107-032-0273

出國報告(出國類別:其他)

新增 106 年度「『離岸風能場遴近海岸漂沙機制探討』試驗室造波機購置赴原廠進行技術交流活動」出國計畫

出國報告

服務機關:交通部運輸研究所
姓名職稱:李政達副研究員、林受勳助理研究員
派赴國家:英國
出國期間:106 年 12 月 12 日至 12 月 20 日
報告日期:107 年 02 月 21 日

新增 106 年度「『離岸風能場遴近海岸漂沙機制探討』試驗室造波機購置赴原廠進行技術交流活動」

出國計畫

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網　　址：www.iot.gov.tw (中文版＞圖書服務＞本所出版品)
電　　話：(02)23496789
出版年月：中華民國 107 年 2 月
印 刷 者：文晃數位科技有限公司
版(刷)次冊數：初版一刷 10 冊

107

新增106年度「『離岸風能場遴近海岸漂沙機制探討』試驗室造波機購置赴原廠進行技術交流活動」出國計畫

交通部運輸研究所

系統識別號：C10700214

行 政 院 及 所 屬 各 機 關 出 國 報 告 提 要

頁數：220　　含附件：無

報告名稱：新增 106 年度「『離岸風能場遴近海岸漂沙機制探討』試驗室造波機購置赴原廠進行技術交流活動」出國計畫--出國報告

主辦機關：交通部運輸研究所

出國計畫主辦機關/聯絡人/電話：

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出國類別：☐1.考察☐2.進修☐3.研究☐4.實習☑5.其他

出國期間：106 年 12 月 12 日至 12 月 20 日

出國地區：英國牛津

報告日期：107 年 02 月 21 日

分類號/目：HO／綜合類（交通類）　　　　HO／綜合類（交通類）

關鍵詞：波浪特性(Wave characteristics)、模型設計(Model design)、浮動結構和船舶繫泊線(Floating structures and vessel mooring lines)、海嘯之建模(Modelling Tsunamis)、漂沙沉積物傳輸模式(Sediment transport)、設備和儀器(Equipment & instrumentation)

內容摘要：

行政院指派交通部協助風電產業開發事項，本所應辦理相關研究及技術發展之「離岸風電場鄰近海岸漂沙機制探討」工作項目，編列試驗室造波機購置，甫經公開招標決標結果，得標採用英國 HR 公司提供之平面造波系統，目前國外製造設備所具有功能優勢，是以國內暫無類似產品或其效能無法取代。依據計畫招標規範需求造波機設備，須以專業和具豐富經驗的製造、維護廠商，所生產製造之長波峰平面水槽造波機系統(Long Crested Basin Wave Generation System)。並建置自用的斷面與平面造波機設備，作為具備運作中造波機設備專業供應商，且長期持續為來自世界各地客戶提供造波機設備和水工模型試驗與研究。

爰此，本次採購外國儀器使用，派人員赴原廠進行技術交流活動，俾能增益本所研究人員職能，並可促使本國具備此方面人才培育機會。此外經參加本次的研討過程，觀察海岸及海洋工程研究主要趨勢，已由過去積極地開發海岸資源、

講究各種施工技術與增進效率管理方面，漸漸轉換成為從事注重海岸保育、近海防災、生態維護等領域去發展；這對目前臺灣海岸建設持續開發，政府部門應予考量注重情形，可以得到一項重要啟示。.

本文電子檔已上傳至出國報告資訊網

摘要

對此次技術交流活動主要目的提出簡單介紹：

1.原廠簡介和活動介紹(HR 造波機技術交流)說明：利用英國原廠設備進行進階之交流活動說明，包含水工模型試驗的實驗設計、實施和分析。可以透過一系列技術交流活動，包括安排和使用原廠水工模型實驗室進行實機測試。本技術交流活動，將分為多種領域(依實際參與時間調整)進行。

2.了解現場設備調整測試工作和使用者/維護人員技術交流活動：英國 HR Wallingford 公司原廠提供線上的支援服務，包括設備工作人員要求和啟用時對技術問題進行診斷和糾正。

3.「操作系統」：平面造波機的操作系統計畫設置在專用控制室，緊鄰或可俯瞰造波水池。包含波浪產生器電腦和一個用於緊急情況下關閉造波機上造波板促動器的緊急暫停安全裝置。

4.「機電控制系統」：專用於每個造波板模組的馬達驅動控制面板（MDCP）位於造波板模組的頂部。包含驅動每個造波板所需嵌入式可程式控制器、伺服驅動器和訊號調節等零組件。控制系統關鍵零組件是由 Beckhoff Automation 公司所生產。

5.「安全機制」：HR Wallingford 平面造波機的設計使其能夠以安全的方式運作。安全系統可由硬體和軟體兩個方面實現，使系統無法超越其設計功能。另外有緊急停止開關，將配置在關鍵位置，以便人員能在緊急情況下關閉造波系統。

6.這個交流活動包括設計、建立、測試和評估一個特定水工模型的結果以加強實務經驗。參加人員可以從原廠的水工模型人員以及提供的內部水工模型試驗計劃中獲得經驗。在現場總學習時間預計約為 1 周(5 工作天)。

對本次技術交流活動之效益，所發表的技術心得與成果：

1.性能：平面造波機造波性能曲線所提供條件是當平均水深為 0.6m、在 0.8～5 秒週期（對當於 0.2Hz～1.25Hz 頻率）等造波板能產生之規則和不規則波。應該注意的是，如果水位對應固定深度有變化時，則可能會降低造波機的性能。

2.波高性能延伸討論：儘管 HR Wallingford 通常採用波高性能更保守的波高陡度（$H < L / 9$）和水深（$H / D = 0.5$）限制，但是也可能有些範

圍會超過這些限制。這些性能限制的上限範圍被認為是當 H / L / 7 陡度限制和 H / D = 0.6 深度受到限制。透過將這些替代性能限制並應用於造波機，可預期性能將會提高。

3.造波板移動精度：所開發造波機控制系統，使用小於 0.001mm 的解析度的編碼器，通常為 1mm 以下的誤差，以高精度重現指定的波浪時間歷史。造波板運動的精度對於在一定範圍水深內產生高品質波浪尤其重要。它允許使用理論上推導的造波板轉換函數（paddle transfer function, PTF），使其容易地針對一定範圍的水深進行計算。這反過來又確保造波板運動，因此造波機將獲得正確的波高。

4.系統設計壽命：平面造波機的電機促動器廣泛用於工業應用中，其通常可連續工作，有時每天超過 8 小時，而且建立模型時經常會需要很長的時間。在許多工業應用中，組件在一個月內比在造波機使用一年內運作更多的時間。水工模型研究通常使用隨機波，並且由於組件的大小適合於規則波的峰值需求，所以它們的磨損和損耗要遠遠低於工業應用。基於上述原因，預計 HR Wallingford 造波機的使用壽命超過 20 年。在 Wallingford 的水工模型研究中使用這系統的經驗也證明了這一點，目前為止，21 個淺水多單元 Wallingford 的造波機使用時間超過 46,000 小時，只需要少量維護。

5.操作軟體：通訊與訊號線組 HR Wallingford 的造波系統提供 HR Merlin 造波軟體，能夠產生造波機所有常用規則和不規則波波譜。波浪頻譜和造波板轉換函數為使所需的波浪頻譜生成正確的造波板運動，HR Merlin 創造了原型和模型波浪頻譜及相關的造波板轉換函數。造波板轉換函數(PTF)是波高與造波板衝程比值，隨頻率和水深而變化。理論值是自動新增的，使用者可以選擇新增自定義的轉換函數。

6.既有 WR Davis 油壓造波系統整合：HR Wallingford 造波控制系統能夠接受來自另一個造波系統的類比輸入訊號，這將允許系統跟隨 DAVIS 造波板位置時間序列。由於 HR Wallingford 系統使用雙促動器的回饋響應要比 DAVIS 油壓系統快得多，因此要合併 2 個不同系統若只依靠初始訊號源方法將是不切實際。如果 DAVIS 系統具位置回饋迴路，則馬達促動器可以將其造波板位置與透過位置回饋量測的位置相匹配。WR Davis 系統 4 個現有的造波板都有位置回饋訊號，因此 HR Wallingford 計畫監控回饋訊號，可與使用這些回饋訊號來為所有其他 HR Wallingford 馬達促動器造波機模組建立類比輸入訊號。

7.現場港灣工程相關研究及產業觀摩活動：可藉由實際考察了解英國港口重要設施、建設及港灣工程發展現況、運作模式，以為我國借鏡並培養宏觀的國際視野。

最後對安排的幾項技術交流活動參觀地點作一簡介，能以當地的實務經驗與港灣工程技術學習，達到讀萬卷書及行萬里路雙重收穫；希望海洋及工程領域內各方面能夠天涯若比鄰地快速達到交換新知與資訊互通的相輔相成效果。則對此次奉派參加新增106年度「『離岸風能場遴近海岸漂沙機制探討』試驗室造波機購置赴原廠進行技術交流活動」出國計畫整個過程，作出一總結與心得報告，並提出一些看法與建議。

新增106年度「『離岸風能場遴近海岸漂沙機制探討』試驗室造波機購置赴原廠進行技術交流活動」出國計畫-出國報告

目次

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李政達[*]　林受勳[**]

一、　目的

本案為行政院指派交通部協助風電產業開發辦理事項，本部運輸研究所承辦相關技術發展，其中「離岸風電海氣象觀測與特性分析」與「離岸風電場鄰近海岸漂沙機制探討」工作項目，需採購國外現場監測儀器使用。爰此，須派人員赴原廠進行實地教育訓練和作業操作研習，俾增益提升研究、技術職能，並促使本國具備培訓此方面人才機會。

「離岸風能場鄰近海岸漂沙機制探討」試驗室造波機購置赴原廠進行技術交流活動，2016交通部運輸研究所因公出國(HR平面造波系統作業人員赴英國訓練)之必要性說明：

1. 針對現場海氣象觀測及海岸漂沙機制調查技術發展方面，可以直接獲得與儀器原廠工作人員面對面的指導說明和教育訓練，並相互討論交換意見，真正達到教學合一成效。
2. 對於本國人才培訓可藉此增加國外專業職能學習機會，推廣臺灣海洋港灣領域成就能見度，落實國際間科技人員、研究技術實質上交流。
3. 透過進行技術交流活動可以提供從事近海與港灣的相關工程，在施工與維護技術上之支援，俾促使計畫順利執行。

本次為行政院指派交通部協助風能產業開發事項，本所承辦相關研究及技術發展，其中「離岸風能場鄰近海岸漂沙機制探討」工作項目，編列進行試驗造波機購置，甫經公開招標決標結果，得標廠商採用英國HR公司提供之平面造波系統，目前國外製造之設備所具有功能優勢，是以國內暫無類似產品或其效能無法取代。議題範圍甚廣其內容豐富值得本所進行研究時學習借鏡；且廣泛討論海岸工程及海域環境保育，與中心研究業務密切相關；希望藉由檢討與建議，除了使得在學術與知能方面能夠獲得最大助益，更期待將來在從事海洋工程等領域時，能發揮所學而有所貢獻。

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新增 106 年度「『離岸風能場遴近海岸漂沙機制探討』試驗室造波機購置赴原廠進行技術交流活動」出國計畫，前往國家及城市如附表 1 所示：

表 1 原核定赴原廠進行技術交流活動出國計畫及城市地點

	日期	地點	主要行程概述
出國行程說明	12/12 (二)	臺灣➔英國	搭機啟程抵達
	12/13 (三)	英國	原廠簡介和參訪活動介紹(HR 造波機技術交流)說明並進行試驗室人員訪談與作業技術交流活動
	12/14 (四)	英國	參訪了解現場設備調整測試工作和使用者/維護人員技術交流活動
	12/15 (五)	英國	試驗室造波機原廠進行實地「操作系統」技術交流活動
	12/16 (六)	英國	港口重要設施現場參觀及港灣工程技術觀摩活動
	12/17 (日)	英國	港口重要設施現場參觀及港灣工程技術觀摩活動
	12/18 (一)	英國	試驗室造波機原廠進行實地「機電控制系統」技術交流活動
	12/19 (二)	英國	試驗室造波機原廠進行實地「安全機制」技術交流活動
	12/20 (三)	英國➔臺灣	返程搭機

日期/星期	工作內容	時間/地點
12/12 (二)	長榮航空 EVA Air (BR67) 08:50 臺灣桃園機場 (TPE) 19:20 倫敦希斯洛機場 (LHR)飛行時間 18:30，1 停靠站 BKK 泰國技術停降 1:15	全天/臺中-桃園-倫敦-牛津 (Wallingford)
12/13 (三)	**HR 原廠的介紹、系統整體分析及操作教育說明**	全天/牛津
12/14 (四)	**1.機械電力部分：系統整體分析及操作教育說明**	全天/牛津
12/15 (五)	**2.控制面板部分：系統整體分析及操作教育說明**	全天/牛津
12/16 (六)	港灣工程技術觀摩紀錄、海岸及港埠設施訪察 (Wallingford)-倫敦港口或鄰近城市港區、海岸	全天/牛津-鄰近港口
12/17 (日)	港灣工程技術觀摩紀錄、海岸及港埠設施訪察 (Wallingford)-倫敦港口或鄰近城市港區、海岸	全天/牛津-鄰近港口
12/18 (一)	**3.軟體模擬部分：系統整體分析及操作教育說明**	全天/牛津
12/19 (二)	**HR 系統彙整討論與原廠工程師進行探討及相關人員訪談交流；**長榮航空 EVA Air (BR68) 21:20 倫敦希斯洛機場 (LHR)飛行時間 16:25，1 停靠站 BKK 泰國技術停降 1:25	全天/牛津 (Wallingford)-倫敦
12/20 (三)	21:45 臺灣桃園機場 (TPE)搭機返程+1 日抵達臺灣	全天/桃園-臺中

現場了解及確認 HR Wallingford 規則與不規則波平面造波系統提供：

1. 高規格不銹鋼（304 型）防鏽與防水處理材質施工、高品質零件、保證維護保養，設計壽命超過 20 年。
2. 主動吸波系統以減少從造波板和造波水池中重新反射的波浪。
3. 造波機安裝框架後方的整體被動吸波板，減少從造波板向後的波浪飛濺。選用 AC 伺服馬達具智能數位驅動，可以精確控制波峰。
4. 每個造波板模組，由位於每個模組頂部的馬達驅動控制面板（Motor Drive Control Panel, MDCP）控制。
5. 造波機的運動控制，使用具有工業乙太網路協定的嵌入式可程式控制器進行，提供出色的即時性能。
6. HR Merlin 波浪生成軟體使用白雜訊法(white noise method)建立規則波和不規則波。亦可產生使用者自定義的波浪，並允許建立專用波，例如聚焦波(focused waves)和孤立波(Solitary waves)。
7. 英國 HR Wallingford 公司原廠提供線上支援服務，包括設備工作人員要求和啟用時對技術問題進行診斷和糾正。
8. 提供的造波系統符合歐洲機械指令(European Machinery Directive)的所有要求，並通過 CE 歐洲合格認證。

依據規範設計採購之規則與不規則波平面造波系統製作，分別由不同的組件構成，約略針對各主題來進行探討與研究。包括下列主要項目：

1. 提供 4 個 6 公尺長、0.8 公尺高的往復平推式(Piston Type)造波板模組，總長 24 公尺。每個模組可獨立使用或合併使用，以延展水工模型所需的波浪寬度。
2. 造波系統中同時提供訊號生成的 HR Merlin 造波軟體，此軟體可產生規則波和不規則波(包含所有常用波譜)。
3. 提供造波系統轉換裝置(adapter)，使用一個或多個 HR Wallingford 造波板模組與現有的 WR Davis 造波機組合併聯操作造波。可以併聯港研中心現有 Davis 油壓式平面造波機系統，進行造波與控制。允許 Davis 油壓式平面造波機系統可以與 1 個、2 個、3 個或 4 個造波模塊併聯造波，最高可達 8x6m=48m 造波寬度。
4. 造波板後方的被動吸波灘(passive absorbing beach)，吸收由造波機產生的反向波能量。
5. 主動吸波系統。每個造波板將安裝阻抗式波高計來量測造波板前的水位。量測資訊用於主動吸波系統的輸入之用。
6. 設備的現場調整測試和使用者/維護人員的教育訓練工作。

二、 技術交流活動與行程

HR Wallingford 總部位於英國牛津郡的 Howbery Park 校園位於泰晤士河畔 70 英畝的鄉村之中。以作為世界領先的組織的聲譽而自豪，認識到他們的成功歸功於員工之工作品質和專業技能。HR Wallingford 是一個獨立的土木工程和環境水力學組織。能為國際客戶面臨的複雜水務挑戰提供切實可行的解決方案。憑藉 70 年的成就記錄，獨特的專有技術、資產和設施組合包括最先進的物理建模實驗室，全套的數值建模工具，以及熱情積極具有世界知名技能和專業知識人員。總部設在英國的 HR Wallingford 公司在卓越和創新方面享有盛譽，將運營利潤重新投入到研究和開發項目而贏得了聲譽。HR Wallingford 遍布全球的辦事處，為代理商和聯盟網絡可向全球客戶和合作夥伴提供服務。

HR Wallingford 公司成員擁有科學研究協會的地位。是一個擔保有限責任公司而不是股東，有一個支持和指導他們活動的成員小組，幫助公司保持成為卓越中心地位。其成員來自英國的組織，包含政府部門和與有關行業的機構作為擔保人(最大負擔 10 英鎊)，參加股東大會選舉董事和其他活動。在過去的 70 年裡，HR Wallingford 已經走過了漫長的道路。原先為政府實驗室，始於 1947 年的 Teddington 起源，以及 1982 年的私有化，現在全球範圍內為廣泛的公共和私營部門客戶提供服務，為土木工程和環境水力領域問題提供領先的解決方案，如下列 HR Wallingford 技術交流活動場所建築外觀及現場作業圖示。



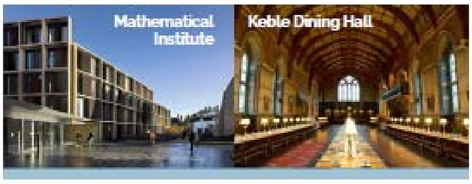

HR Wallingford 並於 2106 年 9 月 12-15 日在英國牛津地區舉辦第 8 屆有關海岸沖刷和侵蝕之國際研討會，可見該單位積極支持和致力解決各項海洋相關議題的活動，俾使他們保持並成為英國政府對此方面具卓越中心地位。未來可增加本所於海岸沖刷和侵蝕參與國際研討會投稿和心得交流的機會。

正如在過去的 37 年裡，本所港研中心在港灣工程、海洋環境各項工作努力已經走過了漫長的道路。為政府單位唯一具有水工模型試驗室以及專業海氣象觀測的機關，現為國內的公務縣市和國營部門港務公司提供服務，為土木工程和環境水力領域問題提供領先的解決方案。

ICSE|2016 8th INTERNATIONAL CONFERENCE ON SCOUR AND EROSION
12th-15th September 2016, Mathematical Institute, Oxford, UK

8th International Conference on Scour and Erosion 2016

HR Wallingford is proud to host the 8th International Conference on Scour and Erosion 2016 which will be held at the Mathematical Institute in Oxford, United Kingdom from 12 to 15 September 2016.



The conference provides a platform for scientists and engineers from various disciplines (e.g. hydraulic and geotechnical engineering) to exchange ideas and report advances in research and practice on scientific and engineering challenges related to scour and erosion.

Contact us

Sarah Moxon and Jackie Harrop
ICSE 2016 Secretariat c/o HR Wallingford

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Email: info@icse2016.com

Registration

The conference website is now open for participant registration. www.icse2016.com

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本交通部運輸研究所因公出國(HR 平面造波系統採購)赴英國原廠技術交流活動，另申請(補)休假 3 天探究港研中心現有購置使用儀器設備：BIRAL - Bristol Industrial and Research Associates Limited 能見度儀、WERA 陣列式觀測雷達 Helzel Messtechnik GmbH 遠端海洋遙測系統、GILL Instruments Ltd 風速計，其整體的活動相當緊湊且具知識性與整體性；這些議題或許在未來研究或計畫中，我國也將可以有積極參與發展的機會。2017 預定行程安排主要行程概要如附表 2 所示：

表 2　出國計畫主要行程概要

日期/星期	工作內容	時間/地點
12/7 (四)	長榮航空 EVA Air (BR67) 08:50 臺灣桃園機場 (TPE) 飛行時間 18:30, 1 停靠站 BKK 技術停降 1:15	全天/機上-英國 19:20 倫敦希斯洛機場 (LHR)
12/8 (五)	BIRAL 能見度儀(簡介劇烈天候閃電監測儀器設備與落雷預測系統)及進行相關討論	全天/Bristol 原廠現地裝置探究
12/9 (六)	Eurowings EW7465 Airbus A320 Flight is operated by Air Berlin-11:25 AM Hamburg (HAM)	8:50 AM London Heathrow (LHR)
12/10 (日)	港灣工程技術活動記錄、海岸及港埠設施探討	全天/鄰近港口
12/11 (一)	WERA 陣列觀測雷達進行相關探討 Eurowings EW7460 Airbus A320 Flight is operated by Eurowings - 6:40 PM London Heathrow (LHR)	全天/德國原廠 Hamburg (HAM) 6:00 PM
12/12 (二)	GILL 風速計(風洞實驗校正儀器、新型多功能氣象站)及進行相關討論、HR 的原廠介紹交流、系統整體分析及活動說明	全天/ Lymington - Howbery Park, Oxfordshire
12/13 (三)	機械電力技術交流：系統整體分析及活動說明	全天/OX10 8BA
12/14 (四)	控制面板技術交流：系統整體分析及活動說明	全天/OX10 8BA
12/15 (五)	試驗室操作技術交流：系統整體分析及活動說明	全天/OX10 8BA
12/16 (六)	Seaview Sensing Ltd (現地雷達資料的後端處理軟體原廠現場成果展示)	全天/Sheffield - HR Wallingford
12/17 (日)	港灣工程技術活動記錄、海岸及港埠設施探討	全天/鄰近港口
12/18 (一)	軟體模擬部分參訪：系統整體分析及活動說明	全天/OX10 8BA
12/19 (二)	HR 系統彙整討論(與原廠人員訪談交流以及工程師進行相關探討)；長榮航空 EVA Air (BR68)飛行時間 16:25，1 停靠站 BKK 技術停降 1:25	全天/OX10 8BA -21:20 倫敦希斯洛機場 (LHR)
12/20 (三)	搭機返程 ，21:45+1 日臺灣桃園機場 (TPE) 抵達	全天/機上-臺灣

備註：黃色標示區域日期 12/12-20 為因公出國 9 天(國外差旅預算經費核支)，藍、綠色標示區域日期 12/21-25 為申請(補)休假 3 天及星期六、日之例假日。

2017「離岸風能場遴近海岸漂沙機制探討」試驗室造波機購置赴原廠進行技術交流活動：

12/7(Thu AM-PM) : EVA Air (BR67) 08:50 (TPE) - 19:20 (LHR) **London Heathrow Airport**△

12/8(Fri AM-PM) : Biral (Bristol Industrial and Research Associates Limited) Unit 8 Harbour Road Trading Estate Portishead BRISTOL BS20 7BL UK□

12/9(Sat AM) - 10(Sun AM) : Eurowings EW7465 Airbus A320 Flight is operated by Air Berlin 8:50 AM London Heathrow (LHR) - 11:25 AM Hamburg (HAM) **Free Days**

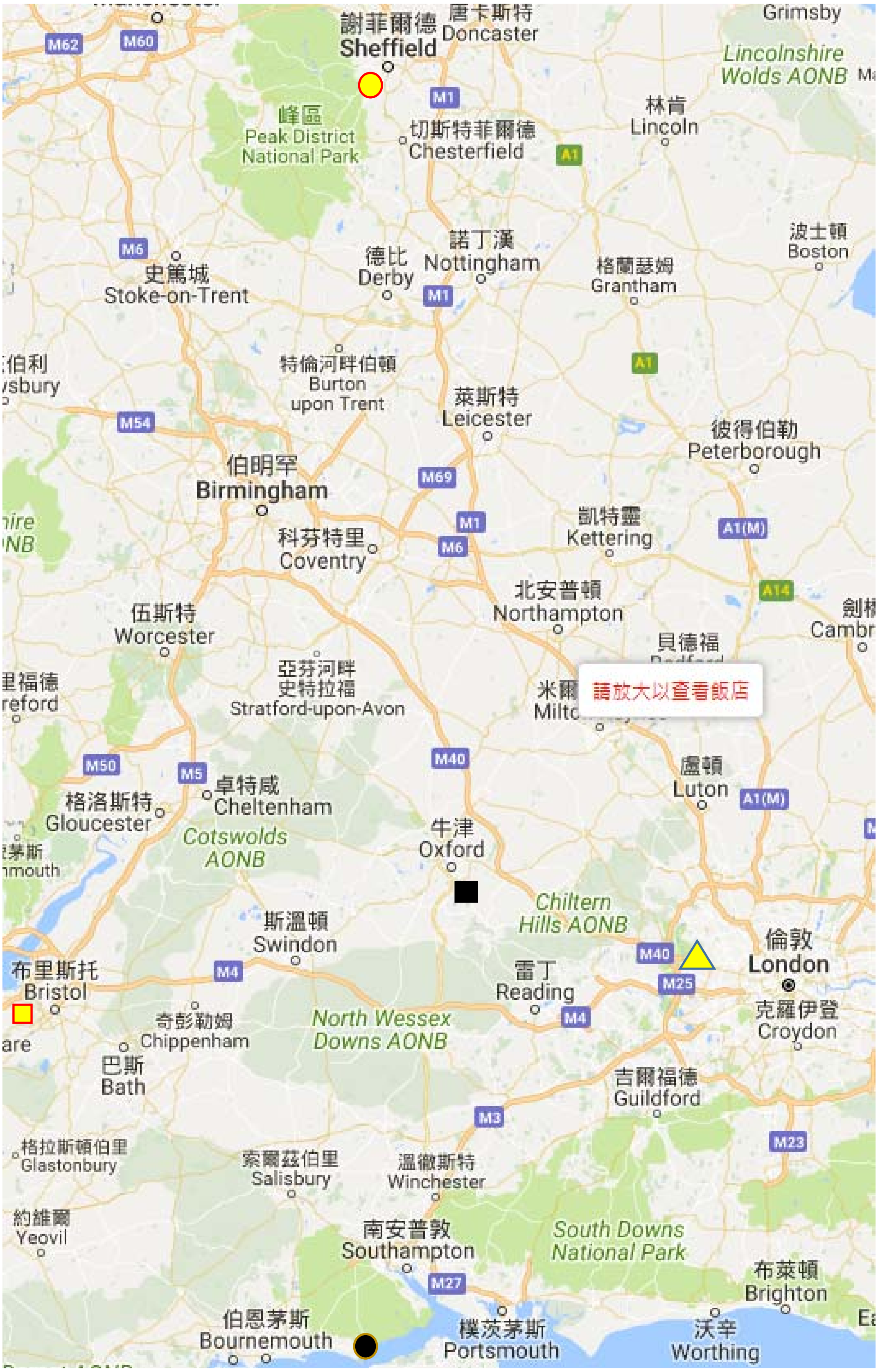
12/11(Mon AM) : Helzel Messtechnik GmbH WARA Carl-Benz-Str. 9 D-24568 Kaltenkirchen Germany▲Eurowings EW7460 Airbus A320 Flight is operated by Eurowings Hamburg (HAM) 6:00 PM - 6:40 PM London Heathrow (LHR)

12/12(Tue AM) : GILL INSTRUMENTS LTD Saltmarsh Park 67 Gosport Street Lymington Hampshire SO41 9EG UK●

12/12(Tue PM) - 15(Fri PM) : HR Wallingford Howbery Park, Wallingford Oxfordshire, OX10 8BA United Kingdom■

12/16(Sat AM)-17(Sun AM) : Seaview Sensing Ltd 211 Graham Road Ranmoor Sheffield S10 3GR UK○**(Free Days)**

12/18(Mon AM)-19(Tue PM) : HR Wallingford Howbery Park, Wallingford Oxfordshire, OX10 8BA United Kingdom■**London Heathrow Airport**△ EVA Air (BR68) 21:20 (LHR) - 21:45+1 (TPE)



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M1
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伯恩茅斯
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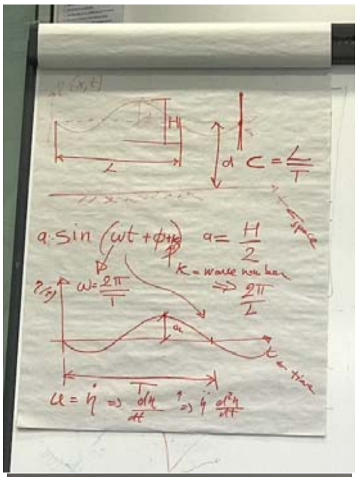
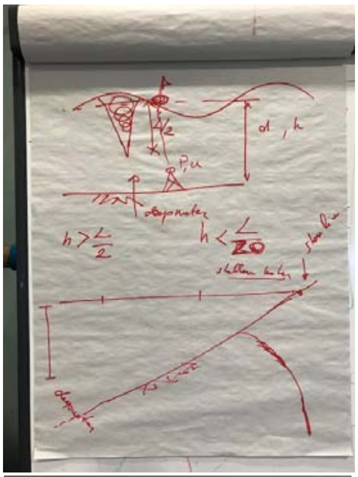
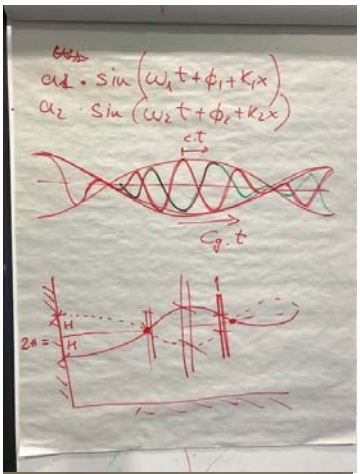
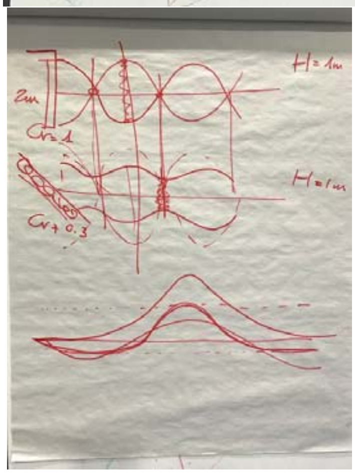
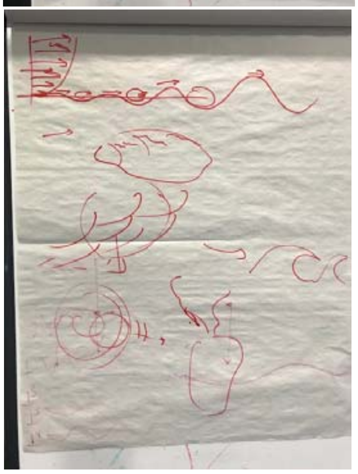
Portsmouth
沃辛
Worthing

三、　波浪理論研討與概述

本次活動首先為基本之波浪理論教授現有海洋工程所需研究方法及海岸結構設計、應用的開發與新知，主辦單位藉由深入淺出和淺顯易懂的教學資料等研討方式，說明發表其自有技術與成果，供參與者易學易懂與討論，是一項極為成功的研發的展示行程。


經依照學術領域及施工技術加以分類共可分為 3 大主題，分別為：

(一)、　第一部分：波浪的定義和特點(Part I:Water Waves Definitions and Characteristics)之研究。

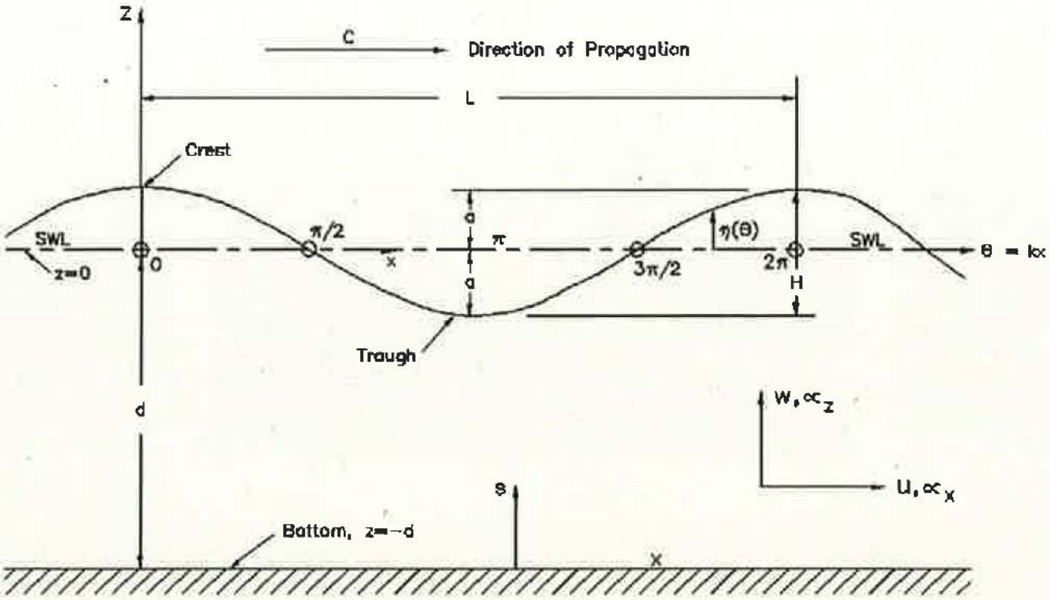
(二)、　第二部分：波浪的產生和傳播(Part II':Water Waves Generation and Propagation)之研究。

(三)、　第三部分：·波浪解析(Part Ill:·water Waves Ana lysis)之研究。

Water Wave Mechanics Course
HR Wallingford, 13/12/2017

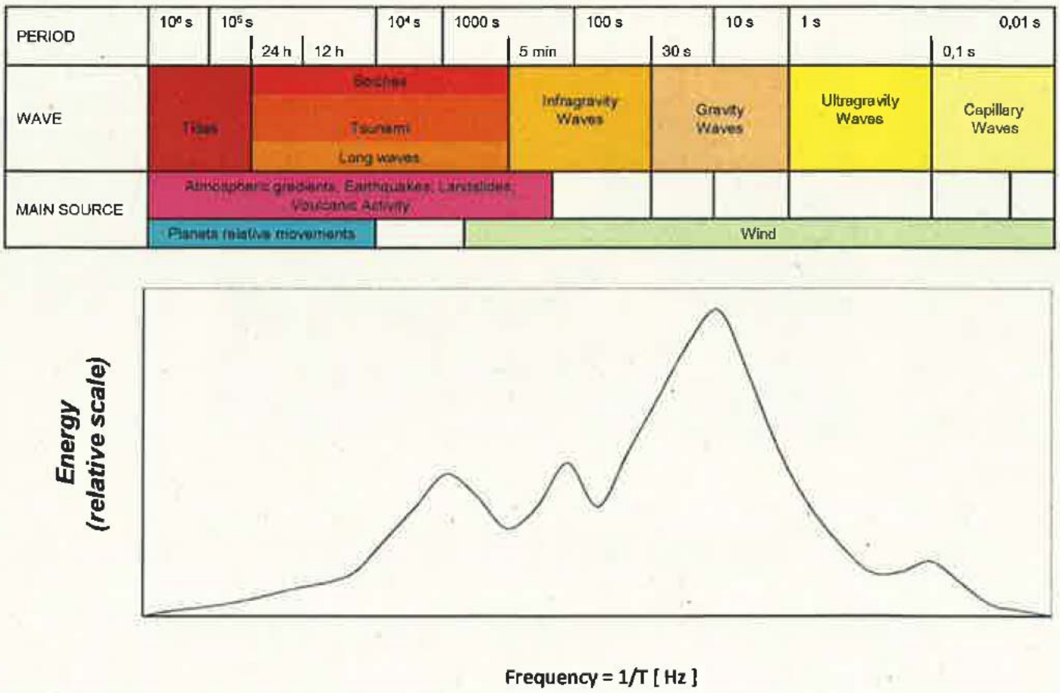
Part I: Water Waves
Definitions and Characteristics

DEFINITIONS



$$L = \frac{gT^2}{2\pi}\tanh\frac{2\pi d}{L} \qquad C = \frac{L}{T} = \frac{gT}{2\pi}\tanh\frac{2\pi d}{L}$$

Wave Classification as a function of their Period

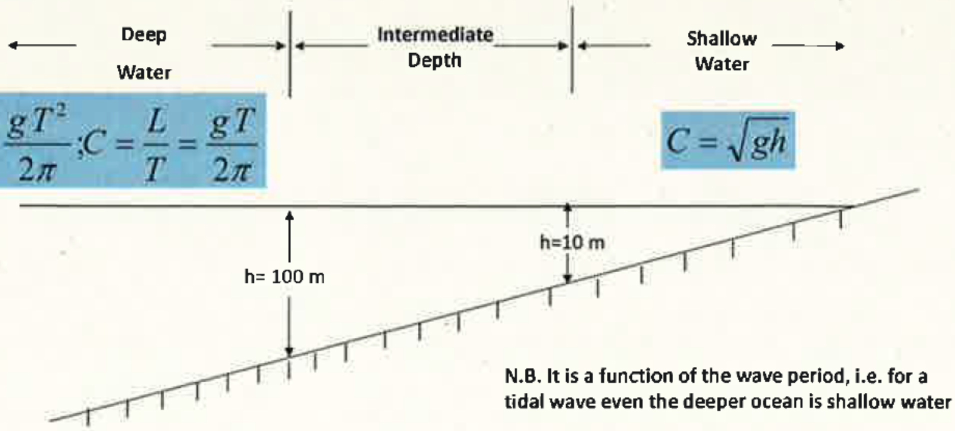


Wave Classification as a function of the "Relative" Water Depth

- Shallow water h/L < 1/20
- Intermediate depth 1/20 < h/L < 1/2
- Deep water h/L > 1/2

$$L = \frac{gT^2}{2\pi}\tanh\frac{2\pi h}{L}$$

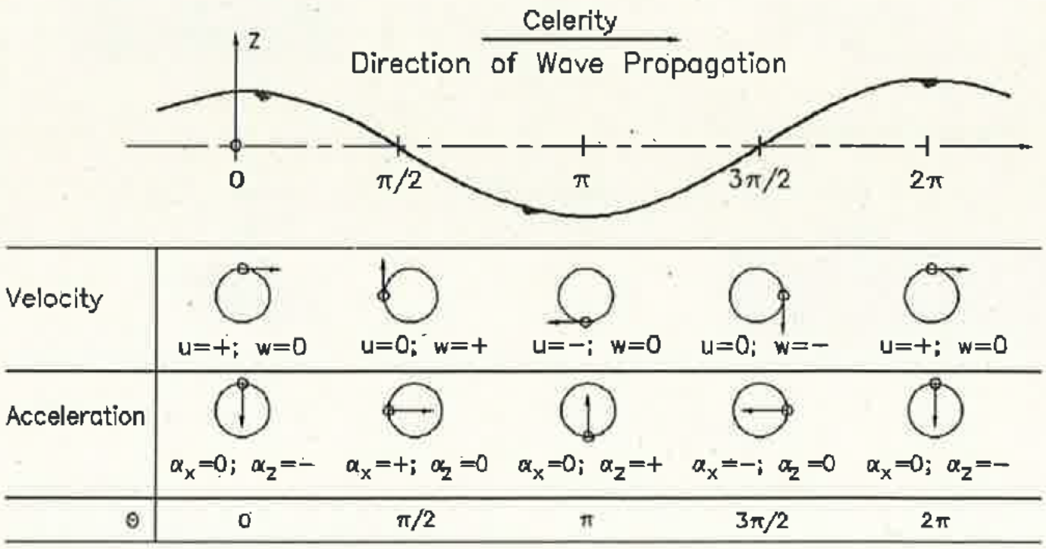
Example: L =200 m



$$L = \frac{gT^2}{2\pi};C = \frac{L}{T} = \frac{gT}{2\pi}$$

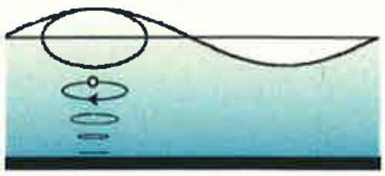
$$C = \sqrt{gh}$$

Water particles Displacement and Velocity



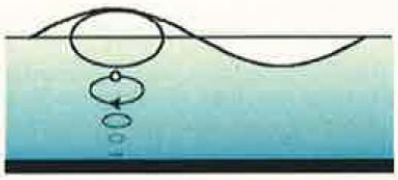
Wave-induced orbital motion as a function of the Relative Water Depth

- Shallow water



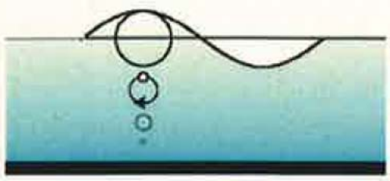
$L/h > 20$

- Intermediate depth



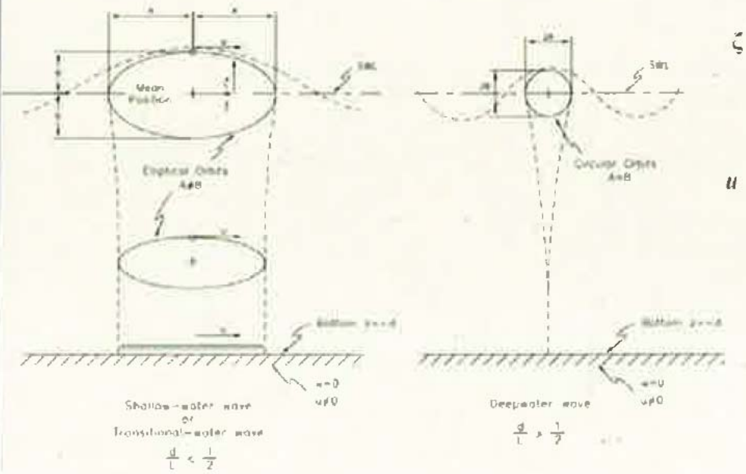
$2 < L/h < 20$

- Deep water



$L/h < 2$

Water particles Displacement, Velocity & Pressure



$$\zeta = + \frac{H}{2} \frac{\sinh\left(\frac{2\pi(z+d)}{L}\right)}{\sinh\left(\frac{2\pi d}{L}\right)} \cos\theta$$

$$u = \frac{H}{2}\frac{gT}{L}\frac{\cosh[2\pi(z+d)/L]}{\cosh(2\pi d/L)} \cos\theta$$

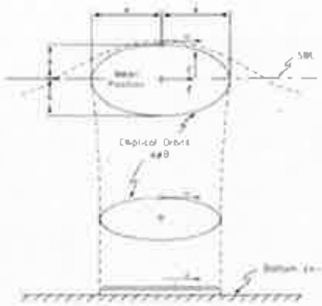
$$p = \rho g(\eta K_z - z)$$

$$K_z = \frac{\cosh\left[\frac{2\pi(z+d)}{L}\right]}{\cosh\left(\frac{2\pi d}{L}\right)}$$

$$\bar{E}_k = \int_x^{x+L}\int_{-d}^{\eta} \rho\frac{u^2 + w^2}{2}\, dz\, dx \qquad \bar{E}_p = \int_x^{x+L} \rho g \left[\frac{(\eta + d)^2}{2} - \frac{d^2}{2}\right] dx$$

$$E = E_k + E_p = \frac{\rho g H^2 L}{16} + \frac{\rho g H^2 L}{16} = \frac{\rho g H^2 L}{8}$$

Wave characteristics

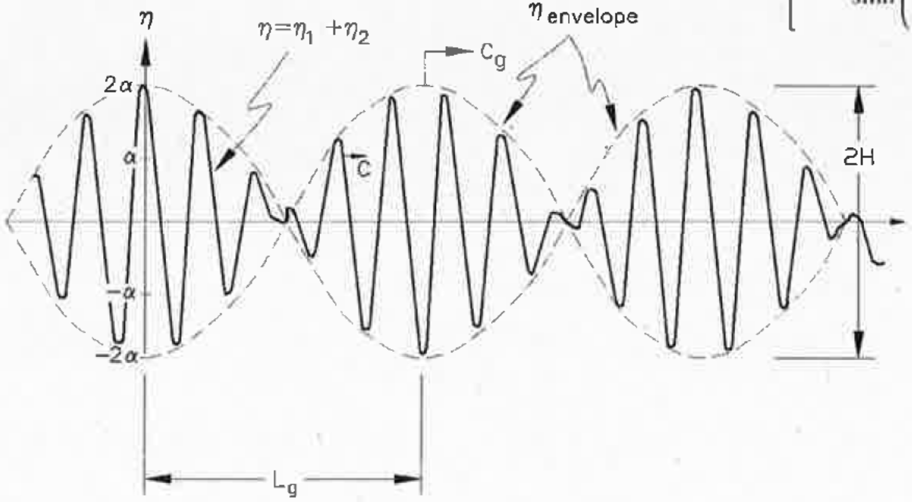


Relative Depth	Shallow Water $\frac{d}{L} < \frac{1}{25}$	Transitional Water $\frac{1}{25} < \frac{d}{L} < \frac{1}{2}$	Deep Water $\frac{d}{L} > \frac{1}{2}$
1. Wave profile	Same As	$\eta = \frac{H}{2}\cos\left[\frac{2\pi x}{L} - \frac{2\pi t}{T}\right] = \frac{H}{2}\cos\theta$	Same As
2. Wave celerity	$C = \frac{L}{T} = \sqrt{gd}$	$C = \frac{L}{T} = \frac{gT}{2\pi}\tanh\left(\frac{2\pi d}{L}\right)$	$C = C_0 = \frac{L}{T} = \frac{gT}{2\pi}$
3. Wavelength	$L = T\sqrt{gd} = CT$	$L = \frac{gT^2}{2\pi}\tanh\left(\frac{2\pi d}{L}\right)$	$L = L_0 = \frac{gT^2}{2\pi} = C_0T$
4. Group velocity	$C_g = C = \sqrt{gd}$	$C_g = nC = \frac{1}{2}\left[1 + \frac{4\pi d/L}{\sinh(4\pi d/L)}\right]C$	$C_g = \frac{1}{2}C = \frac{gT}{4\pi}$
5. Water particle velocity (a) Horizontal	$u = \frac{H}{2}\sqrt{\frac{g}{d}}\cos\theta$	$u = \frac{H}{2}\frac{gT}{L}\frac{\cosh[2\pi(z+d)/L]}{\cosh(2\pi d/L)}\cos\theta$	$u = \frac{\pi H}{T}e^{\left(\frac{2\pi z}{L}\right)}\cos\theta$
(b) Vertical	$w = \frac{H\pi}{T}\left(1+\frac{z}{d}\right)\sin\theta$	$w = \frac{H}{2}\frac{gT}{L}\frac{\sinh[2\pi(z+d)/L]}{\cosh(2\pi d/L)}\sin\theta$	$w = \frac{\pi H}{T}e^{\left(\frac{2\pi z}{L}\right)}\sin\theta$
6. Water particle accelerations (a) Horizontal	$a_x = \frac{H\pi}{T}\sqrt{\frac{g}{d}}\sin\theta$	$a_x = \frac{g\pi H}{L}\frac{\cosh[2\pi(z+d)/L]}{\cosh(2\pi d/L)}\sin\theta$	$a_x = 2H\left(\frac{\pi}{T}\right)^2 e^{\left(\frac{2\pi z}{L}\right)}\sin\theta$
(b) Vertical	$a_z = -2H\left(\frac{\pi}{T}\right)^2\left(1+\frac{z}{d}\right)\cos\theta$	$a_z = -\frac{g\pi H}{L}\frac{\sinh[2\pi(z+d)/L]}{\cosh(2\pi d/L)}\cos\theta$	$a_z = -2H\left(\frac{\pi}{T}\right)^2 e^{\left(\frac{2\pi z}{L}\right)}\cos\theta$
7. Water particle displacements (a) Horizontal	$\xi = -\frac{HT}{4\pi}\sqrt{\frac{g}{d}}\sin\theta$	$\xi = -\frac{H}{2}\frac{\cosh[2\pi(z+d)/L]}{\sinh(2\pi d/L)}\sin\theta$	$\xi = -\frac{H}{2}e^{\left(\frac{2\pi z}{L}\right)}\sin\theta$
(b) Vertical	$\zeta = \frac{H}{2}\left(1+\frac{z}{d}\right)\cos\theta$	$\zeta = \frac{H}{2}\frac{\sinh[2\pi(z+d)/L]}{\sinh(2\pi d/L)}\cos\theta$	$\zeta = \frac{H}{2}e^{\left(\frac{2\pi z}{L}\right)}\cos\theta$
8. Subsurface pressure	$p = \rho g(\eta - z)$	$p = \rho g\eta\frac{\cosh[2\pi(z+d)/L]}{\cosh(2\pi d/L)} - \rho gz$	$p = \rho g\eta e^{\left(\frac{2\pi z}{L}\right)} - \rho gz$

Wave interference : wave groups

$$\eta_{envelope} = \pm H \cos\left[\pi\left(\frac{L_2 - L_1}{L_1 L_2}\right)x - \pi\left(\frac{T_2 - T_1}{T_1 T_2}\right)t\right]$$

$$C_g = \frac{1}{2}\frac{L}{T}\left[1 + \frac{\frac{4\pi d}{L}}{\sinh\left(\frac{4\pi d}{L}\right)}\right]$$



$C_{g_0} = \frac{1}{2}\frac{L_0}{T} = \frac{1}{2}C_0$ (deep water)

$C_{g_s} = \frac{L}{T} = C \approx \sqrt{gd}$ (shallow water)

Wave interference : wave reflection

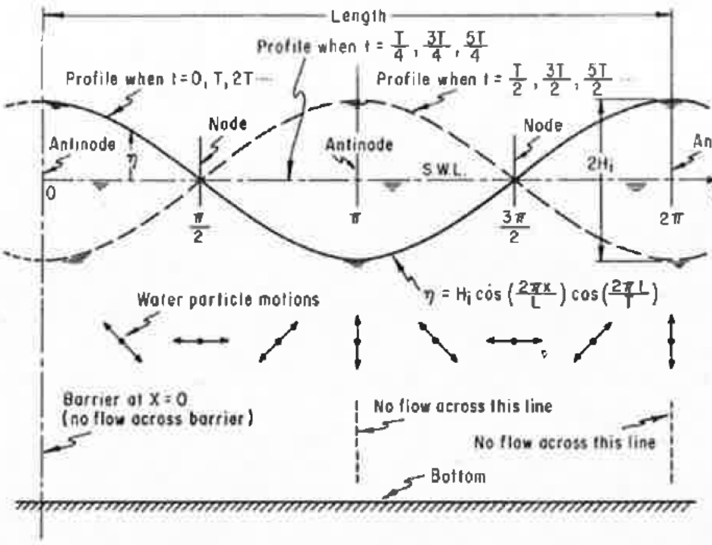
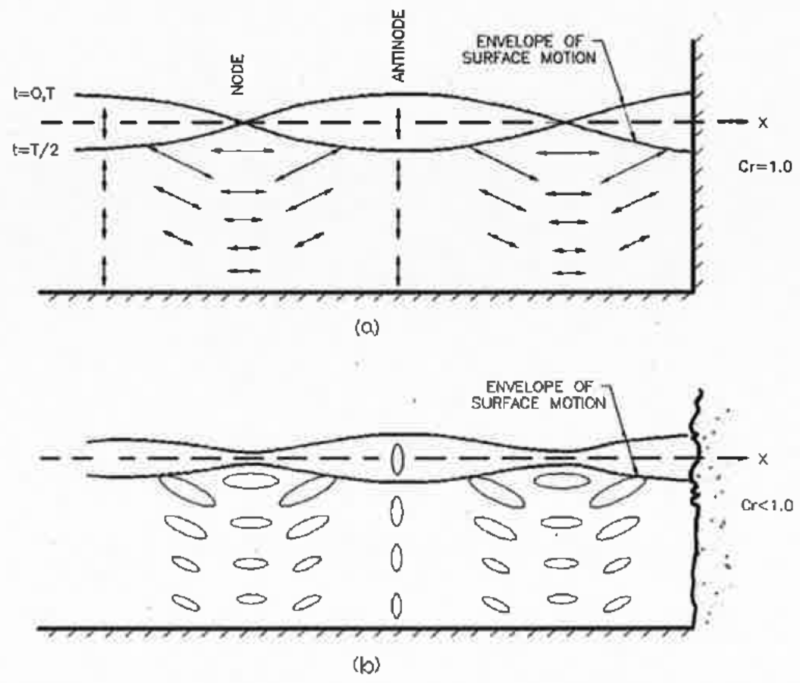
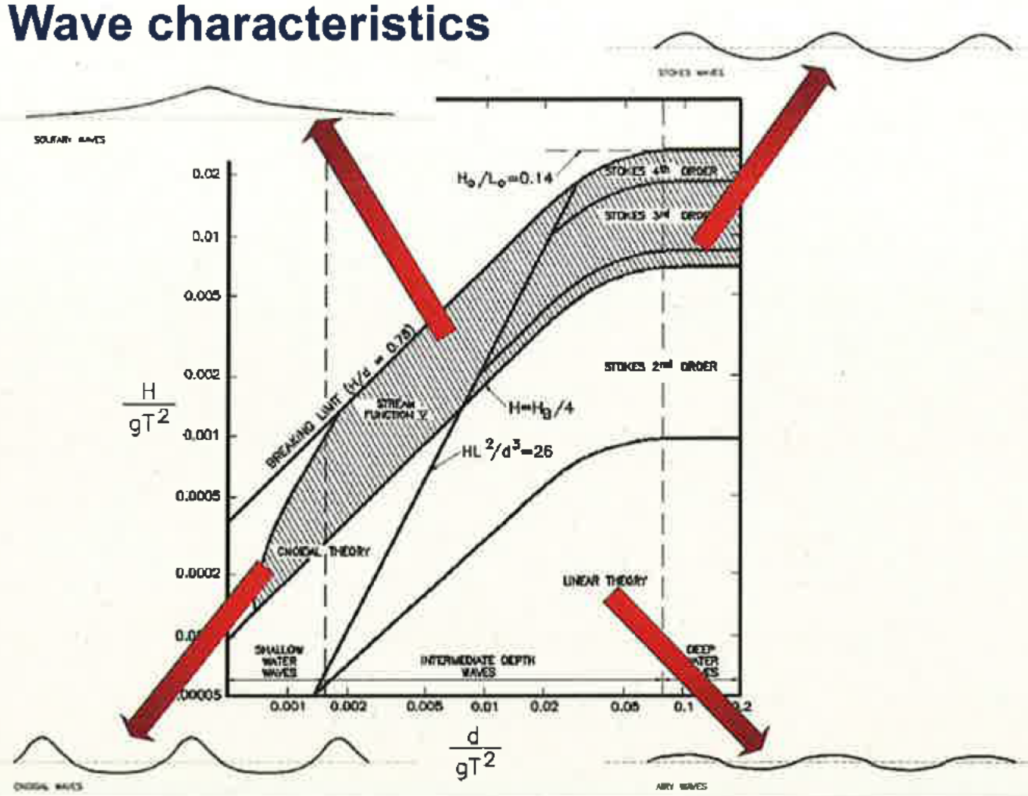


Figure 2-63. Standing wave (clapotis) system, perfect reflection from a vertical barrier, linear theory.

Wave interference : wave reflection



Wave characteristics



Wave characteristics: Stokes' 2nd order

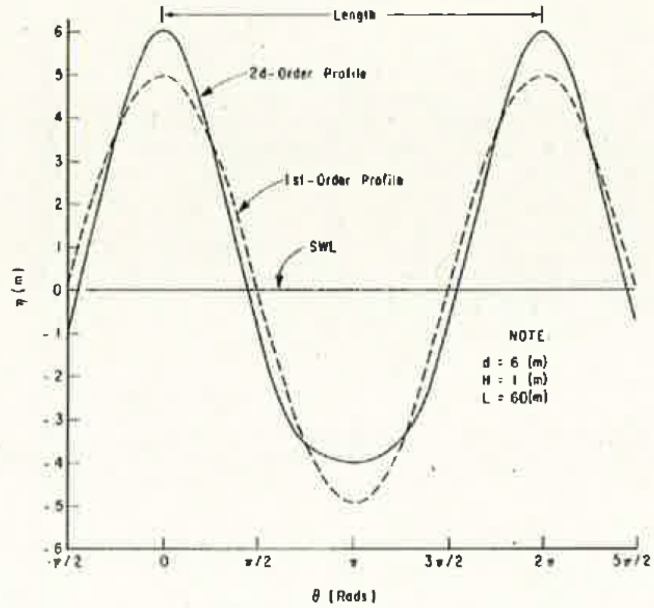
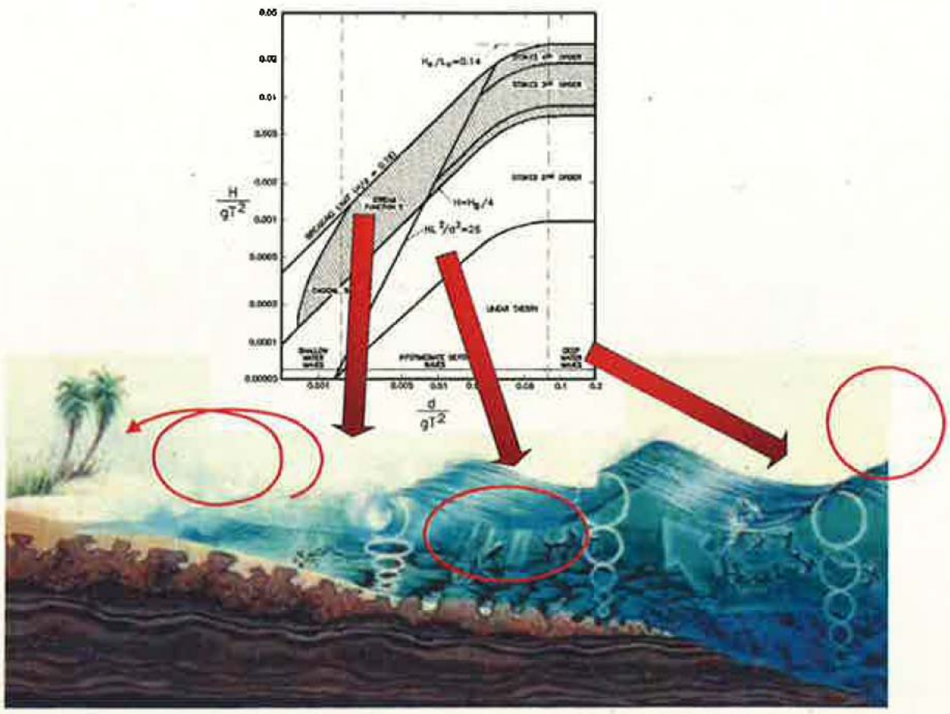


Figure 2-8. Comparison of second-order Stokes' profile with linear profile.

