸配水池修復基本資料

水池名稱	屏南工業區 6,500 噸配水池
啟用年份	80 年
形狀	矩形
容量(M^3)	6,500
水位高(M)	3
破壞位置(方式)	池底伸縮縫、池牆龜裂滲漏
破壞原因	材料老化
修復時間	105 年 7 月
修復方式	伸縮縫填縫料拆除重做、龜裂填補
施工流程	舊有伸縮縫、FRP 切割拆除→橡膠條安裝→外牆防水水泥處理→施工完成
檢驗方式	水位試水
施工注意事項	注意塗佈面乾燥及整潔
修復成效	至今仍維持修復後水準，成效良好

2. 施工照片，詳圖 3-5

	
1.原潮濕地面	2 原潮濕地面
	
3.舊有 FRP 切割	4.舊有 FRP 切割

 5.舊有 FRP 拆除	 6.舊有橡膠條拆除
 7.新橡膠條安裝	 8.橡膠條安裝完成
 9.橡膠條安裝完成	 10.修復完成地面無潮濕

 11.修復完成地面無潮濕	

圖 3-5 東港 6,500 噸配水池修復施工照片

3.2.6 花蓮支亞干 200 噸配水池等

1. 基本資料

(1) 支亞干，詳表 3-7

表 3-7 支亞干 200 噸配水池修復基本資料

水池名稱	支亞干配水池
啟用年份	92 年
形狀	圓形
容量(M^3)	200
水位高(M)	3
破壞位置(方式)	伸縮縫滲漏
破壞原因	腐蝕老化
修復時間	103 年 11 月
修復方式	伸縮縫填縫料拆除重做
施工流程	舊有伸縮縫拆除清理→PE 棒施作→聚氨脂填縫劑→膨脹橡膠條→環氧樹脂接著劑→FPO 防水帶→表面處理→施工完成
檢驗方式	水位試水
修復成效	至今仍維持修復後水準，成效良好

(2) 富源，詳表 3-8

表 3-8　富源 100 噸配水池修復基本資料

水池名稱	富源配水池
啟用年份	71 年
形狀	圓形
容量(M^3)	100
水位高(M)	3
破壞位置(方式)	池底滲漏
破壞原因	腐蝕老化
修復時間	103 年 11 月
修復方式	聚脲防水材塗佈
施工流程	表面清洗→底漆→聚脲防水材塗佈(分層)→施工完成
檢驗方式	水位試水
修復成效	至今仍維持修復後水準，成效良好

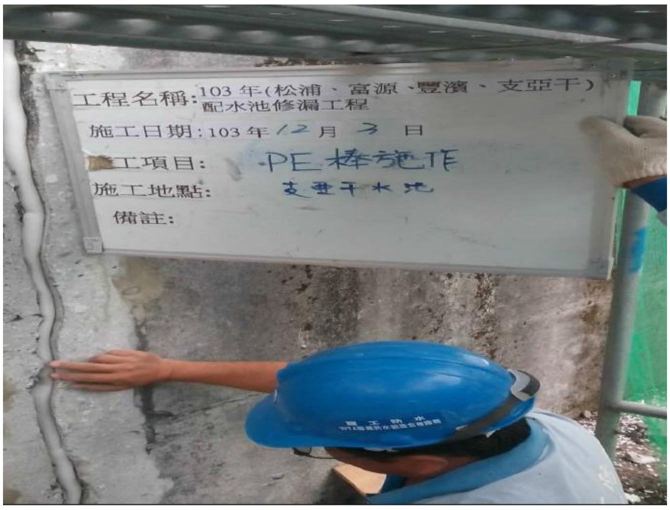
(3) 松浦、豐濱，詳表 3-9

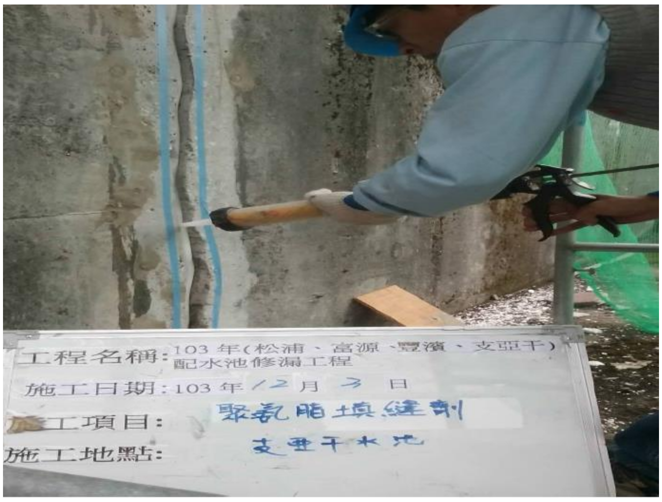
表 3-9　松浦配水池、豐濱配水池修復基本資料

水池名稱	松浦配水池、豐濱配水池
啟用年份	71 年(松浦)、查無資料(豐濱)
形狀	圓形
容量(M^3)	300(松浦)、200(豐濱)
水位高(M)	3
破壞位置(方式)	池底滲漏
破壞原因	腐蝕老化
修復時間	103 年 11 月
修復方式	水性填縫膠修補、裂縫高分子水泥沙漿修補、聚脲防水材塗佈
施工流程	表面清潔處理→水性填縫膠修補、裂縫高分子水泥沙漿修補→底面鋼筋綁紮、灌漿→底漆塗佈→聚脲防水材塗佈(分層)→施工完成
檢驗方式	水位試水
施工注意事項	RC 表面若嚴重剝落不平整，應重新灌漿打底後再行施作
修復成效	至今仍維持修復後水準，成效良好

2. 施工照片

(1)支亞干，詳圖 3-6

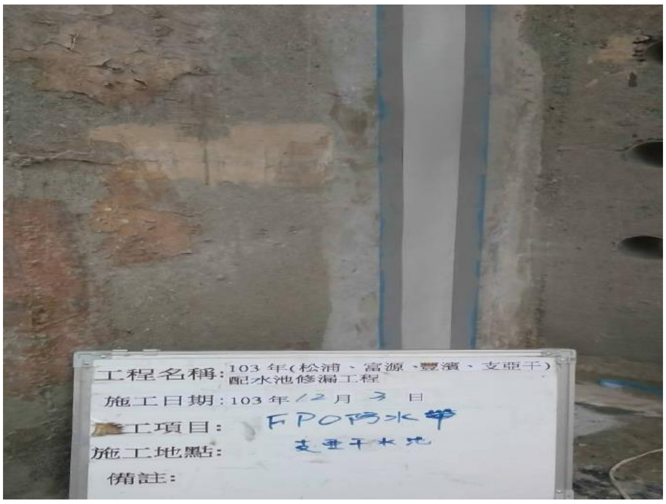
	
1.池頂舊有面材打除	2.池頂舊有面材打除
	
3.舊有伸縮縫打除	4.PE 棒施作



5.聚氨脂填縫劑

6.膨脹橡膠條施作

7.環氧樹脂接著劑



8.FPO 防水帶

	
9.池頂表面修復	

圖 3-6 支亞干配水池修復施工照片

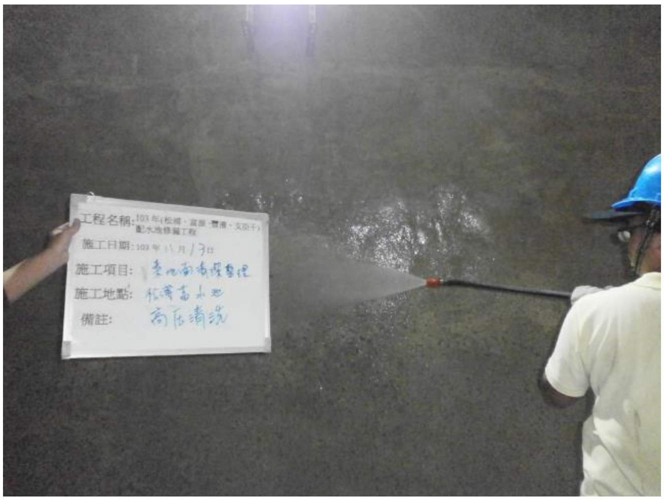
(2)富源，詳圖 3-7

	
1.池牆清洗	2.池底清洗

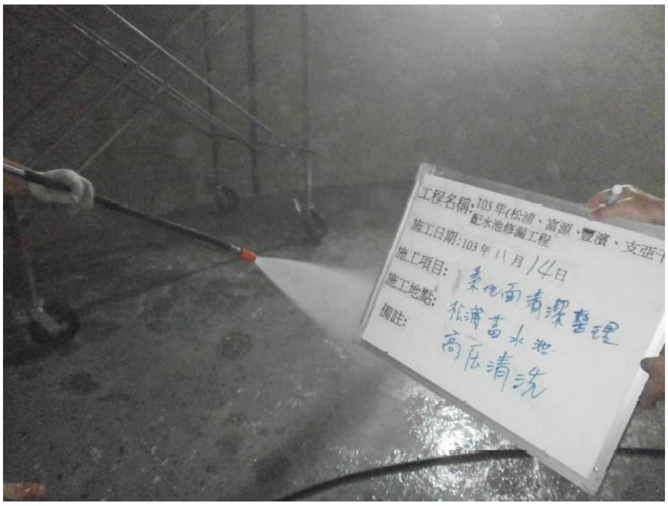
 **3.** 池牆底漆塗佈	 4.池底底漆塗佈
 5.施工完成	

圖 3-7 富源配水池修復施工照片

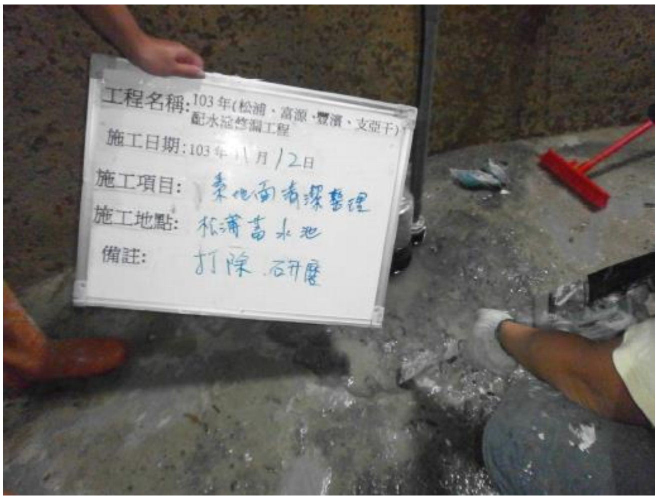
(3)松浦，詳圖 3-8



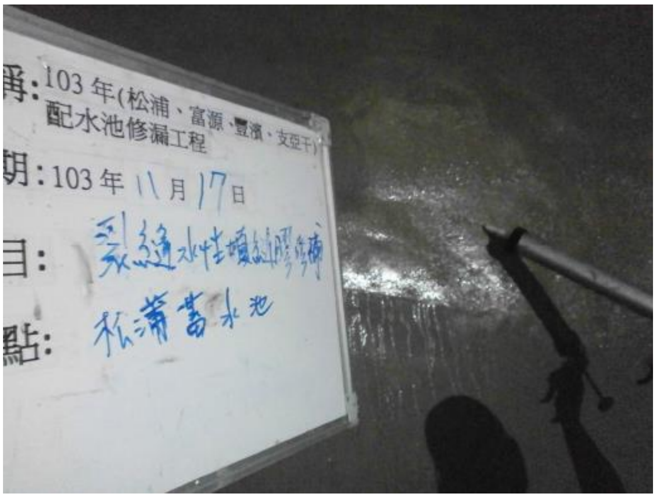
1.池牆清洗



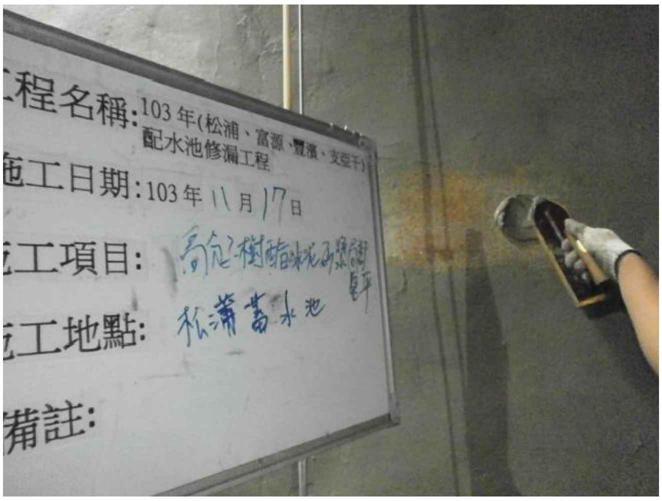
2.池底清洗



3.表面處理(打除、研磨)



4.水性填縫膠修補裂縫



5.高分子樹脂水泥砂漿局部整平

6.池底鋼筋綁紮

7.池底灌漿

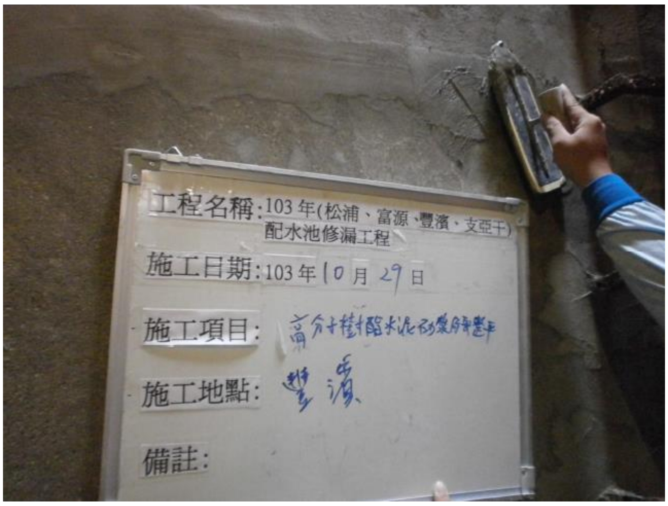
8.底漆塗佈

9.聚脲防水材塗佈

10.施工完成

圖 3-8 松浦配水池修復施工照片

(4)豐濱，詳圖 3-9

	
1.池牆清洗	2.池底清洗
	
3. 水性填縫膠修補裂縫	4.高分子樹脂水泥砂漿局部整平

<table>
<tr><td>
5.局部整平完成</td><td>
6.池底鋼筋綁紮</td></tr>
<tr><td>
7.池底灌漿</td><td>
8.底漆塗佈</td></tr>
<tr><td>
9.聚脲防水材塗佈</td><td>
10.施工完成</td></tr>
</table>

圖 3-9 豐濱配水池修復施工照片

3.2.7 員林 6,500 噸清水池

(1)基本資料，詳表 3-10

表 3-10　員林 6,500 噸清水池修復基本資料

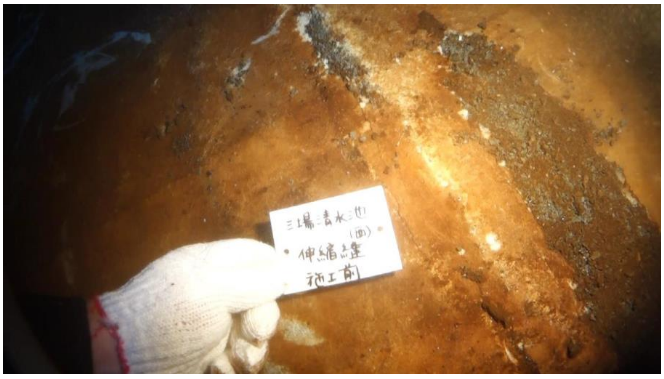
水池名稱	員林三場清水池
啟用年份	86 年
形狀	矩形
容量(M^3)	6,500
水位高(M)	3~3.7
破壞位置(方式)	底板及池牆伸縮縫、池牆裂縫
破壞原因	水池施工時未注意部分細節導致
修復時間	104 年 8 月
修復方式	伸縮縫填縫料拆除重做，並以無毒環保類水泥材質封填
施工流程	潛水員消毒作業→伸縮縫切割、鑿除清理→橡膠止漏條安裝→施工完成
檢驗方式	觀察有無滲漏、施作過程全程錄影
施工注意事項	1. 水下作業人員應有合格潛水證照 2. 作業人員配備、程序應符合規定 3. 不斷水作業，填縫料須為無毒材質 4. 施作過程全程錄影等
修復成效	至今仍維持修復後水準，成效良好

(2)施工照片，詳圖 3-10

1.潛水員消毒作業

2.施工前底泥清理

3.施工前排沙



4.池內伸縮縫老化、龜裂

5.池牆 FRP 切割

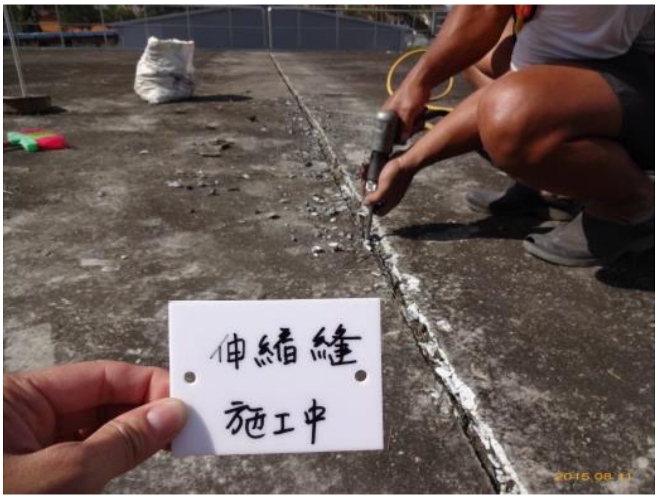
6.池底伸縮縫鑿除清理

7.伸縮縫清理完成

8.橡膠止漏條安裝

9.橡膠止漏條安裝完成

10.池頂伸縮縫龜裂情形



11.池頂伸縮縫鑿除

12.池頂伸縮縫清潔

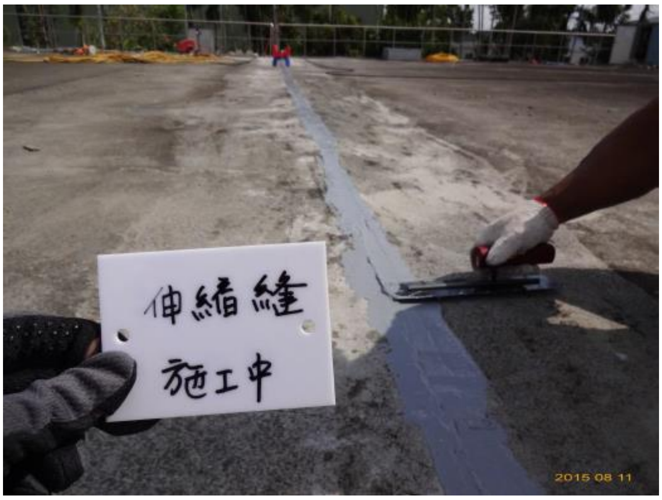
 13.池頂伸縮縫膠條填補	 14.表面處理
 15.施工完成	

圖 3-10 員林 6,500 噸清水池修復施工照片

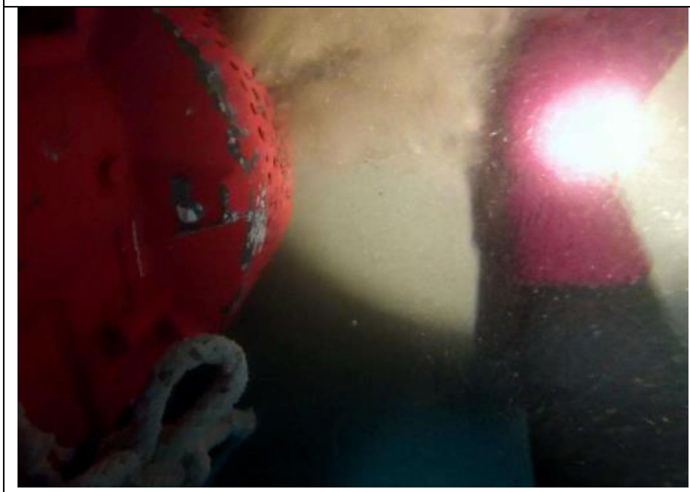
3.2.8 鯉魚潭 50,000 噸清水池

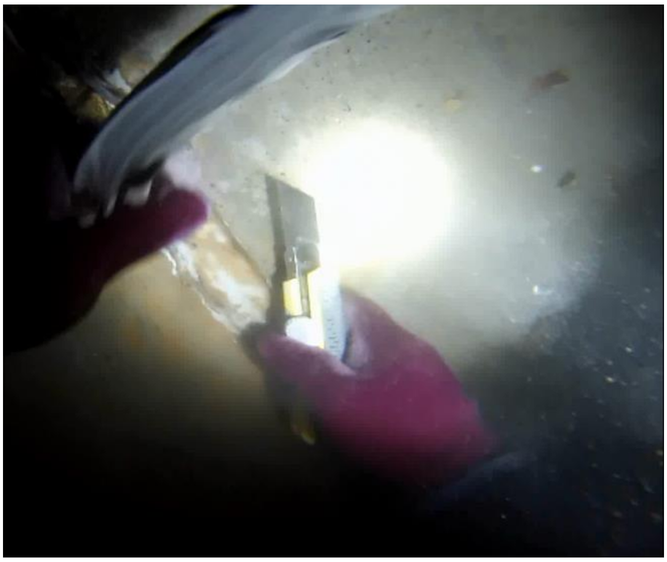
(1)基本資料，詳表 3-11

表 3-11　鯉魚潭 50,000 噸清水池修復基本資料

水池名稱	鯉魚潭淨水場二期五萬噸清水池
啟用年份	90 年 3 月
形狀	矩形
容量(M^3)	50,000
水位高(M)	2~5
破壞位置(方式)	伸縮縫滲漏
破壞原因	因震動導致伸縮縫錯位開裂
修復時間	106年4月
修復方式	1. 伸縮縫填縫料拆除重做(不斷水作業) 2. 池底地盤改良
施工流程	潛水作業→底泥清除→伸縮縫拆除→打鑿清創→橡膠止漏條填裝→水中鑽孔灌漿地改→施工完成
檢驗方式	觀察地面潮濕、水位試水
施工注意事項	局限空間、潛水作業
修復成效	至今仍維持修復後水準，成效良好

(2)施工照片，詳圖 3-11

 1.潛水作業前消毒	 2.潛水作業
 3.底泥清除	 4.底泥清除

	
5.伸縮縫切割拆除	6.伸縮縫打鑿清理
	
7.橡膠止漏條填裝	8.橡膠止漏條安裝完成

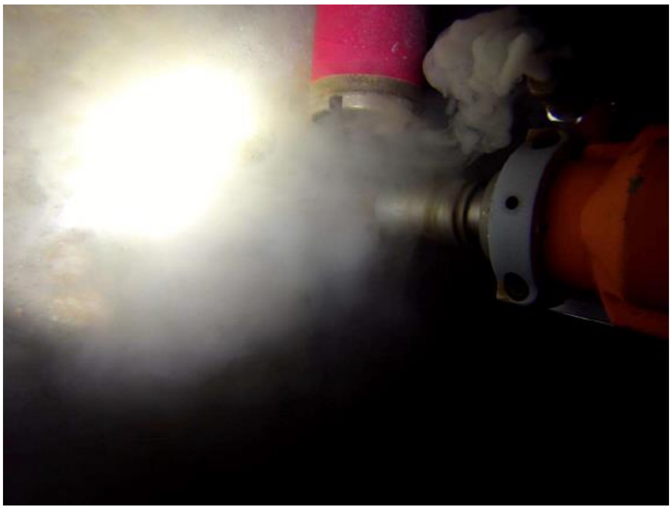
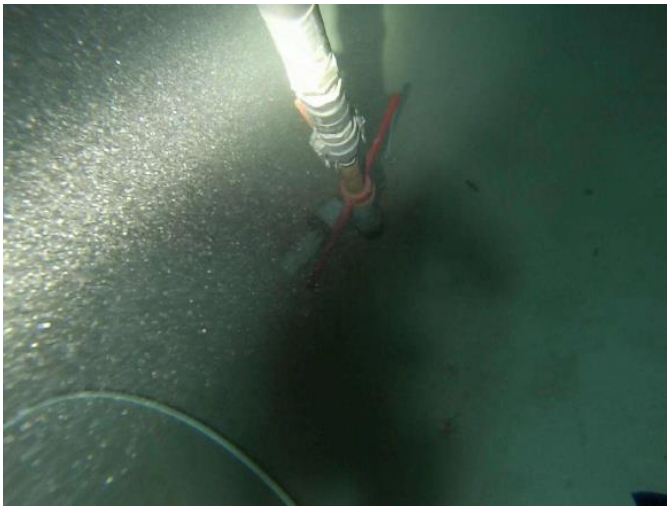
 9.池底鑽孔作業	 10.池底灌漿作業
 11.池底灌漿作業	

圖 3-11 鯉魚潭 50,000 噸清水池修復施工照片

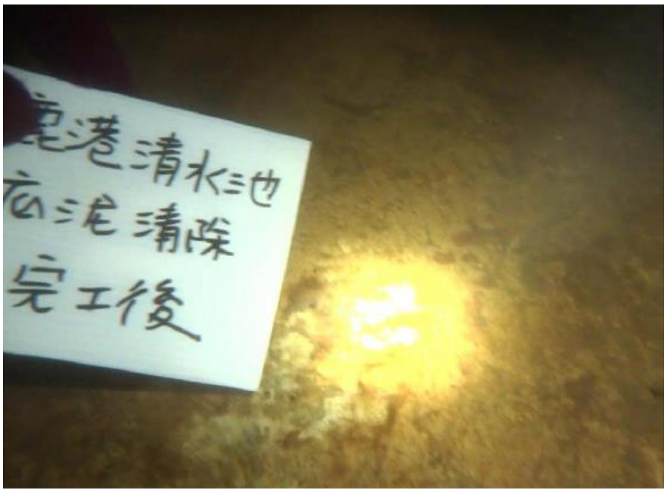
3.2.9 鹿港 1,700 噸配水池

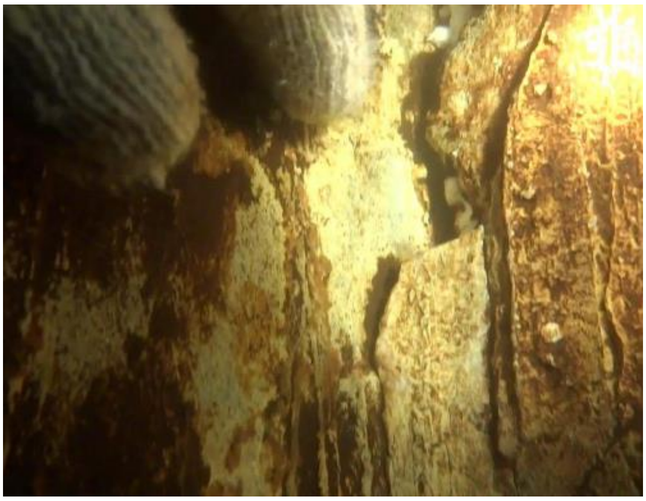
(1)基本資料，詳表 3-12

表 3-12 鹿港 1,700 噸配水池修復基本資料

水池名稱	鹿港淨水場 1,700 噸配水池
啟用年份	60 年 5 月
形狀	
容量(M^3)	1,700
水位高(M)	
破壞位置(方式)	隔間牆滲漏
破壞原因	建造時一期與二期隔間牆位移裂縫造成滲漏
修復時間	106年6月
修復方式	彈性填縫劑由內向外修補
施工流程	裂縫處打鑿拆除→彈性填縫劑無毒膠體修補→施工完成
檢驗方式	
施工注意事項	1.局限空間、潛水作業 2.照明及打鑿牆壁需防漏電 3.不斷水潛水施工，需注意清水池內濁度變化
修復成效	

(2)施工照片

	
1.底泥清除	2.底泥清除完成

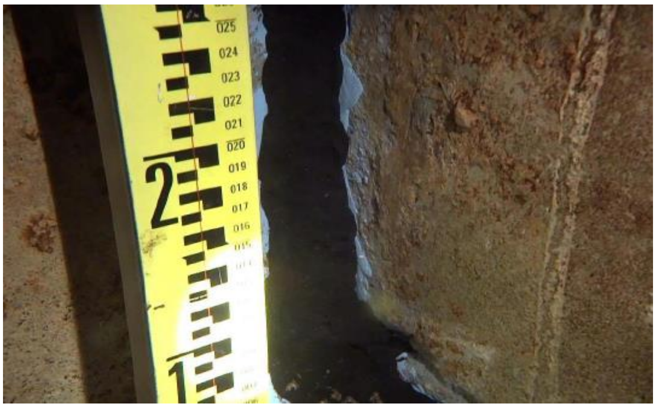


3.舊有伸縮縫老化龜裂

4.伸縮縫鑿除

5.伸縮縫填補中

6.伸縮縫填補中



7.施工完成

圖 3-12 鹿港 1,700 噸配水池修復施工照片

3.2.10案例綜合分析

表 3-13 案例綜合分析

水池名稱	破壞位置(方式)	破壞原因	修復方式	修復成效
魚池 3,000 噸配水池	池底滲漏	地震	整池 FRP 及無毒環氧樹脂塗佈	至今地面均無潮濕現象，成效良好
沙鹿 40,000 噸配水池	底板、池牆伸縮縫錯動	地震	伸縮縫填縫料拆除重做	至今仍維持修復後水準，成效良好
拷潭 10,000 噸清水池	伸縮縫滲漏(早期以柏油及蔗板做為填縫劑)	材料老化、地震	低壓噴射地質改良	至今仍維持修復後水準，成效良好
牡丹 10,000 噸清水池	伸縮縫滲漏、池體龜裂	材料老化	伸縮縫填縫料拆除重做及 RC 結構裂縫修補	修復後成效良好，惟近期有發現新滲水現象
東港 6,500 噸配水池	池底伸縮縫、池牆龜裂滲漏	材料老化	伸縮縫填縫料拆除重做、龜裂填補	至今仍維持修復後水準，成效良好
支亞干 200 噸配水池	伸縮縫滲漏	腐蝕老化	伸縮縫填縫料拆除重做	至今仍維持修復後水準，成效良好
富源 100 噸配水池	池底滲漏	腐蝕老化	聚脲防水材塗佈	至今仍維持修復後水準，成效良好
松浦 300 噸配水池、豐濱 200 噸配水池	池底滲漏	腐蝕老化	水性填縫膠修補、裂縫高分子水泥沙漿修補、聚脲防水材塗佈	至今仍維持修復後水準，成效良好
員林 6,500 噸清水池	底板及池牆伸縮縫、池牆裂縫	水池施工時未注意部分細節導致	水性填縫膠修補、裂縫高分子水泥沙漿修補、聚脲防水材塗佈	至今仍維持修復後水準，成效良好
鯉魚潭 50,000 噸清水池	伸縮縫滲漏	因震動導致伸縮縫錯位開裂	伸縮縫填縫料拆除重做(不斷水作業)及池底地盤改良	至今仍維持修復後水準，成效良好
鹿港 1,700 噸配水池	隔間牆滲漏	建造時一期與二期隔間牆位移裂縫造成滲漏	彈性填縫劑由內向外修補	至今仍維持修復後水準，成效良好

3.3 廠商訪談

除文獻蒐集彙整外，本研究亦安排訪談承攬台水公司水池修復工程之廠商，針對施工細節、材料、注意事項、遭遇問題及日後改進方向等交換意見。訪談結果以重點式摘要如下：

3.3.1 廠商 1(訪談時間：106 年 6 月 3 日)

1. 水池修復可概分為二大類型，局部裂縫修補及整體結構性補強，前者較輕微修復成本低；嚴重如後者通常伴隨裂縫發生，修復成本高。
2. 修復漏水從池體內部比外部更為有效。
3. 依廠商經驗水池漏水好發於過牆管處，原因為持續且微小之震動累積造成之損壞。
4. 水池修復之困難點其一是尋找實際漏水點，有裂縫不一定會漏水，除地上式從池體外牆可明顯觀察外，地下式或由水池內部則不易看出漏水點，此時透過細砂或生物性螢光劑(避免汙染水質)觀察流向可進行判斷，詳圖 3-13。

細砂流向示意圖

生物性螢光劑示意圖

圖 3-13 水中漏水點查察示意圖

5. 水中施工人員須有合格之潛水夫執照，若為清水池施工則下水前需徹底消毒，施工時於出水口檢測濁度，若超過標準則停止施工。
6. 整體性結構補強成效仰賴施工人員之經驗與判斷，灌漿位置及預留孔位置需準確評估，灌漿過程潛水夫透過預留孔狀況控制灌漿量與時間。
7. 池體修復材料品項相似但等級(產地)差異大，一般合約為避免綁標嫌疑通常僅列出品名,最低標的結果常導致施工成效不佳，為通過驗收而使用高級材料之費用往往由廠商吸收。

圖 3-14 廠商 1 訪談情形

3.3.2 廠商 2(訪談時間：106 年 6 月 14 日)

1. 水池修復以樹脂材料為大宗，用於自來水設施之樹脂必須為無毒性，並能符合飲用水水質標準之檢驗。
2. 一般裂縫之修復可用灌注工法，其簡要工序為：發泡樹脂→彈性密封灌注樹脂→膠結並硬固，詳圖 3-15~3-16。

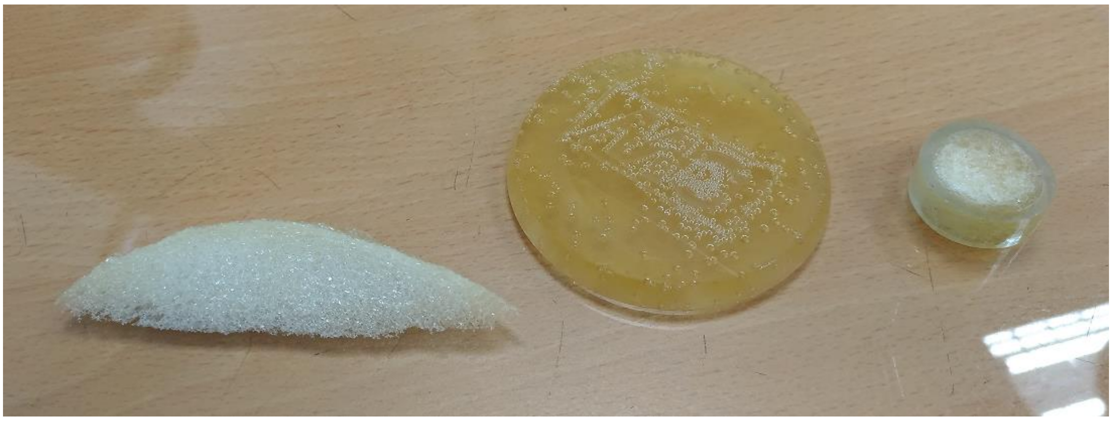


圖 3-15 灌注材料成形示意圖

3. 整體結構物伸縮縫或螺栓孔之修復則可利用彈性填縫劑，其完全硬化約需 14 天。

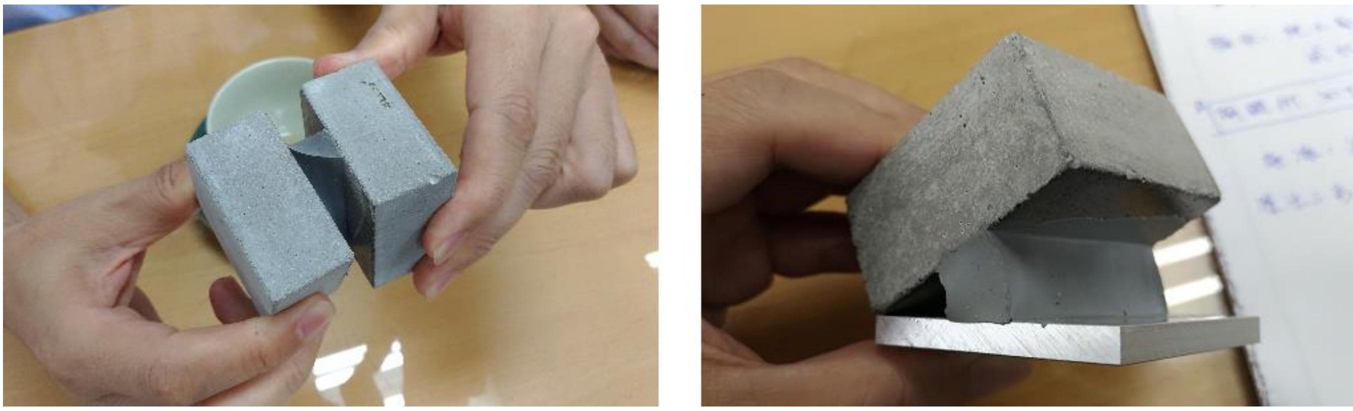


圖 3-16 彈性填縫劑成形示意圖

4. 可停水修復之水池可考慮採用 FRP 配合樹脂塗佈之工法，施工前表面需處理清潔、乾燥且平整，先塗一道底油樹脂(清潔、膠合用)、再以黏結樹脂與 FRP 層層交疊施做，可視需要調整施做層數，一般至少三層。
5. FRP 可長期泡於水中但應避免陽光曝曬，其裂化後可能分解出纖維，故較適合在密閉水池中施做，且以樹脂層疊塗佈可加強其穩固性。垂直面施做極限高約 3M。
6. 修復工程一般以實做數量計價，但以成果驗收，如觀察原滲漏潮濕之地面是否乾燥(不停水施做)或進行試水觀察水位(可停水施做)等。裂縫修補若以 M 計價，忽略裂縫深度之影響，將增加廠商計價風險。

圖 3-17 廠商 2 訪談情形

3.4 臺北自來水事業處訪談(時間：106 年 8 月 18 日)

臺北自來水事業處(以下簡稱北水處)與台水公司為台灣兩大供水事業，本研究期間恰得知北水處正進行水池修復相關計畫與工程，故特別安排訪談交流，除針對北水處整備計畫及部分案例進行了解外，亦赴現場觀摩內湖配水池整修工程。以下將訪談資料彙整為背景說明及案例介紹兩大部分。

3.4.1 背景說明

1. 北水處從 1976 年以來歷經自來水擴建一~五期、五期二階計畫至今，有許多水池已使用數十年，甚者部分老舊設計之水池已不符合現行法規，為了永續經營北水處擬定並執行一「整備計畫」，而配水池耐震安全評估及補強改善設計即為其中一環，並優先選定轄內 10 座損壞較為嚴重之配水池進行評估與補強改善。表 3-14 節錄 10 座配水池基本資料及現況問題。

2. 北水處辦理之配水池耐震安全評估及補強改善設計係委託技術服務之勞務採購案，廠商依配水池現況需求先行規劃相關補修工作項目，編製預約式(開口)契約施工標準圖、規範、材料檢驗總表及預算書等，並協辦工程招標及決標。後續配合停水期間進行各配水池內檢視及現場檢測工作，最後提出耐震評估分析成果與維修補強或功能改善設計方案，以進行各配水池維修分案設計，期間並提供工程施工諮詢等。

