出國報告（出國類別：開會）

參加第 28 屆國際離岸與極地工程學會 ISOPE2018 及宏偉再生能源國際研討會 GRE2018 出國報告

服務機關：核能研究所
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林獻洲 技術員
派赴國家/地區：日本/札幌、橫濱
出國期間：107 年 6 月 10 日~107 年 6 月 22 日
報告日期：107 年 7 月 19 日

摘要

此次公差主要為配合核能研究所執行科技部離岸風力及海洋能源主軸計畫「離岸風機固定式水下結構關鍵技術開發」、「防颱抗震型離岸風機支撐結構整合設計驗證技術精進」及中央計畫「風能系統工程技術開發與研究」，前往日本札幌參加第 28 屆國際離岸與極地工程學會(ISOPE, International Society of Offshore and Polar Egnineering)研討會及出席於橫濱舉行的 2018 年宏偉再生能源國際研討會及展覽(GRE 2018, Grand Renewable Energy 2018 International Conference and Exhibition)，分別發表計畫研究會議論文與邀請專題演講。本所機械系統工程專案計畫主持人黃金城博士、助理研究員樊庭宇先生、助理研究員賴文政先生與技術員林獻洲先生共 4 員前往參加 ISOPE 並發表論文三篇，黃金城博士於結束 ISOPE 國際研討會之後，則應邀前往出席 GRE 2018 研討會並進行風能研究專題演講。

會議期間聆聽各國專家學者離岸風機技術簡報並交換研究心得、技術討論及蒐集有關技術資料，以了解及增進國際離岸風機發展走勢及研究方向。目前國際風機大廠 Senvion 已經宣布 10MW 風機樣機(Prototype)訊息，以及 MHI Vestas 及 Siemens 公司皆有 8MW 風機機組之量產及風場應用；特別是 MHI Vestas 公司更是著手準備升級旗下 9MW 離岸風機 V164 以應付台灣多颱風的運轉條件，顯示超大型離岸風機已確定為目前國際離岸風電發展趨勢。除了已被廣泛使用的固定式水下結構，與超大型風機結合的浮動式基礎結構相關研究增加許多。其次則是著重於基礎載重計算的分析方法，如何同時考量風、波及地震等負載研究對於離岸風機基礎結構影響。

經濟部已完成我國 2025 年完成離岸風電 5.5GW 裝置容量的規劃，總計遴選 3.84GW 容量及競價 1.66GW 裝置容量，建議應進行具目標性的整合技術研究開發，結合產業界合作，建構國內自主化的離岸風力發電技術，協助推動國內離岸風場之技術支援及產業發展。

關鍵字：再生能源、離岸風力、支撐結構、疲勞分析、可靠度分析

目 錄

一、目　的

此次公差主要為配合核研所目前執行的科技部離岸風力及海洋能源主軸計畫「離岸風機固定式水下結構關鍵技術開發」、「防颱抗震型離岸風機支撐結構整合設計驗證技術精進」及中央計畫「風能系統工程技術開發與研究」，前往日本札幌參加第 28 屆國際離岸與極地工程學會(ISOPE, International Society of Offshore and Polar Egnineering)研討會及出席於橫濱舉行的 2018 年宏偉再生能源國際研討會及展覽(GRE 2018, Grand Renewable Energy 2018 International Conference and Exhibition)，分別發表計畫研究會議論文與邀請專題演講。於 107 年 6 月 10 日 ~107 年 6 月 15 日參加 ISOPE 2018，並在會議中發表「Numerical Fatigue Analysis for Jacket-type Substructure of Offshore Wind Turbines under Local Environmental Conditions in Taiwan」、「Study on Fragility Curves for Support Structures of Wind Turbines Under Earthquake in Taiwan」與「Dynamic Load Comparison between Fully Coupled and Simplified Models on Offshore Wind Turbines with Jacket Support Structures under Seismic Conditions」三篇研究論文，以增添科技研究計畫的研究成果。

本所機械系統工程專案計畫主持人黃金城博士、助理研究員樊庭宇先生、助理研究員賴文政先生與技術員林獻洲先生參加 ISOPE 研討會，除了發表計畫研究成果相關論文，亦參加其他領域論文發表場次，聽取各國專家學者簡報以掌握國際研究趨勢與發展。而配合目前所執行的研發計畫需求及相關專長，主要參與離岸浮動風機負載計算、支撐結構疲勞簡化分析、可靠度分析應用等相關議題，並與國外離岸風電技術相關領域專家學者交換研究心得，了解國外於離岸風機設計研究等相關技術，獲益良多。藉由參與此盛大的國際技術研討會議除發表會議論文，並蒐集離岸風力相關的研發技術資料，以了解目前各國研究單位最新的發展及方向，將有利於本所後續研發工作執行、技術精進與未來離岸風電研發計畫之規劃與推展。

黃金城博士於結束 ISOPE 2018 海洋與極地工程國際研討會之後，應邀前往出席於橫濱舉行的 2018 年 GRE 2018 宏偉再生能源國際研討會及展覽，並發表離岸風力專題演講，講題為「THE DEVELOPMENT OF OFFSHORE WIND POWER IN TAIWAN: CHALLENGES AND PROSPECTS」與國際學者專家及相關業者，進