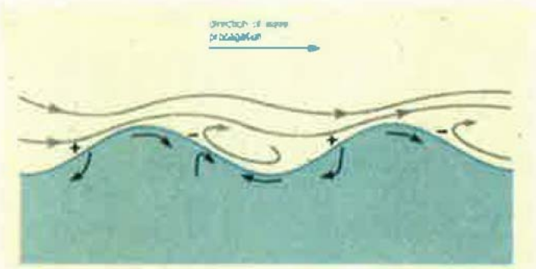
Wave transformation in shallow water



Part II: Water Waves Generation and Propagation

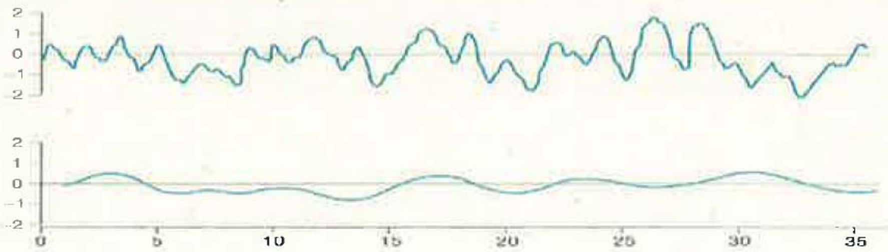
Wind-generated Waves

wind →



Spectral evolution away from source : Wave Dispersion

$$L = \frac{gT^2}{2\pi}\tanh\frac{2\pi h}{L}$$



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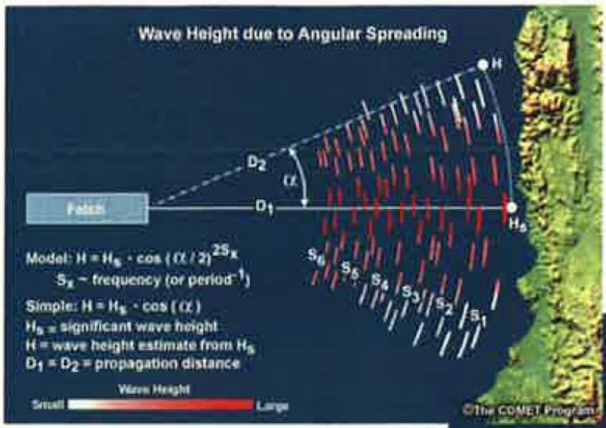
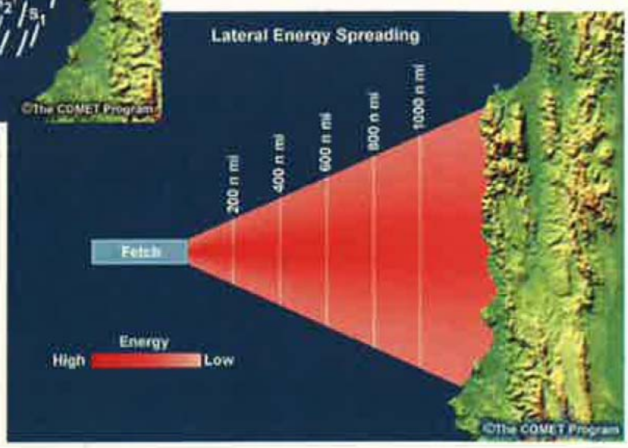
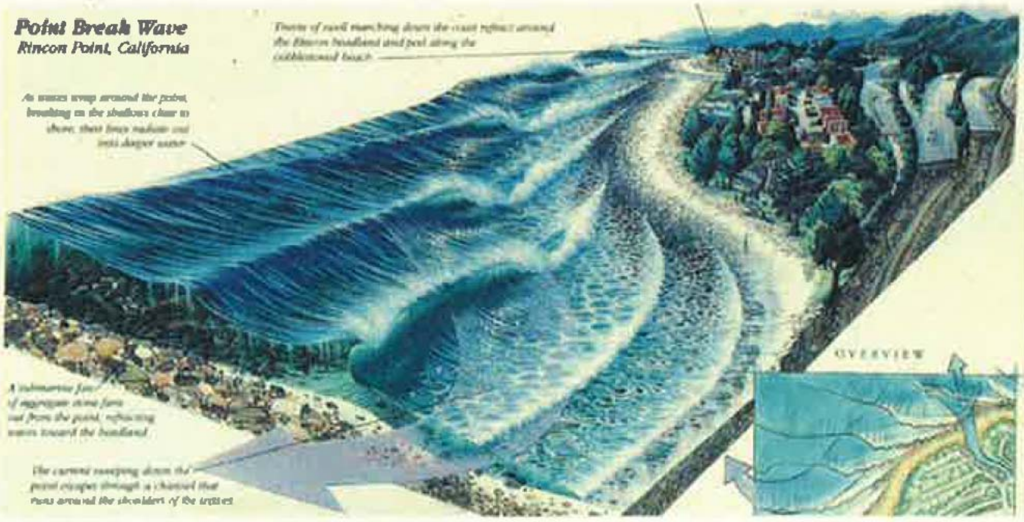
Spectral evolution away from source : Angular Spreading

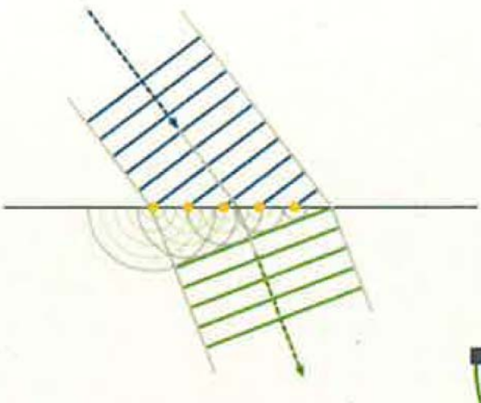


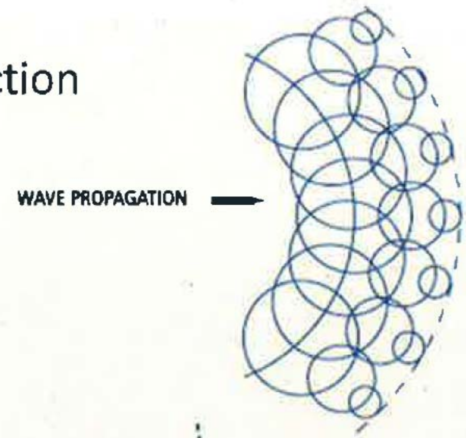


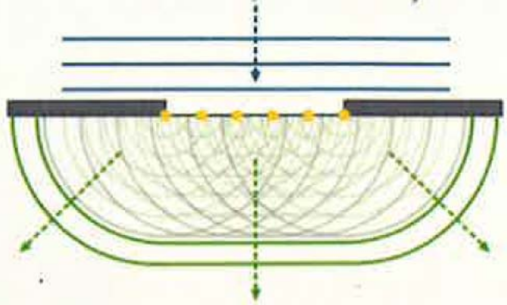
Wave transformation in shallow water



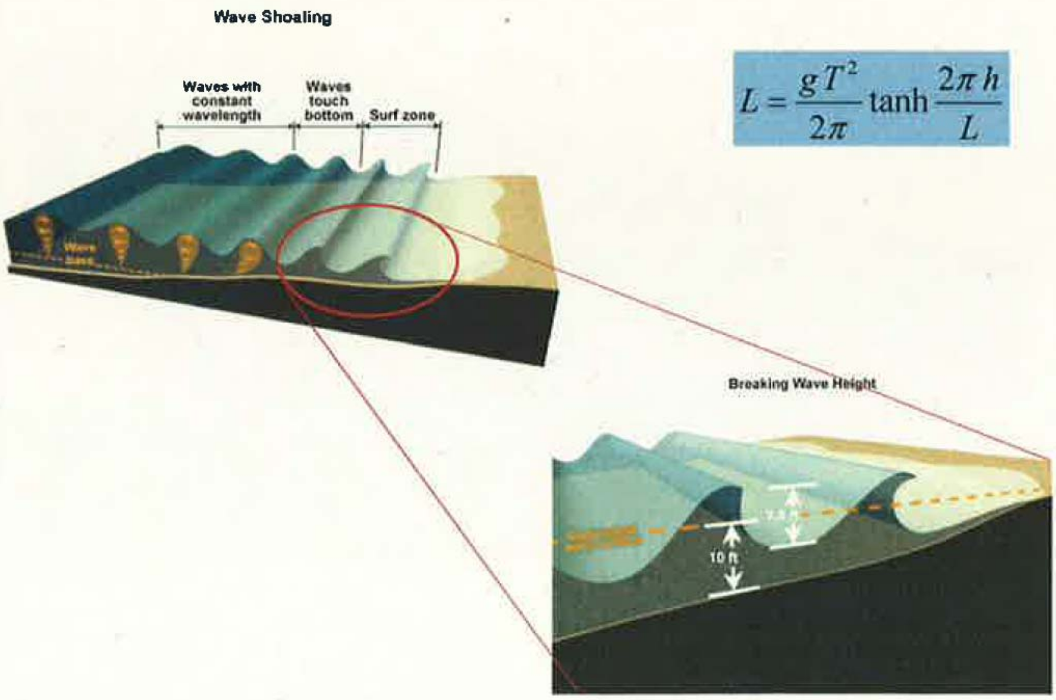
Huygen's principle:
Shoaling, Refraction, Diffraction





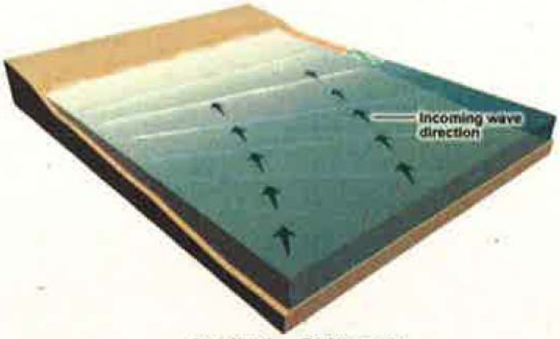


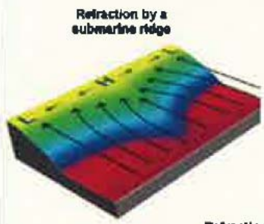
Wave Shoaling

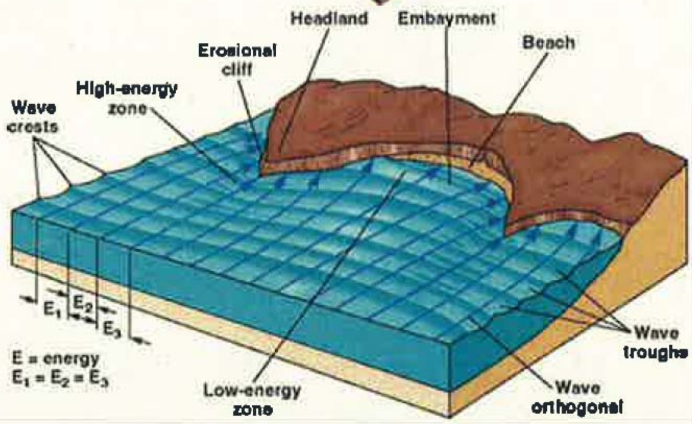


$$L = \frac{gT^2}{2\pi}\tanh\frac{2\pi h}{L}$$

Wave Refraction

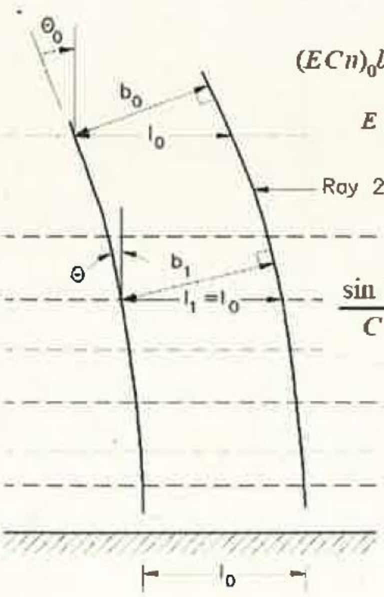






Ray tracing theory:
Refraction and Shoaling

$$K_r = \left(\frac{b_o}{b_1}\right)^{\frac{1}{2}} = \left(\frac{\cos\,\theta_0}{\cos\,\theta_1}\right)^{\frac{1}{2}} = \left(\frac{1-\sin^2\,\theta_0}{1-\sin^2\,\theta_1}\right)^{\frac{1}{4}}$$



$$(ECn)_0 b_0 = (ECn)_1 b_1$$

$$E = \frac{1}{8}\rho g H^2$$

$$\frac{\sin\,\theta}{C} = \frac{\sin\,\theta_0}{C_0}$$

$$H_1 = H_0 \sqrt{\frac{C_{g_0}}{C_{g_1}}}\sqrt{\frac{b_0}{b_1}}$$

$$H_1 = H_0\, K_s\, K_r$$

$$C_g = \frac{1}{2}\frac{L}{T}\left[1 + \frac{\frac{4\pi d}{L}}{\sinh\left(\frac{4\pi d}{L}\right)}\right] = nC$$

$$C_{g_0} = \frac{1}{2}\frac{L_0}{T} = \frac{1}{2}C_0 \text{ (deep water)}$$

$$C_{g_s} = \frac{L}{T} = C \approx \sqrt{gd} \text{ (shallow water)}$$

Edge Waves

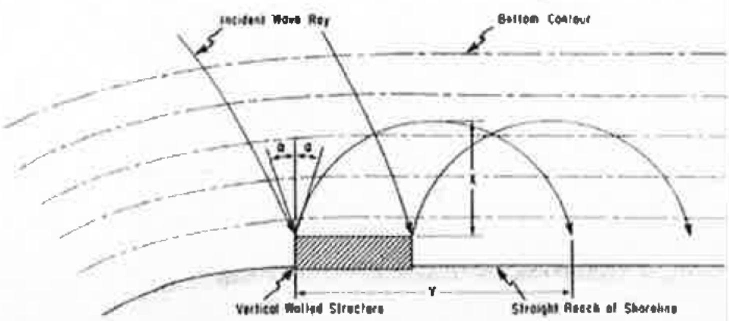
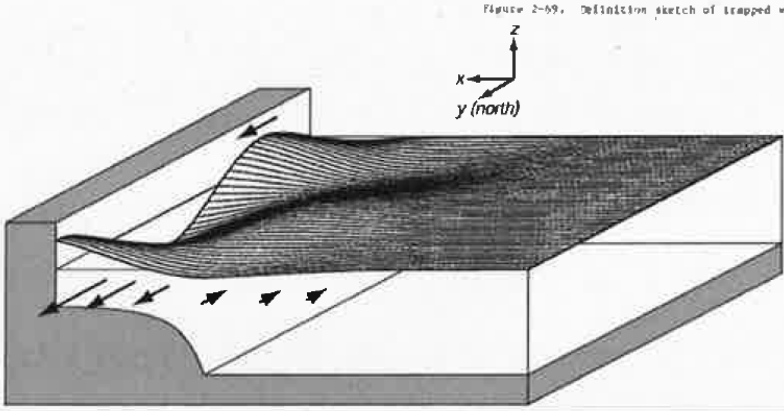
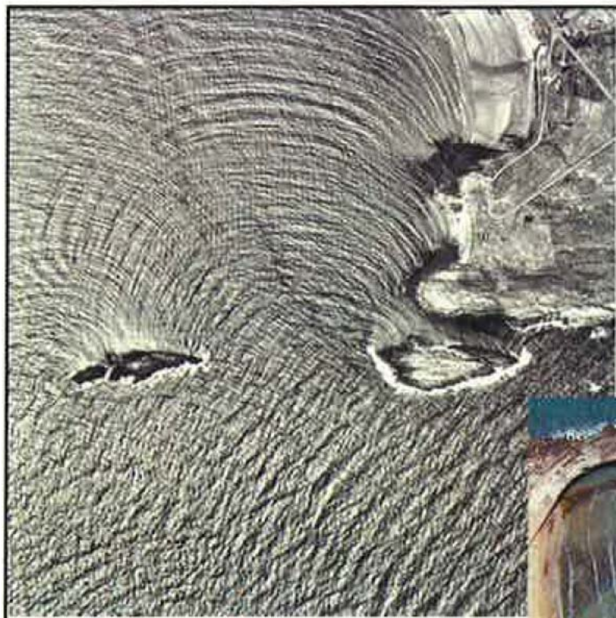


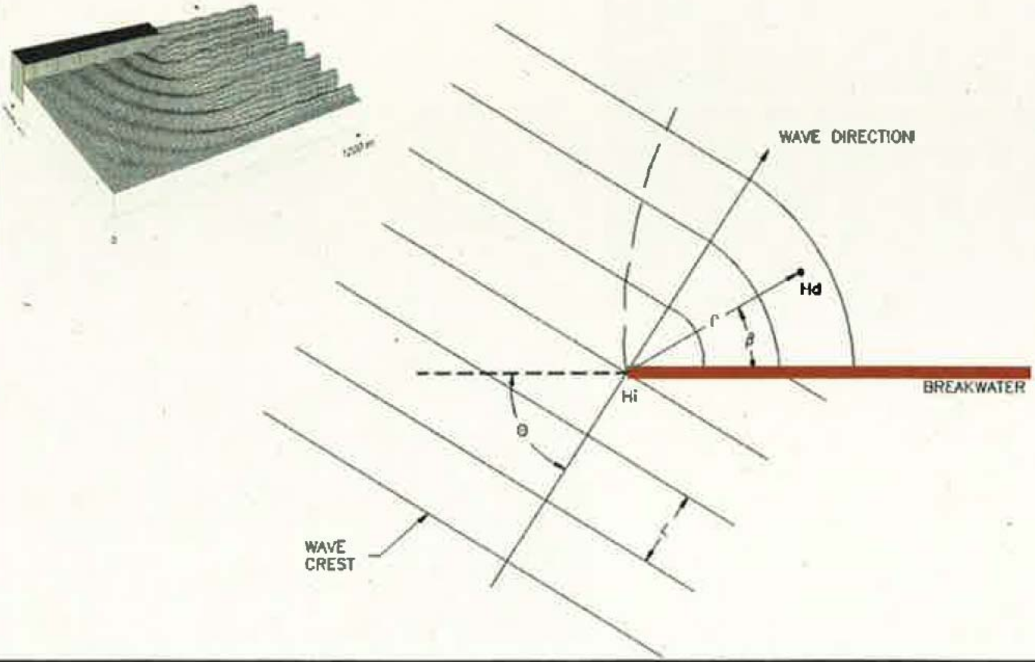
Figure 2-69. Definition sketch of trapped wave rays.



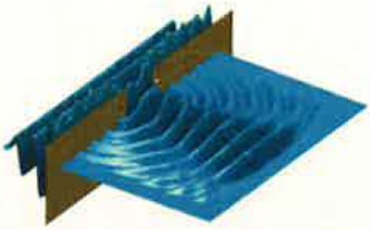


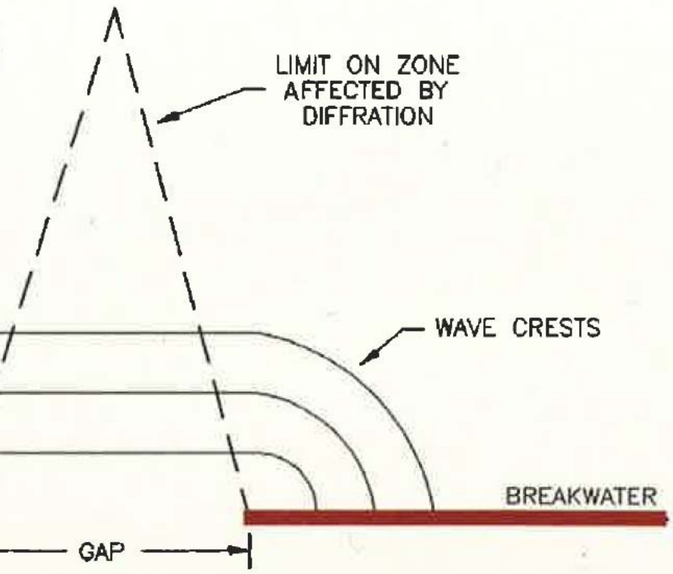
Wave Diffraction

Wave Diffraction - Definitions

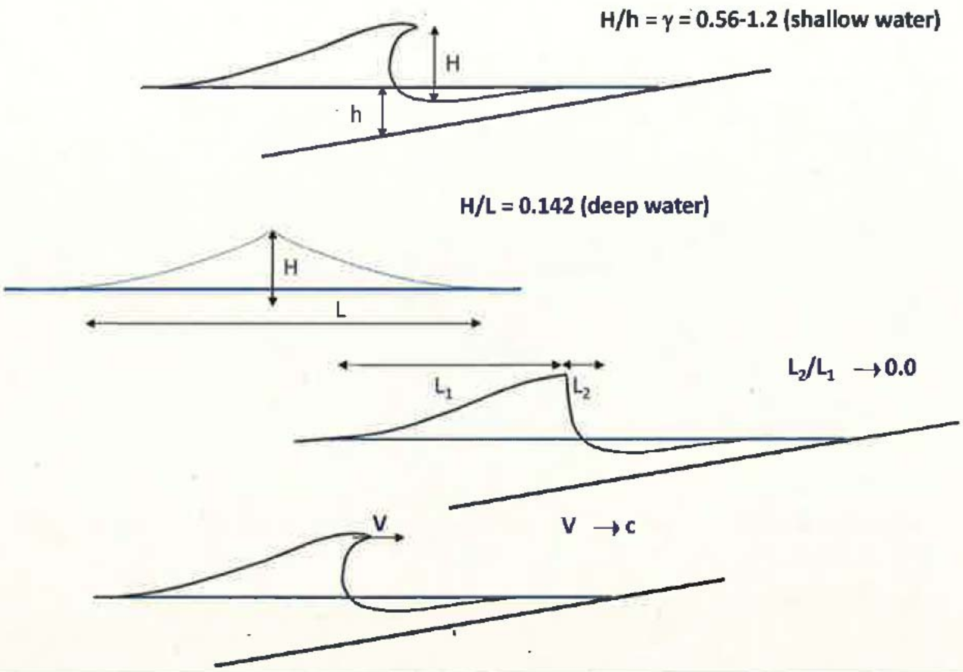


Wave Diffraction Through a Gap

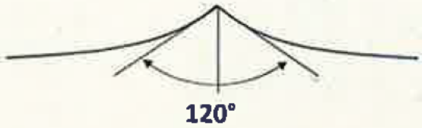




Wave breaking



Deep water breaking – White-capping



H/L = steepness

H = wave height

L = wave length

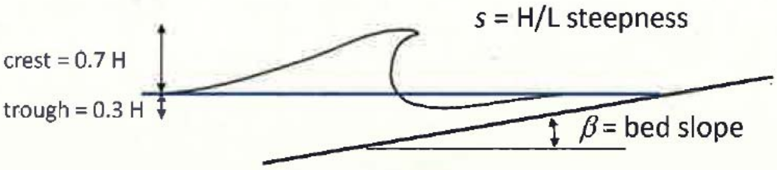
h = water depth

Breaking limit (Miche, 1951):

$$H_{\max} = 0.14L\tanh(kh)$$

In deep water → **H/L = 1/7**

Shallow water wave breaking



Iribarren Number

$$\xi_0 = \frac{\tan\beta}{\sqrt{\frac{H_0}{L_0}}}$$

H_0= wave heigth
L_0 = wave length
β = bed slope

Breaker Types

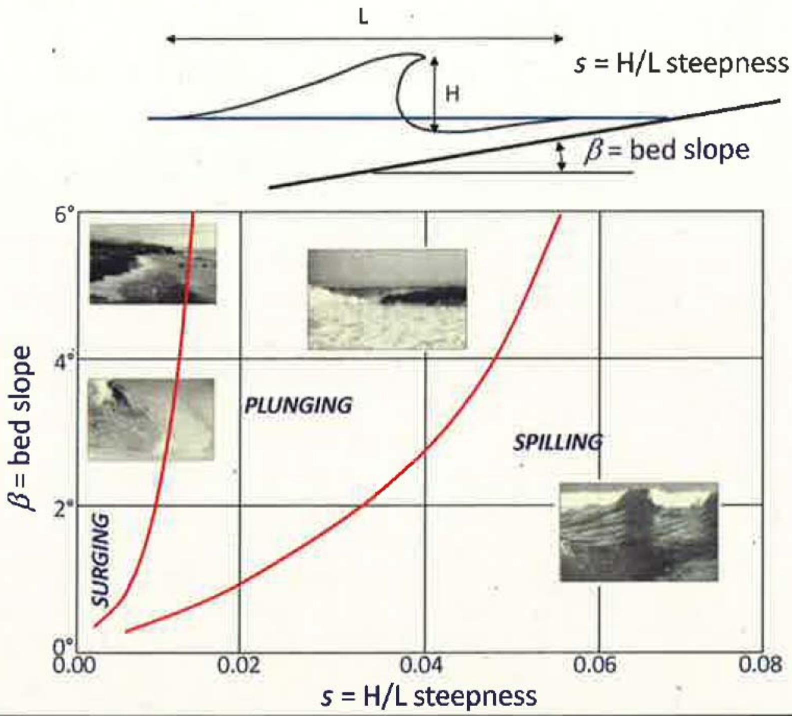
ξ < 0.5
Spilling

0.5 < ξ < 3.3
Plunging

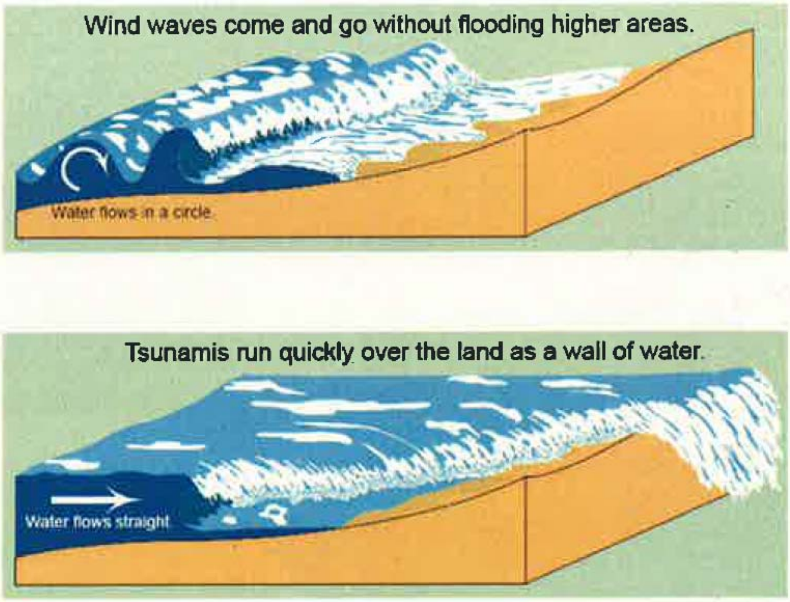
3.3 < ξ < 5
Collapsing

ξ > 5
Surging

Breaker Types



Tsunami wave breaking



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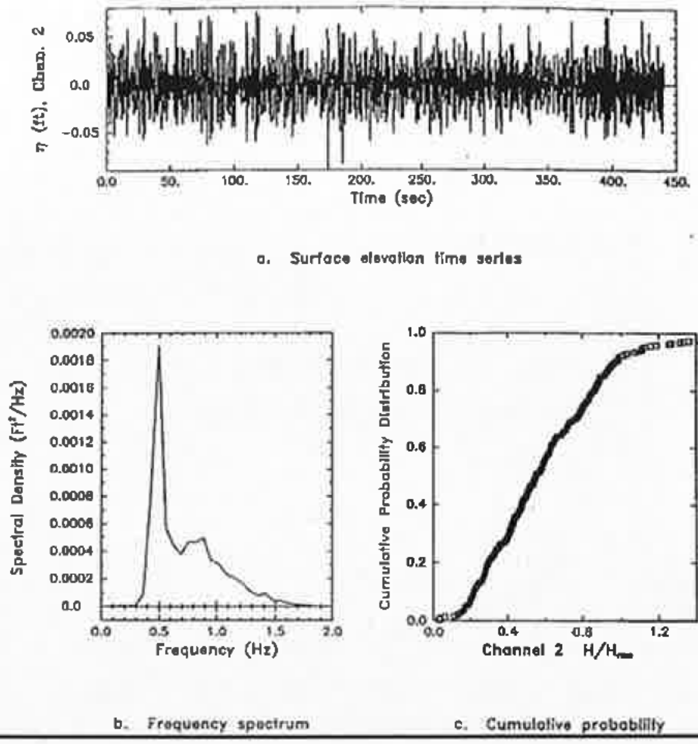
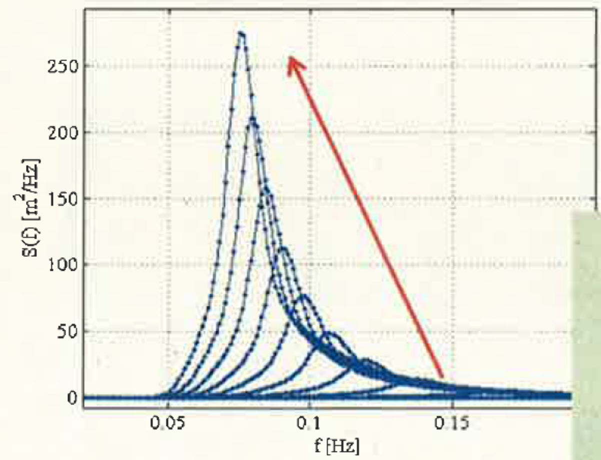
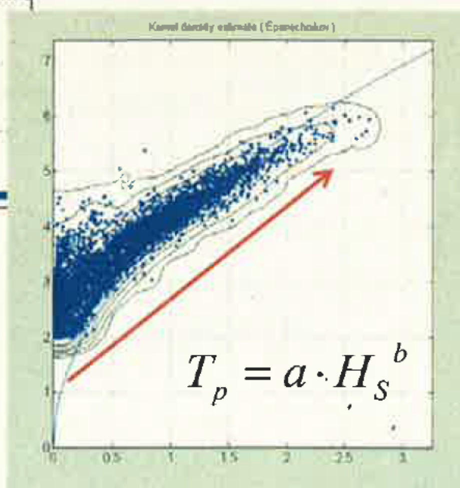
Part III: Water Waves Analysis

Wave Analysis – Spectra and Statistics



Wave Spectra



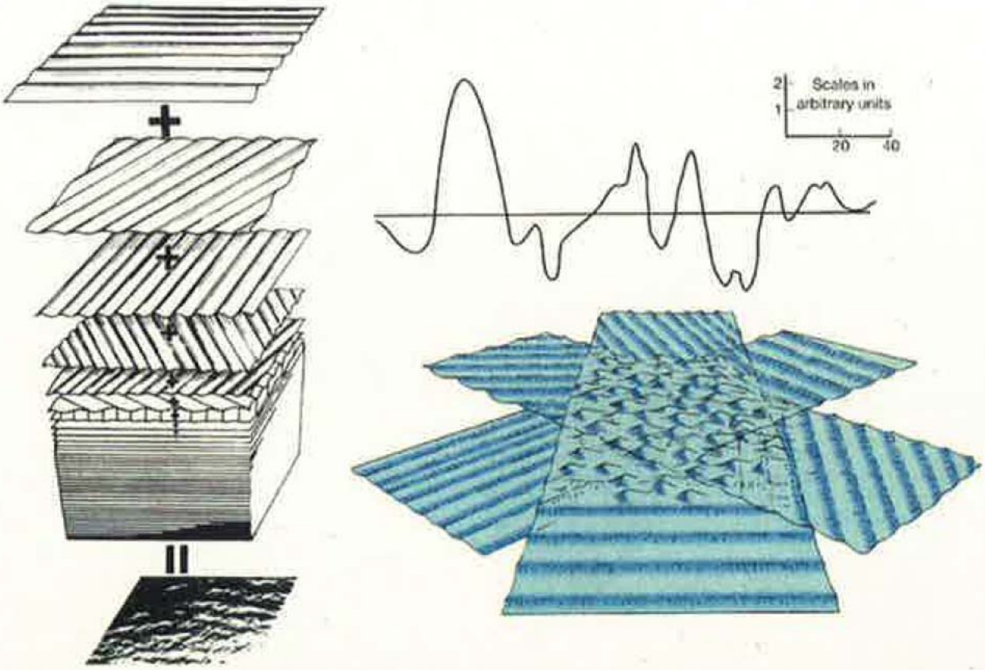


$$T_p = a \cdot H_S^{\ b}$$

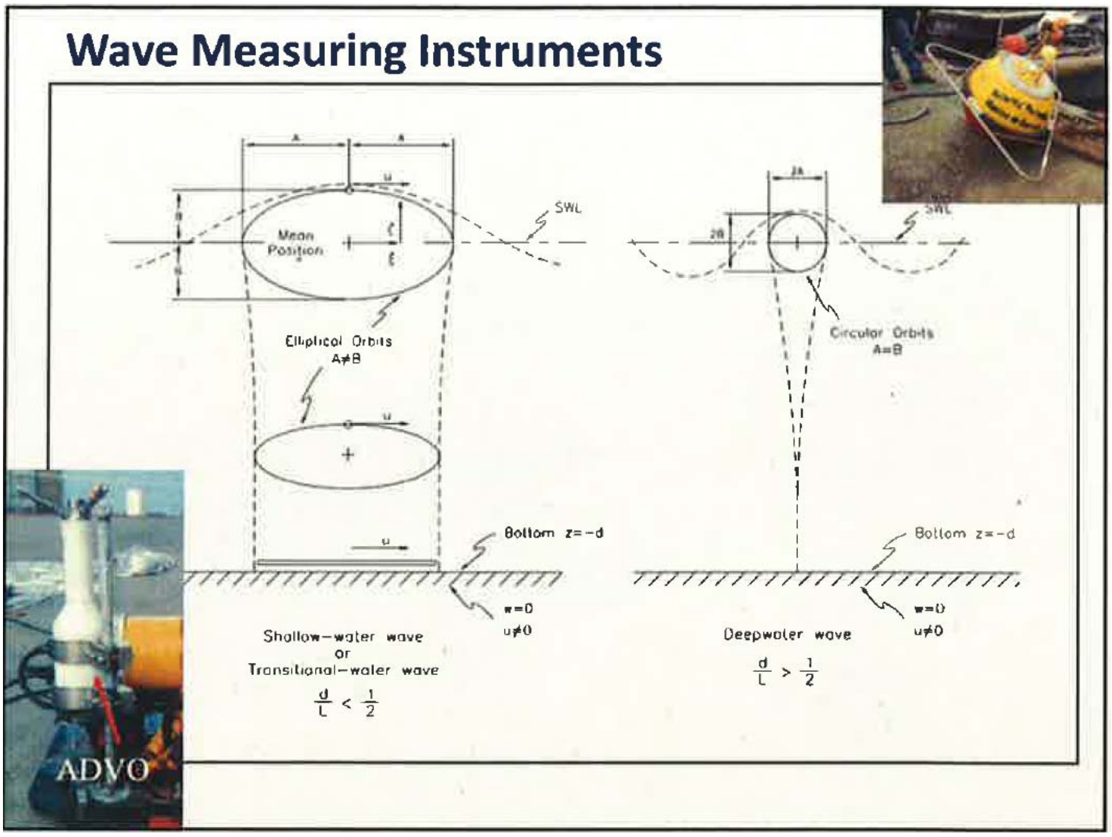
$$H_S \Leftrightarrow H_{m0} = 4\sqrt{m_0} = 4\sqrt{\int_{f1}^{f2} S(f)\,df}$$

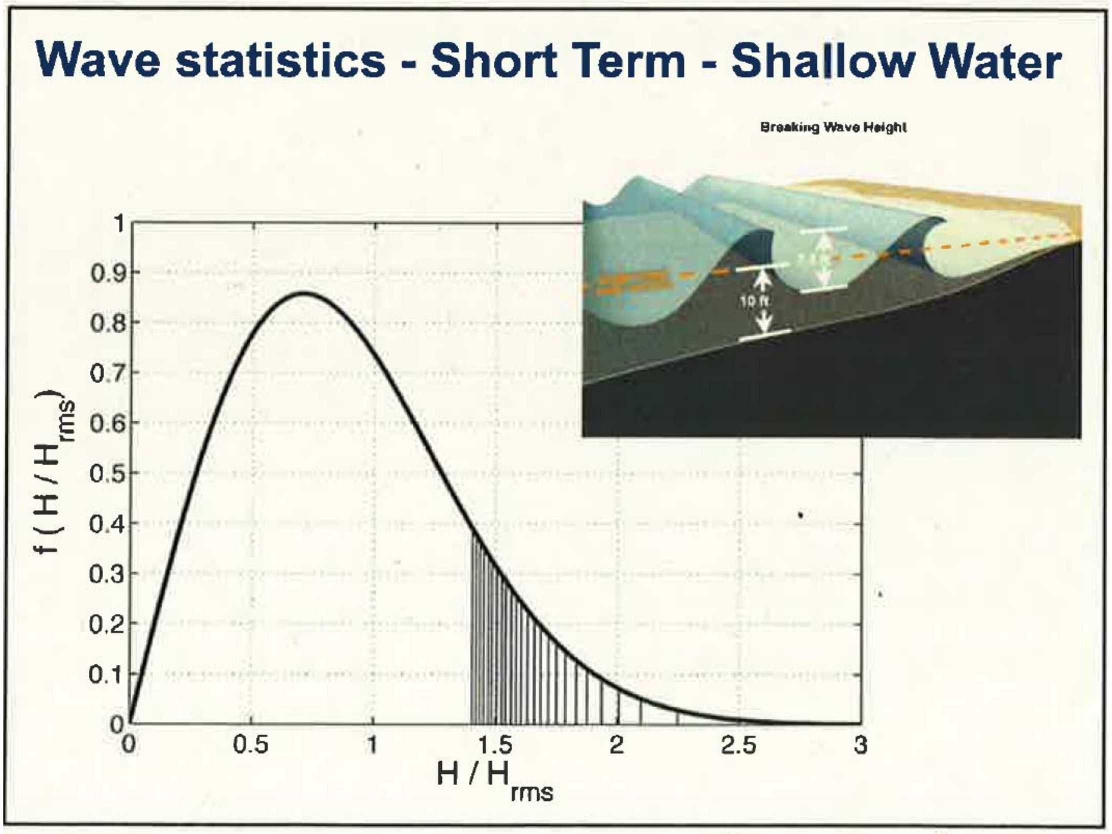
$$T_p = T\{\max[S(f)]\}$$

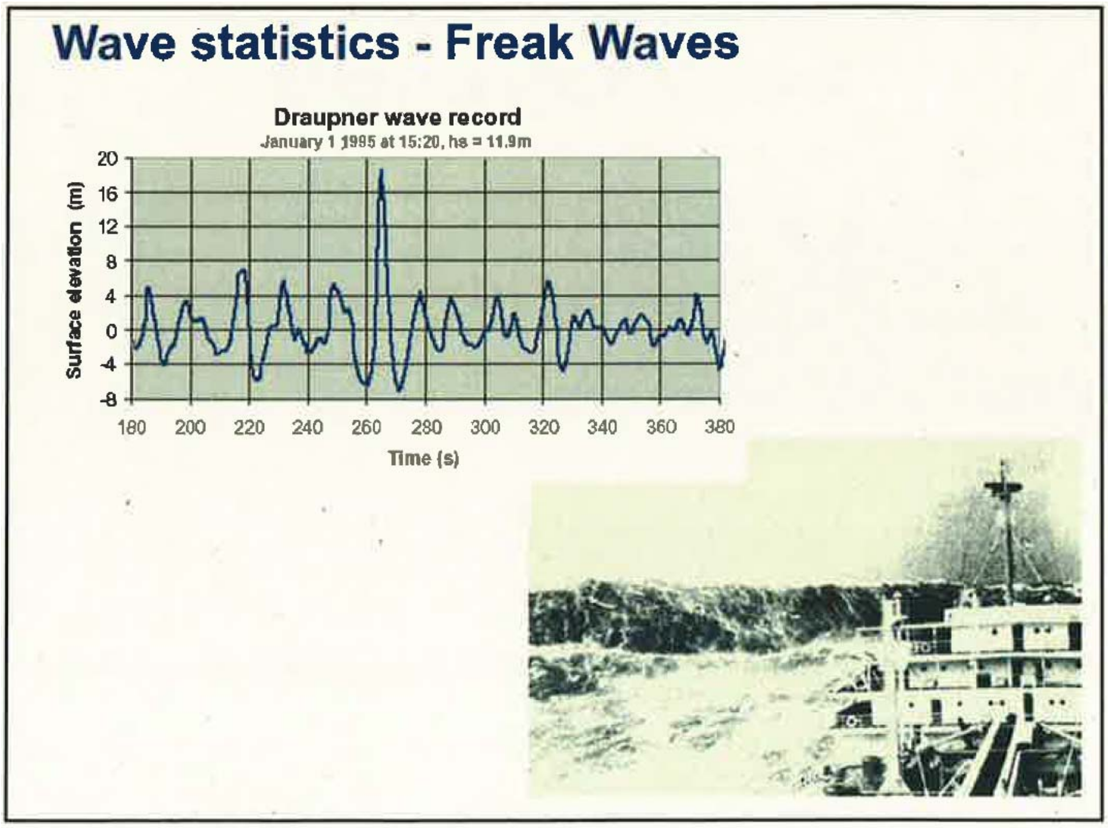
Real Sea States



Wave Measuring Instruments







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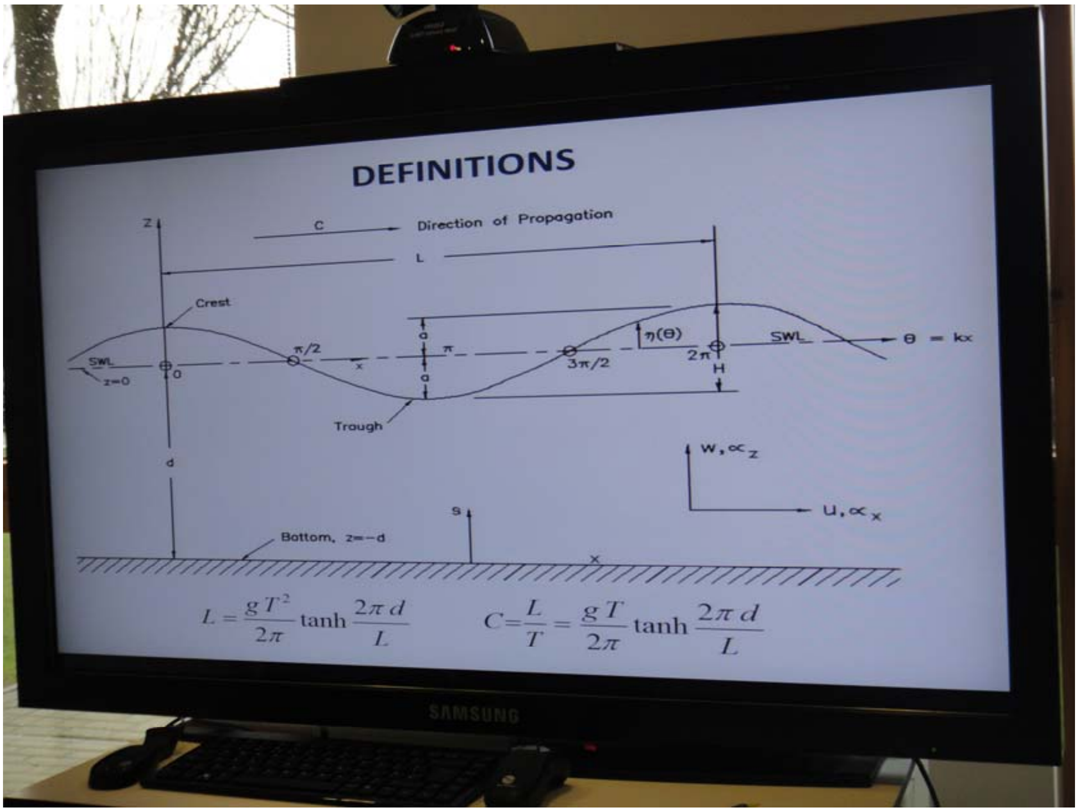
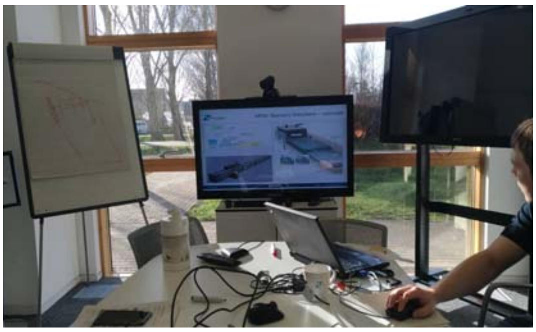

DEFINITIONS
Direction of Propagation
Crest
Trough
SWL
z=0
Bottom, z=-d
θ = kx
η(θ)
$L = \frac{gT^2}{2\pi} \tanh \frac{2\pi d}{L}$
$C = \frac{L}{T} = \frac{gT}{2\pi} \tanh \frac{2\pi d}{L}$
SAMSUNG

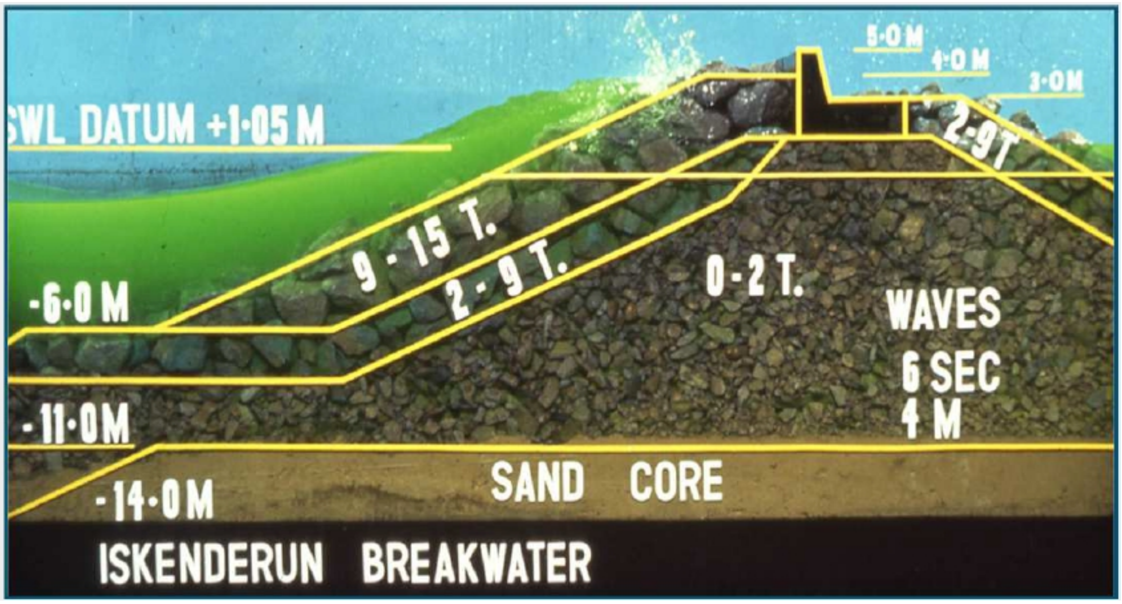
四、　造波技術及試驗操作

海岸工程由於受力情形的複雜與環境的多變，牽涉航運安全及港灣保護問題，日漸受到各國重視，考量面臨的主要威脅來自：異常洪水、海岸越波、海岸侵蝕、港池內波浪擾動等，研究人員逐漸發現基本研究以無法滿足時需，面對各種解析的蓬勃發展，包括非線性之數學解析、經驗公式、數值模式以及物理模型，故現場與 HR Wallingford 公司的技術人員 Dr. Ian 將進行造波技術交流與試驗操作，其透過試驗條件需求及造波輸出，來計算模型結構體之鋪設和設計作業之過程，以符合期待值，達到現實情況改善之解決方案。水工模型的好處在於，其為國際中接受度最高的研究方式，它可重現問題並予以解決，可研究一般問題，探索現象交互作用的過程，校正經驗公式或模式等，對於解決問題相當有幫助，Dr. Ian 表示目前 HR Wallingford 公司的研究包括：純波、波流交互作用、沉積物傳輸、越波行為與波力分析、港池模型繞射、消波塊安定、船舶運動等都有辦理研究。Dr. Ian(伊恩)以深入淺出的方式說明水工模型試驗的原理與用途，並講授造波各方面之技術及注意事項。

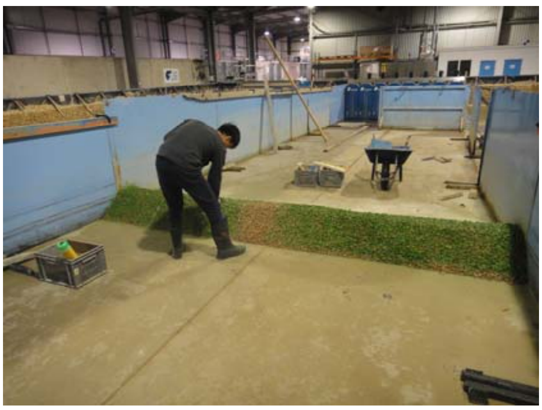


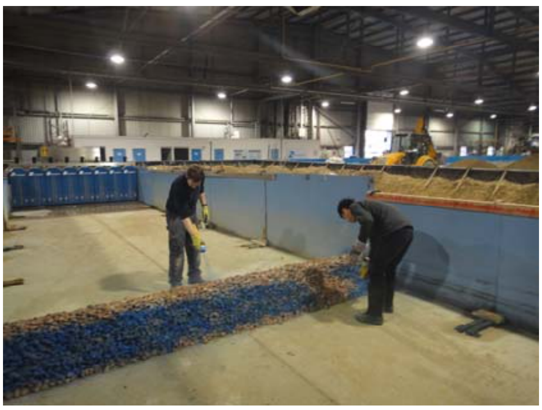



Dr.伊恩解說搭建的碎石堆防波堤須滿足幾何、運動及動力相似，經計算可得本次實務訓練水工模型，將以 1:62.4 的比例將防坡堤縮小，研究波浪越波後防坡堤受波力作用後之變化，變化量將以光達儀掃描堤體受力前後的成像差異分析堤身破壞的情形，藉此達成實驗佈設之學習目標、越坡與堤體安定分析、以及造波機 HR-DAQ 系統操作。

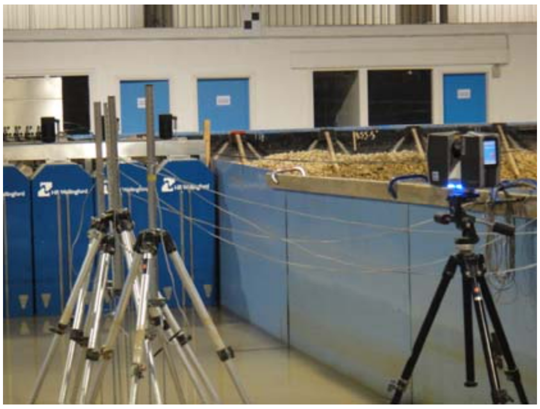


基本工作先由選定岩石粒徑開始，Dr.伊恩先引導學員至工具區領取防護具，再至木工工作室領取碎石堆防坡堤之標準斷面，這些專用手板都係經由模型縮尺比例計算裁製而成之，緊接著至水工模型部門之戶外粒料堆放區，那裡設有一臺全自動分類過篩的機器，可將粒料分級分類，實驗者再依需求取用，學員以手推車鏟取適量粒料石塊前往試驗地進行防坡堤鋪設，先將專用斷面隔板放置於適當位置後，底部先均勻鋪設底部細沙層，再依據隔板斷面型式以次級粒料鋪設堤身主體至位置線，為使堤身堆疊緊實，堆置過程需以木條或鏝刀反覆壓實，見空隙未平處需適時補充粒料鋪設，眼睛需專注位置線是否對齊，留意鋪面是否傾斜，鋪設過程需保持堤體水平為原則，最後在外層再鋪設兩層保護拋石層，第一層拋石層鋪設時需留意厚度均勻問題，不可過薄或太厚，拋石拋放時請以由下而上方式鋪設，避免由上而下拋放破壞堤身，完畢後第一層拋石面以綠色噴漆噴塗表面，緊接鋪設第二層粒料至完成面，完畢後第二層拋石面以藍色噴漆噴塗表面，堤趾以黃色噴漆噴塗完成面，目的係為了研究防坡堤受波力破壞後拋石之上層及下層如何運動，以及拋石掏刷行為，我們幾乎花費 1 整天的時間搬運骨材並進行模型鋪設，才進行至下一個步驟。

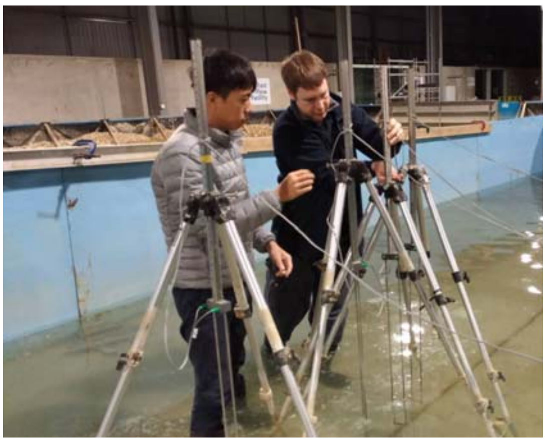




在試驗前 Dr.伊恩向我們介紹光達掃描儀功能，圖像將以點雲形式成像展示出來，靠近掃描儀的位置點雲密度較高精度較高，遠離儀器的點雲密度較疏精度變低。

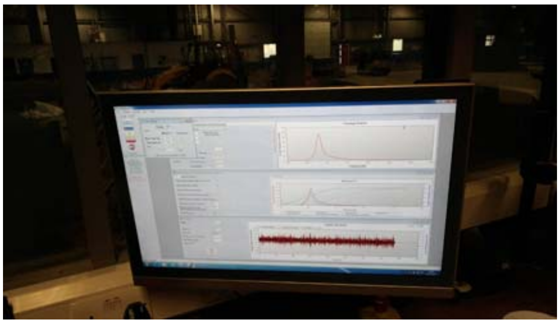



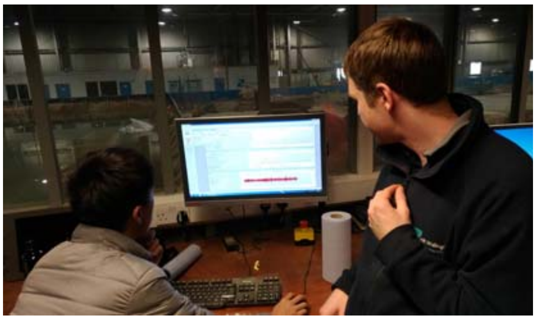
緊接著回到控制小屋中向我們介紹 HR Wallingford 公司試驗過程中所採用之儀器資料擷取系統，並講授試驗開始前的準備動作；整個試驗操作過程大致上分為三個步驟，第一是儀器校正，第二是資料擷取，第三是資料的後處理，因此要先學習儀器資料擷取系統的介面，視覺化可由瀏覽器直接目測目前有什麼儀器安裝在資料擷取系統當中(如濾波器、增幅器、波高計、壓力計、荷重計、計錄器)，某些儀器出廠時時有些矯正校正可供輸入，其中操作軟體前他們必須將試驗的細節說明清楚，比如說實驗者填列，試驗水池及控制小屋編號、試驗名稱等這部分的要求，讓我們回想起臺灣農業之產銷履歷，他們並不是為了追究實驗者責任，而是為了管理實驗室，以利後續追朔實驗細節本身。實驗儀器的校正需要先點選儀器種類並輸入設定單位，再做電壓的調整，本次訓練主要校正的儀器為波高計，首先利用抽水馬達為試驗水槽注水，由於 HR 水工模型試驗廠棚十分龐大，廠棚內有 9 個試驗場地，因此用水量十分可觀，但場地位置因鄰近泰晤士河，用水無虞，故未設有儲放水槽儲放用水，可說十分便利，回到試驗場地利用三角架及調整叉銷調整波高計以獲取三種不同水深電壓，予之率定波高計的線性關係，此部分與臺灣並無太大差異。

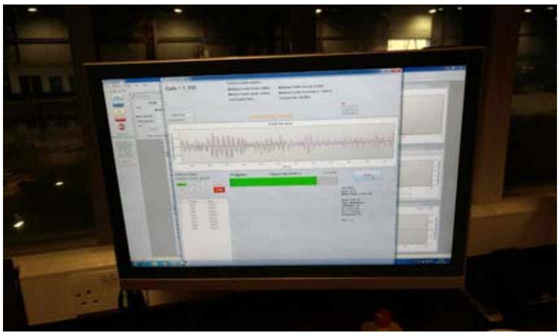



HR Wallingford 公司造波機系統與本所既有造波機設計上略有不同，本所造波機歸零，將自動化使造波板回到促動器中線，但新系統的設計則是將造波板停車至促動器原點，每次造波前再將造波板推回促動器中線再進行造波，此設計可避免造波機搬運時因碰撞造成促動器軸心偏移影響日後實驗結果，故需特別注意使用造波系統時需先歸零及停車，值得一提的是 HR Wallingford 公司為了讓使用者便於控制小屋中了解造波板位置及狀態，特別設有紅綠藍燈及閃爍號誌提示使用者，藍色閃爍號誌表示造波板目前正再移動位置，紅色燈號長亮表示造波板目前位置於停車位置處無法造波，綠色燈號長亮表示造波板目前位於促動器中線可隨時準備造波，十分便利。

整個實驗的過程相當迅速，令人印象深刻的是造波操作介面的複雜度較過去使用的介面更加視覺化，面板設計無多餘的步驟，簡化的介面更利於試驗者使用，使實驗過程更加得心應手，造波時所使用之資料擷取系統可將試驗結果進行頻譜分析，並與造波頻譜比對，以確認過程中是否發生異常。

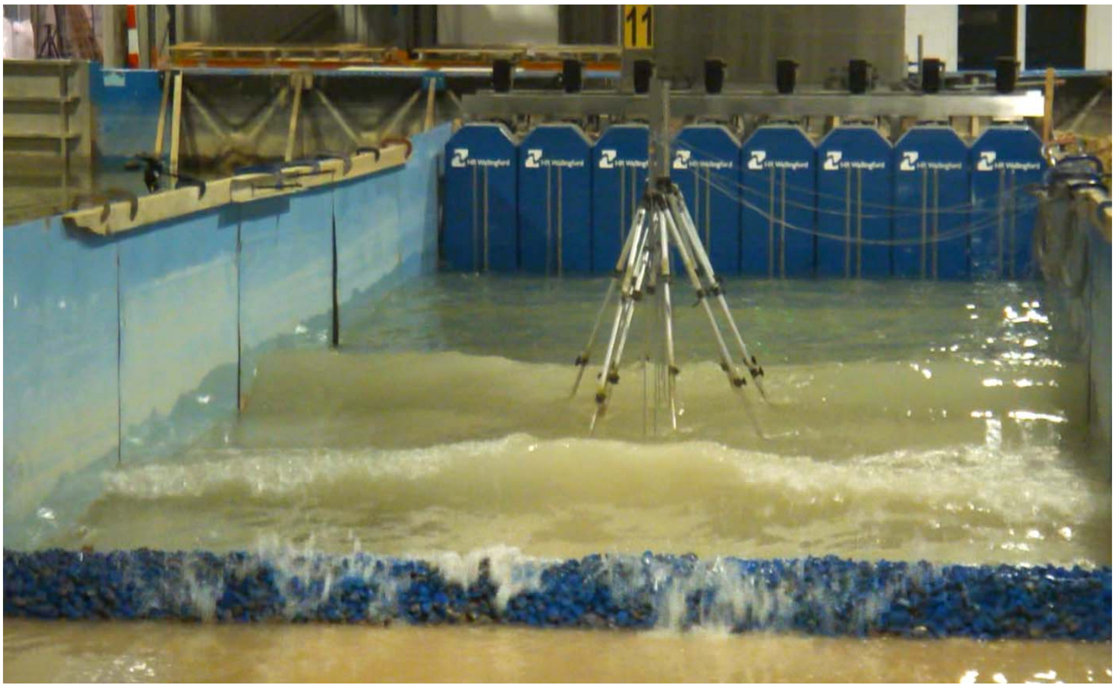


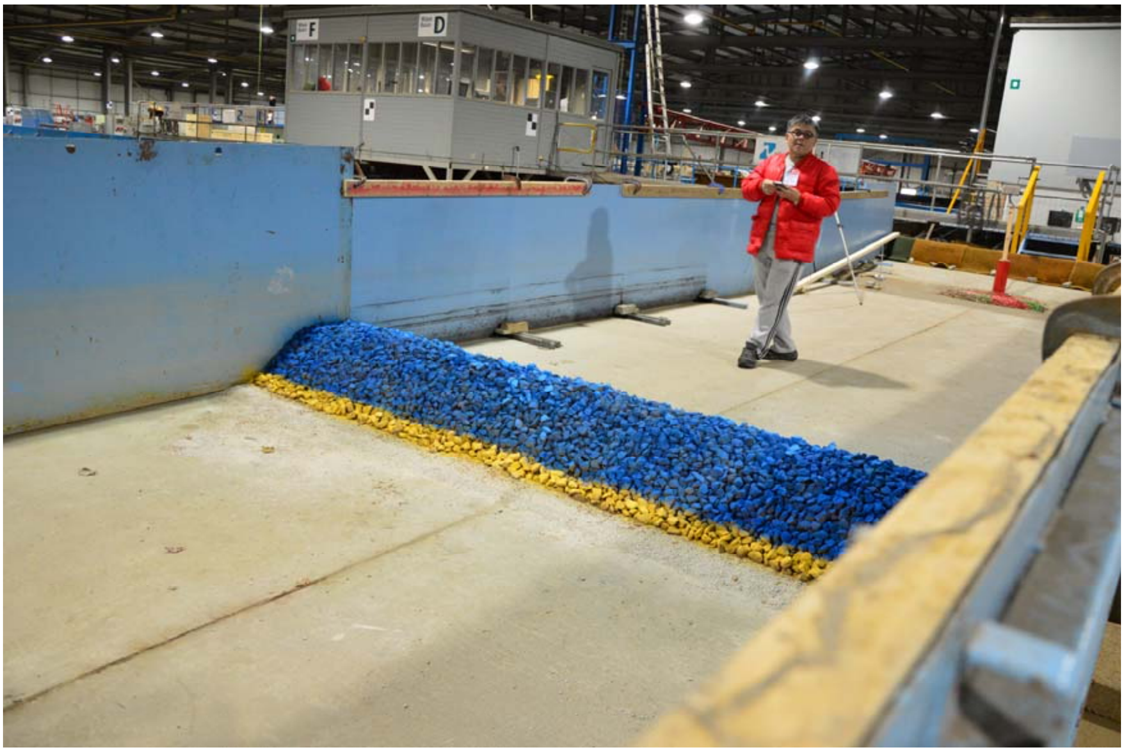




1. 水工模型操作各種試驗條件特性比較：

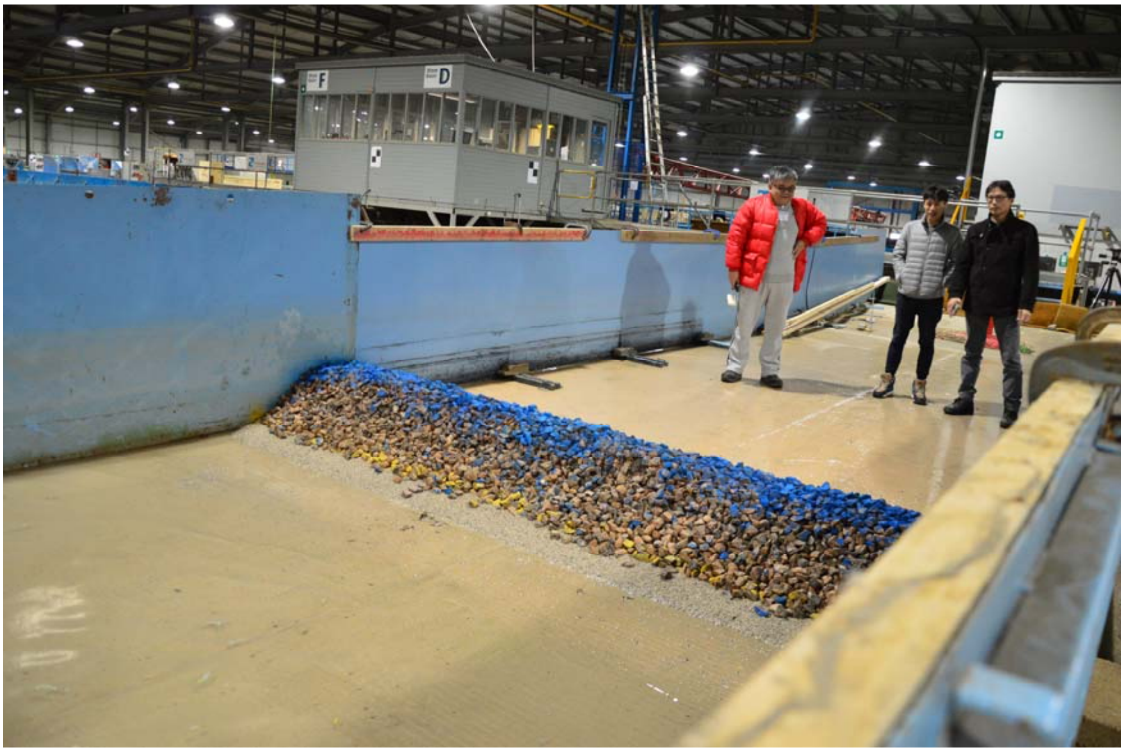
整個試驗過程中波浪條件由小而大增加，而當波浪條件逐漸開始增加時，波浪對堤體掏刷亦逐步加大，破壞時先由堤趾基礎開始發生，再由下層逐步往上層發展，外層往內層掏空，故外層藍色拋石骨材開始滾動，緊接著內層綠色拋石骨材發聲滾動，最後發生兩層雙色拋石骨材同時掏空且損及堤身，特別是波浪條件發生越波時，對於防波堤損壞情形最大，且破壞程度最為明顯。