表 3-14 臺北自來水事業處 10 座配水池及現況問題

水池名稱	基本資料	現況問題
中和 配水池	30,000 噸高地調節性配水池 水池深度 9m、面積 3289.6 m^2 (81 年竣工)	1. 滿水位時配水池滲水，外牆混凝土破損，池內頂板裂縫滲水。 2. 池頂積水、底部基座掏空
木柵 配水池	25,000 噸高地調節性配水池 水池深度 12.5m 、面積 2463m^2 (84 年竣工)	1. 配水池外牆固定模版之螺桿處多處滲水 2. 池頂積水且有伸縮縫滲水情形
萬芳二 配水池	5,000 噸中繼配水池 水池深度 5.5m 、面積 1050 m^2 (73 年竣工)	池內頂版有混凝土剝落及鋼筋鏽蝕外露嚴重
內湖 配水池	25,000 噸調節用配水池 水池深度 6.7m 、面積 7,383m^2 (68 年竣工)	配水池池頂積水、頂板裂縫滲水。
天母平地 配水池	15,000 噸，水池深度 7.4m、面積 2,981m^2 (81 年竣工)	1. 配水池周圍排水系統需整建 2. 蓄滿水位需辦理安全監測評估
南港 配水池	5,000 噸地下式水池 水池深度 5m 、面積 883m^2 (77 年興建(南二場))	1. 部分柱接頭處混凝土剝落.鋼筋變形及銹蝕 2. 部分池頂及池牆鋼筋裸露銹蝕 3. 池牆與頂版交界處疑有地下水滲入造成白華現象
大屯 配水池	1,500 噸配水池 水池深度 5.8m 、面積約 257m^2	未曾停水檢視，俟新水池啟用後，始可停水檢視後，評估改善
觀星台北上 配水池	563 噸配水池 水池深度 3.1m 、面積 181m^2	水池底板有混凝土剝落鋼筋銹蝕外露嚴重。
福德加壓站 上、下水池	下水池(270 噸) 上水池(100 噸)	1. 下水池池頂水泥剝落、鋼筋裸露 2. 上水池下方地面掏空，邊坡有裂縫。

3.4.2 案例介紹

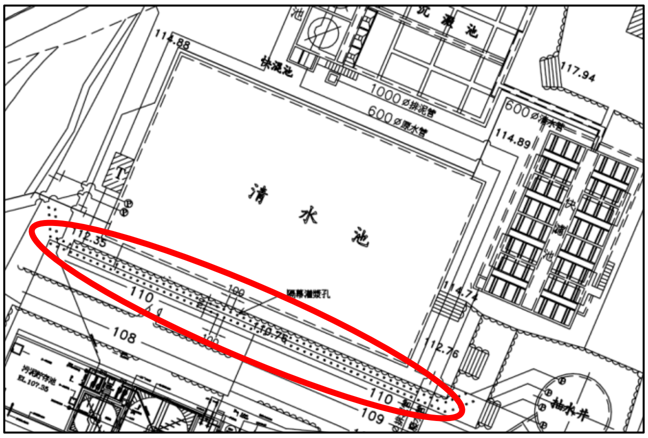
1. 雙溪淨水場清水池維修工程

(1)基本資料詳表 3-15

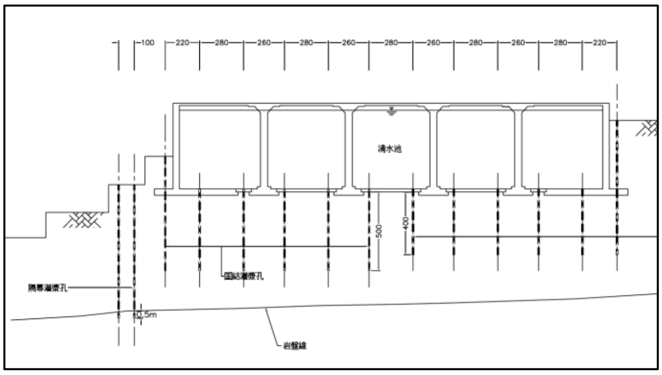
表 3-15 雙溪淨水場清水池維修工程基本資料

基本資料	1. 容量約 6,000 噸，池深 5.3m 2. 76 年改建至今，94 年整修完成
滲漏情形	1. 年度檢修時發現清水池有漏水現象。 2. 經基礎探查及地質鑽探工作，發現水池底下岩塊間孔隙有掏空現象。 3. 施作伸縮縫修漏工程，仍無法完全止水效果。
目的	預估漏水量為 500CMD，擬全面整修減少漏水
修復方式	1. 水池內牆面及底板包覆 SU316 不銹鋼板(6mm，120* 240cm) 2. 水池外部及底部施作高壓噴射樁(JSP) 3. 以無毒 FRP 包覆進出水口 4. 底板出水口灌注液態膨脹止水劑
施工流程	水刀清洗牆面→鋼板焊接→以角鋼及膨脹螺栓固定→鋼襯板背側填灌注無收縮水泥砂漿
檢測方式	1. 進行鋼板焊道非破壞性檢測 2. 注入無毒加色水觀察檢測有無漏水現象

(2)施工照片，詳圖 3-18



1.隔幕灌漿位置



2.隔幕灌漿剖面圖

	
3.水刀清洗牆面	4.鋼板包覆施工
	
5.無毒 FRP 包覆進出水口	6.底板出水口灌注液態膨脹止水劑
	
7. 焊道非破壞性檢測	8. 無毒加色水

圖 3-18 雙溪淨水場清水池維修工程施工照片

2. 新民加壓站配水池整修工程

(1)基本資料詳表 3-16

表 3-16　新民加壓站配水池整修工程基本資料

基本資料	1. 容量約 6,000 噸，池深 5m 2. 65 年建造，101 年整修完成
滲漏情形	1. 使用已逾 30 年 2. 地盤不均勻沉陷產生池面裂縫，造成水池漏水 3. 池內頂版鋼筋鏽蝕、混凝土剝落。
目的	使水池能回復原有蓄水量
修復方式	1. 於水池內牆面、底板及柱子包覆 SU316 不銹鋼板(6mm) 2. 以無毒 FRP 包覆進出水口 3. 頂版以碳纖維貼片工法補強結構強度
施工流程	1. 水刀清洗牆面→鋼板焊接→以角鋼及膨脹螺栓固定 2. 敲除混凝土→置換鋼筋→混凝土補強→裂縫注射環氧樹脂→表面塗佈環氧樹脂→碳纖維貼片黏貼施作

(2)施工照片，詳圖 3-19

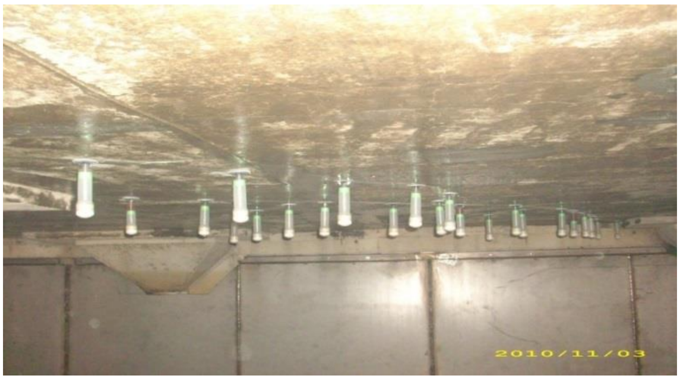
1.鋼板焊接

2. 以無毒 FRP 包覆進出水口

3.敲除混凝土

4.置換鋼筋

5.混凝土補強



6.裂縫注射環氧樹脂

7.表面塗佈環氧樹脂

8.碳纖維貼片黏貼施作

圖 3-19 新民加壓站配水池整修工程施工照片

3. 內湖配水池整修工程

(1)基本資料詳表 3-17

表 3-17　內湖配水池整修工程基本資料

基本資料	1. 容量約 25,000 噸 2. 水池深度 6.7m，面積 7,383m^2，68 年竣工
滲漏情形	發現水池下方有冒水現象，初步判定伸縮縫漏水。
目的	預估漏水量約為 200CMD，修復伸縮縫改善漏水
修復方式	水池內部底板伸縮縫處以耐震可撓式接頭整修
施工流程	混凝土打毛→植筋→玻纖混凝土填溝→玻纖混凝土→組模→柱間填無收縮水泥→螺栓植筋→安裝壓條

(2)施工照片詳圖 3-20

1.混凝土打毛

2.植筋

	
3.玻纖混凝土填溝	4.玻纖混凝土
	
5.組模	6.柱間填無收縮水泥

		
7.螺栓植筋	8.安裝壓條	9.完成

圖 3-20 內湖配水池整修工程施工照片

3.5 專家學者座談會議(時間：106 年 9 月 21 日)

本研究邀請國內之專家學者舉行座談會，與會專家包括北處代表、台水公司資深工程師、顧問公司代表、國家地震中心博士等，針對水池修復議題及本研究提出寶貴意見，相關意見及研究情形彙整如下：

3.5.1 專家學者意見

1. 本研究蒐集之案例建議可補充水池結構型式，或可作為滲漏原因判斷之參考。
2. 本研究第二章滲漏型式及修復工法等，建議可分為板、牆、裂

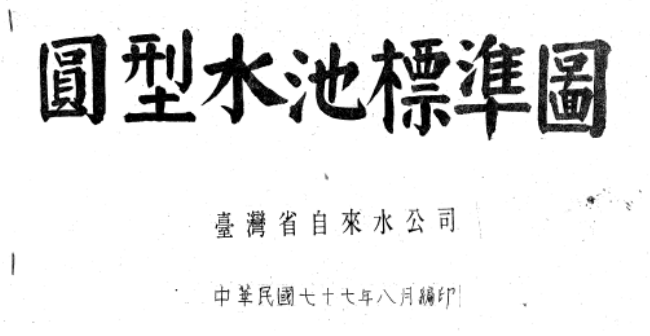
縫等三大類敘述，日後修復人員參考使用時可更加清楚。

3. 第五章結論與建議部分應加強描述本研究之成果，及未來可努力之方向。
4. 本研究係由施工案例出發，建議可安排與規劃、設計單位進行訪談，由設計端了解如何避免或減緩滲漏之發生。
5. 修復工法所使用之材料種類眾多，建議補充其性質、規範等。
6. 水池之滲漏能否即早發現，建議可由維護管理端著手，特別針對修復過之滲漏水池，更進一步建立完整之水池歷程記錄。

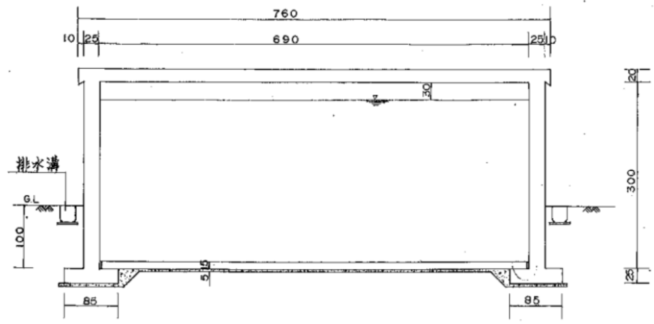
圖 3-21 專家學者座談會情形

3.5.2 意見回應及研究情形

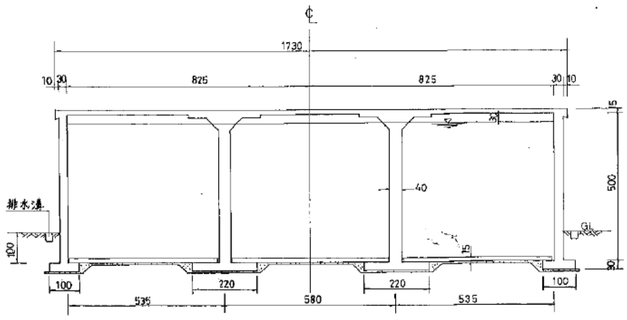
1. 本研究於第三章之水池基本資料中已補充水池形狀、水位高、檢驗方式、修復成效等資料，另因所蒐集之案例多為 80 年代水池，其當初設計圖多已不可考，惟本研究另蒐集到台水公司民國 77 年建立之圓形水池標準圖，早期水池多以圖 3-22 為標準進行設計，說明如下：



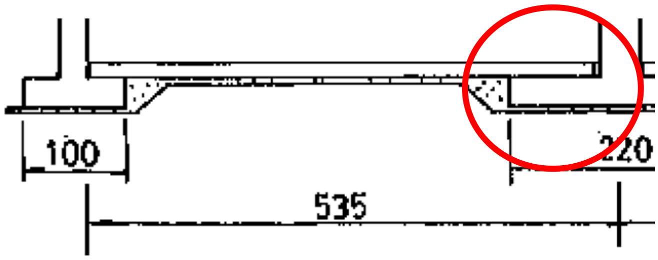
標準圖封面



100 噸圓形水池標準圖



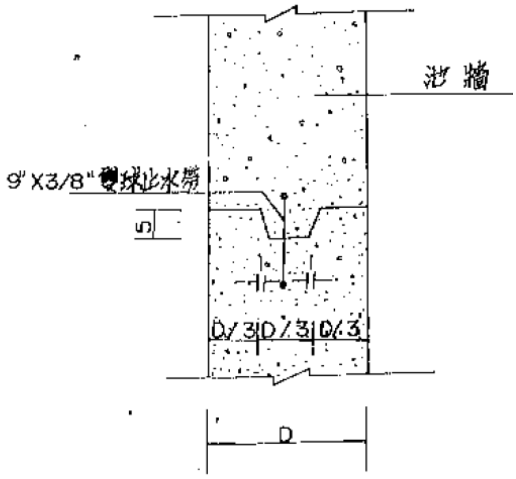
1000 噸圓形水池標準圖



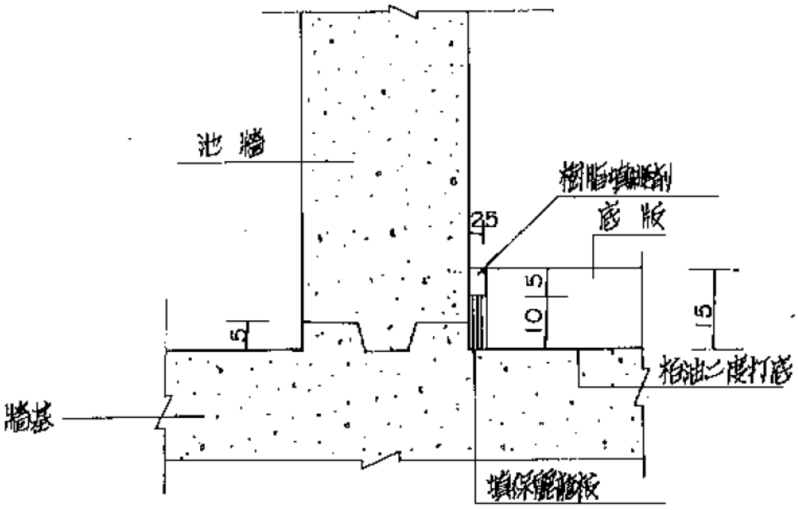
底板放大圖

圖 3-22 台水公司早期圓形水池標準圖

由標準圖可看出早期水池設計構造簡單，以類似獨立基腳之結構排列成一圓形，底板完成後下方以水泥砂漿連結、穩固，此種設計方式很容易在結構受外力錯動或材料老化後由接縫處(紅圈處)開始滲漏。



水平垂直施工縫大樣圖



牆基伸縮縫大樣圖

圖 3-23 台水公司早期圓形水池接縫標準圖

另由接縫標準圖(圖 3-23)可看出，早期伸縮縫使用保麗龍板配合樹脂填縫劑，當樹脂填縫劑老化或破損，其下之保麗龍板則無法發揮止水效果，且緊鄰其後之施工縫亦無設置止水帶，這些都是造成日後滲漏之可能原因，於水池設計時應予避免。

2. 以板、牆、裂縫等三大類將第二章滲漏型式及修復工法進行分類，初步結果如下表 3-18：

表 3-18　水池滲漏型式分類表

滲漏型式	
板	施工縫、伸縮縫、轉折接頭處、溫度變化龜裂、地震或不均勻沉陷、鋼筋生鏽、移位、蜂窩現象處、防水層破損、不足、混凝土的水密性不夠、泌水現象
牆	施工縫、伸縮縫、轉折接頭處、溫度變化龜裂、地震或不均勻沉陷、鋼筋生鏽、移位、蜂窩現象處、穿孔處、防水層破損、不足、混凝土的水密性不夠、泌水現象
裂縫	施工縫、伸縮縫、轉折接頭處、溫度變化龜裂、地震或不均勻沉陷、鋼筋生鏽、移位、蜂窩現象處
修復工法	
板	外覆防水層、內塗防水塗料、穿越壁體外側隔幕灌漿、混凝土深層滲透塗封劑
牆	外覆防水層、內塗防水塗料、穿越壁體外側隔幕灌漿、混凝土深層滲透塗封劑
裂縫	打 V 字型槽塗抹防水劑水泥砂漿、裂縫高壓灌漿止漏、混凝土深層滲透塗封劑、橡膠壓條(配合不鏽鋼壓版)

由上表分類可知，水池滲漏型式及修復工法均重覆出現，故修復人員在判斷滲漏及選擇工法時，發生滲漏之「位置」或許並非主要依據，而係裂縫大小、水池損壞程度(點狀、面狀或基礎不穩固)、水池供水條件(可否斷水施工)等才是決定工法適用性之依據。

3. 已於第五章加強描述本研究之成果，及未來可努力之方向。

4. 本研究於 106 年 10 月 24 日與規劃設計單位進行訪談，相關內容如報告 3.6 節。

5. 本報告第四章補充材料之特性、檢驗標準及國外參考規範等。

6. 水池修復之工作往往由發現滲漏開始，此則仰賴平時管理人員之巡查與檢驗，如水池構造物之混凝土裂紋、伸縮接縫、新舊介面施工接縫等有無漏水，下游地表是否有水滲出等，應定期進行調查[9]。如水池進出水管有設置水量計，則可以查察水池進出水量之差距，或關閉進出水進行水池漏水測試等以判斷漏水量。以台水公司為例，水池之檢查分為每 3 個月檢查 1 次之定期檢查及災害發生後馬上執行臨時檢查之特別檢查。在檢查當中如果發現漏水或銹蝕龜裂等異常情形時，應調查其原因，並填列「清（配）水池漏水或銹蝕修復改善辦理情形調查表」(如下表 3-19)，據以陳報修復經費，以利及早進行修護整理。[10]

表 3-19 水池漏水或銹蝕修復改善辦理情形調查表

本公司第○○區管理處清（配）水池漏水或銹蝕修復改善辦理情形調查表

區處別	管轄單位（廠所/淨水場）	清（配）水池名稱	容量（m^3）	漏水或銹蝕原因	改善對策	改善經費（元）	改善工程主辦單位	預定改善完成期限（年/月）	備註

填表人簽章：　　股長審核簽章：　　廠所主管核章：

水池一旦發生漏水,其日後再發生漏水之機率亦相對較高,因此,如能建立類似病歷表之水池維修紀錄表，將每一次維修情形，包含漏水原因、漏水型式、修復工法、工程經費及修復成效等詳實紀錄，除可作為下次發生漏水之處置參考外,亦可作為日後統計分析之資料庫。本研究建議之紀錄表內容如下表 3-20：

表 3-20 水池維修紀錄表

<table>
<tr><td>清(配)水池名稱</td><td colspan="3"></td></tr>
<tr><td>容量(M3)</td><td></td><td>啟用年月</td><td></td></tr>
<tr><td>設計單位</td><td></td><td>管理單位</td><td></td></tr>
<tr><td colspan="4">1. 發生漏水日期：
2. 漏水發現形式及位置：
3. 破壞位置(方式)：
4. 破壞原因：
5. 完成修復時間：
6. 修復方式：
7. 施工流程：
8. 工程經費：
9. 修復成效：</td></tr>
<tr><td>填表人</td><td></td><td>單位首長</td><td></td></tr>
</table>

3.6 設計單位及顧問公司訪談(時間：106 年 10 月 24 日)

本研究邀請設計經驗較為豐富之台水公司資深員工及顧問公司，針對設計端考量之重點進行訪談。訪談結果以重點式摘要如後。

1. 減少伸縮縫之設置可有效降低水池滲漏之發生，利用 A、B 池之分池設計方式，除可縮小池體規模減少伸縮縫，亦可方便於單池清洗時由另一池維持供水，惟分池設計方式將增加施工工期及經費，應進一步評估後採用。
2. 若池體採無(少)伸縮縫之設計，因混凝土量體較大需特別注意澆置進度及養護作業，此種設計往往失敗在澆置過快產生蜂窩形成弱面，或養護不確實混凝土乾縮過劇導致裂縫。
3. 若欲進行水池修復，應先完整評估後選擇適當工法，包括池體老舊者應先進行結構補強，再針對滲漏逐一修復，但現實狀況常因供水壓力被迫選擇最迅速之修復方式，造成修復成效不佳或耐久度不足。
4. 目前有蓋式水池設計之頂板內部很少考量防水措施，而自來水大多以加氯消毒，其頂板經年累月與揮發之氯氣接觸將造成混凝土咬蝕剝落，進而使鋼筋鏽蝕膨脹，混凝土加速破壞後由頂板往池牆開裂，最後成為滲漏之根源。
5. 混凝土大部分之乾縮於數個月內即完成[11]，此時若進行二次施

工(如水泥砂漿粉刷或防水塗佈)將可進一步確保混凝土之水密性，減緩滲漏之發生。

6. 倘若伸縮縫之設置無法避免，則應特別加強伸縮縫材料之選用、施工方式，並於設計時評估伸縮縫之耐震程度，必要時以地錨、預力環繞或預立鋼鍵等方式加強，避免因外力造成巨大開裂或錯動，危及水池周邊居民之生命財產安全。

圖 3-24 設計單位及顧問公司訪談情形

第四章　修復材料

本章依據第三章各修復案例彙整出修復材料特性，並補充中華民國國家標準(CNS)、美國水工協會(American Water Works Association, AWWA)及英國飲用水稽查處(Drinking Water Inspectorate, DWI)相關建議。

4.1 修復材料特性

4.1.1 環氧樹脂

環氧樹脂依 CNS4938「環氧樹脂漆」(詳附錄一)之品質規定可分為四種：(1)底漆(配合鋅鉻黃等防銹顏料)；(2)面漆(配合耐酸鹼等之顏料)；(3)透明(供化學品貯槽或油槽內壁之防蝕用)；(4)鋁粉漆(配合銀漿供著色用)，然水池修復所用之環氧樹脂需與飲用水長時間接觸，其特性可另參考 CNS13273「延性鑄鐵管及管件內面用環氧樹脂粉體塗裝」(詳附錄二)之規定，摘要如下：

1. 塗料：不含使用上有害之成分，硬化後不溶於水，且不得使水質有不良影響。
2. 成分：使用環氧樹脂、硬化劑及顏料為主原料之熱固性粉體塗料。
3. 品質：如表 4-1 規定

表 4-1 環氧樹脂品質檢驗表

項目	品質	檢驗方法
塗膜比重	1.8 以下	第 5.4.1 節方法
塗膜附著性	評估點數 8 以上	第 5.4.2 節方法
塗膜耐衝擊性	衝擊變形後無龜裂及剝離	第 5.4.3 節方法
塗膜可撓性	無龜裂發生	第 5.4.4 節方法
塗膜刮痕抵抗性	無異常	第 5.4.5 節方法
塗膜防蝕性	無銹污、起泡、膨脹、龜裂等現象	第 5.4.6 節方法
塗膜耐溫度反覆性	無發生皺紋、龜裂、膨脹、剝離及無顯著變色	第 5.4.7 節方法
塗膜溶出性 (僅適用於自來水管)	濁度:0.5 度以下 色度:1 度以下 過錳酸鉀消耗量:2mg/L 以下 餘氯減量:0.7ppm 以下 酚類:0.005 mg/L 以下 胺:無檢出 氰:無檢出 臭味及味道:無異常	第 5.4.8 節方法 (溶出試驗)

4. 溶出試驗:以聚偏二氯乙烯(polyvinylidene chloride)薄膜(預先以 5%硝酸洗過後再充份水洗)包裹的良質橡皮塞封住試片之一底端,以自來水流水洗淨 1 小時後倒空並以供試水清洗,再注滿供試水,上面以聚偏二氯乙烯薄膜覆蓋,靜置於常溫陰暗處經 24 小時後,以此水作為試樣水。同時將供試水盛滿於 2L 之燒杯,以聚偏二氯乙烯薄膜覆蓋,並靜置於試樣水同一地點經 24 小時候當作空白試驗水。供試水之調製方法及試驗方法依附錄之規定。其試驗溫度為常溫,而上表所示數值係由與空白試驗之差數求得。

4.1.2 樹脂 L-11

1. 二液型、長溫硬化之無溶劑型樹脂，配合玻離纖維夾襯，有抗龜裂、抗漏水之補強效果，使結構物恢復其整體性及延長使用年限。
2. 材料特性：如表 4-2

表 4-2 樹脂 L-11 材料特性表

濁度	增加量 1NTU 以下
色度	增加量 3 度以下
臭度	無特別臭味
pH	增減量 0.2 以下
高錳酸鉀消耗量	增加量 5ppm 以下
酚	增加量 0.05ppm 以下
游離氯	減失量 1.5ppm 以下
有毒物質	鉛、硒、砷、鉻、鎘、銀、汞、氰化物符合自來水水質標準
※浸漬水：試片以常溫之自來水流水中沖洗六小時後擦乾之並將該試驗片放入盛有含氯 2ppm 之清水一公升之瓶內加蓋靜置於溫度 20±1℃之室內，經二十四小時後取其浸水為浸漬水。 ※對照水：與浸漬水同時採取之含氯量 2ppm 之清水一公升加蓋放置於 20±1℃之室內經二十四小時者。	

4.1.3 灌注發泡樹脂

1. 單劑式聚氨脂基灌注發泡樹脂，與水接觸時可產生發泡膨脹反應，可依現場需求調整反應發泡時間，對潮濕裂縫表面具極佳黏著性，無收縮、無溶劑，適用於細微裂縫灌注。

2. 材料特性：如表 4-3，試驗報告(詳附錄三)

表 4-3　灌注發泡樹脂材料特性表

密度	1.15 kg/dm^3
黏度	400 mPa.s
最大膨脹比率	100%
與水反應發泡倍率	1.3
硬度	50
施作時間	100 分鐘
施作溫度	6-35 ℃

4.1.4 彈性密封灌注樹脂

1. 低黏度聚氨脂基彈性體樹脂，與水接觸加速反應時僅產生有限的體積膨脹。

2. 材料特性：如表 4-4，試驗報告(詳附錄四)

表 4-4　彈性密封灌注樹脂材料特性表

密度	1.05 kg/dm^3
黏度	100 mPa.s
無反壓力下與 5%水反應體積膨脹倍率	1,000-2,000
施作時間	6-8 小時
施作溫度	6-35 ℃

4.1.5 彈性填縫劑

1. 屬於單液型彈性接縫填料。

2. 材料特性：如表 4-5

表 4-5　單液型彈性接縫填料特性表

<table>
<tr><th colspan="3">試　驗　項　目</th><th>規範</th><th>試驗結果</th></tr>
<tr><td colspan="3">成形脫模時間</td><td>72 小時以內</td><td>合格</td></tr>
<tr><td colspan="2" rowspan="2">塌陷(mm)</td><td>20 ± 3℃</td><td>3 以下</td><td>0</td></tr>
<tr><td>50 ± 3℃</td><td>3 以下</td><td>0</td></tr>
<tr><td colspan="3">污染性</td><td>合格</td><td>合格</td></tr>
<tr><td colspan="2" rowspan="2">硬度(HS)</td><td>標準狀態 14 天以後</td><td>15 以上，50・以下</td><td>合格</td></tr>
<tr><td>70℃ 96 小時</td><td></td><td></td></tr>
<tr><td rowspan="10">接著抗拉強度</td><td colspan="2">被接合材質</td><td></td><td>混凝土</td></tr>
<tr><td rowspan="3">初期接合抗拉強度 14 天以後</td><td rowspan="3">150%時最大伸長率接合強度(kgf／c㎡)</td><td>1.0 以上</td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td>合格</td></tr>
<tr><td rowspan="3">浸水後接合抗拉強度 96 小時以後</td><td rowspan="3">150%時最大伸長率接合強度(kgf／c㎡)</td><td>1.0 以上</td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td>合格</td></tr>
<tr><td rowspan="3">加熱後接合抗拉強度 70℃ 96 小時</td><td rowspan="3">150%時最大伸長率接合強度(kgf／c㎡)</td><td>1.0 以上</td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td>合格</td></tr>
<tr><td colspan="3">剝離強度(kgf／3cm 寬)</td><td>9 以上</td><td>符合</td></tr>
<tr><td colspan="3">引張復原性(mm)</td><td>17 以上</td><td>19</td></tr>
</table>

4.1.6 聚脲樹脂

現行國家標準(CNS)中並無聚脲樹脂之規定(部分廠商參考較為接近之 CNS 6986 建築防水用聚胺酯為使用標準)，另根據文獻[12]彙整聚脲樹脂之特性如下：

1. 聚脲樹脂是由異氰酸脂與氨基化合物組成，是快速反應成膜的一種樹脂塗料，又稱速凝固化樹脂材料。
2. 聚脲樹脂材料不另含催化劑，100%固體含量值，低揮發性有機物質，快速反應凝結固化，可在任意曲面、斜面及垂直面上噴塗成型，不產生垂流掛線現象，10~20 秒凝固成膜，1 分鐘即可達到步行強度。
3. 對施工面溼氣較為敏感，會對接著強度有顯著影響。若僅只於成膜，則施工時不受環境溫度、溼度影響(可在冰上、在-28℃下施工，並在冰櫃中固化)，均可固化成膜。
4. 熟成固化後對環境低汙染影響，並具有良好的熱穩定性，可在120℃下長期使用，並可承受 350℃的短時熱衝擊。
5. 聚脲樹脂可像普通塗料加入各種顏色、染料，製程不同顏色的產品，目前也有生產廠商因應市場需求以研發出具有綠建材標章的綠建材防水材料。

本報告 3.2.6 節案例所使用之聚脲防水材鋪設順序如圖 4-1：

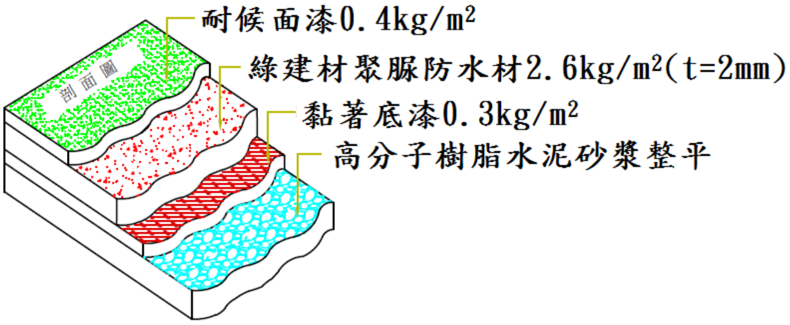


圖 4-1 聚脲防水材鋪設順序示意圖

各層之材料性質彙整如下：

1. 黏著底漆試驗項目如表 4-6

表 4-6 黏著底漆試驗項目表

試 驗 項 目	規 格 值	試 驗 方 法
乾燥時間	4 小時以內半堅結	CNS 11582
耐衝擊性	無龜裂剝離	CNS 11582
耐屈曲性	無龜裂剝離	CNS 11582
耐機油性	無剝離起泡軟化	CNS 11582
鹽霧試驗	無生銹剝離起泡	CNS 11582
耐濕性	無膨脹生銹剝離	CNS 11582
加熱殘份(%)	50 以上	CNS 11582

2. 單液 PU 彈性材料物性規範，如表 4-7

表 4-7 單液 PU 彈性材料物性規範表

試 驗 項 目	測驗要求	試 驗 方 法
硬化方式	單液型自然硬化	--
硬度(Shore A/1sec)	50 以上	CNS 6988
抗拉強度(kgf/cm2)	20 以上	CNS 6988
伸長率(%)	300 以上	CNS 6988
撕裂強度(kgf/cm)	15 以上	CNS 6988
耐磨耗(1kg/1000 轉/g)	3 以下	CNS 6988
透水性(ml)	3 以下	CNS 4684
耐水型(室溫)	無異狀	CNS 10757
耐鹼性(30%氫氧化鈉)	無異狀	CNS 10757
加熱殘份(%)	95 以上	CNS 10880

3. 綠建材聚脲防水材物性規範，如表 4-8

表 4-8 綠建材聚脲防水材物性規範表

試驗項目	測驗要求	試驗方法
比重	1.0~1.3	CNS 6988
硬度(A)	70 以上	CNS 6988
抗拉強度(kgf/cm^2)	100 以上	CNS 6988
撕裂強度(kgf/cm)	50 以上	CNS 6988
伸長率(%)	200 以上	CNS 6988
100%彈性模數(kgf/cm^2)	50 以上	CNS 6988
老化試驗(168hr) 硬度(A) 抗拉強度(kgf/cm^2) 撕裂強度(kgf/cm) 伸長率(%)	70 以上 100 以上 50 以上 200 以上	CNS 6988

4. 耐候面漆，試驗項目如表 4-9

表 4-9 耐候面漆試驗項目表

試驗項目	測驗要求	試驗方法
抗拉強度(Mpa)	5 以上	CNS 8645
透水性(24hr)(ml)	0.5 以下	CNS 4684
擴散反射率(%)	90 以上	CNS 10756-1
冷熱反覆試驗 (-20°C/1h 及 80°C/1h 為一循環，共 10 循環)	能耐冷熱反覆	CNS 11607
耐紫外線	外觀無黃變	ASTM G154
耐老化性(70°C/168h) 抗拉強度保留率(%) 撕裂強度保留率(%)	100 以上 100 以上	CNS 8645
耐濕性(95%RH/168hr)	無異狀	CNS 11607

另台水公司於「頂山腳加壓站土建工程(續)」亦有使用聚脲樹脂防水材，該案係使用於外側防水，其材料特性要求如下：

表 4-10 聚脲防水材材料特性表

聚胺(脲)脂防水塗料（須取得綠建材標章）

測試項目	測試結果	測試方式
硬度(Hs)(TypeA/1sec)	≧70	CNS 6988
抗張強度(kgf/cm^2)	≧150	CNS 6988
伸長率 (%)	≧500	CNS 6988
撕裂強度(kgf/cm)	≧90	CNS 6988
100%彈性模數(kgf/cm^2)	≧85	CNS 6988
透氣性(g/h.m^2)	≦1.0	ASTM E96-10
TVOC逸散濃度(mg/h.m^2)	≦0.19	ASTM D5116
甲醛逸散濃度(mg/h.m^2)	≦0.08	ASTM D5116
耐紫外線性(QUV,2000hr)		
伸長率 (%)	≧350	ASTM D412-06
撕裂強度(kgf/cm)	≧75	ASTM D624-00
吸水率(%)	≦1.3	ASTM D570-98

衛生試驗

試驗項目	規範值	
a.濁度增加度(NTU)	0.0	
b.色度增加度(度)	0.0	
c.臭味	無臭味	
d.pH值增減量	±0.03	
e.高錳酸鉀消耗量(ppm)	1.9±0.1	
f.酚(ppm)	N.D.	
g.游離氯減失量	0.0	

4.2 美國水工協會建議與國家標準

4.2.1 美國水工協會建議

在水池修復塗佈材料方面，本研究並未尋獲美國專門之規範或標準，惟參考美國水工協會 ANSI/AWWA D102-06 標準[13]，其針對金屬儲水槽之塗佈有相關規定，主要分為外塗系統(Outside Coating Systems, OCS)及內塗系統(Inside Coating Systems, ICS)，雖然其主要目的為金屬防蝕及保護，然內塗系統亦直接與水接觸，可做為本研究

之參考，故將內塗系統之規定摘要如下：(詳附錄五)

1. ICS-1：為雙層、雙組成環氧樹脂塗佈系統。其材料應包含(1)不含煤焦油、雙組成環氧樹脂之雙層塗佈系統，並符合 ANSI /AWWA C210 規定，包含底漆、面漆，或是使用兩層相同的環氧樹脂塗料而不用底漆；或(2)符合 D102-06 標準 4.4.1 節之特殊環氧樹脂配方。其最小乾膜厚度規定如表 4-11：(單位：千分之一英吋)

表 4-11 ICS-1 最小乾膜厚度表

System	Prime Coat	Finish Coat	Total System
ICS-1	3.0	5.0	8.0

2. ICS-2：為三層、雙組成環氧樹脂塗佈系統。此系統的底漆需與中層漆有對比顏色，其材料應包含(1)不含煤焦油、雙組成環氧樹脂之三層塗佈系統，並符合 ANSI/ AWWA C210 規定，包含底漆、雙層面漆，或是使用三層相同的環氧樹脂塗料而不用底漆；或(2)符合 D102-06 標準 4.4.1 節之特殊環氧樹脂配方。其最小乾膜厚度規定如表 4-12：

表 4-12 ICS-2 最小乾膜厚度表

System	Primer	Intermediate Coat	Finish Coat	Total System
ICS-2	3.0	4.0	5.0	12.0

3. ICS-3：為三層、無機鋅粉底漆系統。此系統中層漆與面漆為雙組成環氧樹脂，只適用在無水浸泡的區域(水位線以上)，底漆之修飾工作要用與其他中層漆材料相同的環氧樹脂，最後再塗上面漆完成。無機鋅粉底漆需符合 SSPC-Paint 20, Type I-B 或 Type I-C，中層及面漆應包含(1)無煤焦油環氧樹脂材料，並符合 ANSI/AWWA C210 規定；或(2)符合 D102-06 標準 4.4.1 節之特殊環氧樹脂配方。其最小乾膜厚度規定如表 4-13：

表 4-13 ICS-3 最小乾膜厚度表

System	Primer	Intermediate Coat	Finish Coat	Total System
ICS-3	2.0	4.0	4.0	10.0

4. ICS-4：這是一種熱固性聚合物塗佈技術，是 100%固體含量聚氨酯及(或)聚脲樹脂反應成聚異氰酸酯樹脂之產物。其應包含雙組成、100%固體含量、快速成形的聚氨酯或聚脲樹脂材料，可在 30 分鐘內養護完成，並應符合 ANSI/AWWA C222 之規定。本系統最小乾膜厚由製造商建議值及以表 4-14 列值擇優選用：

表 4-14 ICS-4 最小乾膜厚度表

System	Total System
ICS-4	25.0

5. ICS-5：為三層、有機鋅粉底漆系統。此系統中層漆與面漆為雙組成環氧樹脂，只適用在無水浸泡的區域(水位線以上)。有機鋅粉底漆需符合 SSPC-Paint 20, Type II 並進行化學養護，可單獨包裝或與鋅粉隔離後一起包裝。中層及面漆應包含(1)無煤焦油環氧樹脂材料，並符合 ANSI/AWWA C210 規定；或(2)符合 D102-06 標準 4.4.1 節之特殊環氧樹脂配方。其最小乾膜厚度規定如表 4-15：