行技術交流及分享國內離岸風電的開發現況與未來面臨的挑戰及前景。

GRE 2018 宏偉再生能源國際研討會及展覽，每 4 年舉行一次。主要由日本再生能源委員會(Japan Council for Renewable Energy, JCRE)、國際太陽能協會(International Solar Energy Society, ISES)、新能源及產業技術總合開發機構(New Energy and Industrial Technology Development Organization, NEDO)、國立產業技術總合研究所(National Institute of Advanced Industrial Science and Technology, AIST)、日本科技代辦處(Japan Science and Technology Agency, JST)、名古屋工業科學研究院(Nagoya Industrial Science Research Institute, NISRI)、新能源基金會(New Energy Foundation, NEF)、日本太陽能協會(Japan Solar Energy Society, JSES)和日本風能協會(Japan Wind Energy Association, JWEA)共同主辦。本次國際會議中之專題演講，主要邀請來自美國、德國、中國、英國、義大利、冰島、芬蘭、韓國、日本及台灣等各國專家學者參與。黃金城博士則受邀擔任其中風能技術主題的邀請專題演講專家，與各國與會者互相交流並提升台灣於重要國際研討會議的能見度，相當榮幸。而促成本次邀請專題講座的機會，主要是過去幾年本所積極參與科技部能源國家型(NEP-I/II)離岸風力主軸計畫，負責國內離岸風機及支撐結構整合動態載重驗證技術，並特別針對國內極端氣候影響條件如颱風及地震進行考量。而相關技術成果除發表國際會議及期刊論文，也多次針對極端氣候與目前擔任日本風能協會會長的東京大學石原教授(Prof. Ishihara)交流，並曾於 106 年邀請石原教授蒞臨本所參訪及進行講座。由於石原教授亦是 GRE 2018 的專題委員會主席(Program Committee Chair)，因此於 106 年 9 月邀請本所黃研究員擔任 GRE 2018 風能技術專題的邀請講座。而藉由本次參與重要再生能源國際研討會的機會，對於目前國內推動的離岸風電重要建設的科研及技術提升與強化國際合作，相信將有一定程度的貢獻。

二、過　程

本次行程由 107 年 6 月 9 日至 6 月 16 日，共計 8 天，參加於北海道札幌舉行 ISOPE 2018 研討會，相關行程規劃(如表一)。此行目的主要為參與國際研討會發表論文，以提升計畫研發績效，推展離岸風電國際技術交流與合作，並瞭解目前最新國外在風機設計驗證技術、離岸風機負載計算、支撐結構及組件設計分析等之研究成果，俾利本所離岸風力技術團隊未來研發計畫之規劃與執行。

表 1 參加 ISOPE 2018 公差行程表

日期	行程
6/9(星期六)	去程
6/10(星期日)	簡報資料整理與報到
6/11 — 6/15(星期一至星期五)	參加 ISOPE 2018 研討會
6/16(星期六)	回程

(一)、6 月 9 日至 10 日，去程及簡報資料整理與準備

於 106 年 6 月 9 日週六上午由桃園機場搭機前往北海道札幌((圖 1)，約於當地時間 6 月 9 日週六下午 3 點多抵達北海道新千歲機場，再轉搭鐵路前往本次研討會舉辦地點為 Royton Sapporo Hotel。6 月 10 日週日則前往會場辦理報到事宜以及彙整後續研討會簡報之資料。

圖 1 北海道札幌

(二)、6 月 11 日至 6 月 15 日，ISOPE 2018 研討會

6 月 11 日研討會正式開幕，圖 2 為本所與會人員於 ISOPE 2018 會場之合影。本次大會由 ISOPE 主席 Hiromitsu Kitagawa 博士致詞並隆重舉行開幕儀式，如圖 3 由 Hiromitsu Kitagawa 博士主持開幕儀式所示。接著進行多場專題演講，題目分別為「Global Energy Outlook and Its Implications」,「Floatover Installation Technology in South China Sea」,「Sea Ice Research: Recent Findings and Outstanding Issues in Relation to Arctic Development」與「Hydrogen Trapping Sites and Hydrogen Embrittlement of Iron and Steels」等，其中與離岸風電最為相關的專題，則由 Mr. Laurent-Baudoin Krameru，演講關於離岸風機固定式支撐結構之發展現況及前景，其專題題目為「Status & Outlook for Offshore Bottom Fixed Wind Turbine Support Structures」，如圖 4 所示。

圖 2 於 ISOPE 2018 研討會會場合影，由左依序為林獻洲先生、黃金城組長、樊庭宇先生與賴文政先生等

該場專題演講尤其提及離岸風機超大型化趨勢已逐漸發展，目前國際風機大廠 Senvion 已經宣布 10MW 風機樣機(Prototype)訊息，而三菱重工維特斯(MHI Vestas)已經著手準備升級旗下 9MW 離岸風機 V164 以應付台灣多颱風的運轉條件。然而，面臨風機超大型化趨勢下，必須提升支撐材料強度與尺寸大小的挑戰，因此在鋼材的製造與施工上成本提高以及製造組裝的難度。此外，目前世界各國已積極發展再生能源，更以風力發電為積極投入開發的項目之一。截至 2017 年，

全世界風力發電裝置已達 18GW 以上，其中歐洲地區風力發電裝置容量更是佔全球 84%比例，當中英國最高，其次依序為德國、中國與丹麥等。綜觀而言，各國離岸風電項目目前發展規劃主要落在 2022 年至 2025 年間，而國內也預計於 2025 年完成 5.5GW 離岸風電容量設置，因此可參考國外風電發展的經驗，作為有力的借鏡，順利推動國內推動離岸風電之建設。


ISOPE - 2018
Sapporo, Japan, June 10-15
Ocean Arctic Energy
www.isope.org
Hokkaido Government City of Sapporo

圖 3 由 Hiromitsu Kitagawa 博士主持開幕儀式


Status & Outlook for
Offshore Bottom Fixed
Wind Turbine Support Structures
Keynote
by L.B. Kramer
ISOPE-2018 Sapporo Conference
The 28th International Ocean and Polar Engineering Conference
Sapporo, Hokkaido, Japan, June 10–15, 2018: www.isope.org
ISOPE
OWEC