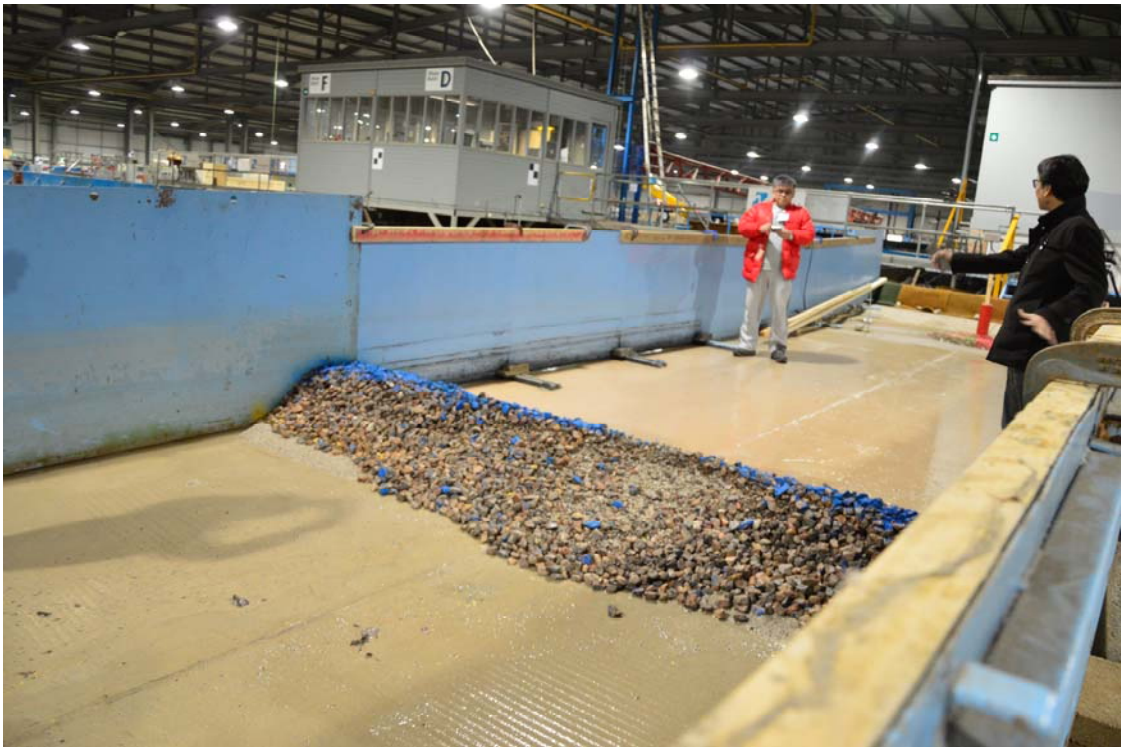


造波技術及試驗操作的現場處理展示(1)

造波技術及試驗操作的現場處理展示(2)



造波技術及試驗操作的現場處理展示(3)



造波技術及試驗操作的現場處理展示(4)

水工模型操作各種試驗結果特性比較表

Chan	00:01	00:02	00:03	00:04	00:01	00:02	00:03	00:04	00:01	00:02	00:03	00:04
Name	Ref_01	Ref_02	Ref_03	Ref_04	Ref_01	Ref_02	Ref_03	Ref_04	Ref_01	Ref_02	Ref_03	Ref_04
Freq (Hz)	Pxx (m^2/Hz)	Pxx (m^2/Hz)	Pxx (m^2/Hz)	Pxx (m^2/Hz)	Pxx (m^2/Hz)	Pxx (m^2/Hz)	Pxx (m^2/Hz)	Pxx (m^2/Hz)	Pxx (m^2/Hz)	Pxx (m^2/Hz)	Pxx (m^2/Hz)	Pxx (m^2/Hz)
0	0.021211	0.027368	0.029288	0.032066	0.105345	0.090249	0.116594	0.067292	0.515099	0.528812	0.514829	0.389039
0.005058	0.042875	0.043502	0.041177	0.069806	0.162836	0.147284	0.188523	0.132945	0.857678	0.8593	0.776228	0.700557
0.010116	0.088466	0.108925	0.127931	0.070982	0.441439	0.356569	0.300779	0.308194	1.825347	1.616388	1.457952	1.159533
0.015175	0.273042	0.33243	0.36309	0.268363	1.145871	1.139215	1.064255	0.985056	6.17536	6.148229	5.984032	4.293818
0.020233	0.247153	0.280887	0.312657	0.360605	0.902928	1.025702	1.148588	1.238523	7.117552	7.69103	8.249187	8.113102
0.025291	0.078011	0.054569	0.056426	0.158431	0.35395	0.325979	0.344264	0.609027	2.075042	2.408855	3.054444	5.382363
0.030349	0.152999	0.136216	0.114603	0.059581	0.499707	0.429453	0.345435	0.239452	1.963128	1.787682	1.554767	2.014027
0.035408	0.107925	0.118313	0.134577	0.089514	0.345555	0.422049	0.477777	0.283859	2.9666	3.160895	3.076598	1.415371
0.040466	0.050433	0.050545	0.057678	0.109709	0.154087	0.170806	0.225005	0.378524	2.48495	2.882756	3.421497	2.870879
0.045524	0.083313	0.062276	0.046228	0.057157	0.243609	0.22794	0.22252	0.169695	3.10664	3.52364	4.569631	8.637691
0.050582	0.059141	0.056407	0.062738	0.043285	0.280714	0.309425	0.314161	0.15597	14.83644	11.84724	11.53559	27.91464
0.055641	0.068223	0.074792	0.080023	0.073746	0.473058	0.467709	0.434494	0.21911	31.35558	27.72633	23.6658	29.85733
0.060699	0.143317	0.198171	0.232213	0.143119	0.976848	1.371696	1.683368	1.057197	48.13948	62.00895	70.03403	40.55295
0.065757	0.43341	0.320639	0.419904	0.976371	2.315965	1.832627	2.616041	6.128949	57.56229	83.06813	115.3521	119.337
0.070815	2.542637	1.773622	1.046983	2.599497	7.442831	4.187497	2.775374	11.69212	106.928	73.8198	68.27535	201.7418
0.075873	5.306143	5.723753	4.651406	2.079454	11.60791	12.82532	11.4554	6.285264	103.8391	79.70246	59.69816	117.39
0.080932	2.432254	4.289661	6.370803	2.155179	10.64033	15.0992	25.70086	16.16311	41.39471	49.74803	54.92057	29.51291
0.08599	9.837436	6.794505	5.233495	12.07862	32.9251	19.8412	26.07532	54.59198	22.06361	24.1783	29.42396	24.18196
0.091048	27.95884	27.78346	18.56564	27.96653	47.16004	48.22383	37.56875	54.45791	18.40068	19.57308	19.09838	16.98701
0.096106	18.9304	21.2112	21.75638	17.42349	36.07756	48.64251	51.6153	41.49961	11.91147	13.08165	16.07169	11.03302

0.101165	37.85032	23.41635	19.88014	21.42286	25.15854	21.06597	18.51181	17.33184	19.18096	13.92643	9.80859	11.95709
0.106223	26.36583	21.21923	14.43903	19.35462	23.42889	25.04382	19.43328	18.91856	16.12816	15.905	12.45627	10.7444
0.111281	7.559199	9.481334	12.73877	7.370386	10.16361	13.65346	16.28193	9.744145	11.06854	12.0405	13.52942	9.161679
0.116339	11.22118	7.057638	7.29277	5.409161	11.28968	8.447718	6.48916	6.477463	14.39782	12.68435	11.11064	12.6519
0.121397	7.904379	7.308067	4.549234	6.109189	6.971927	7.913111	6.208987	7.117363	15.89214	21.94572	19.32405	22.54922
0.126456	3.685022	3.826024	5.54673	4.071726	4.214436	5.212657	8.462039	5.798791	11.93991	15.11855	18.53456	16.85381
0.131514	2.923224	2.803054	3.526892	2.795317	4.397001	6.073309	6.018315	4.939636	11.55392	11.16011	13.38709	11.97976
0.136572	2.240552	2.880386	3.648749	3.281233	3.343619	4.686785	5.204403	5.065275	9.596199	13.31627	12.79576	15.04217
0.14163	2.907209	2.887039	2.370437	2.168513	3.542409	3.059244	2.184791	2.102174	8.713062	10.02346	12.73241	15.22329
0.146689	2.291008	3.318363	2.439992	2.026143	2.975615	3.12541	2.600816	2.274358	11.75586	6.370234	8.721067	9.260134
0.151747	2.626547	2.239776	2.083578	2.07037	3.351346	2.869738	2.428802	2.330977	9.611491	7.023004	5.967573	5.506155
0.156805	2.452996	2.75787	2.382156	1.557443	3.29243	3.616383	3.692064	2.384059	7.988023	7.318856	6.492031	4.54874
0.161863	1.579646	1.536665	1.817752	1.42952	3.651385	3.923992	4.194194	3.130994	5.278611	4.308537	4.722544	3.249413
0.166922	1.232564	1.360492	1.366302	1.177646	2.963502	2.835777	3.115192	2.338424	2.762929	2.863727	3.407661	3.114292
0.17198	1.647165	1.703198	1.647367	1.888408	2.368043	2.852219	2.233559	1.952856	3.304103	3.094982	2.840333	3.144109
0.177038	1.73355	1.777886	1.541383	1.467284	2.474216	2.422799	2.301969	1.5959	4.650891	2.967947	3.272455	2.394404
0.182096	1.534621	1.977876	1.367339	1.685027	2.349456	2.157411	1.965709	2.996182	3.654596	2.213463	2.53327	2.476449
0.187154	0.954043	1.169144	1.086544	1.096046	1.927069	2.277073	2.334834	2.536229	2.379691	1.945527	1.788625	2.471755
0.192213	0.586424	0.37586	0.601114	0.387525	1.823094	1.35425	1.691545	1.320981	1.911326	2.181481	2.316668	3.049253
0.197271	0.352504	0.350185	0.248988	0.606146	0.586448	0.616955	0.527731	1.041928	1.752437	2.317563	2.410716	2.915284
0.202329	0.223776	0.317568	0.231375	0.323351	0.420554	0.593849	0.563909	0.550454	1.092515	1.637634	1.725547	2.289041
0.207387	0.286117	0.330889	0.294096	0.233817	0.543728	0.50644	0.472971	0.528541	1.014381	1.014089	1.258205	1.896608
0.212446	0.223184	0.197905	0.18537	0.19049	0.458925	0.329989	0.313706	0.382042	1.563257	1.265729	1.457177	1.56866
0.217504	0.26265	0.242755	0.186914	0.217514	0.636271	0.479325	0.595557	0.503784	1.566187	1.626507	1.708011	1.283788
0.222562	0.258552	0.162871	0.154129	0.173823	0.377783	0.382393	0.421596	0.315987	1.539488	1.543548	1.502994	1.116076

0.22762	0.155178	0.146244	0.114063	0.107619	0.268195	0.330732	0.300895	0.229294	1.153812	0.99247	1.165158	0.80197
0.232679	0.150054	0.120927	0.103677	0.134576	0.249119	0.261307	0.266919	0.204468	0.660963	0.683476	0.861473	0.786412
0.237737	0.142621	0.084072	0.081233	0.124262	0.236808	0.163623	0.184396	0.238994	0.667136	0.698155	0.70238	0.915964
0.242795	0.081797	0.067009	0.105875	0.080781	0.248102	0.214502	0.185963	0.259324	0.823778	0.8086	0.627142	0.937855
0.247853	0.095657	0.136959	0.104184	0.091278	0.233851	0.245405	0.249796	0.218293	0.689715	0.742098	0.637048	0.638953
0.252911	0.105046	0.120691	0.07612	0.117131	0.264091	0.242384	0.286058	0.174854	0.446679	0.629327	0.530387	0.645059
0.25797	0.08637	0.079504	0.07641	0.125378	0.255371	0.205665	0.221888	0.212211	0.524427	0.592614	0.543128	0.556937
0.263028	0.073495	0.07619	0.059651	0.092384	0.186742	0.206811	0.184161	0.195532	0.53802	0.627111	0.677826	0.560501
0.268086	0.064214	0.061633	0.073283	0.06939	0.196332	0.198115	0.200455	0.196156	0.424804	0.482539	0.68987	0.662751
0.273144	0.082731	0.095984	0.116177	0.101403	0.211526	0.183252	0.175064	0.236023	0.393211	0.332972	0.413126	0.545774
0.278203	0.074443	0.087011	0.094569	0.078767	0.204707	0.172106	0.138489	0.189995	0.33751	0.34931	0.354723	0.583047
0.283261	0.058474	0.049013	0.067016	0.057684	0.146114	0.13449	0.132007	0.132022	0.384451	0.42641	0.387099	0.49624
0.288319	0.062459	0.070008	0.069527	0.060382	0.087188	0.129026	0.09541	0.11302	0.348269	0.367563	0.342815	0.299844
0.293377	0.066062	0.064647	0.046907	0.043752	0.089951	0.112542	0.091308	0.105444	0.280141	0.301402	0.244892	0.304819
0.298435	0.057915	0.054269	0.046287	0.040896	0.135804	0.124771	0.098546	0.100467	0.289782	0.262524	0.189148	0.259482
0.303494	0.033773	0.038332	0.035577	0.041927	0.086205	0.074889	0.064594	0.058264	0.265054	0.219009	0.178445	0.205523
0.308552	0.034779	0.02502	0.023628	0.034574	0.052747	0.047644	0.046983	0.051593	0.18886	0.194748	0.172602	0.198938
0.31361	0.030749	0.018126	0.030776	0.026066	0.060376	0.040092	0.055753	0.052639	0.196316	0.182289	0.168566	0.16507
0.318668	0.017472	0.015399	0.024246	0.02867	0.052611	0.045162	0.054348	0.064463	0.235877	0.165624	0.143468	0.167207
0.323727	0.013054	0.019508	0.021385	0.018442	0.051486	0.049662	0.053924	0.050672	0.18509	0.142763	0.151841	0.168547
0.328785	0.016505	0.02174	0.01908	0.013599	0.039156	0.037583	0.035967	0.048441	0.128657	0.125249	0.180648	0.166219
0.333843	0.018139	0.012751	0.011429	0.015882	0.043038	0.035957	0.042162	0.048307	0.134717	0.132966	0.174746	0.177796
0.338901	0.015187	0.011397	0.00786	0.014464	0.049908	0.032503	0.041906	0.040785	0.141844	0.164741	0.179833	0.200934
0.34396	0.013068	0.013536	0.011474	0.017745	0.038177	0.03849	0.033122	0.036383	0.159573	0.152351	0.140277	0.164435
0.349018	0.009844	0.015484	0.014656	0.01871	0.038104	0.042585	0.038841	0.044608	0.090794	0.102408	0.075189	0.1209

0.354076	0.01002	0.012056	0.009715	0.011727	0.03397	0.040427	0.03506	0.039913	0.087615	0.085705	0.085467	0.098872
0.359134	0.011471	0.007669	0.009182	0.008581	0.027957	0.030605	0.024358	0.027222	0.0906	0.09001	0.07785	0.082601
0.364192	0.010108	0.008844	0.010452	0.007066	0.033765	0.032385	0.034711	0.027514	0.084004	0.074928	0.071361	0.10112
0.369251	0.007992	0.009526	0.009135	0.008899	0.021673	0.024723	0.027633	0.030728	0.081508	0.077879	0.063613	0.069892
0.374309	0.007698	0.008555	0.005939	0.007241	0.033087	0.020216	0.01856	0.023078	0.058964	0.050342	0.064198	0.056288
0.379367	0.005561	0.007023	0.007162	0.007321	0.030602	0.017515	0.01589	0.019128	0.047607	0.052302	0.055949	0.069423
0.384425	0.004755	0.005788	0.005372	0.005604	0.018316	0.017894	0.02095	0.013803	0.04673	0.061209	0.0443	0.056273
0.389484	0.004845	0.005231	0.005434	0.005343	0.015248	0.016603	0.014594	0.014538	0.046639	0.052292	0.051275	0.047023
0.394542	0.003658	0.004318	0.004499	0.005156	0.014404	0.013101	0.012851	0.019089	0.04837	0.05223	0.058273	0.045983
0.3996	0.004241	0.004068	0.003712	0.004676	0.011141	0.009097	0.008757	0.018241	0.032722	0.044799	0.058378	0.060772
0.404658	0.003235	0.003399	0.004863	0.004397	0.011508	0.009071	0.007445	0.013319	0.043361	0.042964	0.049615	0.06903
0.409717	0.003628	0.002818	0.004018	0.003686	0.012244	0.008302	0.010452	0.009997	0.046163	0.045695	0.043614	0.072816
0.414775	0.003106	0.002359	0.002896	0.0032	0.00986	0.008873	0.008575	0.011321	0.041712	0.034638	0.047075	0.046284
0.419833	0.002627	0.001815	0.00241	0.002096	0.008304	0.010776	0.006757	0.009541	0.041673	0.0272	0.032393	0.034026
0.424891	0.001644	0.001813	0.001884	0.001907	0.008318	0.010173	0.009231	0.008949	0.039218	0.03056	0.025205	0.0353
0.429949	0.001437	0.002759	0.001685	0.001798	0.006747	0.008402	0.007512	0.007894	0.038808	0.031873	0.030659	0.035004
0.435008	0.001628	0.002498	0.001819	0.002054	0.007173	0.007046	0.004434	0.007179	0.028835	0.032639	0.02522	0.031829
0.440066	0.001474	0.001651	0.002147	0.002168	0.00663	0.006703	0.006247	0.008166	0.027269	0.026439	0.02482	0.022511
0.445124	0.001478	0.001364	0.002515	0.001446	0.006268	0.007097	0.007316	0.008503	0.027865	0.024317	0.025075	0.016971
0.450182	0.001099	0.001498	0.001621	0.001366	0.006568	0.004788	0.00607	0.006381	0.023155	0.021943	0.026353	0.018442
0.455241	0.001058	0.001125	0.001292	0.00172	0.004671	0.006156	0.005226	0.004601	0.016427	0.018891	0.022077	0.015248
0.460299	0.00125	0.00106	0.001445	0.001298	0.005333	0.005367	0.006078	0.005821	0.015447	0.01544	0.021897	0.014127
0.465357	0.001514	0.000869	0.001273	0.000944	0.005575	0.0054	0.005633	0.004721	0.015356	0.01942	0.022848	0.019793
0.470415	0.001345	0.000818	0.000917	0.000982	0.004913	0.00504	0.005822	0.004081	0.015334	0.024446	0.021965	0.025691
0.475473	0.001223	0.000985	0.00105	0.00131	0.004576	0.004531	0.005125	0.003937	0.018894	0.019685	0.024174	0.031892

0.480532	0.001119	0.000959	0.001287	0.001138	0.004411	0.003485	0.004265	0.00337	0.020697	0.015407	0.019198	0.026181
0.48559	0.001228	0.000983	0.000902	0.001146	0.004534	0.003434	0.004337	0.00335	0.020715	0.019086	0.014532	0.016373
0.490648	0.001261	0.001317	0.000854	0.000942	0.004102	0.003212	0.002745	0.002912	0.018535	0.018863	0.014298	0.014438
0.495706	0.000957	0.001056	0.000879	0.000717	0.003622	0.003202	0.0033	0.003048	0.02211	0.014712	0.017019	0.013571
0.500765	0.000625	0.000866	0.000752	0.000635	0.002908	0.003007	0.003644	0.001983	0.020691	0.014177	0.01504	0.01678
0.505823	0.000842	0.001039	0.000601	0.000629	0.002262	0.002482	0.002491	0.001936	0.016971	0.013785	0.013976	0.017435
0.510881	0.000719	0.000813	0.000575	0.000633	0.002855	0.002424	0.002142	0.0021	0.014804	0.01188	0.011039	0.014311
0.515939	0.000545	0.000674	0.000523	0.000431	0.00161	0.002272	0.001811	0.002396	0.013544	0.01284	0.010887	0.0114
0.520998	0.000546	0.000613	0.000387	0.000383	0.001766	0.001842	0.001902	0.002202	0.013247	0.011542	0.012217	0.011728
0.526056	0.000538	0.000437	0.000509	0.000518	0.002275	0.001686	0.00183	0.002184	0.0127	0.009315	0.01218	0.009364
0.531114	0.000618	0.000511	0.000563	0.000572	0.002322	0.001524	0.001601	0.00187	0.009997	0.009051	0.011509	0.009094
0.536172	0.000683	0.000455	0.000521	0.000406	0.001841	0.001936	0.001604	0.0025	0.010335	0.009411	0.012868	0.010116
0.54123	0.00063	0.000407	0.000411	0.000316	0.001799	0.001792	0.001363	0.002039	0.010186	0.011335	0.011682	0.01169
0.546289	0.000479	0.000343	0.000263	0.000352	0.002206	0.001425	0.001418	0.001973	0.00732	0.009584	0.009999	0.016346
0.551347	0.00041	0.000362	0.00042	0.000402	0.001782	0.001186	0.001781	0.00179	0.009484	0.008092	0.008741	0.011613
0.556405	0.000347	0.00033	0.000407	0.000435	0.001771	0.001321	0.001756	0.001466	0.009997	0.007426	0.01031	0.007701
0.561463	0.000299	0.000301	0.000361	0.000325	0.001514	0.00127	0.00173	0.001614	0.009772	0.007094	0.010403	0.006722
0.566522	0.000374	0.000309	0.000285	0.000223	0.001053	0.001091	0.001609	0.001342	0.008799	0.00829	0.00688	0.006758
0.57158	0.000439	0.000346	0.000309	0.000211	0.001201	0.001263	0.001289	0.001074	0.007083	0.008467	0.006988	0.007354
0.576638	0.000477	0.000246	0.000258	0.000201	0.001352	0.001194	0.001329	0.00109	0.006946	0.006804	0.009266	0.008266
0.581696	0.000295	0.000224	0.000287	0.000289	0.001234	0.00102	0.001217	0.00107	0.008098	0.007303	0.007713	0.00764
0.586755	0.000256	0.000294	0.000319	0.000214	0.001371	0.000995	0.001036	0.0013	0.009056	0.006279	0.00619	0.006217
0.591813	0.000299	0.000241	0.000308	0.000164	0.001392	0.001027	0.001001	0.001113	0.008089	0.005702	0.006626	0.005467
0.596871	0.00023	0.000312	0.000224	0.000155	0.001266	0.001168	0.000723	0.000847	0.006576	0.005949	0.007532	0.00521
0.601929	0.000244	0.000344	0.000186	0.000172	0.000964	0.000988	0.000748	0.000739	0.007134	0.006085	0.006217	0.005628

0.606987	0.000268	0.000308	0.000175	0.000167	0.000995	0.000872	0.000689	0.00067	0.006874	0.005361	0.006543	0.006012
0.612046	0.000248	0.000281	0.000171	0.00014	0.00102	0.001026	0.00075	0.000851	0.005644	0.004954	0.006812	0.006707
0.617104	0.000252	0.000269	0.000139	0.000132	0.000802	0.000812	0.000684	0.000617	0.00534	0.005938	0.005681	0.006037
0.622162	0.000228	0.000222	0.000167	0.000135	0.000864	0.000904	0.000654	0.000693	0.005882	0.008348	0.005975	0.004965
0.62722	0.00017	0.000189	0.000157	0.000124	0.000993	0.00086	0.000657	0.000822	0.005764	0.006967	0.005705	0.003909
0.632279	0.000212	0.000193	0.000169	0.000143	0.00082	0.000774	0.000811	0.0008	0.004623	0.005387	0.005711	0.004836
0.637337	0.000237	0.00021	0.000193	0.000167	0.000832	0.00072	0.00083	0.000593	0.005051	0.005434	0.004144	0.004869
0.642395	0.000249	0.000168	0.000151	0.000115	0.000722	0.000444	0.000516	0.000442	0.004753	0.005421	0.004441	0.005005
0.647453	0.000197	0.000132	0.000166	0.00012	0.001042	0.000485	0.000629	0.000414	0.004497	0.005098	0.004157	0.004538
0.652511	0.000174	0.00015	0.000203	0.000131	0.000932	0.00045	0.000634	0.000416	0.004035	0.004336	0.004223	0.004211
0.65757	0.000201	0.000135	0.000208	0.000127	0.001041	0.000494	0.000523	0.000471	0.004102	0.004023	0.004026	0.002943
0.662628	0.000181	0.000129	0.000202	0.000123	0.000555	0.0005	0.000474	0.000482	0.004328	0.004046	0.004098	0.002767
0.667686	0.000174	0.000163	0.000214	0.000151	0.000655	0.000598	0.000499	0.000428	0.004318	0.004089	0.004055	0.003263
0.672744	0.000185	0.000179	0.000188	0.000174	0.000685	0.000414	0.00043	0.000433	0.004803	0.004047	0.003308	0.003427
0.677803	0.000229	0.000121	0.000156	0.000152	0.000662	0.000482	0.000429	0.000393	0.004385	0.004203	0.003591	0.003396
0.682861	0.000253	0.000147	0.000156	0.000149	0.000431	0.000538	0.000452	0.000439	0.003715	0.003963	0.003646	0.003372
0.687919	0.000176	0.000178	0.000135	0.000109	0.000447	0.00053	0.000389	0.000372	0.003391	0.00347	0.003027	0.003473
0.692977	0.000185	0.000189	0.000136	0.000102	0.000638	0.000407	0.000406	0.000372	0.003522	0.003139	0.002791	0.002753
0.698036	0.000175	0.000162	0.000112	0.000093	0.000666	0.000403	0.00036	0.000329	0.003055	0.002871	0.002696	0.002688
0.703094	0.000133	0.000122	0.0001	0.000092	0.000647	0.000521	0.000482	0.00036	0.003079	0.002615	0.002339	0.003124
0.708152	0.000156	0.000128	0.000144	0.00013	0.000553	0.000381	0.000359	0.000386	0.003544	0.002607	0.001749	0.003669
0.71321	0.00016	0.000105	0.000134	0.000117	0.000534	0.000363	0.000398	0.000398	0.002525	0.002926	0.002013	0.002002
0.718268	0.000139	0.000084	0.00013	0.000105	0.000511	0.000368	0.000376	0.000321	0.002367	0.00296	0.002512	0.002066
0.723327	0.000179	0.000115	0.000131	0.000117	0.000401	0.000415	0.000333	0.000233	0.002494	0.002516	0.002554	0.001661
0.728385	0.000175	0.000102	0.000115	0.000103	0.000486	0.000362	0.000277	0.000315	0.002355	0.002256	0.002551	0.001862

0.733443	0.000179	0.000077	0.000121	0.000098	0.000499	0.000337	0.000317	0.000312	0.00223	0.002057	0.002367	0.001732
0.738501	0.000159	0.000097	0.000135	0.000117	0.00044	0.000329	0.000399	0.000294	0.00278	0.002202	0.002109	0.002044
0.74356	0.000172	0.000121	0.000134	0.000109	0.000384	0.000367	0.000326	0.000338	0.002627	0.002102	0.002324	0.002101
0.748618	0.000178	0.000145	0.000101	0.000106	0.000352	0.000446	0.000357	0.000286	0.002035	0.001933	0.002032	0.001968
0.753676	0.000159	0.000139	0.000114	0.000116	0.000362	0.00043	0.000324	0.000167	0.002064	0.001944	0.002075	0.002081
0.758734	0.00011	0.000078	0.000092	0.000086	0.000399	0.000363	0.000292	0.000181	0.002122	0.002112	0.002185	0.001892
0.763793	0.000115	0.000094	0.000073	0.000077	0.000397	0.000322	0.000224	0.00019	0.00191	0.002333	0.001918	0.001883
0.768851	0.000114	0.000091	0.000091	0.000087	0.000335	0.000327	0.000261	0.000189	0.002313	0.002373	0.001797	0.002078
0.773909	0.000142	0.000087	0.000115	0.000082	0.000391	0.00032	0.000238	0.000187	0.002928	0.002448	0.002099	0.002878
0.778967	0.000139	0.000081	0.000091	0.000073	0.000412	0.000267	0.000207	0.00018	0.002206	0.003037	0.002299	0.002954
0.784025	0.000125	0.000088	0.000093	0.000069	0.000393	0.000286	0.000241	0.000246	0.00253	0.002805	0.002797	0.002474
0.789084	0.00012	0.000125	0.000102	0.000079	0.000329	0.000262	0.000203	0.000224	0.002413	0.002426	0.001845	0.001857
0.794142	0.00015	0.000145	0.000118	0.000098	0.000244	0.000259	0.000176	0.000171	0.001803	0.001926	0.001607	0.001258
0.7992	0.00013	0.000102	0.000097	0.000076	0.000247	0.000231	0.000223	0.000171	0.00152	0.001544	0.001728	0.000941
0.804258	0.000114	0.000084	0.000101	0.000064	0.000263	0.000313	0.000172	0.000179	0.001544	0.001497	0.0014	0.000894
0.809317	0.000127	0.000085	0.000098	0.000086	0.000355	0.000269	0.000164	0.000159	0.001648	0.00138	0.001372	0.001056
0.814375	0.000117	0.000075	0.000096	0.000088	0.000316	0.000208	0.000156	0.00016	0.001519	0.001364	0.001219	0.00101
0.819433	0.000103	0.000078	0.000098	0.000076	0.000229	0.000179	0.000139	0.000168	0.001465	0.001645	0.000971	0.00123
0.824491	0.000142	0.000082	0.00013	0.000116	0.000276	0.000157	0.000195	0.000173	0.001673	0.001668	0.001239	0.001283
0.829549	0.000168	0.000087	0.000121	0.0001	0.000221	0.00014	0.000201	0.000129	0.001845	0.001549	0.001427	0.001326
0.834608	0.000126	0.000068	0.000098	0.000069	0.000227	0.000212	0.000201	0.000119	0.001761	0.001256	0.001201	0.001259
0.839666	0.000135	0.000077	0.000102	0.000082	0.000282	0.000204	0.000173	0.000149	0.001898	0.001409	0.00107	0.001651
0.844724	0.000144	0.000087	0.000099	0.000084	0.000246	0.000209	0.000139	0.000146	0.001625	0.001465	0.001127	0.001649
0.849782	0.000126	0.000097	0.000107	0.000092	0.000215	0.00019	0.000143	0.000118	0.001346	0.001303	0.001083	0.001371
0.854841	0.000106	0.00008	0.000089	0.000091	0.000219	0.000156	0.000209	0.000104	0.001408	0.001532	0.000947	0.001286

0.859899	0.000138	0.000105	0.000144	0.000102	0.000232	0.000175	0.000235	0.000107	0.00139	0.001397	0.001034	0.000934
0.864957	0.000113	0.000101	0.000122	0.000085	0.000234	0.000126	0.000197	0.000111	0.001108	0.001206	0.001168	0.000834
0.870015	0.00011	0.000088	0.000096	0.000083	0.000296	0.000121	0.000162	0.00011	0.001092	0.001186	0.001172	0.000906
0.875074	0.000132	0.000111	0.000107	0.0001	0.00023	0.000126	0.000152	0.000098	0.001083	0.00119	0.001033	0.000821
0.880132	0.000124	0.000095	0.000105	0.000087	0.00018	0.000125	0.00015	0.000104	0.001047	0.001143	0.001	0.000651
0.88519	0.000127	0.000075	0.000106	0.000075	0.000149	0.000121	0.000145	0.000078	0.001026	0.001034	0.000914	0.000644
0.890248	0.000132	0.000083	0.000096	0.000093	0.000157	0.000153	0.000141	0.000085	0.000857	0.000872	0.000935	0.000741
0.895306	0.000122	0.000086	0.000085	0.000087	0.000201	0.000134	0.000156	0.000104	0.000903	0.001048	0.00092	0.000869
0.900365	0.000112	0.000098	0.000082	0.000081	0.000171	0.000138	0.000143	0.000092	0.001151	0.000982	0.000856	0.000859
0.905423	0.000114	0.00007	0.000096	0.000081	0.000146	0.000146	0.000121	0.000094	0.001257	0.000993	0.00072	0.001019
0.910481	0.000136	0.000078	0.000123	0.000088	0.000195	0.000142	0.00014	0.000111	0.001026	0.000976	0.000724	0.001294
0.915539	0.000145	0.000098	0.000125	0.000092	0.000174	0.00012	0.000144	0.000106	0.000872	0.000981	0.0008	0.001055
0.920598	0.000103	0.000067	0.000075	0.000064	0.00017	0.000096	0.000109	0.00011	0.000848	0.000981	0.000694	0.000997
0.925656	0.000096	0.000078	0.000081	0.000067	0.000176	0.000119	0.000106	0.000116	0.000905	0.00104	0.000776	0.000958
0.930714	0.000107	0.000082	0.000091	0.000071	0.00017	0.000158	0.000128	0.000121	0.000858	0.001075	0.000876	0.001052
0.935772	0.000132	0.000079	0.000103	0.000086	0.000187	0.000136	0.000119	0.000113	0.00069	0.000961	0.000789	0.000771
0.94083	0.000145	0.000086	0.000107	0.000093	0.000199	0.000178	0.00016	0.000119	0.000623	0.000965	0.000738	0.000488
0.945889	0.000136	0.000084	0.000084	0.000074	0.000278	0.000164	0.000193	0.000143	0.000588	0.00107	0.000788	0.000449
0.950947	0.000156	0.000112	0.000111	0.000101	0.000214	0.000139	0.000157	0.000118	0.000674	0.000839	0.000709	0.00043
0.956005	0.000171	0.000116	0.000137	0.000114	0.000206	0.000116	0.000118	0.0001	0.000696	0.000821	0.000638	0.000485
0.961063	0.000132	0.000077	0.000103	0.000076	0.000256	0.000146	0.000129	0.000121	0.000736	0.000754	0.000657	0.000594
0.966122	0.000111	0.000074	0.000088	0.00007	0.000206	0.00014	0.000132	0.00012	0.000737	0.000769	0.000607	0.000546
0.97118	0.000115	0.000072	0.000083	0.000076	0.000277	0.000104	0.000152	0.000134	0.000708	0.00078	0.000573	0.000756
0.976238	0.000128	0.000092	0.000093	0.000083	0.000237	0.000123	0.000135	0.00013	0.000648	0.000758	0.000513	0.000765
0.981296	0.000121	0.000079	0.000087	0.000076	0.000203	0.000168	0.000147	0.000122	0.000787	0.00076	0.000539	0.000782

0.986355	0.000158	0.000072	0.000115	0.000098	0.000253	0.000172	0.000189	0.000183	0.000689	0.000778	0.000454	0.000867
0.991413	0.000127	0.000068	0.000099	0.000078	0.000212	0.000127	0.000152	0.000161	0.000763	0.000854	0.000495	0.000786
0.996471	0.000121	0.000075	0.00009	0.000076	0.000213	0.000105	0.000141	0.000129	0.000821	0.000912	0.000525	0.00072
1.001529	0.000136	0.000077	0.000094	0.000078	0.000195	0.000104	0.000139	0.000118	0.000745	0.000806	0.000584	0.000739
1.006587	0.000148	0.000076	0.000108	0.000089	0.000162	0.000109	0.00011	0.000096	0.000572	0.000855	0.000582	0.00067
1.011646	0.000101	0.000065	0.000069	0.000065	0.000168	0.000113	0.000117	0.000098	0.000534	0.000705	0.000464	0.000524
1.016704	0.000135	0.000075	0.000088	0.000083	0.000178	0.000114	0.000115	0.000102	0.000539	0.000579	0.000498	0.00041
1.021762	0.000141	0.000081	0.000104	0.000092	0.000157	0.000107	0.000119	0.000107	0.000407	0.000649	0.0005	0.000347
1.02682	0.000121	0.000084	0.000099	0.000076	0.000168	0.00011	0.000124	0.000104	0.00038	0.000694	0.000435	0.000371
1.031879	0.000114	0.000077	0.0001	0.000069	0.000159	0.000094	0.000117	0.0001	0.000468	0.000757	0.000471	0.000464
1.036937	0.000106	0.000068	0.000088	0.000067	0.000172	0.000112	0.000141	0.000118	0.000525	0.000647	0.000417	0.000398
1.041995	0.000111	0.000081	0.000093	0.00007	0.000164	0.000128	0.000139	0.000124	0.000436	0.00068	0.000478	0.000458
1.047053	0.000113	0.000082	0.000077	0.000071	0.000188	0.000129	0.000131	0.000103	0.000513	0.00068	0.000479	0.000644
1.052112	0.000102	0.000066	0.000071	0.000065	0.000222	0.000135	0.000132	0.000101	0.000569	0.000492	0.00041	0.000805
1.05717	0.000109	0.000069	0.00009	0.000065	0.000229	0.000128	0.000114	0.000114	0.000497	0.000418	0.000383	0.000729
1.062228	0.000111	0.000061	0.000087	0.000065	0.00023	0.000149	0.000148	0.000123	0.000385	0.00044	0.000377	0.000647
1.067286	0.000134	0.000081	0.000101	0.000083	0.000264	0.000154	0.000165	0.000154	0.000458	0.000483	0.00035	0.000659
1.072344	0.000116	0.000071	0.000101	0.00008	0.000205	0.000144	0.000142	0.000141	0.000414	0.000508	0.000389	0.000503
1.077403	0.000121	0.00008	0.000112	0.000096	0.000203	0.000158	0.00014	0.000129	0.000433	0.000687	0.000401	0.000523
1.082461	0.00012	0.00008	0.000098	0.000091	0.000159	0.000114	0.000114	0.000097	0.000425	0.000683	0.000317	0.000452
1.087519	0.000098	0.000083	0.000085	0.000061	0.000135	0.000108	0.000109	0.000079	0.000409	0.000549	0.000315	0.000284
1.092577	0.000101	0.000081	0.000091	0.000069	0.000134	0.000083	0.000098	0.000086	0.000512	0.000632	0.000378	0.000294
1.097636	0.000162	0.000103	0.00012	0.000107	0.000139	0.000089	0.000094	0.000088	0.000442	0.00058	0.000365	0.000327
1.102694	0.000162	0.000104	0.000117	0.000105	0.000123	0.000085	0.000086	0.000074	0.000421	0.00049	0.000359	0.000362
1.107752	0.00017	0.000104	0.000128	0.000107	0.000096	0.000102	0.00008	0.000074	0.000387	0.000506	0.000447	0.000465

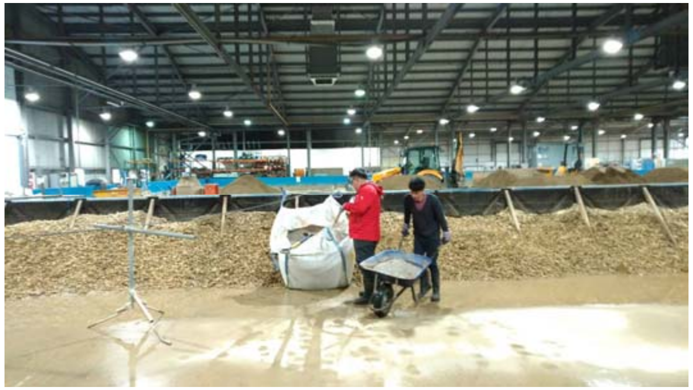
1.11281	0.000194	0.000125	0.000164	0.000136	0.000104	0.000077	0.000093	0.000072	0.00037	0.000463	0.000417	0.000463
1.117868	0.000185	0.000111	0.000161	0.000123	0.00012	0.000076	0.00009	0.000072	0.000333	0.000494	0.000334	0.000365
1.122927	0.000197	0.000113	0.000162	0.00014	0.000149	0.000093	0.00011	0.00009	0.000365	0.000544	0.0003	0.000526
1.127985	0.000165	0.000099	0.000134	0.000119	0.000146	0.000089	0.000115	0.000087	0.000375	0.000521	0.000335	0.000482
1.133043	0.000173	0.000112	0.000145	0.000119	0.000145	0.000087	0.000108	0.000073	0.000439	0.000476	0.000352	0.000562
1.138101	0.000161	0.000123	0.00015	0.000118	0.000124	0.00008	0.000092	0.00007	0.000456	0.000466	0.000345	0.000487
1.14316	0.00013	0.000109	0.000111	0.000108	0.000138	0.000099	0.000098	0.000074	0.000395	0.000396	0.000338	0.000476
1.148218	0.000123	0.000098	0.0001	0.000099	0.000096	0.000102	0.000104	0.000076	0.000444	0.000386	0.000346	0.000401
1.153276	0.000145	0.000105	0.00012	0.000114	0.000118	0.00011	0.000101	0.000098	0.00039	0.000406	0.000328	0.000341
1.158334	0.000155	0.000102	0.000133	0.000111	0.000126	0.0001	0.000098	0.000079	0.000352	0.000375	0.000317	0.000322
1.163393	0.000143	0.000081	0.000127	0.000092	0.000128	0.0001	0.0001	0.000079	0.000399	0.000419	0.000312	0.00028
1.168451	0.000112	0.000067	0.000113	0.00008	0.000156	0.000111	0.000142	0.000105	0.000441	0.000509	0.000365	0.000303
1.173509	0.000152	0.000078	0.000129	0.000107	0.00014	0.000084	0.000122	0.000083	0.00047	0.000577	0.000415	0.000353
1.178567	0.000162	0.000084	0.000113	0.000098	0.00013	0.000084	0.000094	0.000072	0.000495	0.000588	0.000397	0.000399
1.183625	0.000123	0.000082	0.000082	0.000076	0.000147	0.000083	0.000097	0.000088	0.000453	0.000493	0.000373	0.000482
1.188684	0.000108	0.000075	0.000076	0.000067	0.000134	0.000077	0.00009	0.000103	0.00047	0.000463	0.000417	0.000533
1.193742	0.000113	0.00008	0.000079	0.00007	0.000149	0.000106	0.000103	0.000105	0.00041	0.000461	0.000403	0.000418
1.1988	0.000111	0.000068	0.000083	0.000081	0.000143	0.000116	0.000096	0.000088	0.000432	0.000426	0.000421	0.0005
1.203858	0.000122	0.000071	0.000098	0.000087	0.000143	0.000106	0.000099	0.000098	0.000418	0.000404	0.000389	0.000445
1.208917	0.000115	0.000067	0.000103	0.000079	0.000177	0.000143	0.000104	0.000107	0.000465	0.000481	0.00041	0.00043
1.213975	0.000144	0.000091	0.000113	0.00009	0.000202	0.000147	0.000108	0.000102	0.000567	0.00048	0.000467	0.000433
1.219033	0.000135	0.000091	0.000098	0.000084	0.000191	0.000133	0.000113	0.000098	0.000403	0.000337	0.000345	0.000371
1.224091	0.000133	0.000096	0.000105	0.00008	0.000176	0.000127	0.000126	0.000092	0.000362	0.000336	0.000312	0.000307
1.22915	0.000108	0.000071	0.000095	0.000072	0.000185	0.000142	0.000159	0.000117	0.000349	0.000355	0.000301	0.000302
1.234208	0.000107	0.000066	0.000097	0.000074	0.000162	0.000109	0.000137	0.00011	0.000431	0.000343	0.000382	0.000298

1.239266	0.000121	0.000078	0.000093	0.000068	0.00016	0.000095	0.000122	0.000103	0.000379	0.000365	0.000325	0.000315
1.244324	0.00015	0.000086	0.0001	0.00007	0.000162	0.000079	0.000115	0.000095	0.000265	0.00033	0.00028	0.00034
1.249382	0.000114	0.000076	0.000088	0.000066	0.000182	0.000118	0.000133	0.000114	0.000308	0.000367	0.000334	0.000392
1.254441	0.000102	0.00007	0.000086	0.00006	0.000167	0.000114	0.000106	0.000104	0.000338	0.000361	0.00029	0.000418
1.259499	0.000109	0.000073	0.000092	0.000075	0.000122	0.000077	0.000099	0.000079	0.000391	0.000291	0.000317	0.000423
1.264557	0.000117	0.000071	0.000093	0.000083	0.000133	0.00009	0.000125	0.00009	0.000385	0.000246	0.0003	0.000489
1.269615	0.000118	0.000066	0.000096	0.000082	0.000149	0.000114	0.000144	0.000105	0.00036	0.000288	0.000255	0.000454
1.274674	0.000111	0.000069	0.00009	0.000076	0.000138	0.000086	0.000125	0.000097	0.000325	0.000368	0.000294	0.000422
1.279732	0.000115	0.000079	0.000084	0.000072	0.000141	0.000071	0.000107	0.000095	0.000371	0.000409	0.000287	0.000413
1.28479	0.000125	0.00008	0.000102	0.000083	0.000145	0.000083	0.00012	0.000091	0.000453	0.000358	0.000221	0.00034
1.289848	0.000127	0.000078	0.000114	0.00008	0.000153	0.000112	0.00012	0.000104	0.000428	0.000329	0.000226	0.000261
1.294906	0.000115	0.000068	0.000089	0.000071	0.000147	0.000121	0.000118	0.000109	0.000419	0.000348	0.000318	0.000349
1.299965	0.000137	0.000073	0.000086	0.000078	0.000154	0.000112	0.000105	0.000097	0.000364	0.000352	0.000327	0.000307
1.305023	0.000108	0.000063	0.000072	0.000068	0.000141	0.000094	0.000094	0.000091	0.000409	0.000377	0.000358	0.00039
1.310081	0.000102	0.000073	0.000078	0.000066	0.000137	0.000098	0.000115	0.000098	0.000337	0.000343	0.00029	0.000373
1.315139	0.000155	0.000094	0.000117	0.000098	0.000109	0.000093	0.000109	0.000082	0.000446	0.000399	0.000327	0.000398
1.320198	0.000128	0.000075	0.000092	0.000086	0.000105	0.000082	0.000072	0.000067	0.000418	0.000312	0.000331	0.000375
1.325256	0.000114	0.000082	0.000093	0.000078	0.000134	0.000084	0.000096	0.000087	0.000275	0.000273	0.000316	0.000353
1.330314	0.000133	0.000089	0.0001	0.000076	0.000151	0.000105	0.000111	0.000107	0.000243	0.000248	0.000323	0.000425
1.335372	0.000125	0.000065	0.000082	0.000068	0.00017	0.000102	0.000115	0.000111	0.000246	0.000232	0.000293	0.000386
1.340431	0.00008	0.000054	0.000061	0.000051	0.000131	0.000089	0.000095	0.000088	0.000319	0.000274	0.000246	0.000346
1.345489	0.000095	0.00007	0.000092	0.000072	0.00011	0.000082	0.000085	0.000086	0.000313	0.000311	0.0003	0.000356
1.350547	0.000121	0.000087	0.000108	0.000086	0.000118	0.00008	0.00009	0.00009	0.000281	0.000254	0.000324	0.000358
1.355605	0.000114	0.000067	0.000092	0.000078	0.00014	0.000071	0.000108	0.000083	0.000292	0.000235	0.000272	0.000274
1.360663	0.000125	0.000076	0.000105	0.000075	0.000117	0.000051	0.000083	0.000062	0.000369	0.000297	0.000321	0.000291

1.365722	0.000175	0.000114	0.000138	0.000097	0.000107	0.000057	0.000104	0.000075	0.000291	0.00029	0.000256	0.000272
1.37078	0.000189	0.000121	0.000114	0.000104	0.000127	0.000075	0.000116	0.000077	0.000223	0.000248	0.000249	0.000226
1.375838	0.000293	0.000221	0.000173	0.000155	0.000141	0.000094	0.000095	0.000078	0.00026	0.000284	0.000269	0.00026
1.380896	0.000503	0.000411	0.000303	0.000281	0.000117	0.000078	0.000078	0.000065	0.000318	0.000281	0.000195	0.000276
1.385955	0.000601	0.000524	0.00033	0.000348	0.00011	0.000065	0.000086	0.000084	0.000251	0.00027	0.000174	0.00029
1.391013	0.000396	0.000381	0.000252	0.000257	0.00012	0.000084	0.000106	0.00009	0.000247	0.000323	0.000216	0.00028
1.396071	0.000302	0.000264	0.000203	0.000193	0.000117	0.00009	0.000102	0.000082	0.000311	0.000289	0.000217	0.000389
1.401129	0.000195	0.000149	0.000126	0.000113	0.000146	0.000085	0.000119	0.000093	0.000349	0.000267	0.000253	0.000432
1.406188	0.000156	0.000104	0.000108	0.00009	0.000148	0.000092	0.000103	0.0001	0.00033	0.00026	0.000225	0.000356
1.411246	0.000178	0.000106	0.000133	0.000107	0.000143	0.000089	0.000114	0.000102	0.000256	0.00024	0.000228	0.000352
1.416304	0.000235	0.00013	0.000144	0.00014	0.000143	0.000091	0.000125	0.0001	0.000219	0.00022	0.000228	0.000353
1.421362	0.000207	0.000108	0.000118	0.00012	0.000109	0.000069	0.000093	0.000079	0.000212	0.0002	0.00028	0.000282
1.42642	0.000148	0.000105	0.000092	0.000078	0.000129	0.000072	0.000106	0.000076	0.000215	0.000245	0.000307	0.000248
1.431479	0.000159	0.000151	0.000107	0.000096	0.000122	0.000075	0.000094	0.000083	0.000216	0.000247	0.000269	0.000234
1.436537	0.000154	0.00016	0.000112	0.000109	0.000132	0.000091	0.000097	0.000103	0.000194	0.000201	0.000236	0.00022
1.441595	0.000142	0.000129	0.000092	0.000093	0.000108	0.000079	0.000106	0.000089	0.000237	0.000244	0.000279	0.000244
1.446653	0.000151	0.000114	0.00011	0.000098	0.000108	0.00008	0.000108	0.00008	0.000289	0.000281	0.000318	0.000287
1.451712	0.000131	0.000109	0.000125	0.000093	0.000119	0.000086	0.000106	0.000082	0.000275	0.000279	0.000296	0.00025
1.45677	0.000139	0.00008	0.000113	0.000091	0.000107	0.00009	0.000106	0.000083	0.000249	0.000274	0.00022	0.000226
1.461828	0.000175	0.00009	0.000128	0.000104	0.000114	0.00009	0.000107	0.000078	0.00025	0.000241	0.000211	0.000314
1.466886	0.00013	0.000096	0.000125	0.000107	0.000145	0.000099	0.000126	0.000099	0.000244	0.000192	0.000209	0.000335
1.471944	0.000139	0.000106	0.00011	0.000092	0.000127	0.000088	0.0001	0.000091	0.000268	0.000195	0.000282	0.00032
1.477003	0.000154	0.000106	0.0001	0.000097	0.000112	0.000067	0.000087	0.000077	0.000292	0.000232	0.00028	0.000316
1.482061	0.000146	0.000092	0.000103	0.000089	0.00015	0.000085	0.000102	0.000092	0.000271	0.000259	0.000258	0.000267
1.487119	0.000178	0.000099	0.000112	0.00009	0.000148	0.000086	0.000091	0.00009	0.000241	0.000268	0.000209	0.000271

1.492177	0.000184	0.00012	0.000105	0.000088	0.000142	0.000079	0.000099	0.000094	0.000228	0.000246	0.000215	0.000257
1.497236	0.000161	0.00012	0.000103	0.000086	0.000154	0.000075	0.00012	0.000094	0.000307	0.000256	0.000279	0.000301
1.502294	0.000169	0.000101	0.000102	0.000106	0.000147	0.000088	0.000113	0.000086	0.000346	0.000247	0.00033	0.000284
1.507352	0.000143	0.000085	0.000118	0.000087	0.000156	0.000097	0.000139	0.000109	0.000278	0.000239	0.000278	0.000273
1.51241	0.000148	0.00008	0.000114	0.000092	0.000145	0.000085	0.000124	0.000104	0.000232	0.000226	0.00023	0.000284
1.517469	0.000221	0.000098	0.000096	0.000121	0.000137	0.000097	0.00012	0.000097	0.000262	0.00026	0.000261	0.000296
1.522527	0.000235	0.0001	0.000072	0.000117	0.000185	0.000128	0.000162	0.000128	0.000278	0.000294	0.000328	0.000317
1.527585	0.000252	0.000106	0.000087	0.000142	0.000203	0.000128	0.000165	0.000141	0.000253	0.000219	0.000303	0.000327
1.532643	0.000301	0.000143	0.000142	0.000132	0.000192	0.000109	0.000147	0.000126	0.000206	0.00016	0.000242	0.00027
1.537701	0.000413	0.000232	0.000235	0.000155	0.000178	0.000091	0.000139	0.000117	0.000235	0.00016	0.000264	0.000284
1.54276	0.000741	0.000315	0.000227	0.000242	0.000163	0.000083	0.000133	0.000116	0.000284	0.00026	0.000323	0.000446
1.547818	0.000799	0.000293	0.000199	0.000282	0.00013	0.000074	0.000113	0.000096	0.000293	0.000273	0.000333	0.000408
1.552876	0.00059	0.000255	0.000251	0.000202	0.000111	0.000081	0.000084	0.000079	0.0003	0.000255	0.000284	0.000348
1.557934	0.000761	0.000374	0.000331	0.00029	0.00013	0.000085	0.000083	0.000079	0.000332	0.000295	0.000321	0.000397
1.562993	0.000495	0.000252	0.000229	0.000211	0.000134	0.000104	0.000108	0.000101	0.000364	0.000296	0.000359	0.000367
1.568051	0.000196	0.000145	0.000183	0.000136	0.000146	0.0001	0.000122	0.000098	0.000412	0.000254	0.000343	0.000316
1.573109	0.000222	0.000129	0.000162	0.000095	0.000164	0.000087	0.000128	0.000094	0.000299	0.000234	0.000284	0.000329
1.578167	0.000205	0.000116	0.000121	0.000129	0.000159	0.000083	0.000115	0.000102	0.000227	0.000215	0.000234	0.000298
1.583226	0.000178	0.000103	0.000101	0.000101	0.000157	0.000085	0.00011	0.000113	0.000242	0.000197	0.000239	0.000296
1.588284	0.000171	0.000118	0.000101	0.000089	0.00016	0.000089	0.000105	0.000094	0.000227	0.000214	0.000209	0.000237
1.593342	0.000166	0.000134	0.000099	0.000092	0.000153	0.000085	0.000109	0.00009	0.000246	0.000206	0.000196	0.000187
1.5984	0.000169	0.000127	0.000095	0.000091	0.000117	0.000083	0.000092	0.000074	0.000192	0.000143	0.000169	0.000241
1.603458	0.000131	0.000108	0.000091	0.000073	0.000102	0.000076	0.000069	0.000065	0.000167	0.000185	0.000166	0.000286
1.608517	0.000131	0.000082	0.000092	0.000069	0.00013	0.000085	0.000093	0.000081	0.00019	0.000205	0.000201	0.000273
1.613575	0.000174	0.00011	0.000106	0.000096	0.000113	0.000082	0.000085	0.000071	0.000259	0.00022	0.000248	0.000314

1.618633	0.000192	0.000111	0.000108	0.000107	0.000124	0.000092	0.00011	0.000091	0.000288	0.000261	0.000287	0.000298
1.623691	0.000147	0.000095	0.00009	0.000094	0.000155	0.000107	0.000124	0.000105	0.000209	0.000297	0.00025	0.000233
1.62875	0.000141	0.000104	0.000096	0.000094	0.000106	0.000068	0.000092	0.000069	0.000185	0.000275	0.000232	0.000208
1.633808	0.000195	0.000131	0.000119	0.000091	0.000107	0.000075	0.0001	0.00007	0.000288	0.000219	0.000251	0.000302
1.638866	0.007033	0.00453	0.002788	0.001442	0.000132	0.000089	0.000108	0.000088	0.000247	0.000215	0.000245	0.000316
1.643924	0.050606	0.032302	0.01971	0.009891	0.000129	0.000071	0.000091	0.000081	0.000081	0.000114	0.000115	0.000143

2. 模型試驗粒料縮尺及鋪設設計理論：

現場與 HR Wallingford 的技術人員 DR. IAN 進行實際操作，透過試驗條件需求及造波輸出，來計算模型結構體之鋪設和設計作業過程，以符合結果期待值達到現實情況改善方案。

Scaling of granular material

Additional information

1. Model rock design

1.1. Core and underlayer

The core material and underlayer rock of the structures are scaled to ensure the correct reproduction of permeability. Ordinary geometric scaling of the underlayer and core material would not correctly reproduce internal pressures and velocities in the model. The model material will therefore need to be made slightly larger in order to replicate flow behaviours observed in prototype structures. In order to ensure that the correct grading is obtained, the materials are prepared in size sub-divisions and then mixed in the correct proportions. A random 100 rock sample should be taken of the mixed sieved material to ensure that the prototype grading curve has been reproduced.

The reason for this increase in model material size is that at the scale selected for this study, and at the scales of similar model studies, there will be conditions where the flow through the model core is not fully turbulent. Unless corrected, scale effects will affect the flow of water through the core. Therefore, in order to reproduce realistically the permeability of the core, it is necessary to compensate for the scale effects which result from the use of Froude's scaling law. Work by Jensen and Klinting (1983) suggests a method of compensating for scale effects due to laminar flow by applying a correction factor to the ordinary geometric scale when determining core sizes. The calculation of the correction factor uses a special Reynolds number, ξ_p, which is defined as the ratio of turbulent to laminar hydraulic gradients. The special Reynolds number is defined as:

$$\xi_p = (\beta_o/\alpha_o)1/(n(1-n)^2)U_p d/\nu \qquad 1.1$$

Where α_o and β_o are empirical constants, n is the porosity of the prototype rock mound, d is the size of the prototype rock, ν is the kinematic viscosity of water and

U_p is the maximum velocity in the prototype mound, generally taken as 0.5-1.0 m/s in inner layers or 1-10 m/s in outer layers.

The ratio of rock size in prototype to model, K, is then given by:

$$K = \xi_p / 2\sqrt{\lambda} \left((1 + 4\lambda^{3/2}(1 + \xi_p)/\xi_p^2)^{1/2} - 1 \right) \quad 1.2$$

Where λ is the geometric scale. Values of K take an average value of approximately 2% less than the principal model scale (i.e. larger rocks) meaning that the model rock is slightly larger than the prototype.

Throughout it is assumed that the porosity of model and prototype rock is identical. The porosity of the rock, n, was estimated at 35-37%. To enable the above equations to be used in calculating the permeability correction factor certain assumptions have to be made. Experimental work by Engelund (1953) suggested values for the empirical coefficients of α_o = 1500 and β_o = 3.6. The maximum prototype velocity in the mound was estimated at 0.5-1.0 m/s from some simple calculations of wave velocities and comparisons with velocities calculated by a simple mathematical model of flow in rubble.

These guidelines were followed for all rock structures containing core and underlayer material within the model.

1.2. Rock armour

Rock armour, such as that used for the termination and stem wave mitigation structures in this model, should be individually machine weighed to ensure the correct grading is obtained. In order to ensure that the correct grading was obtained the materials were prepared in size sub-divisions and then mixed in the correct proportions. A random 100 rock sample was taken of the mixed sieved material to ensure that the prototype grading curve was reproduced.

Account must be taken of the difference in densities between the fluid and armour unit material used in the model and prototype. The method of calculating the correct scaling for the rock armour is detailed next.

The rock used in the physical model is Carboniferous Limestone of density 2.67 t/m3. The fluid used in the hydraulic model tests was fresh water of density 1.00 t/m3. In the prototype, however, the sea water will have a density of about 1.025 t/m3. The variation in densities means that without compensation, the rock in the model would be slightly more stable than in the prototype. Such a model would therefore underestimate movement and, hence, damage. It was therefore necessary to correct the size of rock to be used in the model, so that it exhibited the same stability characteristics as the prototype.