表 4-15 ICS-5 最小乾膜厚度表

System	Primer	Intermediate	Finish	Total System
ICS-5	2.0	4.0	4.0	10.0

前述 D102-06 標準 4.4.1 節補充如後：當塗層材料參照技術標準時，應敘明一般形式的品質需求，但不禁止額外配方之使用。任何特殊配方只要符合一般形式，且其性能達到或超過標準內定義之效能者，均應可被接受。另在水槽之潮濕內面塗佈時，要依據 NSF/ ANSI 61 來進行飲用水相關檢驗，並在至少 8 個月的長期淡水抗性中仍須滿足服務水準。任何不滿足上述規定的材料，不論有沒有列在標準中都不應使用。

4.2.2 美國國家標準

美國雖未針對修復工法或材料明定專門標準，但對於飲用水系統

的各組成，與健康相關者依材料種類訂有檢驗項目[14]，並分為管線/另件/設備材料、塑膠材料、接合劑材料及阻隔/防水材料等四大類，其中與本研究相關者為阻隔/防水材料，彙整如表 4-16：

表 4-16 美國國家標準與健康相關材料檢驗項目表

材料種類	必要之定性分析
瀝青塗層	管制類金屬(銻，砷，鋇，鈹，鎘，鉻，銅，鉛，汞，硒，鉈)、銅、釩、錳、揮發性有機化合物、氣相層析質譜儀基本/中性掃描(特別是羰基與非芳香族的碳氫化合物)、肽核酸
環氧樹脂塗層(液狀或粉狀)	氣相層析質譜儀(基本/中性/酸性掃描)、雙酚 A、雙酚 A-二環氧甘油醚、丙氧基雙酚 A、環氧氯丙烷、揮發性有機化合物、雙酚 F、雙酚 F-二環氧甘油醚、丙氧基雙酚 F、溶劑和反應稀釋添加劑
聚脂塗層	氣相層析質譜儀(基本/中性/酸性掃描)、揮發性有機化合物、殘留單體
聚氨脂	氣相層析質譜儀(基本/中性/酸性掃描)、揮發性有機化合物
波特蘭及水硬性水泥	氣相層析質譜儀、管制類金屬、戴奧辛和呋喃、放射性核素、乙二醇和乙醇胺

4.3 英國飲用水稽查處

英國飲用水稽查處(DWI)係英國於1990年實施飲用水私有化之後，成立之獨立組織，由英國政府之環境、食品暨鄉村事務部(Department for Environment、Food & Rural Affairs, DEFRA)管轄，主要職責為管理與檢查英格蘭及威爾斯境內的水務公司供應飲用水的數量及品質。它還負責依據歐盟制定的歐洲飲用水指令(European Drinking Water Directive, DWD)及人類飲用水水質指令(Council Directive 98/83/EC)，向歐盟報告飲用水水質。DWI 亦制訂了「LIST OF APPROVED PRODUCTS FOR USE IN PUBLIC WATER SUPPLY IN THE UNITED KINGDOM」[16]，所有認可的產品，都必須按照所列的具體認可條件使用，其中亦針對「密封劑及修復材料(Sealant & Repair Materials)」(詳附錄六)，臚列可使用材料之公司及產品名稱、認可條件及有效期限。因此，有關水池漏水修復，亦可使用該規範認可之材料。

第五章　結論與建議

本報告於第二章回顧了池狀結構滲漏型式及修復工法，第三章蒐集台水公司共四個區處十二座水池之修復案例，並與水池修復廠商、北水處、專家學者、設計單位及顧問公司等進行訪談，第四章彙整修復材料、美國及英國相關標準，綜合以上研究發現，在設計階段有水池結構設計問題、伸縮縫之規劃設置及材料選用問題，施工階段則應注意伸縮縫之施工方式與材質適用性，維護階段則應建立水池相關歷程資料以供處置參考，另外提供修復工法選擇、施工流程圖及參考單價等，分別提出之結論與建議如下：

5.1 結論

5.1.1 早期水池設計缺失

早期圓形水池設計構造簡單，以類似獨立基腳之結構排列成一圓形，底板完成後下方以水泥砂漿連結、穩固，此種設計方式很容易在結構受外力錯動或材料老化後由接縫處開始滲漏。另早期伸縮縫使用保麗龍板配合樹脂填縫劑，當樹脂填縫劑老化或破損，其下之保麗龍板則無法發揮止水效果，且緊鄰其後之施工縫亦無設置止水帶，這些都是造成日後滲漏之可能原因，於水池設計時應予避免。

5.1.2 修復工法之選擇

第 3.5.2 節嘗試以滲漏位置(如板、牆、裂縫等)將水池滲漏型式及修復工法進行分類，惟其結果顯示「位置」並非主要依據，而係裂縫大小、水池損壞程度(點狀、面狀或基礎不穩固)、水池供水條件(可否斷水施工)等才是決定工法適用性之依據。以下彙整各類型修復工法之優、缺點及適用性。

1. 防水材料塗佈類

利用各種塑膠、樹脂類防水材料(詳表 5-1)，分數層塗佈或噴塗，施工前需清理原表面並使其乾燥(依水池是否加蓋、通風等不同條件約需 3~10 天，亦可採用抽風機、瓦斯烘乾等方式加速乾燥)，如表面混凝土已嚴重剝落，則需重新植筋、灌漿打底後再行施工，塗佈完成亦需 3~5 天使其硬化成形，方能蓄水，。

表 5-1 防水材料塗佈類彙整表

材料	適用	優點	缺點
玻璃纖維強化塑膠(FRP)	1. 池體內部修復 2. 面狀修復	1. 價格合理 2. 技術門檻低	施工期間無法蓄水。
彈性填縫劑	1. 局部裂縫修復 2. 小面積漏水	1. 價格合理 2. 施工便利	1. 施工期間無法蓄水 2. 單一代理商
聚脲樹脂(Polyurea)	1. 池體內部修復 2. 面狀修復	1. 耐久性較高 2. 成效良好	1. 價格稍高 2. 施工期間無法蓄水

2. 高(低)壓噴射灌漿(地質改良)類

由池體內部以鑽桿鑽入池牆或貫穿池牆，利用鑽桿前端之壓力噴嘴將添加乳膠藥劑之水泥漿噴射於裂縫或地盤中，使漿液隨漏水向外流動並固結後止漏，其適用情形與優缺點彙整如表 5-2。

表 5-2 高(低)壓噴射灌漿(地質改良)適用情形彙整表

適用	優點	缺點
1. 難以開挖修復(如地下式池體) 2. 池體結構受損嚴重或老化剝落，無法小面積修復 3. 水池基礎已被掏空、不穩固	可不斷水施工	1. 技術門檻高 2. 大面積修復未必能完全杜絕滲漏

3. 裂縫(伸縮縫)修復類

裂縫修復基本工序為舊有材料清理切割→填充材(裂縫較大者)→填縫劑→表面加強→外部處理(如裂縫深度達外部)，配合使用不同材料進行施工，本類材料處理部位及材料種類如表 5-3。

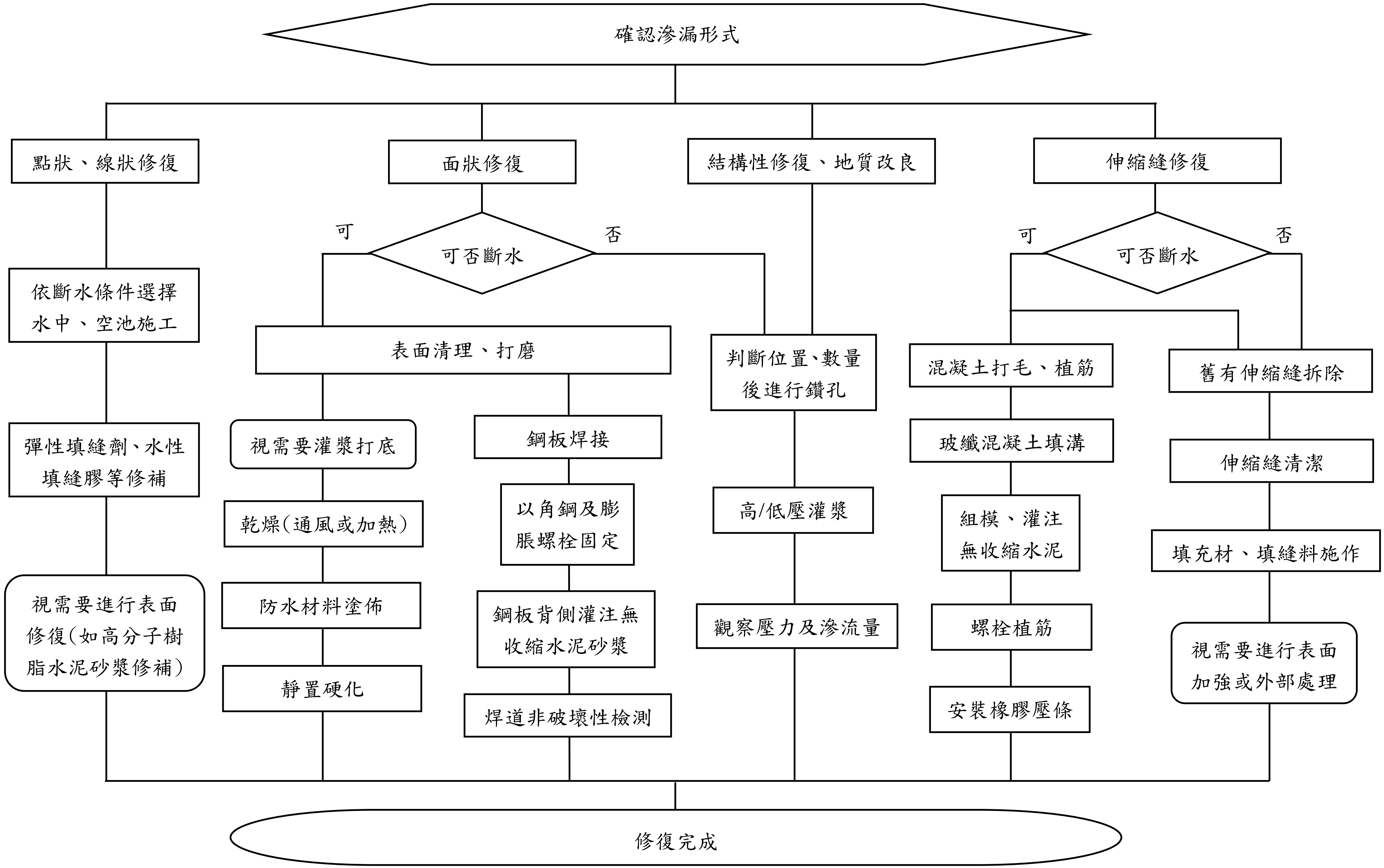
表 5-3 裂縫(伸縮縫)修復類彙整表

處理部位	材料種類
填充材	PE 棒、防水泡棉、膨脹橡膠條
填縫劑	環氧樹脂、聚氨脂(PU)填縫劑
表面加強	FRP、不織布、彈性橡膠止水條、不鏽鋼板
外部處理	彈性橡膠止水條、彈性水泥、不鏽鋼板

5.1.3 工法選擇及施工流程圖

依據水池滲漏形式及修復工法適用性，本研究提出水池滲漏修復工程之工法選擇及施工流程圖(圖 5-1)，供使用單位執行修復作業時之簡易工法選擇及施工參考流程。

圖 5-1 水池滲漏修復工法選擇及施工流程圖


確認滲漏形式
點狀、線狀修復
面狀修復
結構性修復、地質改良
伸縮縫修復
可否斷水
可
否
依斷水條件選擇水中、空池施工
彈性填縫劑、水性填縫膠等修補
視需要進行表面修復(如高分子樹脂水泥砂漿修補)
表面清理、打磨
視需要灌漿打底
乾燥(通風或加熱)
防水材料塗佈
靜置硬化
鋼板焊接
以角鋼及膨脹螺栓固定
鋼板背側灌注無收縮水泥砂漿
焊道非破壞性檢測
判斷位置、數量後進行鑽孔
高/低壓灌漿
觀察壓力及滲流量
可否斷水
可
否
混凝土打毛、植筋
玻纖混凝土填溝
組模、灌注無收縮水泥
螺栓植筋
安裝橡膠壓條
舊有伸縮縫拆除
伸縮縫清潔
填充材、填縫料施作
視需要進行表面加強或外部處理
修復完成

5.1.4 修復參考單價

本研究蒐集之案例分布臺灣各地，即便同樣工法因地區性之差異其單價亦不相同。此節僅彙整較常使用之項目，提供簡單化之參考單價如表 5-4。

表 5-4　水池修復項目參考單價表

項目	單位	參考單價(元)
舊有伸縮縫拆除、清理	M	800
裂縫(較小)清理及填縫劑灌注	M	1,550
裂縫(較大)清理與止漏材安裝施工	M	2,500
底面清潔整理	M^2	75
高分子樹酯水泥砂漿局部整平	M^2	500
Polyurea 聚脲材料鋪設	M^2	1,450
牆壁及樓板碳纖維補強	M^2	2,500
ABS 黏著水泥低壓噴射灌漿施工	M^2	1,050
FRP 及無毒環氧樹脂塗料施工	M^2	1,800
免漏素(材料費，不含施工)	M^2	1,400
清水池底泥淤物清理	M^3	600

5.2 建議

5.2.1 建立水池修復歷程資料

水池一旦發生漏水，其日後再發生漏水之機率亦相對較高，本研究建議將每一次維修情形詳實紀錄，除可作為下次發生漏水之處置參考外，亦可作為日後統計分析之資料庫。本研究建議之紀錄表內容如表 5-5：

表 5-5　水池維修紀錄表

水池維修紀錄表

清(配)水池名稱			
容量(M3)		啟用年月	
設計單位		管理單位	
1. 發生漏水日期： 2. 破壞位置(方式)： 3. 破壞原因： 4. 完成修復時間： 5. 修復方式： 6. 施工流程： 7. 工程經費： 8. 修復成效：			
填表人		單位首長	

5.2.2　減少伸縮縫同時便於操作維護

依據美國混凝土學會資料[15]，伸縮縫可提供熱膨脹及作為有效的收縮接頭，惟使用於儲存液體之結構體時，其往往存在長期發生漏水之最大問題(詳附錄七)。因此，對於非常長之結構(通常大於 45 公尺)或於結構及支撐突變之處，始予設置伸縮縫。

台水公司池狀結構伸縮縫常用型式為全斷面隔離式，其功能可因應溫度變化及混凝土收縮，但對水池結構其為產生長期漏水之弱點。為綜合考量結構安全與長期漏水問題，建議水池設計時，其長邊不超過 45 公尺。例如，以 1 萬立方公尺之水池設計而言，則可採用長寬各 45 公尺及水深 5 公尺。

另外，為利後續水池操作維護，及清洗或修漏所需，建議設計為2個以上之獨立水池，再以連通管及繞流管方式串連各水池。如此則水池長度最大應不至於超過45公尺，即可不需設置伸縮縫。

5.2.3 加強伸縮縫施工品質以降低漏水機率

經由台水公司12個案例及北水處之3個案例可知，伸縮縫之漏水常為水池滲漏之主因，除5.2.2所述減少伸縮縫之設置可降低漏水機率外，如仍有設置伸縮縫之必要時，設計階段除應考量常見之剪力鋼棒、止水帶、填縫材料、分池等設置方式，亦可考慮直接採用耐震可撓式接頭(橡膠壓條)施作，以避免啟用後無法停水辦理檢修；施工階段則應確保止水帶及填縫料之材料品質符合規範，止水帶之對接、填縫料施作前之清潔、詩作後之乾燥養護等皆是重點。唯有正確的設計與施做，方能有效降低使用期間漏水之機率。

5.2.4 採購方式建議

目前水池修復契約大都採最低標決標及實作結算方式採購，而修復之內容如裂縫深度、灌漿數量等常於設計階段不易判斷，而修復之材料規格亦不易訂定，機關可就所轄水池修復使用過之材料及承攬廠商進行評鑑，建立優良廠商制度，以利於採購時篩選材料及廠商。採購方式則可採統包方式採購，以最有利標或評分及格最低標辦理決標，採責任施工方式，確保修復品質。如仍採實作結算方式辦理採購，則

可採實際用料方式作為結算依據，並加強監造，確保品質。

5.2.5 未來研究方向

1. 本研究於 4.1 節雖初步整理出修復材料之性質，然對該些材料造成飲用水之影響等相關衛生試驗仍偏簡易，加以各材料之特性、規範、檢驗機制及使用限制等範疇廣大，未來可專篇進行研究。
2. 本研究以國內案例、規範為主，輔以參考美國水工協會及國家標準，在研究過程中雖有接觸部份日本資料，礙於語言較難即時理解並納入研究，未來擴大研究規模可增加國外相關案例、新工法及規範等。
3. 關於水池修復之預算單價及施工規範，因各地區水池條件與修復需求不一，難以一體適用，未來如案例蒐集量大，或可歸納出一通用範本，供全國各地區採用。

誌謝

本研究計畫得以順利完成，首先感謝台水公司四區處、七區處、九區處及十一區處提供相關水池修復工程之資料，並於研究期間熱心接受各項相關諮詢。另亦感謝湘溢海洋工程行及宏都企業有限公司接受訪談，並熱心提供相關施工影片、材料模型及檢驗報告等，讓本報告增添相當實用資訊可參考。

感謝臺北自來水事業處於百忙之中仍撥冗協助辦理交流訪談及工地參觀，並提供相關水池修復背景資料、施工照片及圖說等，雙方藉由簡報及意見交流，提供本報告許多實用之工法內容，豐富本研究之素材。

感謝黎明工程顧問公司、臺北自來水事業處范川江副總工程司、國家地震工程研究中心劉季宇博士、台水公司退休人員劉廷政副總工程師、台水公司第四區管理處張民岦主任等於專家學者會議及訪談時，提供本案之研究方向，讓本研究可順利圓滿完成。

最後感謝各位委員提供專業意見及細心指正，讓本研究計畫內容更臻完善，謹此敬致萬分謝意。

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期中報告審查委員意見及回覆

委員審查意見	意見回覆
史午康委員	
1. 如何有效傳承，自動隨案例經驗 update，來豐富化規範/教材、提升人員專業能力，有效發揮於關鍵時空，作預防式維護管理？如何建立成長/擴散機制？讓專業有效成長、傳承--專業文化型塑。	本研究做為一開端，彙整各修復工法並於第五章提出建議表單，建立水池修復歷程資料，如人力允許可設置一專屬網站平台，隨時間累積成為大數據資料庫，提供使用者檢索、參考。
2. 建立手冊/指引，讓用戶之水池水塔維護參用？	本報告蒐集 15 個水池修復案例，現階段尚不足以整理出通用之手冊/指引，未來可以此為目標持續進行。
3. 「無毒類材質」之保證機制--出廠/產品安全之客觀性機制，如：德國 UBA、美 NSF、日本？CNS？	4.2 節已補充美國相關建議及標準，然本研究初步以施工案例及修復工法為主軸，至於無毒材料之特性、規範及檢驗機制等範疇廣大，可於未來專篇進行研究。
4. P.37 如何防止劣幣逐良幣？考量對廠商施作績效逐案評鑑並於以回饋，形成成長進步之正面循環(與廠商研商評鑑機制)	可建立優良廠商名單，採準用最有利標或取最有利標精神方式辦理招標。本報告並於 3.2 節水池基本資料中補充檢驗方式供參。
5. 如何將研究結果作完整架構及層次性呈現？	本研究之成果已補充於第五章，包含前面各章節之重點結論與往後設計、工法選擇之建議等。
李丁來委員	
1. 參考文獻之備註方式，請參考一般文獻引用格式處理。	已修正參考文獻之備註方式
2. 水池滲漏之根因建議予以探究(目前資料可能是廠(所)所填)，並對於未來如何從規設及施工上予以防範予以探究。	因大部分水池年代久遠，滲漏之根因較難以現況進行探究，然本研究 3.5.2 節新增過去之設計範本，並於 3.6 節邀請經驗較為豐

	富之設計人員及顧問公司進行訪談，從設計端給予寶貴意見。
3. 請補充各種修補案例之施工規範及預算編列供各單位參考。	本研究之案例因各地區水池客觀條件不一，致施工規範甚有差距，如未來持續研究可將同一工法之規範彙整出通用版本，對往後施工人員參採較有幫助。另5.1.4節已補充修復參考單價。
4. 請增列美國水協會(AWWA)或日本水道協會(JWWA)對水池規設及修補之規範供參。	針對水池修復並未尋獲專門之規範。另於4.2節已補充與本研究相關之AWWA建議及國家標準。
吳振榮委員	
1. 水池滲漏修復案例調查與廠商訪談不應只限於台水公司部分，後續研究將涵括北水處水池之滲漏修復案例調查及其廠商訪談。	本報告於3.4節新增北水處訪談資料及修復案例，後續邀請其顧問公司參與專家學者會議給予寶貴意見，並補充於3.5節。
2. 本研究已調查分析水池滲漏成因，後續將回饋補充水池施工時應注意事項，以減少施工因素導致水池滲漏；另外針對滲漏型式將建議適當修復工法與其施工流程。	本研究於3.5、3.6節補充設計端易失敗之情形，施工時可作為參考。另於5.1.3節提出工法選擇及施工參考流程。
3. 資料補充及文字修正： (1) 本公司、全公司改為台水公司；另文獻呈現方式再做修正。 (2) 修復材料材質規格、優缺點、計價及國內外修補參考規範再做補充。 (3) 修復圖片範例整理。	(1) 已修正完成。 (2) 相關資料分別補充於4.1、4.2、4.3、5.1.2、5.1.3、5.1.4節。 (3) 各案例已挑選較為清晰之照片，並配合施工流程放置。
林財富委員	
1. 現有收集的12處案例，建議能作資料彙整與分析，制表分類說明包括水池特性、裂縫特性、施工特性(方法、期程)、	已於3.2節水池基本資料中補充水池形狀、水位高、檢驗方式及修復成效，並於5.1.2節比較各工法優缺點、5.1.4節提出修復參考

成效(如持續時間)及成本等，以供後續類似案件選擇參考。	單價。
2. 建議能收集國際新的工法，如研討會、展覽會或國際期刊，以了解國際發展趨勢。	本研究初步以國內案例為主，期能彙整出修復工法、優缺點及單價以利維護人員參採，未來如持續研究可擴大蒐集國外案例，並納入材料規格、檢驗規範等範疇。
3. 就現有發生滲漏的水池案例，可否分析其最可能的原因類型？以供後續施工注意及查核要點。	以本研究之案例而言，外力(地震)及材料老化為最主要之滲漏原因，惟若不是在第一時間察覺滲漏，隨時間推移將難以進行根因判斷，故 3.5.2 及 5.2.1 節建議應定期巡查，並做成修復歷程資料。
陳立儒委員	
1. 建議加強各工法工作前處理需求探討，及施作上應預先注意事項。	已於 3.2 節水池基本資料中補充施工注意事項，5.1.3 節流程圖加強施工流程及重新分類工法選擇，協助修復人員進行判斷。
2. 建議探討所用各項樹脂或材料之規範需求。	已於 4.1 節補充相關材料之規定。
陳曼莉委員	
1. 本研究對水池滲漏修復工法及原因做了探討，對自來水從業人員具相當參考價值。	感謝委員指教。
2. 研究所得到之各項結論應能回饋到水池初設時之設計及施工等相關規範。例如：無法停水施工部分，是否可建議在水池設計時，採雙系統或設置隔板；如何選擇適當工法、工序，避免造成水池滲漏等。	本報告邀請經驗較為豐富之設計人員及顧問公司進行訪談，從設計端給予寶貴意見，並補充於 3.5、3.6 節。

期末報告審查委員意見及回覆

委員審查意見	意見回覆
史午康委員	
1. 水池漏水評估診斷，除例行性檢查、維修記錄外，建議增列水量(進出量差異)、操作管理面相關資料。	委員意見增列於 3.5.2　第 6 項說明。
2. 建請考量減化材料品質之把關方式：修復材料屬國內製造者，以溶出試驗規範(CNS)把關，進口材料則建議以國際規範把關，如：NSF/ANS 61 產品，以簡化作業。	第四章修復材料，如環氧樹脂部分本報告已羅列 CNS13273 部分之溶出試驗供參，而如聚脲樹酯則因 CNS 無對應之標準可供參。本報告參考葉宣顯委員意見增列 4.3 英國飲用水稽查處(DWI)制定「List of approved products for use in public water supply in the United Kingdom」內所審定之可用修復材料供使用之依據。
3. 建請藉此案建立"工程技術自動成長機制"，除在工程作業流程從設計/施工/驗收回饋/維護皆完整記錄外，藉工程驗收及實際操作運轉後，針對設計、施工作有利日後精進之「有效回饋」，即不僅是驗收合格而已，而是能促使相關設計/施工規範或相關技術有所 update/revise。	遵照辦理。
4. 除設法透明化優良廠商，建請亦設法透明化優良材料；另為利使用優良材料，減少廠商工程經費預估不足之風險，工程計價方式，可以材料實際「用料量」取代以「M」(長度)計價。	機關可就所轄使用修復之材料及承攬廠商進行評鑑，建立優良廠商制度，或採統包方式採購採責任施工，確保修復品質。如採實作結算，則可參採委員意見，以實際用料作為結算依據，本項增列於 5.2.4 採購方式建議。
林財富委員	
1. 如期中報告提亦，請彙整一張	謝謝指導，增列彙整表如表 3-13。

案例分析表，說明案例整體特性，使讀者能更清楚掌握水池特性、裂縫原因與位置，後續施工方法與期程及經費等，以發揮更大功效。	
2. 由所收集 12 案例及北水處資料可明顯看出，伸縮縫的確是漏水主因，12 案中有 7 件有此問題，建議彙整納入結論中，與 76 頁中結論一併討論。	謝謝指導，委員意見增列於 5.2.3 加強伸縮縫施工品質以降低漏水機率內說明。
洪世政委員	
1. 簡報 66 頁對於使用的防水材料 AWWA 建議有做必要之定性分析，項目很多，如環氧樹脂塗層分析項目包含很多塑化劑。反觀我們的 CNS 與之相較似乎相差甚多，因此建議是否能兩相比較列表，可朝建議未來 CNS 策進作為有哪些。	CNS 對於修復材料之著墨確實很少，如聚脲樹脂無對應之標準可參。本項建議可朝葉宣顯委員意見，參考英國飲用水稽查處 (DWI) 制定「List of approved products for use in public water supply in the United Kingdom」內所審定之可用修復材料供使用之依據，並於適當時機向 CNS 反映。
陳曼莉委員	
1. 建議將本研究中之各種發現依設計、施工、日常維護及滲漏修復等不同階段，分別提出結論及建議。	謝謝委員指導，本研究結論與建議已針對水池結構設計面問題、伸縮縫設計及施工應注意問題、修復工法選擇等分述說明，並於結論與建議起始段增列說明。
2. 所使用各種材料之使用時機及對水質之影響，建議專節處理及說明。	本研究初步已彙整所調查案例使用之材料及對應之工法，因 CNS 目前對於修復材料之著墨甚少，其對水質之影響，尚難深入探討。建議未來如持續研究，可再擴大蒐集國外案例與規範，並進行相關試驗等，以確認其對水質之影響性。本項已於 5.2.5 未來研究方向說明。

3. 期中報告意見及回復中，有些章節在報告本文中未出現，是否誤植，請再確認。	已辦理確認及修正。
葉宣顯委員	
1. 修復材料部分提供另一英語系國家之資料供參考：英國 Drinking Water Inspectorate "List of Approved Products for use in Public Water Supply."	已增列於 4.3 及附錄六供參。
2. 定稿報告請補充圖、表目錄。	遵照辦理，已增列圖、表目錄。
3. P.61&62 試驗報告請補充完整資料。	遵照辦理，並依駱委員意見移至附錄三及四。
4. 表儘量避免切成二頁，如 PP.17&18、PP.58&59 等。	遵照辦理。
駱尚廉委員	
1. 1-2 節「預期成果」請改為「計畫內容與進度」。	遵照辦理，修正為 1.2 計畫目標及預期成果及 1.3 預定進度。
2. 「混合池」建議改為「混和池」。	謝謝指導，已辦理修正。
3. 英文縮寫，在第一次出現時，請附上英文全名。	謝謝指導，已辦理修正。
4. 訪談照片請附上日期。	謝謝指導，已辦理修正。
5. 試驗報告請放在附錄。	謝謝指導，已辦理修正。
6. 防漏塗料是否會影響水質?檢驗標準為何?	因 CNS 目前對於修復材料之著墨甚少，其對水質影響之檢驗標準尚難訂定，本報告參考葉宣顯委員意見增列 4.3 英國飲用水稽查處(DWI)制定「List of approved products for use in public water supply in the United Kingdom」內所審定之可用修復材料供使用之依據，建議未來如持續研究，可再擴大蒐集國外案例與規範，並進行相關試驗等，以確認其對水質之影響性急合適之檢驗標準。

附錄一

CNS-4938-K2089「環氧樹脂漆」

中華民國國家標準 CNS 總號 4938 類號 K2089

環氧樹脂漆

Epoxy Resin Paint

1. 適用範圍：本標準適用於環氧樹脂漆。

備註：環氧樹脂漆主要用於橋樑、鋼管、鑄鐵管、船舶外板、船舶內部貯槽、油槽、鋼板、工廠設施、海上或海邊構造物等受海水、淡水、高濕度等影響引起腐蝕，故為長期間確實防護上述材料而作厚塗塗裝（可作刷塗、噴塗）之塗料，係以環氧樹脂，聚醯胺系或多胺系硬化劑、顏料、溶劑為主要原料，配成主劑與硬化劑分裝成二液型反應型塗料，惟有著色目的於使用時亦有混合銀漿等顏料。

2. 種　類：環氧樹脂漆，依品質分為四種。

第 1 種：底漆（配合紅丹、鋅鉻黃等防銹顏料）。

第 2 種：面漆（配合耐酸鹼等之顏料）。

第 3 種：透明（供化學品貯槽或油槽內壁之防蝕用）。

第 4 種：鋁粉漆（配合銀漿供著色用）。

3. 品　質：本品之品質須符合下表之規定。

表

種類／項目	第一種	第二種	第三種	第四種
容器內狀態	主劑、硬化劑，攪拌時無堅硬結塊且均勻			
研磨細度（μm）	—	30 以下	—	—
混合性	能均勻混合			
作業性	無礙於刷塗或噴塗作業			
乾燥時間（h）	10 以內（半堅結）			
塗膜外觀	塗膜外觀需正常			
混合後可使用時間（h）	8 以上		3 以上	
耐屈曲性	應無龜裂、剝離等現象			
耐衝擊性	應無龜裂、剝離等現象			
耐鹼性（註 1）	—	應無膨脹、龜裂、剝離等現象。	應無膨脹、龜裂、剝離等現象。	—
耐酸性（註 1）	—	應無膨脹、龜裂、剝離等現象。	應無膨脹、龜裂、剝離等現象。	—
耐揮發油性	應無剝離、起泡、起縐、軟化現象。			
鹽水噴霧試驗	應無生銹、起泡、剝離等現象。			
耐濕性	應無膨脹、剝離、生銹等現象。			
混合漆中加熱殘分%	60以上	55以上	50以上	—
環氧樹脂之定性	含有環氧樹脂			

註 1：含鋁顏料時因其塗膜不能用於與藥品類直接接觸之處，故不作耐鹼性及耐酸性試驗。

備註：若明顯地說明使用刷塗時，則用刷塗作試驗。

第一次修訂：72 年 6 月 13 日
第二次修訂：75 年 5 月 14 日
（共 2 頁）

公布日期 68 年 7 月 23 日　經濟部標準檢驗局印行　修訂日期 76 年 5 月 21 日
印行日期94年10月

甲4（210×297）

4. 標　　示：於環氧樹脂漆之容器上須標示下列事項。

(1) 種類或名稱。

(2) 製造廠商稱或代號

(3) 製造日期或代號。

(4) 混合方法（詳細情形亦可記載於其他紙張上）。

(5) 安全注意事項。

5. 檢　　驗：依 CNS 8012〔環氧樹脂漆檢驗法〕。

引用標準：CNS 8012 環氧樹脂漆檢驗法

附錄二

CNS-13273-G3254

「延性鑄鐵管及管件內面用環氧樹脂粉體塗裝」

ICS 77.140.75；77.140.80

中華民國國家標準 CNS	延性鑄鐵管及管件內面用環氧樹脂粉體塗裝	總號	13273
		類號	G3254

延性鑄鐵管及管件內面用環氧樹脂粉體塗裝

Epoxy-powder coating for interior of ductile iron pipes and fittings

1. 適用範圍：本標準適用於延性鑄鐵管(1)(以下簡稱管)內面所形成之環氧樹脂粉體塗膜(以下簡稱塗膜)及其塗裝方法。

   註(1) 延性鑄鐵係指延性鑄鐵管及延性鑄鐵管件。

2. 塗料：須符合第 2.1 節之成分及第 2.2 節之規定。不含使用上有害之成分，硬化後不溶於水，且不得使水質有不良影響。

   2.1 成分：使用環氧樹脂、硬化劑及顏料爲主原料之熱固性粉體塗料。

   2.2 品質：如表 1 所示。

表 1　塗料品質

項目	品質	試驗方法
塗膜比重	1.8 以下。	第 5.4.1 節
塗膜附著性	評估點數 8 以上。	第 5.4.2 節
塗膜耐衝擊性	衝擊變形後無龜裂及剝離。	第 5.4.3 節
塗膜可撓性	無龜裂發生。	第 5.4.4 節
塗膜刮痕抵抗性	無異常。	第 5.4.5 節
塗膜防蝕性	無銹污、起泡、膨脹、龜裂等現象。	第 5.4.6 節
塗膜耐溫度反覆性	無發生皺紋、龜裂、膨脹、剝離及無顯著變色。	第 5.4.7 節
塗膜溶出性(2)	濁度：0.5 度以下 色度：1 度以下 過錳酸鉀消耗量：2mg/L 以下 餘氯減量：0.7ppm 以下 酚類：0.005mg/L 以下 胺：無檢出 氰：無檢出 臭味及味道：無異常	第 5.4.8 節

註(2) 塗膜之溶出性僅適用於自來水管。

確認日期：101 年 10 月

(共 16 頁)

公布日期 82 年 10 月 26 日

經濟部標準檢驗局印行

修訂公布日期 92 年 11 月 18 日

印行年月 94 年 10 月

3. 產品之塗膜品質：依表 2 之規定。

表 2 產品之塗膜品質

項目	品質	試驗方法
塗膜外觀	無異物掺入，塗布不勻，漏塗現象，須表面平滑呈均勻塗膜。 以偵檢器測試，不會有發生火花的針孔等缺陷。	第 6.2 節
塗膜附著性	無剝離。	第 6.3 節
塗膜之硬化程度	無發生破碎，剝離現象。	第 6.4 節
塗膜厚度	如附圖所示，B 部位須 0.3mm 以上。 惟 CNS 10808〔延性鑄鐵管〕 及 CNS 13272〔延性鑄鐵管件〕 之塗裝後 D_3 之尺度，須在容許範圍內。	第 6.5 節
塗膜刮痕抵抗性	須符合表 1 之規定。	第 6.6 節

4. 塗裝方法

4.1 塗裝面前處理

(1)將鑄疤、銹皮及其他有礙塗裝之附著物等，使用研磨機、打磨機等除去，盡可能磨成平滑。

(2)經前處理之鑄鐵面，在施塗之前應妥善保護不得再生銹或沾附灰塵、油污等。

4.2 塗料調配

塗料應依塗料製造廠商所指定之有效期間內使用之。回收之塗料須使用 150～220μm 網篩除去異物後，以新塗料容積之 50%以內比例混合均勻即可使用。

4.3 塗裝

(1)以適當之粉體塗裝裝置，將塗料噴塗於預熱之管而形成塗膜。預熱溫度依塗料製造廠商之指定。經塗裝之管，塗膜須充分硬化。

(2)塗裝時應避免異物掺入、塗布不均，針孔及漏塗等缺陷，必須使塗膜表面平滑均勻。

4.4 塗裝範圍：依附圖所示。

4.5 塗裝修補：依第 6 節試驗結果，若有不符合第 3 節所規定之輕微缺陷，經買方同意得使用常溫硬化型環氧樹脂塗料由塗裝業者施予修補。直管時，使用研磨機、打磨機等研磨塗裝面後，依第 4.3 節規定重複塗裝修補之。

5. 塗料之試驗

5.1 試驗之一般條件：係依 CNS 9007〔塗料一般檢驗法－取樣及試驗一般條件〕第 3 節之規定。試驗須由塗料製造業者經試驗後提出試驗報告給塗裝業者。若買方認為有必要時，可由買方會同試驗，並要求提出該試驗報告。

5.2 塗料之取樣法：每批依 CNS 9007 第 2 節之規定採取試樣。

5.3 塗裝試片之製作。

5.3.1 各試驗項目之試片材料、尺度及數量：依表 3 之規定。

表 3 各試驗項目之試片材料、尺度及數量

試驗項目	試片材料	試片尺度 mm	數量	批之大小
方格試驗	鋼板	150×70×2.0	3	製造批
衝擊變形試驗			3	
鉛筆刮痕試驗			1	
鹽水噴霧試驗			3	相同塗料於 6 個月內製造批
低溫高溫反覆試驗			2	
艾氏凹壓試驗		90×90×1.2	1	製造批
溶出試驗	管	標稱管徑 75×500	1	相同塗料於 6 個月內製造批

5.3.2 試片之製作

(1) 鋼板：使用表 3 所規定之鋼板，並依第 4.3 節之規定，塗裝約 0.2mm 膜厚後放冷至常溫。

(2) 管：使用表 3 所規定之管，並依第 4.3 節將內面塗裝約 0.3mm 膜厚後放冷至常溫。

5.4 試驗方法

5.4.1 塗膜比重試驗：依 CNS 10352〔顏料檢驗法〕第 17 節之規定試驗之。

5.4.2 方格試驗：依 CNS 10757〔塗料一般檢驗法(有關塗膜之物理、化學特性之試驗法)〕第 6 節之規定試驗之。

5.4.3 衝擊變形試驗：依 CNS 10757 第 4 節 B 法之規定試驗之。但落下高度爲 50cm。

5.4.4 艾氏凹壓試驗：CNS 3464〔艾氏凹壓試驗法〕中 A 法之規定試驗之。但衝頭壓下距離爲 3mm。

5.4.5 鉛筆刮痕試驗：依 CNS 10757 第 5 節之規定試驗，但使用鉛筆之硬度爲 H 者。

5.4.6 鹽水噴霧試驗：依 CNS 11607〔塗料一般檢驗法(有關塗膜之長期耐久性之試驗法)〕第 3 節之規定試驗，於 500 小時後以目視確認塗膜無發生銹污、膨脹、龜裂等缺陷。但塗膜不作刮痕。