圖 4 Laurent-Baudoin Krameru 先生之專題演講

研討會正式開幕後，接著連續五天的論文發表與專題討論等議程已預先排定於各會議室，除了首日為開幕儀式，議程從 10:30 開始之外，其餘四天議程皆由

上午 8:00 到下午 18:20，總計 151 個技術會議，3 團體會議，5 個專題演講以及多個重點會議等，顯示此會議規模盛大。大會期間於會場和許多國內外學者專家交流，亦包含來自台灣各大學教授及研究單位的研究人員(如成功大學土木工程系的胡宣德系主任、成功大學水利工程學系的楊瑞源教授、海洋大學的簡連貴教授、財團法人台灣營建研究院的張嘉峰副所長等人)。

藉由本次的參與，不僅了解國際上離岸風電與海事工程之研發趨勢，同時也與國內參與的教授學者交換心得，並於會議期間每日晚上用餐時，職等亦針對今日之見聞與議題內容進行意見交換及討論，同時審慎檢視大會議程以決定接續欲聆聽論文發表場次。

本次發表 3 篇論文，被安排之場次分別於 6 月 11 日(一)上午 10:30 之 RENEWABLE ENERGY Ⅰ ：Support Structures(V.1)以及 6 月 12 日(二)上午 10:30 之 RENEWABLE ENERGY Ⅴ ：Offshore Wind Simulations(V.1)進行，每人簡報時間約 15 分鐘，提問與討論約 5 分鐘。於 6 月 11 日首先由本所助理研究員樊庭宇先生發表論文 「Numerical Fatigue Analysis for Jacket-type Substructure of Offshore Wind Turbines under Local Environmental Conditions in Taiwan」; 論文主要內容為依據台灣預定風場環境參數與土壤條件下，進行離岸風機桁架式支撐結構之結構疲勞分析與疲勞損傷評估，並提出適用於初始設計階段的載重計算程序，成果可有助於國內風場規劃時，支撐結構選定與成本估算之用。本篇論文摘要請參考附錄二。

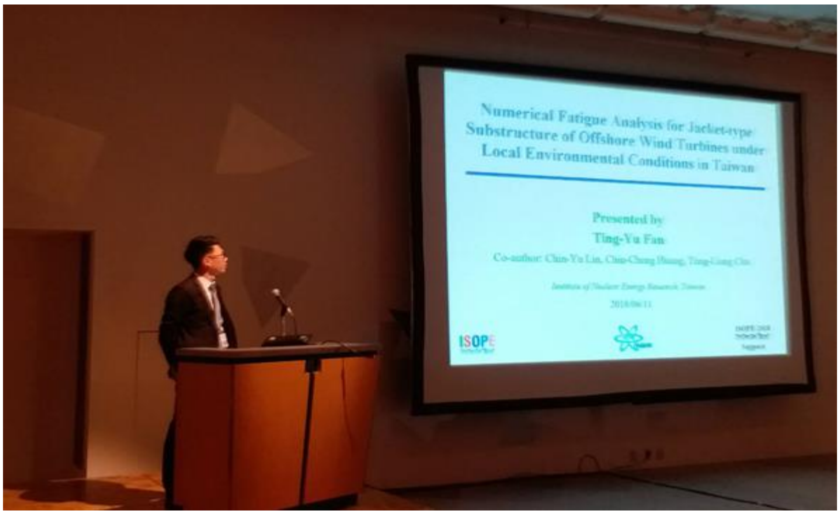
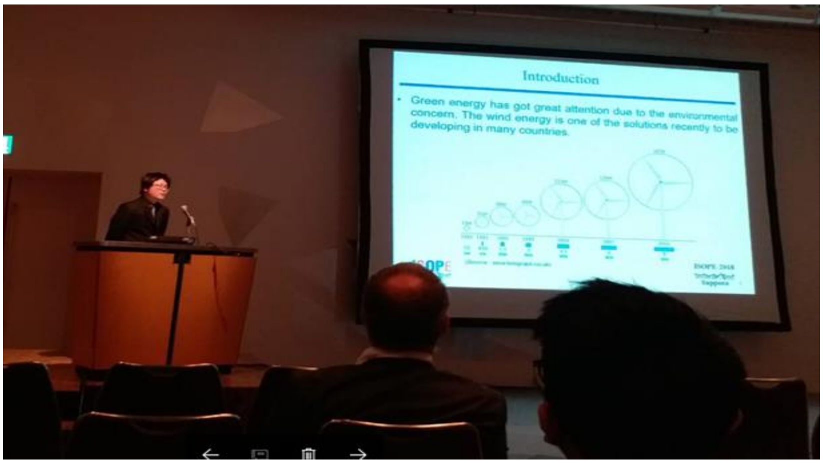


圖 5 樊庭宇助理研究員進行論文發表

其次則由本所技術員林獻洲先生發表論文「Study on Fragility Curves for Support Structures of Wine Turbines under Earthquake in Taiwan」；本研究為蒐集台灣集集地震資料，進行離岸風機系統支撐結構地震反應譜分析以及量化可靠度計算，其研究結果可作為國內離岸風機支撐結構安全評估指標及訂定設計準則之參考依據。本篇摘要則請參考附錄三。

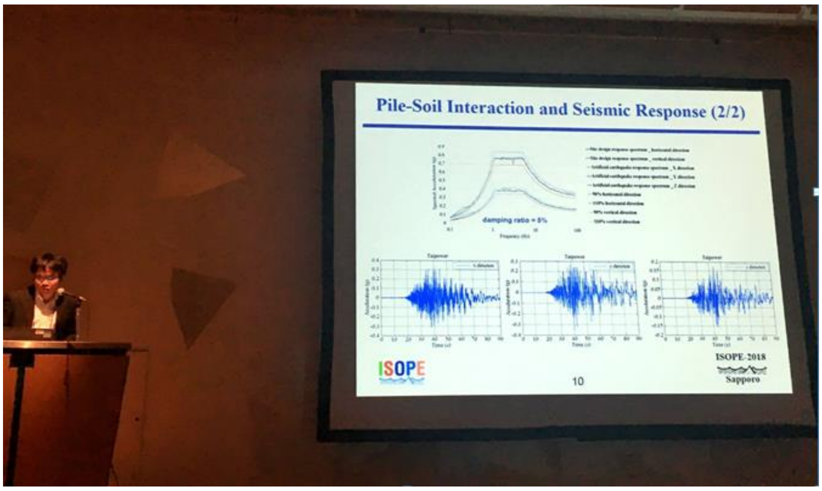


Introduction

- Green energy has got great attention due to the environmental concern. The wind energy is one of the solutions recently to be developing in many countries.