A correction factor for density may be derived by reference to the Hudson equation (CERC, 1984) which states:

$$M \propto \rho_s H_s^3 / (\rho_s/\rho_w - 1)^3 \cot \alpha \qquad 1.3$$

Where M is the mass of the armour unit, H_s is the significant wave height, α is the structure slope angle to the horizontal, ρ_s is the density of the armour and ρ_w is the density of the displacing fluid.

The correction factor (C_f) for the armour mass may thus be calculated from the following equation:

$$M_m = M_p \, C_f / \lambda^3 \qquad 1.4$$

Where λ is the model scale. This leads to the following expression for the correction factor:

$$C_f = \rho_{sm} / \rho_{sp} \, [(\rho_{sp} / \rho_{wp} - 1) / (\rho_{sm} / \rho_{wm} - 1)]^3 \qquad 1.5$$

Where the subscripts p and m respectively refer to parameters in the prototype and model, and where the value of the correction factor calculated for this study was $C_f = 0.862$.

2. References

CERC, (1984) Shore protection manual, Coastal Engineering Research Centre (CERC), US Government Printing Office, Washington, Vols 1 & 2.

CIRIA, CUR, CETMEF (2007). The Rock Manual. The use of rock in hydraulic engineering (2nd edition). C683, CIRIA, London. Engelund F. (1953) 'The Laminar and Turbulent Flows of Ground Water through Homogeneous Sand', Trans. Danish Acad Tech Sci, 3(4).

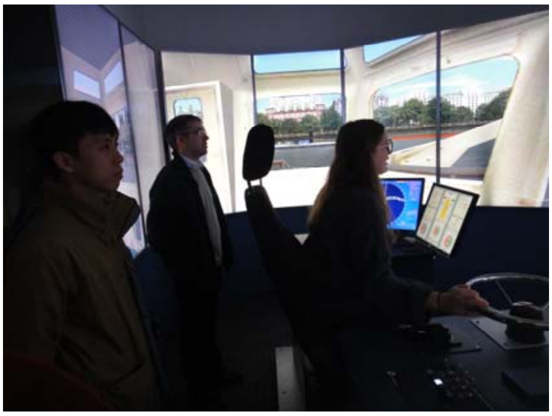
Jensen, O. J. and Klinting, P. (1983) 'Evaluation of Scale Effects in Hydraulic Models by Analysis of Laminar and Turbulent Flows', Coastal Engineering, pp 319-329,.

3. 物理模式試驗場地介紹：

HR Wallingford 自於 1982 年公司化後，提供各項研究設備銷售與經驗移轉超過 25 年以上之經驗，並接受世界各國委託辦理各種海洋實驗模擬監測，並運用不同狀況之物理模式進行水工模型試驗，下就試驗場地進行介紹，惟其因涉及不同國家和政府使用單位的商業行為權益或機密，故很多試驗場地及作業情形無法給予拍攝，但將予以說明。

HR 水工模型試驗廠棚十分龐大，廠棚內部設有 9 座試驗場地，包括：6 座平面水槽、1 座斷面水槽、1 座快速流水槽、特殊試驗水槽 1 座，因此用水量相當可觀，但由於 HR 地理位置鄰近泰晤士河，抽放水可利用河流之便取用及排放，用水無虞，因此本身未設有儲放用水之蓄水塔或地下蓄水池，平面水槽可研究堤體的安定分析、港區船舶動態安定性分析、斷面水槽可研究基本定性定量試驗，快速流水槽可以模擬海嘯、孤立波與波流交互作用的相關試驗，最特別屬於特殊試驗水槽，訓練期間 HR Wallingford 公司正機密進行飛機急迫降水面，研究探討機體衝擊力衝撞流體之運動行為，至於研究本身機密是研究案機密，或者是該飛機發射模擬迫降裝置是機密，技術人員並無更進一步說明，但由於實在過於敏感，每經過該處時技術人員都特別說明請勿拍照；在實驗室的另個出口角落有一群工作人員正在開發儀器設備，當時正開發水下無人探測載具，另側則設有一工具工作室可供技術人員簡易加工實驗所需料件及模型。

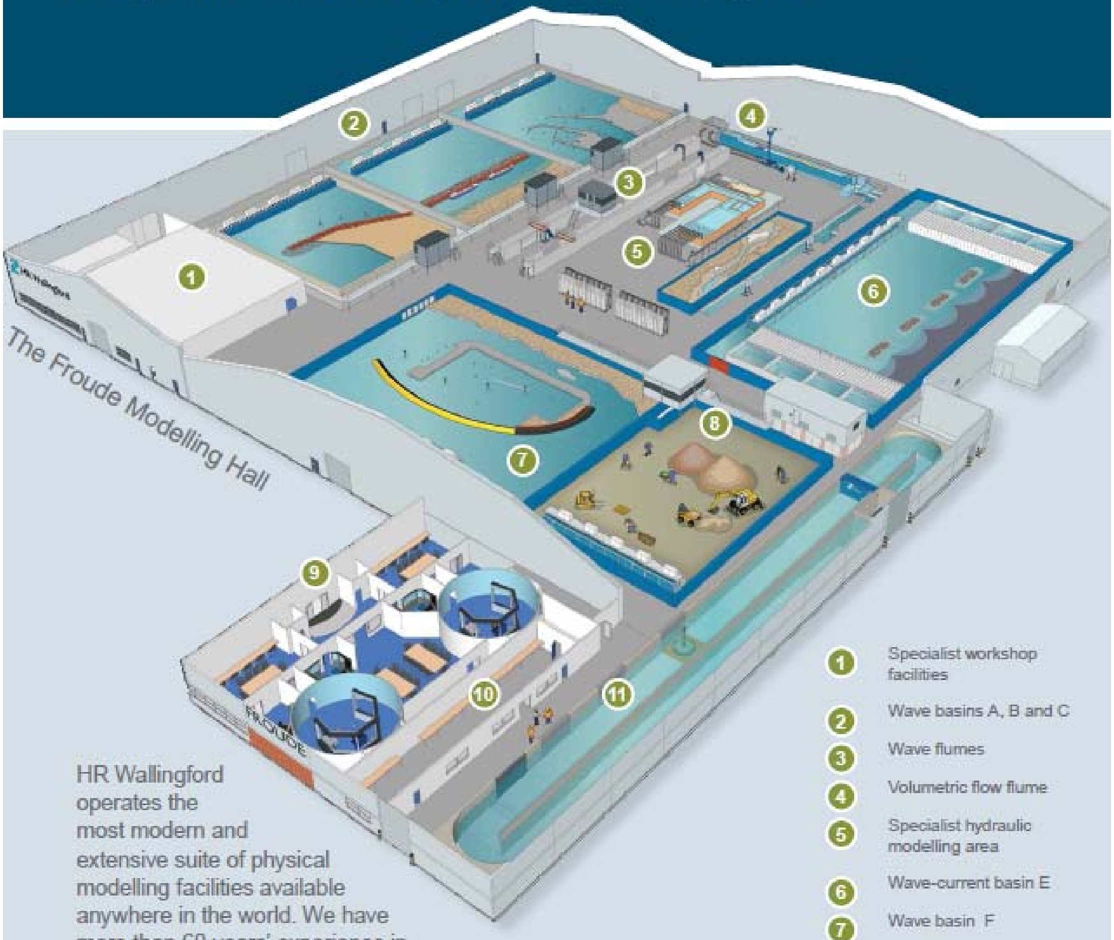
原操船模擬室設置於設備研發室後的小房間內，但由於操船業務量增加，以致原場地空間不足，故遷移至其他建物當中，模擬室一間空間較大，可以背投影式屏幕顯示操作環境，並提供專屬模擬港區之環境現況，進行商船模擬操作，模擬室一間空間較小，且採用液晶螢幕顯示操作環境，可供小型艇駕駛模擬穿梭泰晤士河道之狀況。




整個試驗場棚非常龐大，參觀行進間可見現場堆置多組造波機設備，包括即將交貨的蛇型造波機，以及屆齡退休的造波機，技術人員表示報廢造波機可做為日後試驗造波機維修的備料，因此暫時置放於此處等待再生利用的機會，蛇型造波機與傳統造波機不同在於，傳統造波機如需打設不同入射方向之入射波，則需以吊掛設備重新調整造波位置與方向，蛇型造波機僅需幾個設定即可達成調整方向的目的。


HR Wallingford
Working with water

Physical modelling at HR Wallingford



HR Wallingford operates the most modern and extensive suite of physical modelling facilities available anywhere in the world. We have more than 60 years' experience in the construction and operation of the full range of hydraulic physical models, and more than 25 years experience in the supply of equipment and instrumentation for hydraulic laboratories to institutions and universities throughout the world.

1. Specialist workshop facilities
2. Wave basins A, B and C
3. Wave flumes
4. Volumetric flow flume
5. Specialist hydraulic modelling area
6. Wave-current basin E
7. Wave basin F
8. Wave basin D
9. Ship Simulation Centre
10. Laboratory equipment development
11. Fast Flow Facility (Wave-current-sediment flume)

BE-051 R1

www.hrwallingford.com

4. 波高計及水位電子式自動量測系統使用：

運用 HR Wallingford 各種水工模型試驗儀器使用技術介紹，提供海洋實驗模擬量測、控制操作，進行各項作業之訓練，以利此次技術交流活動目的。

HR Wallingford
Working with water

Laboratory instrumentation and software

Water level electronic float gauge

Key features

- Excellent linearity
- Versatile display unit
- Easy to use
- Rugged design
- Non contacting

HR Wallingford's water level electronic float gauge uses a float which moves up and down a displacement transducer to measure static water levels, typically used in flumes or 3D basins. The water level is determined by accurately measuring the distance from the head of the transducer to the magnetic field produced by a magnet mounted inside the float.

The advantage of this method is that there is no contact, and therefore no friction, between the float and the transducer.

www.hrwallingford.com/equipment

Laboratory instrumentation and software

Wave gauges



Key features

- Extremely linear output
- No hysterisis
- Reliable, proven design
- Easily calibrated
- USB plug-n-play connection cables of any length
- Designed for use with HR DAQ data acquisition and analysis software

The wave gauge is a simple and reliable device for measuring rapidly changing water levels in physical models. When combined with our HR DAQ data acquisition and analysis software it provides a first rate method of measuring wave height and spectral wave energy in a flume or 3D basin.

Wave probe monitor

The wave probe monitors are supplied in cases that can accommodate either four or eight monitors. These cases include the power supply for the modules, the input connections for the wave probes and the output connections directly to a computer or data acquisition card.

The cases can be supplied with a plug-n-play USB output so that they can be connected directly to either a desktop or laptop computer without the need for any additional analogue input cards.

The four-channel cases can also be supplied with four additional analogue input sockets to enable other instruments with voltage outputs to be connected directly to the computer.

Principle of operation

The wave probe operates by measuring the current that flows between two stainless steel wires that are immersed in water. This current is converted to an output voltage that is directly proportional to the immersed depth.

Each wave probe monitor card contains the energising and sensing circuits for the operation of one wave probe. In addition to this, each monitor contains the circuits required to compensate for the resistance of the cable that is connected to the probe. Without this, the output of the wave probe monitor would be non-linear.

In order to avoid polarisation effects at the probe surface, a high frequency square wave voltage is used to energise the probe. The oscillator that produces this square wave may be set to one of six different frequencies. This allows probes to be used close together without causing any interference.

The current in each probe is detected by measuring the voltage drop across two resistors. Because the measured voltage is alternating, the signal is fed to a precision rectifier to produce a DC voltage proportional to the wave height. This signal feeds a small centre-zero balance indicator and a BNC socket on the front of the panel. The signal is also fed to a preset gain stage that may be set for a gain of between 0.5 and 10.

Controls on the front of each wave probe module enable the output signal to be set to zero for any given initial depth of probe immersion. This, together with the gain adjustment, produces a full-scale output of ±10V for all waves.

Calibration

An overall calibration from wave height to output voltage can be performed by measuring the change in output voltage when the probe is raised or lowered by a known amount in still water. This operation is facilitated by means of a calibrated stem which is attached to the wave probe and which has a series of accurately spaced holes drilled along its length.

Wave probes

The wave probes comprise two parallel stainless steel rods with a plastic head and foot. The head is fixed to the calibration stem and a mounting block is supplied that allows the calibration stem to be fixed to any vertical surface. The standard probe lengths are 300, 600 and 900mm, although probes up to 2m in length can be supplied.

Wave probe cables and tripods

Each wave gauge channel will require a cable linking the wave probe monitor to the wave probe. We also have a selection of tripods available for deployment of wave probe in basins.

Specifications

Wave probe monitors

Case configuration	4 or 8 monitors
Output signals:	
Front of monitors	±10V via BNC socket
Rear of case	±10V via 25 way D socket
	USB plug-n-play
Gain	0.5, 0.75, 1.0, 1.5, 2.55, 3.75, 6.0, 10.0
Excitation frequency	4.6 kHz to 11.6 kHz
Filter band width	-3dB at 20Hz
Supply voltage	220 or 110V ±10% 40-60Hz
Case dimensions (mm)	
4 monitor	255 x 150 x 315
8 monitor	470 x 150 x 315

Wave probes

Active length	300, 600, 900
Diameter - 300 mm	1.6 mm
Diameter - 600, 900 mm	6.0 mm

五、 相關工程技術活動參觀

海上風能議題 HR Wallingford 就風電場開發和運營的工程和環境方面提供專家建議。HR Wallingford 總部位於牛津郡，擁有先進的數字和物理模型設施以及由 200 多名專家組成的團隊，負責可再生能源工作之研究與發展；在英國，歐洲和全球範圍內擁有廣泛的業績記錄。

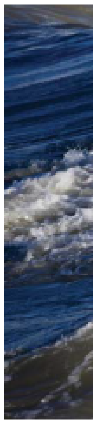
1. 海洋可再生能源發展：

HR Wallingford
Working with water

Marine renewable energy developments

HR Wallingford works with renewable energy clients to optimise their investment returns and minimise the environmental impacts of their projects. We provide the technical capability and specialist expertise needed to inform and support every phase of the development cycle.

Our clients include owners, operators, contractors and consultants, as well as regulators and other national organisations.



Technical capability and specialist expertise

- Concept development and design
- Construction
- Site selection
- Operation and maintenance
- Environmental impact assessment
- Monitoring
- Detailed design
- Decommissioning

Desk studies

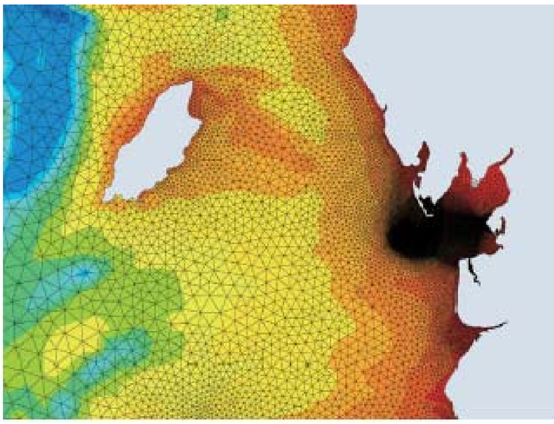
- Review our extensive UK data archives on winds, waves, currents and the seabed
- Assess published reports, charts, geotechnical/ geomorphological information
- Scoping of required studies and field work for development

Field data collection, analysis and management

- Scope, manage and analyse field surveys including waves, currents, winds, bathymetry, suspended material, water levels, soils, geotechnics and geophysics
- Assess baseline conditions
- Monitor during construction and operations phases, including scour monitoring

Environmental condition prediction, modelling and analysis

- Waves - offshore and shallow water wave distributions and extremes
- Currents and water levels - normal and extreme events
- Winds - distributions, extremes, over-water effects



Impacts

- Assess hydraulic impacts on the seabed and coast in support of Environmental Impact Assessment (EIA)
- Review impacts on other coastal and maritime interests
- Cumulative and in-combination effects of clusters of developments

Sediment transport and seabed mobility

- Historical chart analysis
- Assess and model suspended loads, sand wave mobility, potential erosion/deposition and liquefaction risks for EIA and structural design
- Scour assessment for foundations and cables

Structural design support

- Define of metocean criteria
- Wave loading and slam forces due to breaking waves
- Current and wave conditions for fatigue analysis
- Foundation stability
- Joint probability of loading variables - correlation, joint distribution, joint extremes

Cable laying and maintenance

- Route selection, cable protection, trench infill, depth of burial
- Cable landfall - shoreline stability and protection

Managing uncertainty

- Real time forecasting of wind and wave conditions for operational management
- Assess weather downtime for contract risk management
- Sensitivity tests for design optimisation
- Risk assessment for design, construction and maintenance

Recent projects

HR Wallingford has had significant involvement with many of the UK Round 1 and Round 2 offshore wind farms, as well as emerging wave and tidal energy projects in the UK and Europe. We have an active involvement with industry research and have provided modelling and expertise for several overseas projects.

HR Wallingford
Working with water

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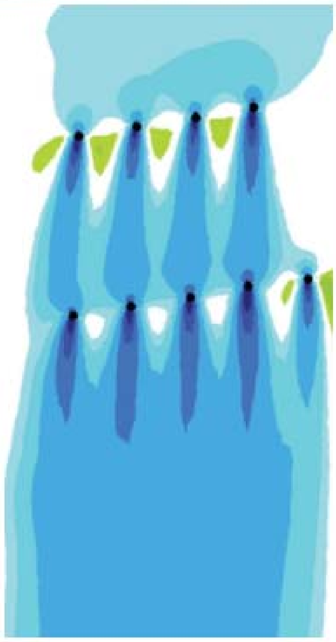

HR Wallingford is an independent engineering and environmental hydraulics organisation. We deliver practical solutions to the complex water-related challenges faced by our international clients. A dynamic research programme underpins all that we do and keeps us at the leading edge. Our unique mix of know-how, assets and facilities includes state of the art physical modelling laboratories, a full range of numerical modelling tools and, above all, enthusiastic people with world-renowned skills and expertise.

2. 離岸風電：

HR Wallingford 為可再生能源行業提供的服務組合包括對選址，資源評估，環境影響評估，工程設計支持（metocean 建模和沖刷評估），建築和維護運營的 meocean 預測。且為離岸風電行業提供商業服務，進行廣泛的研究和投入發展，並廣泛的與政府機構和部門合作，支持這個研發部門在過去 10 多年。和在英國的總部一樣，於世界各地都設有辦事處及網絡，並且有足夠的支持全球可再生能源行業。以下為參訪資料簡介：

HR Wallingford
Howbery Park
Wallingford
Oxfordshire OX10 8BA
United Kingdom

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fax +44 (0)1491 832233
email info@hrwallingford.com

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3. 5 公尺寬快速流試驗水槽：

利用大斷面造流設備達到快速流所引起之波浪及海流現象，如此可用來研究海嘯模擬、樁體或管線底床掏刷等實際發生與防治方法。

HR Wallingford
Working with water

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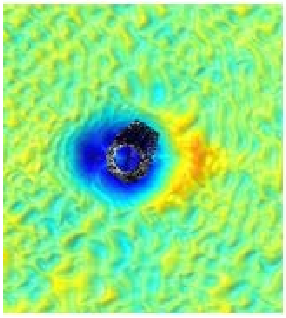
Physical modelling facilities

Fast Flow Facility



The Fast Flow Facility is one of the world's largest marine test facilities. This dual-channel, race track shaped flume is a unique large scale modelling facility offering wave, fast tidal current and sediment capabilities.

Fast Flow Facility

Understanding the complex way waves, currents and sediments interact is vital to the successful delivery of projects in the marine environment. The Fast Flow Facility allows our scientists and engineers to examine these interactions at a larger scale and in more detail than has previously been possible, helping us to more effectively optimise designs for our clients and minimise the water based risks for their projects.

We can study sediment transport, scour and morphology for a wide range of subsea, coastal, estuarine and fluvial engineering projects, as well as the combined impact of waves and currents on structures in a fast flow environment.

The 75 m long, 8 m wide Fast Flow Facility holds a million litres of water, can generate waves up to 1 m high and flows of over 2 m/s. The size of the facility allows us to model complex structures and arrays without compromising on scale. The main working channel has a 60 m long test section, giving us the space to look at array effects, long wakes behind structures and the relative placement of structures and devices.

Reducing scale effects will help to increase certainty for our clients, allowing them to minimise design risks during the early stages of their project.

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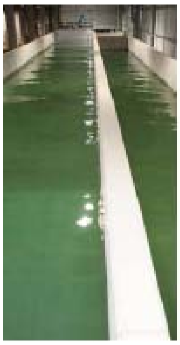


In the marine renewable energy sector, developments in exposed marine environments are high risk: fast currents, deep water and energetic waves present significant technical challenges. The ability to model large structures and arrays, without compromising on scale, means that we can help our clients to plan, install and maintain their assets in the most efficient way possible.

Our physical laboratory test facilities provide a global service to support water related engineering projects. The Fast Flow Facility significantly enhances these capabilities, helping us to expand our role in the offshore, maritime and coastal sectors. In addition to extending the capabilities available for our commercial projects, the facility is also suitable for researchers investigating problems related to hydraulics and sediment transport.

Key features of the Fast Flow Facility

- Main working channel size of 70 m by 4 m, secondary working channel of 50 m by 2.6 m
- Water depth range 0.5 m to 2 m
- 1 m deep (16 m³) test pit for sediment studies
- Significant wave heights up to 0.5 m and maximum wave height 1.0 m
- Reversible pumps to simulate tidal currents, generating flows of over 2 m/s
- State of the art monitoring and data collection instrumentation
- Versatile facility for general science and engineering hydraulic and sediment research

Scientific and engineering research applications

- Foundation stability and scour
- Seabed–structure interaction
- Wave–current interaction
- Sediment transport: flow, waves and currents
- Morphology: rivers, coasts and estuaries
- Loading on structures
- Floating structures
- Sea-keeping tests
- Drag experiments
- Hydrometry

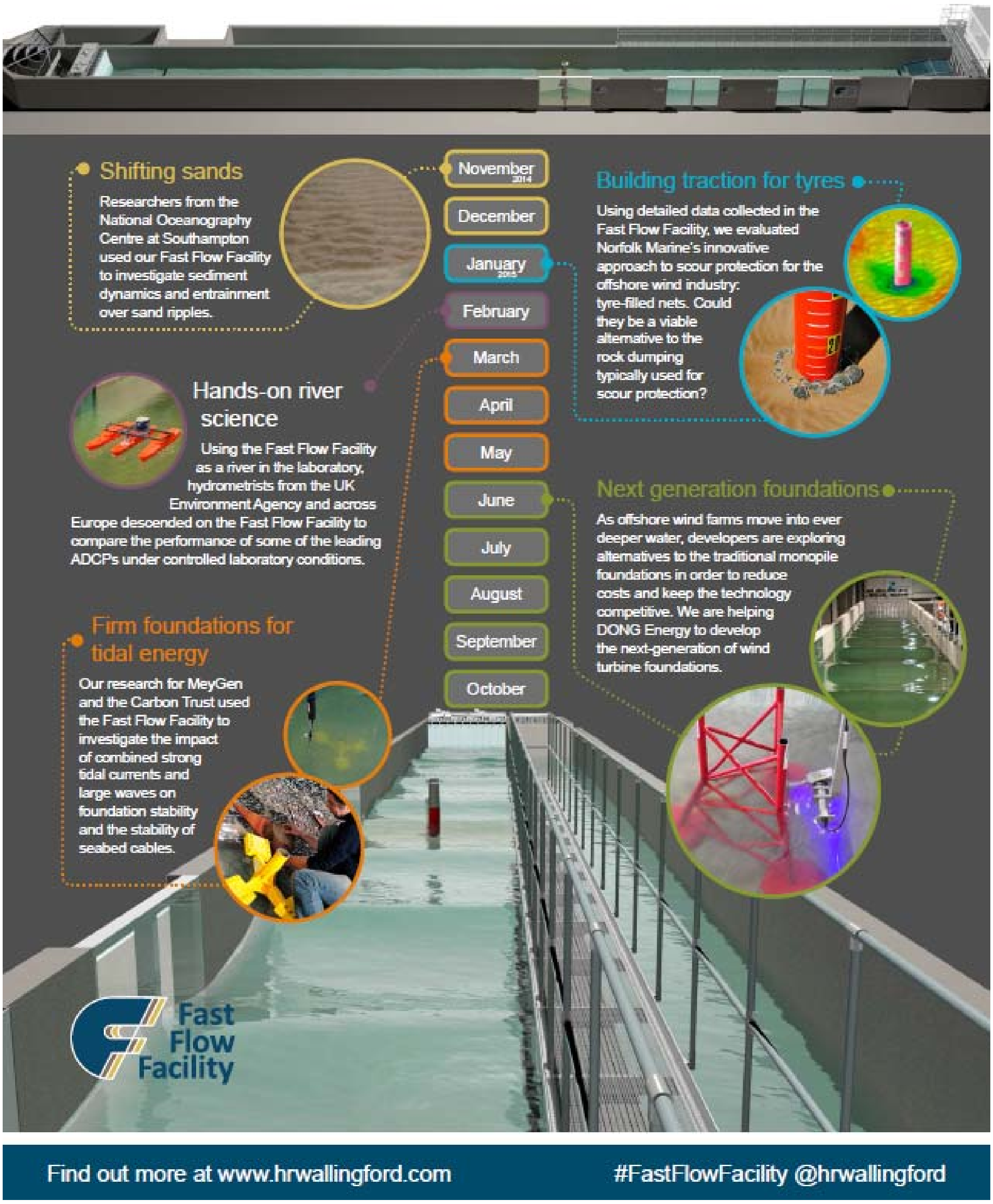
For more information on the Fast Flow Facility contact

Dr Richard Whitehouse
FastFlowFacility@hrwallingford.com
+44 (0)1491 835381

Fast Flow Facility

The **first** year in summary...

HR Wallingford
Working with water



HR Wallingford
Working with water

Fast Flow Facility

Shifting sands

The energy of waves and currents can create a layer of suspended sediment above the seabed, but, while much research has focused on this area, we still don't fully understand very near-bed wave-current-sediment interactions. Researchers from the National Oceanography Centre at Southampton used our Fast Flow Facility to investigate sediment dynamics and entrainment over sand ripples. The data collected will ultimately be used to improve the way we model sediments in numerical models. This research is part-funded by HR Wallingford.

Hands-on river science

Using the Fast Flow Facility as a river in the laboratory, hydrometrists from the UK Environment Agency and across Europe descended on the Fast Flow Facility to compare the performance of some of the leading ADCPs under controlled laboratory conditions.

Firm foundations for tidal energy

By the early 2020s, MeyGen intend to deploy up to 398 MW of offshore tidal stream turbines. These will, by necessity, be located in regions of strong currents and therefore need anchoring securely to the sea bed.

Our research for MeyGen and the Carbon Trust used the Fast Flow Facility to investigate the impact of combined strong tidal currents and large waves on foundation stability and the stability of seabed cables.

We completed tests with waves and currents flowing together and in opposing directions to simulate changes in the tide.

Find out more at www.hrwallingford.com
#FastFlowFacility @hrwallingford

Building traction for tyres

Using detailed data collected in the Fast Flow Facility, we evaluated Norfolk Marine's innovative approach to scour protection for the offshore wind industry: tyre-filled nets. Could they be a viable alternative to the rock dumping typically used for scour protection? Using the Fast Flow Facility's wave-current-sediment capabilities, we built a scale model of a monopile foundation, complete with 1:15-scale tyres, and ran tests that simulated the strong tidal flows and challenging storm waves typically experienced at wind farm sites around the UK. We also looked at deployment strategies for the tyre-filled nets.

Our analysis of short-term impacts showed that the nets were effective in preventing and reducing scour around monopile foundations. Results from the Fast Flow Facility gave Norfolk Marine the data they needed to move on to full-scale field-testing with confidence.

Next generation foundations

As offshore wind farms move into ever deeper water, developers are exploring alternatives to the traditional monopile foundations in order to reduce costs and keep the technology competitive. We are helping DONG Energy to develop the next-generation of wind turbine foundations.

Research in the Fast Flow Facility is informing the design of a novel suction bucket foundation, and will ultimately lead to more cost effective seabed foundation solutions for the renewable energy industry. Our work to determine how these structures interact with, and impact upon, the hydrodynamic conditions and the seabed will be completed in early 2016.

"The ability to have novel designs tested by physical modelling is crucial for development of our foundations. We can observe how the seabed responds to the foundation in the extreme conditions found in the North Sea. The new Fast Flow Facility at HR Wallingford is tailor made for this purpose."
Andreas Roulund, Lead Oceanographic Engineer, DONG Energy Wind Power

4.　其他相關海洋試驗模擬技術交流活動參訪：

如各項試驗量測儀器、船舶繫纜力、方向性造波及控制軟體操作等，可用來研究波浪及操船模擬或底床掏刷等實際發生情況了解與防治方法。

HR Wallingford
Working with water

Laboratory instrumentation and software

Instrument traverse system

Key features

Accuracy of +/- 0.5 mm vertically and horizontally

Supplied with a PC and software which controls the movement of instruments

Lightweight, modular system

All systems are designed to suit the client's individual requirements for horizontal span and vertical movement

The HR Wallingford instrument traverse system is used to move a range of physical modelling instrumentation to a variety of different positions within a flume or basin in either two or three dimensions.

The instruments are secured to the vertical axis of the system, using a variety of fixings. The vertical axis is attached to a carriage which moves along a fixed horizontal beam to allow positioning of the instruments anywhere within the flume or basin.

The traverser can be controlled by a software application that logs the exact time-stamped position of the instruments to an accuracy of ±0.5 mm in both vertical and horizontal axes. A stepper motor with an integral encoder is used to drive each axis into position along the carriage using a toothed belt arrangement.

The application for the traverse system can perform a sequence of moves to position the instruments. It can also be used to define the amount of time the instrument is required to wait before moving between positions. Instrument and traverser data can be logged both during movements and while stationary. Move sequences can then be repeated using a datum position either on the carriage or using an independent external datum reference point in the test facility.

The length of the horizontal beam can be adjusted depending on the facility's requirements.

The x-axis beam generally requires supporting every 2 m along its length, this is usually achieved by attaching the beam along the top of the flume wall or basin floor. The y-axis is provided with additional stiffening for lengths ≥ 2 m.

www.hrwallingford.com/equipment

Laboratory instrumentation and software

Digital point gauges

Key features

- Simple to use
- Versatile display unit
- Rugged design
- Easy to read

Specifications

Range	285, 435, 585 mm
Resolution	0.01 mm
Accuracy	0.05 mm

The measurement of steady state water surface levels on physical models is frequently needed during hydraulic investigations. Conventionally this is done by using a small point or hook which is manually adjusted to touch the water surface and then a reading is taken using a digital scale.

HR Wallingford's digital point gauge works in the same way but has a battery operated LCD display that makes it extremely easy to read.

A quick release device allows fast positioning of the digital point gauge to the water surface, and the ultimate fine adjustment is made with a screw thread. The display reads directly in millimetres and can be set to zero at any position to allow relative measurements to be easily made.

The measurement of the water level can be logged directly to a computer using an optional cable and interface unit.

www.hrwallingford.com/equipment

Laboratory instrumentation and software

Bed profiling system

Key features

- Utilises our traverse system to position the profiler in a 2D or 3D environment
- Operates both with and without water present
- Choice of laser or touch-sensitive probes
- Accuracy of ± 0.5 mm vertically and horizontally
- Positive non-slip drives
- Data stored in ASCII format
- Easy to install

The bed profiling system is the result of much development work by HR Wallingford to meet the exacting requirements of hydraulic modellers and to ensure a high degree of reliability. The system is used to assess the effect flowing water has on mobile sediment beds. It is available with a choice of probes to suit a wide range of applications.

The profiler carriage and support beam

The probes for the profiler are attached to HR Wallingford's proven instrument traverse system which ensures accurate positioning. The traverse is available in a variety of beam lengths between 1 m and 6 m. The overall travel for each axis is 0.2 m less than the beam length. The vertical (z) axis comes as a standard length of 1 m.

The x-axis beam generally requires supporting every 2 m along its length, this is usually achieved by attaching the beam along the top of the flume wall or basin floor. The y-axis is provided with additional stiffening for lengths ≥ 2 m.

The traverse system contains the motors for both the horizontal and vertical drives together with all the associated data acquisition hardware.

Touch-sensitive probe

The touch sensitive probe has a proximity switch which allows it to detect the bed with the minimum of contact pressure. The probe is periodically lowered down on to the bed with a user defined frequency, the encoder in the profiler then determines the bed height z axis. The carriage is stationary while the probe is moving up or down. This probe is particularly suitable for profiling through the air/water interface.

www.hrwallingford.com/equipment

Laser probe

The laser probe has a low-powered, Class 2 visible red, laser distance sensor mounted inside a waterproof housing. The sensor is attached and is driven vertically up and down by a motor in the profiler carriage. When in operation, the laser signal is used to drive the probe up and down to maintain a constant height above the bed as the carriage traverses across the beam. The position of the probe is measured by encoders on the motor shafts, this is used to determine the bed height.

Control of the profiler

The profiler is controlled from a Windows PC and connected using a crossover Ethernet cable (supplied). All controls are easily operated through a single display screen, which allows the user to set parameters such as start point and step size, and allows a file name to be allocated to the data being collected. It also allows the vertical and horizontal readings to be zeroed, to enable the user to set datum points. A graph of the data is displayed as the profile is recorded and the profile can be stopped by the user at any time.

The profiler automatically detects the type of probe that has been connected and displays this to the user. A radio remote control is supplied that allows the probe to be moved vertically and horizontally. This is especially useful when setting up datum points or when checking the route of the profiler whilst the user is working close to the model. The carriage is fitted with limit switches to prevent horizontal movement if the carriage reaches the end of the beam. The blocks that operate the limit switches can be fitted at any point on the beam to protect areas of the model that the user does not wish to profile.

Specifications

Max beam spans	6 m (x-axis) 6 m (y-axis)
Horizontal travel	Beam length less 200 mm (to allow for carriage and end stops)
Horizontal velocity	Up to 50 mm/s
Vertical velocity	Up to 25 mm/s
Horizontal resolution	± 0.5 mm
Vertical resolution	± 0.5 mm
Touch probe: bed contact pressure	10 g over 20 mm diameter *
Laser probe: maintained height above bed	80 mm
Vertical travel	1 m
Power supply	220 or 110 V AC
Standard cable length	25 m *

* other diameters and lengths are available

The profiler software will run on any PC or Laptop (running MS Windows 7) using a standard Ethernet Network Port.

HR Wallingford
Working with water

Laboratory instrumentation and software

Data AcQuisition and analysis software

Key features

- Specifically designed for wave analysis
- Instrument calibration
- Data acquisition
- Spectral analysis
- Statistical and wave counting analysis
- Reflection analysis

The Data AcQuisition software (HR DAQ) is a comprehensive Windows based data acquisition and analysis program that is suitable for 64 analogue input channels. It is used to collect and analyse data from a variety of instruments used in physical models such as wave gauges, Acoustic Doppler Velocimeters (ADV) and pressure sensors.

The program is project based and is split into three sections:

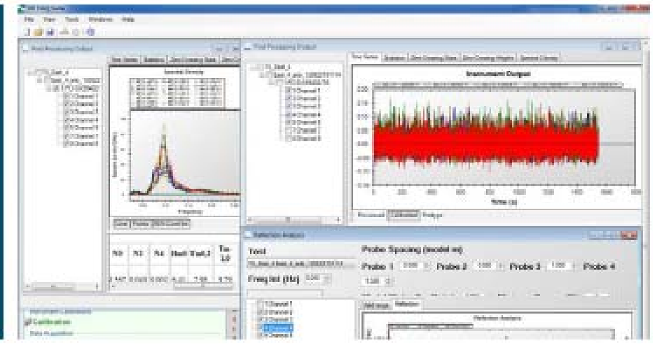
> calibration and scaling of inputs

> data acquisition

> data analysis

www.hrwallingford.com/equipment

HR Wallingford
Working with water



Calibration of inputs

The calibration section allows the creation of instrument identification and specific calibration files for use with the acquisition and analysis sections. It provides a comprehensive set of facilities for setting up the calibration files that are used to convert the analogue voltage signals in the model, to data at full scale, assuming Froude or Reynolds scaling. Where calibration factors are already known, they can be manually entered for each measurement instrument.

If certain channels have to be calibrated for the specific test, such as wave gauges, then HR DAQ uses its own calibration routine. With this routine, the wave gauges are lifted and lowered and HR DAQ records the input voltage signal against the prototype or model value that is entered. After three calibration points have been entered HR DAQ will calculate the Goodness of Fit using the Least Squares Method.

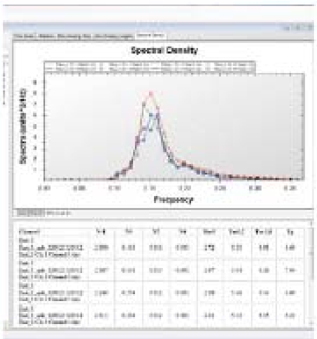
The raw calibration data and the calibration scaling factors are saved to a file that is automatically named with the instrument, project title and the time and date it was saved, this allows full traceability of the calibration, acquisition and analysis data.

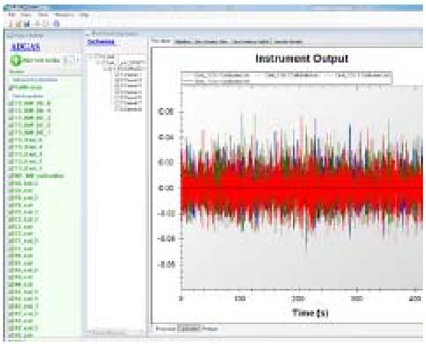
Data acquisition

Raw data is collected and stored in ASCII format. HR DAQ is set to collect data for a specified period of time at a specified frequency.

During data collection HR DAQ displays the time remaining for the test together with a graphical display of the channels being acquired in real time, giving the user confidence that the test is proceeding as expected. At any time the acquisition can be aborted with the data acquired so far being retained on the file. When collecting data for a large number of channels it is possible to select from any of the channels being acquired, however for clarity purposes usually only one or two are shown on the real time display.

The collected data set is saved to a file, which is automatically named within the project hierarchy.





Data analysis

After the data has been collected, HR DAQ can be used to perform a number of analysis routines.

The analysis facility processes the data based on a number of options. The principal analysis program includes two routines; one is a Fast Fourier Transform spectral analysis and the other a statistical one.

The analysis results file includes a summary of the test conditions, data validation checks and the statistical and spectral parameters in addition to a table of the following parameters:

- frequency or period
- energy density
- m0, m2 and m4
- H1/3
- Tm

During the analysis, trends can be removed and the data filtered (low pass or high pass).

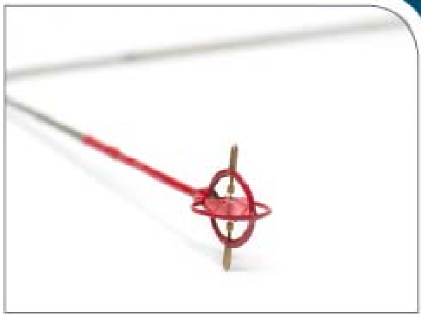
Various options exist for determining how the spectral analysis is performed. For example, the amount of smoothing that is applied to the spectrum can be varied and the number of frequencies can be truncated. It is also possible to perform statistical analysis based on a threshold which can either be the mean or a user defined value.

HR DAQ can also perform a reflection analysis on the data from four wave probes. The Reflection Analysis module also allows the user to determine the best spacing of the wave probes for a given frequency range and also performs a reflection analysis with the incident and reflected spectra and reflection coefficient as outputs.

Besides outputting the analysed results, HR DAQ can export the calibrated time series data as .csv text file for analysis by other proprietary programs.

Laboratory instrumentation and software

Miniature propeller meters



Key features

- Digital display
- Low cost
- Small diameter
- Low speed capability
- Battery and mains operated

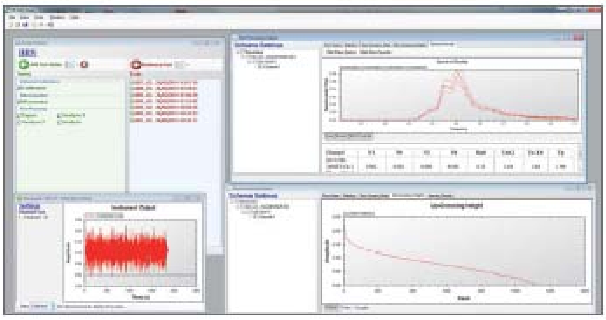
The Nixon miniature propeller meter has been designed to measure water velocities in 2D hydraulic models. The small diameter of the propeller means that it can measure changes in velocity throughout the model and the high quality bearings enable it to measure velocities down to 3 cm/s.

Probes

Two probes are available, one covering the range 5-150 cm/s and the other 60-300 cm/s. The probe head has a five bladed PVC propeller mounted on a hardened stainless steel shaft. This runs in jewelled bearings that are mounted in a protective cage. The cage is joined to a long thin tube inside which is an insulated gold wire that projects to within 0.1mm of the tips of the blades. When the propeller rotates in a conductive liquid, the movement of the blades past the end of the wire varies the impedance between the wire and the tube.

Laboratory instrumentation and software

Ship movement measurement



Key features

- Compact and easy to set up
- 0.18 mm resolution
- Displays all six degrees of freedom
- Runs with HR DAQ for logging and analysis
- No contact with the ship

HR Wallingford's ship movement measurement system is used to measure the movement of model ships, typically when moored, for the design of new harbours or terminals. It has been designed to use non-contact measuring methods and to interface directly with HR DAQ acquisition and analysis software. This means that full spectral analysis and also correlation between any of the six degrees of freedom and wave heights or mooring forces can easily be carried out. The system comprises six laser displacement sensors, controller unit, power supply with interface unit and all necessary interface cabling.

www.hrwallingford.com/equipment

Laboratory instrumentation and software

Force measurement sensors

Key features

- Options for ship fender and mooring line applications
- Strain gauge range 0-5 N
- Range of springs supplied for mooring lines to give non linear responses
- Simple to install and operate
- Made from corrosion resistant materials
- Operates with HR DAQ

HR Wallingford's force transducers have been specifically developed to model the forces on ship mooring lines and fenders in a variety of sea states. The simplicity of operation, together with our own data analysis software HR DAQ, makes these devices an ideal choice for ship modelling requirements.

Strain gauge sensors

The flexible strain gauge beam is made from phosphor bronze to maximize performance properties and is attached to an anodised aluminium support.

All strain gauges are provided with calibration certificates. The range of operation will measure forces of 2.5 N/cm over a distance of 20 mm. The strain gauge can be supplied in two configurations to measure forces in either mooring lines or fenders.

HR Wallingford
Working with water

Laboratory instrumentation and software

High performance pressure sensors

Key features

Covers depth and impact measurements

19 mm diameter sensor

0-10 V output signal

Digital display

Multiple sensor data acquisition via TOPS unit

The high performance pressure sensors are ideally suited for measurements in hydraulic models.

These sensors can measure;

> impact pressures on structures, with a flush mounted diaphragm;

> water depth or the wave pressure under rubble mounds, with a protective nose cone; and

> pressure in pipes or other vessels, with a male G¼ thread.

The all welded diaphragm and body are manufactured from 316 stainless steel and the cable has an internal vent tube and strainer wire.

The sensing element consists of a micro-machined silicon diaphragm with piezo-resistive strain gauges diffused into the surface. The sensing element is mounted behind a thin diaphragm to produce a rugged assembly. The combined linearity and hysterisis errors are less than 0.25 % of full scale range.

www.hrwallingford.com/equipment

The ARC-Boat

The ARC-Boat is a remote controlled boat that is used to collect river and estuarine data including flow, depth and suspended sediment concentrations.

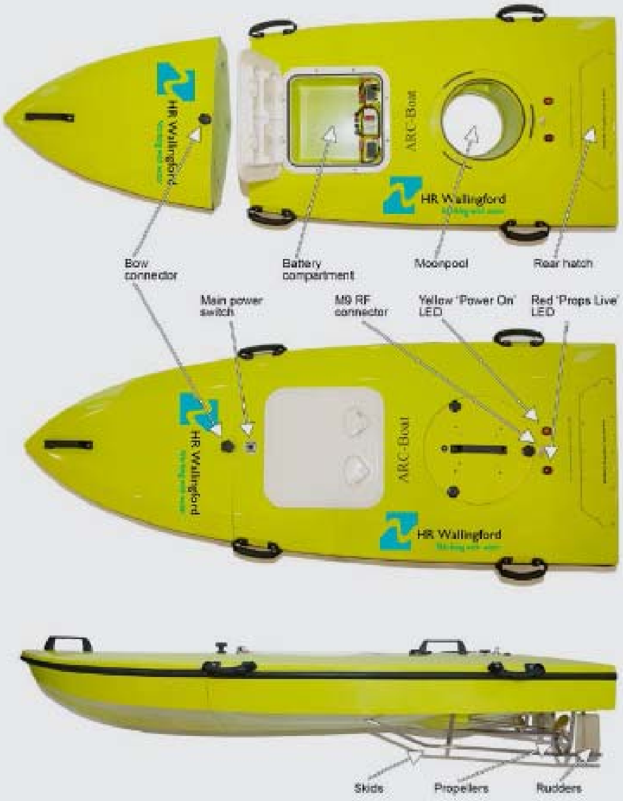
It was developed in partnership with end-users and perfected to meet their exact needs.

HR Wallingford provides outstanding customer support throughout the ownership of an ARC-Boat, from delivery to ongoing training and support.

www.hrwallingford.com/equipment

HR Wallingford
Working with water

The ARC-Boat



Specifications

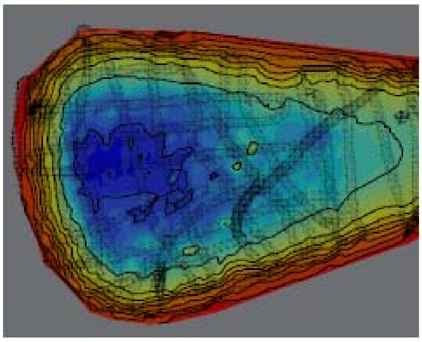
Dimensions

Length without detachable bow	1.20 m
Overall length	1.95 m
Draft	0.18 m
Beam	0.72 m
Draft (inc. skids)	0.22 m
Deployment depth of ADCP	0.12 m

Dry weight

Main hull, deck, propulsion system and electronics	25.6 kg
Detachable bow	4.2 kg
Total unladen weight	29.8 kg
Total unladen weight with batteries	37.2 kg
Largest ADCP fitted	7.6 kg
Total weight	44.8 kg

www.hrwallingford.com/equipment



Technical specification

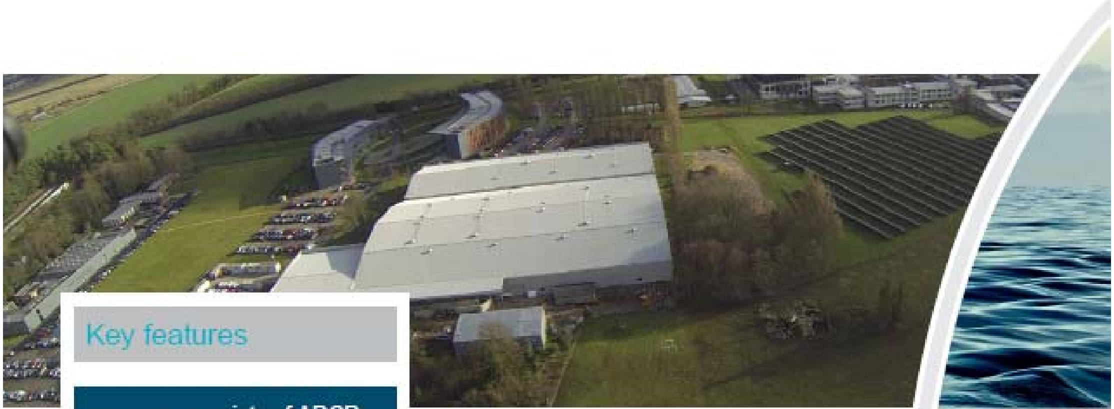
- Designed to provide clean data in flows of up to 5 m/s
- A hull design that offers minimal flow disturbance
- Twin rudders and twin shrouded propellers provide very high maneuverability
- Deployment depth for the ADCP of only 12 cm below the waterline.
- Skids protect the ADCP sensor, propellers and rudders from damage.
- Battery life of up to five hours depending on use. Supplied with spare battery packs and chargers.
- A relatively light and portable vessel with an unladen weight of 29 kg, a length of 1.95 m, beam of 0.72 m and draft of 0.22 m with skids.
- Rigid and robust GRP hull able to accept minor knocks and damage.
- Resistant to UV light.
- A detachable bow that allows road transport in small vehicles and is easy to replace in the event of front-end impact damage.
- Supplied with fairings and adaptor sleeves to allow a wide range of ADCPs, including RDI Rio Grande and Sontek M9 units to be used.
- Operates with industry standard remote control with a minimum range in excess of 200 m.
- Incorporated Bluetooth link for data transmission to an onshore laptop.
- Twelve month warranty from the date of delivery.

Current applications

The Environment Agency is using a fleet of ARC-Boats to monitor water depth and flow up and down the UK, including the River Tyne in Newcastle where the peak tide flow of 903 m3 per second is the highest yet recorded by ARC-Boats in the Yorkshire and north east region.

A further boat has also been deployed to successfully measure tidal velocities over 1 km long transects in the Wirral estuary, in the north west of England.

ARC-Boat's have been used successfully in Germany, United States, Canada, New Zealand and Ireland.



Key features

- can carry a variety of ADCPs and other instruments
- high quality data collection with minimal under-hull air entrainment
- robust and reliable design
- excellent manoeuvrability
- designed with operator safety in mind
- lightweight and easy to transport
- unique detachable bow
- can also be used to measure environmental conditions in lakes

About HR Wallingford

HR Wallingford is an independent engineering and environmental hydraulics organisation. We deliver practical solutions to complex water-related challenges faced by our international clients. A dynamic research programme underpins all that we do and keeps us at the leading edge. Our unique mix of know-how, assets and facilities includes state of the art physical modelling laboratories, a full range of numerical modelling tools and, above all, enthusiastic people with world-renowned skills and expertise.

More information

www.arc-boat.com

Contact

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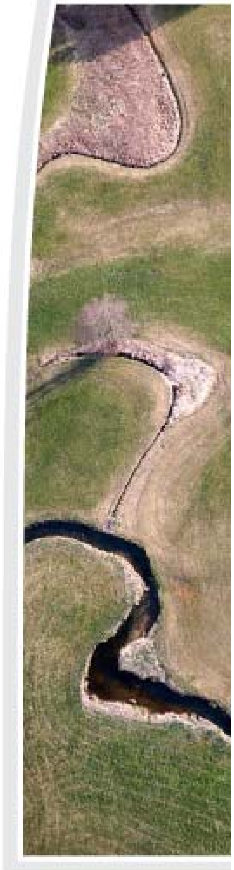


Laboratory instrumentation and software

Flume wavemakers



As one of the world's leading hydraulics laboratories, HR Wallingford has more than 50 years experience in all aspects of physical modelling and has supplied wavemakers to laboratories around the world.

Each wavemaker is custom-built to the client's requirements and is equipped with HR Wallingford's Active Wave Absorption System.

Installation is quick and straightforward with HR Wallingford providing commissioning, training and on-going support.

Flume wavemakers

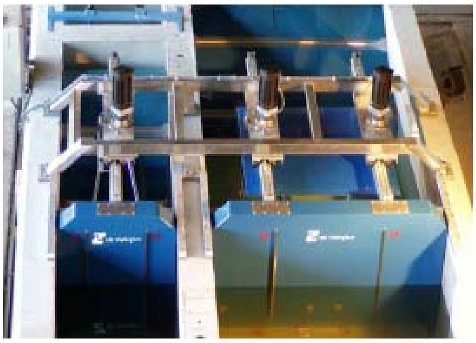
When using physical models to test the design of coastal structures or to investigate wave processes, engineers must be able to work with a wide range of realistic wave conditions.

HR Wallingford has extensive experience in designing and building wave generating systems that realistically simulate sea conditions. We have supplied wavemakers to many laboratories around the world and they have been in use on our own models at Wallingford for many years.

Flume wavemakers are normally driven by AC electric servo motors. Very large wavemakers are hydraulically powered.

Flume wavemakers are based on a wet-back design for simplicity and ease of maintenance. All flume wavemakers have active wave absorption fitted as standard.

www.hrwallingford.com/equipment



Electrically powered wavemakers

Piston type wavemakers

For water depths up to 1.5 m the wavemaker is typically a piston type design where the paddle moves backwards and forwards horizontally. The advantage of this type of design is that the stroke is not generally limited, making the piston wavemaker ideal for producing solitary waves, absorbing reflected waves and compensating for long period set down phenomena.

Depending upon the width of the flume, the paddle is mounted underneath either one or two electric drive actuators. These actuators are suspended from a structure that spans the flume walls. Alternatively the structure can be free-standing if required. With this arrangement all the bearings and precision components are situated well above the water level.

Each drive actuator comprises a specially designed extruded beam which runs between a series of linear bearings. This beam is driven backwards and forwards by digital AC servo motor that operates through a gearbox with rack and pinion. The motor has a low inertia which is necessary for high frequency operation and the rack and pinion allows the high velocity to be achieved which would not be possible with other types of drive.

The gearbox has an eccentric mounting to allow the rack and pinion to mesh without backlash. The rack and pinion method of driving the paddle is simple and does not require a sealed lubrication system. All that is required is an occasional wipe down and re-grease to maintain it in good condition. The result is a reliable wavemaker with low maintenance requirements.

Stainless steel is used for all the metal work of the wavemaker. The rack is also made of stainless steel and the bearings and bearing slides have a special corrosion resistant coating.

An absorbing beach is fitted behind the paddle to prevent splashing. The beach consists of an open cell foam material which is held in place within the framework of the wave maker.

The AC servo motor is controlled by an intelligent digital drive. The drive provides all the gain and damping for the motor to ensure that the paddle accurately follows the position demand signal. While the wavemaker is running, the drive can be interrogated and a variety of parameters can be monitored such as the motor speed, current and drive temperature.

Hinge flap type wavemakers

This type of wavemaker is best suited to deeper water applications and is often used for ship towing tanks.

The wavemaker comprises a paddle that is hinged either on the bottom of the flume or on a raised supporting structure. The movement of the paddle is limited to approximately ±15 degrees to prevent wave distortion.

Again the design of this wavemaker ensures all of the drive actuation system is kept well above the water level with the use of a flexible belt and quadrant to drive the paddle. For wider flumes and towing tanks a dual actuator is used to achieve the required wave heights. The control system for the hinged flap wavemaker is the same as that for the piston type.

www.hrwallingford.com/equipment

Control system

The motor drive and electronics for the paddle are housed in a Motor Drive Control Panel (MDCP) that is mounted beside the flume.

The output from the signal generation computer is transferred to an embedded PLC, which is located in the MDCP. For installations where the control room is some distance from the wavemaker we provide a remote control unit to provide an emergency stop button for the operator. There is a second emergency stop button mounted on to the MDCP.

Design life

The motor, drive and bearing assembly of the wavemaker are standard components in a wide range of industries where they often run continuously. In comparison, wavemakers tend to be used for only a few hours a day and there are often long periods between studies while models are built and bathymetry constructed.

Studies also usually use random waves which impose less wear on the components than the peak demands of the regular waves that they have been designed for. For these reasons a wavemaker can be expected to have an operational life well in excess of 20 years.

Active wave absorption

In many studies, there can be considerable reflection from the model being tested.

However active wave absorption overcomes this problem and provides precise control of wave conditions throughout the model.

Without active wave absorption, these reflected waves will be re-reflected from the paddle and build up in the flume. This results in the wave spectra becoming distorted and, in the extreme case, the waves becoming unstable

Dynamic wave absorption prevents waves being reflected back from the paddle by measuring the wave height at the paddle. It then modifies the demand signal in real time to take account of the additional waves that have been reflected from the model at the other end of the flume.

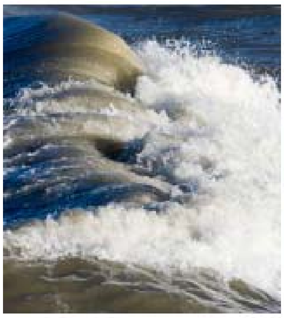
Hydraulically powered wavemakers

Hydraulically powered wavemakers are usually of the piston type. The largest wavemaker supplied by HR Wallingford to date was hydraulically powered and was for a flume 5m deep and 3m wide.

HR Wallingford
Working with water

Laboratory instrumentation and software

Multi-element wavemakers



The multi-element wavemaker is used to create long and short crested waves for either deep or shallow water. Each wavemaker is custom-built to meet the client's requirements and is equipped with HR Wallingford's Active Wave Absorption System.

Installation is straightforward with HR Wallingford providing commissioning, training and on-going support.

Multi-element wavemakers

When using physical models to test the design of ports and harbours, coastal protection schemes or off-shore structures, engineers must be able to work with a wide range of realistic wave conditions.

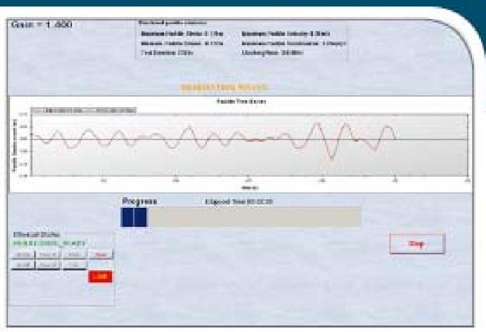
HR Wallingford has extensive experience in designing and building wave generating systems that realistically simulate sea conditions. We have supplied wavemakers to many laboratories around the world and they have been in use on our own models at Wallingford for over 50 years.

www.hrwallingford.com/equipment

HR Wallingford
Working with water

Laboratory instrumentation and software

Wave generation software



HR Merlin is an advanced software package designed to simulate a variety of sea states for both single and multi-element wavemakers. It can generate regular and irregular waves and can also produce compensation for set down or very long period infra-gravity waves.

HR WaveMaker runs under Windows 7 and is supplied with a security dongle and comprehensive user documentation.

Irregular waves generated using the white noise method

This method of signal generation produces random waves in a direction normal to the paddle. It is based on the principle of digitally filtered white noise and is generated in real time. The white noise source is generated and passed through a digital filter to produce the required position demand signal for each paddle. The characteristics of this filter are obtained by performing a Fast Fourier transformation based on the spectral shape that has been selected.