5.4.7 低溫高溫反覆試驗：經下列操作後，以目視檢查二個試片之塗膜狀況。首先將試片置於保持溫度 20±1℃ 之恆溫箱經 2 小時後，移入保持溫度-30±1℃ 之恆溫箱經 2 小時後，再移入保持溫度 20±1℃ 之恆溫箱經 1 小時後，接著置於保持溫度 70±1℃ 之恆溫箱經 2 小時後，再度移入保持溫度 20±1℃ 之恆溫箱經 17 小時。以上爲 1 循環共反覆操作 4 循環。

5.4.8 溶出試驗：以聚偏二氯乙烯(polyvinylidene chloride)薄膜([3])包裹的良質橡皮塞封住試片之一底端，以自來水流水洗淨 1 小時後倒空並以供試水清洗，再注滿供試水，上面以聚偏二氯乙烯薄膜覆蓋，靜置於常溫陰暗處經 24 小時後，以此水作爲試樣水。

同時將供試水盛滿於 2L 之燒杯，以聚偏二氯乙烯薄膜覆蓋，並靜置於試樣水同一地點經 24 小時後當作空白試驗水。供試水之調製方法及試驗方法依附錄之規定。其試驗溫度爲常溫，而表 1 所示數值等係由與空白試驗之差數求得。

註([3]) 所使用的聚偏二氯乙烯(PVDC)薄膜須預先以 5%硝酸洗過後再充分水洗。

6. 產品之塗膜試驗

6.1 試驗一般條件

(1)塗膜試驗範圍，如附圖所示。

(2)試驗係由塗裝業者及買方實施。除了硬化試驗外，試驗數量爲全數。

6.2 外觀試驗

(1)以目視檢查是否摻雜異物、塗布不勻、漏塗等現象。

(2)針孔係用針孔偵測器(Holiday Detector)施加 1000 V 電壓測試。

6.3 附著性試驗：使用試驗錘輕敲塗裝面測試。

6.4 硬化試驗：承口內面或標稱管徑 150mm 以下之管，於外面特定部位塗裝的塗膜上，使用 CNS 10756-1〔塗料一般檢驗法(有關塗膜之視覺特性之試驗法)〕第 3 節所規定之美工刀，刻劃長度 25mm 而交叉 30 度的兩條達底材的〝X〞刻痕，並以目視檢查塗膜有無碎落、剝離現象。

此時之試驗數量，係將一日之塗裝管中同一標稱管徑時每 10 個及其餘數爲一組，由各組任取一個。又試驗後〝X〞刻痕部位，應使用與外塗裝相同之塗料修補。

6.5 塗膜厚度測定

(1)使用電磁微厚計或其他適當的測定器具測定之。測定部位爲對長方向任選二處，而在該處圓周上之任選四點。

(2)承口內徑尺度係使用最小界限規等測定之。

6.6 鉛筆刮痕試驗：依第 5.4.5 節之方法試驗。

7. 再試驗：若有經過第 4.5 節之塗裝修補時，須依第 6 節之規定再作試驗。

8. 檢驗

8.1 塗料之檢驗：依第 5 節之規定檢驗，塗膜比重、塗膜附著性、塗膜耐衝擊性、塗膜可撓性、塗膜刮痕抵抗性、塗膜防蝕性、塗膜耐溫度反覆性及塗膜之溶出性等均應符合第 2 節之規定。

8.2 產品之塗膜檢驗：依第 6 及第 7 節之規定檢驗，產品之塗膜外觀、塗膜附著性、塗膜之硬化程度、塗膜厚度及刮痕抵抗性等均應符合第 3 節之規定。

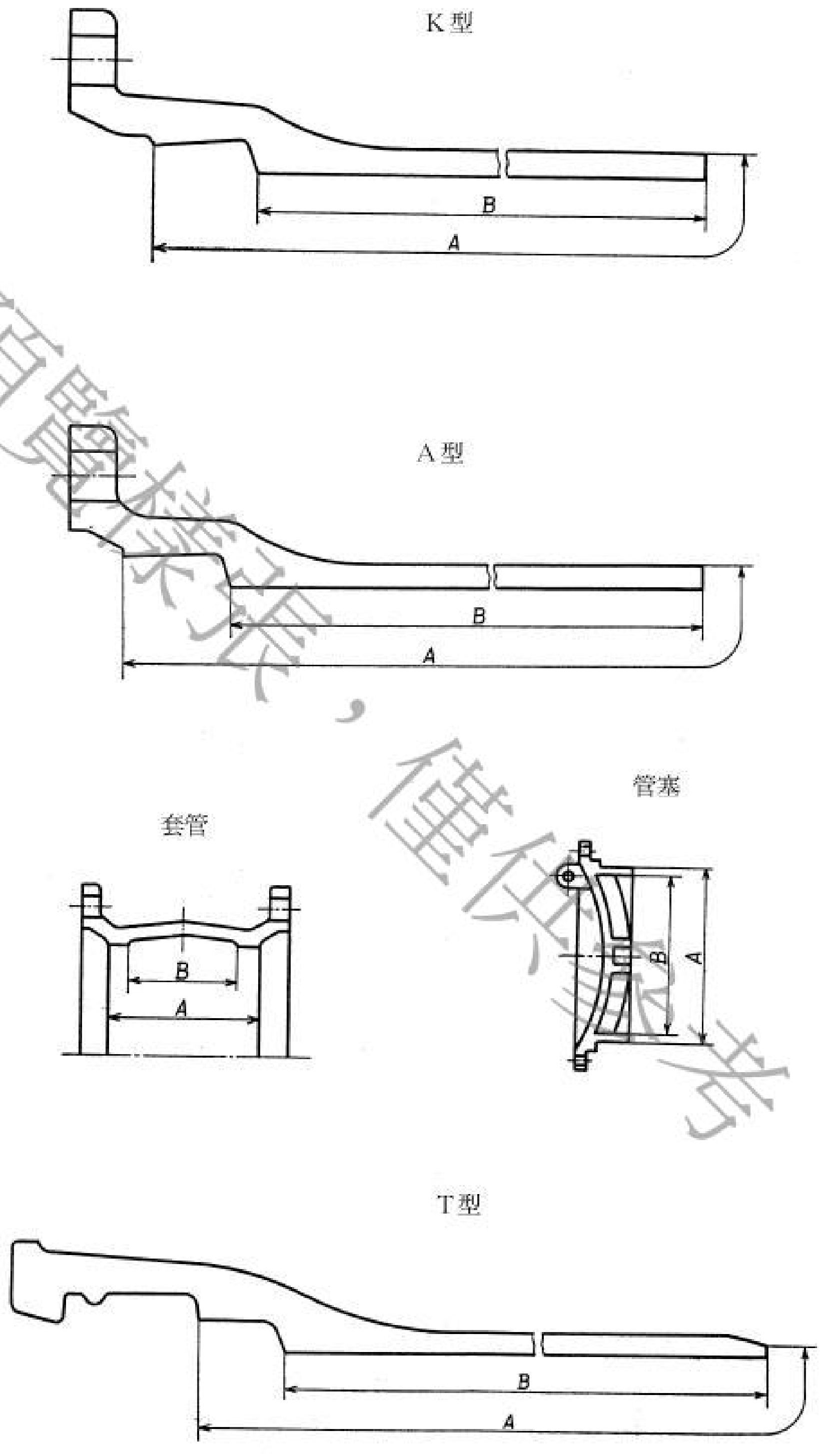
9. 標示：於產品之承口內面易見部位，以不易消失之方法標示下列事項。

(1) 塗裝年月或代號。

(2) 塗裝業者名稱或其商標。

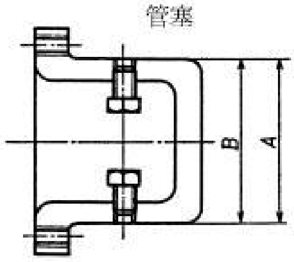
10. 塗裝面之保護：經檢驗合格之產品，須在承口或插口部位加蓋適當護蓋以保護塗裝面。

附圖　塗裝及塗膜之試驗範圍

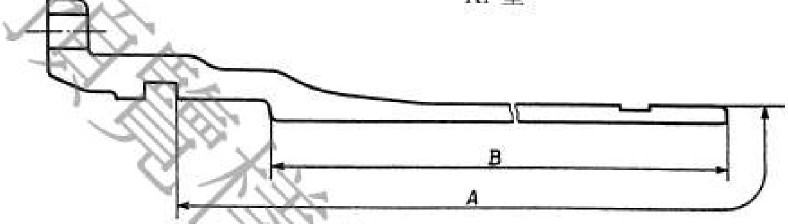


附圖　塗裝及塗膜之試驗範圍(續)

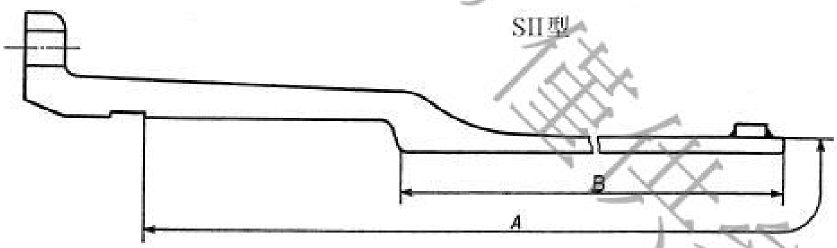
管塞



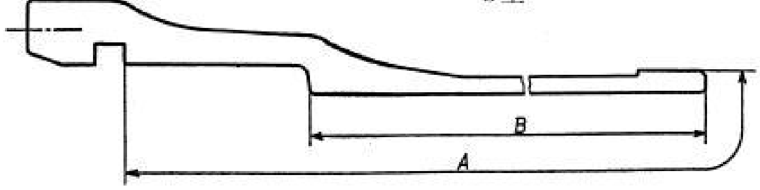
KF型



SII型

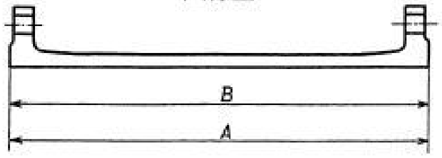


S型



附圖　塗裝及塗膜之試驗範圍(續)

凸緣型



備考 1. 塗裝範圍：A 部位。

2. 塗膜試驗範圍：B 部位。

3. A 範圍中 B 範圍以外部位，原則上再施予與外面塗裝相同之塗裝。

附錄 延性鑄鐵管及管件內面用環氧樹脂粉體塗料之溶出試驗方法

1. 供試水之調製方法

1.1 試藥

1.1.1 石灰水：取約 100 分精製水於適當的容器內，加入 2 分消石灰後密栓充分振搖，然後靜置 24 小時，使用濾紙(JIJ F)過濾上澄水，放入預先盛約 100 分精製水的容器內，密封貯存，作爲石灰水。若產生上層膜或沈澱時須過濾。

此石灰水中之鈣定量，係取約 100mL 精製水於 300mL 錐形燒瓶，添加 1mL 約 0.1%氯化鎂($MgCl_2$)溶液，並加入 2mL 氨緩衝液及 5～6 滴 EBT 指示劑後，滴加 0.1M EDTA 溶液至溶液呈藍色（注意不過量滴加）。

接著準確添加 1mL 石灰水於此溶液中，而呈酒紅色的溶液 0.01M EDTA 溶液滴定，求出所需 EDTA 溶液量（a，單位 mL），依下式算出石灰水之鈣濃度(ppm)。

$$石灰水中之鈣(Ca\ ppm)=a\times\frac{40}{100}\times100$$

1.1.2 精製水：蒸餾水或通過離子交換樹脂層之脫鹽水，導電率爲 3μS/cm 以下者。

1.1.3 氨緩衝液：取 67.5g 氯化銨（NH_4Cl）於燒杯，溶解於約 300mL 精製水後，加入 570mL 氨水(28%)再用精製水配成 1L。

1.1.4 EBT 指示劑：取 0.5g 毛染鉻黑 T (Eriochrome Black T)及 4.5g 氫氯化胺(Hydroxylamine Hydrochloride)溶於 100mL，95%乙醇，保存於色瓶中（約一個月內有效）。

1.1.5 0.01M EDTA 溶液：取 4g 伸乙二胺四乙酸二鈉鹽(Ethylenediamine tetraacetic acid，$C_{10}H_{14}N_2O_8Na_2 \cdot 2H_2O$)溶於精製水配成 1L。

本溶液濃度因屬滴定法，係準確量取 25mL 之 0.01M 氯化鋅溶液於 300mL 錐形燒瓶，添加約 75mL 精製水、2mL 氨緩衝液及 5～6 滴 EBT 指示劑後，使用待測 EDTA 溶液滴定至葡萄酒紅色變爲藍色，而求出所需 EDTA 溶液量（a，單位 mL），以下式算出濃度因素。

$$EDTA 溶液濃度因素(F)=\frac{25}{a}$$

接著取上述 EDTA 溶液 $\frac{1000}{F}$mL 於 1L 量瓶，加精製水配成 1L。

1.1.6 0.01M 氯化鋅溶液：標準試藥鋅(Zn)預先依序用氫氯酸(1+3)、精製水、丙酮洗淨，隨即放置於氯化鈣或硫酸乾器燥中，經乾燥 24 小時後秤取 0.654g 於燒杯，加入約 20mL 精製水及 3mL 之 35%氫氯酸，置於水浴上加溫溶解之。

冷卻後移入 1L 量瓶，並用精製水充分洗淨燒杯，洗液一併加入量瓶後，添加精製水配成 1L。

1.2 供試水調製法：精製水中添加石灰水使用鈣含量 12ppm（硬度 30ppm），將二氧化碳氣體通入此液中調整 pH 爲 7.5～8.0，此中加入氯後靜置經 12～24 小時，使含游離餘氯爲 1.0～1.2 ppm。

接著取此溶液之一部分（1/5～1/10)於別的容器，通入二氧化碳氣體作成低 pH 值溶液，將此液徐緩小量添加於原溶液中調整 pH 爲 7.0±0.2，而將此溶液作爲供試水。

2. 試驗方法

2.1 濁度：濁度係表示水之混濁程度，1L 水中含 1mg 高嶺土(Kaolin)時之混濁度爲 1 度。

2.2 試藥及器具

(1)濁度用高嶺土：取約 10g 市售高嶺土於 500mL 燒杯，加入 300mL 精製水、0.2g(a)焦磷酸鈉($Na_4P_2O_7 \cdot 10H_2O$)，使用攪拌器等激烈攪拌 3 分鐘。然後移入 1L 共栓量瓶，並用精製水充分洗淨燒杯，洗液一併加入量瓶後，添加精製水配成 1L，振搖 1 分鐘混合分散之。

於常溫靜置 1 小時後，利用虹吸管捨棄表面起 250mL 之溶液，取下層 500mL(b)於質量已知之蒸發皿。採取的溶液置於水浴上蒸發乾涸，再於 105～110℃乾燥約 3 小時，移入乾燥器中放冷後秤量求出濁度用高嶺土之質量(c)。然後用瑪瑙研缽研磨微粉碎後貯存於廣口瓶中。

由此調配所得之純高嶺土質量(d)爲

$$d = c - (a \times \frac{b}{1000} \times \frac{141.959 \times 2}{446.057})$$

因而若要秤取 1g 純高嶺土，即可取濁度用高嶺土 $\frac{c}{d}$g。

(2)濁度標準原液：取濁度用高嶺土 $\frac{c}{d}$g於 1L 量瓶，加入 10mL 甲醛液（福馬林）用精製水配成 1L，作爲保存液。

將此保存液邊充分搖混，邊準確量取 100mL 於別的 1L 量瓶、用精製水配至量爲 1L。此液 1mL 含 0.1mg 高嶺土。

(3)試管：全長度約 37cm 底面經研磨的共栓平底無色試管，距管底 30cm 高度處刻劃 100mL 之標線者。

2.3 試驗步驟：分別各取 100mL 試樣水及空白試驗水於個別試管。另一邊充分搖混濁度標準原液，邊取適當量(0.5～10mL)於數支同型試管中，分別加入精製水成爲 100mL，加栓並輕輕搖混作爲標準液。

接著將這些試管置於黑紙上，由上方透視比較試樣水及空白試驗水與標準液之濁度，而求出符合濁度標準原液之量(mL)，依下式算出試樣水之濁度。

$$濁度(度) = (a \times \frac{1000}{S} \times 0.1) - (b \times \frac{1000}{B} \times 0.1)$$

式中，a：符合試樣水濁度之濁度標準原液(mL)

b：符合空白試驗水濁度之濁度標準原液(mL)

S：試樣水(mL)

B：空白試驗水(mL)

3. 色度：色度係表示水之顏色程度者，色度標準原液 1mL 用水配成 1mL 時呈現的顏色爲 1 度。

3.1 試藥及器具。

3.1.1 色度標準原液：取 2.49g 氯鉑化鉀(K_2PtCl_6)（含鉑 1g），2.02g 結晶氯化亞鈷($CoCl_2 \cdot 6H_2O$)（含鈷 0.5g）及 35%氫氯酸 200mL 於 1L 量瓶，溶解於精製水配成 1L。此溶液 1mL 含 1mg 鉑(Pt)。

3.2 試驗步驟：分別各取 100mL 試樣水及空白試驗水於個別試管。另取適量(0.1～1.5mL)色度標準原液於數支同型試管中，分別加入精製水成爲 100mL，加栓並輕輕搖混作爲標準液。

接著將這些試管置於白紙上，由上方透視比較試樣水及空白試驗水與標準液之色相，而求出符合色度標準液之 mL，依下式算出試樣水之色度。

$$色度(度)=(a\times\frac{1000}{S})-(b\times\frac{1000}{B})$$

式中，a：符合試樣水色相之色度標準原液(mL)

b：符合空白試驗水色相之色度標準原液(mL)

S：試樣水(mL)

B：空白試驗水(mL)

4. 過錳酸鉀消耗量

4.1 試藥及器具

(1)稀硫酸：於精製水 2 容積內徐緩攪拌中加入 1 容積 95%硫酸後，於水浴上邊溫熱邊滴加 0.5%過錳酸鉀溶液至微紅色不消失而殘留爲止。

(2)0.01N 草酸鈉溶液：將標準草酸鈉($Na_2C_2O_4$)於 150～200℃乾燥 1～1.5 小時，並於硫酸乾燥器中放冷，秤取 0.670g 於 1L 量瓶，以精製水溶解配成 1L，貯存於褐色瓶中（經過約 1 個月以上者不得使用）。

本溶液 1 mL 相當於 0.316g 過錳酸鉀。

(3)0.01N 過錳酸鉀溶液：取 0.32～0.34g 過錳酸鉀($KMnO_4$)於 2 L 燒杯，加入 1050 mL 精製水徐緩煮沸 1～2 小時後，於陰暗處放冷 1 夜，接著用玻璃過濾器(3G4)濾過上澄液（過濾前後不得水洗），將此濾液放入於預先經蒸氣洗淨 30 分鐘之褐色瓶並保存於陰暗處。此水溶液於每次使用時求濃度因素。此水溶液濃度因屬滴定法，係取 100mL 精製水於 300mL 錐形燒瓶，加入 5mL 稀硫酸，數顆玻璃珠及上述過錳酸鉀溶液準確添加 5mL。接著煮 5 分鐘後熄火，隨即準確添加 10mL 之 0.01N 草酸鈉溶液而脫色後，並繼續滴加過錳酸鉀溶液至液相呈微紅色而殘留不消失爲止。然後於此液中加入 5mL 稀硫酸及 5mL 過錳酸鉀溶液經煮沸 5 分鐘後，依前回同樣準確添加 10mL 之 0.01N 草酸鈉溶液，隨即用過錳酸鉀溶液滴定至稍微殘留微紅色不消失爲止。於第 2 回滴定最初添加之過錳酸鉀溶液 5mL 與滴定所耗過錳酸鉀溶液之合計量（a，單位 mL）求出後，依下式算出濃度因素。

0.01N 過錳酸鉀溶液濃度因素(F)= $\frac{10}{a}$

(4)玻璃珠：直徑約 2mm 之良質玻璃製小珠，首先於 4N 硫酸中煮沸約 30 分鐘後用熱精製水充分洗淨至洗液呈石蕊試紙中性爲止。然後放入 110℃ 烘箱中乾燥後貯存於玻璃瓶中。

(5)潔淨錐形燒瓶(300mL)：預先充分洗滌後，放入 100mL 精製水、5mL 稀硫酸、10mL 之 0.01N 過錳酸鉀溶液及數顆玻璃珠，煮沸約 5 分鐘。隨即加入 10mL 之 0.01N 草酸鈉溶液脫色後，滴加 0.01N 過錳酸鉀溶液至稍微殘留微紅色不消失爲止。然後小心倒掉溶液只留玻璃珠於燒瓶中，隨即供試驗用。

4.2 試驗步驟：取 100mL 試樣水於潔淨錐形燒瓶，加入 5mL 稀硫酸，接著利用褐色滴定管添加 10mL 之 0.01N 過錳酸鉀溶液，置於石棉鐵絲網上（或電熱盤上）煮沸 5 分鐘（煮至沸騰約需 5～7 分鐘）。然後熄火隨即添加 10mL 之 0.01N 草酸鈉溶液脫色，此液中立即滴加 0.01N 過錳酸鉀溶液，滴定至稍微殘留紅色不消失爲止。求出前後所耗用之 0.01N 過錳酸鉀溶液之合計量（a，單位 mL）。另對 100mL 空白試驗水依試樣水同一條件步驟操作後，求出空白試驗水所耗用 0.01N 過錳酸鉀之合計量（b，單位 mL），依下式算出過錳酸鉀消耗量(ppm)。

$$過錳酸鉀消耗量(ppm)= (a-b)F\times\frac{1000}{L}\times0.316$$

式中，a：試樣水 100mL 所耗用 0.01N 過錳酸鉀溶液(mL)

b：空白試驗水 100mL 所耗用 0.01N 過錳酸鉀溶液(mL)

F：0.01N 過錳酸鉀溶液之濃度因素。

L：試樣水及空白試驗水(mL)

5. 餘氯減量

5.1 試藥及器具

(1) O-Tolidine 溶液：取 1.35g 鄰二甲基‧對二氨基聯苯二氫氯酸鹽〔(CH_3‧C_6H_3‧NH_2)$_2$‧2HCℓ〕溶於 800mL 精製水後，添加 35%氫氯酸 150mL，再加精製水配成 1L、貯存於褐色瓶中。

(2)無二氧化碳精製水：如第 6.1(14)節。

(3)緩衝液：預先經 105～110℃ 烘乾後置於乾燥器內放冷的磷酸氫鈉(Na_2HPO_4)秤取 22.86g，及磷酸二氫鉀(KH_2PO_4)秤取 46.14g，溶於無二氧化碳精製水配成 1L，經靜置數日後過濾析出沉澱物，以母液作爲原液。接著於 400mL 原液中加入無二氧化碳精製水配成 2L，此液作爲緩衝液。此緩衝液之 pH 爲 6.45。

(4)鉻酸鉀，重鉻酸鉀溶液：取 4.65g 鉻酸鉀(K_2CrO_4)及 1.55g 重鉻酸鉀($K_2Cr_2O_7$)於 1L 量瓶，溶解於緩衝液配成 1L。此溶液須密栓保存於陰暗處，若產生沉澱物時，使用玻璃過濾器(G3)或濾紙(JIF)過濾。此溶液經過 6 個月以上者不得使用。

(5)餘氯標準比色液：係將鉻酸鉀，重鉻酸鉀溶液依附錄表所規定之比率混合後個別取於 100mL 比色管，並記載表示符合餘氯之濃度(ppm)。

附錄表　餘氯標準比色液（液層 20cm）

餘氯 ppm	鉻酸鉀，重鉻酸鉀溶液 mL	緩衝液
0.1	1.0	99.0
0.2	2.0	98.0
0.3	3.0	97.0
0.4	4.0	96.0
0.5	5.0	95.0
0.6	6.0	94.0
0.7	7.0	93.0
0.8	8.0	92.0
0.9	9.0	91.0
1.0	10.0	90.0
1.2	12.0	88.0
1.3	13.0	87.0
1.5	15.0	85.0
2.0	19.7	80.3

(6)比色管(100mL)：係全長約 25cm 之共栓附平底無色試管，由管底 20±0.3cm 之高度處，刻劃 100mL 之標線者。

5.2 試驗步驟：取 5ml 鄰二甲基‧對二氨基聯苯溶液〔第 5.1(1)節〕於 100mL 比色管，加試樣水至標線（pH 1.3 以下）靜置 5 分鐘。接著將試樣水之呈色與調製於同型比色管的餘氯標準比色液進行比較，而且由符合標準比色液求出試樣之餘氯(ppm)然後同樣操作求出空白試驗水之餘氯(ppm)，而將此餘氯與試樣水之餘氯(ppm)之差數當作餘氯之減量。

6. 酚類：因試樣中之酚類極易分解，因此須於 4 小時以內(1)作試驗。

註(1) 若無法於採樣 4 小時以內進行試驗時，須在取樣後隨即加磷酸溶液調整 pH 爲 4 以下，並以 0.1%比率加入硫酸銅溶液，在 24 小時以內進行試驗。

6.1 試藥及器具

(1)活性炭粉末

(2)精製水：係不含酚類及餘氯者。係於精製水中以 10～20ppm 之比例添加活性炭並充分搖混，靜置 1 夜後過濾之。本試驗全部使用經此調製之精製水。

(3)硫酸銅溶液：將 10g 硫酸銅（$CuSO_4 \cdot 5H_2O$）溶於精製水配成 100mL。

(4)4-氨基安替比林溶液：將 4－氨基安替比林〔4-Aminoantipyrine，〔$CH_3 \cdot C : CH(NH_2)OC \cdot N(C_6H_5) : N(CH_3)$〕〕0.25g 溶於精製水配成 100mL，保存於陰暗處。本溶液之使用期限約爲一星期。

(5)鐵(III)氰化鉀溶液：將 0.5g 鐵(III)氰化鉀〔$K_3Fe(CN)_6$〕溶於精製水配成

100mL。本溶液於每回使用時重新調製。

(6)甲基橙指示劑：將 0.5g 甲基橙($C_{14}H_{14}N_3O_3SNa$)溶於精製水配成 1L，保存於褐色瓶中。

(7)磷酸溶液：將磷酸以精製水稀釋爲 10 倍。

(8)磷酸緩衝液：取 104.5g 磷酸氫二鉀(K_2HPO_4)及 72.3g 磷酸二氫鉀(KH_2PO_4)一起溶解於精製水配成 1L。

(9)酚標準原液：將 1g 酚(C_6H_5OH)溶於精製水配成 1L，移入褐色瓶保存陰暗處，當作酚保存溶液。於試驗時每回由此保存溶液調製酚標準原液。

酚標準原液調製係取 50mL 精製水於 300mL 共栓錐形燒瓶，並準確加入 25mL 酚保存溶液混合後準確加入 25mL 之 0.1N 溴酸溴化鉀溶液蓋栓充分搖動混合。接著添加 3mL 之 35%氫氯酸，再蓋栓充分搖動混合後靜置。經 15 分鐘後加入 2g 碘化鉀(KI)蓋栓搖動 1 分鐘使充分混合。

在此離析的碘以澱粉溶液爲指示劑，用 0.1N 硫代硫酸鈉溶液滴定，求出在此所耗用之硫代硫酸鈉溶液之量(a，單位 mL)。另取 75mL 精製水於錐形燒瓶，與前述同樣準確加入 25mL 之 0.1N 溴酸溴化鉀溶液，3mL 之 35%氫氯酸及 2g 碘化鉀，析出之碘用 0.1N 硫代硫酸鈉溶液滴定，並求出在此所耗用之硫代硫酸鈉溶液之量(b，單位 mL)，依下式算出酚保存溶液 1mL 中酚之量(mg)。

$$X=\frac{(b-a)F\times 1.569}{25}$$

式中，X：酚(ppm)

a：25mL 酚保存溶液所耗用之 0.1N 硫代硫酸鈉溶液(mL)

b：25mL 之 0.1N 溴酸溴化鉀溶液所耗用之 0.1N 硫代硫酸鈉溶液(mL)

F：0.1N 硫代硫酸鈉溶液之濃度因數

準確取 $\frac{10}{X}$mL 酚保存溶液於 1L 褐色量瓶，加入精製水配成 1L，充分混合後，取此液 100mL 於另一個 1L 量瓶，加精製水配成 1L，將此液作爲酚標準原液。

(10)澱粉溶液：取 1g 馬鈴薯澱粉與 100mL 精製水充分混合，將此混合物徐徐添加於一邊攪拌的 200mL 熱精製水中，經煮沸至使溶液成半透明狀後靜置放冷，取用其上澄液。

(11)0.1N 溴酸溴化鉀溶液：秤取預先經 100℃乾燥放冷於硫酸乾燥器之溴酸鉀($KBrO_3$)2.783g 及溴化鉀(KBr)20g 共置於 1L 量瓶內，溶解於精製水配成 1L。

(12)0.1N 硫代硫酸鈉溶液：取 26g 硫代硫酸鈉($Na_2S_2O_3\cdot 5H_2O$)及 0.2g 碳酸鈉(Na_2CO_3)一起溶解於約 1L 無二氧化碳精製水後，添加 10mL 異戊醇[$(CH_3)_2CHCH_2CH_2OH$]使成全量 1L。經充分搖動混合後蓋栓靜置 2 日後，標定濃度因數。

標定濃度因數係準確量取 25mL 之 0.1N 碘酸鉀溶液於 30mL 共栓錐形燒

瓶，加入 2g 碘化鉀(KI)及 5mL 之 6N 硫酸，隨即蓋栓輕輕搖動混合、靜置陰暗處 5 分鐘後，加入 100mL 精製水，將游離之碘以上述硫代硫酸鈉溶液滴定，至溶液顏色由褐色變爲淡黃色即添加澱粉溶液，並滴定至所呈之藍色消失爲止。求出在此所耗用之硫代硫酸鈉溶液之量（a，單位 mL），依下式算出濃度因數。

0.1N 硫代硫酸鈉溶液濃度因數(F)= $\frac{25}{a}$

備考：另依同一條件作空白試驗以修正硫代硫酸鈉溶液之消耗量。

(13) 0.1N 碘酸鉀溶液：預先經 120～140℃ 乾燥 1.5～2 小時後，放冷於硫酸乾燥器之標準試藥碘酸鉀(KIO_3)，秤取 3.567g 放於 1L 量瓶，溶解於精製水配成 1L。

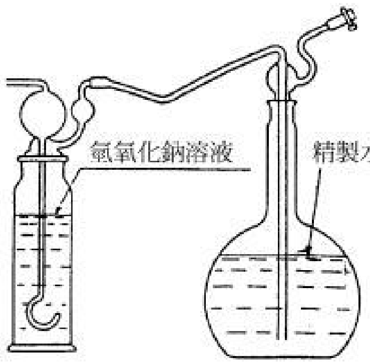
(14) 無二氧化碳精製水：係將再蒸餾精製水經煮沸除去二氧化碳及其他揮發物後，以不使從空氣中吸收二氧化碳狀態放冷至室溫，以如附錄圖 1 所示方法保存之。

(15) 蒸餾裝置：如附錄圖 2 所示者，玻璃製共栓部位爲磨砂共栓，蒸餾瓶內容量爲 300～500mL。

(16) 玻璃珠：如第 4.1(4)節。

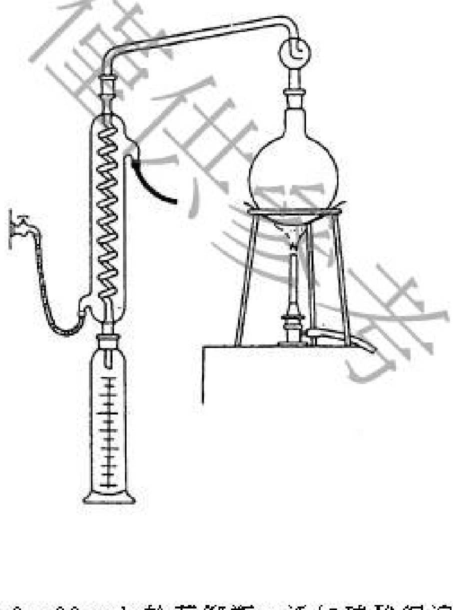
附錄圖 1

無二氧化碳精製水貯存裝置



附錄圖 2

蒸餾裝置



6.2 試驗步驟：取 200mL 供試水（酚含量 0.2～20μg）於蒸餾瓶，添加硫酸銅溶液(7)、數滴甲基橙指示劑及數顆玻璃珠，然後將磷酸溶液加至溶液呈現紅色後，蒸餾之。至餾液到約 180mL 即停止蒸餾，待至蒸餾瓶中之溶液無沸騰後追加 20mL 精製水，再繼續蒸餾出 20mL，使至餾液爲 200mL。

此餾液中添加 10mL 磷酸緩衝液混合後，滴加 10N 氨水調節 pH 爲 9.5(±0.2)(3)，

移入 300mL 分液漏斗後添加 1mL 4-氨基替比林充分混合，然後添加 2.5mL 鐵(III)氰化鉀充分混合，靜置 10 分鐘。接著加入 25mL 氯仿(三氯甲烷)激烈搖動 30 秒鐘混合後，靜置 5 分鐘分取氯仿層，用乾濾紙(JC)過濾(4)，將此濾液當作檢液。

取空白試驗水 200mL 放入燒杯內，另取數個燒杯各裝入適量(0.1～20mL)的酚標準原液並各加精製水配成 200mL，均以和檢液同樣的方法處理後，將其作為空白試驗液及標準液。

另將檢液，空白試驗液及標準液取於吸收槽(40mm 以上)，依吸光光度分析法以 460μm 波長測定吸光度，由此獲得的檢液及空白試驗液之吸光度，依檢量線求出試樣水中之酚類濃度，得酚(ppm)含量。

註(2) 預先加入硫酸銅溶液之保存試樣可省略此操作。

(3) 使用 pH 計較方便。

(4) 在分取所分離之氯仿層前，宜用濾紙捲成細棒拭去分液漏斗腳部之水分。

7. 胺

7.1 試藥

(1) 對二甲氨基苯甲醛粉末〔P-Dimethylamino benzaldehyde，$(CH_3)_2NC_6H_4CHO$〕

(2) 甲苯($CH_3C_6H_5$)

7.2 試驗步驟：取 1mL 供試水於試管，加入 10～20mg 對二甲氨基苯甲醛，然後添加 0.5mL 甲苯混合後添加 0.1mL 之 95%硫酸，靜置 1 分鐘，添加 1mL 乙醇作為檢液。對空白試驗水施予與供試水同樣操作，而將此作為空白試驗液。

將檢液與空白試驗液作比色。此時若含胺時會呈現比空白試驗液顏色較深之黃色、紫色或桃紅色。

8. 氰

8.1 試藥

(1)緩衝液：取 3.40g 磷酸二氫鉀及 3.55g 無水磷酸氫二鈉(Na_2HPO_4)一起溶解於精製水配成 1L。

(2)氯胺 T 溶液：取 1.25g 氯胺 T〔Chloramine T，$(CH_3C_6H_4SO_2NCl Na \cdot 3H_2O)$〕溶於精製水配成 100mL，本溶液於每次使用時重新調配。

(3)吡啶吡唑啡混液：取 0.5g 之 1-苯-3-甲-5-吡唑啡〔1-Phenyl-3-methyl-5-Pyrazolone($C_{10}H_{10}ON_2$)〕溶解於約 70℃之 200mL 精製水後放冷至室溫(此時若未完全溶解亦無妨)。另取 0.04g 雙—〔1-苯-3-甲-5-吡唑啡($C_{20}H_{18}O_2N_4$)〕溶於 40mL 吡啶〔Pyridine，$CH(CHCN)_2N$〕，並將兩液混合。本溶液於每次使用時重新調配。

8.2 試驗步驟：取 20mL 檢水(CN 含量 0.0002～0.01mg)於 50mL 比色管，檢水中添加 10mL 緩衝液及 0.25mL 氯胺 T 溶液，隨即密栓並輕輕搖動混合放置 2-3 分鐘後，加入 15mL 吡啶吡唑啡混液充分混合後於 20～30℃靜置 30 分鐘。若含氰時即呈現由淡紅色經紫色而變為穩定之藍色。

本法之靈敏度爲約 0.01ppm。

備考 1. 由本法可測定之氰係來自氰離子、氰化氫、氯化氰等。

2. 本法亦可由硫氰酸離子(SCN⁻)發色。

9. 臭味及味道

9.1 試驗步驟：試驗水及空白試驗水各取約 100mL 個別裝入共栓錐形燒瓶內，輕輕蓋栓後加溫 40～50℃，開栓同時與比對之空白試驗比較，檢查有無臭味及味道。

引用標準：CNS 3464 艾氏凹壓試驗法

CNS 9007 塗料一般檢驗法－取樣及試驗一般條件

CNS 10352 顏料檢驗法

CNS 10756-1 塗料一般檢驗法(有關塗膜之視覺特性之試驗法)

CNS 10757 塗料一般檢驗法(塗膜抗化學性質之試驗部分)

CNS 11607 塗料一般檢驗法(有關塗膜之長期耐久性之試驗法)

附錄三

灌注發泡樹脂(試驗報告)

Testing Laboratory
2854

試驗報告

報告編號： 105092237　　　　頁次：1/1
工程名稱： 自測
委託單位：
顧客地址：
樣品說明： MC-INJEKT 2088 (A劑)、MC-INJEKT 2088 CAT (B劑)
申請日期： 2016/9/22
試驗日期： 2016/9/22~2016/12/5
報告日期： 2016/12/13
測試方法： CNS 13273(2003)

試驗項目		單位	試驗結果	要求值
溶出試驗	濁度	度	0.0	1 以下
	色度	度	0.0	3 以下
	過錳酸鉀消耗量	mg/L	1.0	5 以下
	餘氯之減量	mg/L	0.2	1.5 以下
	臭味	—	無不良臭味	無不良臭味
	PH值	—	0.07	0.2 以下

— — 以 下 空 白 — —

備註： 1.本報告若有提供規範值時，該規範值僅供參考，合格之判定以委託單位實際要求為主。
2.本報告結果除非另有說明否則僅對送驗樣品負責，且不得部分複製。
3.本報告未蓋鋼印或騎縫章者無效，並不得塗改或分頁使用。
4.試驗環境：溫度23±2℃，濕度50±5%RH。

報告序號：ET051690 -修2

樣品檢驗報告

委託單位：		採樣時間：	105年11月10日一時一分
行 業 別：	自述業別	收樣日期：	105年11月11日10時00分
樣品名稱：	MC-Inject 2088 (A劑)+MC-Inject 2088 cat (B劑)	報告日期：	105年12月06日
樣品編號：	NWD1050488-02	案件編號：	NWD1050488
採樣單位：		聯 絡 人：	
採樣地點：			

檢 驗 項 目	單 位	檢驗值	分析方法	備註	管制值
鉛	mg/L	<0.0005	NIEA W313.53B		0.05
鉻	mg/L	<0.0005	NIEA W313.53B		0.05
鎘	mg/L	ND	NIEA W313.53B	MDL=0.000015	0.01
銀	mg/L	<0.0005	NIEA W313.53B		0.05
硒	mg/L	ND	NIEA W313.53B	MDL=0.00005	0.05
砷	mg/L	<0.0002	NIEA W313.53B		0.05
汞	mg/L	ND	NIEA W313.53B	MDL=0.000029	0.002
氰鹽	mg/L	<0.004	NIEA W410.53A		0.01
酚類	mg/L	ND	NIEA W521.52A	MDL=0.00073	0.05
以 下 空 白					

備 註：

1. 低於方法偵測極限之測定以'ND'表示，並註明其方法偵測極限值(MDL)及單位。
2. 本樣品係由客戶自行送樣，樣品基本資料均為客戶提供，本報告僅對該樣品負責。
3. 本報告於105年11月24日修正，取代原105年11月21日所發行序號為ET051690之檢測報告。
4. 本報告於105年12月06日修正，取代原105年11月24日所發行序號為ET051690-修1之檢測報告。

附錄四

彈性密封灌注樹脂(試驗報告)

SGS

材料及工程實驗室-臺北

Testing Laboratory
0104

試 驗 報 告

拉伸性能

試驗設備：

名稱	廠牌	型號
數位指示計	Mitutoyo	543-691
2kN 材料試驗機	INSTRON	5544

實驗室環境條件：

環境溫度：　23±2℃
相對濕度：　50±5%RH

試驗方法：

ASTM D412-06ae2　Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers-Tension

試驗方法：

試驗樣品：　主劑：硬化劑 =3：1 (體積比)
試片型式：　Die C
標線距離：　25 mm
試驗速度：　500 mm/min

試驗結果：

試驗項目	試驗結果
抗拉強度(kgf/cm^2)	5.14
伸長率(%)	129

附錄五

AWWA Standard

「*Coating SteelWater-Storage Tanks*」

ANSI/AWWA D102-06

ANSI/AWWA D102-06
(Revision of ANSI/AWWA D102-03)

American Water Works Association

The Authoritative Resource on Safe Water®

AWWA Standard

Coating Steel Water-Storage Tanks

American National Standards Institute

Effective date: Feb. 1, 2007.
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This edition approved June 11, 2006.
Approved by American National Standards Institute Nov. 28, 2006.