圖 6 林獻洲技術員進行論文發表

6 月 12 日於研討會則由本所助理研究員賴文政先生，發表論文「Dynamic Load Comparison between Fully Coupled and Simplified Models on Offshore Wind Turbines with Jacket Support Structures under Seismic Conditions」；本篇論文研究為考量極端環境條件下(地震)，進行離岸風機與桁架式支撐結構整合動態載重計算，運用 NREL FAST 建立一套快速簡易的分析方法，並藉由風機分析軟體 BLADED 以驗證其方法的正確性及精確度。該分析方法可提供國內風電業者使用，以利加速整體支撐結構設計所需之時程。本篇摘要請參考附錄四。



Pile-Soil Interaction and Seismic Response (2/2)

圖 7 賴文政助理研究員進行論文發表

職等除發表論文之外，亦參加其他領域之論文發表場次，聽取各國專家學者之研究精髓。配合目前所執行的離岸風力研發計畫需求及相關專長，在會議期間參與離岸風機負載計算、支撐結構及組件設計分析等議題專題討論並與國外離岸風電技術相關領域專家學者交換研究心得，了解國外於風機設計驗證相關技術，收穫豐碩。以下就針對部分參與及蒐集的重要相關之研究議題進行簡述及說明：

1.「Comparison of Integrated and Sequential Design Approaches for Fatigue Analysis of a Jacket Offshore Wind Turbine Structure」

One of the most important criteria in the design of fixed offshore wind turbine structures is fatigue resistance. There is an unabated need for research in order to improve and optimize current design methods. There are mainly two approaches for structural analysis available in the offshore industry: the Integrated Design Approach (IDA) and the Sequential Design Approach (SDA). Within the IDA, the entire wind turbine, consisting of the jacket structure including tower and the rotor nacelle assembly (RNA), is considered as a unique system exposed to wind- and wave-induced loads in an aero-hydro-elastic solver. In SDA, the jacket structure is converted into a superelement and implemented into an aero-elastic solver, where it is expanded by RNA in order to obtain the wind-induced interface loads. The obtained interface loads are used for further analysis in a more advanced offshore code, where the wave-induced loads are simulated. The fatigue damage of the relevant K-joint in the support structure is afterwards compared to the one obtained in terms of IDA. Apart from the judgment about advantages and disadvantages of both approaches, this work benefits from confirming the reliability and applicability of both approaches.

此篇論文目的係探討目前於離岸風機支撐結構分析中廣泛使用的兩個方法，分別為 Integrated Design Approach (IDA)以及 Sequential Design Approach (SDA)。疲勞分析與疲勞損傷的評估是固定式支撐結構在設計上很重要的一環，然而執行完整的疲勞分析程序需要耗費相當大量的計算時間，因此截至目前為止，仍有許多的研究係探討如何改進目前的設計方法與程序。本篇研究成果除了指出上述兩方法的優缺點以外，亦進一步探討其可靠性和適用性。文中說明 IDA 的計算結

果較準確、省時但僅適用於樑元素的分析，而 SDA 透過簡化成超級元素(superelement)時，雖然可作更複雜的設計和殼元素分析卻會降低模型的精度造成誤差。即使如此目前業界大多採用 SDA 法，原因在於可將商業機密相關設計轉化為超級元素，以不洩漏機密方式交付給下游廠商進行風機系統整體動態載重分析等。

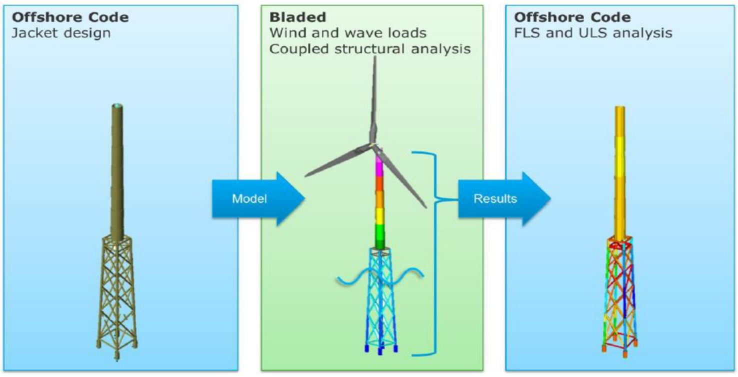


圖 8 Integrated Design Approach (IDA)

2.「Fully Coupled Analysis of a Bottom Fixed Offshore Wind Turbine under Earthquake, Wind and Wave Loads」

The governing equation of motion of offshore wind turbine (OWT) under aerodynamic, hydrodynamic and seismic loads is derived based on blade element momentum theory (BEM), Morison equations and fundamental theories of structural dynamics. Then, a seismic analysis module is developed for the coupled analysis of a bottom fixed OWT under seismic, wind and wave loads according to the derived governing equation. An integrated bottom fixed OWT is presented referred to the NREL 5MW baseline wind turbine and a practical multi-pile offshore wind turbine in China. Dynamic characteristics and structural responses of the integrated OWT under earthquakes are analyzed by using the updated fully coupled analysis model. Then, the influence of the coupling effects of environmental load conditions on the structural responses can be found. Furthermore, the influence of seismic excitations in S-S direction for an operating OWT is investigated; it shows that the structure may confront with comparable responses in F-A and S-S direction simultaneously under such load conditions.