六、 交流活動心得與建議

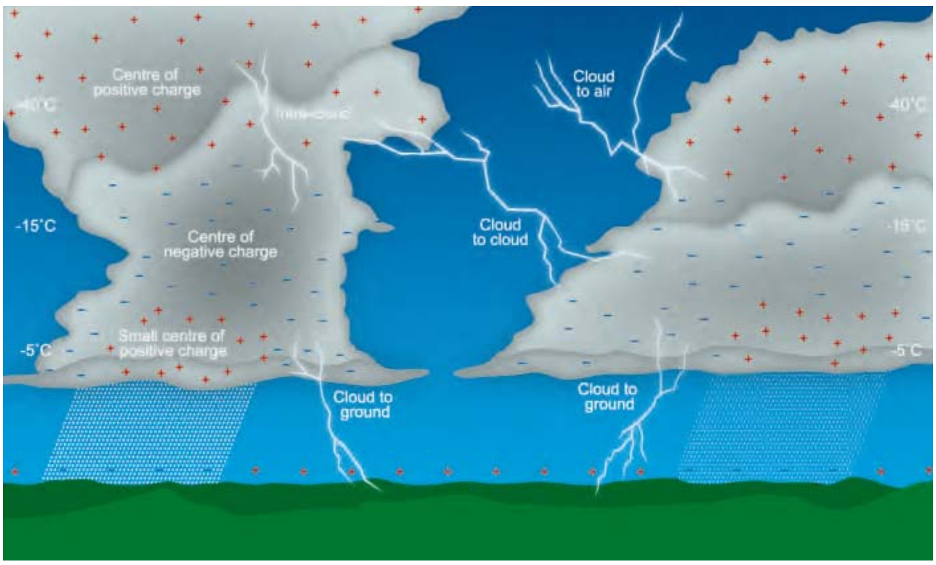
綜觀本次實習訓練與工程技術活動參觀，配合行程 9 天內於英德兩地來回奔波難免舟車勞頓，但見聞寶貴與經驗滿載，深深體會研究單位與外界交流的重要性，一部分可作業檢討手邊業務之參考，一部分可啟發內心的工作態度及強化自身的動機，簡言之本活動共有 4 項工程技術活動參觀、1 項工程實習訓練，下就各項工程技術活動交流提出心得與建議：

(一)、 德國 WERA 海洋雷達：

海洋雷達功能強大且日新月異，近十年來發展十分可觀，由於量測需求可隨雷達頻率與天線數量調整範圍及解析度，故應用於海洋表面波流之量測範圍逐漸加大，解析度亦日漸提升，正好滿足船泊進出港區對海象資料之迫切需求；進一步的利用雷達訊號進行海嘯預測分析，以提早預警及疏散人民生命財產安全，並可將海洋雷達結合 AIS 系統，達成船舶動態追蹤之目標，該技術皆與本所業務相關，如有共同合作機會，將有助於臺灣對於雷達波應用之需求。

(二)、 英國 Biral 落雷系統：

Biral 公司是本所常用能見度儀之專業製造公司，近幾年來研發落雷系統技術與功能逐漸成熟，已以產品型式上線販售，該系統特色可接收雷雨胞之感電訊號，透過該訊號可推估直徑約 160Km 範圍內雷雨胞移動的變化，以及未來發生強降雨之可能區域，這項技術將可滿足臺灣離岸風電區及鄰近港區內降雨推估及災防因應。

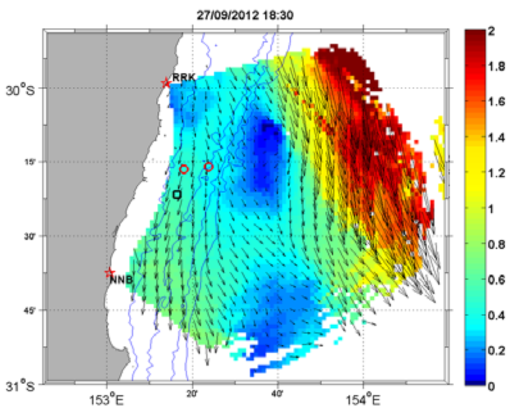


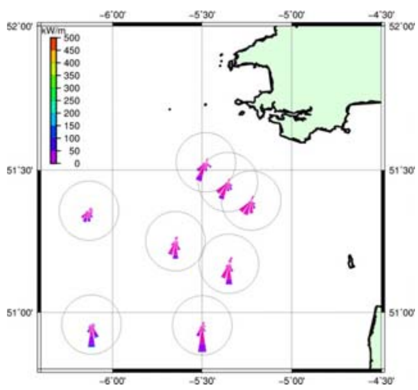
(三)、 英國 Gill 氣象站與即時展示系統：

Gill 公司本身為氣象量測專家，所研製之產品大多應用於各國海軍級船艦，同時普及至世界各地，近年更是研究開發多功能氣象觀測站，可同時量測氣壓、風速、濕度、溫度等，並配有即時展示系統可供查看量測數據，十分方便，非常值得本所重新考量未來既有海氣象觀測站儀器之維護更新使用。

(四)、 英國 Seaview Sensing 雷達訊號處理軟體：

雪菲爾大學教授 Dr. Lucy 所開發的 Seaview Sensing 可同時分析處理多樣海氣象資料，包括：WERA 公司所開發的雷達資料、海上浮標資料、海氣象資料等，皆可透過此軟體辦理分析及後續比對，目前臺灣尚無如此完整的分析軟體，如未來需要發展更嶄新類似的分析軟體，Seaview Sensing 將是一套不錯的開發範本。





最後是技術活動交流於 HR Wallingford 公司工程實習訓練心得，由該課程安排扎實緊湊，由最基礎的核心課程波浪理論開始講授，緊接著實務面的應用、現象的描述及後續實習操作之練習，讓受訓人員以循序漸進及系統化的方式理解水工模型試驗的內涵，受訓期間也花不少時間與國外技師討論本所購置造波機之設計細節，許多盲點都趁此機會一併釐清，最大的心得與收穫舉凡不及備載，經由此次參加實習訓練後所獲得的心得，有以下的建議：

1. 綜觀整個水工模型試驗廠棚，隨處可見造價昂貴之蛇型造波機，反觀臺灣目前僅存一部蛇行造波機於臺灣海洋大學，訓練期間在 HR 公司遇上中國上海船舶運輸科學研究所的工程師及項目經理，他們特此考察已投資購買蛇行造波機，讓我們深覺自身競爭力明顯不足。

2. 走進 HR 公司試驗廠棚內，整個實驗室工作設備一應俱全，不論任何研究課題，技術人員皆能佈設處理試驗場地，觀察棚內的使用情形，察覺每個場區都配有專責人員負責綜理實驗進度，整體使用率高達八成以上，少有閒置場地，顯示該公司業務量龐大，工作應接不暇。

3. 辦公室圖書室內設有咖啡休息區，可供研究人員查詢資料並稍做短暫休憩，讓整個工作士氣全然不同；整個 HR 公司隨處保持整潔乾淨，特別是水工模型試驗場更是維持的井然有序，不經讓我們佩服 HR 公司技術人員的自我紀律。

4. 幾天的訓練課程下來，客觀來說辦理水工模型試驗的架構，其實與臺灣無異，只差別在於環境、設備及軟體，但在實驗上的精神大同小異，可能是保持學習的心情前來，總讓人感覺 HR 公司的各項措施印象深刻。

5. 臺灣過去開發海岸資源，講究各種施工技術與增進港埠管理運量等相關知識，建議應須學習國際社會漸漸轉換成為注重環保節能、海岸保育、海岸防災、生態維護等領域去發展；海洋波浪的生成機制是十分複雜，如果僅靠數值模式的推算方式是無法確實掌握正確海象情況；針對我國港灣工程更應積極重視現場觀測及水工模型試驗之資料獲取，加速全島海象資料庫之建立與整合，才是臺灣海岸工程長治久安之道。

6. 參觀英國布里斯托市、德國漢堡市的港灣建設，可以發現它們海岸工程十分積極得注重在休閒娛樂與交通運輸結合；建議臺灣未來的海岸開發與利用，其實是可以效法觀摩學習，做得更具有親水性及休閒性之護岸工法與環境。

7. 本次訓練受益良多，希望國內從業研究人員能有更多機會出國訪問或訓練，以反省改進不足漸長國家實力。

CQR5855 – IHMT, Long Crested Wavemaker

UK Physical Modelling Training

19th December 2017

Introduction

Training was undertaken for two delegates from the Institute of Harbour and Marine Technology (IHMT) between the dates of 13th December and 19th December 2017. The training formed part of the delivery requirements for the supply of a new wave generation system to IHMT under the HR Wallingford project reference of CQR5855. This document summarises the training undertaken and the tasks completed.

1. Classroom training

Three classroom sessions were undertaken, covering the wavemaker operating control systems and power requirements systems, waves and wave theory and the theoretical design and preparation of basins for physical modelling.

The PowerPoint presentations for the wave and wave theory and the physical modelling training have been made available electronically, along with a guidance document on scaling of granular materials within physical models.

2. Practical training

Two practical training exercises were undertaken, detailed operation of the wavemakers and a short physical modelling study. The wavemaker exercise covered start up, run test conditions and also shut down the wave generation system. Specifically covering:

- Safety briefing
- Setup of sea conditions:
- Wave generation and analysis
- Active wave absorption – paddle wave probe calibration
- HR Merlin post generation reports and output files
- Data export
- Trouble shooting
- Remote support (TeamViewer)

The physical modelling exercise covered construction of a model breakwater, setup and calibration of a wave probe reflection array, testing the breakwater and reviewing photographs and laser scans of the resulting damage. All data has been provided electronically including photographs, laser scan analysis and wave gauge data.

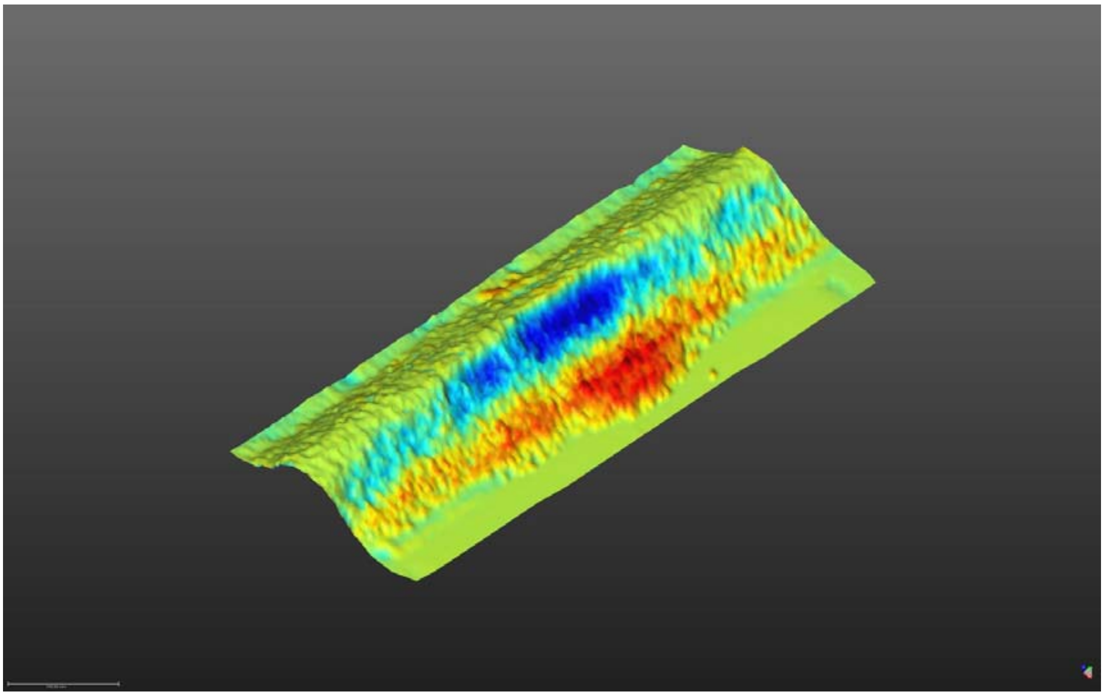


Figure : Difference plot showing damage during testing

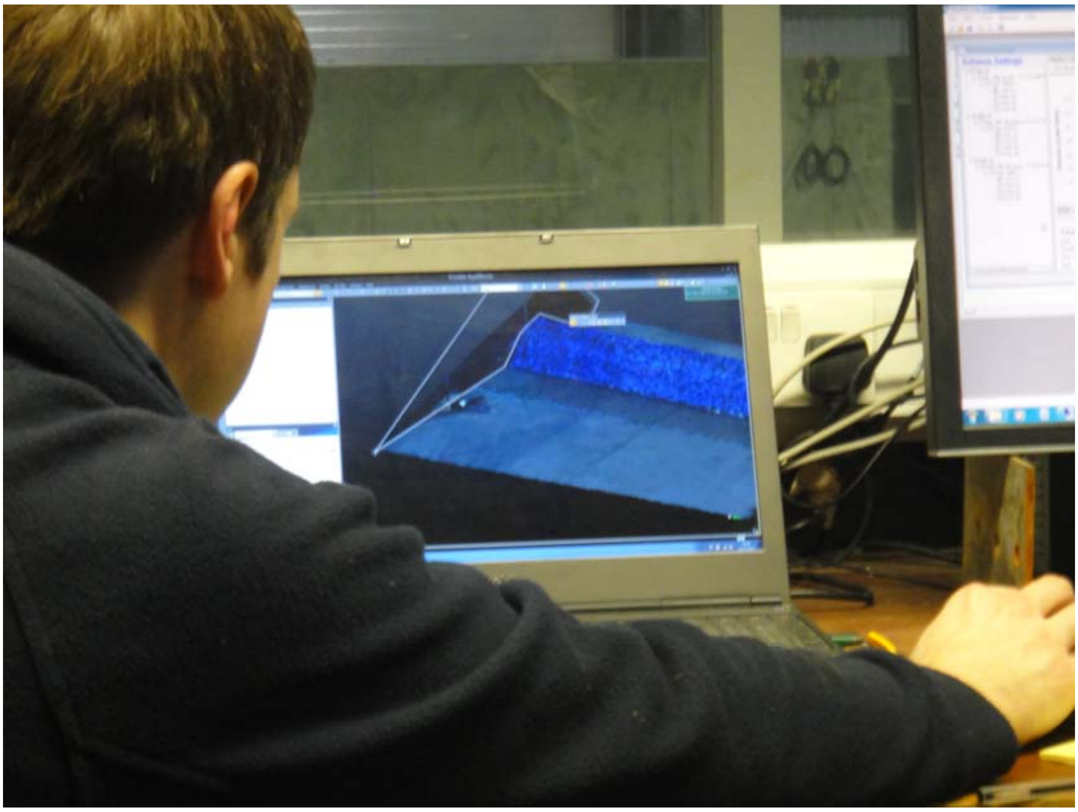
3. Future collaboration and research opportunities

During the duration that the trainees were at HR Wallingford it was possible to conduct a meeting to discuss topics of research and future collaboration where the interests of HR Wallingford and IHMT have common interests.

The topics discussed covered :-

- Port design;
- Propeller scour at the dockside;
- Mooring line analysis for both physical models and numerical models;
- Renewable energy;
- Additional instrumentation and data acquisition systems;

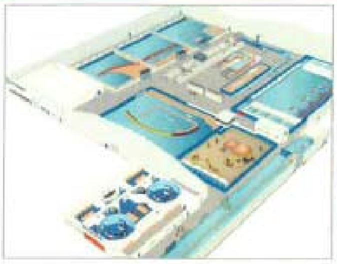
These opportunities will be followed up in due course by HR Wallingford upon the return of the IHMT delegates to Taiwan.




SmartView HD

HR Wallingford
Working with water

Certificate of attendance



Physical modelling training

Title	Physical modelling training
Training delivered by	Gary McIntyre and Simon Tiedeman
Site	HR Wallingford
Date	13 to 19 December 2017

This is to certify that Mr. Lee, Cheng Da attended the training session

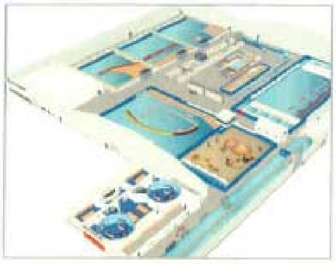
Signature	[signature]	[signature]
Name	Gary McIntyre	Simon Tiedeman
Role	Principal Engineer, Equipment Sales	Equipment Sales Manager, Equipment Sales

HR Wallingford and IHMT 李政達副研究員技術交流活動結業證書

HR Wallingford

Working with water

Certificate of attendance



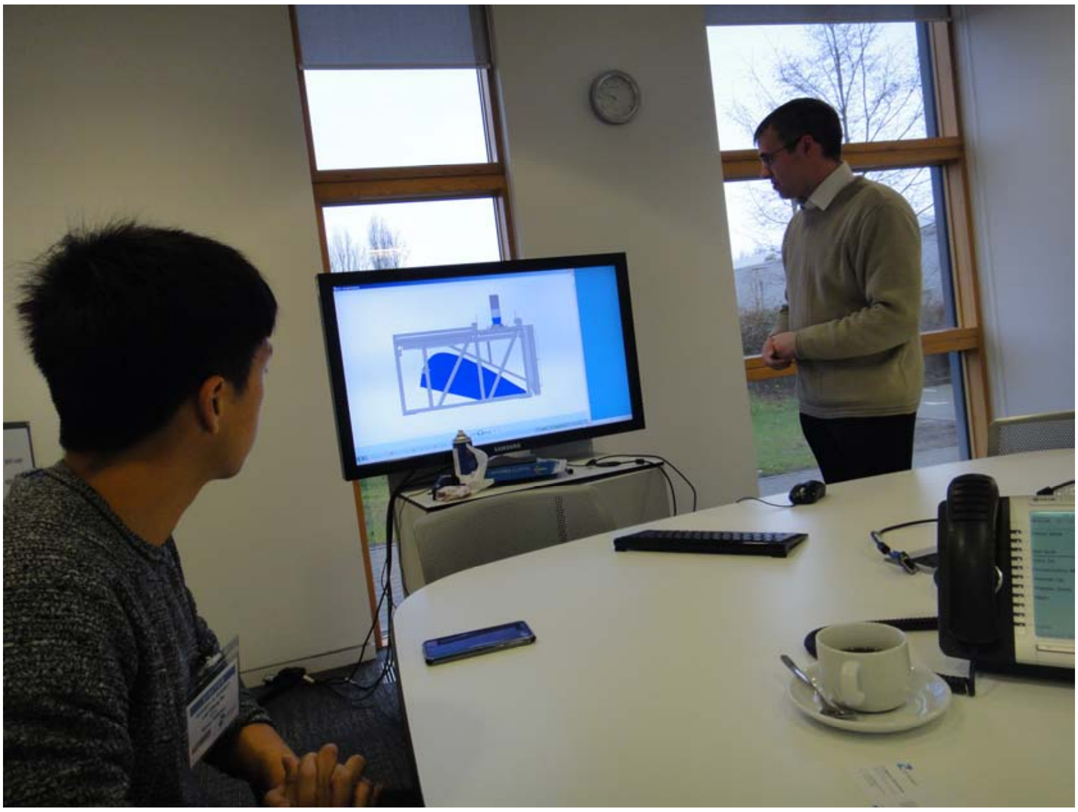
Physical modelling training

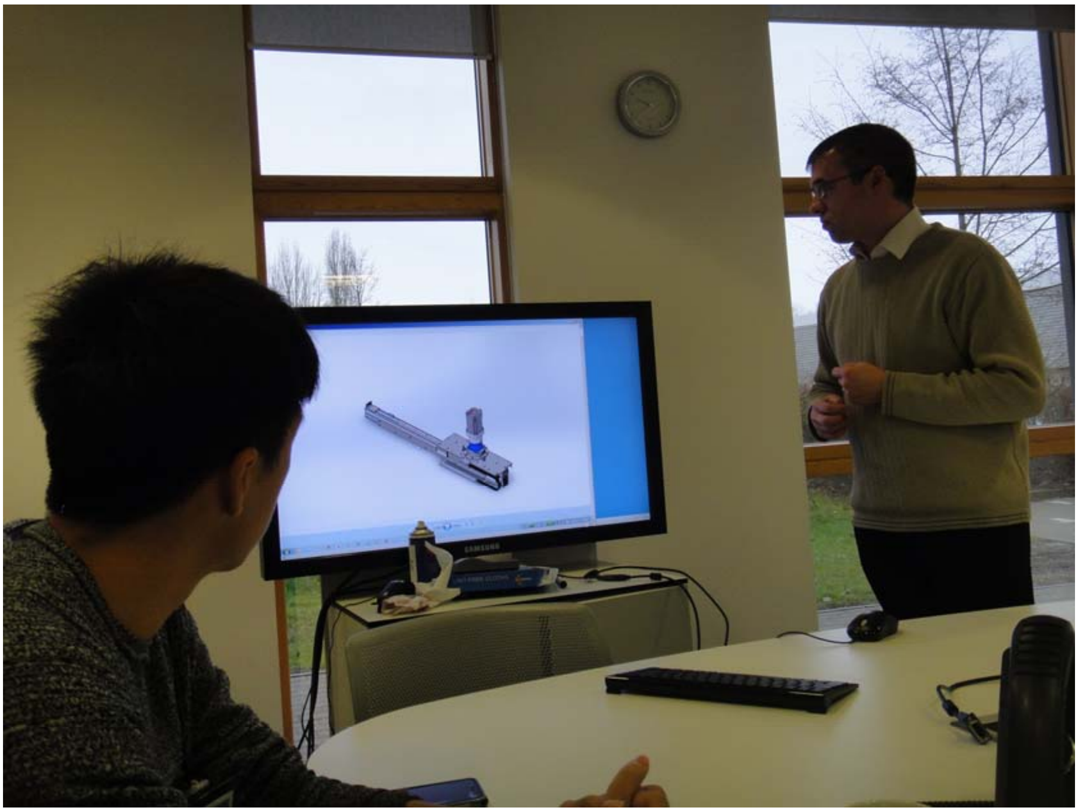
Title	Physical modelling training
Training delivered by	Gary McIntyre and Simon Tiedeman
Site	HR Wallingford
Date	13 to 19 December 2017

This is to certify that Mr. Lin, Shou Shiun attended the training session

Signature	[signature]	[signature]
Name	Gary McIntyre	Simon Tiedeman
Role	Principal Engineer, Equipment Sales	Equipment Sales Manager, Equipment Sales

HR Wallingford and IHMT 林受勳助理研究員技術交流活動結業證書






Modelling Hall

造波機系統組成：

HR Wallingford 的長波峰(long crested)造波機設計用於淺水水池，可在不同的水深下進行操作使用。它們由馬達驅動的濕背(wet-back)平推式(Piston Type) 造波板所組成。

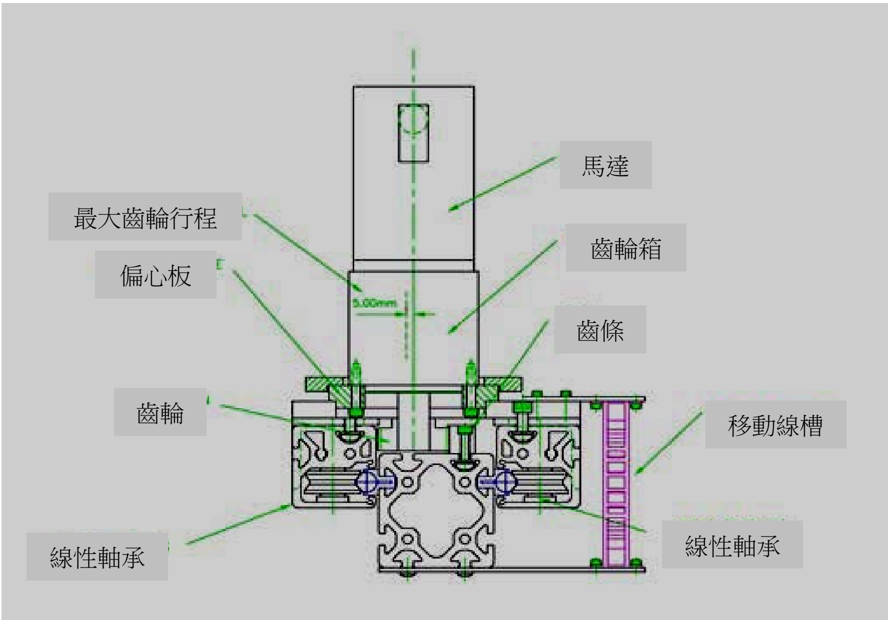
機械元件：

每個造波機的設計都是符合計畫安裝的特定場地，本案完全以模組化的架構而設計，以使系統能夠移動到水槽內的不同實驗位置。主要的機械元件包括如下：

造波板促動器(Actuator)

每個造波板模組上都具有一個平推式造波板，該造波板由安裝在模組支撐框架上的雙馬達驅動促動器驅動。這種配置允許軸承和精密零件都位在水位以上，達到防水效果。

每個造波板促動器都包括一個經過特殊設計和擠壓製造的移動樑，它們在四個線性軸承之間移動，如圖所示。此設計是為了將側面運動減到最小，以避免造波板與相鄰造波板或水池側壁的任何可能碰撞。



造波板促動器的一般配置剖面圖

移動樑透過齒條和齒輪機構，向前和向後動作。而小齒輪設計成偏心安裝，允許調整到最小間隙，進而確保造波板能精確運動。所使用的零件中，齒條和齒輪是由不銹鋼所製成，另外軸承和軸承滑塊具有特殊的耐腐蝕塗層。

驅動造波板的齒輪/齒輪方法簡單，不需要密封的潤滑系統。所需作的維護就是偶爾的擦拭和重新潤滑，以保持它在良好的狀態。採用上述促動器機構將可得到可靠的造波機，所需的維護成本也降低。

每個齒輪由交流伺服馬達透過低間隙的行星齒輪箱驅動。造波板促動器組件具有低慣性飄移，並實現其它形式驅動系統不可能達到的高速造波運動。

所有造波機使用的伺服馬達防護等級為 IP54。此外，所有電纜連接器和軸封等的防護等級亦為 IP54 (註：IP54 為防塵及防水花濺入)。

請注意：計畫不使用具有致動器的伺服馬達，因為這會使系統維護變得複雜，更重要的這代表造波機的一般維護只能在系統啟動的狀況下進行，我們認為這是不安全的作業環境。

極限感測器安裝在造波板促動器上，以檢測造波板運動是否到達極限位置，一旦到達則感測器觸發，並關閉造波板促動器。而後極限感測器也用於開機時造波板的歸位基準。

平推式造波機的交流伺服馬達和齒輪箱零組件

此計畫供應的造波系統當在性能範圍內運行時，將滿足英國工作健康與安全法(HSWA)中的噪音等級要求，而不需要工作人員佩戴噪音防護耳罩。造波機的操作和維護也符合修訂後歐盟機械指令 2006/42 / EC 的所有規範。

造波板

造波板將由折疊後的不銹鋼所建構，並使用支撐臂增加強度以剛性地連接到造波板促動器。

每個造波板將安裝阻抗式波高計來量測造波板前的水位。量測資訊用於主動吸收系統的輸入之用。波高計的尺寸和位置，可以在所有水位下和造波機可能執行的所有波浪條件下，記錄水面位置。

支撐框架

所有 HR Wallingford 造波機的製造均採用 304 不銹鋼材質，並在方形或矩形中空箱體斷面完全焊接(滿焊)。不使用針腳點焊法或其他類似製造方法，以避免造成縫隙腐蝕。

被動吸波板組成

為了減少造波板後面的水花飛濺，因此位於造波板後面設有細胞發泡式能量吸收海灘（cellular foam energy absorption beach）。這個海灘由多孔發泡材料組成，用於吸收造波板的反向運動所產生的能量。

操作系統：

波浪產生系統由造波電腦控制，通常位於可俯視水池的控制室內。電腦透過工業乙太網路電纜線與造波機進行通訊。

電腦所使用的 HR Merlin 造波軟體允許操作人員遠端啟動造波機，並執行啟動程序，包括：

1. 啟動歸位程序，以使得驅動器定位到基準位置。
2. 校正造波板上的波高計。
3. 在造波前選擇主動吸波功能。
4. 選擇操作方法(以下擇一)：
   - 僅 HR Wallingford 造波模組。
   - 同時使用 HR Wallingford 造波模組和 Davis 造波模組輸出訊號。

5. 預先選擇波形條件，以在實驗期間造波。

6. 在實驗期間監測造波板的位置、需要的訊號和波高訊號。

7. 在一系列的實驗完成後，進入收集資料完成報告。

緊急停止按鈕安裝在模組機箱上，也安裝在控制室內與使用者介面電腦相鄰的遠端安全裝置上。

<u>造波控制電腦</u>

主控室將配備高性能電腦，其中附有乙太網連接埠和液晶顯示器。在裝運之前，電腦將搭載 Windows 10 作業系統和 HR Merlin 造波軟體。另外也將同時提供 Microsoft Office 中小企業版。

使用 HR Merlin 軟體的電腦系統

電腦的主要功能是儲存和分配造波板位移時間序列，然後傳遞給位於模組機箱的馬達驅動控制面板(MDCP)中的嵌入式控制器。電腦還可以記錄造波板性能資料和狀態參數。此資料可以模擬即時顯示或以實驗後的報告形式展示。

<u>遠端造波板安全裝置</u>

另外在主控室提供一個遠端安全裝置，以便在緊急情況下可以關閉造波系統。

遠端安全裝置

遠端安全裝置透過工業乙太網路電纜線連接到造波機模組。遠端安全裝置還為使用者提供一個由 5V TTL 訊號組成的外部輸入觸發設備。

<u>機電控制系統：</u>

<u>馬達驅動控制面板(MDCP)</u>

每個造波板模組的電氣控制系統，都包含安裝在造波板模組頂部的馬達驅動控制面板（MDCP）中。

此馬達驅動控制面板 MDCP 將以 CE 電氣標準設計，所有零組件都能夠符合台電公司 60Hz 的工作頻率。這些零組件包括：

- MDCP 內部零組件的電源隔離和分配。
- 每個促動器的交流伺服馬達與馬達控制驅動器。
- 嵌入式 PLC 可程式控制器。
- 用於系統感測器之數位和類比的輸入/輸出訊號。
- 用於主動吸波功能的波高計訊號調節器。
- 過載保護裝置。

造波機控制系統的設計和組裝，都符合國際電工委員會 IEC 61508-3 的規範。

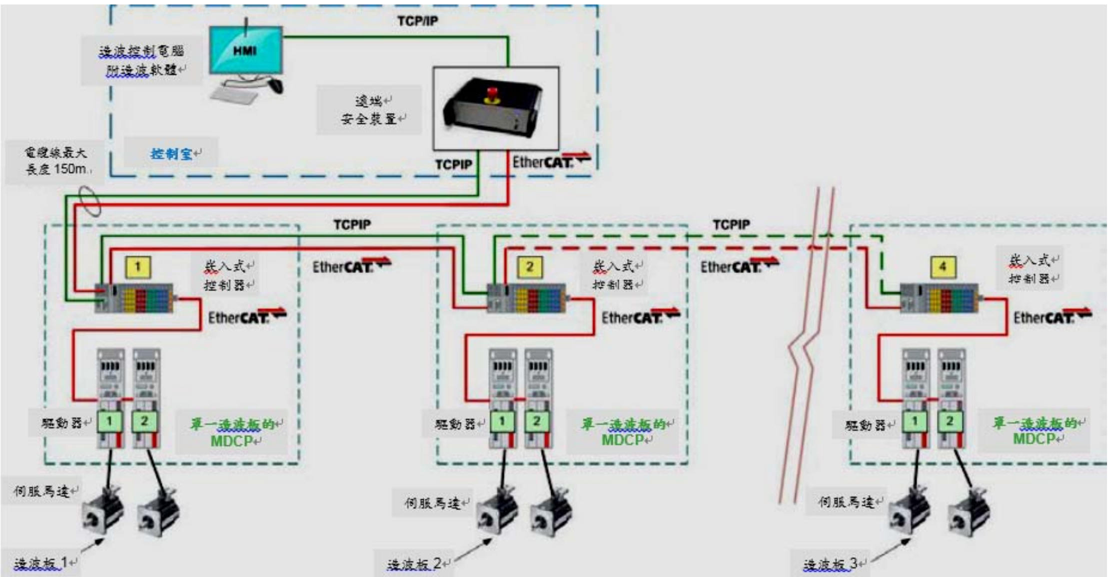
典型馬達驅動控制面板(MDCP)的配置

即時操作系統與工業網路架構

造波電腦和嵌入式 PLC 控制器透過即時乙太網路連接。而訊號產生電腦與馬達驅動控制面板（MDCP）之間的最大連接線距離為 150m。

作業系統控制數位網路，並以控制自動化技術乙太網路(Ethernet for Control Automation Technology, EtherCAT)通訊協定執行。作業系統具有 50 μs 的資料交換週期時間，並整合到專用於工業運動控制的資料庫，以定位造波板。

EtherCAT 是一種工業乙太網路協定，使用標準乙太網路佈線，但提供非常高的性能，例如 1000 個分佈式輸入/輸出操作可以在 30 μs 內進行。該協定具有幾乎無限的網路大小，可以透過乙太網路協定（在這種情況下稱為 TwinSAFE）提供足夠的系統安全性。進一步解釋這個協定的性能，它可以允許每 100 μs 進行多達 100 個伺服軸的通訊。在此周期時間內，提供所有軸具有設定值和控制數據，並報告其實際位置和狀態。該分佈式時鐘技術使所有軸能夠與震動(jitter)同步明顯小於 1 微秒。HR Wallingford 造波機的基本作業層級架構示意圖顯示。



計畫的造波控制系統架構圖採用四個雙促動器模組

<u>**崁入式運動控制器**</u>

造波機的控制是由位於 MDCP 中的嵌入式控制器，並且連接到造波電腦。該控制器處理所有運動控制和主動吸波校正。

在造波電腦中預先產生需要的造波板位置，並在造波期間定期發送到嵌入式控制器。然後將時間序列透過嵌入式控制器進行線性內插至 1ms 的時間長度，並傳遞給驅動控制器。使用前述的目標位置和介於嵌入式控制器與驅動器之間的閉迴路控制，而產生實際的造波板位置。

嵌入式控制器還可以執行造波板歸零定位並監視連接到造波板前的波高計。該波高計提供水面高程，可用於監測造波板性能和主動吸波功能。

<u>**安全機制：**</u>

每個造波機系統配有 HR Wallingford 的標準安全系統，包括安裝在 MDCP 頂部的警示燈和聲音警報器。在詳細列出警示燈和聲音警報器通用功能表。

HR Wallingford 造波機的標準安全功能表

狀態描述	啟動燈號/蜂鳴器
在 HR Merlin 軟體中啟動電源 –顯示“Standby”待命狀態	橙色燈號點亮
零點歸位	橙色燈號閃爍

–顯示“Homing” 歸位中	同時蜂鳴器響起 10 秒
準備接收命令	綠色燈號點亮
開始造波 –顯示“Start”開始	綠色燈號點亮 同時蜂鳴器響起 5 秒
停止 –顯示“Parking”停止中	藍色燈號閃爍 同時蜂鳴器響起 5 秒
錯誤或異常狀態	紅色燈號點亮

緊急停止按鈕安裝在模組機箱上，同時也安裝在控制室內與使用介面電腦附近的遠端安全裝置上。

HR Wallingford 造波系統包括軟體和控制系統中的許多其他安全和緊急功能。造波軟體包括以下安全功能：

- 它可以自動避免使用者產生超過造波機衝程限制的波形，並即時提供造波板回饋狀態。
- 當進入系統操作時以密碼保護，以避免操作人員誤設參數。
- 避免使用者在全部關閉造波視窗或軟體之後，造波機的主動吸波功能仍能使用。
- 提供軟體互鎖功能，所以只有在安全的情況下，才能下達命令給造波機。例如：系統在送電後不能立即操作，直到歸零定位後才允許。另外只有在系統被校正和歸零完成後，才能開啟吸波功能。
- 如果發生通訊錯誤或緊急停止時，在命令發送到造波機前必須先在軟體中清除錯誤，否則即使原來的故障先由硬體清除也無法作動。這可預防系統以不受控制的方式啟動，例如：在控制箱上的緊急停止按鈕按下後又被解除。
- 在軟體中設定造波的持續時間時，避免波浪自動上升和下降，即使波浪比預計時間更早停止。
- 於室溫 40 度，水溫 28 度，最大波浪可以連續操作 6 小時以上。
- 於室溫 40 度，水溫 28 度，一般波浪可以連續操作 12 小時以上。

控制系統和硬體還包括許多安全功能：

- 提供視覺和聲覺警告，以顯示造波機的狀態（表 2.1），特別是當造波板即將移動時。
- 包括使用標準乙太網路連接電纜線的 SIL 3 安全電路，以便將緊急停止裝置輕鬆地放置在所有控制櫃和控制室等關鍵區域。
  註：SIL 為安全完整性等級，3 代表要求失效機率介於 0.001-0.0001 之間。
- 極限感測器由控制器即時監控，控制器在系統機械極限接近的情況下將切斷馬達的電源。
- 如果在造波過程中，超過造波板的供電需求，則馬達自動斷電。
- 對每個驅動器的三相電源進行監控，並且在出現相位錯誤或電壓異常的情況下，將馬達斷電。整個系統設有漏電斷路器裝置，以免人員遭受電擊。
- 在通訊錯誤的情況下，例如系統中的任何位置的電纜線路破損，所有系統都是安全隔離的。

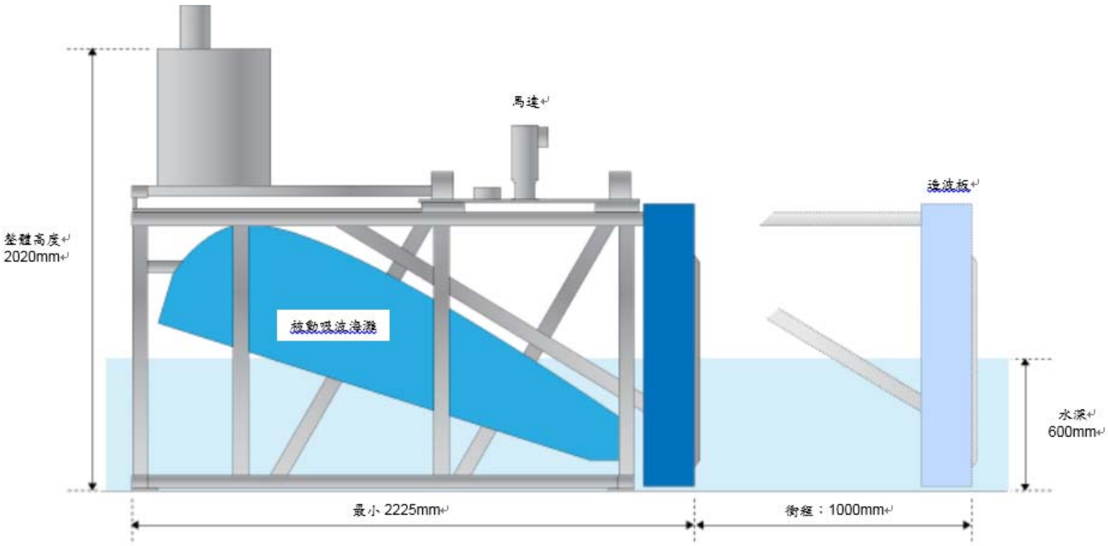
外觀尺寸：

提供計畫造波機的側視示意圖，其中包含造波板、促動器、馬達和附屬機構。

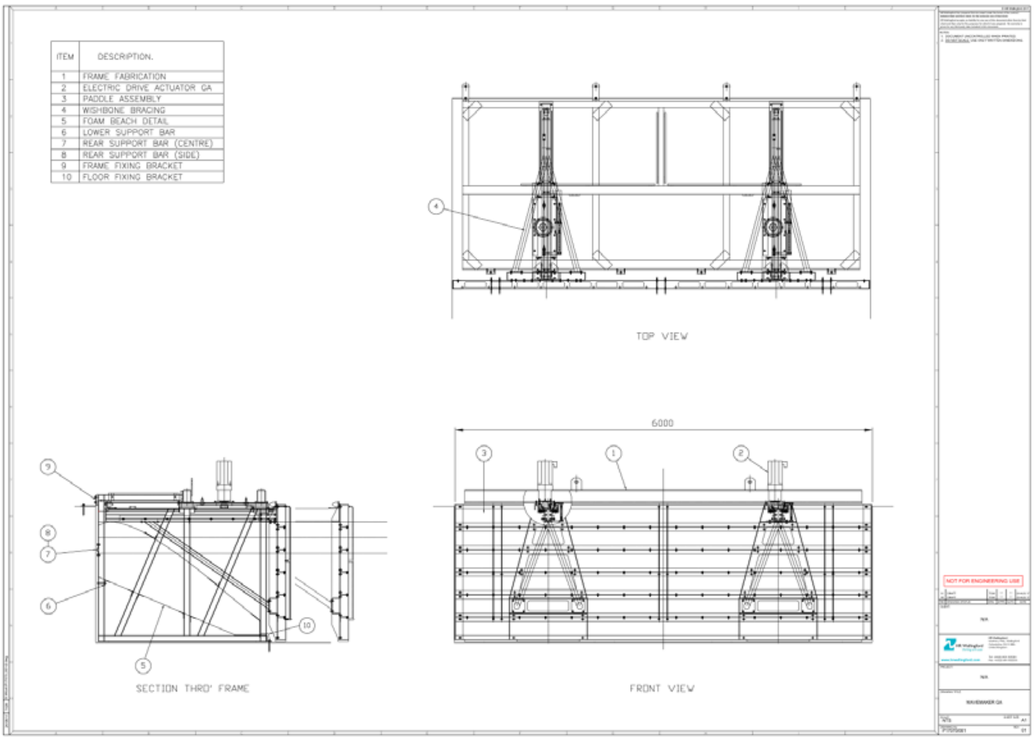
平面造波機的主要尺寸和電源需求計畫表

項目	規格
造波板寬度	6 m
造波模組數量	4個
整體造波板寬度(6mx4個=24m)	24 m
單一模組寬度	6 m
每個造波板的促動器數量	2
Paddle stroke	1.0 m
最大造波板速度	0.5 m/s
最大造波板施力	9.0 kN
每個造波板的標準造波功率 (rms)	5.2 kW

最大額定電源容量	AC3×220V,60Hz,400A
總系統馬達功率（rms）	20.8 kW
每個造波模組重量	1.5 噸



平面造波機的側視示意圖

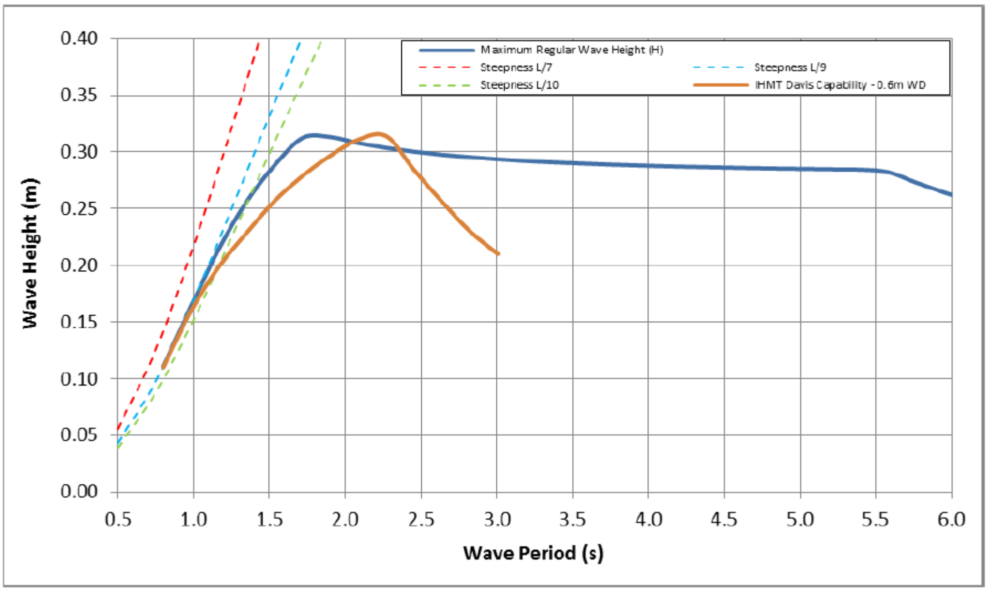


平面造波機的三視圖

註：圖上所標示的最後尺寸將根據規格需求製作。

預期性能：

建議平面造波機的預期造波性能曲線顯示。曲線所提供的條件是當平均水深為 0.6m、在 0.8～5 秒的週期（對當於 0.2Hz～1.25Hz 的頻率）等造波板能產生之規則和不規則波。應該注意的是，如果水位對應固定深度有變化時，則可能會降低造波機的性能。



造波性能預測（陡度 H / L = 9，深度 H / D = 0.5）圖

規則波

規則波時，圖中的藍色實曲線顯示了使用最有效的伺服馬達和驅動器組合，在平坦水池上最大可實現的波高。 由圖上得知，採用計畫提出的馬達和驅動組合在水深 0.6m 時，當介於 1.6～1.8 秒的週期之間，可以產生的預測波高 Hmax 是 0.3m。規則波的時間序列波高大小是一致的，因此理論上規則波的有義波高與最大波高相等，將可大於要求 20cm 以上(H1/3≧20cm)。

值得注意的是，由於波形陡度（H / L 比例的限制），上圖曲線（到達 1.6s）中最大規則波高曲線的左側是受限制的。在這部分性能範圍（較短的較高頻率波）中，將不可能超過在各個週期顯示的極限波高。HR Wallingford 用於淺水應用的標準是 H <L / 9。

對於 0.6m 的水深和週期介於 1.6～1.8 秒之間的情況下，由於水深造成的波浪破碎是有限制的（限制 H / D 比為 0.5）。請注意週期 1.8 秒以後，造波機將受促動器的能力而限制。而若選擇電機式促動器時，將沒有行程限制。

此外還應注意，所顯示曲線圖上的最短週期波，將引起在造波機附近顯著的消逝模式。這些不可避免的非傳播模式，可能導致局部波浪破碎並影響規則波列的穩定性。若時間短於 0.67s 的波浪將受到最大的影響。

最後應該注意的是，造波機可以在 0.6m 以上的水深中產生波浪，然而產生的波浪可能大於水池的總深度，將隨波峰沿著水池的傳播而導致溢出。除此之外，存在放置在水池內的設備或儀器可能產生被波浪所淹沒的風險。此外，如果造波機長時間在較深的水中運轉，波浪能量會由於水池內的反射而逐漸增加。這也可能導致水池溢出。

<u>**不規則波**</u>

對於不規則波，圖中的綠色曲線表示水池上相應的最大有義波高。以建議的馬達和驅動組合可以產生的最大有義波高（Hs），在週期 1.6～1.8 秒之間是 0.16m 波高。不規則波配合波譜設定 T1/3=0.8～2.0sec 之間(TP≧2.5sec)，有義波高可大於 12cm 以上(H1/3≧12cm)。

關於不規則隨機波，從最可能的最大波高（H）計算最大有義波高（Hs），如下所示：

$$\frac{1}{2}\eta^2 = \ln N + \gamma$$

$$\eta = \frac{a}{\sigma}$$

$$a^2 = 2\sigma^2(\ln N + \gamma)$$

$$H^2 = 8\sigma^2(\ln N + \gamma)$$

H is average max in the duration N.Tz

$$\mathrm{H} = \frac{H_s}{\sqrt{2}}(\ln N + \gamma)^{0.5}$$

$$\mathrm{H} = H_s(\frac{\ln N + \gamma}{2})^{0.5}$$

其中：

a= Wave amplitude

σ= Standard deviation

N= Number of zero downcrossings

H = Average maximum wave height

Hs = Significant wave height

N = Number of waves

γ = Euler’s constant 0.5772

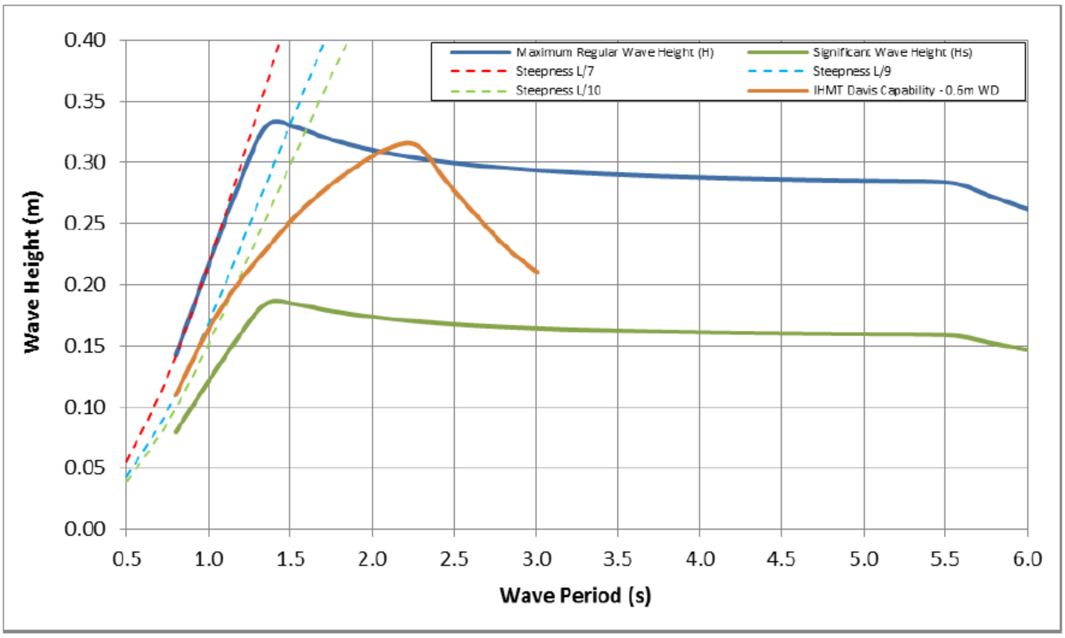
Thus for a test of N = 500 waves

$$H_s = 0.54\,H$$

該因子可以應用於提到所有標準不規則波譜，以預測設定波高和周期時的有義波高。

波高性能的延伸討論

儘管 HR Wallingford 通常採用前面波高性能，更保守的波高陡度(H <L / 9）和水深（H / D = 0.5）限制，但是也可能有些範圍會超過這些限制。這些性能限制的上限範圍被認為是當 H / L / 7 的陡度限制和 H / D = 0.6 的深度受到限制。 透過將這些替代的性能限制並應用於造波機，可以預期性能將會提高到如圖所示。



延伸造波性能預測（陡度 H / L = 7，深度 H / D = 0.6）

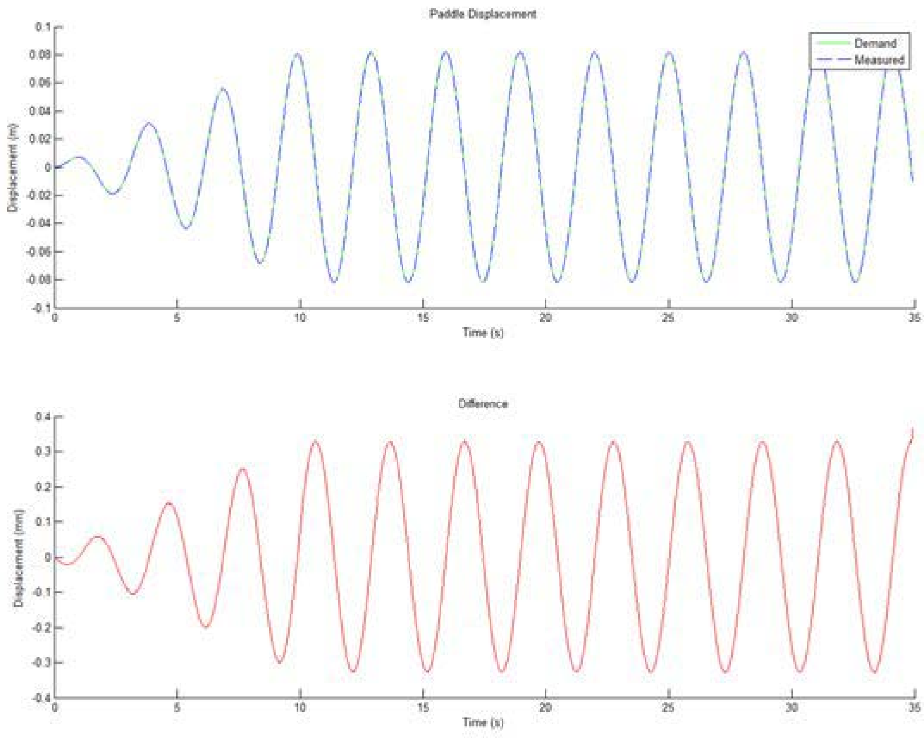
從圖表可以看出，所建議的造波機可以產　生的修正最大波高可以在 1.47 秒達到 0.34m 的最大規則波高。相同週期的等效不規則波形性能為 0.19m 的有義波高（Hs）。 不規則波配合波譜設定 T1/3=0.8～2.0sec 之間(TP≧2.5sec)，有義波高可以符合規範要求大於 12cm 以上(H1/3≧12cm)。

造波板移動精度

所開發造波機控制系統，使用小於 0.001mm 的解析度的編碼器，通常為 1mm 以下的誤差，以高精度重現指定的波浪時間歷史。顯示了波浪位移為±8cm 的規則波獲得的精度範例。顯示差異訊號，單位為 mm，誤差為±0.33mm。

造波板運動的精度對於在一定範圍的水深內產生高品質的波浪尤其重要。它允許使用理論上推導的造波板轉換函數（paddle transfer function, PTF)，使其容易地針對一定範圍的水深進行計算。這反過來又確保造波板運動，因此造波機將獲得正確的波高。

請注意，漸進式和逐漸消逝的 PTF 都被利用，可以準確預測造波板表面的總自由面。可以實現的典型精度是目標有義波高的 1%至 2%，這個精度不須在平面水池中進行校正就可實現。在具有測深或淺深度的模型中可以實現類似的準確度。然而，前述情況可能需要校準，以便考慮由於作用在波浪傳播上的物理過程而導致的任何傳播和相互影響所造成的損失。



造波板準確度範例

圖中，上圖涵蓋需求（藍色）和測量（綠色）造波板位移的時間序列。下圖 2 個移位時間序列之間的差異。請注意，下圖的垂直軸為 mm。

在平面的水池中量測並使用單位增益的範例波譜如圖所示。圖上同時顯示目標值。

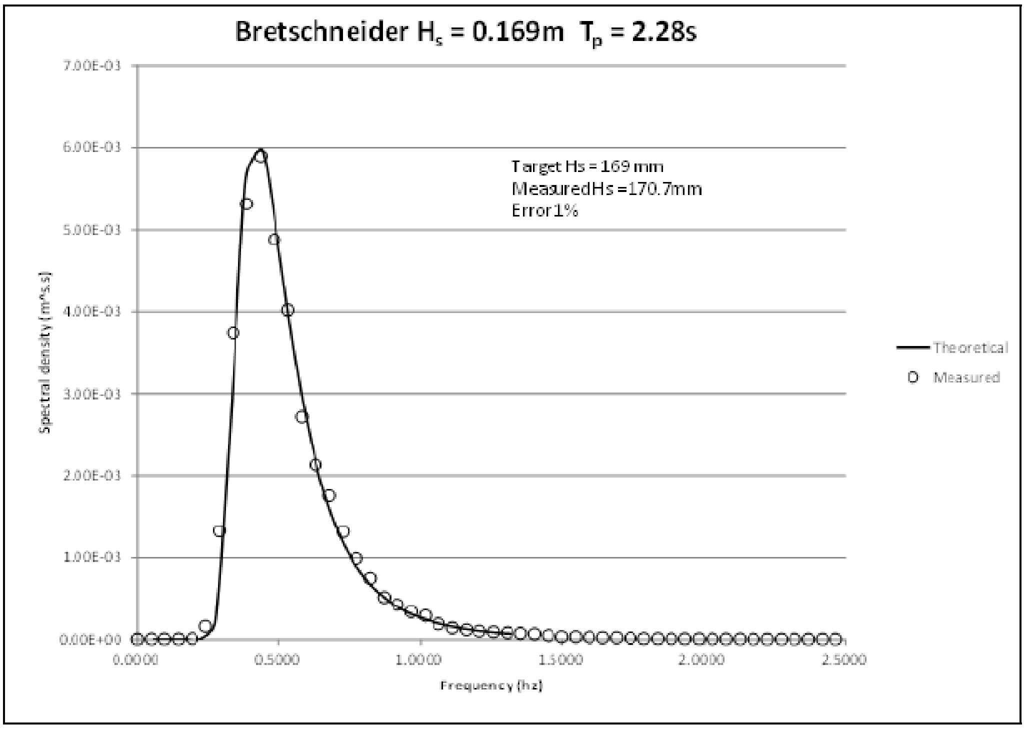


圖 2.15 Bretschneider 波譜範例

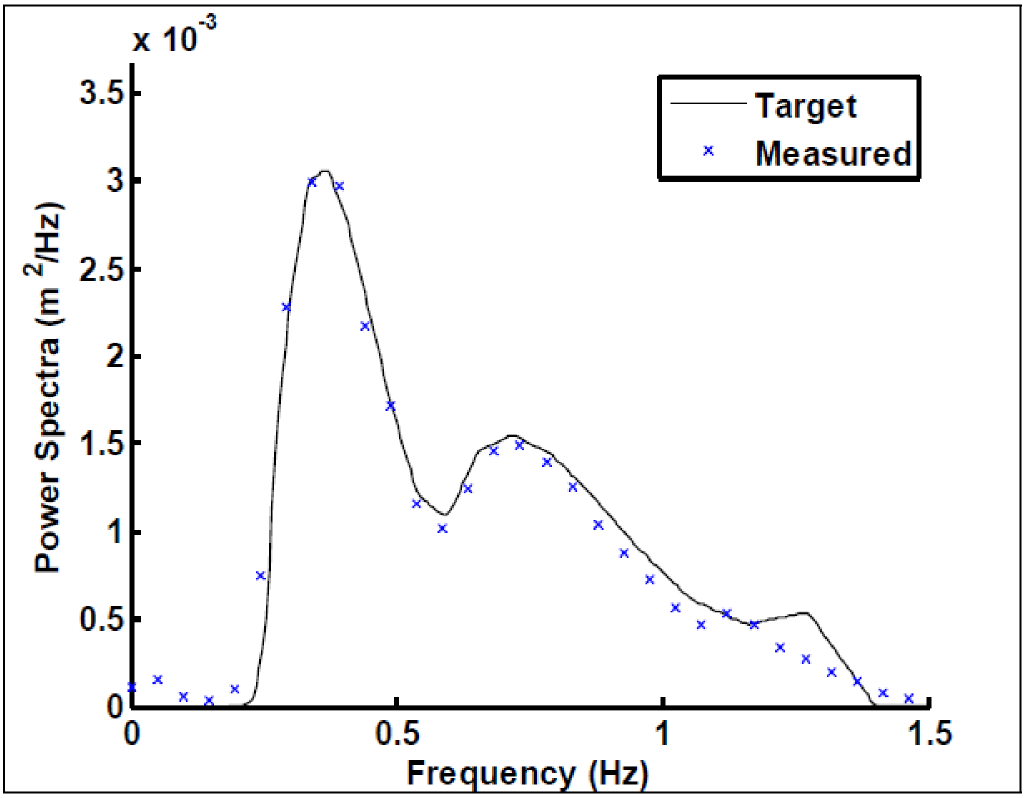


圖 2.16 bi-modal 雙模波譜範例

系統設計壽命：

平面造波機的電機促動器廣泛用於工業應用中，其通常可連續工作，有時每天超過 8 小時。相比之下，造波機往往每天只能使用幾個小時，而且在建立模型時經常會需要很長的時間。在許多工業應用中，組件在 1 個月內比在造波機使用 1 年內運作更多的時間。

水工模型研究通常使用隨機波，並且由於組件的大小適合於規則波的峰值需求，所以它們的磨損和損耗要遠遠低於工業應用。基於上述原因，預計 HR Wallingford 造波機的使用壽命超過 20 年。在 Wallingford 的水工模型研究中使用這系統的經驗也證明了這一點，1998 年首次引入了第 1 台直流供電的多單元淺水系統到這種機械設計，目前為止，21 個淺水多單元 Wallingford 的造波機使用時間超過 46,000 小時，只需要少量維護。

在目前的多單元淺水造波機中使用的電氣/電子控制系統同樣堅固，與深水造波機相同。在最近對疲勞載荷的評估中，一組造波機的運行時間（每天 24 小時）相當於 500 萬次循環（代表造波機的典型設計壽命）。造波機和控制系統沒有問題，目前正在繼續用於商業研究，從而證實了整個造波系統的穩健性。

操作軟體：

造波控制電腦附造波軟體(HR Wavemaker wave generation software)。通訊與訊號線組長為 150 公尺。HR Wallingford 的造波系統提供 HR Merlin 造波軟體，能夠產生造波機所有常用的規則和不規則波波譜。

只有搭配 HR Wallingford 馬達促動器運作時才能控制造波機的軟體功能。若與 DAVIS 液壓促動器造波機配合使用時， HR Merlin 可在 Windows XP、7、8 或 10 作業系統下操作，並提供安全加密鎖(security dongle)和全部的文件。HR Merlin 軟體透過 Windows 圖形使用介面進行控制。

以下是 HR Merlin 各種造波技術的簡介：

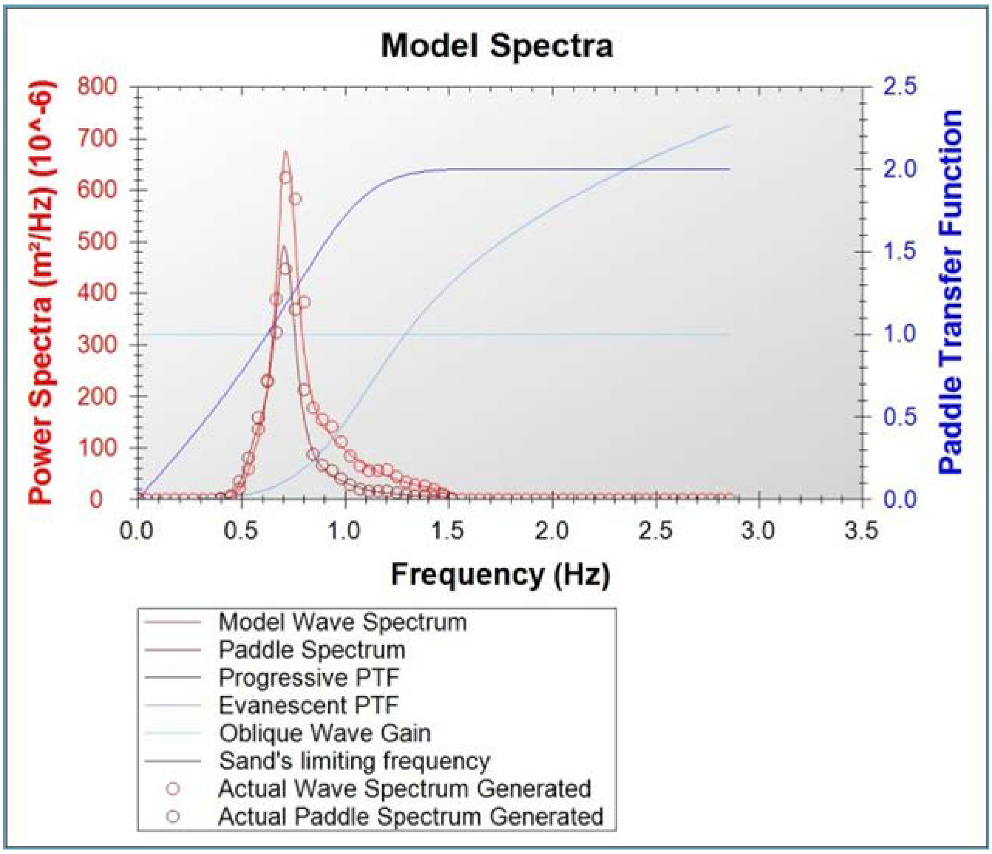
- 規則（單頻）波 - 支援多個同步模組，每個模組可具有不同的振幅、頻率和相位。
- 不規則 2D 長波峰波採用白雜訊法進行濾波。
- 雙模(Bi-model)規則波和不規則 2D 長波峰波使用正弦波法求和。
- 軟體內建大量的波譜形式，如 JONSWAP、Pierson-Moskowitz、TMA，Bretschneider and ISSC、TMA、Ochi double peak、SIWEH 波群模擬等。