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Sections

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All AWWA standards follow the general format indicated subsequently. Some variations from this format may be found in a particular standard.

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Foreword

This foreword is for information only and is not a part of ANSI/AWWA D102.

I. Introduction.

I.A. *Background.* The object of this standard is to provide an outline of methods and coating systems that can be used when coating or recoating steel tanks for water storage. Several months before the final approval of ANSI/AWWA D102-03, the AWWA Standards Committee on Steel Elevated Tanks, Standpipes and Reservoirs asked the Revision Task Force to start work on this edition. The final draft of this edition was submitted for Steel Tank Committee ballot on Dec. 19, 2005.

I.B. *History.* The first edition of this standard was prepared by a joint committee of AWWA and New England Water Works Association (NEWWA) and was approved as tentative on May 9, 1952. Revisions were made on June 2, 1953, May 24, 1954, and Aug. 5, 1955. The second edition was approved as tentative on Jan. 23, 1962, and was approved by the AWWA Board of Directors on Feb. 11, 1964. The third edition of this standard was approved on Jan. 28, 1978, and subsequently withdrawn on June 23, 1991. ANSI/AWWA D102 was reissued as the fourth edition and subsequently approved on Feb. 2, 1997. The fifth edition was approved on Jan. 19, 2003. This sixth edition was approved on June 11, 2006.

I.C. *Acceptance.* In May 1985, the US Environmental Protection Agency (USEPA) entered into a cooperative agreement with a consortium led by NSF International (NSF) to develop voluntary third-party consensus standards and a certification program for all direct and indirect drinking water additives. Other members of the original consortium included the American Water Works Association Research Foundation (AwwaRF) and the Conference of State Health and Environmental Managers (COSHEM). The American Water Works Association (AWWA) and the Association of State Drinking Water Administrators (ASDWA) joined later.

In the United States, authority to regulate products for use in, or in contact with, drinking water rests with individual states.* Local agencies may choose to impose requirements more stringent than those required by the state. To evaluate the health effects of products and drinking water additives from such products, state and local agencies may use various references, including

*Persons outside the United States should contact the appropriate authority having jurisdiction.

1. An advisory program formerly administered by USEPA, Office of Drinking Water, discontinued on Apr. 7, 1990.

2. Specific policies of the state or local agency.

3. Two standards developed under the direction of NSF International, NSF*/ANSI† 60, Drinking Water Treatment Chemicals—Health Effects, and NSF/ANSI 61, Drinking Water System Components—Health Effects.

4. Other references, including AWWA standards, *Food Chemicals Codex*, *Water Chemicals Codex*,‡ and other standards considered appropriate by the state or local agency.

Various certification organizations may be involved in certifying products in accordance with NSF/ANSI 61. Individual states or local agencies have authority to accept or accredit certification organizations within their jurisdiction. Accreditation of certification organizations may vary from jurisdiction to jurisdiction.

Annex A, "Toxicology Review and Evaluation Procedures," to NSF/ANSI 61 does not stipulate a maximum allowable level (MAL) of a contaminant for substances not regulated by a USEPA final maximum contaminant level (MCL). The MALs of an unspecified list of "unregulated contaminants" are based on toxicity testing guidelines (noncarcinogens) and risk characterization methodology (carcinogens). Use of Annex A procedures may not always be identical, depending on the certifier.

ANSI/AWWA D102 does not address additives requirements. Users of this standard should consult the appropriate state or local agency having jurisdiction in order to

1. Determine additives requirements, including applicable standards.

2. Determine the status of certifications by all parties offering to certify products for contact with, or treatment of, drinking water.

3. Determine current information on product certification.

II. Special Issues.

This standard has no applicable information for this section.

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*NSF International, 789 N. Dixboro Road, Ann Arbor, MI 48113.

†American National Standards Institute, 25 West 43rd Street, Fourth Floor, New York, NY 10036.

‡Both publications available from National Academy of Sciences, 500 Fifth Street N.W., Washington, DC 20001.

III. Use of This Standard. It is the responsibility of the user of this AWWA standard to determine that the products described in this standard are suitable for use in the particular application being considered.

III.A. *Purchaser Options and Alternatives.* The following items should be provided by the purchaser:

1. Standard used—that is, ANSI/AWWA D102, Coating Steel Water-Storage Tanks, of latest revision.
2. Size, shape, height, and location of structure.
3. ANSI/AWWA D102 contains optional requirements that the purchaser may incorporate into the project documents.
4. Details of other federal, state or provincial, and local requirements (Sec. 4.0).
5. Required coating systems (including finish color) to be used for interior and exterior surfaces (Sec. 4.0).
6. SSPC-SP10/NACE requirements (Sec. 4.0).
7. Required documentation of paint test or field service data (Sec. 4.1).
8. Required number of dry-film thickness measurements (Sec. 5.1).
9. Quality control test and recording requirements (Sec. 5.1).
10. First anniversary inspection requirements (Sec. 5.2).
11. Establish the date, method, and responsible party for first anniversary inspection (Sec. 5.2).
12. Requirement for delivery of an Affidavit of Compliance (Sec. 6.3).

III.B. *Modification to Standard.* Any modification to the provisions, definitions, or terminology in this standard must be provided by the purchaser.

IV. Major Revisions. Major revisions made to the standard in this revision include the following:

1. References made to federal and military paint specifications for various inside and outside coating systems have been replaced with applicable references to SSPC coating standards and specifications.
2. Testing and certification in accordance with NSF/ANSI 61, Drinking Water System Components—Health Effects, for inside coating systems has been made a requirement of this standard (see Sec. 4.3.1).
3. Preconstruction primers may be used when specified.

V. Comments. If you have any comments or questions about this standard, please call the AWWA Volunteer & Technical Support Group at 303.794.7711, FAX at 303.795.7603, write to the group at 6666 West Quincy Avenue, Denver, CO 80235-3098, or e-mail standards@awwa.org.

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ANSI/AWWA D102-06
(Revision of ANSI/AWWA D102-03)

American Water Works Association

AWWA Standard

Coating Steel Water-Storage Tanks

SECTION 1: GENERAL

Sec. 1.1 Scope

This standard describes coating systems for coating and recoating the inside and outside surfaces of steel tanks used for potable water storage in water supply service. Coating systems for new bolted steel tanks are not described in this standard (see ANSI/AWWA D103).

Sec. 1.2 Purpose

The purpose of this standard is to provide the minimum requirements for coating steel water-storage tanks, including materials, coating systems, surface preparation, application, and inspection and testing.

Sec. 1.3 Application

This standard can be referenced in purchase documents for coating steel water-storage tanks. The stipulations of this standard apply when this document has been referenced and only to coating steel water-storage tanks.

SECTION 2: REFERENCES

This standard references the following documents. These documents in the edition specified, or latest edition if not specified, form a part of this standard to the extent specified within the standard. In any case of conflict, the requirements of this standard shall prevail.

AAMA* 2604—Performance Requirements and Test Procedures for High Performance Organic Coatings on Aluminum Extrusions and Panels.

ANSI†/AWWA C210—Liquid Epoxy Coating Systems for the Interior and Exterior of Steel Water Pipelines.

ANSI/AWWA C222—Polyurethane Coatings for the Interior and Exterior of Steel Water Pipe and Fittings.

ANSI/AWWA D100—Welded Carbon Steel Tanks for Water Storage.

ANSI/AWWA D103—Factory-Coated Bolted Steel Tanks for Water Storage.

EMMAQUA‡—Equatorial Mount with Mirrors for Acceleration with Water.

NACE§ RP0188—Discontinuity (Holiday) Testing of Protective Coatings.

NSF**/ANSI 61—Drinking Water System Components—Health Effects.

SSPC††-PA 2—Measurement of Dry Coating Thickness with Magnetic Gages.

SSPC-PS Guide 17.00—Painting System Guide 17.00, Guide for Selecting Urethane Painting Systems.

SSPC-PS 24.00—Latex Painting System for Industrial and Marine Atmospheres, Performance-Based.

SSPC-PS 27.00—Alkyd Coating System Materials Specification, Performance-Based.

SSPC-Paint 20—Zinc-Rich Coating (Type I, Inorganic, and Type II, Organic).

SSPC-Paint 21—White or Colored Silicone Alkyd Paint (Type I, High Gloss, and Type II, Medium Gloss).

*American Architectural Manufacturers Association, 1827 Walden Office Square, Suite 104, Schaumburg, IL 60173.

†American National Standards Institute, 25 West 43rd Street, Fourth Floor, New York, NY 10036.

‡Atlas Material Testing Technology LLC, 414 Ravenswood Avenue, Chicago, IL 60613.

§NACE International, 1440 South Creek Drive, Houston, TX 77084.

**NSF International, 789 N. Dixboro Road, Ann Arbor, MI 48113.

††SSPC: The Society for Protective Coatings, 40 24th Street, Sixth Floor, Pittsburgh, PA 15222.

SSPC-Paint 22—Epoxy Polyamide Paints (Primer, Intermediate, and Topcoat).

SSPC-Paint 35—Medium Oil Alkyd Primer (Air Dry/Low Bake), Type I and Type II.

SSPC-Paint 36—Two-Component Weatherable Aliphatic Polyurethane Topcoat, Performance-Based.

SSPC-Paint 101—Aluminum Alkyd Paint, Leafing (Type I) and Non-Leafing (Type II).

SSPC-SP6/NACE No. 3—Commercial Blast Cleaning.

SSPC-SP7/NACE No. 4—Brush-Off Blast Cleaning.

SSPC-SP10/NACE No. 2—Near-White Blast Cleaning.

SSPC-SP11—Power Tool Cleaning to Bare Metal.

SSPC-SP15—Commercial Grade Power Tool Cleaning.

SSPC-SP COM—Surface Preparation Commentary for Steel and Concrete Substrates.

SSPC TU 3—Overcoating.

SECTION 3: DEFINITIONS

The following definitions shall apply in this standard:

1. *Coating:* Liquid, powder, or mastic composition that has been converted to a solid, durable, and functional adherent film after application as a thin layer.

2. *Constructor:* The party that furnishes the work and materials for placement or installation.

3. *Exterior surfaces:* External surfaces of the tank roof, shell, pedestal, legs, accessories, and appurtenances that are exposed to the elemental atmosphere.

4. *Inaccessible areas:* Areas of the finished structure that, by virtue of the configuration of the completed structure, cannot be accessed to perform surface preparation or coating application (with or without the use of scaffolding, rigging, or staging). Inaccessible areas include such areas as the contact surfaces of roof plate lap joints, underside of roof plates where they cross supporting members, top surface of rafters directly supporting roof plates, contact surfaces of bolted connections, underside of column base plates, contact surfaces of mating parts not intended to be removed or disassembled during routine operation or maintenance of the tank, underside of the tank bottom for ground-supported flat-bottom tanks, and inside of risers less than 36 in. in diameter.

5. *Interior dry surfaces:* Surfaces of the finished structure that are not exposed to the elemental atmosphere or the stored water or its vapor. Examples are the interior of the access tube, interior of the pedestal, and underside of a suspended bottom within the pedestal.

6. *Interior wet surfaces:* Internal surfaces to the tank roof, shell, bottom, accessories, and appurtenances that are exposed to the stored water or its vapor. Examples are the interior of the roof, shell, bottom, and exterior of the access tube within the tank.

7. *Manufacturer:* The party that manufactures, fabricates, or produces materials or products.

8. *Preconstruction primer:* Primers shop applied at relatively low (0.75–2.0 mil) dry film thickness.

9. *Purchaser:* The person, company, or organization that purchases any materials or work to be performed.

10. *Tank:* As defined in this standard, tank includes steel standpipes, reservoirs, and elevated tanks.

SECTION 4: REQUIREMENTS

Sec. 4.1 Materials

Materials shall comply with the requirements of the Safe Drinking Water Act and other federal requirements.

Sec. 4.2 Data to Be Provided

4.2.1 *Coatings manufacturer.* The name of the company that manufactures the coatings to be applied.

4.2.2 *Application method.* The application method for inside and outside coatings; that is, brushing, rolling, or spraying.

4.2.3 *Materials.* The identification of each coating material intended for use on the project.

4.2.4 *Material safety data sheets.* Current material safety data sheets (MSDS) for each product to be used.

Sec. 4.3 Outside Coating Systems

4.3.1 *General.* This section describes coating systems for the exterior, weather-exposed surfaces of steel tanks. When coating materials are referenced to technical standards, the reference shall define the general type and quality required but shall not limit acceptable materials to an exact formulation. Proprietary formulations will be acceptable provided the coating is of the same generic type and that the performance of the formulation offered meets or exceeds the performance of the formulation defined in the referenced coating standard.

4.3.1.1 Shop priming. Primers for the exterior systems outlined in this section may be shop applied. Most of the exterior primers referenced in this section are not qualified as weld-through primers. On surfaces where weld quality might be affected, the shop-applied primer may be eliminated or applied at reduced thickness within 2 in. to 4 in. of the area to be welded. Alternatively, preconstruction zinc-rich primers, specially formulated for welding may be shop applied without weld margins, so long as the weld-through primer is compatible with the paint system primer (see Sec. 4.3.1.2). When the shop prime option is used, fieldwork after the tank is erected consists of spot cleaning and spot priming exposed weld margins and primer abrasions, as required for the particular coating system. The intact shop primer must be clean and, when recommended by the coating manufacturer, scarified to provide a proper surface for the subsequent topcoats that make up the complete system.

4.3.1.2 Preconstruction priming. If specified, a fully compatible preconstruction primer may be shop applied. Most of these primers are formulated and tested for compatibility with the weld processes so that they may be applied edge to edge without weld margins. Field surface preparation is the same as that noted above for standard shop primers. However, a full field coat of the primer specified for the selected outside system is applied over the spot-cleaned bare steel and remaining preconstruction primer. Refer to Sec. 4.6.5 regarding cleaning of shop-applied prime coats prior to application of finish coats.

4.3.1.3 Preparation of surfaces to be welded. Refer to ANSI/AWWA D100 regarding weld-related shop primer or preconstruction requirements.

4.3.2 *Outside coating system No. 1 (OCS-1).* This is a three-coat or optional four-coat system consisting of one or two (optional) prime coat(s) of rust-inhibitive pigmented alkyd primer, followed by an intermediate coat of alkyd coating and a finish coat of alkyd or silicone alkyd enamel. The following systems are included:

System Designation	Intermediate Coat	Finish Coat
OCS-1-A	Aluminum	Aluminum
OCS-1-B	Metallic	Metallic
OCS-1-C	Alkyd	Alkyd
OCS-1-D	Alkyd	Silicone Alkyd

4.3.2.1 Materials. The prime coat shall be red iron oxide, zinc oxide, oil and alkyd primer without lead or chromate pigments, in accordance with performance requirements of SSPC-Paint 35.

For System OCS-1-A, the aluminum finish coats shall be aluminum alkyd, in accordance with performance requirements of SSPC-Paint 101.

For System OCS-1-B, the aluminum intermediate and finish coats shall be a nonleafing aluminum alkyd in accordance with performance requirements of SSPC-Paint 101 tinted with phthalocyanine blue or green.

For System OCS-1-C, the intermediate and finish coats shall be gloss alkyd enamel in accordance with performance requirements of SSPC-PS 27.00. The intermediate and finish coat colors shall be specified and shall be contrasting colors.

For System OCS-1-D, the intermediate coat shall be alkyd coating in accordance with performance requirements of SSPC-PS 27.00. The finish coat shall be high-gloss silicone-alkyd coating in accordance with Type I performance requirements of SSPC-Paint 21. The intermediate and finish coat colors shall be specified and shall be contrasting colors.

4.3.2.2 Thickness. Minimum dry-film thickness, in mils, of the coating system shall be as follows:

System	Primer 1	Primer 2 (Optional)*	Intermediate Coat	Finish Coat	Total System	
OCS-1-A	2.0	(1.5)	1.0	1.0	4.0	(5.5)
OCS-1-B	2.0	(1.5)	1.0	1.0	4.0	(5.5)
OCS-1-C	2.0	(1.5)	1.5	1.5	5.0	(6.5)
OCS-1-D	2.0	(1.5)	1.5	1.0	4.5	(6.0)

NOTE: Consult the coating manufacturer for coating thickness limitations.

*Numbers in parentheses indicate thickness when optional second prime coat is used.

4.3.3 *Outside coating system No. 2 (OCS-2).* This is a three-coat system consisting of a single-component moisture-cure polyurethane zinc-rich primer, an intermediate coat of single-component moisture-cure polyurethane, normally pigmented with micaceous iron oxide, and a finish coat of single-component moisture-cure polyurethane coating.

4.3.3.1 Materials. The primer shall be a zinc-rich primer in accordance with SSPC-Paint 20, Type II, chemically cured. The intermediate coat materials shall be in conformance with SSPC-PS Guide 17.00, Type II (Aromatic). The finish coat shall be in conformance with SSPC-Paint 36, Level 1.

4.3.3.2 Thickness. Minimum dry-film thickness, in mils, of the coating system shall be as follows:

System	Primer	Intermediate Coat	Finish Coat	Total System
OCS-2	2.0	3.0	1.5	6.5

NOTE: Consult the coating manufacturer for coating thickness limitations.

4.3.4 *Outside coating system No. 3 (OCS-3).* This is a three-coat, water-based, industrial-type acrylic or modified acrylic emulsion system consisting of a rust-inhibitive pigmented, single-component water-based primer and intermediate and finish coats of single-component water-based industrial acrylic or modified acrylic emulsion.

4.3.4.1 Materials. The prime coat, intermediate coat, and finish coat shall be in accordance with SSPC-PS 24.00.

4.3.4.2 Thickness. Minimum dry-film thickness, in mils, of the coating system shall be as follows:

System	Primer	Intermediate Coat	Finish Coat	Total System
OCS-3	2.0	2.0	2.0	6.0

NOTE: Consult the coating manufacturer for coating thickness limitations.

4.3.5 *Outside coating system No. 4 (OCS-4).* This is a three-coat system consisting of an inorganic or organic zinc-rich primer, an intermediate coat of an aliphatic polyurethane, and a finish coat of two-component aliphatic fluorourethane. If a shop-applied inorganic zinc-rich primer is specified for new tanks, field touch-up shall be performed using the organic zinc-rich primer.

4.3.5.1 Materials. If an inorganic zinc-rich primer is specified, it shall be in accordance with SSPC-Paint 20, Type I-B or I-C. If an organic zinc-rich primer is specified, it shall be in accordance with SSPC-Paint 20, Type II, chemically cured. The organic zinc-rich primer may be single-package or multipackage with the zinc dust packaged separately. The intermediate coat shall be a two-component aliphatic polyurethane coating in accordance with SSPC-Paint 36, Level 1. The finish coat shall be a two-component aliphatic fluoroethylene/vinyl ether fluorourethane coating conforming to the weathering requirements of AAMA 2604 and a 95 percent gloss retention after a minimum of 1,252 MJ/m^2 when exposed per EMMAQUA.

4.3.5.2 Thickness. Minimum dry-film thickness, in mils, of the coating system shall be as follows:

System	Primer	Intermediate	Finish	Total System
OCS-4	2.0	3.0	2.0	7.0

NOTE: Consult the coating manufacturer for coating thickness limitations.

4.3.6 *Outside coating system No. 5 (OCS-5).* This is a three-coat system consisting of a first coat and an intermediate coat of two-component epoxy and a finish coat of a two-component, aliphatic polyurethane coating. The epoxy first coat may be formulated with or without rust-inhibitive pigments.

4.3.6.1 Materials. The first and intermediate coats shall be a two-component epoxy coating in accordance with SSPC-Paint 22. The finish coat shall be a two-component aliphatic polyurethane coating in accordance with SSPC-Paint 36, Level 1.

4.3.6.2 Thickness. Minimum dry-film thickness, in mils, of the coating system shall be as follows:

System	First Coat	Intermediate Coat	Finish Coat	Total System
OCS-5	2.0	2.0	2.0	6.0

NOTE: Consult the coating manufacturer for coating thickness limitations.

4.3.7 *Outside coating system No. 6 (OCS-6).* This is a three-coat system consisting of an inorganic or organic zinc-rich primer, an intermediate coat of two-component epoxy, and a finish coat of two-component aliphatic polyurethane coating. If a shop-applied inorganic zinc-rich primer is specified for new tanks, field touch-up shall be performed using the organic zinc-rich primer followed by complete topcoats of epoxy and polyurethane.

4.3.7.1 Materials. If an inorganic zinc-rich primer is specified, it shall be in accordance with SSPC-Paint 20, Type I-B or I-C. If an organic zinc-rich primer is specified, it shall be in accordance with SSPC-Paint 20, Type II, chemically cured. The organic zinc-rich primer may be single-package or multipackage with the zinc dust packaged separately. The intermediate coat shall be a two-component epoxy coating in accordance with SSPC-Paint 22. The finish coat shall be a two-component aliphatic polyurethane coating in accordance with SSPC-Paint 36, Level 1.

4.3.7.2 Thickness. Minimum dry-film thickness, in mils, of the coating system shall be as follows:

System	Primer	Intermediate Coat	Finish Coat	Total System
OCS-6	2.0	2.0	2.0	6.0

NOTE: Consult the coating manufacturer for coating thickness limitations.

Sec. 4.4 Inside Coating Systems

4.4.1 *General.* This section describes coating systems for the inside surfaces of steel water tanks. When coating materials are referenced to technical standards, the reference shall define the general type and quality required but shall not limit acceptable materials to an exact formulation. Proprietary formulations will be acceptable provided the coating is of the same generic type and that the performance of the formulation offered meets or exceeds the performance of the formulation defined in the referenced coating standard.

Coatings used on wet interior surfaces of the tank shall have been tested and certified for potable water contact in accordance with NSF/ANSI 61. They shall have been evaluated for long-term freshwater resistance, and the system shall have demonstrated satisfactory service in fresh water for at least eighteen months. Any coating that cannot meet these requirements, whether or not included in this standard, shall not be used.

4.4.1.1 Shop priming. On surfaces where weld quality might be affected for those systems where the primer may be shop applied, the shop-applied primer may be eliminated or applied at a reduced thickness within 2 in. to 4 in. of the area to be welded. Alternatively, preconstruction zinc-rich primers specially formulated for welding may be shop applied without weld margins, so long as the weld-through primer is compatible with the paint system primer and meets testing and certification requirements of Sec. 4.4.1. When the shop prime option is used, fieldwork after the tank is erected consists of spot cleaning and spot priming exposed weld margins and primer abrasions, as required for the particular coating system. The intact shop primer must be clean and, when recommended by the coating manufacturer, scarified to provide a proper surface for the subsequent topcoats that make up the complete system. For those systems where the primer may be shop applied, refer to ANSI/

AWWA D100, Sec. 10.2, Preparation of Surfaces to be Welded, for further information regarding weld-related shop primer requirements.

4.4.1.2 Preconstruction priming. If specified, a fully compatible preconstruction primer may be shop applied. Most of these primers are formulated and tested for compatibility with the weld processes so that they may be applied edge to edge without weld margins. Field surface preparation is the same as that noted above for standard shop primers. However, a full field coat of the primer specified for the selected outside system is applied over the spot-cleaned bare steel and remaining preconstruction primer. Refer to Sec. 4.6.5 regarding cleaning of shop-applied prime coats prior to application of finish coats. Refer to ANSI/AWWA D100 for further information regarding weld-related shop primer. Preconstruction primers used on interior surfaces, excluding dry risers or dry pedestals, shall have been tested and certified for potable water contact in accordance with NSF/ANSI 61, Drinking Water System Components—Health Effects, by an ANSI-accredited laboratory.

4.4.2 *Inside coating system No.1 (ICS-1).* This is a two-coat, two-component epoxy coating system. The prime coat may be shop applied.

4.4.2.1 Materials. The materials shall consist of (1) Paint 1, a two-coat system of noncoal tar-containing two-component epoxy material in accordance with ANSI/AWWA C210, consisting of a prime coat and finish coat or, alternatively, two coats of the same epoxy coating without the use of a separate primer; or (2) Paint 2, proprietary epoxy formulations in accordance with Sec. 4.4.1.

4.4.2.2 Thickness. Minimum dry-film thickness, in mils, of the coating system shall be as follows:

System	Prime Coat	Finish Coat	Total System
ICS-1	3.0	5.0	8.0

NOTE: Consult the coating manufacturer for coating thickness limitations.

4.4.3 *Inside coating system No. 2 (ICS-2).* This is a three-coat, two-component epoxy coating system. The prime coat may be shop applied.

4.4.3.1 Materials. The coating system shall include a primer that shall contrast in color with the color of the intermediate coat. The materials shall consist of (1) Paint 1, a three-coat system of noncoal tar-containing two-component epoxy material in accordance with ANSI/AWWA C210, consisting of a prime coat and two finish coats, or alternatively, three coats of the same epoxy coating without the use of a separate primer; or (2) Paint 2, proprietary formulations in accordance with Sec. 4.4.1.

4.4.3.2 Thickness. Minimum dry-film thickness, in mils, of the coating system shall be as follows:

System	Primer	Intermediate Coat	Finish Coat	Total System
ICS-2	3.0	4.0	5.0	12.0

NOTE: Consult the coating manufacturer for coating thickness limitations.

4.4.4 *Inside coating system No. 3 (ICS-3).* This is a three-coat system consisting of an inorganic zinc-rich primer and intermediate and finish coats of two-component epoxy. This system is only for interior non-immersed surfaces above the top capacity level where the zinc-rich primer is shop applied. Field touch-up work of zinc-rich primer shall be performed using the epoxy coating to be applied as the intermediate coat on other interior surfaces, followed by complete topcoats of epoxy applied in the field.

4.4.4.1 Materials. The prime coat shall be an inorganic zinc-rich primer in accordance with SSPC-Paint 20, Type I-B or Type I-C. The intermediate and finish coats shall consist of (1) Paint 1, a noncoal tar epoxy in accordance with ANSI/AWWA C210; or (2) Paint 2, proprietary epoxy formulations in accordance with Sec. 4.4.1.

4.4.4.2 Thickness. Minimum dry-film thickness, in mils, of the coating system shall be as follows:

System	Primer	Intermediate Coat	Finish Coat	Total System
ICS-3	2.0	4.0	4.0	10.0

NOTE: Consult the coating manufacturer for coating thickness limitations.

4.4.5 *Inside coating system No. 4 (ICS-4).* This is a thermoset polymer that is the reaction product of a polyisocyanate resin that includes both 100 percent solids polyurethane and/or polyurea technologies.

4.4.5.1 Materials. The materials shall consist of a self-priming two-component 100 percent solids fast-setting polyurethane or polyurea that is cured to touch in under 30 min. The material shall be in accordance with ANSI/AWWA C222.

4.4.5.2 Thickness. Minimum dry-film thickness of the coating system, in mils, shall be that recommended by the manufacturer or the following minimum dry-film thickness, in mils, whichever is greater:

System	Total System
ICS-4	25.0

NOTE: Consult the coating manufacturer for coating thickness limitations.

4.4.6 *Inside coating system No. 5 (ICS-5).* This is a three-coat system consisting of an organic zinc-rich primer and intermediate and finish coat of two-component epoxy. This system is for interior tank surfaces, above and below the top capacity level. The prime coat may be shop applied.

4.4.6.1 Materials. The prime coat shall be an organic zinc-rich primer in accordance with SSPC-Paint 20, Type II, chemically cured. The organic zinc-rich primer may be single package or multipackage with the zinc dust packaged separately. The intermediate and finish coats shall consist of (1) Paint 1, a noncoal tar epoxy in accordance with ANSI/AWWA C210; or (2) Paint 2, proprietary epoxy formulations in accordance with the requirements of Sec. 4.4.1.

4.4.6.2 Thickness. Minimum dry-film thickness, in mils, of the coating system shall be as follows:

System	Primer	Intermediate	Finish	Total System
ICS-5	2.0	4.0	4.0	10.0

NOTE: Consult the coating manufacturer for coating thickness limitations.

Sec. 4.5 Coating Materials

4.5.1 *General.* Coatings used on the interior and exterior surfaces of the tank shall be merchantable and suitable for the intended service and shall be delivered in unopened containers. Coating materials shall be those that have been selected for the specific service in accordance with Sec. 4.3.1 and 4.4.1.

4.5.2 *Labels.* The containers in which coating materials are delivered shall be marked with the manufacturer's name, product name or number, identification of components shipped in separate containers, date of manufacture or expiration of shelf-life date, batch number, and safety precautions.

4.5.3 *Product information.* The following manufacturer's information shall be provided for each product. The product information may be printed on the label or package or provided in an accompanying instruction sheet.

4.5.3.1 Mixing instructions. Complete mixing instructions shall be provided, including acceptable tinting pigments when applicable.

4.5.3.2 Thinning. The maximum allowable quantity and type of thinner recommended shall be listed for each application method.

4.5.3.3 Percent solids. The percent solids by volume for liquid materials. In the case of two-component materials, the mixed solids by volume.

4.5.3.4 Spreading rate. The theoretical spreading rate in square feet per gallon at 1-mil dry-film thickness, unthinned as packaged.

4.5.3.5 Weight. The unit weight per US gallon for component materials.

4.5.3.6 Application, drying, and cure time. Recommended minimum and maximum drying time between coats and cure time before immersion. The drying time shall be stated as the number of hours at 75°F ±2°F (21°C ±1°C) and 50 percent relative humidity and at the upper and lower limits of recommended application temperature and humidity.

4.5.3.7 Pot life. The pot life of two-component or multicomponent coatings shall be stated. A description of variations caused by changes in temperature, humidity, or other ambient conditions shall be stated.

4.5.3.8 Application method. The method(s) by which the coating may be applied (i.e., brush, roller, spray).

4.5.3.9 Shelf life. Coatings shall be applied within the coating manufacturer's recommended shelf life. If the shelf-life date has expired, the coating material shall be segregated from the material acceptable for use and the manufacturer consulted for possible shelf-life extension. If the shelf-life extension is granted, the extended shelf-life date shall be certified in writing.

Sec. 4.6 Surface Preparation

4.6.1 *General.* This section describes surface preparation for all coating systems. These surface preparation requirements shall be followed unless the coating manufacturer has more stringent requirements, in which case the more stringent requirements shall prevail.

4.6.2 *Exterior surfaces.*

4.6.2.1 New tanks. Exterior surfaces shall be cleaned in accordance with SSPC-SP6/NACE No. 3. If specified, tanks located in coastal areas or industrial environments shall be blast cleaned to SSPC-SP10/NACE No. 2. Blast-cleaned surfaces shall have a surface profile that is appropriate for the specific primer and coating system, as recommended by the manufacturer of the coating.

4.6.2.2 Existing tanks. Overcoating may be an option depending on the condition of the existing coating system. Determine the condition of the existing coating system and, if applicable, conduct a test patch with the candidate overcoat system(s) in accordance with SSPC-TU 3. When the new coating system will adhere to and is compatible with the existing coating, all corrosion products and deteriorated coatings shall be removed by spot cleaning in accordance with SSPC-SP11, SSPC-SP15, or SSPC-SP6/NACE No. 3, and the remainder of the exterior surfaces shall be cleaned in accordance with SSPC-SP7/NACE No. 4 or by washing with an alkaline cleaner, as described in Sec. 11.1.2 of SSPC-SP COM, to remove dirt, dust, coating/paint chalk, and foreign matter. If the existing coating system is determined not to be a candidate for overcoating when evaluated in accordance with SSPC-TU 3 or the candidate overcoat system(s) is (are) not compatible with the existing coating system, all existing coatings shall be removed and the surfaces blast cleaned in accordance with SSPC-SP6/NACE No. 3 or, if specified, to SSPC-SP10/NACE No. 2.

4.6.3 *Inside surfaces.*

4.6.3.1 New tanks. The interior surfaces of new tanks, excluding inaccessible areas, shall be cleaned in accordance with SSPC-SP10/NACE No. 2, excluding interior surfaces of dry risers and dry pedestals. Interior surfaces of dry risers and dry pedestals shall be cleaned in accordance with SSPC-SP6/NACE No. 3. Blast-cleaned surfaces shall have a surface profile that is appropriate for the specific primer and coating system as recommended by the manufacturer of the coating.

4.6.3.2 Existing tanks. When existing coatings have not deteriorated extensively and the new coating system will adhere to and is compatible with the existing coating, corrosion products and deteriorated coatings shall be removed by spot blasting in accordance with SSPC-SP10/NACE No. 2, and the remainder of the interior surfaces shall be cleaned in accordance with SSPC-SP7/NACE No. 4. When existing coatings have deteriorated extensively or the new coating system is not compatible with the existing coating, existing coatings shall be removed and the surfaces cleaned in accordance with SSPC-SP10/NACE No. 2. Blast-cleaned surfaces shall have a surface profile that is appropriate for the specific primer and coating system, in accordance with the coating manufacturer's recommendations.

4.6.4 *Field welds and abrasions.* After field welding has been completed, accessible weld areas on which the shop coating has been damaged shall be cleaned as follows:

4.6.4.1 Outside surfaces. Exterior surfaces shall be cleaned in accordance with SSPC-SP6/NACE No. 3 or SSPC-SP15 or, if specified, SSPC-SP10/NACE No. 2 or SSPC-SP11.

4.6.4.2 Inside surfaces. Interior surfaces, excluding inaccessible areas and interior dry surfaces, shall be cleaned in accordance with SSPC-SP10/NACE No. 2.

Interior dry surfaces of dry risers and dry pedestals shall be cleaned in accordance with SSPC-SP6/NACE No. 3.

4.6.5 *Field preparation of shop-primed surfaces.* Accessible shop-primed surfaces shall be cleaned of dirt, mud, oil, grease, and foreign materials. When required by the coating manufacturer's written instructions for the product, shop-primed surfaces shall be scarified prior to application of the following coats.

Sec. 4.7 Application

4.7.1 *General.* The requirements of the coating manufacturer's written instructions shall be followed with regard to storage of coatings and thinner, mixing and thinning, application of shop and field coating, and drying of coated steel. Some coatings may require additional coats to achieve the specified thickness when applied by brush or roller. The finish coat color shall be specified and shall contrast to the underlying coat color.

4.7.2 *Prime coat.* Coating materials shall be applied after surface preparation and before any surface rusting occurs or any dust or soil has accumulated. Prime coats for exterior surfaces may be applied by any method recommended by the coating manufacturer that attains an acceptable coating. Interior surfaces shall be sprayed with the exception that difficult-to-coat areas may be additionally stripe-coated with brush or roller. Difficult-to-coat areas include pitted surfaces, weld seams, edges, corners, and exposed portions of bolts.

When plates have been shop primed, accessible weld areas and accessible areas on which shop primer has been damaged shall be cleaned again in the field and primed with the same primer applied to the same dry film thickness as the shop coat. An exception to this is found in paragraph 4.3.7 (System OCS-6) and paragraph 4.4.4 (System ICS-3).

4.7.3 *Intermediate and finish coats.* Intermediate and finish coats for exterior surfaces may be applied by any method that attains an acceptable coating. Interior surfaces shall be sprayed, with the exception that difficult-to-coat areas may be additionally stripe-coated with a brush or roller. Difficult-to-coat areas include pitted surfaces, weld seams, edges, corners, and exposed portions of bolts.

4.7.4 *Touch-up and repair coats.* Touch-up and repair coats for inside and outside surfaces may be applied by any method that attains an acceptable coating.

4.7.5 *Ventilation.* Ventilation shall be used for worker safety and proper curing of the coating system.

4.7.6 *Lighting.* Provide sufficient lights and intensity to allow proper abrasive blasting, coating application, inspection, and worker safety.

Sec. 4.8 Safety Precautions

4.8.1 *General.* Applicable federal, state or provincial, and local regulations shall be followed.

SECTION 5: VERIFICATION

Sec. 5.1 Inspection and Testing

5.1.1 *General.* Before the primer coating is applied, verify that the required surface preparation parameters as outlined in Sec. 4.6 have been satisfied. The wet film thickness of each coat shall be measured during application. Before application of successive coats, the dry-film thickness shall be measured for compliance. When film thicknesses are indicated without an indicated tolerance, the allowable gauge tolerance shall be twice the indicated accuracy of the measurement; that is, for a measurement with an indicated accuracy of ±0.25 mil, the allowable tolerance is ±0.5 mil.

5.1.2 *Film thickness.* The dry-film thickness of the total system shall be measured in accordance with SSPC-PA2.

5.1.3 *Holiday testing.* For inside coating systems, the coating on interior wet surfaces below the top capacity level (TCL), excluding inaccessible areas, shall be tested in accordance with NACE RP0188. Locations where holidays are detected shall be marked for repair and retested after repair work has been completed.

5.1.4 *Test report.* When specified, results of quality control tests and records shall be provided.

Sec. 5.2 First Anniversary Inspection

5.2.1 *General.* When specified, the interior surfaces and exterior surfaces of the tank shall be inspected within one year after coating work has been completed to determine whether any repair work is necessary.