此篇論文基於葉片單元動量理論、Morison 方程以及結構動力學基礎理論，

推導離岸風機在空氣動力、水動力和地震載重作用下之運動控制方程，進而開發地震分析模組。該模組適用於海床邊界為固定端的離岸風機支撐結構系統，受地震、風和波浪載重作用的耦合分析。藉由修正後的全耦合分析模型，執行離岸風機支撐結構受地震作用的動力分析，探討結構的動力特性和動態響應。我國位於亞熱帶多颱風及地震頻繁之特殊地理環境，與本篇研究的分析條件相彷，故私下與作者更深入探討離岸風機分析軟體 NREL FAST 運用技術，將地震力納入整體風機耦合分析等相關技術交流。目前國內預定風場之海床地質係由含粉土之砂土層與軟弱黏土層組成，易受地震力作用而導致土壤液化，進而影響風機系統動態行為以及基礎結構承載力喪失等問題。因此針對預定風場環境分析條件需要更符合台灣現況，以確保風場長期運維的可靠性與安全性。

3.「Comparison of Laboratory and in-situ Small Strain Soil Stiffness for Modelling Lateral Bearing Capacities of XL Monopiles」

In this real case study two data sets of small strain shear modulus G_{max} from laboratory and in-situ measurements are compared. The two data sets are used as inputs to a linear elastic 3D finite element numerical model to estimate the initial lateral pile-soil stiffness. The question of how much the pile deflection curve depends on the different G_{max} derivation methods is discussed throughout the paper. The study reveals a high importance of stratigraphy for this task, and shows that average input stiffness differences up to 20% throughout the profile do not lead to pile deflection changes at the midline for the discussed regime.

此篇論文以實際案例研究指出現場離岸風機單樁基礎之相關資料監測，其中量測的結構自然頻率高於設計預估值，原因在於小應變狀態下低估了土壤勁度參數。基礎總勁度必須提供特定範圍內的結構頻率，以避免與轉子(1P)和葉片通過頻率(3P)、風以及波浪的外力頻率形成共振，而自然頻率的低估與勁度的高估會導致在共振範圍內有結構響應被激發。藉由實驗室和現場的兩組小應變剪切模量 Gmax 進行數據量測與採集，並將數據輸入至三維線彈性有限元數值模型以估計初始側向樁—土勁度。研究結果揭示了地層分布對於這項研究的重要性，在整個土層剖面上平均勁度差異高達 20%。目前國內預定風場之海床地質係由砂土層

夾雜粉土與黏土層之軟弱土層所組成，而土壤性質會顯著影響整體風機結構之自然振動頻率。我國基礎設計應考量海床土壤液化、淘刷地形變動與長期反覆載重下之土壤勁度衰減評估等現象，並透過數值模擬與縮尺模型試驗之驗證，建立適合我國天然環境的地工設計參數與基礎結構特性參數。另一方面，更可提升國內工程顧問公司離岸風機基礎設計能量，以利未來具備爭取國內外離岸風機基礎細部設計之有力設計工具。

4.「Hydrodynamic Performance of a Novel Floating Foundation for Offshore Wind Turbine」:

A novel semi-submersible platform, referred to as HexaSemi, is proposed with a completely new designed heave plate. Compared with WindFloat, the new heave plate has a single hexagonal shape with a moonpool. From the structural point of view, its integral design can increase the integrity of the structure. In this paper, we mainly study its hydrodynamic performance for offshore wind turbine. A numerical model is set up to simulate the motion characteristics of the floating wind turbine system, based on WADAM, Star-CCM+ and FAST. The comparative analysis of HexaSemi and WindFloat under the storm condition is conducted and discussed. It is found that the integral design can increase the viscous hydrodynamic damping, reduce the motion response, and reduce the mooring cable force.

此篇論文主要是提出一個有別於 WindFloat 半潛式平台的新穎設計，稱為 HexaSemi design，作者將平台底部由懸臂樑支撐的方式修改為固定樑支撐，由模擬結果可知能有效降低平台 6 個自由度的運動響應及增加平台的穩定性。

Fig. 1 WindFloat design

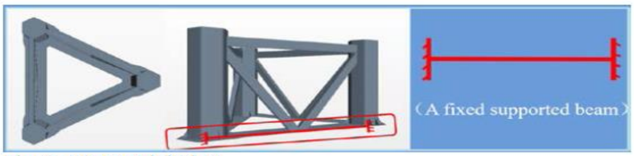


Fig. 2 HexaSemi design

圖 9 WindFloat 與 HexaSemi 設計比較

5.「Uncertainty Modeling and Fatigue Reliability Assessment of Concrete GravityBased Foundation for Offshore Wind Turbines」

Evaluation of the fatigue limit state (FLS) for offshore wind turbine foundations is normally based on deterministic design approaches, where partial safety factors are used to account for load and resistance uncertainties. In this paper, the propagation of uncertainties related to structural, environmental and fatigue damage model parameters is evaluated by performing Monte Carlo fatigue simulations of a reference Gravity Based Foundation (GBF) supporting a 5 MW offshore wind turbine. A linear model for concrete fatigue damage is formulated based on the S-N approach, and fatigue structural reliability is evaluated using the FORM technique. Results indicate that the uncertainty related to wind turbulence intensity has the highest influence on fatigue loads during power production. Adopting a probabilistic damage model for concrete also increases the fatigue damage standard deviation by 60% and 85% for structures in water and in air, respectively. In addition, the assumption on Miner’s rule uncertainty has a large influence on the structural reliability. A reduction of this uncertainty from ΔCOV=0.40 to ΔCOV=0.30 could increase the annual reliability index by 22%.