- 可根據業主需要增加其他常用波譜。
- 使用者自定義的波譜，可離線建立並儲存在檔案中作為波譜坐標。
- 可產生特殊波浪，如瞬態、斷裂或聚焦波群。可產生孤立波。
- 外部生成的造波板位置時間序列以 ASCII 檔格式輸入。
- 造波機的主動吸波功能。提供超級和次諧波分量的二階轉換函數。
- 時變濾波器逐漸引入不同頻率的波分量，透過最大限度減少試驗水池長周期反射波的污染，使可用的時間最大化。
- 時間列之位相具隨機性，且可無限延長造波序列時間。

以下提供 HR Merlin 軟體中所使用波形生成技術的詳細描述。

波浪頻譜和造波板轉換函數

為了使所需的波浪頻譜生成正確的造波板運動，HR Merlin 創造了原型和模型波浪頻譜以及相關的造波板轉換函數。造波板轉換函數(PTF)是波高與造波板衝程的比值，隨頻率和水深而變化。理論值是自動新增的，但如果需要，使用者可以選擇新增自定義的轉換函數。



由 HR Merlin 生成的典型波譜和傳遞函數圖

HR Merlin 基於預測造波板運動涵蓋要量測的波浪頻譜，而產生波浪頻譜和轉換函數。

在每次測試之前，目標和預測波浪頻譜以及造波板運動的順序可以用圖形方式進行回顧。系統還檢查是否達到造波板衝程極限。

規則波

可以在指定的時間週期、振幅、相位和方向從造波板面產生規則諧波。造波板轉換函數（PTF）用於將所選擇波的特性轉換為適當的造波板運動。可以使用自定義的或內建的理論 PTF。支援線性和二階（Schaffer 1996）造波。

透過 HR Wallingford 的造波機，可以在所需波浪週期的波譜範圍內產生寬範圍的波高。顯示了規則波正常傳遞下可實現的最大波高。

如前所述，波浪尖銳度和波浪破裂是相關的物理特性，決定了造波機能產生的最大波高。

不規則波

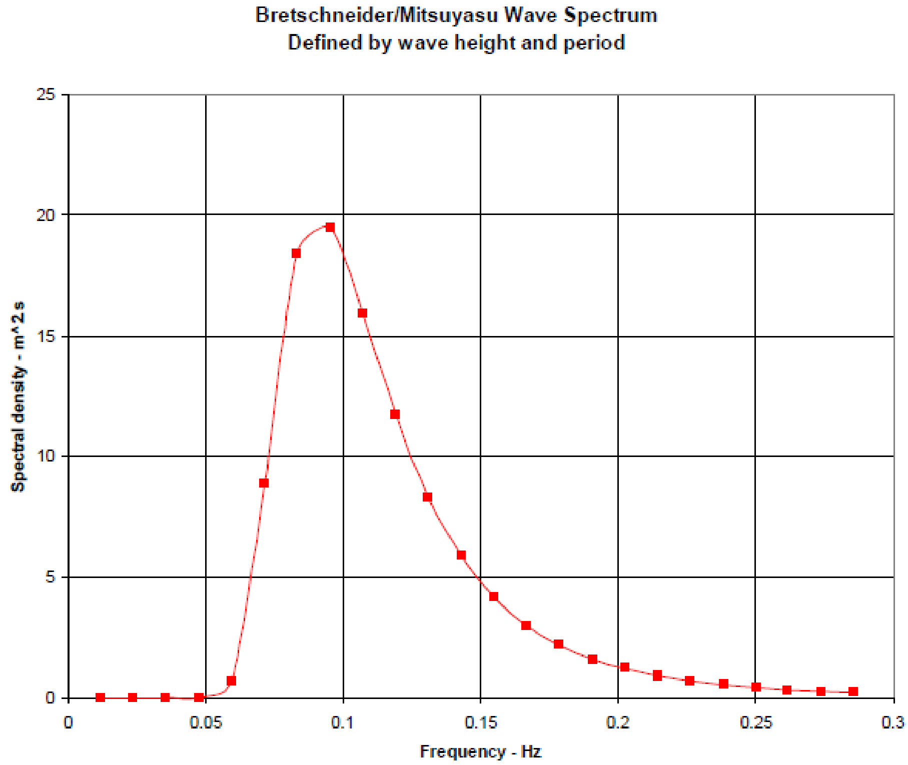
不規則 2D 長波峰波使用白雜訊濾波法來產生。這種訊號產生方法在垂直於造波板的方向產生隨機波。它是基於數位濾波白雜訊的原理即時生成。白雜訊來源產生並透過數位濾波器，產生每個造波板要求位置的需求訊號。透過基於所選擇的波浪頻譜形狀執行快速傅立葉轉換（FFT）來獲得該濾波器的特性。使用這種方法的優點是：

- 創造不間斷的時間序列，可以在幾秒到幾個小時之間變化。當測試模型具有非線性回應的時候，產生長且非重複的時間序列能力非常重要。
- 使用白雜訊法，可以每次產生完全相同的隨機序列；這是對比較測試至關重要的特徵。
- 能產生連續性的能量波譜。這表示模型的反應可以更準確地分析，而且對於其他方法所產生的離散頻率之間被高度調諧的諧振頻率下降並沒有危險。
- 由於能譜中沒有不連續性，波群會與本質上完全相同的方式自動進行。

HR Wallingford 進行了大量測試，證明該系統產生的波是實際的，並符合海浪的統計學理論。

需要輸入的資料有：

- 模型比例
- 測試時間
- 波譜形狀
- 轉換方程式



由 HR Merlin 生成的典型波譜圖

註：注意上圖使用的實際波譜座標為 256 以上點數

HR Merlin 目前包含一系列波譜類型，包括：

- JONSWAP
- Pierson Moskowitz
- Bretschneider and ISSC
- TMA
- Ochi double peak
- SIWEH 波群模擬
- Derbyshire coastal

● Derbyshire ocean

● International towing tank congress (ITTC)

● Neumann

● BTTP

● Top hat (Pink Noise)

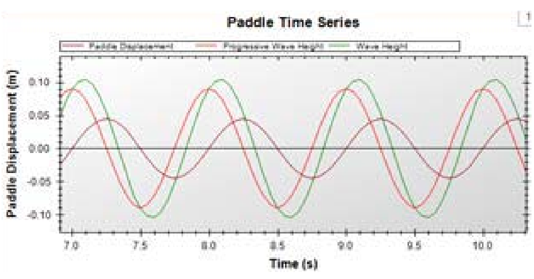
● 使用者自設波譜(user-defined spectrum)

如果上述波譜仍不足，則可依需求提供波譜詳細資料再行增加。

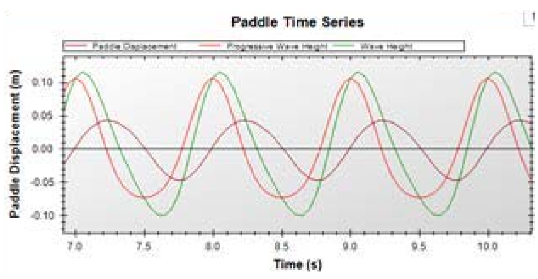
<u>二階波浪產生</u>

HR Merlin 引入了完整的二階波生成理論，該理論已被實施用於規則和不規則的長波峰波，包括補償二次諧波（差頻）和超諧波（和頻）二階分量。補償抑制使用線性造波板訊號時無意中產生自由傳遞的偽二次項。二階限波自然地存在於產生的波中，並且隨著自由二階項被抑制，所產生的波場對於二階正確。

採用二階校正是根據 Schaffer 1996 和 Schaffer 2003 中提出的理論版本。該理論考慮了二階與初級線性漸進波分量之間的相互作用，以及二階與漸逝波之間的相互作用。這使得方程式相當複雜且無限求和。然而，當漸逝波很大時這是非常重要的，例如當造波機剖面對波浪內的粒子運動學產生很差的擬合。在較深水中的較短波活塞造波系統可能也是這種情況，並將顯著影響週期小於 0.5s 的波浪的潛在產生。Schaffer 1993 的漸近求和法也被併入造波軟體之中，以減少二階造波轉換函數中無限求和項的計算時間。此外，當需要長訊號時，透過計算較粗頻率網格的二階轉遞函數，對其進行插值，進一步優化計算效率。例如，規則波的線性和二階造波的造波板運動和相關的自由表面(造波板上)的時間序列顯示。



規則波線性造波的範例圖



以二階造波修正規則波範例圖

<u>暫態波、碎波或聚焦波</u>

HR Merlin 造波軟體也可用於合成暫態波、聚焦波或碎波。這些分散

波群由多個單正弦波分量組成，它們在一個時間點和空間上相位相同。在任何時間和任何空間點，使用線性波理論的表面高程可以透過諧波分量的總和來描述：

$$\sum_n a_n \cos(k_n(x - x_f) - \omega_n(t - t_f) + \varphi)$$

其中 a_n, k_n 和 ω_n 分別表示振幅、波數和單分量的角波頻率，且 φ 代表波群在焦點中的相位。在上述的式子中，x_f 為焦點，也被稱為集中點，t_f 是分量對準的時間。當 x = x_f 且 t = t_f ，全部的波分量都在相位之中。

在實驗室中，可以透過在造波板上正確地抵消各個波分量來產生具有所需壓縮點和時間的波群，以解決其不同的傳播速度。對每個第 n 個分量施加 −kn xf + ϕ 個相位偏移 (假設 tf = 0s)。當聚焦時，各個分量之間會發生建構性干擾，並且波群會產生大的能量。由於頻率分散、遠離聚焦，波群不太緊湊、浪況較平穩。峰值聚焦波群 ϕ = 0，波峰在對焦點進入相位。波谷聚焦波群則是 ϕ = π，波谷在聚焦位置對齊。

瞬態波可以產生在 0 和 2π 之間的任何相位角。當然，也可以產生一個傾斜的聚焦波群，以一定的角度傳離造波器。此外，對造波板訊號的二階校正可以疊加在線性造波板運動上，以正確地重現波群下的二階設置。

暫態聚焦波可用於描述極端波浪事件，如 Jonathan and Taylor (1997) 和 Taylor and Williams (2004)所述。基本的統計理論在 Lindgren (1970)、Boccotti (1983)，與 Tromans et al (1991) 中提出更易讀的方法。

使用 HR Merlin 軟體，可以從標準波譜中分出暫態波群生成的造波板訊號。在單一波群中，實驗室從包含這些波的完整波譜訊息中實驗受益，並且與隨機波實驗相比，快速而便宜。此外，由於這些波群的暫態特性，實驗可以更容易地避免波浪反射的問題。

孤立波 Solitary waves

HR Merlin 也可用於生成孤立波。理論上，孤立波是無限長的波，無形變化地傳播。這是淺水波的現象。孤立波的形狀包括一個對稱的正高程，平滑地趨向於靜止水位。利用 Goring 的非線性生成算法（參考 Goring（1978）），其中造波板速度與正在產生的孤立波的局部深度平均粒子速度相配。

雙峰波 Bi-modal waves

HR Merlin 也可以生成雙波形波譜。這可以透過組合兩個預設的波譜或自定義的雙峰值波譜來實現。

離線建立海洋狀態

HR Merlin 內建的外部海洋模組，允許輸入時間序列的造波板運動或水面高程。 要輸入的時間序列是一個純 ASCII 檔案，其中包括：

- 造波板數量
- 水深
- 實驗長度
- 造波板位置/水面高程時間序列

淺水校正

HR Merlin 軟體為預設和自定義的波譜坐標提供淺水校正。如果任何波譜分量的波長超過水深 2.5 倍，則應使用淺水波校正的選項。每個波譜縱坐標的頻率都應滿足對於相同的深水波長和淺水和深水能量之間比例的頻率校正。

時變濾波器

對於操船試驗拖曳箱(towing tanks)中的應用，HR Merlin 還包含時變高通濾波器，以最大化測試持續時間。由於長度限制，拖曳箱(towing tanks)在遠端（遠離造波機）可能具有有限的波能量耗散，這表示很大部分的波能可能在較低頻率時反射。為了最大限度來自海灘的示性反射(significant reflection)到達之前的時間，並使拖曳測試(towing test)的長度最大化，使用時變高通濾波器加入延遲更快移動的長周期波，使得船隻僅遇到完整的波譜而不是反射波的分量。

由造波板上的波高計校正

在造波板正面上的波高計校正是自動化的，只需要造波水池內的水面靜止，通常需要 30～40 秒才能完成造波系統中的所有波高計校正。驅動波高計的電路設計成提供輸出電壓和水高度之間的線性關係。水的傳導性是隨著溫度和水的傳導性而變化，在模型測試之前，模型操作員可以選擇校正控制軟體中的波高計。波高計底座的高度是已知的，當乾燥時波高計的輸出設置為 -10V。在操作期間，使用者輸入水的高度，並且系統接通波高計以在輸入的水的高度達到零輸出。軟體根據 2 點訊息計算梯度校正。

HR Wallingford 的造波機波高計系統在全球範圍內已廣泛應用，溫度極限可在-10˚C 至> 40˚C 的範圍內使用。沒有遇到溫度波動的問題。

<u>HR Merlin 軟體的執行壽命和升級政策</u>

HR Wallingford 造波系統的 HR Merlin 軟體設計用於在標準 Windows 電腦上執行，也就是不需要專門的硬體只需要簡單的網路連接。軟體生命週期與 HR Wallingford 控制系統硬體相同，一起更新將確保可以滿足軟體的設計壽命和使用要求。該軟體還包括透過網路的遠端支援功能。

控制系統的其他方面，如 PLC 控制器硬體來自工業元件，這些元件是專為連續服務而設計的，並保證至少 10 年的類似品更換和 20 年的同等品更換。

此外，控制系統使用開放來源和現代工業乙太網路控制匯流排作為通用控制匯流排，這將允許整合各式各樣的替換零件，例如使用新型的 PLC 控制器或驅動控制器，而不會影響整體系統的性能。

<u>與既有 WR Davis 油壓造波系統整合：</u>

HR Wallingford 造波控制系統能夠接受來自另一個造波系統的類比輸入訊號，這將允許系統跟隨 DAVIS 造波板位置時間序列。由於 HR Wallingford 系統使用的雙促動器的回饋響應要比 DAVIS 油壓系統快得多，因此要合併兩個不同系統若只依靠初始訊號源方法將是不切實際的。

然而，如果 DAVIS 系統具位置回饋迴路，則馬達促動器可以將其造波板位置與透過位置回饋量測的位置相匹配。

在詳查 WR Davis 系統的手冊後，所有四個現有的造波板都有位置回饋訊號。因此 HR Wallingford 計畫監控這些回饋訊號，並使用這些回饋訊號來為所有其他 HR Wallingford 馬達促動器造波機模組建立類比輸入訊號。

與港研中心既有 WR Davis 油壓系統造波機整合，其計畫架構如圖。為了使系統在整合情況下運行，必須遵循的多個設置步驟。這些設置包括如下：

1. HR Wallingford 造波機應如圖 2.25 所示連接。
2. 在電腦中 HR Merlin 造波軟體應開啟，並接受外部來源的類比輸入訊號。
3. 需要輸入以下訊息：

A. 回饋迴路中將使用的預期電壓範圍。

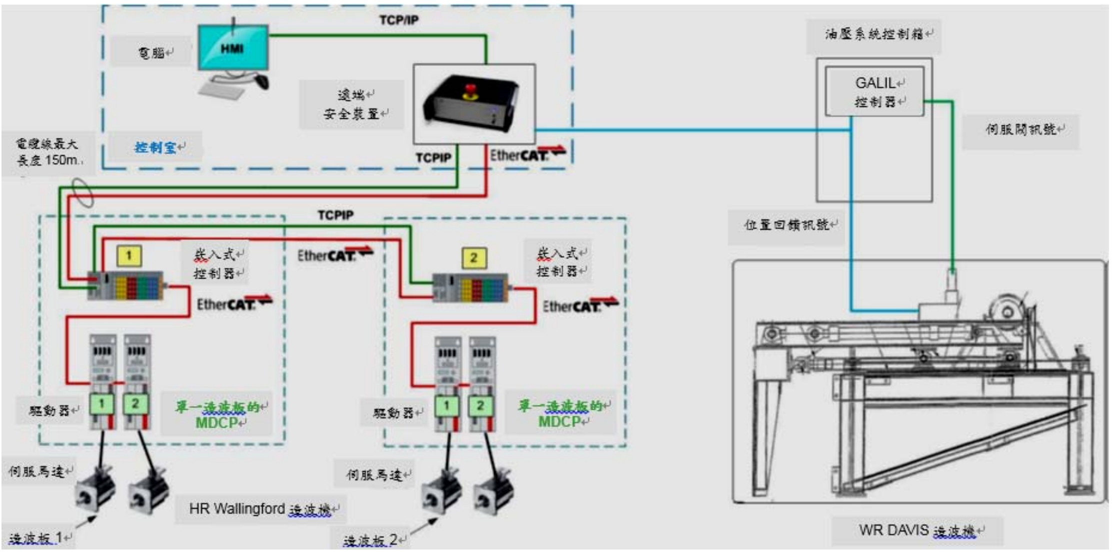
B. 還應輸入油壓造波機的全衝程長度。

4. HR Wallingford 造波機開啟電源，系統必須按照標準的歸位順序做歸零動作。

5. 接下來，油壓造波機應該準備好執行造波，但還不須按啟動按鈕。

6. 在啟動油壓造波板之前，需要點擊 HR Merlin 造波軟體中的開始按鈕，這樣可以讓 Wallingford 電控式造波板按照 DAVIS 油壓回饋訊號提供的位置訊號作動。

7. 最後透過啟動液壓造波系統開始造波過程。



與 Davis 造波機整合時的控制系統架構圖

<u>**原廠技術支援：**</u>

在 HR Wallingford 的造波系統內提供 TeamViewer 軟體，允許遠端登入和操作造波機（如果客戶端啟用）。因此 HR Wallingford 能夠利用這種線上遠端支援功能來診斷和支援大多數觀察到的問題並修復。請注意，如果要求原廠從英國遠端操作造波機，客戶端的造波機現場必須有工作人員才能提供此服務，以確保符合健康和安全要求。線上支援服務可以取代以往透過電話或電子郵件的支援方式，提供技術和操作上的即時支援服務。

線上和電話支援通常可以在問題出現的 24 小時內提供協助。以電子郵件發送通常可以在發生問題的 48 小時內提供協助。如果線上支援系統出現問題，則可以直接與 HR Wallingford 的服務部門聯繫。

Training Schedule

CQR5855, IHMT, Long Crested Wavemaker

All Star Technology Corporation

Summary

Details of the training schedule proposed for two delegates from the Institute of Harbor and Marine Technology (IHMT), HR Wallingford project reference CQR5855, are contained within this document.

1. Day 1 – Wednesday 13 December 2017

Topic	Location	Comments / Topic Content	Training Group	Time
Welcome, introduction & site tour	**Cedar**	**Meet at Kestrel House, then tour of the physical modelling facilities and Ship Simulator.**	**CQ**	**09:00 – 10:30**
Review of HR Wallingford wave generation systems (Classroom & Lab based)	Cedar	Review of operating control systems, power requirements systems, includes a visit to the small model area for inspection of wave generation system components.	CQ	10:30 – 12:00
Lunch	**Manor House**	**Walkthrough lunch with table laid up.**		**12:00 – 13:00**
Waves and Wave theory (Classroom based)	Ash	Wave components, wave types, wave energy,	CS	13:00 – 17:00
Proposed break				**14:30 – 14:45**

2. Day 2 – Thursday 14 December 2017

Topic	Location	Comments / Topic Content	Trainin g Group	Time
Model scaling theory (Classroom based)	Ash	Froude scaling laws, restrictions in model scaling. Set the model design & testing objectives.	CS	09:00 – 12:00
Proposed break				10:30 – 10:45
Lunch	Manor House	Walkthrough lunch with table laid up.		12:00 – 13:00

Topic	Location	Comments / Topic Content	Trainin g Group	Time
Setting up and running test conditions **Model construction (Lab based)**	**Basin D**	**Basin/Flume for demonstrating the process to start up, run test conditions and also shut down the wave generation system. To cover –** • **Safety briefing** • **Setup of sea conditions:** • **Wave generation and analysis** • **Active wave absorption – paddle wave probe calibration** • **HR Merlin post generation reports and output files** • **Data export** • **Trouble shooting** • **Remote support (TeamViewer)**	**CQ**	**13:00 – 17:00**
Break				**14:30 – 14:45**

3. Day 3 – Friday 15th December 2017

Topic	Location	Comments / Topic Content	Training Group	Time
Instrumentation, calibrations and data acquisition systems (Classroom & Lab based)	K10 / Basin D	Set up and position instrumentation ahead of the tests. Conduct calibrations of the instruments and the model in the basin.	CS	09:00 – 12:00
Proposed break				10:30 – 10:45
Lunch	Manor House	Walkthrough lunch with table laid up.		12:00 – 13:00
Model construction (Lab based)	Basin D	Complete the construction of a partially built model.	CS	13:00 – 17:00
Proposed break				14:30 – 14:45

4. Saturday 16th and Sunday 17th December 2017

Please note that HR Wallingford offices will not be open during the weekend of the 16th and 17th December 2017.

- Each session can be extended wherever possible.
- If operational requirements dictate that facilities become unavailable for any reason, then HR Wallingford will endeavour to provide alternative test facilities to meet the training objective.
- All trainees must bring suitable clothing for use when working in a physical modelling environment which is often dusty or damp.
- Note all trainees must have sturdy foot ware that has protective steel toe-caps and a steel sole plate.

Document information

Document permissions	Confidential - client
Proposal title	Training Schedule
Proposal Sub title	CQR5855, IHMT, Long Crested Wavemaker
Proposal number	CQR5855
Release number	R01-03
Proposal date	20 November 2017
Client	All Star Technology Corporation

Document history

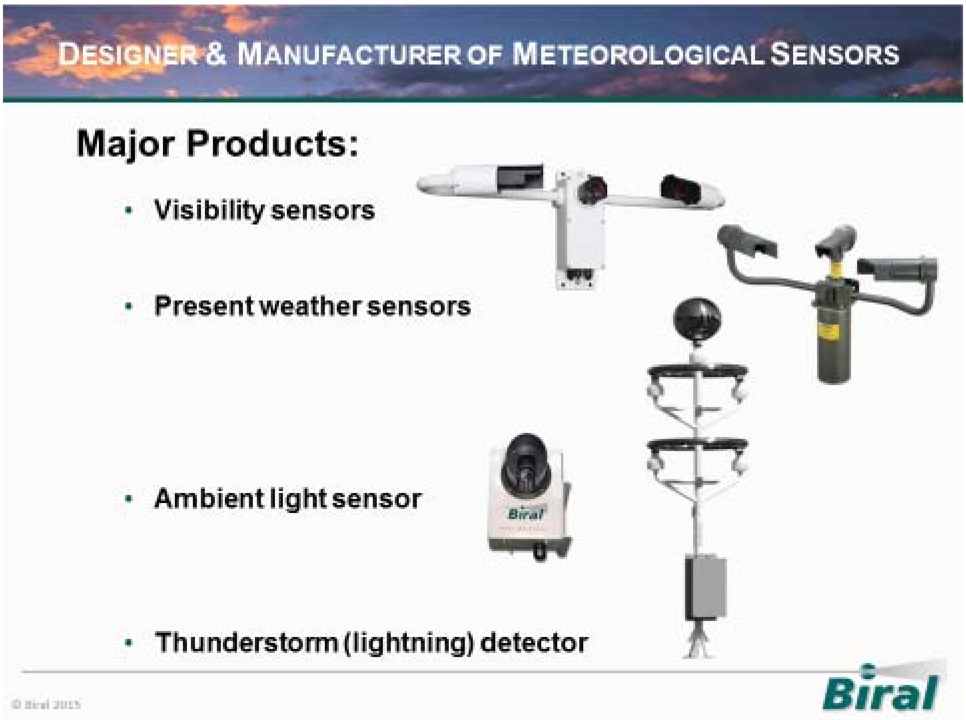
Date	Release	Prepared	Approved	Authorised	Notes
15 Dec 2017	01-03	GMC	GMC	GMC	Meeting added Monday 18 December. Training on Tuesday to close at 13:30.
12 Dec 2017	01-02	GMC	GMC	GMC	14th & 15th afternoon sessions swapped
05 Dec 2017	01-01	SAT	SAT	SAT	Training locations added. Start time changed for Day 3.
20 Nov 2017	01-00	SAT	SAT	SAT	Introduced

CQR5855

20 November 2017

附錄 B　技術交流簡報資料

(一)能見度儀及閃電落雷系統介紹：



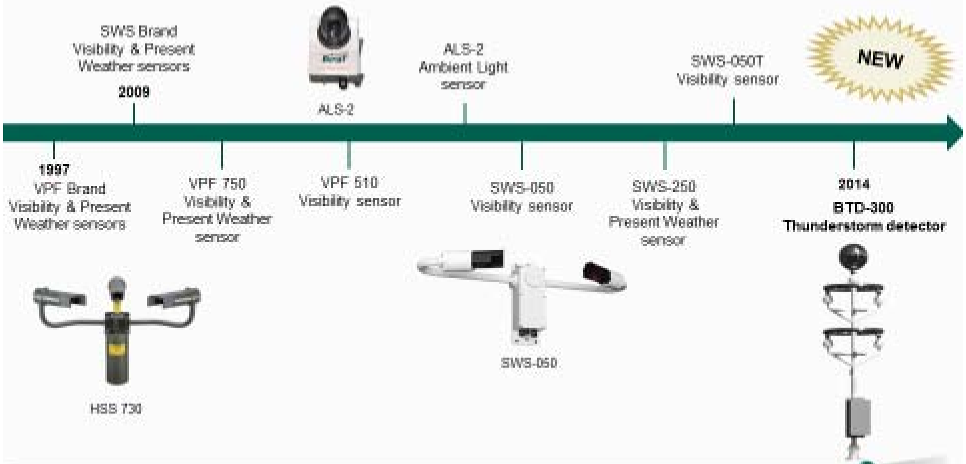
Corporate Vision

We focus on providing our customers with **technically advanced meteorological sensors** that fulfil their measurement and business needs. We design and manufacture industry leading quality products which satisfy the uncompromising needs of the markets we serve.

Mission

'Our aim is to remain an internationally respected supplier and manufacturer of scientific and industrial measuring instruments, with a reputation for commercial and technical expertise, ***FOCUSED ON THE NEEDS OF OUR CUSTOMERS****.'*

TECHNOLOGICAL MILESTONES
DEVELOPMENT OF METEOROLOGICAL PRODUCTS




OUR CAPABILITIES
Biral designs and manufactures:
• Visibility Sensors
• Visibility & Present Weather Sensors
• Ambient Light Sensor
• Thunderstorm Detector
• SERVICE, REPAIR and CALIBRATION
• Quality processes: ISO 9001:2008
• CE, WEEE & RoSH compliant
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Biral


MARKETS WE SERVE
Aviation
Marine
Renewable Energy
Roads, Rails & Tunnels
Offshore
General Meteorology
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EXAMPLES OF INSTALLATIONS

Wind turbine (Germany)

Kuala Lumpur Airport (Malaysia)

Road (France)

Bridge Bacalan (France)

Offshore Rig (UK)

SUMMARY

- Highly specialised meteorological sensor manufacturer
- Focused on quality, accuracy and longevity
- Flexible enough to produce customer specific sensors
- Competes well in the World market against international peers 10 or 20 times our size
- Interested in long-term working relationships rather than just tender to tender bids

Main Product Ranges

Nathan Neal B.Sc. (HONS)
Sales and Marketing Director

Forward Scatter Meters

All Biral visibility and Present Weather sensors are Forward Scatter Meters (FSM's)

We have the widest range of FSM's available from any vendor

Our FSM's are in two distinct ranges:

- The VPF Series…

- The SWS Series…

Which Sensor, which application?

VPF Sensors:

- Harsh operating conditions:
  - Marine platforms
  - Marine oil rigs
  - Marine wind farms
  - Ports and harbours
- High accuracy / high specification
  - Aviation systems
  - National weather monitoring
  - Remote, harsh locations

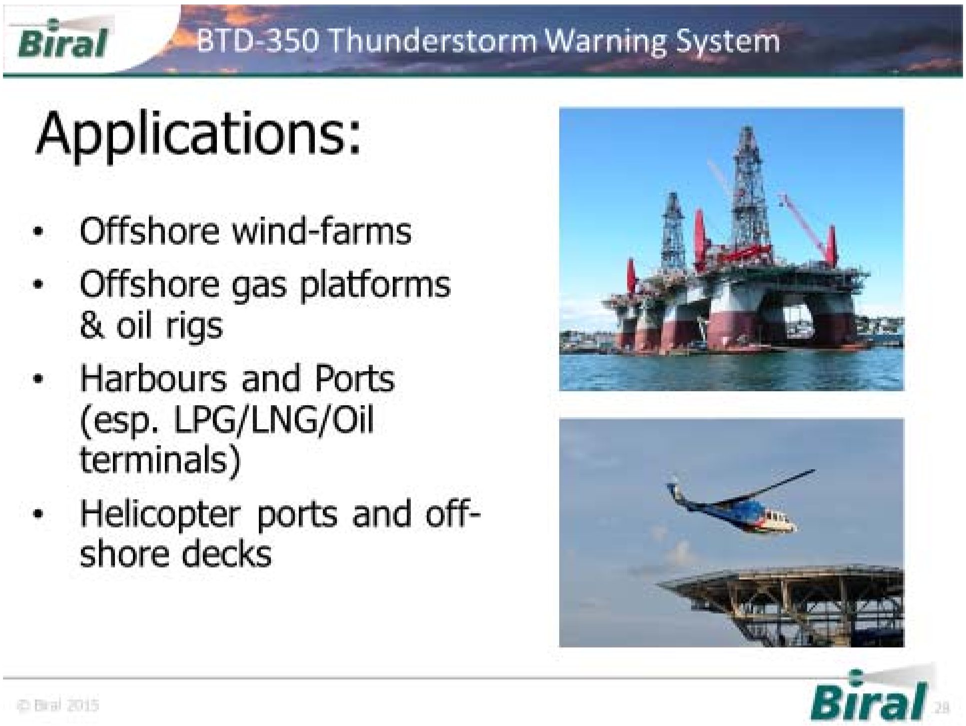
Which Sensor, which application?

SWS Sensors:

- Normal operating conditions:
  - Road weather monitoring
  - Land based wind turbines
  - Meteorological networks
  - Aviation systems

SWS has a price / performance ratio comparable to that of our competitors'


BTD-350 Marine Thunderstorm Warning System
Introducing the NEW
BTD-350 Thunderstorm Detector
Standalone lightning detector, especially for the marine environment
© Biral 2015
Biral


Biral
BTD-350 Thunderstorm Warning System
Applications:
• Offshore wind-farms
• Offshore gas platforms & oil rigs
• Harbours and Ports (esp. LPG/LNG/Oil terminals)
• Helicopter ports and off-shore decks
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Visibility & Present Weather Sensor

ADP Technical Training Presentation

Biral

Visibility Measurement

- What is visibility measurement?
  - How far can you see
  - Differences between day and night-time measurements
  - Human observers and sensors
- Methods of Measurement
  - Human Observer
  - Transmissometer
  - Back Scatter Meter
  - Forward Scatter Meter

Biral

Present Weather Measurement

- Present weather measurement
  - What is happening now!
  - What happened in the immediate past
  - Generally automated measurement

- Combined Visibility & PW Sensors limited to:
  - Visibility (Fog, Haze, Smoke, Dust)
  - Liquid precipitation (Drizzle & Rain)
  - Solid Precipitation (Snow, Hail, Ice pellets, Diamond dust,)
  - Precipitation amount

Biral

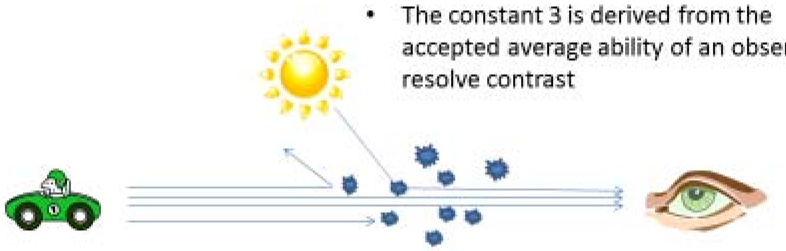
Visibility Measurement

- For a human observer during the day visibility is related to EXCO by Koschmieders Law

$$Visibility = \frac{3}{\beta}$$

  - Where $\beta = EXCO$

- The constant 3 is derived from the accepted average ability of an observer to resolve contrast



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Visibility Measurement

- For a human observer during the night visibility is related to EXCO by Allards law

$$E_T = \frac{Ie^{-\beta R}}{R^2}$$

E_T	= Illumination threshold	I	= Luminous Intensity of light
R	= Visual Range	β	= Extinction coefficient

- E_T relates to the ability of an average observer to observe a light source
- Equation has no direct solution for visual range

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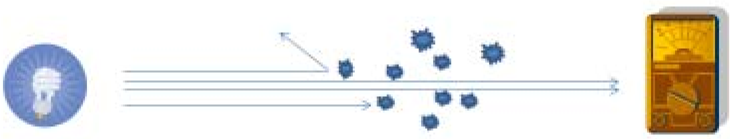
Visibility Measurement

- Meteorological Optical Range (MOR)

$$MOR = \frac{3}{\beta}$$ (Same as daytime visibility)

- Often used by instruments to report visibility
- The length of the path in the atmosphere required to reduce the luminous flux in a collimated beam from an incandescent lamp to 0.05 of its original value.
- Independent of human observer capabilities



About Design and Manufacture Weather Sensors Aerosol Analysers Bio-detectors Contacts

Calibration Checks

- Conditions
  - Visibility greater than 10Km
  - No precipitation
  - Sensor running for 30 minutes
  - Beware of local reflections – High viz jackets
  - Difficult to do indoors

- Refer to the individual sensor manual for details

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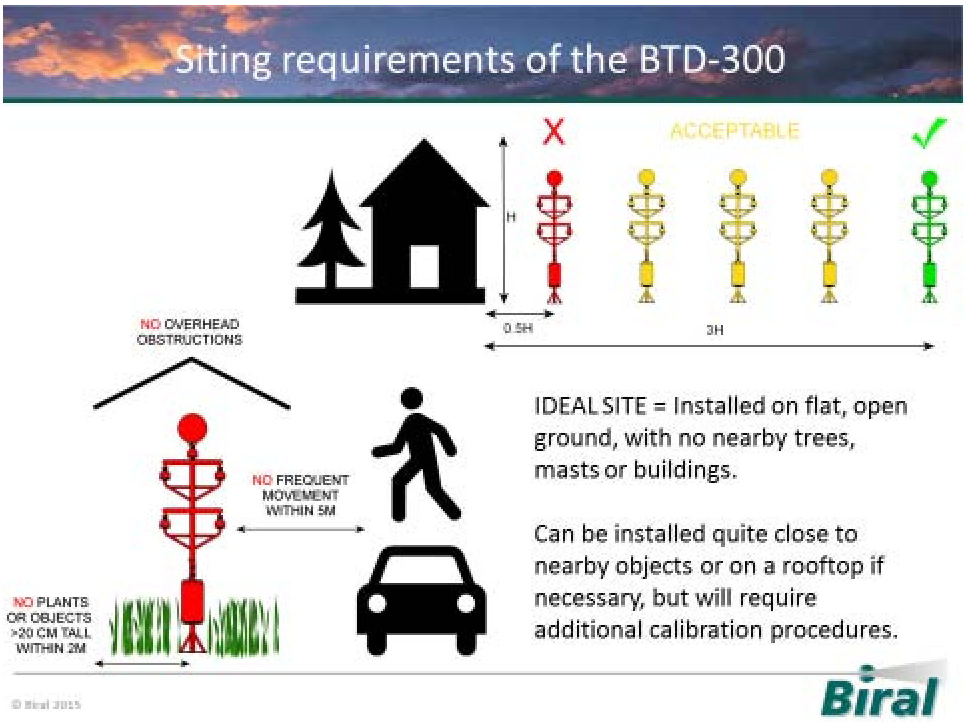
BTD-300 Thunderstorm Detector

Dr Alec Bennett
Meteorological Products Manager


Siting requirements of the BTD-300
X
ACCEPTABLE
H
0.5H
3H
NO OVERHEAD OBSTRUCTIONS
NO FREQUENT MOVEMENT WITHIN 5M
NO PLANTS OR OBJECTS >20 CM TALL WITHIN 2M
IDEAL SITE = Installed on flat, open ground, with no nearby trees, masts or buildings.
Can be installed quite close to nearby objects or on a rooftop if necessary, but will require additional calibration procedures.
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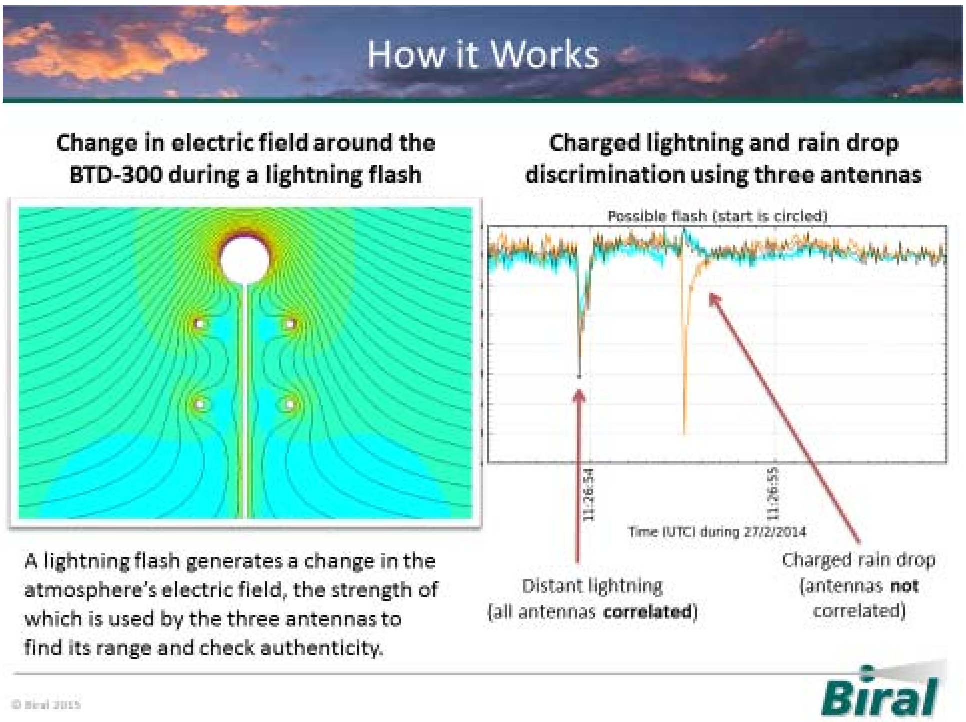
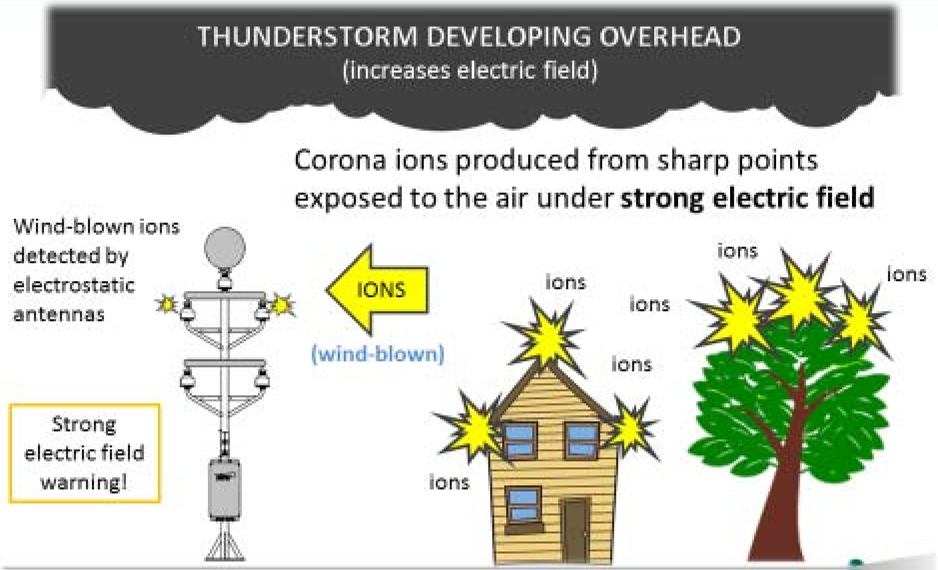

How it Works
Change in electric field around the BTD-300 during a lightning flash
Charged lightning and rain drop discrimination using three antennas
Possible flash (start is circled)
11:26:54
11:26:55
Time (UTC) during 27/2/2014
Distant lightning (all antennas correlated)
Charged rain drop (antennas not correlated)
A lightning flash generates a change in the atmosphere's electric field, the strength of which is used by the three antennas to find its range and check authenticity.
© Biral 2015
Biral

How it Works – Strong electric field (no precipitation)



Biral

Electrostatic vs. radio lightning detection

Biral's electrostatic technology has the advantage due to:

- Operation below all forms of radio transmission – no false alarms from radio interference!
- More accurate ranging due to inverse-cube relationship
- Detects and ranges all forms of lightning, producing exceptionally high flash detection efficiency
- Monitors overhead cloud electrification before the first lightning flash
- No day-night change in performance (not optical or ionospheric dependent)

Better than subscription to lightning location network:

- User owned – no on-going subscription costs
- No reliance on external providers and internet communication links (which may be unreliable during a severe thunderstorm)
- Real-time warnings – 2 second update period!
- Networks only provide lightning data, not strong electric field warnings
- Networks struggle to detect the weaker flashes from early-stage storms

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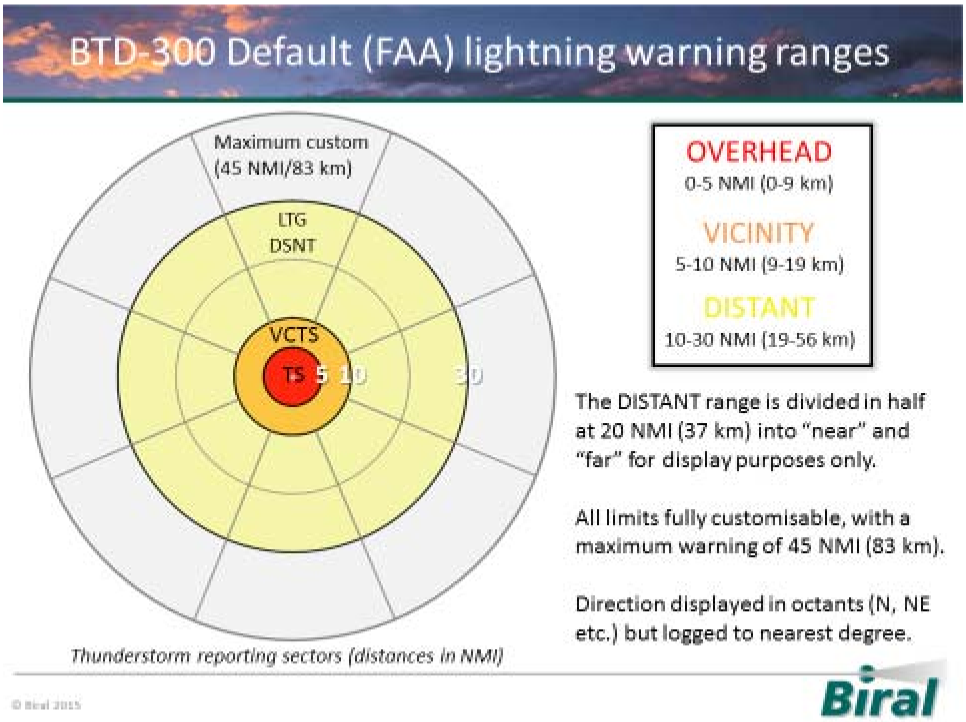
BTD-300 Default (FAA) lightning warning ranges
Maximum custom (45 NMI/83 km)
LTG DSNT
VCTS
TS
5
10
30
Thunderstorm reporting sectors (distances in NMI)
OVERHEAD
0-5 NMI (0-9 km)
VICINITY
5-10 NMI (9-19 km)
DISTANT
10-30 NMI (19-56 km)
The DISTANT range is divided in half at 20 NMI (37 km) into "near" and "far" for display purposes only.
All limits fully customisable, with a maximum warning of 45 NMI (83 km).
Direction displayed in octants (N, NE etc.) but logged to nearest degree.
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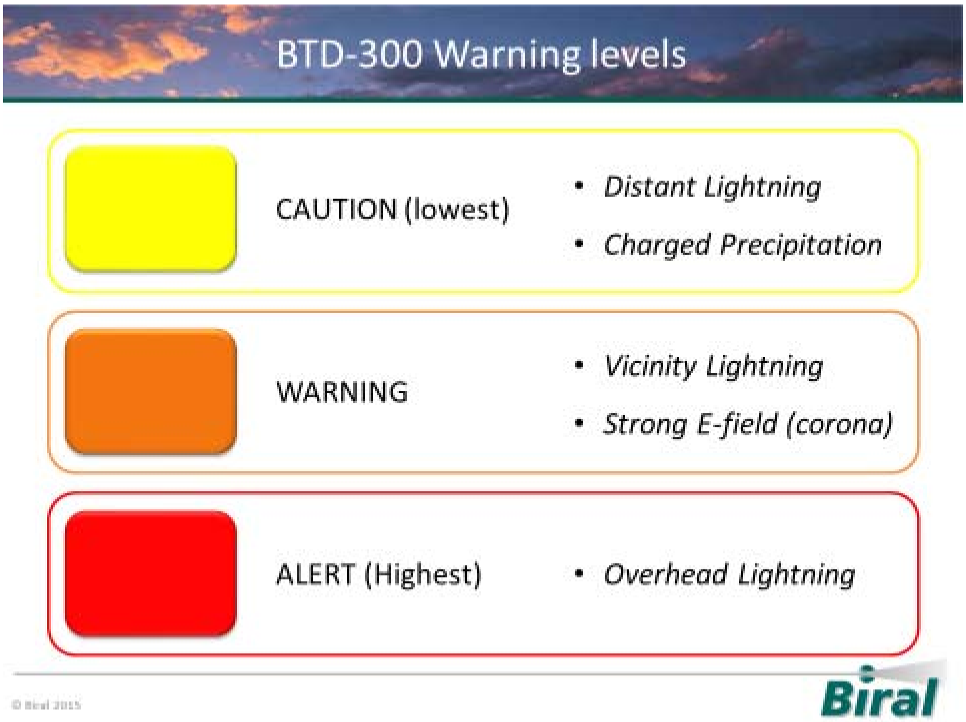
BTD-300 Warning levels
CAUTION (lowest)
• Distant Lightning
• Charged Precipitation
WARNING
• Vicinity Lightning
• Strong E-field (corona)
ALERT (Highest)
• Overhead Lightning
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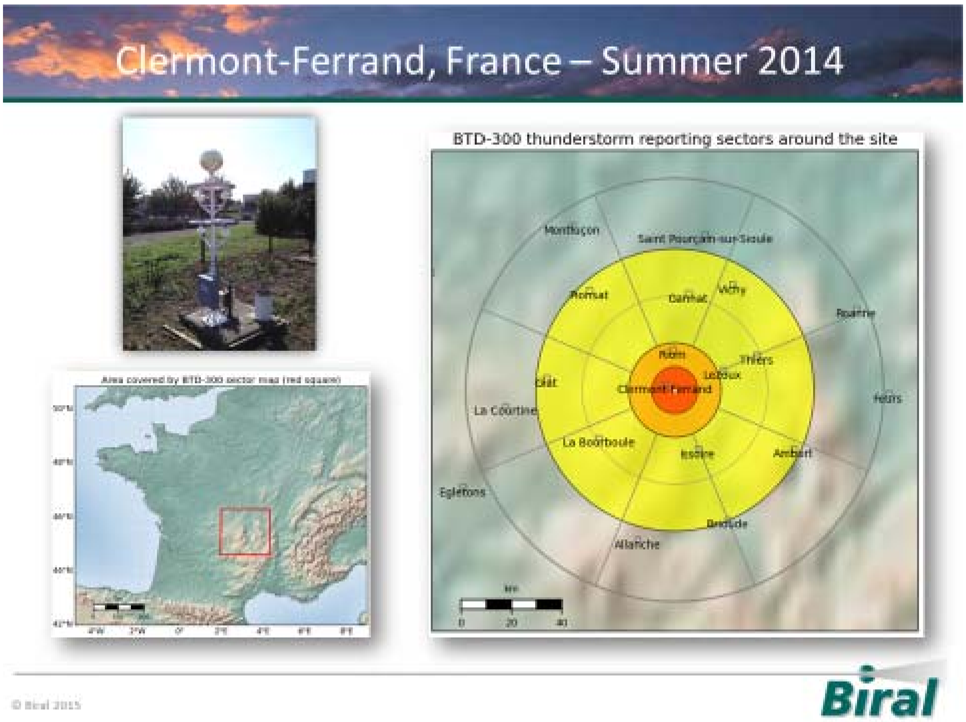
Clermont-Ferrand, France – Summer 2014
Area covered by BTD-300 sector map (red square)
BTD-300 thunderstorm reporting sectors around the site
Montluçon
Saint Pourçain-sur-Sioule
Vichy
Riom
Roanne
Thiers
Clermont-Ferrand
Feurs
La Courtine
La Bourboule
Issoire
Ambert
Egletons
Brioude
Allanche
km
0
20
40
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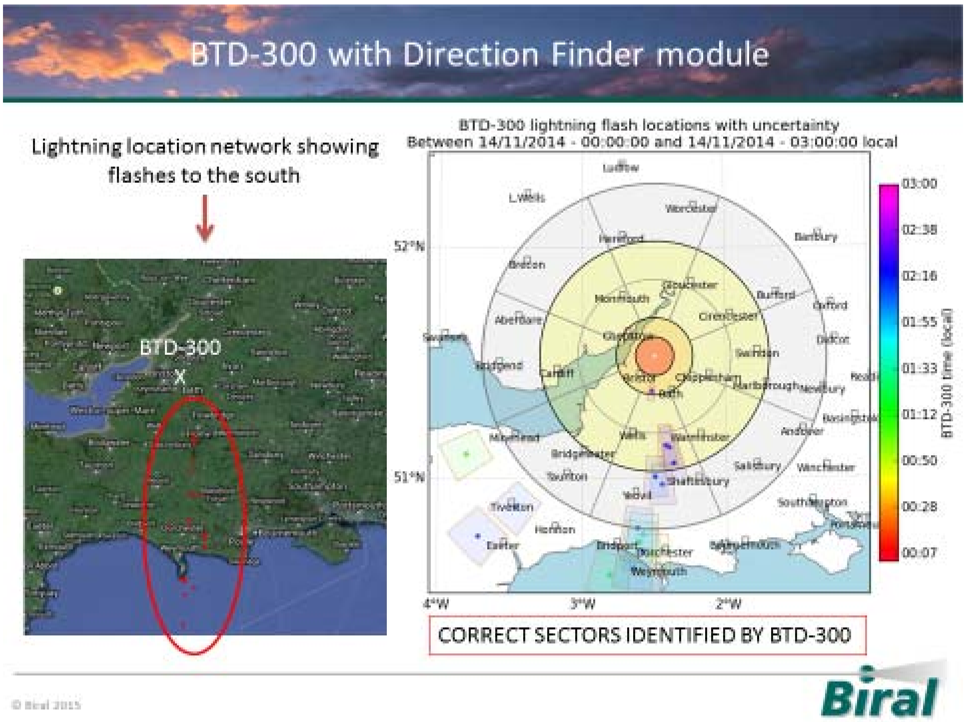
BTD-300 with Direction Finder module
Lightning location network showing flashes to the south
BTD-300
X
BTD-300 lightning flash locations with uncertainty
Between 14/11/2014 - 00:00:00 and 14/11/2014 - 03:00:00 local
52°N
51°N
4°W
3°W
2°W
03:00
02:38
02:16
01:55
01:33
01:12
00:50
00:28
00:07
BTD-300 time (local)
CORRECT SECTORS IDENTIFIED BY BTD-300
© Biral 2015
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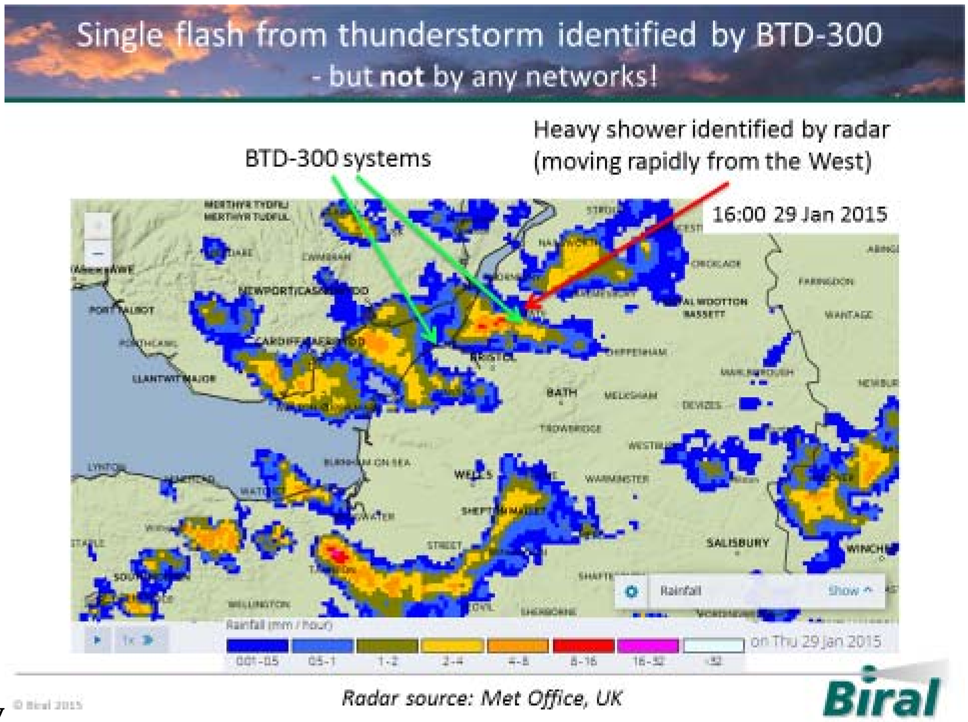
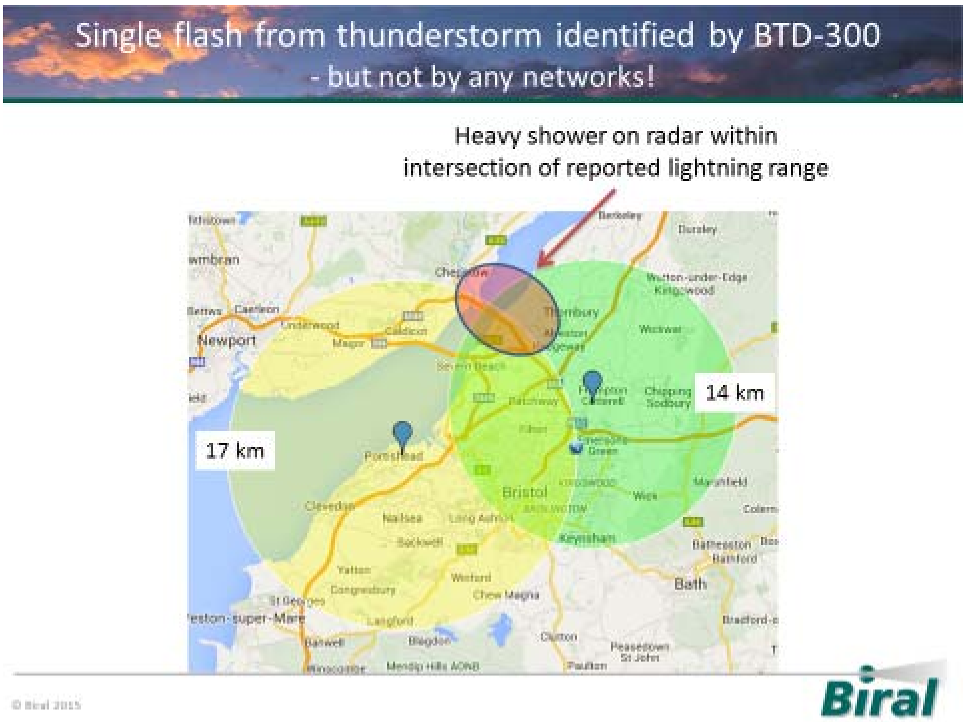


v



***資料來源：由英國 BIRAL 儀器製造商及臺灣代理智統科技工程(股)**

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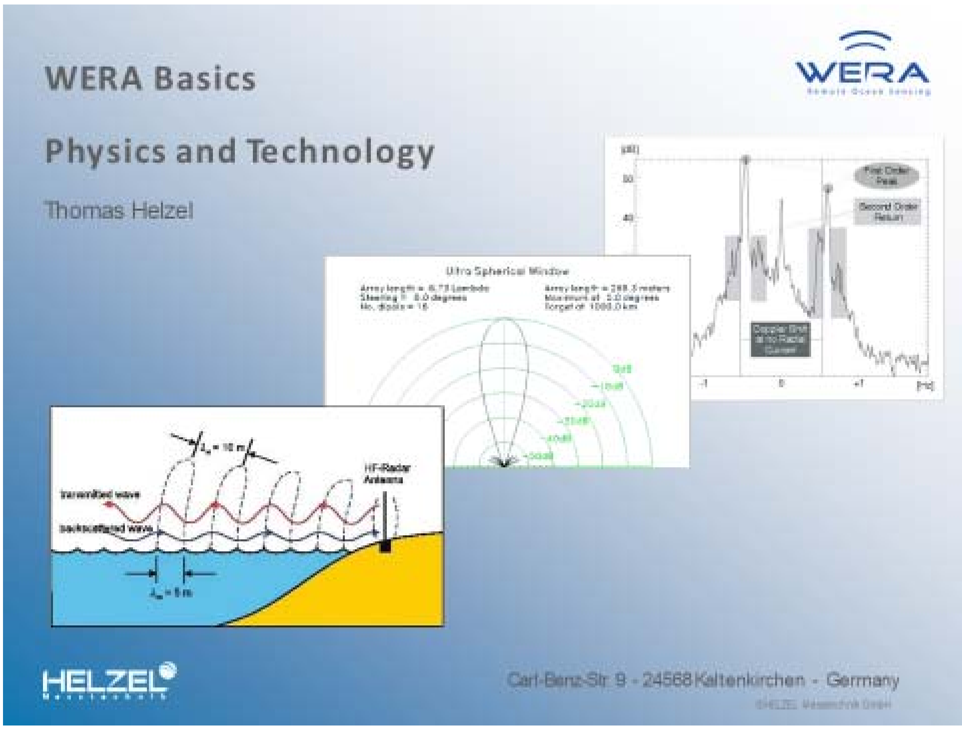
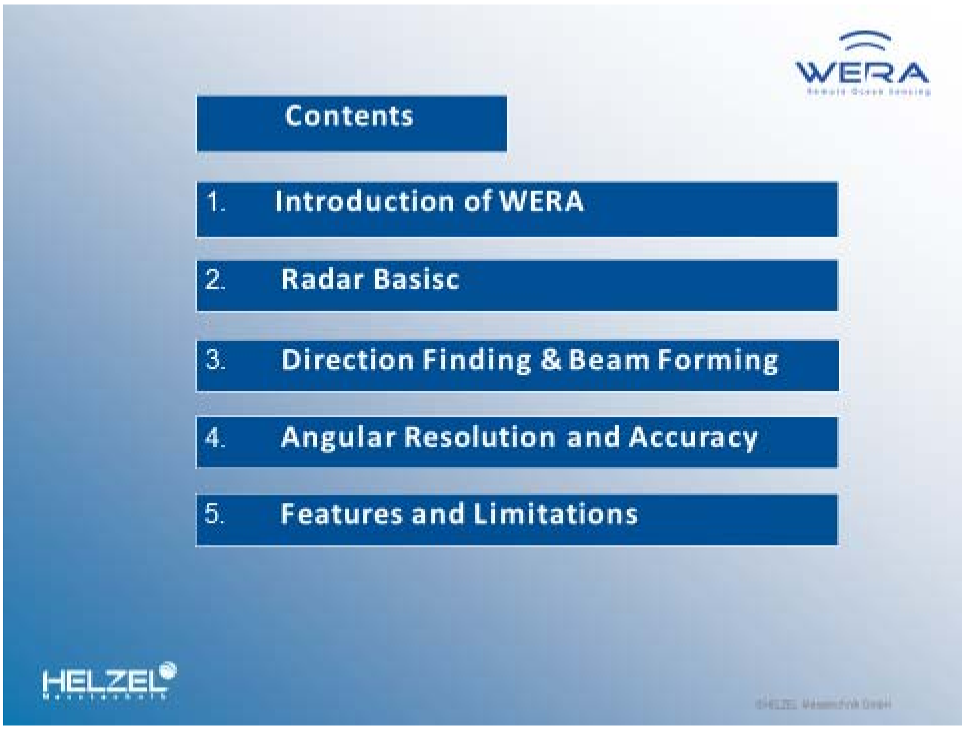
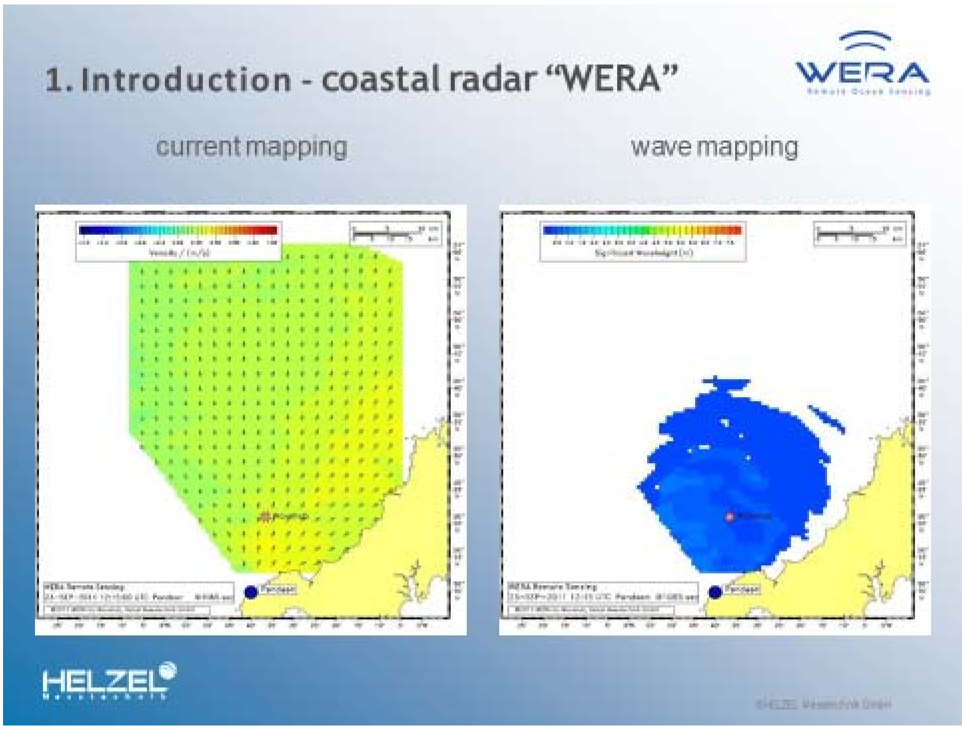
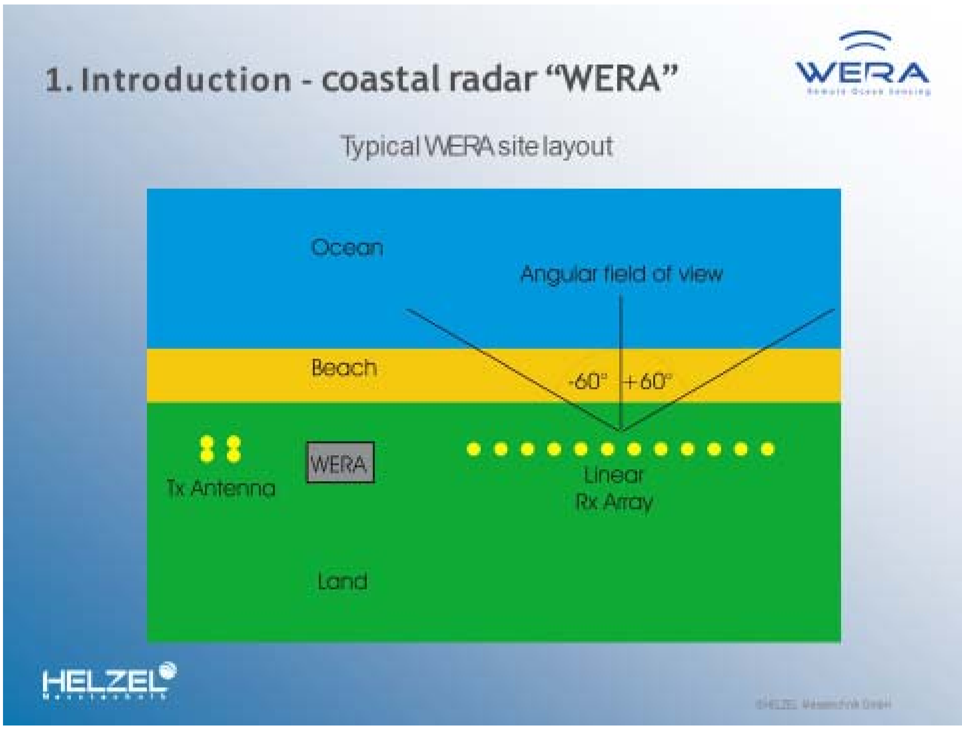
(二)海洋及陣列雷達系統應用介紹：