5.2.2 *Arrangements.* The method of inspection to be used shall be specified. The date of the inspection shall be established and notification given at least 30 days in advance.

5.2.3 *Remedial work.* Any location where layers of coating have peeled off, bubbled, or cracked, and any location where rusting is evident, shall be considered to be a failure of the coating system. Rust stains emanating from inaccessible areas, such as unwelded roof plate lap joints and where roof plates cross supporting members, are acceptable as the rust stains do not affect the integrity of the coating surface. Repairs shall be made at points where failures are observed by removing the deteriorated coating, cleaning the surface, and recoating with the same coating system. The manufacturer's cure time requirements for coating repair shall be observed. If the area of failures exceeds 25 percent of the area of a portion of the tank surface, then for that portion, the entire coating system shall be removed and that section recoated. For purposes of determining the need for complete recoating, the following separate area, and any individual accessories not specifically identified, shall each be considered differently:

	Ground-supported Flat-bottom Tanks	Single-pedestal Elevated Tanks	Multi-legged Elevated Tanks
Interior Wet Surfaces			
Wet riser (36-in. dia. and larger), inside surfaces	n/a	X	X
Dry risers, access tubes, dry wells	n/a	X	X
Floor or suspended bottom	X	X	X
Cone, bell	n/a	X	X
Shell, upper knuckle, roof plates below the TCL	X	X	X
Roof support rafters, girders, and columns	X	n/a	n/a
Knuckle and roof plates above TCL	X	X	X
Interior Dry Surfaces			
Wet riser (outside surfaces within pedestal)	n/a	X	X
Dry riser, access tube, dry well	n/a	X	X
Pedestal	n/a	X	n/a
Floor or suspended bottom	X	X	X
Cone, bell	n/a	X	X
Exterior Surfaces			
Wet riser, dry riser	n/a	X	X
Pedestal or leg	n/a	X	X
Floor or suspended bottom	n/a	X	X
Cone, bell	n/a	X	X
Shell and upper knuckle	X	X	X
Roof	X	X	X

5.2.4 *Inspection report.* An inspection report covering the first anniversary inspection, stating the number and type of failures observed, if any, the percentage of the surface area where failure has occurred, the names of the persons making the inspection, and the type and location of coatings repairs shall be prepared. Color photographs illustrating each type of failure shall be included in the report.

SECTION 6: DELIVERY

Sec. 6.1 Marking

This standard has no applicable information for this section.

Sec. 6.2 Shipping

This standard has no applicable information for this section.

Sec. 6.3 Affidavit of Compliance

When specified, an affidavit that materials and work provided comply with the applicable requirements of this standard shall be provided.

APPENDIX A

Selection and Use of Coating Systems

This appendix is for information only and is not a part of ANSI/AWWA D102.

SECTION A.1: GENERAL

Several generic types of coating systems are included in ANSI*/AWWA D102 (see Sec. A.12, Bibliography) because it has been determined that no single type is best for all conditions of exposure. Thus, the coating systems covered are not necessarily equivalent in terms of expected service life, which depends on site-specific conditions of external atmospheric exposure, internal water chemistry, and temperature variations. Neither are they equivalent in terms of initial cost. As an aid in selecting coating systems for a particular site, it is recommended that the purchaser establish the site-specific conditions of exposure and conduct an economic evaluation of the several coating systems using life-cycle cost analysis techniques.

Because it is impractical for an occasional purchaser of coatings to make sufficient laboratory tests to determine whether coating constituents are in accordance with the standard, it is recommended that the coatings be purchased from a manufacturer whose products have the proven performance for the intended service through in-place use or satisfactory evidence of laboratory tested equivalency.

Some primers, notably those containing certain epoxy vehicles, dry hard and glossy. When these primers are shop applied, surface preparation of the prime coat in order to accept the first field-applied coat should be in accordance with the coating manufacturer's recommendations, which may include scarification of the surface (brush-off blast). These primers are suitable for field application, provided that the second coat is applied as soon as the primer is sufficiently dry or cured, in accordance with the coating manufacturer's recommendations. The coating manufacturer's recommendations for surface preparation of the prime coat should be followed.

For a definition of atmospheric/environmental conditions of service, refer to Sec. 5, Table 1, and Table 3 of Chapter 1 of SSPC Steel Structures Painting Manual Vol. 2, Systems and Specifications.

*American National Standards Institute, 25 West 43rd Street, Fourth Floor, New York, NY 10036.

SECTION A.2: OUTSIDE COATING SYSTEMS (OCS)

Outside coating system No. 1 (OCS-1) may blister or fail prematurely when applied to water tank exteriors that are subjected to frequent condensation ("sweating") as a result of cold substrate temperatures (i.e., tanks containing cold well water) and located in areas of high humidity. Other outside systems provide superior performance when this condition is encountered.

Sec. A.2.1 Outside Coating System No. 1

This is a three-coat or optional four-coat alkyd system that provides reasonable and durable protection in mild environments. The four-coat system includes a second coat of primer that upgrades corrosion protection and service life. System OCS-1-B has a pleasing appearance; however, in some locations the color tends to change to light gray with weathering. System OCS-1-D uses a silicone alkyd finish coat that provides improved color and gloss retention when compared to nonsilicone alkyd enamels. For optimum color and gloss retention, it should be specified that the silicone content be a minimum of 30 percent of the total resin binder.

Sec. A.2.2 Outside Coating System No. 2

This is a three-coat, single-component moisture-cure polyurethane system that provides very good protection in mild to moderately severe environments. Color and gloss retention of the finish coat is similar to that provided by two-component aliphatic polyurethane. The primary distinguishing characteristic of this system is a relatively wide range of temperature and humidity conditions within which it can be successfully applied. The primer is also relatively surface tolerant. The polyurethane finish coat is generally graffiti resistant in that selected solvents or commercial cleaners can be used to remove graffiti from the surface without damaging the completely cured finish coat. Coatings making up this system cure by reaction with moisture. Therefore, thickness in excess of manufacturer's recommendations may result in poor adhesion, blistering, pinholing, or solvent entrapment.

Sec. A.2.3 Outside Coating System No. 3

This is a three-coat water-based, acrylic emulsion system that exhibits corrosion resistance comparable to OCS-1. Acrylic emulsion coatings generally dry faster and provide improved color and gloss retention when compared to alkyd enamels.

Sec. A.2.4 Outside Coating System No. 4

This is a three-coat system comprised of a zinc-rich primer, aliphatic urethane intermediate coat, and a fluorourethane finish coat. This system provides gloss and color retention exceeding that of aliphatic polyurethane finish coats. The zinc-rich primer may be either shop or field applied and will provide increased corrosion protection compared to a barrier-type prime coat. The coating manufacturer should be consulted regarding recoat parameters and unique application characteristics. Applicators should be specifically trained in the application of the fluorourethane topcoat. The fluorourethane finish coat is generally graffiti resistant in that selected solvents or commercial cleaners can be used to remove graffiti from the surface without damaging the completely cured finish coat.

Sec. A.2.5 Outside Coating System No. 5

This system consists of a two-component epoxy prime and intermediate coat and a two-component aliphatic polyurethane finish coat. This system provides very good color and gloss retention and is also highly abrasion resistant to windblown debris. The system can generally be applied by spray, brush, or roller. The polyurethane finish coat is generally graffiti resistant in that selected solvents or commercial cleaners can usually be used to remove graffiti from the surface without damaging the completely cured urethane finish coat. The addition of an optional second finish coat consisting of a clear aliphatic polyurethane coating containing UV absorbers can further enhance the long-term color and gloss retention of this system. The clear coat is a particularly useful option to enhance the color and gloss retention of bright-colored logos on tank exteriors. The coating manufacturer should be consulted for clear-coat-application parameters and film-thickness requirements.

Sec. A.2.6 Outside Coating System No. 6

This system consists of a zinc-rich primer and the same two-component epoxy intermediate coat and two-component aliphatic polyurethane finish coat as OCS-5. The zinc-rich primer provides improved corrosion protection compared to a barrier-type prime coat. The polyurethane finish coat is generally graffiti resistant in that selected solvents or commercial cleaners can be used to remove graffiti from the surface without damaging the completely cured finish coat. The addition of an optional second finish coat consisting of a clear aliphatic polyurethane coating containing UV absorbers can further enhance the long-term color and gloss retention of this system. The clear coat is a particularly useful option to enhance the color and gloss retention of bright-colored logos on tank exteriors. The coating manufacturer should be consulted for clear-coat-application parameters and film-thickness requirements.

SECTION A.3: INSIDE COATING SYSTEMS (ICS)

Inside Coating Systems Nos. 1, 2, 3, and 5 utilize two-component epoxies. These inside systems do not restrict the use of 100 percent solids epoxies as long as they meet the requirements of Sec. 4.4.1. A single-coat 100 percent solids epoxy system in excess of 16 mil dry-film thickness is sometimes specified as an alternative to ICS-3. These products typically have short pot life and applicators should closely follow the manufacturer's application instructions to avoid material setting-up in spray lines and spray equipment. Use of plural-component spray equipment may be required.

If a cathodic protection system is provided for additional corrosion protection below the top capacity level (TCL) for any inside coating system, it should meet the requirements outlined in ANSI/AWWA D104.

Sec. A.3.1 Inside Coating System No. 1

This is a two-coat, two-component epoxy system for normal service. To obtain curing with some two-component epoxy products, surface and ambient temperatures of 50°F (10°C) and higher are required. Two-component epoxy products are available with factory-applied accelerators (or packaged separately) that allow curing below 50°F (10°C). Consult manufacturer's recommendation for minimum and maximum temperature requirements. If temperatures are lower than specified by the coating manufacturer, heating of the interior of the tank may be required for proper curing. This coating is generally self-priming and should be applied directly to the properly prepared steel surface.

Sec. A.3.2 Inside Coating System No. 2

This is a three-coat, two-component epoxy system for extended service as compared to ICS-1. To obtain curing with some two-component epoxy products, surface and ambient temperatures of 50°F (10°C) and higher are required. Two-component epoxy products are available with factory-applied accelerators (or packaged separately) that allow curing below 50°F. Consult manufacturer's recommendation for minimum and maximum temperature requirements. If temperatures are lower than specified by the coating manufacturer, heating of the interior of the tank may be required for proper curing. This coating is generally self-priming and should be applied directly to the properly prepared steel surface.

Sec. A.3.3 Inside Coating System No. 3

This is a three-coat zinc-rich primer, two-component epoxy intermediate, and epoxy topcoat system to be used in conjunction with shop-priming operations. The zinc-rich coating is applied in the shop to surfaces that will be above the TCL of the tank. The field-applied touch-up, intermediate, and finish coats are the same two-component epoxy coatings used for ICS-2. The zinc-rich primer provides improved corrosion protection above the TCL compared to a barrier-type prime coat. To obtain curing with some two-component epoxy products, surface and ambient temperatures of 50°F (10°C) and higher are required. Two-component epoxy products are available with factory-applied accelerators (or packaged separately) that allow curing below 50°F (10°C). Consult manufacturer's recommendation for minimum and maximum temperature requirements.

Sec. A.3.4 Inside Coating System No. 4

This is a single-coat direct-to-metal thick-film 100 percent solids coating based on polyurethane and/or polyurea technology. This material provides increased film build in a single-coat multipass technique allowing for higher film-build coverage over deteriorated or pitted steel. Because of rapid-cure characteristics, plural component or specially designed equipment is required. The use of this system in elevated water-storage tanks may require the use of additional staging equipment. Climate control equipment may be required to maintain environmental conditions suitable for continuous coating application. The application of the coating should be completed by individuals that have been trained by the manufacturer in the application of the coating being applied.

Sec. A.3.5 Inside Coating System No. 5

This is a three-coat organic zinc-rich primer, two-component epoxy intermediate, and two-component epoxy finish coat system. Interior surfaces, above and below the TCL, are to be coated with this system. It uses the same two-coat epoxy intermediate and finish coatings as ICS-2. The zinc-rich primer provides improved corrosion protection compared to a barrier-type prime coat. To obtain curing with some two-component epoxy products, surface and ambient temperatures of 50°F (10°C) and higher are required. Two-component epoxy products are available with factory-applied accelerators (or packaged separately) that allow curing below 50°F (10°C). Consult manufacturer's recommendation for minimum and maximum temperature requirements.

SECTION A.4: UNDERSIDE OF FLAT-BOTTOM TANKS

For ground-storage reservoirs and standpipes, it is seldom considered necessary to apply protective coatings to the underside of flat tank bottoms resting on well-drained granular material, on a concrete ring-wall foundation with treated sand cushion, or on a concrete slab. The bottoms should slope gently downward from the center of the tank to the perimeter. The foundation ring-wall should be maintained sufficiently above grade to prevent water infiltration and should be sloped downward from the edge of the bottom plate to the outside edge of the ring-wall. If there is no ring-wall, a water diversion ditch should be constructed around the stone berm. If coating the underside of flat tank bottoms is desired, the underside of the bottom plates should be coated with a coating or coating system suitable for the specific service. Refer to Sec. 12 of ANSI/AWWA D100 regarding recommended materials and methods of the base construction.

SECTION A.5: INSIDE OF NONWATER-CONTAINING ELEVATED TANK PEDESTALS

Since the elimination of low-solubility corrosion inhibitors in outside coating system primers, some outside coating systems are no longer considered suitable for interior dry surfaces of pedestals that are subject to condensation. Also, these surfaces are not subject to ultraviolet degradation as with outside coating systems. In such cases, application of a specific inside system is acceptable. ICS-1 is a frequently specified system for this application. Consult the coating manufacturer for specific recommendations.

SECTION A.6: SURFACE PREPARATION

Sec. A.6.1 General

Effective coating life depends on surface preparation. SSPC*-SP6/NACE† No. 3 and SSPC-SP10/NACE No. 2 should be referenced for proper surface preparation. When environmental conditions, such as humidity, dew point, or surface and ambient temperature, are such that appropiate surface preparation and application of the specified inside coating system cannot be achieved, climate control equipment may be used (heating, cooling, or dehumidification). Coatings applied over mill scale are subject to a short and uneconomical life. Mill scale should be removed completely by blast cleaning. Coatings should not be applied over unacceptable sharp gouges and pits, sharp welds, weld arc strikes, burrs, welding and torch-cut slag, welding flux, spatter, and so forth. These unacceptable areas should be remedied prior to blast cleaning. Filling of gouges or other unacceptable areas may be required. Prior to coating application, the steel surfaces must meet the surface preparation requirements for the coating system being applied.

Sec. A.6.2 New Tanks

Mill scale should be removed completely from accessible surfaces to be coated, in accordance with the specified blast cleaning standards for fabricated parts of new steel tanks either in the shop or in the field. When the mill scale is removed, the steel must be primed before rusting or surface soiling occurs. Accessible welded joints should be cleaned and weld slag and weld spatter removed by grinding, sanding, or wire brushing prior to surface preparation by blast cleaning. The tank constructor should be assigned the responsibility for repairing unacceptable sharp gouges and pits and also removing burrs, weld slag, weld spatter, slivers, laminations, or other unacceptable imperfections.

Sec. A.6.3 Existing Tanks

Before purchase documents are prepared for the recoating of an existing tank, the tank should be drained and inspected to determine the condition of the existing

*SSPC: The Society for Protective Coatings, 40 24th Street, Sixth Floor, Pittsburgh, PA 15222.
†NACE International, 1440 South Creek Drive, Houston, TX 77084.

coating. See appendix B, Environmental Concerns, for environmental issues. The highly aggressive conditions inside a tank dictate that questions of compatibility of new and old coatings are best resolved by removing all traces of the existing interior coating before applying a new coating. Refer to appendix B for hazardous material considerations.

For tanks that have been previously coated with wax–grease-type coatings and for which a recoat with a different type of coating system is desired, all traces of the former coating must be removed. The wax–grease-type coatings can be properly removed and the surfaces recoated with most of the inside coating systems referenced in ANSI/AWWA D102. It is usually necessary to chemically or steam clean wax–grease-coated surfaces both before and after abrasive blast cleaning to ensure adhesion of newly applied nonwax–grease-type coatings.

Whenever new coatings are to be applied to tank exteriors without removing the old coating, dust, chalk, and other surface contaminants on existing intact coating should be removed by washing with an appropriate cleaner using the methods described in SSPC-SP COM. All rust and loose coating should be removed by power tool cleaning according to SSPC-SP11 or by blast cleaning conforming to SSPC-SP6/NACE No. 3. Areas cleaned to bare steel should be primed before any visible rusting takes place. New coatings must be compatible with the existing coating system. Consult the coating manufacturer for specific recommendations.

Purchasers should be aware that old tanks may contain contaminated steel surfaces from prior service. Deeply pitted tanks are of particular concern because blast cleaning alone may not remove contaminants from the bottom of deep pits. The purchaser should consult NACE 6G 186 report, Surface Preparation of Contaminated Steel Surfaces, for information on the detection of and removal of surface contaminants.

Sec. A.6.4 Degree of Cleaning

The cost of surface preparation is proportional to the cleaning effort required. Blast cleaning conforming to SSPC-SP10/NACE No. 2 has proved successful for application of interior coatings. Commercial blast cleaning to SSPC-SP6/NACE No. 3 has proved successful for most exterior coatings; however, in severe environments, cleaning to SSPC-SP10/NACE No. 2 may extend the coating life of exterior coatings because of the improved degree of surface cleanliness. Pictorial surface preparation standards illustrating the various degrees of surface preparation are available from SSPC-VIS 1 and ASTM D2200.

Sec. A.6.5 Sealing Lap Joints

Seal welding of accessible interior roof plate lap joints and contact surfaces of roof plates on supporting members is not required by ANSI/AWWA D100. Consequently, some rusting occurs in these joints. Seal welding of these joints should provide an improved condition for coating and extends the service life of the coating system. However, seal welding may increase tank erection costs significantly and may cause severe distortion and roof plate wrinkles.

SECTION A.7: COATING APPLICATION

Sec. A.7.1 Brushing

An advantage of brushing is that the coating may be worked into voids or irregular surfaces. When applying coating along welds, seams, and irregular surfaces, brushing is more effective than other application methods and should be performed in multiple directions. When coating has been formulated for spraying, brush application may be unacceptable. Coated surfaces must be free of dust, soil, and moisture or the brushed material may lie on top of the contaminants and not adhere tightly to the surface. Brush application is usually more costly than other methods.

Sec. A.7.2 Spraying

Spraying is a rapid and effective method of coating application. To be effective, coated surfaces must be free of dust, soil, and moisture or the sprayed material will lie on top of the contaminant and not adhere tightly to the surface. When spraying, it is difficult to fill cracks and to cover uniformly along edges and inside angles. It is recommended to use a brush around rivets, welds, edges, and inside angles before spraying when coating formulation allows. A serious objection to spraying exterior surfaces is that the overspray can carry some distance and cause damage to property. This is especially a problem with slower-drying coatings, such as long-oil alkyds, epoxies, and polyurethanes.

Sec. A.7.3 Roller Application

Many coatings may be applied effectively to smooth surfaces by rollers. To be effective, coated surfaces must be free of dust, soil, and moisture or the rolled material will lie on top of the contaminant and not adhere tightly to the surface. Rollers are available as either fed by coating under pressure or replenished by the use of the bucket–screen method. By the proper selection of roller material and suitable manipulation of the roller, which usually involves rolling in two directions for each coat, a fairly uniform coat may be applied over smooth surfaces. It is recommended that sharp corners, inside angles, welds, and rivets be brushed and allowed to dry before the remaining surfaces are rolled.

NOTE: Most coatings formulated for proper flow and leveling during roller application cannot be roller applied to achieve single-coat dry-film thickness greater than 2 to 3 mils. The number of coats versus total dry-film thickness requirements of some purchase documents may only be achievable by spray application. If jobsite location dictates roller application only, additional coats may be required to achieve the minimum total dry-film thickness specified.

Sec. A.7.4 Climate Control

When environmental conditions, such as humidity, dew point, surface and ambient temperature, are such that appropiate surface preparation and application of the specified inside coating system cannot be achieved, climate control equipment may be used (heating, cooling, or dehumidification). For information regarding dehumidification, see NACE 6A192.

Sec. A.7.5 Ventilation

Design ventilation for abrasive dust and solvent vapor removal. The tank configuration, the location and size of openings, the placement of blowers and ducts, the rate and method of coating application, and weather conditions will determine the required ventilation. A combination of forced and natural ventilation should be continued after coating application is completed to ensure complete curing and solvent removal. Coating life may be shortened if there is inadequate ventilation during the curing period and residual coatings solvent may contribute to taste and odor problems in stored water. Lower temperature or higher humidity may extend the time that ventilation is necessary. Heating can be used to shorten the forced ventilation period in accordance with manufacturer's recommendations. Heat sources that emit hydrocarbon fumes into the tank should not be used. Where negative pressure ventilation is employed, the tank shall be adequately vented to avoid structural damage.

SECTION A.8: TESTING AND INSPECTION

Testing of the work as it progresses is important to ensure appropriate procedures are being used. When making film-thickness measurements, remember that some variation in film thickness is normal. The requirements of SSPC-PA2 indicate methods of coating measurements and minimum allowable coating thicknesses.

Inspection should be used to verify that the surface preparation and coating application have been completed in accordance with the purchase documents.

Sec. A.8.1 Wet-Film Thickness

Wet-film thickness is a rough measure of whether the proper quantity of coating is being applied. Because repair of the coating is done more easily while the coating is wet, it is practical to measure wet-film thickness frequently.

Sec. A.8.2 Dry-Film Thickness

Dry-film thickness measurements are used to determine acceptability of the coating-system thickness (see SSPC-PA2). If the total dry film is less than the specified thickness, additional coats must be applied to bring the coating system to the specified thickness. Ordinarily, between coats, it is possible to make enough dry-film thickness measurements to obtain reasonable assurance that the specified thickness has been applied without access to all parts of the tank. Coating application and testing must be scheduled to provide a mutually agreeable time interval for testing prior to removing the access rigging. Each coating material and manufacturer has a certain maximum thickness per coat and for the total system so that the total system will perform as intended. The manufacturer of the coating should be consulted to determine if there is a maximum permissible thickness for the coating system.

Sec. A.8.3 Holiday Testing

Holiday testing is used to detect faults in a coating film that allow electrical current to flow to the base metal. Holiday testing is not effective when metal-filled coatings are used in the system. Holiday testing is very effective on smooth and flat surfaces. The interface between roof rafters and roof plates, faying surfaces, bolted flanges, and other joints that have not been continuously welded or sealed with mastic are difficult to cover with coating well enough so that they will pass a holiday test. In fact, it may be impossible for some joints to pass the holiday test if the joint is not continuously welded or sealed with mastic. For this reason, this standard does not require holiday testing for inside non-immersed surfaces above the TCL and other non-immersion surfaces, such as the interior dry surfaces and interior wet surfaces. If holiday testing interior surfaces above the TCL or other non-immersed surfaces is desired, it must be specified.

SECTION A.9: FIRST ANNIVERSARY INSPECTION

First anniversary inspections are conducted to determine whether the coating system is performing properly. Inspections may be performed by dive inspections, by inspection using remotely operated underwater vehicles, by floating drain-down inspection, or by draining the tank. If inspection methods other than draining the tank are used, special safety personnel and sanitary precautions may be required. Regardless of the inspection method used, trained personnel using proper tools and equipment following safety precautions pertinent to the inspection method employed should perform the inspection. The life of the coating system will be extended if the defective areas, if any exist, are repaired at this time. The purchaser should identify which party will be responsible for making the tank ready for inspection, for providing the necessary access, staging, scaffolding, and lighting and for performing the inspection.

AWWA Manual M42 provides additional information regarding inspection options. Refer to ANSI/AWWA C652 for information regarding disinfection requirements for in-service inspections.

SECTION A.10: PLACING IN SERVICE

After interior coatings have been cured in accordance with the coating manufacturer's recommendations and project purchase documents, all inside surfaces should be flushed with potable water. Water, dirt, and foreign material accumulated in the cleaning process should be discharged from the facility. The tank should then be disinfected, using one of the methods described in ANSI/AWWA C652, before placing the tank in service.

SECTION A.11: CATHODIC PROTECTION SYSTEM CONSIDERATIONS

When an impressed current cathodic protection system is installed, it is recommended that the system not be energized until after the first anniversary inspection. When a sacrificial cathodic protection system is used, it is recommended that the anodes not be activated until after the first anniversary inspection. This is recommended to rule out the possibility that the cathodic protection system could be responsible for coating system defects discovered during the first anniversary inspection.

SECTION A.12: BIBLIOGRAPHY

The following documents are referenced in appendix A:

ASTM* D2200—Standard Preparation Standards for Painting Steel Surfaces.

ANSI/AWWA C652—Disinfection of Water-Storage Facilities.

ANSI/AWWA D100—Welded Steel Tanks for Water Storage.

ANSI/AWWA D104—Automatically Controlled, Impressed-Current Cathodic Protection for the Interior of Steel Water Tanks.

ANSI/AWWA Manual M42, Steel Water-Storage Tanks.

NACE TG142—Surface Preparation of Contaminated Steel Surfaces.

SSPC-PA 2—Measurement of Dry Paint Thickness with Magnetic Gages.

SSPC-SP6/NACE No. 3—Joint Surface Preparation Standard Commercial Blast Cleaning.

SSPC-SP10/NACE No. 2—Joint Surface Preparation Standard Near-White Blast Cleaning.

SSPC-SP11—Power Tool Cleaning to Bare Metal.

SSPC Painting Manual Volume 2—Systems and Specifications.

*ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

SSPC-SP COM—Surface Preparation Commentary.

SSPC-VIS 1—Visual Standard for Abrasive Blast Cleaned Steel.

The following documents are not referenced in this appendix but may be useful. Caution and discretion should be used in the application of the provisions of the following references as these recommendations are considered above minimum industry standards and can significantly increase the cost of the coating system. Users of this standard should use their own experience with coating projects and input from industry professionals in deciding how or if to apply the recommendations in any of the references listed below.

NACE RP0178—Fabrication Details, Surface Finish Requirements, and Proper Design Considerations for Tanks and Vessels to Be Lined for Immersion Service.

NACE RP0388—Impressed Current Cathodic Protection of Internal Submerged Surfaces of Steel Water Storage Tanks.

NACE TM0170—Visual Standard for Surfaces of New Steel Airblast Cleaned with Sand Abrasive.

NACE TM0175—Visual Standard for Surfaces of New Steel Centrifugally Blast Cleaned with Steel Grit and Shot.

NACE 6A192—Dehumidification and Temperature Control During Surface Preparation, Application, and Curing for Coatings/Linings of Steel Tanks, Vessels, and Other Enclosed Spaces.

SSPC-SP1—Surface Preparation Specification No. 1, Solvent Cleaning.

SSPC-SP2—Surface Preparation Specification No. 2, Hand Tool Cleaning.

SSPC-SP3—Surface Preparation Specification No. 3, Power Tool Cleaning.

SSPC-SP5/NACE No. 1—Joint Surface Preparation Standard White Metal Blast Cleaning.

SSPC-SP12/NACE No. 5—Surface Preparation and Cleaning of Steel and Other Hard Materials by High- and Ultrahigh-Pressure Water Jetting Prior to Recoating.

SSPC Guide to VIS 1-89—Visual Standard for Abrasive Blast Cleaned Steel.

APPENDIX B

Environmental Concerns

This appendix is for information only and is not a part of ANSI/AWWA D102.

Most of the regulatory requirements pertinent to coating operations can be classified by the following broad categories:

1. Drinking water contamination.
2. Air pollution by volatile compounds and fugitive dusts.
3. Hazardous wastes.
4. Hazardous chemical content of new and old coatings (lead, chromium, etc.).
5. Water pollution.

Over the years, thousands of raw materials have been used in coatings. While many of these materials are innocuous, others are considered hazardous, as determined by evolving government and private company findings. For example, a typical environmental regulation enacted since the early 1970s by the US Environmental Protection Agency (USEPA) is one that involves coatings whose rust-inhibitive qualities were based on pigments that contained lead. Lead can no longer be used in coatings that will be in direct contact with potable water. Coating manufacturers responded with reformulated or alternative coatings.

Similarly, when limitations were placed on solvent usage, the coatings industry reformulated its products to meet regulatory requirements. More recent air pollution regulations in many states require that volatile organic compound (VOC) content of coatings be reduced to meet specific limitations. The coatings industry is striving to meet these additional government regulations while maintaining a high level of coatings standards and performance.

Environmental and occupational health officials recently have become concerned about the composition and waste from old coatings being removed from facilities in preparation for recoating. Removal of these coatings by abrasive blasting may produce airborne concentrations of hazardous materials greater than the maximum amount allowed by USEPA and the Occupational Health and Safety Administration (OSHA). In addition, the coating and abrasive particles may have been deposited on residences, public buildings, roadways, waterways, and adjacent ground. The extent to which these particles pose a health hazard is subject to much study. Steps must be taken to protect not only those doing the abrasive blasting, but also those who are allied with the blasting and coating operations, as well as people, vegetation, animals, fowl, and fish in the vicinity of the abrasive and particulate matter fallout.

One of the methods used to minimize air, water, and ground pollution has been the attachment of shrouds, draping, or other means of enclosing tanks and their supporting towers. The attachment of shrouds, draping, or other enclosures must be done only when consideration is given to the additional local and total structure loads imposed by such attachments. The use of shrouds, draping, etc., can significantly increase the cost of the painting project.

An additional potential problem associated with abrasive blasting of coatings containing hazardous materials is disposal of the spent abrasive. If toxic materials are present, the disposal of the blast media falls under USEPA's Resource Conservation and Recovery Act (RCRA) guidelines on solid waste disposal. Information provided by manufacturers of existing coatings or laboratory analysis may be used to determine the hazardous or nonhazardous nature of the materials. Testing of the spent debris is necessary to determine acceptable methods of its disposal.

Purchasers and constructors of tanks and other steel structures should investigate the disposal of waste abrasive and industrial residue of old coating films prior to their removal.

Another concern relates to coatings that are spilled or scattered about the jobsite. Partly full or empty containers that contain solvents or coatings must be cleaned and stored in a secured location. Spills must be cleaned up, including any earth contaminated by the spill.

The previous paragraphs discuss various conditions that deserve attention, but the list is not complete. Every effort should be made to be aware of and adhere to federal, state, or provincial environmental, health, and safety regulations.

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AWWA is the authoritative resource for knowledge, information, and advocacy to improve the quality and supply of water in North America and beyond. AWWA is the largest organization of water professionals in the world. AWWA advances public health, safety, and welfare by uniting the efforts of the full spectrum of the entire water community. Through our collective strength we become better stewards of water for the greatest good of the people and the environment.

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附錄六

DWI

「*LIST OF APPROVED PRODUCTS FOR USE IN PUBLIC WATER SUPPLY*」

LIST OF APPROVED PRODUCTS FOR USE IN PUBLIC WATER SUPPLY IN THE UNITED KINGDOM

All approved products must be used in accordance with the specific conditions of approval, listed against the product names in Parts A-E. In addition, the following general conditions of approval apply to all approved products:

1. That use is in accordance with an Instructions for Use document. Approval holders must provide drinking water suppliers with copies of the Instructions for Use Document that was considered by the Drinking Water Inspectorate (DWI) when approval was recommended.
2. That the approval of the Authorities is obtained on condition that there shall be:
   - no change in the formulation of the approved product, including change in the source or identity of raw materials
   - no change in the manufacturing process, including location of manufacture
   - no change in designation of the approved product
   - no change in name or ownership of the organisation holding the approval
3. That the producer shall ensure that the product is tested for conformity with its formulation, and the source or identity of its raw materials, at such intervals and by such persons, as may be determined by the Authorities. The results of such testing shall be sent to the Authorities.
4. If there is suspicion that any of the above is not being followed or has been changed then notify DWI Regulation 31 team who will investigate (reg31.enquiries@defra.gsi.gov.uk)
5. That the approval is still valid

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PART C LINING, COATINGS, SEALANT AND REPAIR MATERIALS

C.1 In-situ Installed (tubular) pipe linings

Aqualiner Ltd

Water Pipe Lining DWI 56/4/910

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: Instructions for Use: Water Pipe Lining. Version No 5 Issue Date: 21 October 2010

Approval expiry date: 6 November 2021

C.2 In-situ applied Pipe Coatings

In-situ applied lining products approved for use by the Authorities for the relining of existing water mains/pipes must be applied in accordance with strict operational requirements as documented in the Water Industry Information & Guidance Note IGN 4-02-02 http://www.water.org.uk/home/member-services/wis-and-ign/archived-documents/ign-4-02-02.pdf "Code of Practice: In-situ resin lining of water mains" and the Water Industry Specification WIS 4-02-01 http://www.water.org.uk/home/member-services/wis-and-ign/archived-documents/wis-4-02-01-v2.1---march-2009.pdf "Operational Requirements: In situ resin lining of water mains".

The coatings listed in this section have been subject to review by DWI (including testing), on the basis of their proposed use with inert substrates such as metallic or cement based structures (or as specified in the manufacturer's Instructions for Use (IFU)), and upon the detailed application and curing requirements set out in the IFU. They have not been evaluated for any other aspect, such as fitness for purpose.

For use with other non-metallic non-cementitious materials, such as plastics, other coatings/linings, and rubbers, a specific application for approval would be required for use of the coating with a specific substrate.

C.2.2 Coatings based on polyurethane

These products must be applied by a certified contractor.

3M United Kingdom

3M Scotchkote Pipe Protection Liner 2100 DWI 56/4/1037

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: Instructions For Use Document 29P-2100. In-Situ Rapid Setting Polymeric Lining Of Potable Water Mains. Coating System 3M Scotchkote Pipe Protection Liner 2100. Issue No: 5 Issue Date: December 2014

Approval expiry date: 15 March 2018

3M Scotchkote Pipe Renewal Liner 2400 DWI 56/4/1031

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: 3M Scotchkote Pipe Renewal Liner 2400 Instructions for Use Document 29P-2400 June 2017 Issue number 6

Approval expiry date: 2 October 2022

Subterra – a part of RadiusPlus Ltd

Subcote FLP DWI 56/4/698a

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: SUBTERRA SUBCOTE FLP PRODUCT DESCRIPTION AND MANUFACTURER'S INSTRUCTIONS FOR USE. Document Reference –Subterra Subcote FLP Issue 17 dated 19 February 2015 – A two part solvent free polyurethane resin approved for the in situ lining of potable water mains.

The minimum cure time is one hour at a minimum temperature of 3'C.

Approval expiry date: 1 November 2020

C.2.3 Coatings for small diameter pipes

This section covers pipes up to 75 mm internal diameter. The products listed in this section shall be applied by certified contractors in accordance with strict operational requirements as documented in the Water Industry Specification WIS 4-02-03 "Operational Requirements : In-situ polymeric lining of service pipes" (document is available from https://www.water.org.uk/publications/WIS-IGN)

3M United Kingdom

3M Scotchkote Rapid Setting Polymeric Lining 166L DWI 56/4/1032

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: 29P-SP. Issue No: 7. Issue Date: March 2017

Approval expiry date: 29 July 2022

Pipe Restoration Technologies LLC

ePipe UK DWI 56/4/995

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: IN-SITU HYDROPHOBIC POLYMERIC LINING OF POTABLE

WATER SERVICE LlNES. lnternal Coating System ePIPE® UK

lssue Date: July 6, 2017 lssue No: 010

Approval expiry date: 1 October 2022

C.3 Site applied coatings for water retaining structures

The products listed below in this section, in addition to being approved for site applied coatings for water retaining structures, are suitable for use in large diameter mains where they can be applied by hand e.g. brush or spray.

The coatings listed in this section have been subject to review by DWI (including testing), on the basis of their proposed use with inert substrates such as metallic or cement based structures (or as specified in the manufacturer's Instructions for Use (IFU)), and upon the detailed application and curing requirements set out in the IFU. They have not been evaluated for any other aspect, such as fitness for purpose.

For use with other non-metallic non-cementitious materials, such as plastics, other coatings/linings, and rubbers, a specific application for approval would be required for use of the coating with a specific substrate.

C.3.1 Coatings based on epoxy resins

The following conditions apply unless otherwise indicated:

(i) the minimum cure time is 16 hours; and

(ii) the minimum cure temperature is 3°C.

3M United Kingdom

3M Scotchkote Epoxy Coating 162PWX plus 3M Scotchkote Epoxy Coating 162PW Stripe Coat DWI 56/4/300

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: Instructions For Use Document 10T – E. Coating System, 3M Scotchkote Epoxy Coating 162PWX. Issue No: 7 Issue, Date: March 2015

This product must be cured for a minimum of 21 days at a minimum temperature of 7°C days or in accordance with the cure curve provided in the manufacturer's instructions for use document.

Approval expiry date: 24 August 2020

Sherwin-Williams Protective and Marine Coatings

Macropoxy P300 DWI 56/4/253

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: IFU Issue Number 7 (May 2016)

Approval expiry date: 1 September 2021

Sika Ltd

Sikagard 62 DWI 56/4/197

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: Instructions for Use Sikagard 62 -2 part Epoxy protective coating Issue No :002 Issue Date: May 2012

The product must be cured in accordance with the cure curves provided in the Instructions for Use. The required cure time can be calculated by the user from the minimum daily temperature at the site of application. If the temperature cannot be measured and recorded then a minimum cure period of 21 days must be used.

Approval expiry date: 3 September 2022

C.3.2 Coatings based on polyurethane

BASF plc Construction Chemicals (UK) Ltd

Masterseal M 808 DWI 56/4/1080a

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: MasterSeal M 808 Ref CG/Rev4 25/05/2016

This product must be cured for a minimum of 7 days at a minimum temperature of 7°C days or in accordance with the cure curve provided in the manufacturer's instructions for use document

Approval expiry date: 16 December 2018

Masterseal M 808 additional light grey colour DWI 56/4/1080b

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: MasterSeal M 808 Ref CG/Rev4 25/05/2016

This product must be cured for a minimum of 7 days at a minimum temperature of 7°C days or in accordance with the cure curve provided in the manufacturer's instructions for use document

Approval expiry date: 16 December 2018

Irathanefutura A Division of ITW Ltd

Aqualine 650 with Irabond BC50 DWI 56/4/276

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: Instructions for Use – Lining Potable Water Structures using the Aqualine 650 and Irabond BC50 System. Issue 3 October 2017

The product must be cured for a minimum of 21 days at a minimum temperature of 7°C.

Approval expiry date: 1 January 2020

Line-X Protective coatings

Aquaurethane Extreme DWI 56/4/874

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: Instructions for Use (IFU). LINE-X Aquaurethane Extreme. Issue number 7, August 2016

i) The product must be cured for a minimum of 5 days at a minimum substrate temperature of 3°C and

ii) this product is for use on water retaining structures only.

Approval expiry date: 18 September 2021

Spencer Coatings Limited

Acothane DW Blue DWI 56/4/1059

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: Instructions For Use Document - Acothane DW. Issue 7, dated February 2014

The product must be cured for a minimum period of 7 days at a minimum temperature of 3°C.

Approval expiry date: 24 November 2019

Acothane DW Cream DWI 56/4/1052

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: Instructions For Use Document - Acothane DW. Issue 7, dated February 2014

The product must be cured for a minimum period of 7 days at a minimum temperature of 3°C.