此篇論文針對離岸風機重力式基礎進行疲勞極限狀態進行結構分析，分析方法有別於過往定論式，經常使用數倍安全因子以涵蓋強度、負載、環境以及分析模型等參數之不確定性，但卻無法準確掌握不確定性之真實性。因此此研究提供機率式參數模型，並搭配不同參數離散性進行可靠度分析。結構可靠度分析中，配合蒙地卡羅模擬以及一階可靠度分析法，計算年度可靠度因子。分析結果顯示參數離散性對於可靠度因子有非常顯著的影響，因此如何使用實地資料配合統計方法，計算符合本土化之參數統計分佈以更真實呈現當地參數變化，可有助於分析模型的精確度。

6.「ModelingUncertaintyinExtrapolatedExtremeLoadsforOffshoreWindTurbineSupportStructures」

Inthispaperweshowhowanewideaforhowtocalculatethederivatives of extrapolated 50-year return values, used in extreme load safety criteria,can be used to estimate the uncertainty in these return values resulting from uncertainty in the simulations and in the load extrapolation procedure itself. The method yields uncertainty estimates with a high degree of accuracy. Additionally, to highlight one of the subtler uncertainties involved in this setting, we also make a small study of how changing the block size used in the extraction of maxima from load time series affects the 50-year return value.

風機結構極端負載分析中，如何有效地呈現環境風力負載變化成為最大的挑戰，因此此篇論文提出創新數學計算模型，可以準確計算五十年回歸極端負載之數學表示式。同時進行 11 組不同負載之實地資料，比較結果發現全部僅有 10% 差異。此篇論文更進一步配合蒙地卡羅模擬法計算結果與實地結果也有高度相似結果，因此加深此方法的正確性。

7.「Advanced reliability assessment of offshore wind turbine monopiles by combining reliability analysis method and SHM/CM technology」

In this work, advanced reliability assessment of OWT (offshore wind turbine) monopiles is proposed by combining reliability analysis method and SHM (structural health monitoring) / CM (condition monitoring) technology. A 3D (three-dimensional) parametric FEA (finite element analysis) model of OWT monopiles is developed, considering soil-structure interactions. A number of stochastic FEA simulations of OWT monopiles are performed, taking account of stochastic variables, such as wind loads, wave loads and soil properties. Multivariate regression is then used to post-process the FEA results, obtaining the performance functions expressed in terms of stochastic variables. After that, FORM (first order reliability method) is used to calculate the reliability index, evaluating the reliability of the OWT monopiles. In the presence of SHM/CM data, the reliability of monopile structures is reassessed and updated. The updated reliability index provides valuable information for decision making for inspection and maintenance of OWT monopiles. The application of the proposed advance reliability assessment method to a 45m-length OWT monopile is presented, showing great potential to reduce the OPEX (operating expenditure) of OWT monopiles by using the proposed method.

此篇論文針對離岸風機單樁結構配合結構健康監測技術提出改進式可靠度分析方法，當中建立 3 維參數化單樁結構有限元素以及土壤結構互置模型，以蒙地卡羅法針對風、波負載及土壤等參數進行隨機模擬分析，最後使用一階可靠度

法計算單樁結構可靠度因子。分析過程中結構健康監測數值不斷更新模型參數並再分析求得最終之可靠度因子。最後以 45 公尺單樁結構為案例並與過往分析結果進行比較，發現改進可靠度分析模型之結構設計成本有顯著降低，有助於節省過度安全假設之結構成本。

(三)、6 月 16 日，樊庭宇、賴文政及林獻洲先生搭機回程

結束本次 2018 ISOPE 會議後，樊庭宇、賴文政及林獻洲先生於 6 月 16 日下午 16 點由北海道新千歲機場返回台灣，於台灣時間 6 月 16 日下午 7 點 15 分抵達桃園國際機場， 順利圓滿的結束本次公差行程。

(四)、6 月 16 日至 17 日，黃金城博士前往日本橫濱、簡報資料整理與報到

於 ISOPE 2018 國際研討會完成會議論文發表後，依據規劃，本所黃金城博士則應邀由札幌前往橫濱參加 GRE 2018 國際再生能源研討會並發表專題演講。主要搭乘火車由札幌前往新千歲機場，並搭機飛往東京成田機場，再轉往位於東京近郊的橫濱，參加於橫濱國際會議中心(PACIFICO YOKOHAMA)舉行的 GRE 2018 國際再生能源研討會及展覽。

表 2 參加 GRE 2018 公差行程表

日期	行程
6/16(星期六)	去程
6/17(星期日)	演講資料準備與報到
6/18 ~ 6/22(星期一至星期五)	參加 GRE 2018 研討會
6/23(星期六)	回程

(五)、6 月 18 日至 6 月 22 日參加 GRE 2018 研討會

GRE 2018 再生能源國際研討會及展覽於橫濱國際會議中心舉行，並於 6 月 18 日 13:00 正式開幕。研討會開幕由總主席東京大學 Ogimoto 教授及共同主主席國際太陽能協會主席 Renne 博士共同擔任，並說明本次會議主題「How to accelerate Renewable Energy Integration」，揭示再生能源系統整合應用及技術開發為當前重要的課題。 其次，日本 NEDO 主席 Ishizuka 先生發表專題演講「NEDO’s Activities to realize 2030 Target and Further」說明當前 NEDO 於再生能源領域的主要研究活動以實現 2030 年甚至更遠的日本的國家再生能源目標。另外，接續則邀