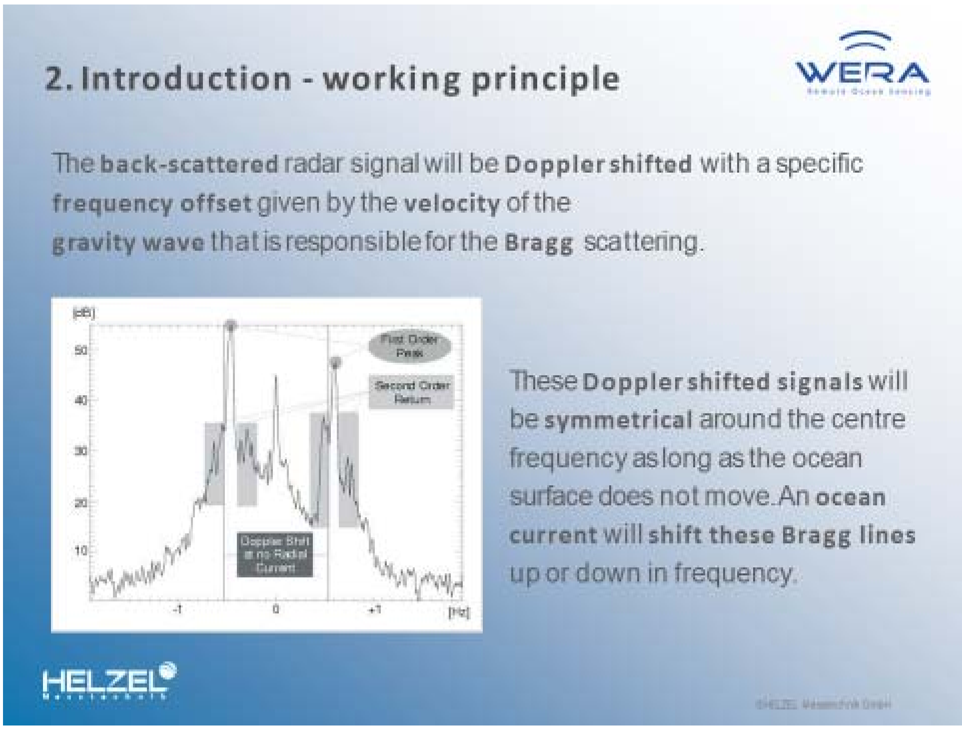


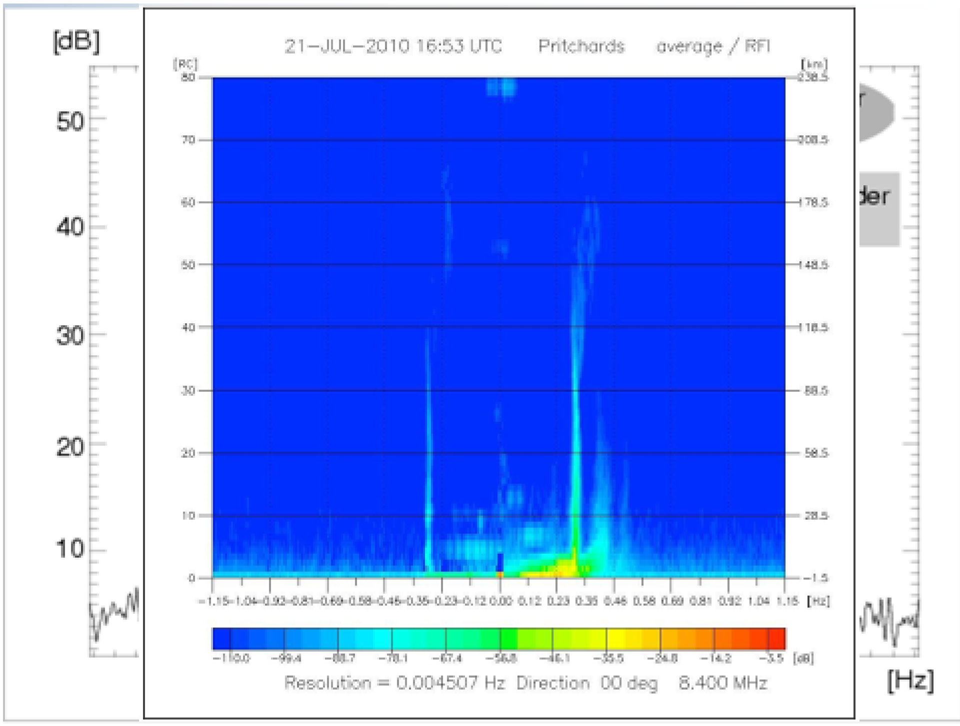


1. Introduction - coastal radar "WERA"
WERA
current mapping
wave mapping
Pendeen
Pendeen
HELZEL
©HELZEL Messtechnik GmbH



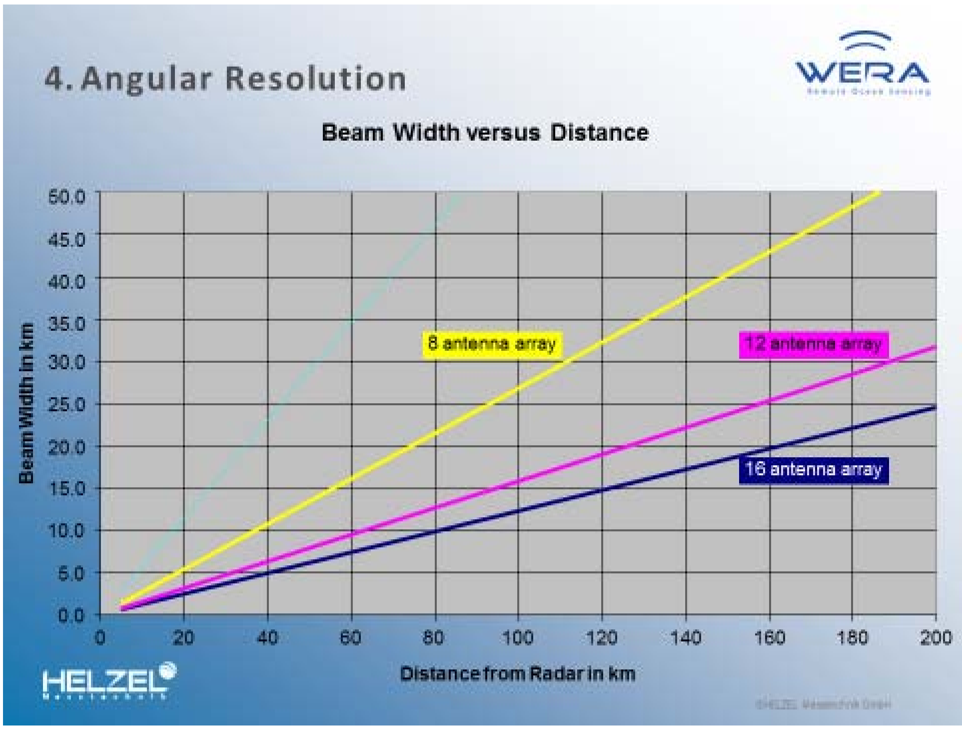
1. Introduction - coastal radar "WERA"
WERA
Typical WERA site layout
Ocean
Angular field of view
Beach
-60°
+60°
WERA
Tx Antenna
Linear
Rx Array
Land
HELZEL
©HELZEL Messtechnik GmbH

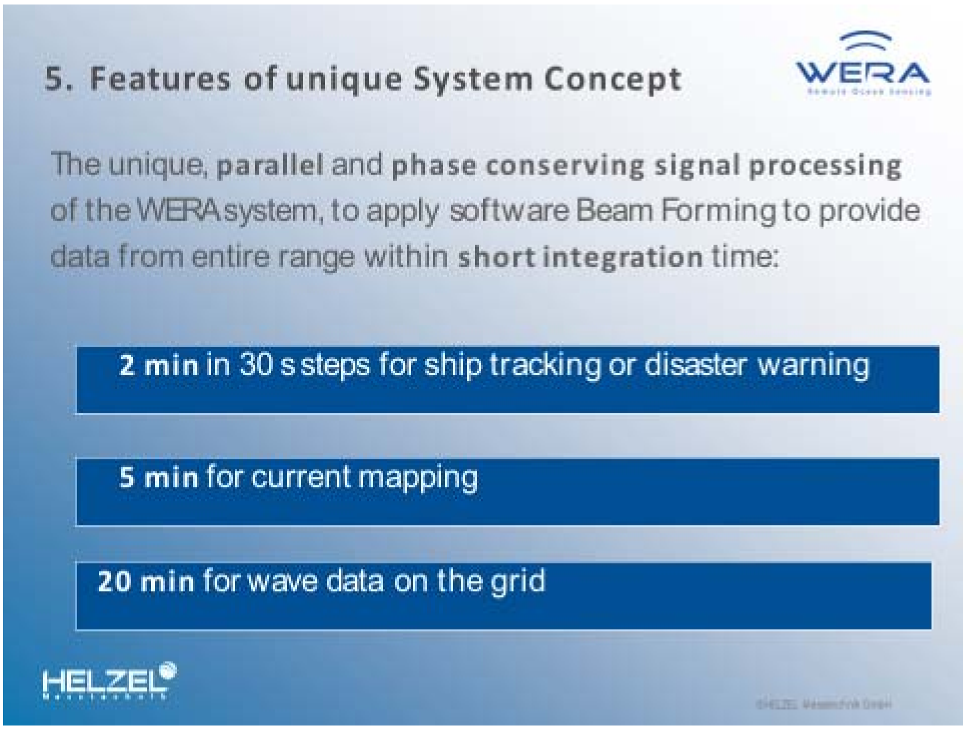

2. Introduction - working principle
WERA
The back-scattered radar signal will be Doppler shifted with a specific frequency offset given by the velocity of the gravity wave that is responsible for the Bragg scattering.
[dB]
First Order Peak
Second Order Return
Doppler Shift at no Radial Current
[Hz]
These Doppler shifted signals will be symmetrical around the centre frequency as long as the ocean surface does not move. An ocean current will shift these Bragg lines up or down in frequency.
HELZEL


[dB]
21–JUL–2010 16:53 UTC Pritchards average / RFI
[km]
[Hz]
[dB]
Resolution = 0.004507 Hz Direction 00 deg 8.400 MHz
[Hz]

3. Direction Finding & Beam Forming Mode

Parameter	Compact Antenna (Direction Finding)	Array Type Antenna (Beam Forming)
Receive Antenna Array:	Square of 4 Poles	8 to 16 Poles
Provided Data:	Currents and Wind direction	Dynamic Currents, Waves and Wind
Field of View:	up to 270°	120° (more if curved)
Angular Accuracy:	< 10° typical Antenna calibration recommended !	< 1° Antenna calibration not required !
Temporal Resolution:	> 20 minutes	> 30 seconds
Noise Reduction:	standard	unique WERA noise reduction method




5. Features of unique System Concept
WERA
The unique, parallel and phase conserving signal processing of the WERA system, to apply software Beam Forming to provide data from entire range within short integration time:
2 min in 30 s steps for ship tracking or disaster warning
5 min for current mapping
20 min for wave data on the grid
HELZEL


WERA
Samples of WERA applications
WERA Seminar 2017
Jan Widera
Helzel Messtechnik GmbH, Germany
HELZEL
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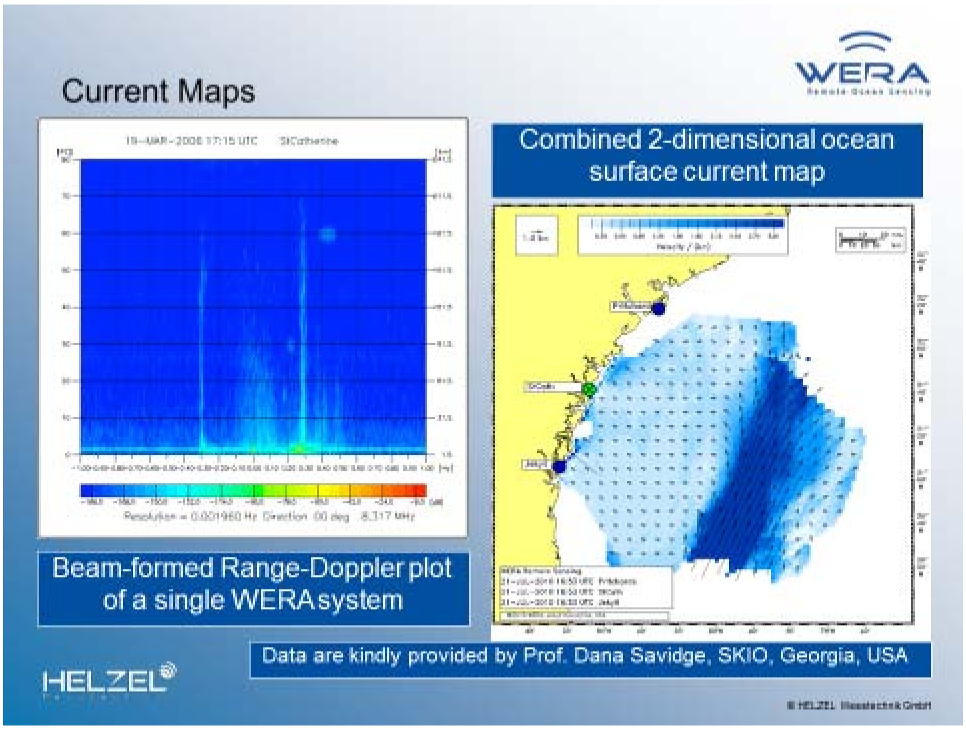
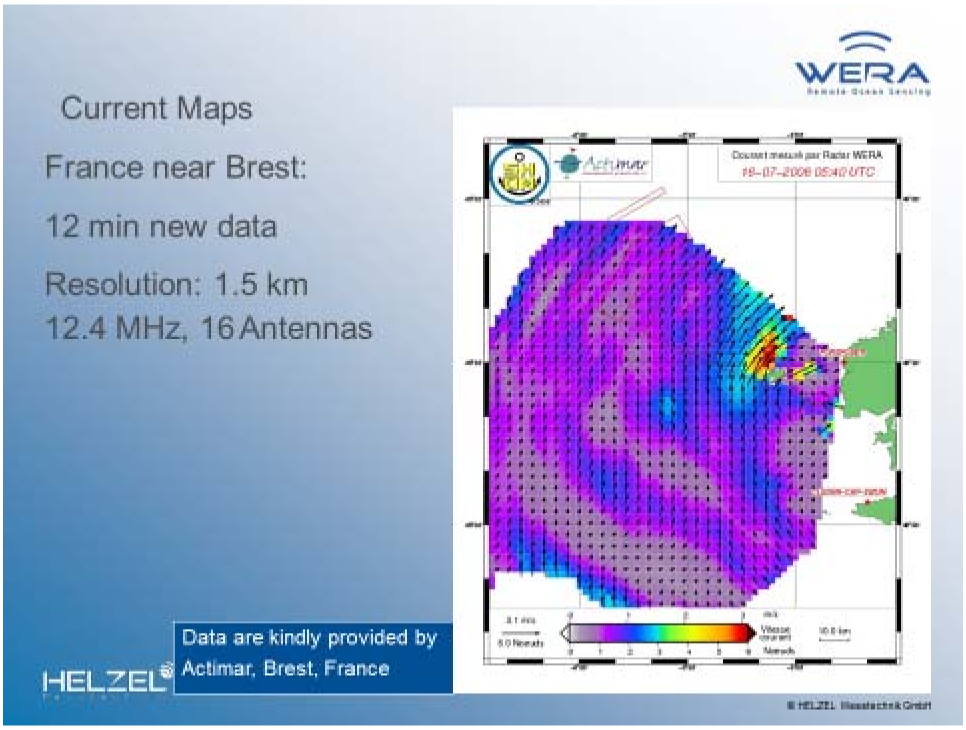
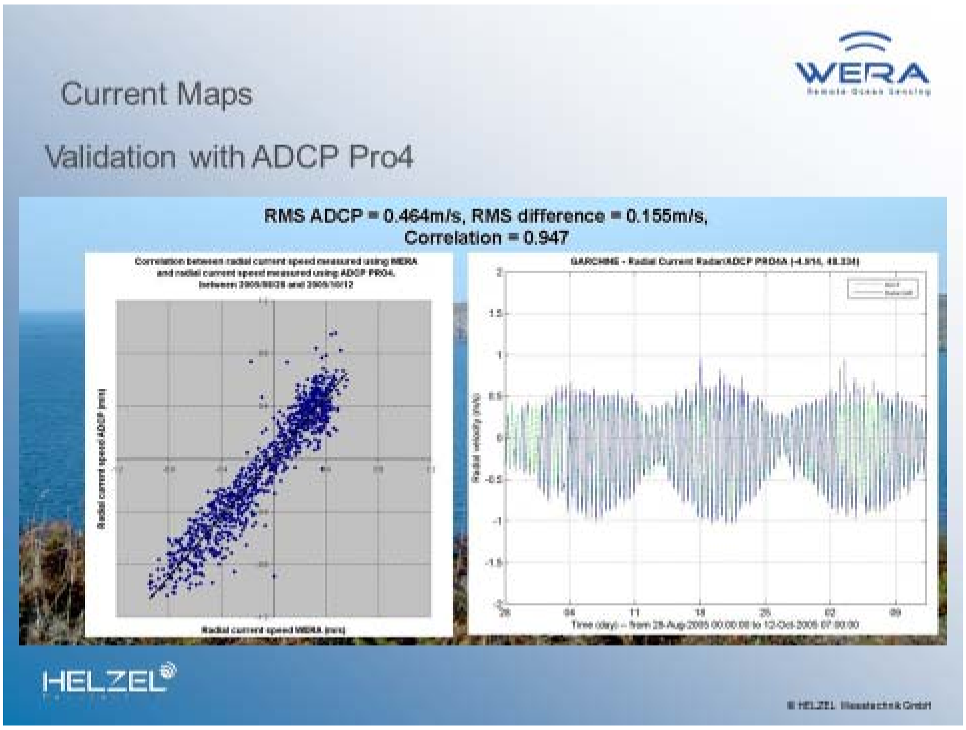
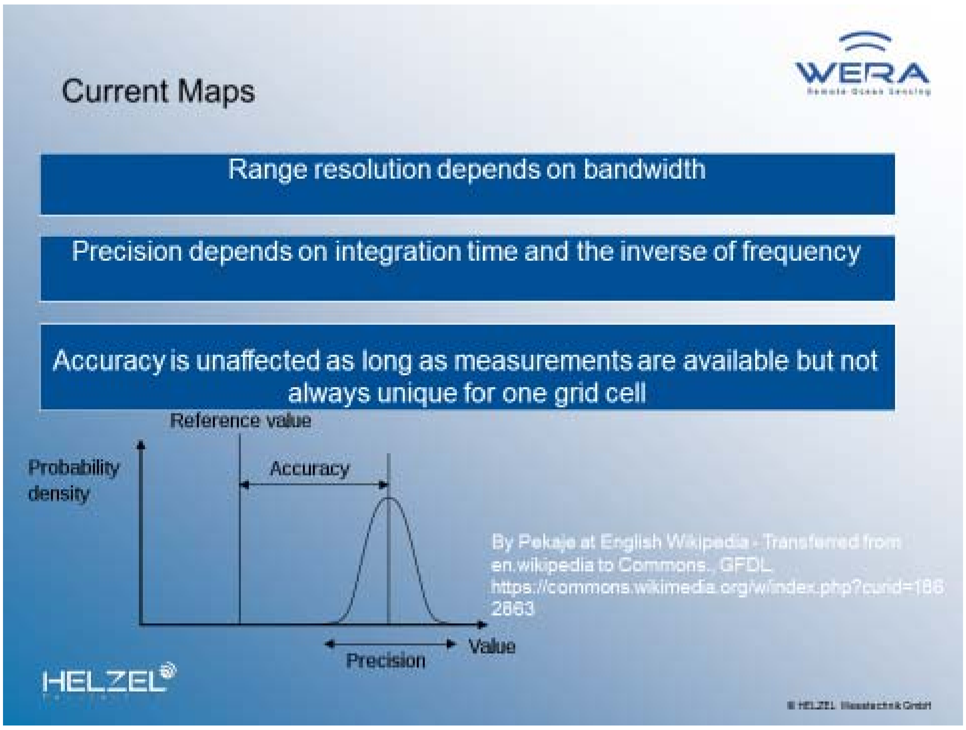

Current Maps
WERA
Combined 2-dimensional ocean surface current map
Beam-formed Range-Doppler plot of a single WERA system
Data are kindly provided by Prof. Dana Savidge, SKIO, Georgia, USA
HELZEL
© HELZEL Messtechnik GmbH


WERA
Current Maps
France near Brest:
12 min new data
Resolution: 1.5 km
12.4 MHz, 16 Antennas
Data are kindly provided by Actimar, Brest, France
HELZEL
© HELZEL Messtechnik GmbH



Current Maps
WERA
Validation with ADCP Pro4
RMS ADCP = 0.464m/s, RMS difference = 0.155m/s,
Correlation = 0.947
HELZEL
© HELZEL Messtechnik GmbH



Current Maps
WERA
Range resolution depends on bandwidth
Precision depends on integration time and the inverse of frequency
Accuracy is unaffected as long as measurements are available but not always unique for one grid cell
Reference value
Probability density
Accuracy
Precision
Value
By Pekaje at English Wikipedia - Transferred from en.wikipedia to Commons., GFDL, https://commons.wikimedia.org/w/index.php?curid=1862863
HELZEL
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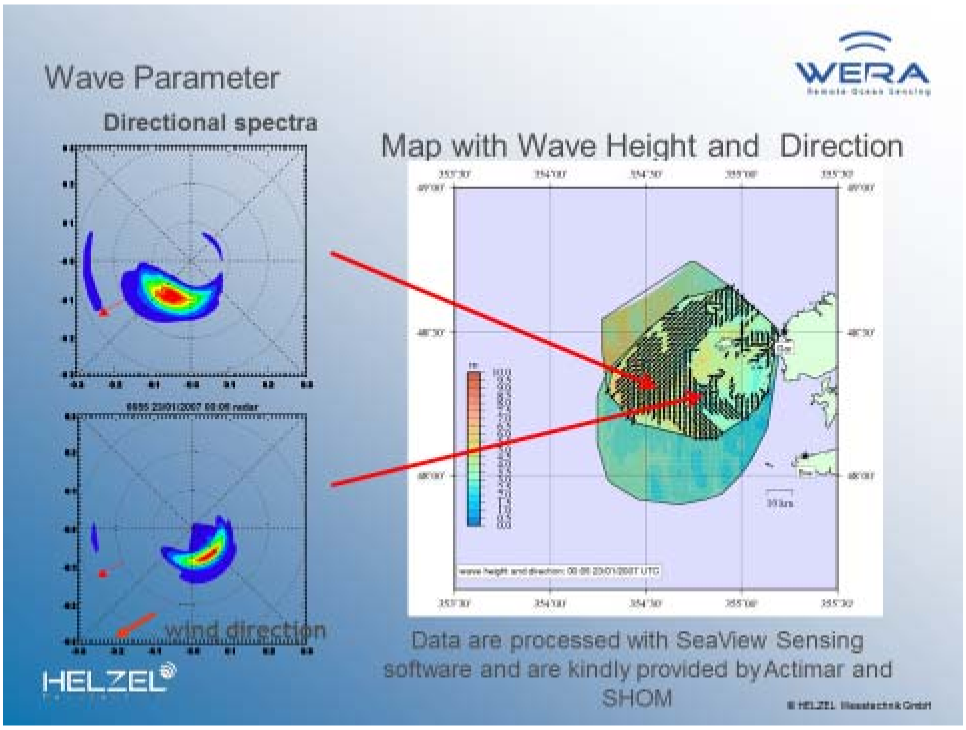
Wave Parameter
WERA
Remote Ocean Sensing
Directional spectra
Map with Wave Height and Direction
wind direction
Data are processed with SeaView Sensing software and are kindly provided by Actimar and SHOM
HELZEL
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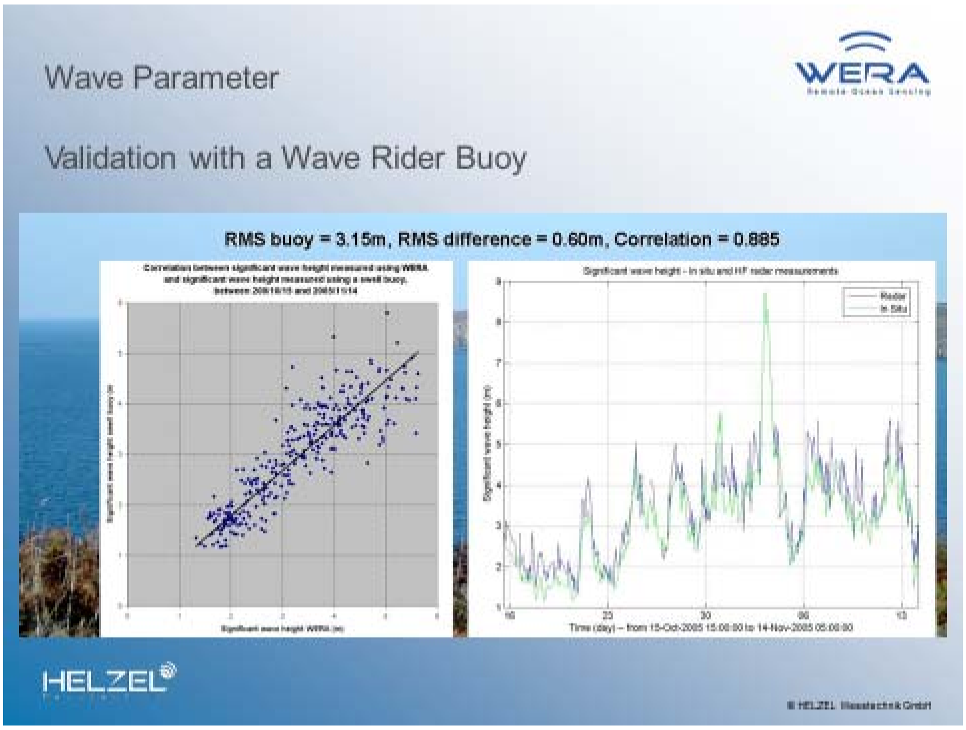
Wave Parameter
WERA
Remote Ocean Sensing
Validation with a Wave Rider Buoy
RMS buoy = 3.15m, RMS difference = 0.60m, Correlation = 0.885
Significant wave height - In situ and HF radar measurements
Radar
In Situ
Time (day) – from 15-Oct-2005 15:00:00 to 14-Nov-2005 05:00:00
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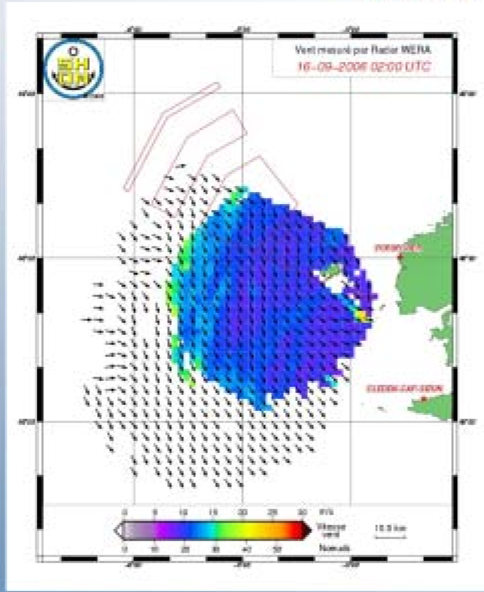
Wind Parameter

WERA
Remote Ocean Sensing

The longer the wave, the longer it takes to transport energy from wind into the ocean.



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Additional parameters

WERA
Remote Ocean Sensing

Additional information about ship tracking and Tsunami waves will be covered in the next session

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Usage of information

WERA Remote Ocean Sensing

Large datasets:
Oceanographic science, Energy management

Actual state:
Monitoring
(eg. Actual currents and waves, Ships, Tsunamis)

Future:
Integrate the informationions into models
(Data assimilation) for weather, SAR, offshore works

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Usage of information

WERA Remote Ocean Sensing

Large datasets:
Oceanographic science, Energy management

Reported data availability:

SHOM	Port of Rotterdam
98.6 %	> 98 %

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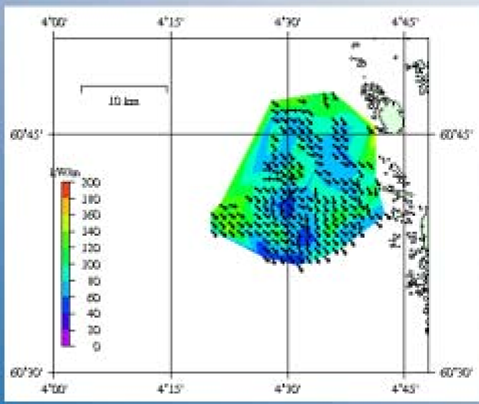
Usage of information

**Large datasets:
Oceanographic science, Energy management**



Map of Wave Power

WERA @ 27MHz
at Norwegian
coast near Bergen

Data kindly provided by
SeaView Sensing Ltd.

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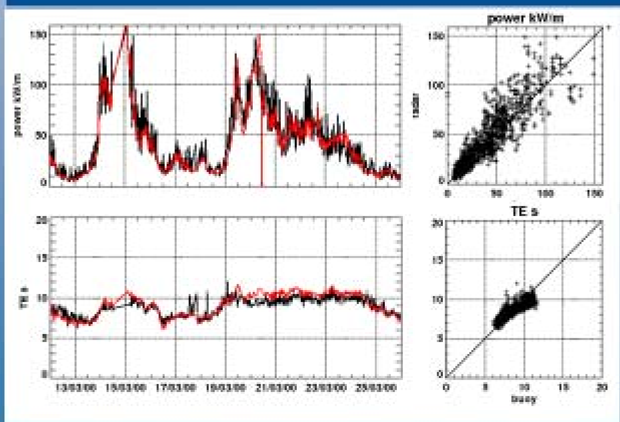
Usage of information

**Large datasets:
Oceanographic science, Energy management**



WERA: black
buoy: red

Power:
correlation: 0.91
rms:13.2 kW/m

Energy period:
correlation: 0.9
rms: 0.7s

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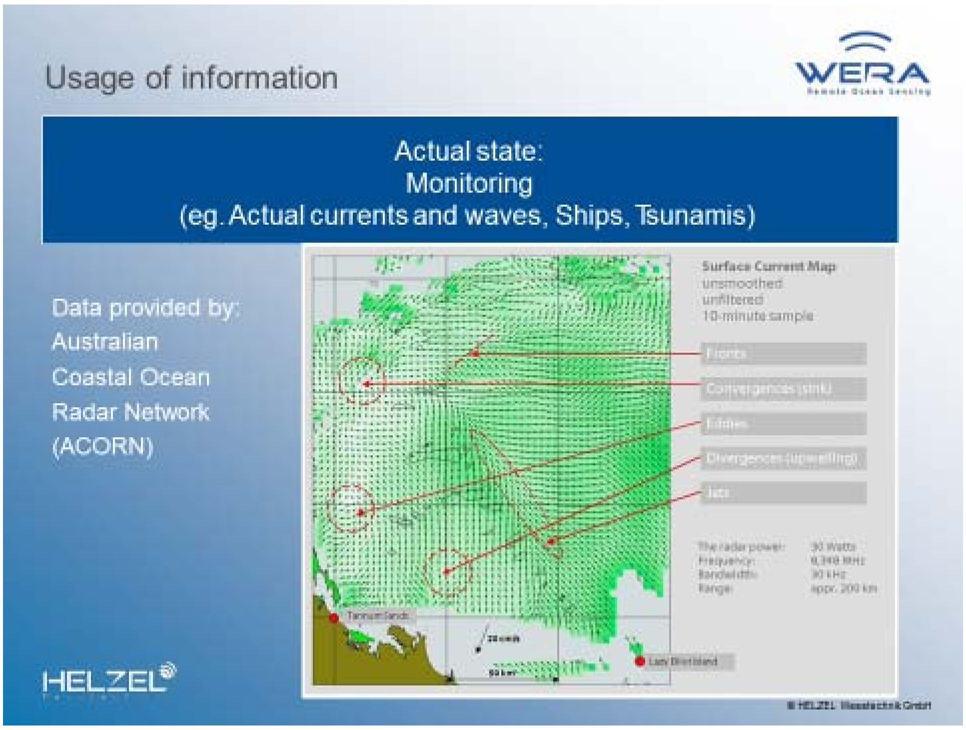
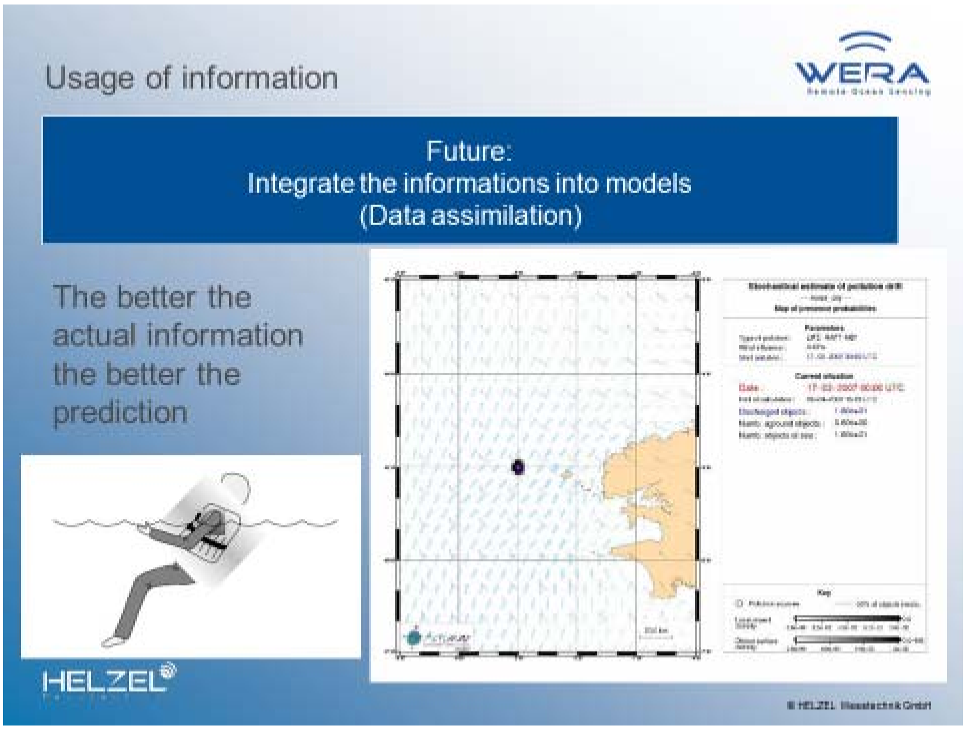
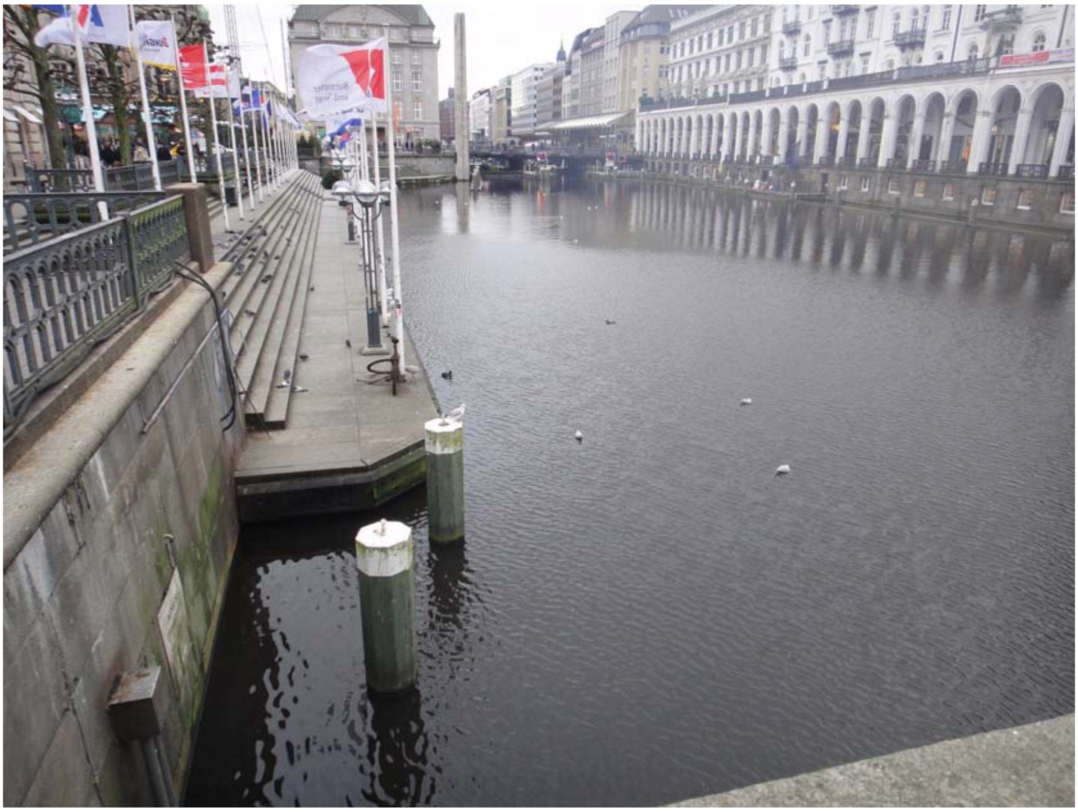
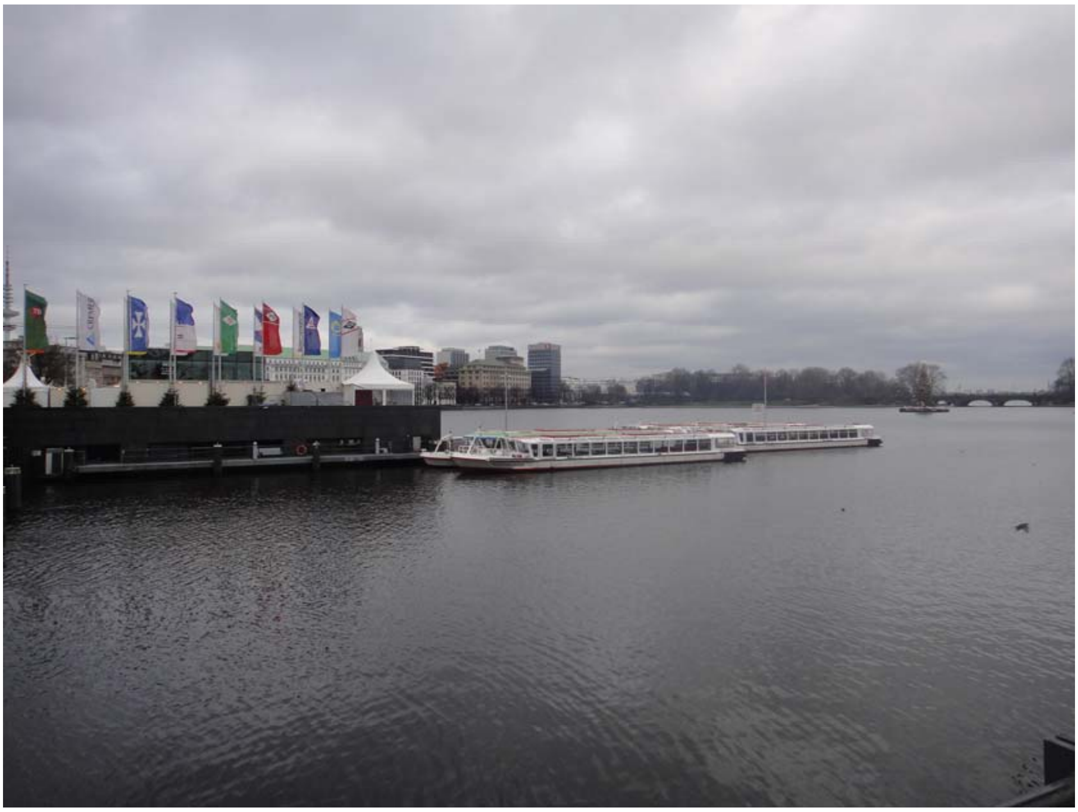


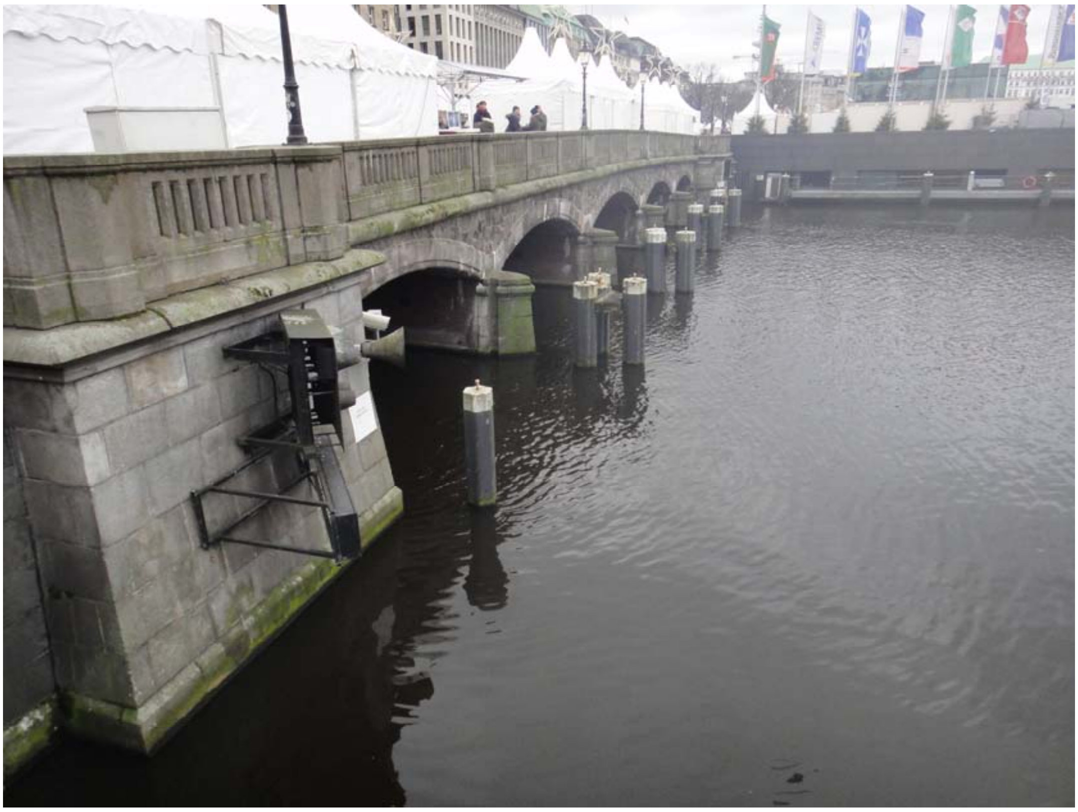


***資料來源：由德國 WERA 儀器製造商及臺灣代理智統科技工程(股)**

公司提供或協助說明







WERA
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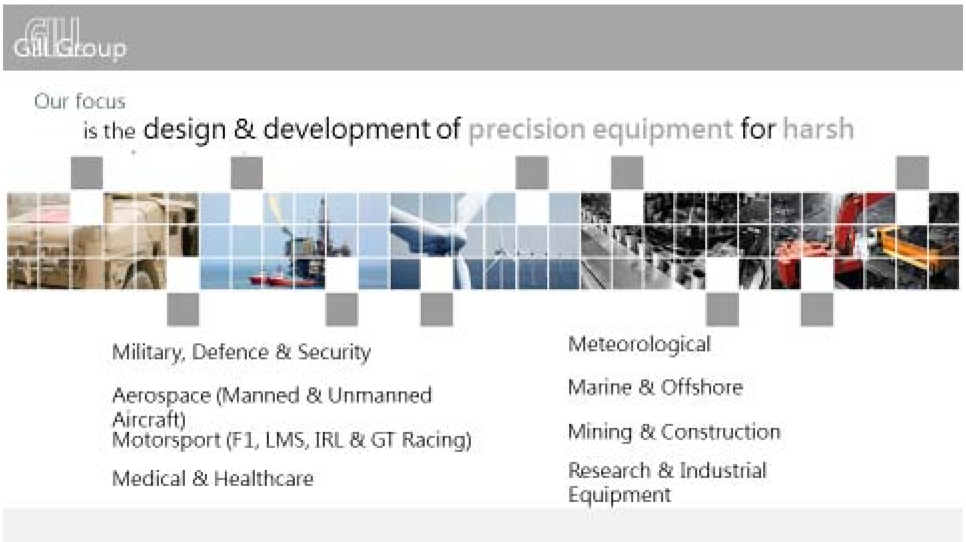
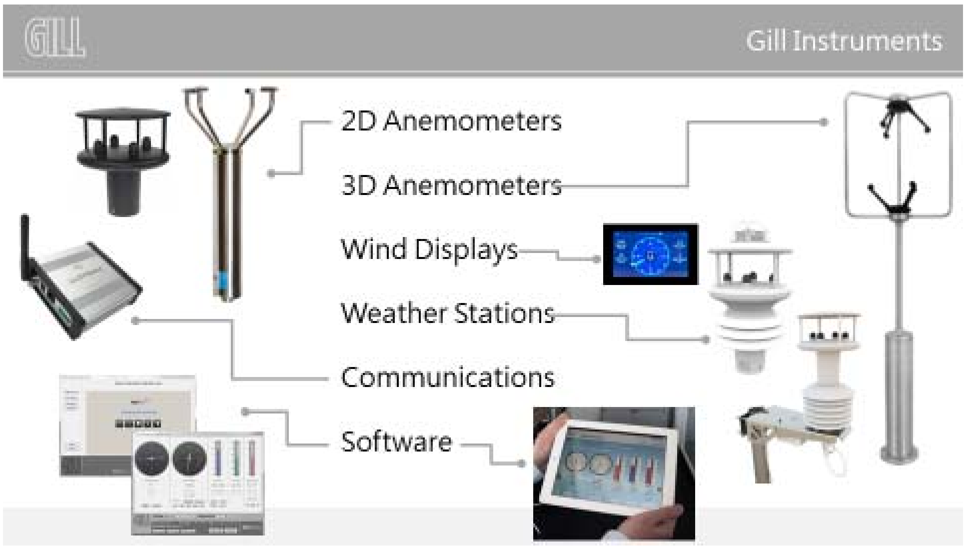
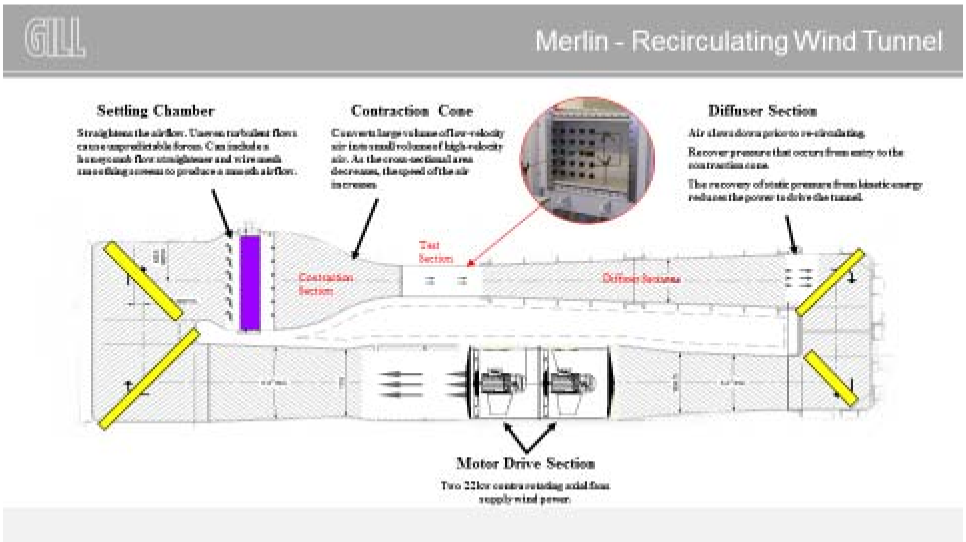
SE HZ 111

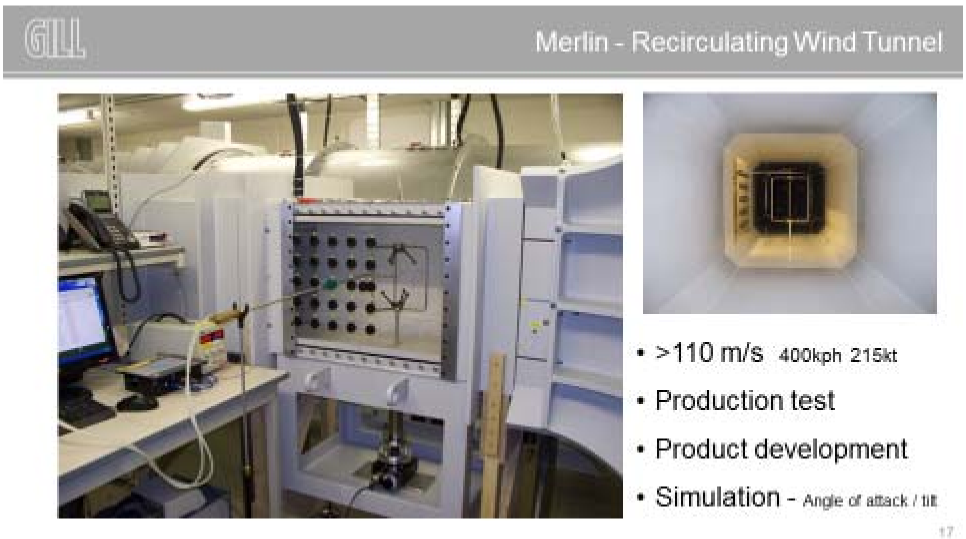

WiFi Seminar Room

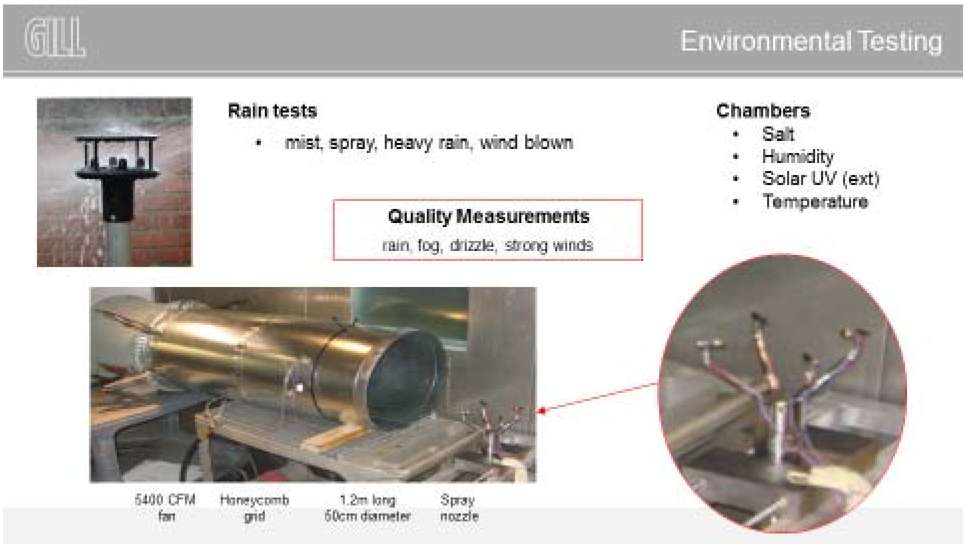
(三)海洋超音波式風速風向計製造生產及風洞試驗室校正技術介紹：

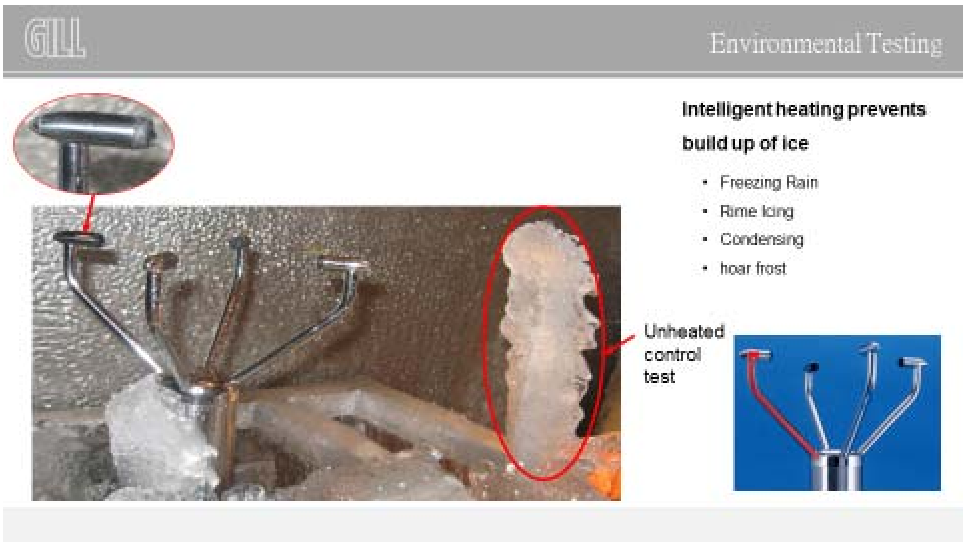


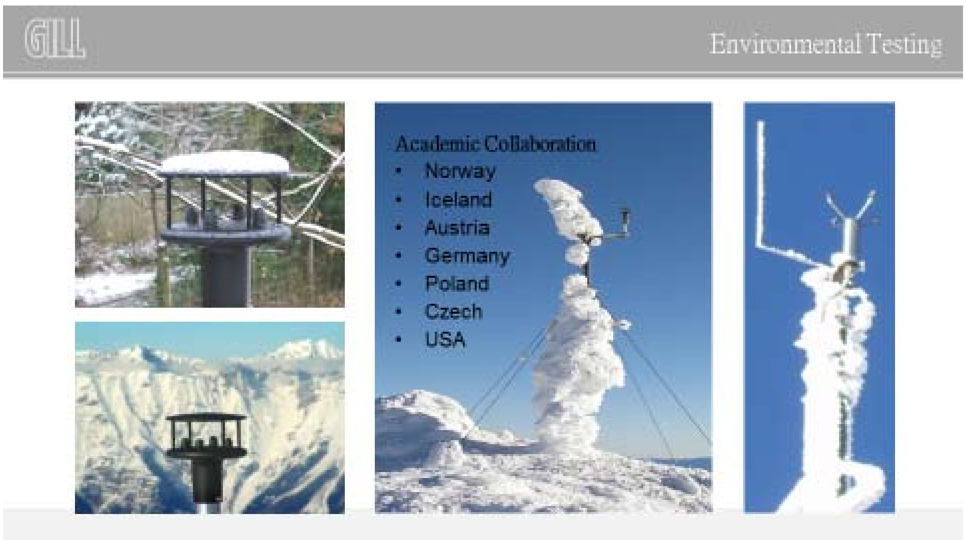

Gill Instruments
2D Anemometers
3D Anemometers
Wind Displays
Weather Stations
Communications
Software


Merlin - Recirculating Wind Tunnel
Settling Chamber
Straightens the airflow. Uneven turbulent flows cause unpredictable forces. Can include a honeycomb flow straightener and wire mesh smoothing screens to produce a smooth airflow.
Contraction Cone
Converts large volume of low-velocity air into small volume of high-velocity air. As the cross-sectional area decreases, the speed of the air increases.
Diffuser Section
Air slows down prior to re-circulating.
Recover pressure that occurs from entry to the contraction cone.
The recovery of static pressure from kinetic energy reduces the power to drive the tunnel.
Test Section
Contraction Section
Diffuser Sections
Motor Drive Section
Two 22kw contra-rotating axial fans supply wind power.