Approval expiry date: 24 November 2019

Acothane LV Sealer DWI 56/4/1058

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: Instructions For Use Document - Acothane DW. Issue 7, dated February 2014

The product must be cured for a minimum period of 3 hours at a minimum temperature of 3°C, this product must then be overcoated with Acothane DW.

Approval expiry date: 24 November 2019

Subterra – a part of RadiusPlus Ltd

Subcote FLP DWI 56/4/698b

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: Subterra Subcote FLP Tanks & Reservoirs Issue 1 dated 30 September 2015 - A two-part solvent-free polyurethane resin approved for the in-situ lining of steel water tanks and concrete reservoirs

Approval expiry date: 5 November 2020

C.4 Flexible covers and linings for water retaining structures

Note: Laminated flexible covers and linings for water retaining structures may not necessarily have been assessed for uses totally immersed in water, e.g. as baffles. For information on use see individual product Instructions for Use (IFU) document.

BASF Polyurethanes GmbH

Elastocoast 6551/102 DWI 56/4/954

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: Instructions for Use (IFU) Application of Elastocoast 6551/102 for water reservoirs before treatment. Issue 1.1 -05/07/2010

(i) this product is for use on raw water reservoirs only

(ii) this product must be cured for a minimum period of 7 days at a minimum cure temperature of 7°C

Elastocoast 6551/103 DWI 56/4/953

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: Instructions for Use (IFU) Application of Elastocoast 6551/103 for water reservoirs before treatment. Issue 1.2 -05/07/2010

(i) this product is for use on raw water reservoirs only

(ii) this product must be cured for a minimum period of 48 hours at a minimum cure temperature of 7°C

Sensor (UK) Ltd

Sensorline DWI 56/4/1066

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: SENSORLINE – PE GEOMEMBRANES (IFU VERSION 4.8). 9 August 2012

Approval expiry date: 19 March 2018

C.5 Cementitious coatings

BASF plc Construction Chemicals (UK) Ltd

MasterSeal 581 DWI 56/4/1227

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: MasterSeal 581 Application to potable water contact areas IFU Issue No:- Rev1, Date of Issue 10/06/2016

This product must be cured for a minimum of 3 days at a minimum temperature of 3°C days or in accordance with the cure curve provided in the manufacturer's instruction for use document

Approval expiry date: 30 June 2021

MasterSeal 581 with MasterSeal 600 DWI 56/4/1103

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: IFU issue ref CG/Rev 1- 09/01/2014.

Approval expiry date: 28 April 2019

MasterSeal 588 DWI 56/4/1128

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: IFU issue ref CG/ Rev 1- 09/01/2014.

Approval expiry date: 28 April 2019

MasterSeal M586 with MasterSeal M600 DWI 56/4/86

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: IFU issue ref CG/Rev 1- 11/03/2015.

Approval expiry date: 30 March 2020

British Cement Association

Cemline II DWI 56/4/465

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: NA

Use of these generic products must conform to the In-situ cement mortar lining-Operational Guidelines and Codes of Practice published by Water Research Centre plc,1990 (ISBN 0902156 84 5).

Flexcrete Technologies Ltd

Flexcrete Cementitious Coating 851 Grey DWI 56/4/1159

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: INSTRUCTION FOR USE IN PUBLIC WATER SUPPLY. CEMENTITIOUS COATING 851 GREY & WHITE. Bulletin No. 851/851W/031/009. Issued: October 2016

This product must be cured for a minimum of 21 days at a minimum temperature of 7°C or in accordance with the cure curve provided in the manufacturers IFU

Approval expiry date: 27 December 2021

Flexcrete Cementitious Coating 851 White DWI 56/4/1160

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: INSTRUCTION FOR USE IN PUBLIC WATER SUPPLY. CEMENTITIOUS COATING 851 GREY & WHITE. Bulletin No. 851/851W/031/008. Issued: July 2016

This product must be cured for a minimum of 7 days at a minimum temperature of 7°C or in accordance with the cure curve provided in the manufacturers IFU

Approval expiry date: 17 August 2021

Monolevel 844SP DWI 56/4/1161

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: INSTRUCTION FOR USE IN PUBLIC WATER SUPPLY. MONOLEVEL 844SP. Bulletin No.844SP/031/008 October 2016

Approval expiry date: 6 November 2020

International Paint Ltd

Intercrete 4820 DWI 56/4/1054

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: IFU in Public Water Supply_4820_200117, Issue Jan 17

The product must be cured in accordance with the cure curves provided in the Instructions for Use. The required cure time can be calculated by the user from the minimum daily temperature at the site of application. If the temperature cannot be measured and recorded then a minimum cure period of 21 days must be used. The minimum temperature for application is 5°C.

Approval expiry date: 17 May 2022

Intercrete 4841 DWI 56/4/1053

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: IFU in Public Water Supply_4841_200117, Issue Jan17

The product must be cured in accordance with the cure curves provided in the Instructions for Use. The required cure time can be calculated by the user from the minimum daily temperature at the site of application. If the temperature cannot be measured and recorded then a minimum cure period of 21 days must be used. The minimum temperature for application is 7°C

Approval expiry date: 17 May 2022

National Cement Distribution Ltd

NATCEM AC DWI 56/4/840

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: Issue no.2 September 2013

Approval expiry date: 5 May 2020

Sika Ltd

Sikatop-Seal 107 DWI 56/4/1083

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: SikaTop Seal 107 Waterproofing/damp-proofing cementitious slurry. Issue No: 03. November 2012

The product must be cured for a minimum 7 days at a minimum temperature of 7ºC.

Approval expiry date: 12 February 2018

Vandex International Ltd

CEMLINE BB G DWI 56/4/1092

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: VXI IFU UK CEMLINE BB-G, 12.2015 / 1

Approval expiry date: 2 December 2018

CEMLINE UM1 DWI 56/4/1099

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: VXI IFU UK CEMLINE UM1, 12.2015 / 1

Approval expiry date: 2 December 2018

CEMLINE BB-W DWI 56/4/1093

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: VXI IFU UK CEMLINE BB-W, 12.2015 / 1

Approval expiry date: 2 December 2018

CEMLINE CG DWI 56/4/1094

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: VXI IFU UK CEMLINE CG, 12.2015 / 1

Approval expiry date: 2 December 2018

Vandex Premix DWI 56/4/1097

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: 1.12.2013/1st issue

Approval expiry date: 2 December 2018

Vandex Super DWI 56/4/1098

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: 1/12/2013/1st issue

Approval expiry date: 2 December 2018

Xypex (UK) LLP

Xypex Concentrate DWI 56/4/1261

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: Issue No. 0610C - 6th October 2016

Approval expiry date: 16 February 2022

Xypex Modified DWI 56/4/1262

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: INSTRUCTIONS FOR USE. XYPEX MODIFIED. ISSUE NO: 1210M – 12th October 2016

Approval expiry date: 16 February 2022

C.6 Sealant & Repair Materials

BASF plc Construction Chemicals (UK) Ltd

MasterEmaco S420 with MasterSeal 600 DWI 56/4/1064

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: Ref CG/Rev 1 – 08/09/2015

Before connection to the supply, the water undertaker or their appointed agent, must carry out tests to establish that migration from the cement mortar lining will not cause a contravention of the upper prescribed concentration for hydrogen ion in the relevant Regulations .

Approval expiry date: 26 February 2018

MasterSeal 930 and MasterSeal 933 DWI 56/4/144

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: MasterSeal 930 Bandage and MasterSeal 933 Adhesive Application to potable water contact areas Instructions for Use Ref CG/Feb 2014

This product must be cured in accordance with the cure curve provided in the IFU document otherwise this product must be cured for a minimum of 10 days at a minimum temperature of 7°C.

Approval expiry date: 28 April 2019

Flexcrete Technologies Ltd

Fastfill DWI 56/4/1162

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: INSTRUCTION FOR USE IN PUBLIC WATER SUPPLY. FASTFILL. Bulletin No.FF/031/008. Issued: September 2016

This product must be cured for a minimum of 21 days at a minimum temperature of 7°C or in accordance with the cure curve provided in the manufacturers IFU

Approval expiry date: 5 October 2021

Monomix DWI 56/4/1163

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: INSTRUCTION FOR USE IN PUBLIC WATER SUPPLY. MONOMIX. Bulletin No.MON-031-008. Issued: October 2016

Approval expiry date: 28 October 2020

Monomix WS DWI 56/4/397

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: INSTRUCTION FOR USE IN PUBLIC WATER SUPPLY. MONOMIX. Bulletin No. MONWS/031/008. Issued: October 2016

Approval expiry date: 25 April 2021

Steel Reinforcement Protector 841 DWI 56/4/1164

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: Instructions for Use in Public Water Supply for Flexcrete Steel Reinforcement Protector 841. Bulletin No. 841031/007 Issued October 2016.

This product must be cured for a minimum of 21 days at a minimum temperature of 7°C or in accordance with the cure curve provided in the manufacturers IFU

Approval expiry date: 17 August 2021

Tiefill DWI 56/4/1287

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: Tiefill Bulletin No. TF/031/001 Issued: September 2016

Approval expiry date: 1 October 2022

Fosroc Ltd

Renderoc Plug 20 DWI 56/4/297

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: Renderoc Plug 20. Instructions for use. Ref: RRP20 IFU v3; Apr 13

Approval expiry date: 26 April 2018

International Paint Ltd

Intercrete 4802 DWI 56/4/1055

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: IFU in Public Water Supply_4802_200117, Issue Jan 17

The product must be cured in accordance with the cure curves provided in the Instructions for Use. The required cure time can be calculated by the user from the minimum daily temperature at the site of application. If the temperature cannot be measured and recorded then a minimum cure period of 21 days must be used. The minimum temperature of application is 10°C

Approval expiry date: 17 May 2022

Intercrete 4871 DWI 56/4/1056

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: IFU in Public Water Supply_4871_200117, Issue Jan 17

The product must be cured in accordance with the cure curves provided in the Instructions for Use. The required cure time can be calculated by the user from the minimum daily temperature at the site of application. If the temperature cannot be measured and recorded then a minimum cure period of 21 days must be used. The minimum temperature of application is 10°C

Approval expiry date: 17 May 2022

MG Solutions (UK) Ltd

Aquron 2000 DWI 56/4/1291

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: Aquron 2000 Colliodal Silicate for waterproofing of concrete IFU. Issue Date 21/08/2017; Issue Number 1.1

Approval expiry date: 2 November 2022

National Cement Distribution Ltd

NATCEM 35 DWI 56/4/1090

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: Product Information: NATCEM 35 Fast Setting Mortar Pre-Mix. Issue 3 Oct 2012

Approval expiry date: 11 March 2018

NATCEM AC DWI 56/4/840

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: Issue no.2 September 2013

Approval expiry date: 5 May 2020

NATCEM D DWI 56/4/1216

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: INSTRUCTIONS FOR USE DRY PRE-BLENDED GROUT NATCEM D

Issue Date: 23/03/16, Issue Number 1

Approval expiry date: 27 December 2021

NATCEM DW DWI 56/4/1049

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: Issue 1, 20 March 2013

Approval expiry date: 21 March 2018

Shotcrete 513 DWI 56/4/1089

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: Issue 2 October 2012

Approval expiry date: 11 March 2018

Waterstop DWI 56/4/1217

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: FAST SETTING NATURAL CEMENT WATERSTOP

Issue: 2, Date: 20/10/2016

Approval expiry date: 27 December 2021

Penetron UK Ltd

Penecrete Mortar DWI 56/4/1130

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: Instruction for Use PENECRETE MORTAR CRYSTALLINE WATERPROOF MORTAR. Issue No: I/1, Issue date: 12/02/2014

Before connection to the supply, the water undertaker or their appointed agent, must carry out tests to establish that migration from the cement mortar lining will not cause a contravention of the upper prescribed concentration for hydrogen ion in the relevant Regulations.

Approval expiry date: 18 September 2019

Penectron Crystalline Waterproof Coating DWI 56/4/1137

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: Instruction for Use PENETRON CRYSTALLINE WATERPROOF COATING. Issue No: I/1, Issue date: 19/05/2014

Approval expiry date: 19 September 2019

Sika Ltd

Sika Monotop 610/612 DWI 56/4/216

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: Issue 2, Jan 2013

The product must be cured in accordance with the cure curves provided in the Instructions for Use. The required cure time can be calculated by the user from the minimum daily temperature at the site of application. If the temperature cannot be measured and recorded then a minimum cure period of 21 days at a minimum substrate temperature for application is 5°C.

Approval expiry date: 14 May 2018

Sika Monotop 610/615 Concrete Repair System DWI 56/4/834

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: Sika Mono Top – 615 Cementitious High Build Concrete Repair Mortar. Issue No: 001. September 2007

The product must be cured in accordance with the cure curves provided in the IFU. The required cure time can be calculated by the user from the minimum daily temperature at site of application. If the temperature cannot be measured and recorded then a minimum cure period of 21days at a minimum substrate temperature for application is 5°C.

Approval expiry date: 12 March 2022

Sikacem 133S Gunite DWI 56/4/1084

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: Issue No: 003 Issue Date: January 2017

The product must be cured in accordance with the cure curves provided in the Instructions for Use. The required cure time can be calculated by the user from the minimum daily temperature at the site of application. If the temperature cannot be measured and recorded then a minimum cure period of 21 days must be used. Minimum substrate temperature for application is 5°C.

Approval expiry date: 30 May 2018

Sikadur Combiflex SG jointing system using Sikadur 31 DW DWI 56/4/94

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: Sikadur Combiflex SG Jointing system Issue No:006 October 2011

The minimum cure temperature is 7°C for a minimum cure time of 21 days. At temperatures greater than 7°C the product must be cured in accordance with the cure curve provided in the Instructions For Use. The required cure time can be calculated by the user from the minimum daily temperature which must be recorded at site.

Approval expiry date: 3 October 2021

Sikadur Combiflex SG jointing system, using Sikadur 31 DW Rapid DWI 56/4/1124

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: Sikadur Combiflex SG Jointing System, using Sikadur 31 DW Rapid. Issue No: 01, September 2013

This product must be cured for a minimum cure period of 7 days at a minimum temperature of 7°C.

Approval expiry date: 10 December 2019

Vandex International Ltd

CEMLINE STON DWI 56/4/1095

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: VXI IFU UK CEMLINE STON, 12.2015 / 1

Approval expiry date: 2 December 2018

Vandex Plug DWI 56/4/1096

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: 1.12.2013/1st issue

Approval expiry date: 2 December 2018

Xypex (UK) LLP

Xypex Admix C-1000 NF DWI 56/4/1263

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: Issue No 1210A1 - 12th October 2016

Approval expiry date: 16 February 2022

Xypex Patch'n Plug DWI 56/4/1100

Conditions of Approval: Use of the product must be in accordance with the Instructions for Use: 014 P 1 April 2013

Approval expiry date: 5 June 2019

附錄七

ACI 350.4R-04

「Design Considerations for Environmental Engineering Concrete Structures」

ACI Committee 350

Design Considerations for Environmental Engineering Concrete Structures

Reported by ACI Committee 350

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Environmental engineering concrete structures provide conveyance, storage, and treatment of water, wastewater, and other materials. This report outlines special design considerations such as loads, stability, joint details, and special design conditions that are unique to these types of structures as well as ancillary structures.

Keywords: buoyancy; clarifier; contraction; design; expansion; filler; flood; flotation; forces; hazardous; ice; impact; joint; load; overturning; reservoir; safety; sealant; sliding; stability; tank; tension; torque; vibration; waterstop; weights.

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CHAPTER 1—GENERAL

1.1—Scope

This report outlines design considerations that are unique to environmental engineering concrete structures and associated buildings. Environmental engineering concrete structures are defined in ACI 350 as concrete structures intended for conveying, storing, or treating water, wastewater, or other nonhazardous liquids, and for the secondary containment of hazardous liquids. Applicable building codes and other industry standards should be consulted for load and design considerations not included herein. The engineer should check with the local building department to confirm the applicable building code for the project location and determine if there are any local amendments.

The structural design recommendations given herein should be regarded as common industry practice and are recommended for general use. Any special structural features, unusual loading conditions, or unusual exposure conditions may require special design considerations to achieve a higher level of performance than implied by these minimum recommendations.

1.2—Related documents

Environmental engineering concrete structures should be designed and constructed in conformance with ACI 350/350R, 350.1, 350.2R, and 350.3. References 1 through 3 may also be useful in the design of liquid-containing structures.

CHAPTER 2—DESIGN LOADS

2.1—Floor live loads

Floor live loads in equipment and process areas generally take into account fixed equipment weights, stored material loads, and normal live loads due to personnel and transient loads. Floor live loads should account for installation, operation, and maintenance of equipment, and possible modifications or changes in use.

During installation or maintenance, portions of equipment may be laid down at various locations on the floor. For example, heavy electrical equipment may be temporarily placed near the center span of a floor during installation or maintenance, even though its final location may be near support locations. Weights of concrete bases for equipment may also be included in floor live loads, and consideration should be given to weights of piping, valves, and other equipment accessories that may be supported by the floor slab. Consequently, conservative uniform live loads are recommended.

Information on estimated equipment weights and footprints should be obtained so that design floor live loads can be verified. The engineer may consider distribution of the equipment loads over an area greater than the footprint dimensions using engineering judgment. Because actual equipment weights from various equipment suppliers may vary, conservative estimates of equipment weights should be used. A minimum floor live load of 150 lb/ft^2 (7.2 kPa) is commonly used for slabs that support equipment. Heavier live loads are common in electrical equipment rooms. Generally, stairways and walkways should be designed for a minimum live load of 100 lb/ft^2 (4.8 kPa). Where loads on catwalks are expected to be limited, a minimum live load of 40 lb/ft^2 (1.9 kPa) may be used in accordance with ASCE 7.

Large pieces of equipment may be assembled in their final fixed location. While temporary laydown of individual pieces of equipment should still be considered, it may be permissible to consider the total weight of the equipment only in its fixed location on the floor. Additionally, operational loads should be considered with the equipment in its fixed location. Operational loads may include thrusts, torques, contained fluids or sludge, or impact. For example, supports for vertical turbine pumps should include the weight of the vertical column of water in the riser, and sludge press loads should include the weight of the sludge being processed in the press.

In areas where chemicals or other materials are stored, the maximum weight of stored material should be determined based on the height and density or specific gravity of the material and its container(s). The material densities listed in Table 2.1(a) and (b) may be used for estimating applicable loads. ASCE 7 may be referenced for other common material densities and floor live loads. Chemicals can be delivered and stored by a variety of methods and mediums, including bags, barrels, bottles, cylinders, drums, kegs, pails, rail cars, sacks, totes, or trucks. The engineer should confirm the delivery method and storage method for design.

Caution should be used in applying floor live load reductions as permitted by building codes, due to the greater likelihood of simultaneous distributed loading in some equipment and chemical storage areas. Consider the potential change of use of adjacent areas when setting the floor live load. It is preferable to use the same design live load in adjacent areas where practical. Floor live loads should be posted as indicated in the applicable building code and should be identified on the design drawings.

2.2—Contained fluid and sludge loads

The principal applied loads on liquid-containment structures are due to the fluid pressures on the walls and slabs caused by the contained fluids. The following densities are conservative values for calculating equivalent fluid pressures of common environmental materials encountered that may be used in structural design:

- Raw sewage 63 lb/ft^3 (1000 kg/m^3)

- Grit excavated from grit chamber 110 lb/ft^3 (1800 kg/m^3)
- Digested sludge, aerobic 65 lb/ft^3 (1000 kg/m^3)
- Digested sludge, anaerobic 70 lb/ft^3 (1100 kg/m^3)
- Thickened or dewatered sludge 63 to 85 lb/ft^3 (1000 to 1400 kg/m^3) (depending on moisture content)

Fluid loads should be considered for both the normal fluid levels and for the worst-case fluid level. One such worst-case design condition is where the fluid is at the top of the containment structure or at the level at which overflow would occur elsewhere in the hydraulic system, such that high fluid levels could not occur at the location being evaluated. Many liquid-containment structures have encountered such overflow conditions in the past. The code-required load factors and environmental durability factors apply to normal maximum fluid levels. Code-required

Table 2.1(a)—Densities in inch-pound units of chemical for structural design (refer to Reference 4 for listing of selected chemicals)

Chemical	Density, lb/ft^3		Chemical	Density, lb/ft^3
Acetic acid	65 (liquid)		Fluosillicic acid	79 (liquid at 30%)
Activated carbon	Powder 8 to 28; average 12		Hydrochloric acid	73 (liquid at 35%)
Activated silica	Approximately 90 (liquid)		Hydrofluoric acid	73 (liquid at 55%)
Alum, liquid	83 (liquid at 60 °F)		Hydrogen peroxide	75 (liquid at 50%)
Aluminum ammonia sulfate	70 (granular or powder)		Methanol	98 (liquid)
Aluminum chloride solution	72 (liquid)		Oxygen	71 (liquid)
Aluminum potassium sulfate	70 (granular or powder)		Phosphoric acid	98 (liquid at 75%)
Aluminum sulfate	60 to 75 (granular, powder); 84 (liquid at 50%)		Polyaluminum chloride	91 (liquid at 5%)
Ammonia, anhydrous	43 (liquid at –28 °F)		Polyelectrolyte or polymer	Dry 88; liquid 62 to 92
Ammonia, aqua (ammonium hydroxide)	56 (liquid at 60 °F)		Polyphosphate (zinc orthophosphate)	80 to 100 (liquid)
Ammonia silicoflouride	80 (crystals)		Potassium aluminum sulfate	67 (crystals)
Ammonium aluminum sulfate (ammonium alum)	75 (crystals)		Potassium permanganate	102 (powder); 64 (3% solution)
Ammonium sulfate	60 (damp); 49 to 64 (dry) (crystals)		Sodium aluminate	High-purity 50; standard 60 (powder, crystals); 98 (45% solution)
Barium carbonate	52 to 78 (powder)		Sodium bicarbonate	62 (granular, powder)
Bentonite	Powder 45 to 60; granules 75		Sodium bisulfate	70 to 85 (powder, crystals)
Bromine	194 (liquid)		Sodium carbonate (soda ash)	Dense 65; medium 40; light 30 (granular, powder)
Calcium carbonate	Powder 35 to 60; granules 115		Sodium chloride	Rock 60; crystal 78; powder 66
Calcium hydroxide (hydrated lime)	20 to 50 (powder)		Sodium chlorite	80 (25% solution)
Calcium hypochlorite	Granules 80; powder 32 to 52		Sodium fluoride	Powder 65 to 100; granules crystal 106
Calcium oxide (quick lime, pebble lime)	55 to 70; 60 typical hopper load (pebbles)		Sodium fluorosilicate	72 (powder)
Carbonic acid (carbon dioxide solution)	62 (liquid)		Sodium hexametaphosphate (sodium polysulfate)	Glass 64 to 100; powder and granular 44 to 60
Chlorinated lime	50 (powder)		Sodium hydroxide	Pellets 70; flakes 46 to 62; 95 (50% solution)
Chlorine	92 (liquid)		Sodium hypochlorite	76 (liquid at 15%)
Citric acid	77 (liquid at 50%)		Sodium silicate	88 (liquid)
Copper sulfate	Crystal 90; powder 68		Sodium silicoflouride	Granular 85 to 105; powder-granular 60 to 96
Diatomaceous earth	Natural 5 to 18; calcined 6 to 13; flux-calcined 10 to 25 (fibrous material)		Sodium sulfate	70 to 100 (crystals, powder)
Disodium phosphate	Crystal hydrate 90; anhydrous 64		Sodium sulfite	Powder 80; granular 107; liquid 82 (at 12.5%)
Dolomitic hydrated lime	30 to 50 (powder)		Sodium thiosulfate	60 (granules, crystals)
Dolomitic lime	Pebble 65; ground or lump 50 to 65; powder 37 to 65; average 60		Sulfur dioxide	89.6 at 32 °F (liquid)
Ferric chloride	93 (liquid); crystal 64; anhydrous 45 to 60		Sulfuric acid	115 (liquid)
Ferric sulfate	72 (granular)		Tetrasodium pyrophosphate	Crystal 50 to 70; powder 46 to 68
Ferrous chloride	86 (liquid at 35%)		Trisodium phosphate	Crystal 60; monohydrate 65; anhydrous 70
Ferrous sulfate	66 (granular, powder)			

factors intended to improve durability may not be applicable to worst-case load conditions.

For enclosed liquid-containment structures, consideration should also be given to internal positive or negative air pressures caused by rapid filling or emptying of the containment structure. Positive and negative air pressures can also be caused by induced ventilation, such as for odor control. The worst-case design for negative pressure may be due to pipe rupture and rapid drawdown of the tank contents, and the maximum positive pressure is related to the maximum fill rate of the equipment. Generally, suitably sized gooseneck vents should be provided at top slabs to alleviate significant variations in

Table 2.1(b)—Densities in metric units of chemicals for structural design (refer to Reference 4 for listing of selected chemicals)

Chemical	Density, kg/m^3	Chemical	Density, kg/m^3
Acetic acid	1000 (liquid)	Fluosillicic acid	1300 (liquid at 30%)
Activated carbon	Powder 100 to 450; average 190	Hydrochloric acid	1200 (liquid at 35%)
Activated silica	Approximately 1400 (liquid)	Hydrofluoric acid	1200 (liquid at 55%)
Alum, liquid	1300 (liquid at 16 °C)	Hydrogen peroxide	1200 (liquid at 50%)
Aluminum ammonia sulfate	1100 (granular or powder)	Methanol	1600 (liquid)
Aluminum chloride solution	1200 (liquid)	Oxygen	1100 (liquid)
Aluminum potassium sulfate	1100 (granular or powder)	Phosphoric acid	1600 (liquid at 75%)
Aluminum sulfate	960 to 1200 (granular, powder); 1300 (liquid at 50%)	Polyaluminum chloride	1500 (liquid at 51%)
Ammonia, anhydrous	690 (liquid at –33 °C)	Polyelectrolyte or polymer	Dry 1400; liquid 990 to 1500
Ammonia, aqua (ammonium hydroxide)	900 (liquid at 16 °C)	Polyphosphate (zinc orthophosphate)	1300 to 1600 (liquid)
Ammonia silicoflouride	1300 (crystals)	Potassium aluminum sulfate	1100 (crystals)
Ammonium aluminum sulfate (ammonium alum)	1200 (crystals)	Potassium permanganate	1600 (powder); 1000 (3% solution)
Ammonium sulfate	960 (damp); 780 to 1000 (dry) (crystals)	Sodium aluminate	High-purity 800; standard 960 (powder, crystals); 1570 (45% solution)
Barium carbonate	830 to 1200 (powder)	Sodium bicarbonate	990 (granular, powder)
Bentonite	Powder 720 to 960; granules 1200	Sodium bisulfate	1100 to 1400 (powder, crystals)
Bromine	3100 (liquid)	Sodium carbonate (soda ash)	Dense 1000; medium 640; light 480 (granular, powder)
Calcium carbonate	Powder 560 to 960; granules 1800	Sodium chloride	Rock 960; crystal 1200; powder 1100
Calcium hydroxide (hydrated lime)	320 to 800 (powder)	Sodium chlorite	1280 (25% solution)
Calcium hypochlorite	Granules 1300; powder 510 to 830 (pebbles)	Sodium fluoride	Powder 1100 to 1600; granules crystal 1700
Calcium oxide (quick lime, pebble lime)	880 to 1100; 960 typical hopper load (pebbles)	Sodium fluorosilicate	1200 (powder)
Carbonic acid (carbon dioxide solution)	990 (liquid)	Sodium hexametaphosphate (sodium polysulfate)	Glass 1000 to 1600; powder and granular 700 to 960
Chlorinated lime	800 (powder)	Sodium hydroxide	Pellets 1100; flakes 740 to 990; 1520 (50% solution)
Chlorine	1500 (liquid)	Sodium hypochlorite	1200 (liquid at 15%)
Citric acid	1200 (liquid at 50%)	Sodium silicate	1400 (liquid)
Copper sulfate	Crystal 1400; powder 1100	Sodium silicoflouride	Granular 1400 to 1700; powder-granular 960 to 1500
Diatomaceous earth	Natural 80 to 290; calcined 100 to 210; flux-calcined 160 to 400 (fibrous material)	Sodium sulfate	1100 to 1600 (crystals, powder)
Disodium phosphate	Crystal hydrate 1400; anhydrous 1000	Sodium sulfite	Powder 1300; granular 1700; liquid 1300 (at 12.5%)
Dolomitic hydrated lime	480 to 800 (powder)	Sodium thiosulfate	960 (granules, crystals)
Dolomitic lime	Pebble 1000; ground or lump 800 to 1000; powder 590 to 1000; average 960	Sulfur dioxide	1400 at 0 °C (liquid)
Ferric chloride	1500 (liquid); crystal 1000; anhydrous 720 to 960	Sulfuric acid	1800 (liquid)
Ferric sulfate	1200 (granular)	Tetrasodium pyrophosphate	Crystal 480 to 1100; powder 740 to 1100
Ferrous chloride	1400 (liquid at 35%)	Trisodium phosphate	Crystal 960; monohydrate 1000; anhydrous 1100
Ferrous sulfate	1100 (granular, powder)		

internal air pressures. Where pressure or vacuum relief valves are provided to limit such pressures, structural design should account for minimum and maximum settings of such valves. Vents and relief valves should be designed such that they do not plug, freeze, or become inoperable due to corrosion.

At filter basins, walls may be subject to full hydrostatic pressure during backwashing, even though pressures may be less during the normal filtering mode. Where internal walls of liquid-containment structures will not be exposed to unbalanced static fluid loads due to flow arrangement, such walls should be designed for a minimum 6 in. head differential unless hydraulic analysis indicates a higher differential. Larger differential heads might occur during filling or draining operations than during normal flow conditions. Trashracks (bar racks) and other screening devices should be designed considering differential water pressure due to clogging. Such screening devices are often designed assuming a fully clogged condition with full hydrostatic head.

2.3—External earth loads

Walls subject to earth pressure should be carefully evaluated for structure-soil interaction. This evaluation should include determinations as to whether the wall is able to deflect sufficiently to reduce lateral earth pressures from at-rest soil pressures to active soil pressures and whether pressure diagrams due to backfilling are more trapezoidal than triangular. Because of conservative criteria used for design of liquid-containment structures, such walls are typically stiffer than common retaining walls. At-rest earth pressures should be assumed unless calculated deflections justify lower lateral earth pressures. Equivalent fluid pressures representing at-rest pressures resulting from equivalent fluid density values of 60 lb/ft^3 (960 kg/m^3) above the ground water table and 95 lb/ft^3 (1500 kg/m^3) below the ground water table are commonly assumed for preliminary design, but should be confirmed for final design.

Fully developed passive earth pressures may be associated with relatively large movements and, therefore, should be used with caution. The deformation required to mobilize 1/2 of the passive pressure is significantly smaller than that required for full mobilization.[5] Where the soil can be relied on to resist lateral loads and the resulting movement can be tolerated, passive pressures may be used. If passive pressure is used to resist lateral loads, pipes and other utilities connected to the structure should be designed for the expected movement. Design pressures on the structure should be based on the passive pressures developed to resist the lateral loads. For overturning and bearing-capacity analyses, resisting pressures used in design should not exceed 1/2 the maximum passive pressure.[5] Where the effects of lateral soil resistance are included in the design of retaining walls for some loading conditions, consideration should also be given to construction loading conditions. For construction loading conditions, the resisting soil may not be in place.

Where structures are buried, the roof loads should include the weight of the earth cover and applied loading due to vehicles or equipment used for placing the earth fill or accessing the interior of the structure. Pattern loading effects can be critical for buried roofs, and consideration should be given to some spans subjected to full earth and equipment loads with adjacent spans unloaded. These effects are particularly significant in flat slab roof systems and similar continuous span systems. Construction documents should indicate any restrictions on the placement, type, or weight of equipment to be used, and on the sequence or lift thicknesses for the earth cover. For the completed structure, surface live loads should be included to account for the proposed use. Loading limits should be posted to avoid overloading the structure during operation.

Where vehicles have access adjacent to walls, a surcharge equal to 2 ft (600 mm) of soil is commonly used in accordance with AASHTO Standard Specifications for Highway Bridges.

2.4—External fluid loads

External fluid pressures should be considered in addition to external earth pressures. Hydrostatic pressures outside of structures may occur due to high ground water conditions and floods. Elevated ground water conditions may occur due to leakage from adjacent liquid-containing structures and pipes or due to inadequate drainage around a structure. External fluid loads increase the effective lateral loads on the walls and may also cause flotation of the structure. All liquid-containing structures or individual cells of structures should be evaluated for the empty condition. Refer to Section 3.1 for additional discussion relating to floods and flotation.

2.5—Environmental loads

Environmental structures should also be designed for common environmental design loads such as wind, snow, thermal effects, and earthquakes. Such loads are typically defined in building codes and other industry standards. An appropriate importance factor should be selected from the building code unless a higher factor is requested by the client for improved reliability. Ice loads may also be significant for some structures.[6] Analysis and design should be in conformance with the ACI 350 code.

Seismic design for liquid-containment structures should be in accordance with ACI 350.3 where applicable. Interior walls and baffle walls that are designed for minimum static pressure should be designed for differential pressures due to fluid sloshing loads. Effects of lateral loads on equipment design and on equipment anchorages, including dynamic fluid loads, should also be considered. Fluid sloshing may induce additional loads on equipment appurtenances, such as for clarifiers and for paddle mixers. The center column supports for clarifiers should be designed to accommodate such additional forces.

Lateral earth pressures may be increased or decreased due to horizontal ground acceleration caused by earthquakes. The Mononobe-Okabe pseudostatic approach is commonly used to evaluate such load effects.[7-9] The seismic component of the lateral soil pressure is commonly assumed to be located at the upper third point of the soil height.[5] Vertical accelerations due to earthquakes may also increase or decrease effective fluid pressures and effective weights of materials.

2.6—Other design loads

2.6.1 *Impact loads*—Impact loads should be included where appropriate, such as from cranes and monorails, vehicles, elevators, lifting hooks, transient pressures in pipes, and due to equipment operation. An appropriate impact allowance as a percentage of the equipment weight may be used in accordance with recommendations of standard codes and specifications. Alternatively, a detailed transient load, dynamic analysis may be performed.

2.6.2 *Loads at pipe penetrations*—Pressure thrust loads at pipe penetrations through walls should be considered in wall design. The transfer of thrust from the pipe to the wall depends on restraint of the pipe within the wall and on restraint of the pipe joints on each side of the wall penetration. A fully restrained pipe may be able to carry thrust forces internally within the pipe material without transmitting external thrust to the wall of the structure. Each case should be examined for balancing the internal pipe thrust forces at bends and at joints. The design thrust force should be based on maximum test pressure or on transient pressure conditions, as applicable.

Horizontal pipe sections on the exterior side of walls may induce loads into the wall due to settlement of soil below the pipe section. Design and detailing should account for such conditions.

2.6.3 *Forces at gates*—At sluice gates and slide gates, gate hoists may induce significant loads into the structure, including eccentric loading on walls where brackets or corbels are provided for support of floor stands. Gates are often forced open or closed when sticking occurs or when obstructions are encountered, and concrete support members have often cracked due to the large upward or downward forces that develop.

AWWA C 560 and AWWA C 513 specify required design forces in stems for cast-iron sluice gates and fabricated-metal slide gates. Based on these requirements, concrete corbels and metal brackets used to support gate operators should be designed for the following forces:

- A minimum of 2-1/2 times the output thrust of the gate operator based on a 40 lb (180 N) effort applied at the crank for all gates with cranks; and
- The output thrust of the operator based on the stalled motor torque for electric motor operators or the cylinder capacity at maximum working pressure for hydraulic and pneumatic operators.

These forces may act in either direction. Both the supporting wall and corbel or bracket need to be designed to resist these forces.

2.6.4 *Forces at clarifiers*—Mechanisms in circular clarifiers generally are supported on a center column. This center column should resist large torques due to sludge loads on the long radial scrapers. As a minimum, the center column should be designed to resist the stalling torque of the scraper mechanism or the torque corresponding to the setting of the mechanism limit switch. This force can be considerable—as much as 5000 ft-kip (7000 kN-m) on a center column in a 500 ft (150 m) diameter clarifier.

The center column foundation should also be designed to resist this torque. The resisting moment arms of the soil friction and the earth pressure on the center foundation are relatively small, and it is possible for the center column foundation to slip and rotate. One solution for resisting this torque is to connect the center column foundation to the clarifier base slab. The torsional resistance of the foundation can also be increased by the use of batter piles at the perimeter of the foundation. Increasing the friction by increasing the foundation weight or increasing the area of the foundation to give a bigger lever arm, or both, will also provide greater torsional resistance.

Refer also to Section 2.5 regarding seismic forces at clarifiers.

2.6.5 *Internal pressure and vacuum*—Some environmental engineering concrete structures are designed for positive or negative gas pressures relative to atmospheric pressure. For example, anaerobic digesters typically operate at a low gas pressure of a few inches of water column. Air handling equipment for odor control will typically cause a slight negative gas pressure. Structures should be designed for the maximum anticipated internal pressures.

For safety, pressure and vacuum relief valves, or functionally equivalent systems, are installed on digesters to prevent the buildup of excessive gas pressure or vacuum. The pressure and vacuum relief valves are typically set to relieve at a few inches of water column. The digester should be designed for the maximum pressure and vacuum.

CHAPTER 3—STABILITY CONSIDERATIONS

3.1—Flood considerations

3.1.1 *Determination of flood design*—Special considerations are required for the design and construction of reinforced concrete structures that are subjected to forces caused by external flooding. Such flooding could be due to surface water, rising ground water, or a combination of both.

Environmental structures, particularly wastewater treatment plants, are frequently sited in areas subject to stream flooding and high ground water tables, where hydrostatic uplift pressures can significantly reduce the overall stability of the structure. Flood hazard maps, as produced by the Federal Emergency Management Agency (FEMA), may be available for sites in the vicinity of streams and rivers. Information and FEMA flood maps are available on the web at http://www.hazardmaps.gov/atlas.php. Most projects are designed for a 100-year flood event, unless higher flood levels such as the probable maximum flood, are appropriate for critical structures. The term probable maximum flood refers to the flood that would result from the critical combination of precipitation, ground saturation, and runoff factors considered reasonably possible in a particular drainage basin. Because of increased costs involved in protecting against the probable maximum flood and its extremely small chance of occurrence, its application is normally limited to design of spillways for dams, the sudden failure of which would result in extraordinary hazards to human life or in disastrous property damage.[10]

Where flood maps are not available, meteorological records may be available for evaluation of elevations and frequency of flooding for a given location. A qualified individual should review the available records to determine the project design flood.[11] The reliability of flood-frequency estimates is limited by the length and quality of hydrologic records available for the project drainage basin, the record's accuracy with respect to long-period characteristics, the probability of changes in factors that influence flood characteristics, the adequacy of analytical methods used, and other considerations. Experience and analysis have shown that estimates of flood data are usually subject to a relatively large margin of error and that extrapolations to events substantially less frequent are of questionable value in selecting design-flood criteria for a particular project. These factors should be considered in the selection of an appropriate project design flood and applicable factors of safety.