請中國國家氣候變化戰略研究中心主任李俊峰先生專題發表「Renewable Energy Development in China: Challenges and Opportunities」說明中國目前再生能源的開發現況與未來的挑戰與機會，當前中國各項再生能源技術與市場的成熟，將大力投資並放眼全球，展現強大的企圖。其次，則由國際能源總署(IEA)再生能源組組長 Frankl 博士進行「IEA Renewables Perspective」的專題演講說明目前 IEA 於再生能源領域的國際合作現況。以及，由美國國家再生能源實驗室(NREL)主任 Keller 博士進行「Advances in Next Generation Energy Technologies: Enabling the Transformation of Global Energy Systems」專題演講，說明美國 NREL 於最新再生能源科技的研發技術將引領全球能源系統的轉換。最後，則由德國 Fraunhofer 研究院太陽能系統中心主任 Henning 博士進行壓軸的專題演講「Sector Coupling and System Integration- Key elements of the next phase of the energy system transformation」說明在不同能源產業及系統整合的關鍵元素以因應下一世代於能源系統轉換的應用，並闡述能源系統整合應用技術的重要地位。在完成以上 5 場專題演講後，並進行後續的問答後，完成研討會的開幕儀式。

圖 10 黃金城研究員攝於 GRE 2018 再生能源國際研討會

本次研討會主題包括(1)政策和整合概念(Policy & Integrated Concept); (2)光伏(Photovoltaic);(3)太陽熱能應用(Solar Thermal Applications);(4)創新生物氣候建築(Innovative Bioclimatic Architecture);(5)風能(Wind Energy);(6)生質物應用和轉換(Biomass Utilization & Conversion);(7)氫能和燃料電池(Hydrogen & Fuel Cell);(8)海洋能(Ocean Energy);(9)地熱和地源熱泵(Geothermal Energy & Ground-Source Heat Pump);(10)能源網路(Energy Network);(11)節約能源和熱泵(Energy Conservation & Heat Pump);(12)小型水力和其它非傳統能源(Small Hydro & Non-Conventional Energy)等 12 項，如附錄六。研討會主題規劃相當完整，涵蓋再生能源各主要的研發與應用領域，相當符合宏偉再生能源國際研討會的宗旨及目標。本所近年來積極從事再生能源技術研發，也都完全被 GRE 2018 本次主題項目所涵蓋。由於本所於離岸風力技術研究主要參與科技部能源國家型離岸風力主軸計畫，而本所黃金城博士目前擔任本所機械及系統工程專案主持人，並擔任 NEP-II 離岸風力整合計畫主持人，負責離岸風機固定式水下結構關鍵技術開發。黃博士本次則應日本風能協會會長東京大學石原教授邀請出席本次 GRE 2018 並擔任第五項主題風能技術的邀請演講，講題為「THE DEVELOPMENT OF OFFSHORE WIND POWER IN TAIWAN: CHALLENGES AND PROSPECTS」，如附錄七。專題演講時間為 6 月 20 日 15:00，如圖 11 為當日於會場的演講照片。本演講則主要向與會國際研討會專家學者及國際相關產業界說明目前國內的再生能源及離岸風力國家目標及政策，台灣海峽離岸風力資源及離岸風場預定場址的規劃現況，以及科研技術與產業鏈的建構及研發情形等。由於離岸風電為國家重要再生能源項目之一，而從去年(2017)下半年開始能源局加速規劃及推動離岸風電的國家目標，並於今年(2018)2 月發布離岸風電場址遴選及競價等地作業辦法，透過積極策略由風場遴選及競價雙軌並行，同時提升 2025 年的離岸風電安裝目標至 5.5 GW。而依據 2018 年 4 月底的遴選結果，2025 年以前為 3836 MW，而其餘的離岸風場競價結果也恰好於 GRE2018 會議期間 6 月 22 日公布結果，由國際上三家開發商加拿大北陸電力 NPI，新加坡玉山能源及丹麥沃旭取得 4 個競價離岸風場開發權共計 1664 MW，加上離岸風場遴選結果，預計於 2025 年遴選及競價雙軌並行達成 5.5 GW 的離岸風電國家政策目標。本次黃博士於 GRE 2018 國際研討會進行離岸風力專題演講，過程順利，詳盡介紹目前國內的離岸風力科研、技術、工程及開發現況並說明為未來的挑戰及前景，與出席的國際學長專家及產業界進行經

驗分享，並獲得一致的好評及回響。

圖 11 黃金城博士於 GRE 2018 進行專題演講

圖 12 黃金城博士與石原教授(左)於專題演講後合影

(六)、6 月 23 日搭機回程

本所黃金城博士於結束 GRE 2018 再生能源國際研討會後，於 6 月 23 日由東京成田機場搭機回台。

三、心　得

此次職等參加日本札幌 ISOPE 2018 研討會及黃金城博士應邀前往橫濱 GRE 2018 研討會中，依大會統計資料分別有 747 篇與 900 篇論文發表，涵蓋各種不同專業領域且參與人數皆是歷屆前幾名，有此可知此兩個有關再生能源及離岸風力的國際研討會規模盛大。而國際間在推展再生能源方面，也正積極鏈結科研及產業各界，藉由技術研討，以提升及拓展技術研發能量。職等參加此國際研討會，過程順利獲益良多並將參與心得整理如下：

(一) 在 ISOPE 2018 方面，本次主要參加 Renewable Energy 專題， 其中浮動式基礎離岸風機系統相關研究增加許多，包含中國與韓國等皆投入為數不少的研究。另外此次歐洲各國發表的論文，部分著重於探討載重計算程序的分析方法，主要原因在於現階段工業實務上，進行風機系統與支撐結構載重計算時，為考量整體結構系統之動態響應包含風機轉子氣動力(Aerodynamic response)與支撐結構之動態互制、水下結構的水動力彈性響應(Hydro-elastic response)、樁—土—結構互制非線性響應等多物理(Multi-physics)量耦合的動態結構系統，因此採用時間域進行疲勞分析，然而時間域分析需要耗費大量的計算時間，因此有幾篇論文提出有效快速與簡化的載重計算方法。而近幾年於 ISOPE 會議中，可觀察到中國對離岸風機研發持續積極參與，許多大學派員參加本次研討會，分別有上海交通大學、天津大學、哈爾濱大學、武漢大學、大連理工大學等，人數可能超過上百位，其中許多論文發表成果皆需耗費大量人力、時間與經費之實驗，由此可見中國大陸在離岸風電技術研發的投入遠遠超過台灣。