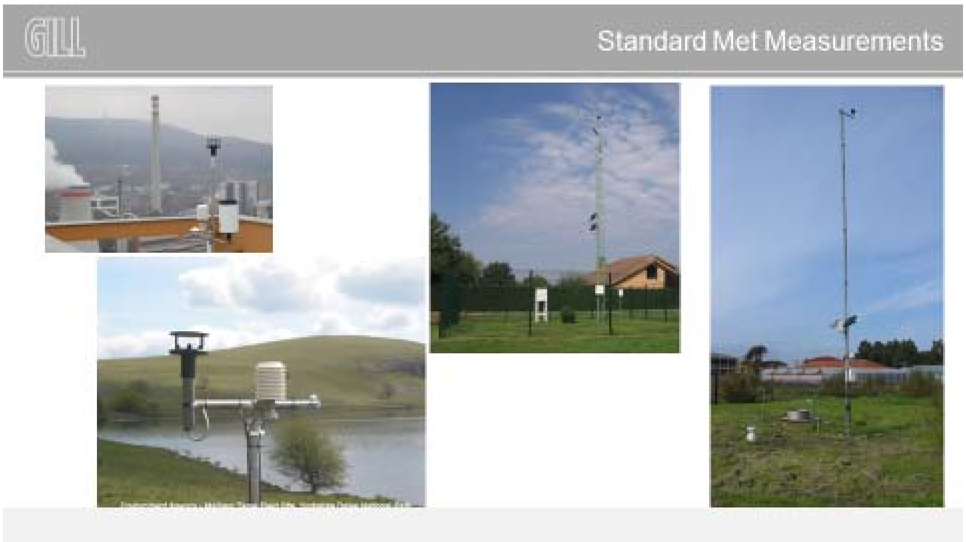

Merlin - Recirculating Wind Tunnel
• >110 m/s 400kph 215kt
• Production test
• Product development
• Simulation - Angle of attack / tilt
17


Environmental Testing
Rain tests
• mist, spray, heavy rain, wind blown
Quality Measurements
rain, fog, drizzle, strong winds
Chambers
• Salt
• Humidity
• Solar UV (ext)
• Temperature
5400 CFM fan
Honeycomb grid
1.2m long 50cm diameter
Spray nozzle


Environmental Testing
Intelligent heating prevents build up of ice
• Freezing Rain
• Rime Icing
• Condensing
• hoar frost
Unheated control test


Environmental Testing
Academic Collaboration
• Norway
• Iceland
• Austria
• Germany
• Poland
• Czech
• USA


Small Coastal Data Buoys

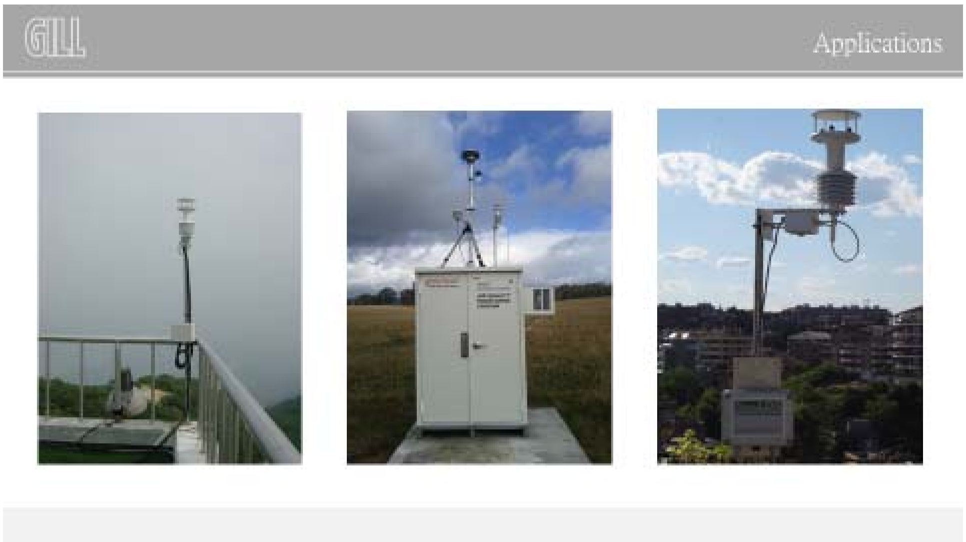

Standard Met Measurements


Wind Energy Application

Harbour Master Vessel Traffic Conditions

Fisheries

Bridges



***資料來源：由英國 GILL 儀器製造商及臺灣代理智統科技工程(股)公司提供或協助說明**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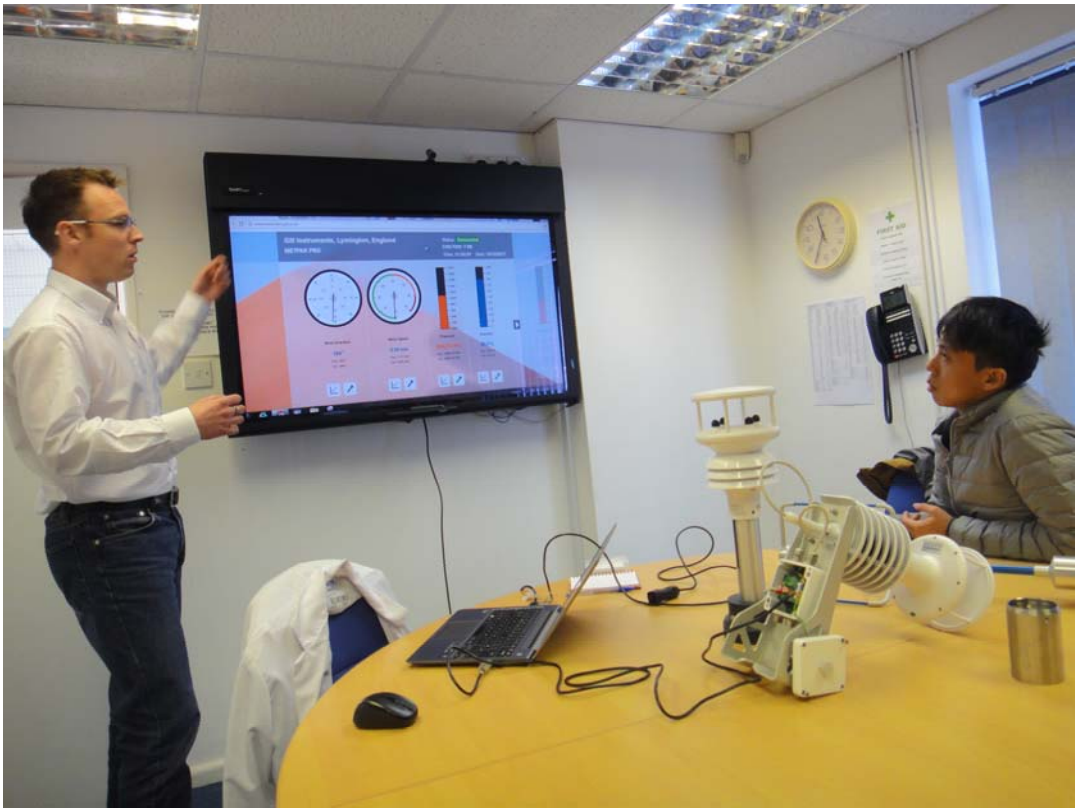

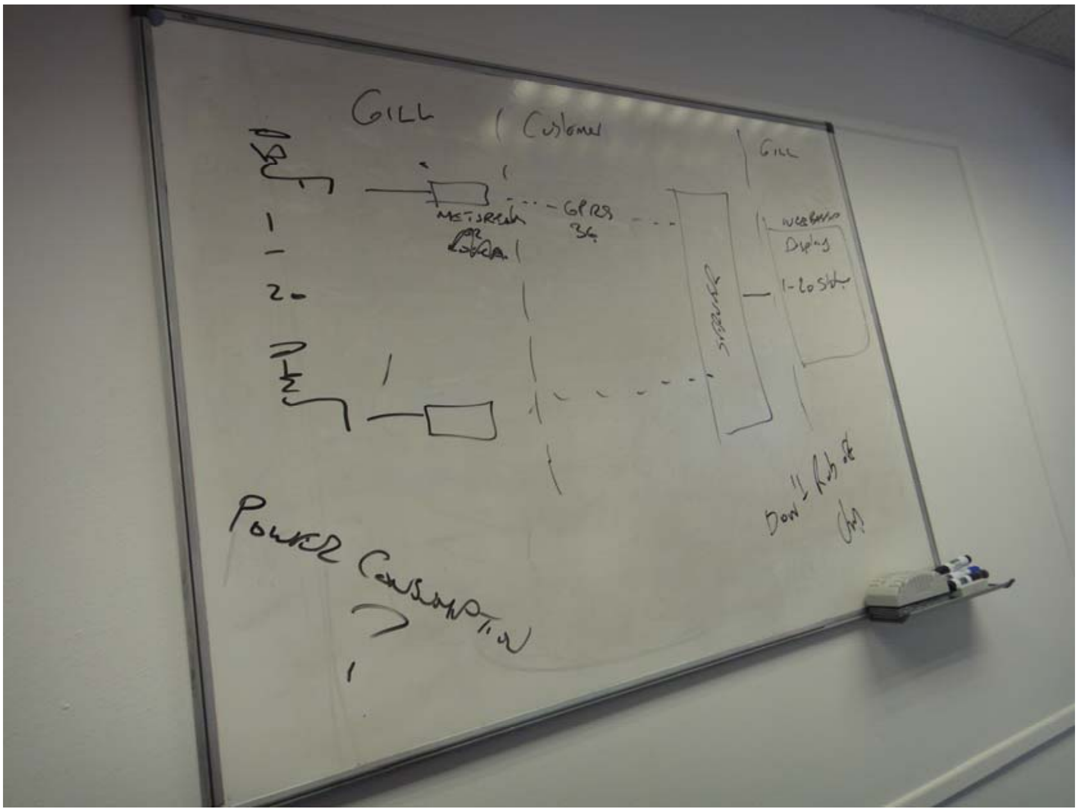

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POWER CONSUMPTION

(四) 海洋陣列雷達系統波流量測計算應用技術介紹：

Seaview Sensing Software

Lucy R. Wyatt

Seaview Sensing Ltd
and School of Mathematics and Statistics
University of Sheffield

email: lucywyatt@seaviewsensing.com

1

Outline

- Seaview Sensing Ltd
- What are we measuring and why?
- What methods are available?
- The Sheffield-Seaview method
- Accuracy and limitations
- The software package
- Some examples

References are indicated with [n] and listed at the end.

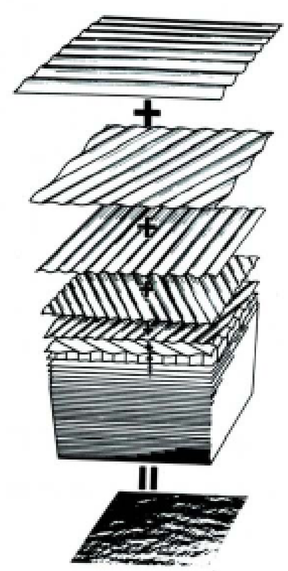
2

Seaview SensingLtd

- Established in 2004 to commercialise software developed at University of Sheffield
- Small team of consultants undertaking research and software development, installation, support.
- Our software provides surface current, wave (including the directional wave spectrum), and wind (wind speed less robust) accessible as file downloads and via a Data Viewer.
- Software has been installed on systems in UK, France, Germany, USA, Australia, OMAN, Turkey
- Data has been processed on our servers from radars in UK, USA and Korea.

3

What are we measuring and why?



from Pierson et al. 1955 [25]

The sea surface can be described by waves of different amplitudes, wavelengths (or frequencies) propagating in different directions - a directional spectrum $S(k,\theta)$ ($S(f,\theta) = S(k,\theta) \times \frac{dk}{df}$).
From this we can determine:

- Energy spectrum $E(f) = \int S(f,\theta)d\theta$,
- Significant waveheight $Hs = 4 \times sqrt(\int E(f)df)$,
- Mean period $T_1 = \frac{\int E(f)df}{\int fE(f)df}$,
- Mean direction $\theta_m = \tan^{-1} \frac{\int\int S(f,\theta)\sin(\theta)d\theta df}{\int\int S(f,\theta)\cos(\theta)d\theta df}$

and many other parameters.e.g wavepower and energy period, all using standard methods.

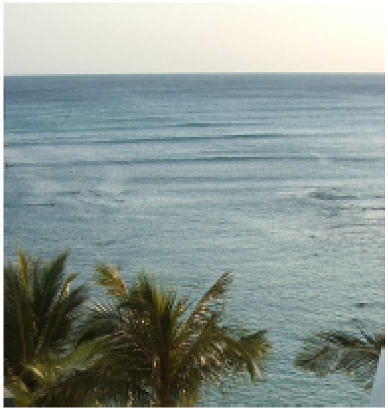
4

What are we measuring and why?

Waves are categorised as:

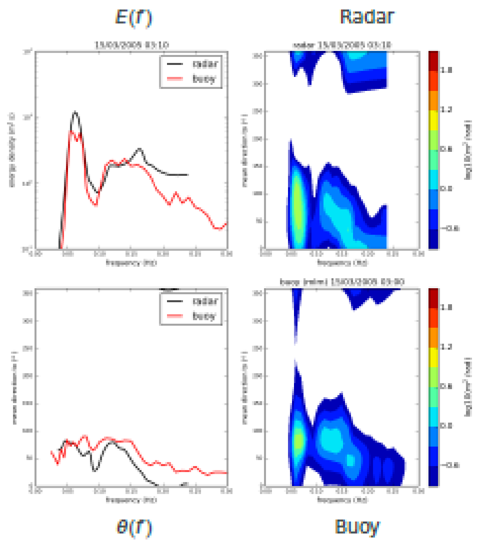
wind waves – generated by the local wind.

swell – generated a long way from the observation point.



5

What are we measuring and why?



Example of a directional spectrum.

The larger lower frequency (higher period, longer wavelength) peak, 0.06Hz, is swell.

The higher frequency peak, 0.12Hz, could be the wind wave peak although there is evidence of higher frequency waves, > 0.2Hz, in a different direction (spectrum is multi-modal).

6

What are we measuring and why?

Wave data are important for:

- Design, maintenance and monitoring of coastal structures e.g. piers, harbours, breakwaters, wind farms, marine renewable installations;
- Operational assistance for coastal construction projects;
- Monitoring severe weather conditions, storm surge forecasting;
- Beach erosion and sediment transport;
- Baseline data for monitoring the impact of climate change;
- Oceanographic research,
- ...

What are we measuring and why?

With the radar we are measuring the magnitude of backscattered signal from the sea surface Doppler shifted by waves of half the radio wavelength - Bragg scattering.

Wave measurement is possible because non-linear wave-wave interactions generate such waves propagating at different speeds from the linear waves used for surface current measurement.

Non-linear electromagnetic-ocean wave interactions also contribute but are less important.

These two mechanisms are described by a non-linear integral equation.

What are we measuring and why?

Barrick's equations

The basic measurement is the power spectrum of radar backscatter, $\sigma(\omega, \phi, d)$, which is the sum of the first $\sigma_1(\omega, \phi, d)$ [5] and second $\sigma_2(\omega, \phi, d)$ [4], [6], [3] order parts of the spectrum:

$$\sigma_1(\omega, \phi, d) = 2^6 \pi k_0^4 \sum_{m,m'=\pm 1} S(-2m'\mathbf{k}_0)\delta(\omega - \sqrt{2gk_0 \tanh 2k_0 d})$$

$$\sigma_2(\omega, \phi, d) = 2^6 \pi k_0^4 \sum_{m,m'=\pm 1} \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} |\Gamma|^2 S(m\mathbf{k})S(m'\mathbf{k'})\delta(\omega - \sqrt{gk \tanh kd} - \sqrt{gk' \tanh k'd})dpdq$$

where

$\mathbf{k}_0 = (k_0 \cos\phi, k_0 \sin\phi)$ is the radio wavenumber at bearing ϕ,

$\mathbf{k} + \mathbf{k'} = -2\mathbf{k}_0$ Bragg condition,

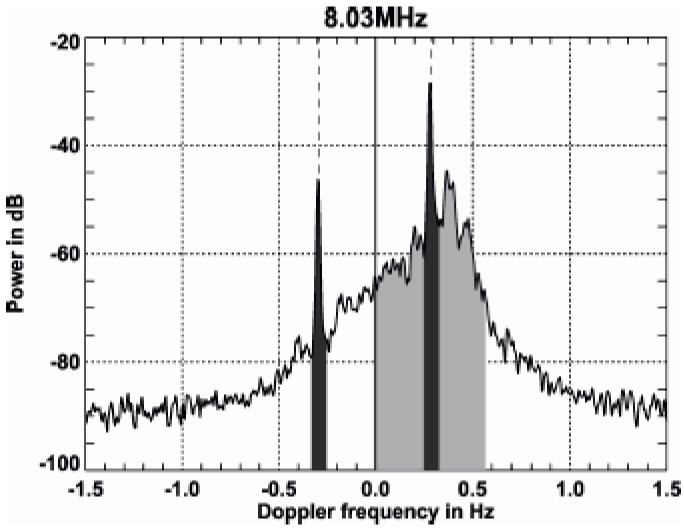
$|\Gamma|^2|$ coupling coeffiicient containing the physics associated with 2nd order hydrodynamic and electromagnetic processes,

d is water depth, $S(\mathbf{k}) = \dfrac{S(k,\theta)}{k}$ and $\mathbf{k} = (p - k_0, q)$.

Our aim is to solve for S(**k**) and/or parameters thereof.

What are we measuring and why?

The Doppler spectrum



Pisces measured Doppler spectrum.

2 first order Bragg peaks – darker shading.

Second order around higher Bragg peak – lighter shading.

What methods are available?

- Short-wave (wind) direction and spreading – from σ_1.

  [21], [11], [33], [32]
- Highly linearised or empirical estimates of waveheight, period, direction and $E(f)$ – from σ_2 normalised by σ_1

  [2], [1], [22], [28], [12], [31], [8], [26]
- Integral inversion – from σ_2 normalised by σ_1

  [19], [20], [29], [14], [23], [13], [30]

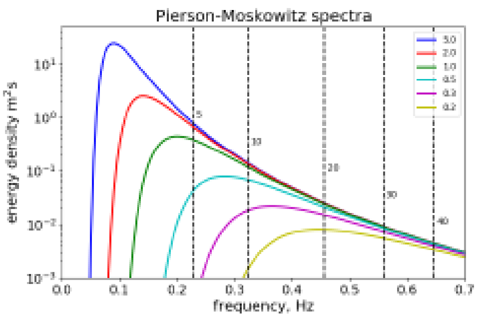
These methods have been applied to single and/or dual (or more) radar data.

11

What methods are available?

Short-wave (wind) direction and spreading

These methods make the assumption that the first order Bragg waves are local wind waves aligned with the local wind direction.



Pierson-Moskowitz ocean wave spectra [24] for the significant waveheights (metres) indicated.

Vertical dashed lines show the 1st order Bragg-matched linear wave frequencies for the radio frequencies (MHz) indicated.

The short-wave assumption is best at high frequencies and high sea-states.

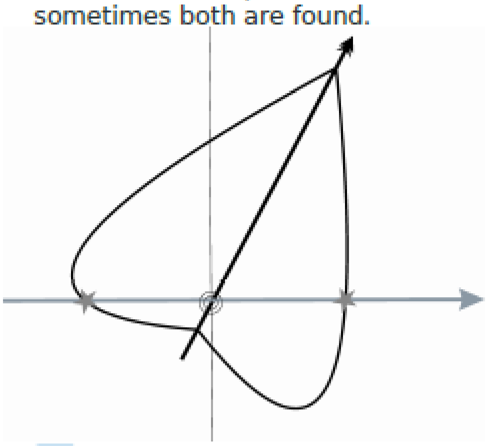
12

What methods are available?

Short-wave (wind) direction and spreading

Assume a short wave directional model e.g. $D(\theta_W, s) = \cos^s \frac{\theta - \theta_W}{2}$ or $D(\theta_W, \beta) = \mathrm{sech}^2 \beta(\theta - \theta_W)$ where θ_W is shortwave or wind direction, s or β describe the spreading about θ_W and $S(f_{sw}, \theta) = E(f_{sw}) D(\theta_W, spread)$.

Sometimes the spread is set to a fixed value e.g. $s = 4$ is quite common, sometimes both are found.



wind direction

radar look direction

★ magnitudes in and opposed to the radar look direction.

These are directly proportional to the first order peak amplitudes - see equation for $\sigma_1(\omega)$.

What methods are available?

Linearised and empirical methods

Barrick [2] showed how and under what conditions his equations could be linearised to obtain a weighted linear relationship between σ_2 and $E(f)$ thus confirming the suggestion of Hasslemann [9].

This has motivated other similar methods mostly involving modifications to the weighting using empirical methods (buoy data) [12], [8], [26].

At the time it was claimed that the result was independent of wave direction but this was subsequently questioned [27].

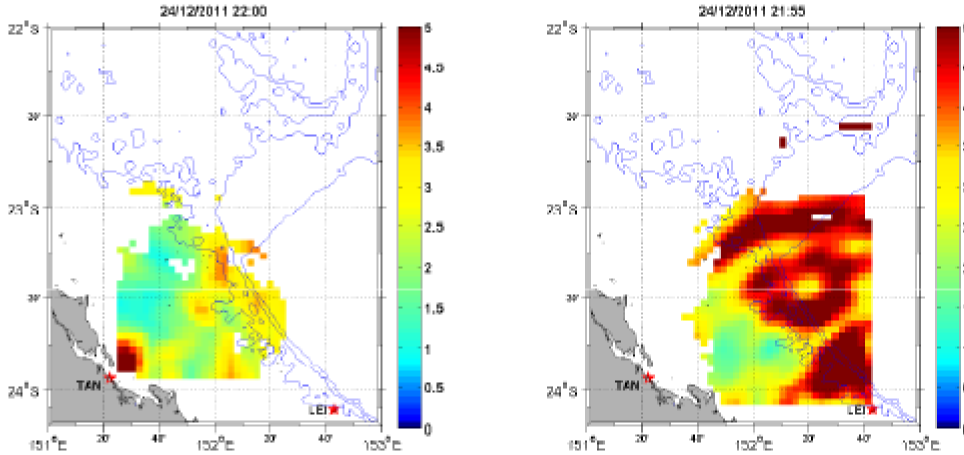
Others have derived empirical expressions for Hs, T1 by comparing integrals (possibly weighted) of σ_2 with buoy data [22],[28], [31].

In general these methods:

- cannot account for changes in water depth
- are sensitive to changes in wave direction, are often calibrated using buoy data for the local wave conditions and dominant directions and are thus not generally transferrable to other locations.

What methods are available?

Sensitivity to direction and averaging



Very different waveheights from the two radar systems looking at the sea from different directions. Need to combine information from at least 2 radars (or possibly different directions or frequencies) to get accurate measurements. More averaging also needed.

NB the above data are obtained with the standard WERA algorithm.

15

What methods are available?

Inversion

This involves simplifying [18]and discretising the equations, in some cases linearised by assuming a wind-wave model for $S(k', \theta')$, and solving using a numerical method which could involve:

- regularisation ([19], [20], [17]),
- singular value decomposition ([14]),
- constrained iteration ([29], [30], [7]),
- Bayesian methods ([23]),
- optimisation ([13]).

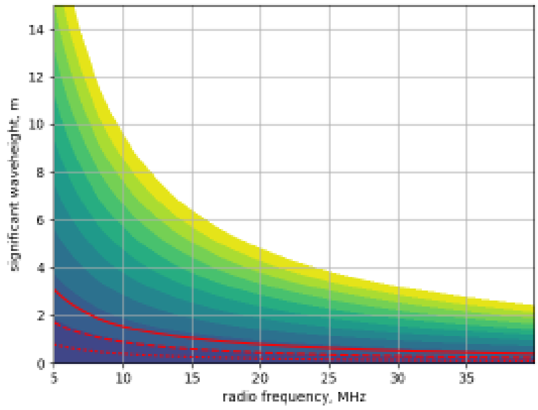
The solution in some cases gives the first five Fourier coefficients of the directional distribution (equivalent to a buoy measurement) and in others gives the spectrum on a wavenumber or frequency-direction grid from which all the Fourier coefficients can be obtained.

16

What methods are available

Frequency limitations

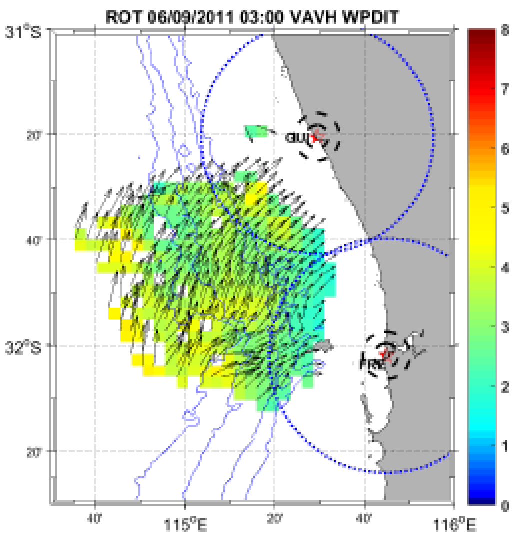
The important parameter that determines the maximum waveheight for validity of inversion and empirical methods is the **radio wavenumber x waveheight** shown here.



Linearisation becomes increasingly inaccurate as you move into the white region of the plot. Red lines mark lower limits for directional spectra (solid), waveheight (dashed) and wind direction (dotted).

What methods are available?

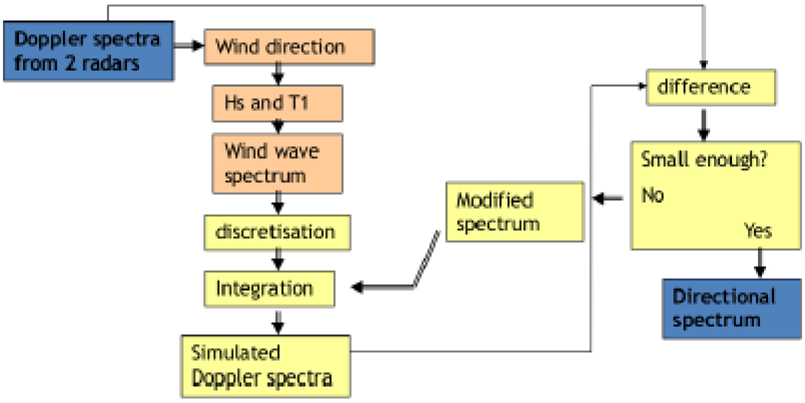
Difference between phased array and compact systems



1-hour average map of waveheight and peak direction measured with 8.512MHz WERA in West Australia. Maximum measured range is about 90km.

- SeaSonde inversions assume spatial homogeneity over a measurement annulus and use the antenna pattern.
- In 2014 paper [16] (4.5MHz in Scotland) waveheight and period were measured by averaging over 10 range bins (41km - blue dotted line - little variability reported over that range) and over 3 hours.
- Measured direction found to vary so only measurements close to the radar sites used - black dashed annulus.

The Sheffield-Seaview method



Wind direction - using maximum likelihood method

Hs and T1 using empirical formulae

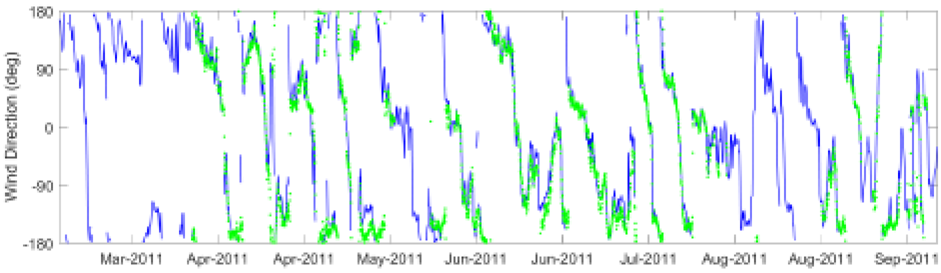
Integration - evaluation of RHS of 2nd order equation.

Modification - uses difference and the value of the coupling coefficient.

19

Accuracy and Limitations

Wind (short-wave) direction and spreading



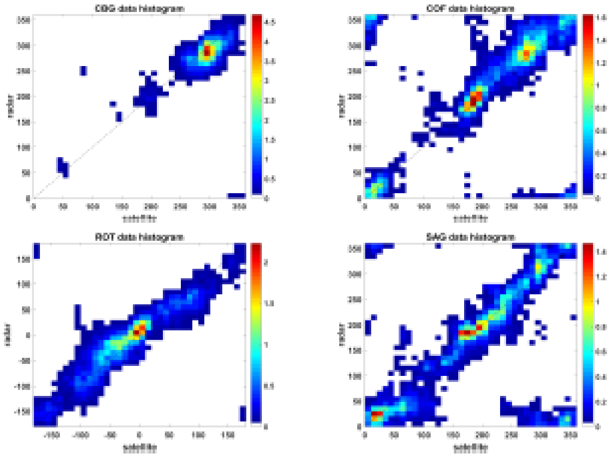
Tne series of wind directions measured with the WERA radar in South Australia compared with winds from a nearby Bureau of Meteorology automated weather station.

figure provided by Charles James, SARDI, SA, Australia.

20

Accuracy and Limitations

Wind (short-wave) direction and spreading



Comparisons of radar and scatterometer wind directions from locations around Australia.

The colour coding is percentage of observations in each 10° bin.

Maximum on the scale is set at 0.9 x the maximum percentage in any bin.

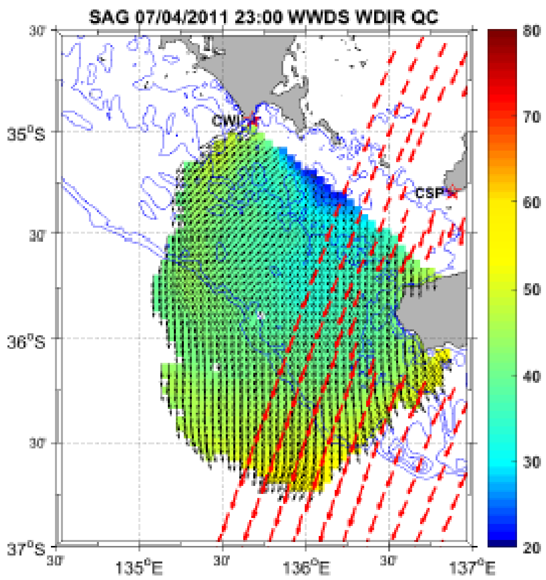
Bins with < 2% of the maximum are not shown

Statistic	CBG	COF	ROT	SAG
Number of data pairs	*11192*	*7058*	*18061*	*8426*
Direction difference °	*-8.13*	*8.08*	*6.80*	*3.33*
95% confidence interval	*0.43*	*0.68*	*0.39*	*0.56*
concentration	*6.71*	*4.37*	*5.09*	*5.30*
Complex correlation	*0.92*	*0.88*	*0.90*	*0.90*
circular correlation	*0.68*	*0.76*	*0.80*	*0.79*

21

Accuracy and Limitations

Wind (short-wave) direction and spreading

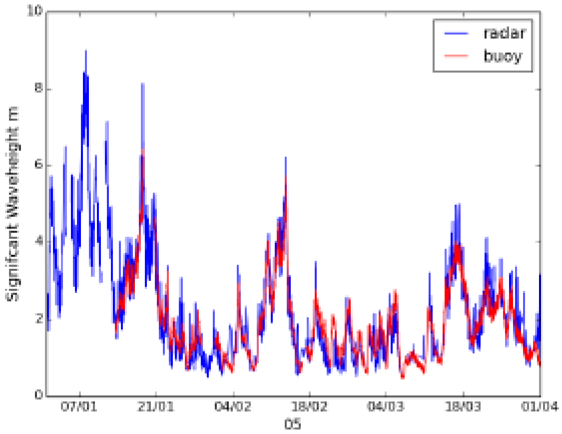


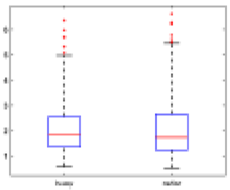
Radar wind directions (small black arrows) and spreading (colour-coded) with occasional overlays of scatterometer winds (red arrows scaled by wind speed).

22

Accuracy and Limitations

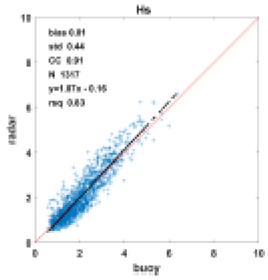
Waveheight



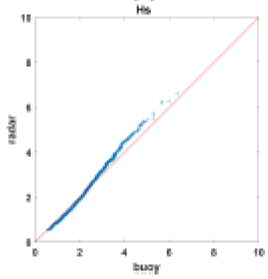


Box

scatter



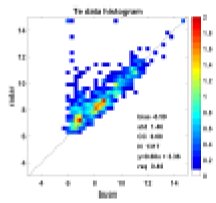
qq



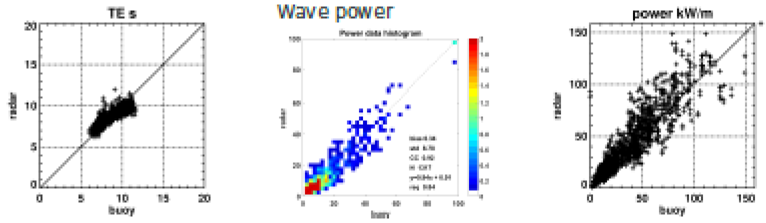
Accuracy and Limitations

Other wave parameters

Te



Wave power



Hs, Peak direction, Peak Period

Radar, wavebuoy, **SWAN wave model**

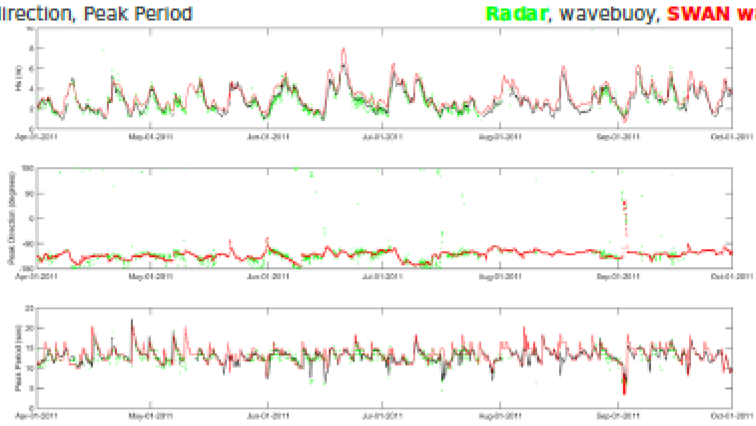
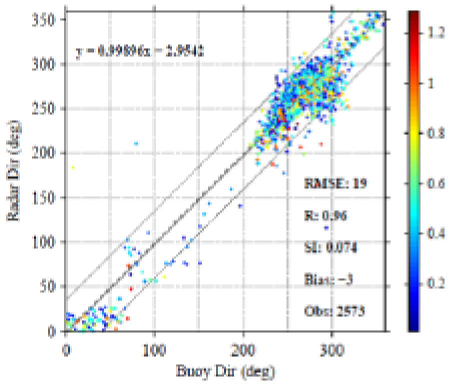


figure provided by Charles James, SARDI, SA, Australia.

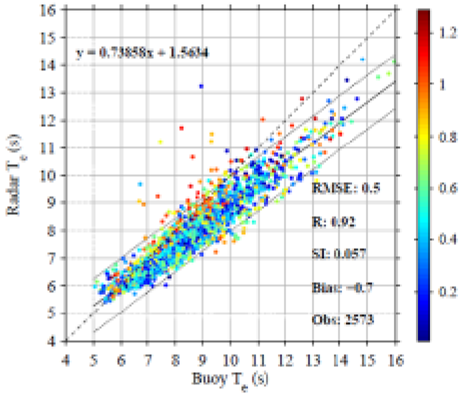
Accuracy and Limitations

Wave validations at Wavehub

Mean direction



Energy Period, Te

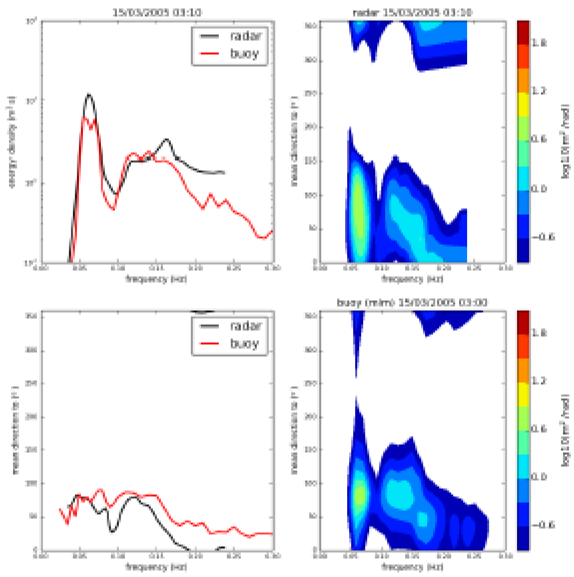


Colour-coding is current speed.

Kindly provided by Daniel Conley, University of Plymouth.

Accuracy and Limitations

Spectra



Notes

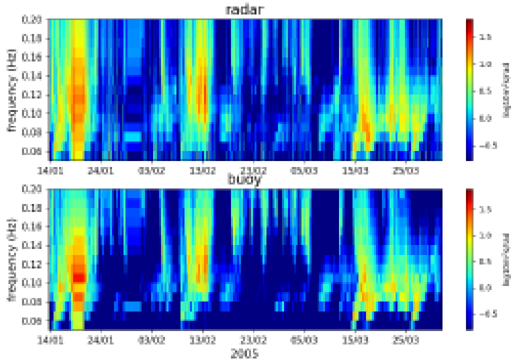
- Amplitude ranges are fixed and are logarithmic to allow better dynamic range.
- Radar has a high frequency cut-off that depends on radio frequency.
- Main differences tend to be at low frequencies (sidelobes, separation of 1st and 2nd order) , high frequencies (cut-off) and low seas (noise).

How can the comparison be quantified? [15], [10]

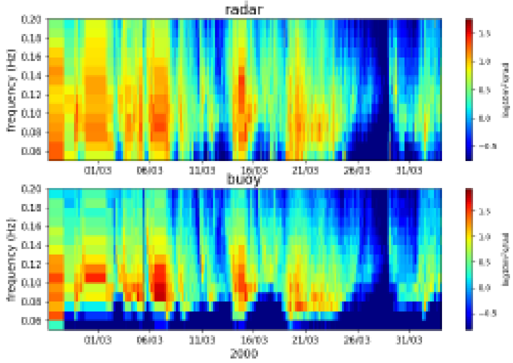
Accuracy and Limitations

Spectra timeseries

Pisces in Celtic Sea



WERA in Norwegian Sea



upper panel –radar
lower panel –buoy.

Accuracy and Limitations

Limitations, constraints and requirements

- Radar configurations not always optimised for waves.
- Separation of wave from current signal in noisy or highly dynamic environments is tricky.
- High waveheights cannot be measured with high radio frequencies (needed for high spatial resolution and interference avoidance), aiming to extend waveheight range using Creamer et al/Janssen formulation, preliminary results encouraging, yet to be fully implemented.
- Low waveheights cannot be measured with low radio frequencies (needed for long range and high sea measurement). Solution is to use a radar capable of operating over a range of radio frequencies with automated waveheight monitoring.
- Range and coverage not fixed – depends on radio frequency, interference environment, shipping, waveheight.
- Phased-array radars need to maintain low sidelobe levels for good quality wave measurement. *Need at least 16 antennas in the receive array to achieve this.*
- Averaging Doppler spectra over 20 minutes or more is needed – now implemented on some systems

The Seaview Software package

comprises:

- Creation of static data (and graphics) files containing deployment information '**.sdt**';
- Inversion configuration file editable by the user '**.conf**';
- Utility to read Doppler spectra files in various formats (WERA: '**.spec**');
- Core inversion in C: '**sea** *parameters Doppler-spectra*' ;
- Output to an hdf file '**.sea**';
- Post processing utilities mostly in Perl and GMT for plotting, text file creation, grib available, netcdf to come, database upload;
- Web-based data viewer;
- **man** pages and site-specific documentation.

Can be run offline (any Linux system) or within a server (Debian or Ubunutu).

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The Software package

The Sea program

Command line:

```
sea -c dual.conf -s SB2.sdt -v -o 201212032305.sea spec/20123382305_pen.SB2.spec spec/20123382305_per.SB2.spec
```

```
This is sea (version 5.45-pre7)
Copyright (c) 2004-2013 Seaview Sensing Ltd.
Copyright (c) 2001-2004 University of Sheffield
   exclusively licensed to Seaview Sensing Ltd.
All rights reserved
Using static data file
  ./SB2.sdt
Using configuration file
  ./dual.conf
Using Doppler spectrum files
  ./spec/20123382305_pen.SB2.spec
  ./spec/20123382305_per.SB2.spec
Directional wave spectrum output file is
  201212032305.sea
Inverting all cells.
      9 in total
      9 initial quality values
      9 with radials
      9 with current data
      9 pass current quality test
      9 have neighbours
      9 segmented
      9 model beams
      9 model cells
      9 with feasible HF spectrum
      9 of invertible quality
      9 have neighbours
      9 to invert
Wrote global data
LKB discretisation is square grid 1:3
Inverting with Chahine-Twomey-Wyatt (CTW)
  iterations 100
  relaxation 1.00
Row-access is heuristic fold
Linear Creamer multiplier 1.00
3.24 0.912 0.911 [1] 3.22 0.913 0.912 [2] 3.17 0.916 0.915 [3] 3
0.896 [4] 3.41 0.903 0.902 [5] 3.30 0.909 0.908 [6] 3.19 0.914 0
3.15 0.916 0.916 [8] 3.16 0.916 0.916 [9]
9 cells inverted
[1] [2] [3] [4] [5] [6] [7] [8] [9]
9 cells post-processed
Inversion completed (0 sec, 0.05 sec/cell)
```

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The Software package

Post-processing Utilities

Command line: *seahs -b all -o hstest 201212032305.sea*

Output file:

1	-5.622746	58.350728	0.0452	0.2525	2.538	7.577	7.121	6.922	93.17	28.896
2	-5.622746	58.341723	0.0466	0.2545	3.144	7.639	7.098	6.973	98.94	37.250
3	-5.622746	58.332723	0.0470	0.2778	3.132	7.128	6.576	6.719	94.03	37.255
4	-5.608562	58.350728	0.0452	0.2635	3.819	7.408	6.936	7.119	97.58	34.459
5	-5.608562	58.341723	0.0466	0.2755	2.835	7.143	6.612	6.899	97.43	34.835
6	-5.608562	58.332723	0.0480	0.2795	3.487	7.047	6.508	6.812	98.25	34.578
7	-5.594380	58.350728	0.0486	0.2658	3.434	7.229	6.742	7.069	102.10	35.262
8	-5.594380	58.341723	0.0507	0.2895	3.564	7.113	6.678	7.535	96.66	38.298
9	-5.594380	58.332723	0.0499	0.2725	3.497	6.888	6.656	6.630	95.59	36.129

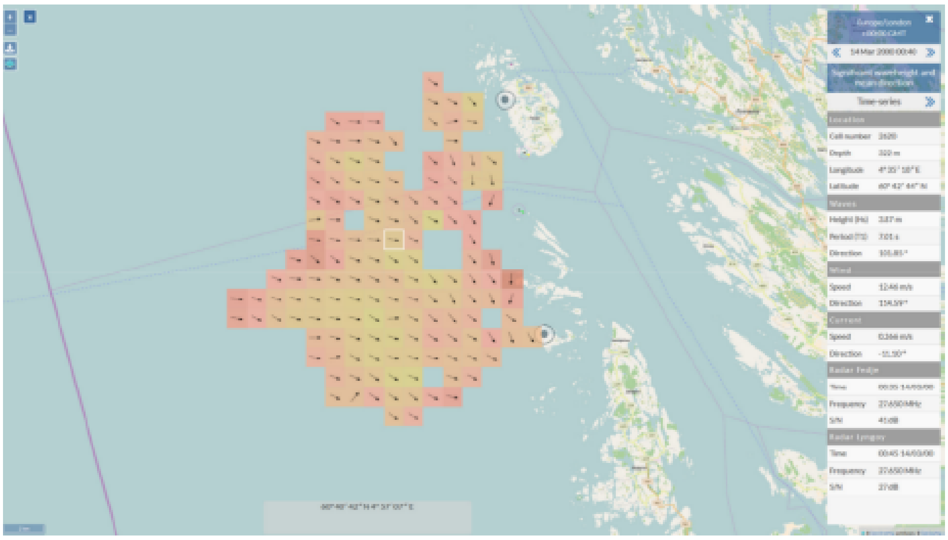
The whole '***.sea***' file can be explored using ***h5dump***.

Corresponding *man* page:

```
HSI(5)                    File Formats Manual                    HSI(5)

NAME
       hsi - sea inverted significant waveheight file format.

DESCRIPTION
       The hsi file format describes the multi-beam inverted significant wave-
       height data extracted from sea(5) files by the seahs(1) utility.

       The data is obtained by integration over the directional wave spectrum,
       the  upper  and  lower limits (in frequency) of the integration are the
       bands of the data. The seahs(1) can create files of several bands,  but
       all are identical in their format.

       The  format  is plain ASCII. Each file consists of a number of records,
       one per line. There are no header or footer lines.

       See the sea format documentation, seaspi.pdf for  more  information  on
       these data.

       A record consists of the

              the cell id

              The latitude in degrees

              The longitude in degrees

              the lower limit of integration of wave frequency (Hz)

              The upper limit of integration of wave frequency (Hz)

              the significant waveheight (metres)

              the period's first moment T1 (seconds)

              The period's second moment T2 (seconds)

              Period of the spectral peak (seconds)

              the wave direction (degrees clockwise from North)

              The wave spread (degrees)

SEE ALSO
       seahs(1)

AUTHOR
       J.J.Green
       SeaView Sensing Ltd

                              19 March 2008                      HSI(5)
```


The Software package

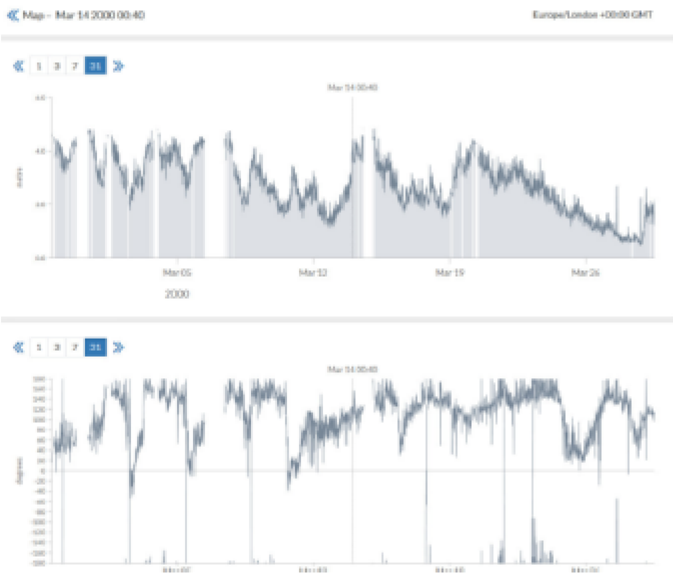
The Data Viewer



▸ viewer

The Software package

The Data Viewer



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Endorsements

"Empirical and theoretical wave algorithms provide reliable estimates of Hs. Seaview delivers high quality direction estimates and good frequency distribution of energy"

Daniel Conley, University of Plymouth, UK, from a presentation at UK Challenger Conference, 2016.

" I am happy to endorse Seaview HF radar processing software. I would especially like to complement Seaview on customer support during our preparation phase, through onsite installation, and in supporting our desired use of the software. We found your team to be informative and responsive as we developed our onsite hardware planning in preparation for installation. I would argue that the scientific expertise resident in Seaview's human capital should be considered a significant selling point."

Dana Savidge, University of Georgia, Skidaway Institute of Oceanography, USA, extracts from a letter of support

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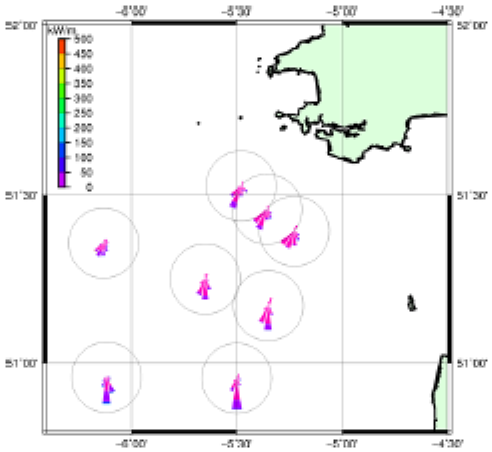
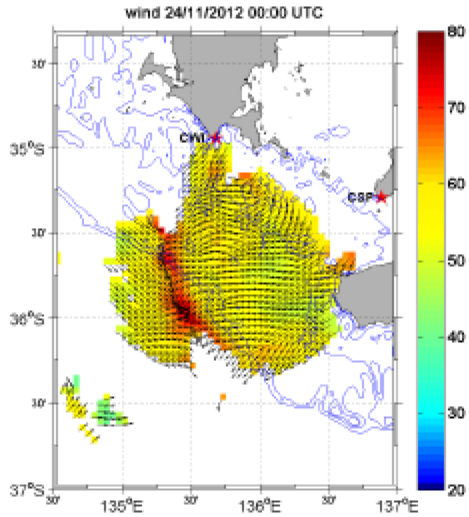
Some examples

Directional distribution of wave power during Feb 2005 in Celtic Sea.

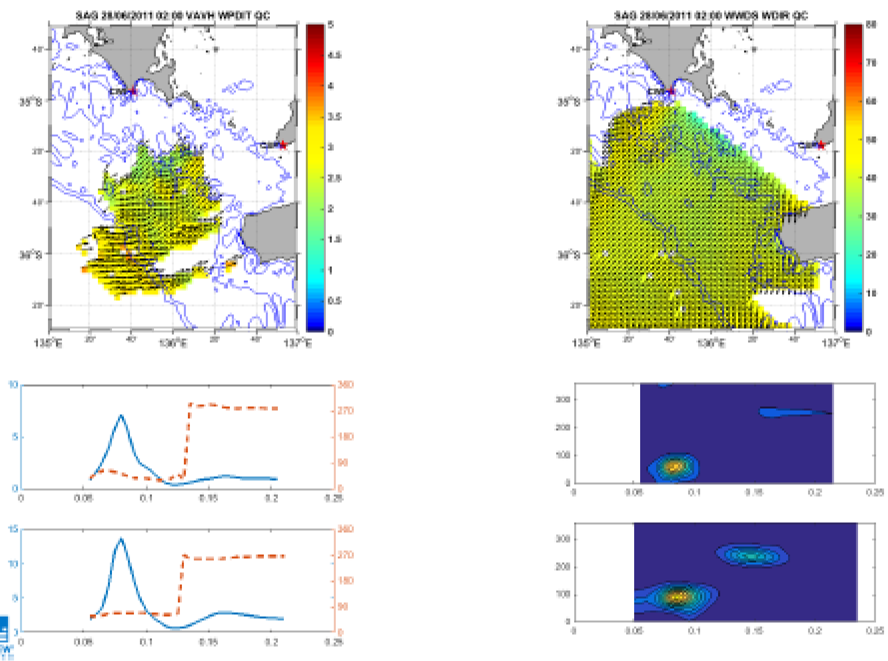




Weather front seen in radar wind direction and spreading map.

Some examples

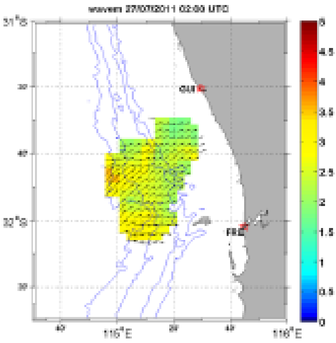
Wave data from South Australia



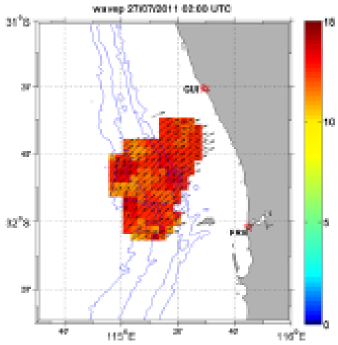
Some examples

Wave data from West Australia

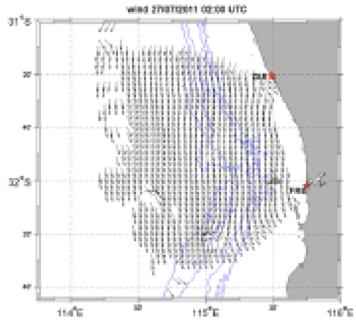
Hs



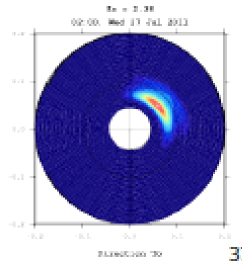
Tp



Wind direction



Depth contours at 50, 100, 200, 500m



Directional spectrum

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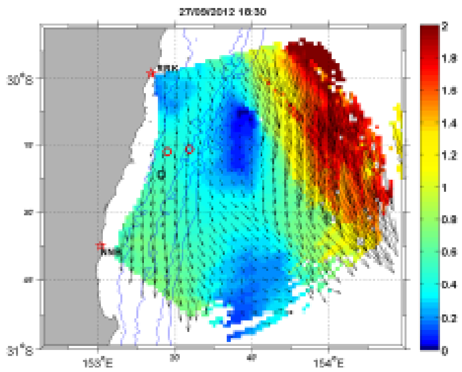
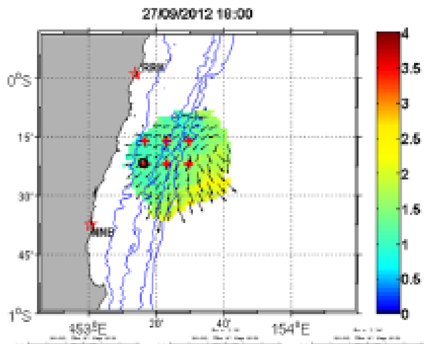
Some examples

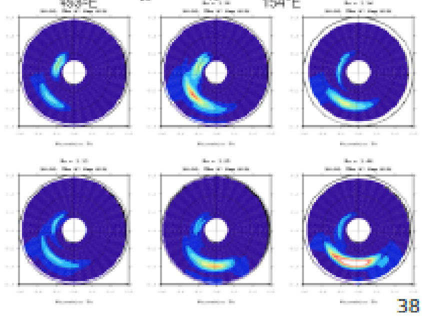
Data from Coffs Harbour, NSW

Current



Hs and mean direction





directional spectra at red crosses

38

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***資料來源：Seaview Sensing Software軟體由英國Seaview Sensing Ltd and School of Mathematics and Statistics University of Sheffield (Lucy R. Wyatt教授)製造商及臺灣代理智統科技工程(股)公司提供或協助說明**

附錄 C　　出國報告簡報

『離岸風能場遴近海岸漂沙機制探討』-
試驗室造波機購置赴原廠進行技術交流活動
簡報人：李政達、林受勳
Institute of Transportation,MOTC
交通部運輸研究所
出國計畫簡報
中華民國 107 年 2 月

簡報大綱
簡報大綱
出國行程
實習訓練
技術交流
心得建議
第一部份 實習訓練 (HR Wallingford)
第二部份 技術交流 (Biral / Gill / WERA)
第三部份 心得建議
研究人員 林受勳
研究人員 李政達
Biral
WERA
GILL
SEAVIEW
106.12.12(二)~12.20(三)
HR Wallingford

倫敦：希斯洛機場

終於抵達 倫敦

實習訓練

HR公司-牛津附近
瓦靈福德

實習訓練

HR公司-上學路線

- 每天上學的路線=downtown+ Thames river + Benson road
- 氣溫0~5度
- 距離2km，每天走30分鐘(早出晚歸)

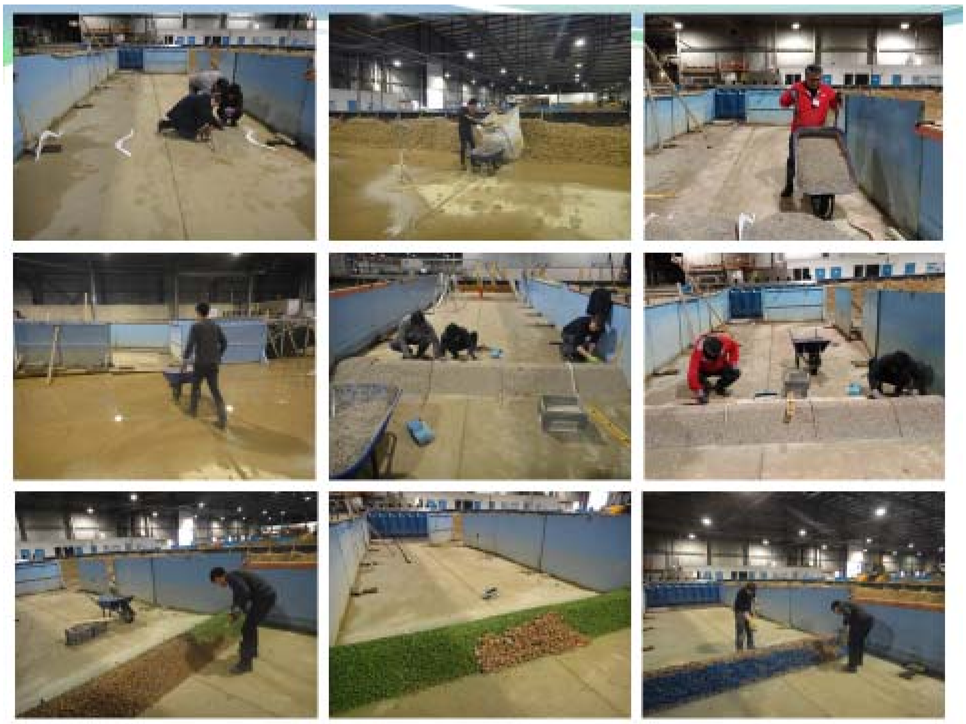
實習訓練

本訓練-2大目的

- 討論造波系統細部設計
- 實習訓練


實習訓練
認識環境
DEFINITIONS


實習訓練
水工模型試驗



實習訓練
學習操作軟體
■ HR DAQ 資料擷取系統
■ 造波程式

實習訓練

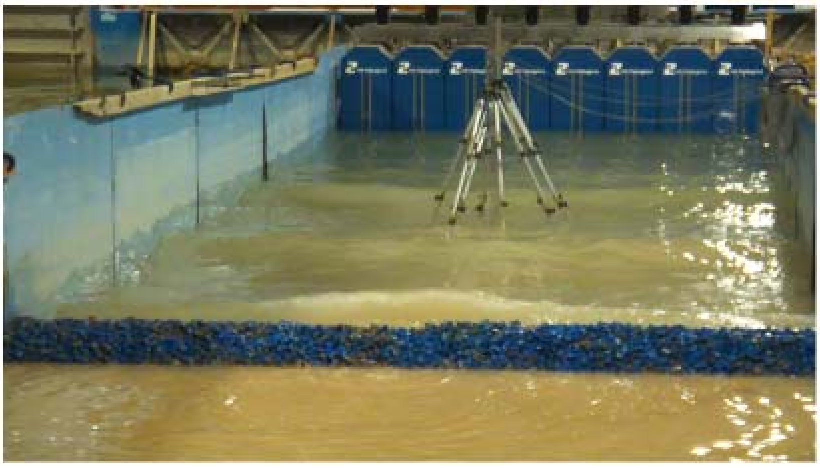
學習 HR rating 方式

- DR Ian 向我們解說波高計率定的方式
- 光達掃描器

實習訓練

學習HR造波系統

- 歸零
- 輸入 JONSWAP 頻譜造波

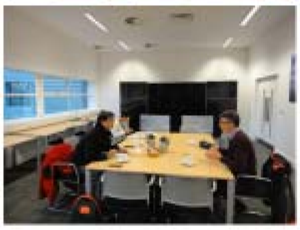


實習訓練

LiDar 防波堤穩定分析

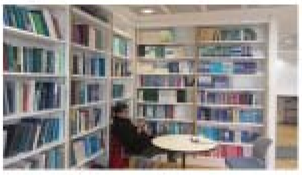
實習訓練

Day4 各部門會議



實習訓練

圖書與咖啡室



- 咖非-閱讀-社交-小憩

Biral

能見度專家


Biral
能見度專家


WERA
海洋雷達的專家
HÄFELE
Hamburg 漢堡
Germany
WERA


WERA
技術交流臺中計畫
■舊系統說明
■未來擴充的需求(地點、範圍加大)
船舶追蹤、海嘯模擬


WERA
未來技術交流-臺德計畫
WERA

GILL（英國）

氣象儀器專家

- ■Gill產品：風、流速計…
- ■買儀器送即時網站Show出目前天候

製造工廠

全自動化生產設備
銷售全球

風洞實驗

全自動化校正設備

GILL

循環風動實驗室

SEAVIEW

海洋處理軟體

- 地點：瓦林福德小鎮
- Seaview sensing Lucy教授
- 介紹軟體，並以澳洲案例，分析具體成效。

心得結論

1. 綜觀整個水工模型試驗廠棚，隨處可見造價昂貴之蛇型造波機，反觀臺灣目前僅存一部蛇行造波機於臺灣海洋大學，訓練期間在HR公司遇上中國上海船舶運輸科學研究所的工程師及項目經理，他們特此考察已投資購買蛇行造波機，讓我們深覺自身競爭力明顯不足。
2. 走進HR公司試驗廠棚內，整個實驗室工作設備一應俱全，不論任何研究課題，技術人員皆能佈設處理試驗場地，觀察棚內的使用情形，察覺每個場區都配有專責人員負責綜理實驗進度，整體使用率高達八成以上，少有閒置場地，顯示該公司業務量龐大，工作應接不暇。
3. 辦公室圖書室內設有咖啡休息區，可供研究人員查詢資料並稍做短暫休憩，讓整個工作士氣全然不同；整個HR公司隨處保持整潔乾淨，特別是水工模型試驗場更是維持的井然有序，不經讓我們佩服HR公司技術人員的自我紀律。
4. 幾天的訓練課程下來，客觀來說辦理水工模型試驗的架構，其實與臺灣無異，只差別在於環境、設備及軟體，但在實驗上的精神大同小異，可能是保持學習的心情前來，總讓人感覺HR公司的各項措施印象深刻。
5. 本次訓練受益良多，希望國內從業研究人員能有更多機會出國訪問或訓練，以反省改進不足漸長國家實力。

簡報結束

敬請給予指教與建議