3.1.2 *Flotation safety factors*—The safety factor against flotation is usually computed as the total dead weight of the structure divided by the total hydrostatic uplift force. Weight of soil directly above structural components may also be considered in the dead weight. In some cases, frictional resistance due to soil embedment or a soil failure wedge may be considered to increase resistance against flotation. The hydrostatic uplift force may be determined either by calculating the displaced volume and multiplying that volume by the density of water or by calculating uplift forces due to hydrostatic pressures at the base of the structure. Eccentricities between the centroid of the dead weight and the centroid of the applied uplift should be considered.

The flotation safety factor should reflect the risk associated with the hydrostatic loading condition. Commonly used safety factors are 1.10 for worst-case conditions, such as flood to the top of structure and using dead weight resistance only, or 1.25 for well-defined design flood conditions (such as from a FEMA flood map) below the top of structure. A minimum safety factor of 1.25 is also recommended where high ground water conditions exist. Where maximum ground water or flood levels are not well defined, or where soil friction is included in flotation resistance, higher safety factors should be used. In any case, the maximum design condition need not exceed the condition of water to the top of structure, as the structure would either flood or become submerged under higher flood levels. Factors of safety against flotation apply to overall structure stability; individual structure components should be designed in accordance with ACI 350 for the design flood and ground water conditions.

3.1.3 *Design for flotation resistance*—Structures that extend below the design flood level or the maximum ground water level should resist flotation. If the dead weight of the structure does not provide an adequate factor of safety against flotation, then the following options should be considered, individually or in combination:

- Increase the base slab thickness, roof slab thickness, wall thicknesses, or soil cover to increase flotation resistance. When increasing the base slab thickness, be sure to account for increased uplift forces if the structure depth is increased.
- Extend the base slab beyond the walls of the structure to engage soil overburden loads to increase flotation resistance. Hydrostatic uplift at such slab extensions should be accounted for in the analysis.
- Depending on foundation conditions, tension piles, drilled piers, or drilled soil or rock anchors may be used resist uplift pressures. Overall flotation stability, including the buoyant weight of the engaged soil or rock mass, should be considered in addition to design of individual piles or anchors. Also note that where softer soils overlie stiffer soils or rock, compressive loads from the structure and settlement should also be considered when using these foundation systems.
- Where ground water can be drained away from the structure by gravity, a well-designed drainage system may be relied on to lower ground water. Perforated pipes embedded in free-draining material and provided with pipe cleanouts provide improved reliability. It may be difficult or impractical to provide reliable ground drainage systems that are subject to flooding conditions.

The above methods of improving flotation resistance are considered to be passive systems, as they do not rely on human intervention or on a mechanical system becoming or remaining active. Where such passive systems are not practical, the following active systems may be considered:

- In some cases, uplift pressures can be reduced by using foundation drainage systems in combination with pumps. Where drainage systems rely on pumping to maintain low ground water conditions at the location of a structure, backup pumps and emergency power should be provided to ensure reliability, or there should be specific plant-operating procedures to address precautions to be taken before dewatering a basin or tank.
- In some cases, uplift pressures can be limited by the use of pressure-relief systems in the base slab or sidewalls. Flap valves in sidewalls are generally considered to be more reliable than pop-up valves in base slabs. Pressure-relief systems can become clogged and non-functional, especially when used where sludge may collect in the vicinity of the relief valve. Also, open valves may interfere with mechanisms such as clarifier scrapers. Where relief valves are used, ground water should be assumed to be at least 1 ft (300 mm) above the elevation of the relief valve due to the pressure required to open the valve and the possible head buildup in the surrounding soil. The engineer should consider a drainage layer below the entire base slab to be hydraulically connected to the relief valves. This will reduce the possibility of pressure buildup between drained areas and will improve reliability. The rapid drainage of a tank or basin might not allow sufficient time for relief valves to lower ground water. Relief valves, which permit external water to enter and mix with the contained water, are not permitted to be used in potable water applications, such as in finished water tanks.
- Slab blowout panels may be provided where allowance can be made for repair time, if needed. The blowout panel should be designed to fail and allow water intrusion

before damage occurs to the remainder of the structure. Significant downtime may result if failure of the blowout panel occurs. Thus, such blowout panels are often used as a backup to other active systems.

- When none of these methods are practical, and when approved by the owner, an alarm system may be considered. The alarm system should alert the operator when a dangerous ground water elevation is reached so that the operator can start filling the containment structure to balance the uplift. There should be at least two independent alarm systems that are tested at regular intervals. Plant-operating manuals should include procedures to be followed when alarms indicate required action.

Higher safety factors are recommended for active systems than for passive systems because they may not be as reliable in an emergency event. Monitoring wells may also be advisable for monitoring ground water levels when using the above active systems for flotation resistance.

3.2—Sliding and overturning considerations

Sliding and overturning can occur to environmental structures and to individual components of environmental structures due to unbalanced soil conditions, unbalanced liquid levels, or wind or earthquake effects. The required factor of safety against sliding may be adjusted based on risk and probability of loading conditions, similarly to adjustments in load factors for such conditions. The sliding safety factor also accounts for the uncertainty that exists in determining in-place soil properties. The bearing capacity and minimum base area in compression, which also provide overturning resistance, may also be adjusted according to the design loading condition.

The minimum recommended safety factor against sliding, the minimum recommended base area to remain in compression, and the recommended bearing capacity safety factor are included in Table 3.1 for various loading conditions.

The usual condition includes loading conditions that are expected to occur during normal operation of the plant. The "earthquake condition" refers to load conditions that include seismic forces. The "unusual condition" includes temporary construction conditions and worst-case fluid levels. Special consideration should be given to stability at corners of liquid-containment structures and to effects of joint discontinuities, such as at expansion joints, on structural stability.

The sliding safety factor is determined by dividing the calculated sliding resistance along an assumed sliding plane by the applied shear forces acting along that plane. Sliding resistance should be based on soil friction, cohesion, or both, as applicable. Applied shear forces may be reduced by resisting earth or fluid pressures, as applicable. When designing a structure to satisfy a given factor of safety against sliding, the engineer should confirm that a realistic coefficient of friction is being used to calculate the factor of safety provided. The use of an excessively low coefficient of friction in design may result in a greater degree of conservatism than is intended. If a key is used to prevent sliding, the earth pressure on both sides of the key should be considered in the analysis. If passive earth pressure is being generated on one side of the key, generally, active pressure is occurring on the other side of the key. The resistance to sliding provided by the passive earth pressure is reduced somewhat by the opposing active earth pressure. Where hydrostatic uplift exists for a given loading condition, the uplift force should be included in the total forces on the sliding plane (that is, the sliding resistance may need to be reduced due to the buoyant effect.)

Table 3.1*—Safety factors for stability[5]

Loading condition	Minimum safety factor against sliding	Minimum base area in compression	Minimum foundation bearing capacity safety factor†
Usual	1.5	100%	3.0
Unusual	1.33	75%	2.0
Earthquake	1.10‡	Resultant within the base	1.0‡

*Table is not intended to apply to retaining structures that rely on anchorage devices, such as rock or soil anchors, for stability. Loads used to calculate safety factors should be service loads.

†Bearing-capacity safety factors may be adjusted based on recommendations of geotechnical engineer considering site-specific geotechnical conditions.

‡Low safety factor was established based on short-term nature of load, the ability of soil to resist higher short-term loads, and the rarity of sliding and overturning failures in earthquakes.

When the resultant falls within the middle 1/3 of the base, assuming a rigid rectangular foundation, the maximum and minimum pressure may generally be calculated using the following equations for a unit width, uniform strip.[5]

$$q_{max} = \left(\frac{P}{B}\right)\left(1 + \frac{6e}{B}\right) \qquad (3\text{-}1)$$

$$q_{min} = \left(\frac{P}{B}\right)\left(1 - \frac{6e}{B}\right) \qquad (3\text{-}2)$$

where

B = width of the base;
e = eccentricity of P relative to the centerline of the base;
P = total applied force normal to the foundation plane;
q_{max} = maximum foundation bearing pressure; and
q_{min} = minimum foundation bearing pressure.

When the resultant falls outside of the middle 1/3 of the base, assuming a rigid rectangular foundation, the maximum base pressure may generally be calculated using the following equation for a unit width, uniform strip[12]

$$q = \frac{\left(\frac{4P}{3}\right)}{B - 2e} \qquad (3\text{-}3)$$

The base width remaining in compression may generally be calculated using the following equation

$$B_c = \frac{3(B - 2e)}{2} \quad (3\text{-}4)$$

where B_c = base width remaining in compression.

CHAPTER 4—SPECIAL DESIGN CONDITIONS

4.1—Load combinations

4.1.1 *Loading combinations for walls*—Walls of liquid-containing structures are commonly subjected both to liquid pressure from the inside and earth pressure from the outside. Such walls and their supports should be designed for each of these loads acting independently. External earth pressure generally should not be relied on to resist liquid pressure because:

- Wall backfill may not be in place when the tank is filled initially for leakage testing;
- Earth pressures may be removed due to excavating for an addition, modification, or repair adjacent to the structure; and
- The resulting change in earth pressures due to the outward wall movements are difficult to predict.

For multicell fluid-containment structures, the effects of combinations of empty and full cells should be considered in the design.

4.1.2 *Tension loads*—Continuous walls and slabs between ends of rectangular liquid-containing structures should be designed to transfer tension forces between endwalls to balance the lateral forces due to the contained liquid. This direct tension force should be considered in the reinforcement design at corners, wall-to-slab connections, and along the entire length of the wall or slab. Where the cross section is fully in tension, the required tensile reinforcement should be distributed proportionately to each face. If significant flexural loads are present, the required area of tension reinforcement may either be conservatively added directly to the required area of flexural tension reinforcement, or the combined flexure and tension may be evaluated in accordance with ACI 340R (SP-17).

4.2—Expansion and contraction conditions

Roofs over environmental engineering concrete structures often cover large areas and they may be exposed to significant thermal movements. Stresses can occur in the walls and roof due to difference in thermal movement between the walls and roof. The stresses can be reduced by providing movement joints between the walls and the roof and within the wall and roof elements. Low-friction bearings or suitable flexible bearing pads should be incorporated into the design of the movement joints to prevent spalling and other damage due to direct tension.

Stresses can also occur in the walls and roof due to the difference in temperature and moisture through the thickness of the wall and roof section. These stresses should be considered in the design where applicable.

Large-diameter tanks expand and contract appreciably due to thermal changes, shrinkage, creep, and elastic deformations as they are filled and drained. The connection between the wall and footing of such tanks should be detailed to permit these movements to occur freely or design them strong enough to resist the movements without cracking. Similarly, the roof-to-wall connection should account for such movements.

Refer to Chapter 5 for additional discussion of design of joints in concrete structures.

4.3—Foundation conditions

Foundation design is critical to control cracking and maintenance of liquid tightness in liquid-containing structures. Differential movements can cause cracking in structures, failure of joints, failure of rigid pipe connections, or damage to operating equipment. Thus, variations in foundation stiffness should be avoided; for example, soil-supported elements should not be combined with elements supported on deep piles or drilled piers unless differential vertical movements are taken into consideration.

Similarly, where a portion of a structure is much shallower than an adjacent portion of the structure, the shallower portion may be prone to differential settlement due to the relative depth of fill materials below it. In some cases, the shallower portion of the structure may need to be supported on a deep foundation.

Typically, sliding resistance between the bottom of the structure and the soil is neglected when the structure is supported on piles or drilled piers.

4.4—Design and detailing considerations

Proper consolidation of concrete is essential in a liquid-tight structure. Thin, cast-in-place, reinforced concrete walls make placement and consolidation of concrete more difficult. The minimum thickness for walls that are greater than or equal to 10 ft (3 m) in height is 12 in. (300 mm) (ACI 350-01, Section 14.6.2). For lower walls, 10 in. (250 mm) is the practical minimum thickness for walls with reinforcement in each face. If 8 in. (200 mm) walls are used, a single mat of reinforcement placed 2 in. (50 mm) from one face is preferred to allow space for placing and consolidating the concrete. Greater thicknesses are desirable where waterstops are used, due to the limited space available for both reinforcement and waterstop placement with adequate concrete cover. For walls greater than 10 ft (3 m) in height, a reasonable rule of thumb is to use a minimum wall thickness equal to 1/12 the wall height for cantilever walls and 1/16 the height for propped cantilever walls. The minimum thickness of footings and mat foundations should generally be 12 in. (300 mm).

Liquid-containment walls may be designed as cantilever walls, propped cantilever walls, pinned endwalls, or two-way plates with various edge conditions, depending on support conditions. For propped cantilever walls and two-way plate walls, the assumption of full fixity at the base may not be entirely accurate, especially if supported on soil. A fixed-base assumption is normally conservative for design of the reinforcement at the base of the wall, but it may not be conservative for midspan reinforcement. Thus, consideration should be given to assuming partial fixity at the base. A conservative approach is to bracket the design by detailing wall reinforcement for both the fixed-base and pinned-base design conditions.

Except near corners and intersecting walls, long walls may be designed as one-way vertical spans. Near corners and intersecting walls, two-way plate action should be considered. A reasonable approximation of corner moments is to use two-way plate design tables based on a wall with the maximum tabulated aspect ratio.

Where two-way plate tables are used for wall design, the actual fluid depth may be somewhat less than the full wall height, as shown in the design tables. An approximate design method is to calculate the total lateral force on a unit length of wall due to the actual fluid depth and then redistribute this total lateral force over the full height of the wall.

The minimum required area of flexural tension reinforcement for structural slabs and footings of uniform thickness can be reduced to that permitted for minimum shrinkage and temperature reinforcement per ACI 350. Where one-way slabs and walls are uniformly loaded by liquid or earth loads and are intended to be liquid-tight, consideration should be given to the use of the minimum recommended flexural reinforcement as required for beams where an overload condition could result in a sudden or brittle failure.

Reinforcement in each face of structural members should be extended for the full length of the member for improved crack control and structural ductility. For crack control, smaller bars at closer spacing are preferred over larger bars at a wider spacing.

4.5—Vibration conditions

4.5.1 *General*—Most types of process equipment associated with treatment plants, such as clarifiers, scrapers, and paddle mixers, are relatively slow moving and will not cause structural vibrations. For such equipment, a separate design for dynamic loading is unnecessary. Other commonly used equipment, such as centrifugal pumps, fans, blowers, compressors, centrifuges, and generator engines, however, can have much higher operational frequencies and will require special consideration in the design of their support structures and foundations. Usually, the value of such equipment and its reliability is much greater than the cost of the foundation, so that it is imprudent to economize on foundation costs and run the risk of shortened machine life, increased maintenance costs, and breakdowns.

In treatment plants, machines that most often cause vibration problems are large forced-draft fans (blowers), as used for aeration tanks, and centrifuges, as used for dewatering of sludge. These are very sensitive machines and require carefully designed foundations to prevent resonant vibration. Chemical mixers may also produce of significant dynamic loads that should be considered in the design of their supports.

4.5.2 *Design for vibration*—The key to successful dynamic design is to ensure that the natural frequency of the equipment support structure is significantly different from the frequency of the disturbing force caused by the equipment. If the two frequencies approach each other, resonant vibrations will occur in the support structure. Resonant vibrations in the support structure that result in large amplitude oscillations can cause damage to the structure, to the equipment, or both. To minimize resonant vibrations, the ratio of the natural frequency of the structure to the frequency of the disturbing force should be outside of the range of 0.5 to 1.5. It is difficult to obtain an accurate determination of the natural frequency of concrete members due to variations in concrete strength, modulus of elasticity, and cracked or uncracked sections.

Theoretically, the structure can be designed to have a natural frequency that is lower than the operating frequency of the equipment. This practice is commonly referred to as low tuning and is intended to avoid resonant vibration. This method is generally not recommended, but sometimes cannot be avoided. Low-tuned structures tend to be relatively flexible and have higher deflections. Low tuning is most practical for equipment that has an operating frequency that is much higher than the natural frequency that can be practically achieved for the supporting structure. A disadvantage of low tuning is that the machine would pass through the resonant frequency of the supporting structure at startup and shutdown. If the resonant condition is transient, it is unlikely that it would cause damage to the machine, but it is generally preferable to keep operational deflections low. Many types of equipment come up to full operating speed in a few seconds. For this equipment, the short period when a resonant condition exists would not be long enough to allow excessive amplitude to build. The resonant condition can be more of a concern for equipment that takes a long time to reach full operating speed. Of special concern is equipment where the operating speed can be adjusted over a range that includes the resonant frequency of the supporting structure. If the equipment was set to operate at the resonant frequency of the supporting structure, excessive amplitude may occur, possibly causing damage to the supporting structure and the equipment. Furthermore, if the supporting structure is stiffer than estimated, its natural frequency may be higher than calculated. Some causes of the supporting structure being stiffer than calculated would include the concrete being stronger than the design strength, a cracked section being assumed for calculations and the concrete cracks less than assumed, construction tolerances resulting in larger members than used in design, and the length of members used in calculations not taking into account the member thickness at joints. Simplified analysis methods that overestimate structure deflections may also result in the structure's actual natural frequency being higher than calculated. Therefore, it is preferred to use a stiff structural support system with a natural frequency at least 1-1/2 times the equipment frequency (also known as high tuning). With high tuning, any underestimation of the support structure natural frequency will not create a risk of resonant vibration.

If the equipment is not supported directly on a solid foundation but is supported on columns and beams, the natural frequency of the support members is of primary importance. The supporting members should have both sufficient stiffness and strength to eliminate the risk of resonant vibrations. It may be desirable to use vibration isolators, especially on elevated structures, to reduce the magnitude of vibrations transferred to the structure. This should not be used as an alternate to considering dynamic effects because all isolators transmit some vibration. The amount of equipment vibration transmitted through the vibration isolators will vary with the operating frequency of the equipment and the design of the vibration isolators. Detailed information on transmissibility can be obtained from the isolator vendor.

The natural frequencies of a structure should be calculated for the vertical direction and for the two principal horizontal directions. In some cases, torsional frequency may also need to be examined. To combine the effects of several masses, the combined natural frequency can be estimated using the Raleigh Method. Where masses are not closely coupled dynamically (that is, natural frequencies are not too close to one another), the following Southwell-Dunkerley[12] formula may be used

$$\frac{1}{F_n^2} = \frac{1}{F_1^2} + \frac{1}{F_2^2} + \frac{1}{F_3^2} + \frac{1}{F_4^2} + \dots \quad (4\text{-}1)$$

where

F_n = combined natural frequency;
F_1 = natural frequency due to mass 1;
F_2 = natural frequency due to mass 2;
F_3 = natural frequency due to mass 3; and
F_4 = natural frequency due to mass 4.

Drilled-in expansion anchors that rely solely on friction for pullout resistance should not be used to anchor vibrating equipment, as they can work loose. Cast-in-place anchor bolts are preferred. Alternately, epoxy-grouted anchor bolts may be considered where drilled-in anchors are necessary.

4.5.3 *Calculating natural frequency*—Readily available commercial software programs can be used to calculate the natural frequency of structures and members of structures. Formulas are also available in technical books on vibration for calculating the natural frequency of beams.

A method of estimating the natural frequency of a structure is to apply gravity to the masses being considered, with gravity applied in the direction being considered (that is, apply gravity horizontally instead of vertically for horizontal natural frequency). Then calculate the deflection due to this loading assumption and calculate the fundamental natural frequency (due to the first mode of vibration) from the following formula for a single degree of freedom system

$$F_n = \frac{1}{2\pi}\sqrt{\frac{g}{D}} \quad (4\text{-}2)$$

where

D = calculated deflection;
F_n = fundamental natural frequency; and
g = acceleration due to gravity.

This formula is derived from the general equation for natural frequency of a single degree of freedom system as follows

$$F_n = \frac{1}{2\pi}\sqrt{\frac{k}{M}} \quad (4\text{-}3)$$

where

F_n = fundamental natural frequency;
k = W/D = spring constant (force per unit deflection);
M = W/g = mass; and
W = weight of considered mass.

The masses multiplied by the acceleration due to gravity (equivalent to the weight of the masses under consideration) are applied to obtain the effective spring constant of the structure, which is directly related to the stiffness of the structure as calculated by its deflection. Thus, the deflection calculation for determining natural frequency should not include any live loads or dynamic operational loads. The deflection calculations should only include the weights associated with the masses that contribute to the frequency of the system (for example, the equipment mass, the mass of any contained fluids, and the supporting structure mass).

Natural frequency of beams in cycles per second can be calculated using the expressions given in Table 4.1. These equations provide a simple method of calculating the approximate natural frequency of a beam from its static deflection; D is the immediate elastic deflection at the noted location due to the uniform or concentrated weight applied in the direction under consideration to a beam with the noted end

Table 4.1—Natural frequency of beams

End condition End 1-End 2	Load	Position of deflection D	Natural frequency (cycles per s)
Fixed-Free	Uniform	End 2	$0.20\sqrt{\frac{g}{D}}$
Pin-Pin or Fixed- Fixed	Uniform	Midspan	$0.18\sqrt{\frac{g}{D}}$
Fixed-Fixed or Fixed-Free or Pin-Pin	Concentrated (any position)	Under load	$0.16\sqrt{\frac{g}{D}}$

Notes: D = deflection in inches (mm); g = 386 in./s^2 (9804 mm/s^2). Multiply natural frequency by 60 to calculate RPM.

Table 4.2—Recommended maximum static deflections of beams supporting vibratory equipment

Operating frequency of equipment, cycles per min	Minimum natural frequency of structure, cycles per min	Maximum static deflection due to dead load and equipment load, in. (mm)
400	600	0.10 (2.5)
600	900	0.044 (1.1)
800	1200	0.025 (0.64)
1000	1500	0.016 (0.41)
1200	1800	0.011 (0.28)
2000	3000	0.004 (0.10)
2400	3600	0.0027 (0.069)

conditions. Instead of a comprehensive deflection analysis, *D* can be estimated using the methods outlined in ACI 318.

Table 4.2 shows the minimum recommended natural frequency of the structure to be at least 1-1/2 times the operating speed of the equipment. Table 4.2 also shows the maximum static deflection permissible for the supporting structure, as calculated using the equation for a concentrated mass on a beam. The effect of the mass of the beam can be approximated as a concentrated load at the center of the beam, or a more refined analysis accounting for uniform loads can be developed. This approximation will result in a larger deflection and in a lower calculated natural frequency. The resulting natural frequency should be evaluated in comparison with the equipment operating frequency and checked for susceptibility for resonance. The small deflections (or stiffer structures) required for high-frequency equipment (that is, greater than 1200 cycles per minute) may not be practical to achieve, and low tuning may be required. Motors used to drive pumps and other equipment often operate at high rotational speeds, but electrical motors are generally well balanced and do not tend to cause significant vibrational problems. Consequently, motor supports are generally not designed for vibrational effects due to the usually high motor speed, but such supports should be relatively stiff to avoid vibrational problems. Vibration isolators may be desirable at the motor support points.

4.5.4 *Foundations at grade*—Where dynamic equipment loads are to be supported using spread foundations, the safe design bearing load is often assumed as 1/2 of the allowable foundation bearing load for a statically loaded foundation at the same location.[13,14] Some sources recommend minimum foundation-to-equipment mass ratios, generally in the range of 2 to 5.[9] Adherence to this rule has not always proven satisfactory,[15] and to ensure that critical equipment will not be in resonance with the foundation, the natural frequency of the foundation system should be calculated. For natural frequency calculations, follow the methods recommended in Reference 13. For pile-supported foundations, follow the recommendations found in References 16 through 18. Often the equipment foundation is intentionally isolated from the floors or other parts of the structure to minimize the transmission of vibrations to other parts of the structure.

Block foundations should typically be at least 24 in. (600 mm) in thickness and have a width greater than the vertical distance from the top of foundation to the center of gravity of the equipment. Preferably, the center of gravity of the foundation in plan should match the center of gravity of the equipment.[12]

More detailed information on dynamic analysis methods and the dynamic design of foundations can be found in References 19 through 23. Additional information may be available for the design of equipment foundations from ACI Committee 351, Foundations for Equipment and Machinery.

4.6—Hazardous design conditions

Superstructures of environmental engineering concrete structures are frequently similar to conventional structures. In some facilities, the gases generated within the structure, adjacent to it, or below it may be toxic or may present an explosion hazard. Where buildings or equipment rooms are located over or adjacent to tanks or digesters, the tanks may require gas-proofing by means of liners, installation of gas-detection equipment, or both.

At least one access point should be provided into each enclosed cell for inspection and maintenance. Where practical, two access points should be provided at opposite ends of enclosed structures for improved safety.

Confined space entry (CSE) requirements, as defined by OSHA, should be considered in the design of all below-grade or unventilated structures. Provisions for adequate ventilation and safe exit passage may eliminate CSE limitations for operating personnel.

4.7—Corrosive conditions

Special consideration should also be given to the possible hazardous and corrosive effects of gases such as chlorine, oxygen, ozone, hydrogen sulfide, and methane gases in closed tanks. Corrosion-resistant linings may be required to protect the concrete, especially where hydrogen sulfide gases occur above the water surface in closed structures. Corrosive effects on metal embedments are also very important. Furthermore, consideration should be given to corrosive effects of stored or applied chemicals in the treatment process. Where hazardous chemicals are stored, containment basins should be provided to contain the chemicals in case of leakage. Corrosion-resistant linings in the containment basins may be necessary to protect the concrete in the event of a spill or leakage. Refer to ACI 350-01 for a listing of chemicals commonly associated with environmental structures and their relative effects on concrete.

4.8—Construction conditions

Low-permeability concrete is obtained by using a water-cementitious material ratio (*w/cm*) as low as possible and consistent with satisfactory workability and good consolidation. The use of a water-reducing admixture will generally permit the use of a lower *w/cm*. Air entrainment increases workability and reduces segregation and bleeding, thus, the use of an air-entraining admixture generally permits the use of a lower *w/cm*. Pozzolans also improve workability and reduce permeability. Permeability is reduced with extended moist curing and with the use of smooth forms or troweling. The filling and patching of tie holes is also essential to long-term durability. Form ties with waterstop collars should be used in walls intended to be liquid-tight.

Liquid-containment structures are generally tested for liquid-tightness before backfilling around the structure. Such testing should be performed in accordance with the recommendations of ACI 350.1.

The contractor is normally responsible for construction loading conditions. The engineer, however, should anticipate interim loading conditions, design for such conditions, and note permitted interim conditions on the drawings where such designs will simplify construction and reduce costs. For example, a wall may be designed to resist backfill loads before the top slab is in place, where it will simplify construction. This condition may be especially important if an upper slab-on-ground cannot be constructed until backfill is placed against a lower foundation wall.

Where the dewatering of excavations is required due to the presence of ground water, the engineer should identify at what stage of construction dewatering can be terminated based on the strength and flotation resistance of the structure.

CHAPTER 5—JOINTS IN CONCRETE

5.1—General

The engineer should consider the structural effects of joint locations and details on the design. Generally, the engineer should show all required joints on the construction documents. Any joints proposed to be added or deleted by the contractor should be reviewed by the engineer after consideration of effects on the structure's design and crack control.

Movement joints permit dimensional changes in concrete due to load, thermal effects, drying shrinkage, or differential foundation movements; serve to separate or isolate areas or members that could be affected by such dimensional changes; and allow relative in-plane movements or displacements due to such dimensional changes. Dowels are often used in movement joints to resist out-of-plane movements. The design should provide for slippage of the dowel on one side of the joint. Keyways may be used in nonmovement joints but should be used with caution in movement joints due to the potential for a crack to occur across the keyway and around the outside of the waterstop. Figure 5.1 illustrates some of the most common types of movement joints.

All joints should be considered as potential sources of leakage. Leakage tends to occur more frequently in movement joints, with expansion joints being the most likely to leak. While closer spacing of movement joints may reduce cracking between joints, the additional joints may increase the potential for overall basin leakage. Thus, increased joint spacing, in conjunction with increased reinforcement to control crack widths, may reduce total basin leakage.

Effects of movement joints on load transfer should be considered in design. For example, at joints in which reinforcement is interrupted, the transfer of tension across the joint is also interrupted. Movement joints may also affect continuity of shearwalls or diaphragms.

Where joint materials will be in contact with water being treated for use as potable water, the materials must be nontoxic, generally after 30 days of curing.

5.2—Construction joints

Construction joints are generally located at natural breaks in concrete placements, such as between wall and slab placements, and at intervals to limit length and volume of concrete placements. Movement joints also function as effective construction joints, that is, breaks in concrete placements. Unless otherwise noted or shown, construction joints are typically designed for full transfer of stresses across the joint. Keyways or roughened surfaces with shear-friction reinforcement are typically used for shear transfer at construction joints.

Cracking can occur in long wall or slab placements due to the effects of thermal movements and drying shrinkage in combination with movement restraints on the element. The maximum length of wall placed at one time for conventionally reinforced straight walls should usually not exceed 60 ft (18 m), with 30 to 50 ft (9 to 15 m) being more common.[2] At vertical construction joints, 48 h should be allowed between placement of adjacent wall sections. Extra horizontal reinforcement may be desirable near the base of the wall to assist in control of cracks near the base.

Large circular basins typically use only construction joints and no movement joints. Typically, a center circular concrete placement is made, with the remainder of the slabs and walls placed in equal segments.

5.3—Movement joints

5.3.1 *Contraction joints*—Contraction joints are often used to dissipate shrinkage stresses and to control cracking. Where used, contraction joints should be located at intervals not exceeding 30 ft (9 m), unless additional reinforcement is provided as required in ACI 350-01, Section 7.12. Shrinkage will occur regardless of the amount of reinforcement provided; however, the increased reinforcement tends to distribute cracks and limit crack widths. Because cracks occur at weak points, the intent of contraction joints is to concentrate full-depth cracks at specific locations where measures can be taken to protect against leakage.

Two types of contraction joints, known as full and partial contraction joints, are in common use. In full contraction joints, all reinforcement should be terminated 2 in. (50 mm) clear of the joint. In partial contraction joints, at least 50% of the reinforcement should be terminated 2 in. (50 mm) clear of the joint, with the remainder being continuous through the joint. The surface of the joint should be treated to prevent bonding with the adjacent concrete placement where fresh concrete is placed against hardened concrete. Full contraction joints provide less restraint against shrinkage at the joint; however, partial contraction joints provide some shear transfer and limit differential movements across the joint due to partial continuity of the reinforcement. Because the use of a partial contraction joint creates a weak plane, consideration should be given to seismic performance of these joints (for

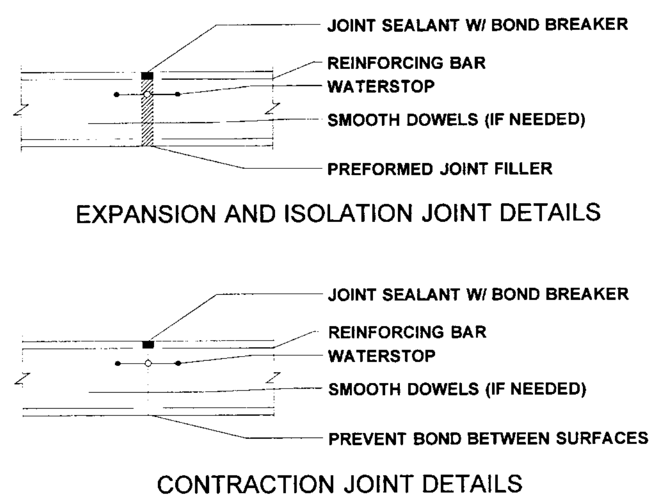

Fig. 5.1—Movement joints.

example, effects due to high, localized energy dissipation). Partial contraction joints are typically spaced at about 2/3 the spacing used for full contraction joints. Even though partially reinforced, such joints should be assumed to open when considering the moment, shear, and diaphragm shear capacity at such joints.

5.3.2 *Expansion joints and isolation joints*—Expansion joints allow for thermal expansion and act as effective contraction joints. Expansion joints tend to have the most problems with long-term leakage in liquid-containment structures, so their usage should be limited. Expansion joints are generally used in very long structures (typically over 150 ft [45 m] in length) or where abrupt changes in configuration or support occur.

All expansion joints should include some type of preformed compressible filler and a joint sealant at the liquid face. If the structure must be liquid-tight, a suitable waterstop should be included to act as the primary barrier against leakage. The waterstop, preformed filler, and joint sealant should be selected to allow for the anticipated movement and should be suitable for the service environment. Refer to ACI 504R for recommended joint design and materials of construction.

Isolation joints serve to separate portions of a structure, such as between vibrating equipment foundations and building foundations or between column foundations and floating slabs. Such joints should include some type of preformed compressible filler and a joint sealant at the exposed face to keep dirt, debris, and water from entering the joint, as well as a waterstop, where required, for liquid tightness.

5.4—Waterstops

Waterstops are required in all types of joints where liquid tightness is required. Rubber waterstops permit the greatest joint movement and last indefinitely when placed in a dark and humid environment that is not corrosive to rubber. Polyvinyl chloride (PVC) waterstops permit somewhat less movement than rubber but are less sensitive to light exposure during construction and to drying. Another advantage of PVC waterstops is the simplicity of splicing by applying heat. The minimum sizes of either type of flexible waterstop commonly used in environmental structures is 3/8 x 9 in. (10 x 230 mm) for expansion joints and 1/4 x 6 in. (6 x 150 mm) for construction or contraction joints. Minimum 3/8 x 6 in. (10 x 150 mm) waterstops should be used at wall base joints where possible to avoid folding under wet concrete placement. Copper waterstops have also been used effectively. Stainless steel waterstops are typically used in ozone process environments, due to the damaging effect of ozone on other materials used for waterstops. Refer to ACI 504R for additional discussion of waterstop materials.

Rigid (metal) waterstops should not be used in movement joints. Rubber or PVC waterstops with a center bulbs are common in movement joints. Concrete cover at flat waterstops should be equal to or greater than 1/2 the width of the waterstop. Adequate support and careful concrete placement should be provided to ensure proper position and embedment of the waterstop in the concrete. For vertical waterstops, the use of tie wires tied to the reinforcement to anchor the waterstop in position should be considered. For flexible horizontal waterstops, the following construction sequence should be considered:

a. Fold the waterstop upward along its entire length and hold in position;

b. Place and consolidate concrete up to the elevation of the waterstop;

c. Reposition the waterstop into the top of the fresh concrete; and

d. Complete concrete placement and consolidation around the remainder of the waterstop.

A number of alternative waterstop types have become available, such as premolded adhesive waterstops; premolded, expansive, water-reactive waterstops; and injection tube waterstops that are injected with water-reactive chemical grout. Some waterstops are available that combine more than one of the above types. The effectiveness and applicability of a particular waterstop system to any given situation should be evaluated by the engineer. Some of these alternative waterstops can provide solutions where new construction is to be tied to existing construction and should be liquid-tight or where backup systems to ensure liquid-tightness are required. Waterstops that expand and contract with varying exposure to moisture may leak initially until the reaction with moisture takes full effect. Such waterstops may be less desirable where frequent wetting-and-drying cycles may occur or where water is not in contact with the joint during normal operations. Also, such waterstops may not be effective for containment of liquids other than water, and most of these alternative waterstops are not recommended for movement joints. Where such alternative waterstops intersect rubber or PVC waterstops, the method of connecting for continuity of liquid tightness should be specified.

5.5—Joint fillers

Preformed joint filler serves dual tasks: it serves as a form for the second placement of concrete while preserving the space into which the concrete may intrude, and it prevents dirt and water from filling the formed space in service. An ideal joint filler will permit compression to 1/2 its original width and will re-expand to fill the joint when the adjacent members contract. Cork, rubber, foam, and other materials conforming to ASTM D 1056 and D 1752 are satisfactory joint fillers. In general, these joint fillers are not capable of expanding beyond their initial width and require precompression to exhibit expansion characteristics. The effect of precompression, however, may be reduced with time due to relaxation.

5.6—Joint sealants

Sealants used in movement joints should be placed on the liquid side and should be suitable for the service environment, such as submerged service and exposure to wastewater and chemicals. Sealants and joint fillers should be compatible with each other. Joint sealants are not expected to function for the entire life of a structure. Owners should be advised of the need to repair, maintain, and reseal joints with proper sealants at proper maintenance intervals. Joint sealants should not be relied on to act as the primary barrier to leakage in containment structures.

Where the movement will be not more than 25% of the joint width, polyurethane elastomers, as referred to in ACI 504R, are suitable joint sealants. These materials are available in two types: self-leveling or pourable for horizontal joints, and nonsagging for vertical or sloping joints. Bituminous joint fillers should not be used in conjunction with polyurethane sealants, as they may impair adhesion (ACI 504R).

Polysulfide sealants are not suitable for use in wastewater treatment plants because they generally have low resistance to the chemical and biological reactions inherent to wastewater treatment. In addition, the chemical reactions necessary for the curing process of these sealants are impeded by the presence of moisture.

CHAPTER 6—REFERENCES

6.1—Referenced standards and reports

The standards and reports listed below were the latest editions at the time this document was prepared. Because these documents are revised frequently, the reader is advised to contact the proper sponsoring group if desired to refer to the latest version.

American Association of State Highway and Transportation Officials

Standard Specifications for Highway Bridges

American Concrete Institute

318 Building Code Requirements for Structural Concrete

350/350R Code Requirements for Environmental Engineering Concrete Structures and Commentary

350.1 Tightness Testing of Environmental Engineering Concrete Structures

350.2R Concrete Structures for Containment of Hazardous Materials

350.3 Seismic Design for Liquid-Containing Concrete Structures

504R Guide to Sealing Joints in Concrete Structures

SP-17 ACI Design Handbook

American Society of Civil Engineers

ASCE 7 Minimum Design Loads for Buildings and Other Structures

American Water Works Association

C 560 Cast-Iron Slide Gates

C 513 Open-Channel Fabricated-Metal Slide Gates

American Water Works Association/American Society for Civil Engineers

Water Treatment Plant Design

ASTM International

D 1056 Standard Specification for Flexible Cellular Materials—Sponge or Expanded Rubber

D 1752 Standard Specification for Preformed Sponge Rubber and Cork Expansion Joint Fillers for Concrete Paving and Structural Construction

These publication may be obtained from the following organizations:

American Association of State Highway and Transportation Officials
444 Capitol St NW Suite 249
Washington, DC 20001

American Concrete Institute
P.O. Box 9094
Farmington Hills, MI 48333-9094

American Society of Civil Engineers
1801 Alexander Bell Dr.
Reston, VA 20191

American Water Works Association
6666 West Quincy Ave.
Denver, CO 80235

ASTM International
100 Barr Harbor Drive
West Conshohocken, PA 19428

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22. Skipp, B. O., ed., *Vibrations in Civil Engineering*, Butterworths, London, 1966, 298 pp.

23. Major, A., *Vibration Analysis and Design of Foundations for Machines and Turbines*, Colets, London, 1962, 828 pp.