(二) 在 ISOPE 2018 研討會與會期間有機會與許多國外學者專家交流，其中也包含許多來自台灣各大學教授及研究單位研究人員。本次會議，本所風機技術團隊發表三篇會議論文，一篇為進行本土化離岸風機桁架式支撐結構考量我國特有之地震環境條件時，以完全耦合及簡化模型進行動態負載分析，研究成果可在初步設計時縮短離岸風機整機系統載重的模擬時間，以及得到良好的一致性。另一篇為針對風機支撐結構考慮本土地震反應譜分析，建立台灣地震環境支撐結構易損性曲線；最後一篇則為依據台灣預定風場環境參數與土壤條件下，進行離岸風機桁架式支撐結構之結構疲勞分析與疲勞損傷評估。而透過論文之發表，不僅

增進目前所執行科技部離岸風力主軸計畫的研發績效，並透過與國外專家學者的研討，了解國外於離岸風機設計研發之相關技術。

(三) 在風機大型化方面，2017 年 6 月歐洲風能協會研討會，國際風機大廠 Senvion 已經宣布 10MW 風機樣機(Prototype)訊息，而 MHI Vestas 及 Siemens 亦都已經有 8MW 風機之量產及風場應用；今年(2018)三菱重工維特斯(MHI Vestas)更是著手準備升級旗下 9MW 離岸風機 V164 以應付台灣多颱風的運轉條件，顯示超大型離岸風機已確定為目前國際離岸風電發展趨勢，本次研討會中，研究關於離岸風機系統載重計算的論文，皆以 6~10MW 裝置容量離岸風機作為研究的對象，除了採用已被廣泛使用的固定式水下結構，包含單樁、桁架式以及重力式等，亦逐漸將超大型風機結合浮動式基礎結構進行研究開發，該議題值得本所離岸風機技術團隊持續關注，並投入相關研發。

(四) 本所目前執行科技部離岸風力主軸計畫，計畫內容主要為引進過去 OC3/OC4 的技術成果與報告進行技術消化與重新建模，目前以國內的特殊氣候與地理條件包括颱風、海波流及地震執行離岸風機及支撐結構的本土化技術建立為目標。藉由此次研討會的參與可知目前國外主要研究方向為浮動風機的動態載重分析技術建立、利用頻率域方法計算 MW 級的固定式支撐結構的疲勞損傷以取代及簡化耗時的時域計算以及利用開放原始碼軟體(open source software)建立自主的軟體模擬能力，可讓研究學者任意的理解及修改程式碼和增加新的數值求解器以開發專屬團隊自有的內部程式(in-house code)。

(五) 近年來離岸風機結構分析方法中可靠度分析以獲得越來越多關注，有別於傳統定論式分析採用數倍安全因子涵蓋各種因素的不確定性，包含：承受負載、結構強度、環境擾動以及分析模型理想化等等。而機率式分析法使用統計機率模型搭配實驗、實地或是數值模擬建立參數統計分佈，當中不確定性化參數可以因地制宜，為本土場址環境建立專屬不確定參數模型，可以有效改善分析結構安全性準確性與結構設計製造成本。本次會議多篇研究探討風力、波浪力、疲勞負載以及土壤性質等參數不確定性模型建立與應用，並進一步配合可靠度分析法計算年度可靠度因子。除了探討定論式與機率式差別，同時提供很好的量化可靠度於結構設計與政策決策等參考。

(六) 台灣位於環太平洋地震帶，主要由菲律賓海板塊不斷擠壓歐亞大陸板塊形成，因此經常引發旺盛的地震活動。相對於國外許多風力發電場址而言並不用考慮地震負載對於離岸風力支撐結構完整性影響，因此國際風機廠商對於風機結構設計及製造鮮少考量地震衝擊結構影響，大多重於風力與波浪力於疲勞破壞考量，這也是本次會議中多篇有關風機支撐結構疲勞破壞研究發表。而此議題目前在台灣風機研究領域也著墨不多，因此針對離岸風機支撐結構遭受地震負載衝擊之結構完整性分析值得本所離岸風機技術團隊持續關注，並投入相關研發。

(七) GRE 2018 再生能源國際研討會及展覽，為規模相當龐大的再生能源國際會議，分為技術研討會會議論文發表及再生能源產學研的展覽，展場部分也是在橫濱會議中心的展館舉行自 6 月 20 日至 6 月 22 日舉行三天。而在技術研討會方面則分為 12 項主題，依大會安排逐日發表。依大會統計資料於超過 900 篇論文中，有 98 篇為有關風能技術論文宣讀，而海報論文也有 53 篇之多。目前國內離岸風電正值大力發展之際，於今年 4 月及 6 月也分別剛完成國內離岸風場的遴選與競價的兩個階段重要的離岸風場區塊開發規劃，以達成國家政策目標於 2020 年完成 738 MW 離岸風電安裝容量及 2025 年達成 5.5 GW 的離岸風電安裝容量。而台電第一期離岸風場開發計畫於今年 2 月已順利完成招標，由比利時楊德諾公司(JDN)及日商日立公司(Hitachi)共同獲得，預計於 2020 年完成 110MW 位於彰化外海的台電的第一期離岸風場。由於 Hitachi 預計提供的離岸風機為 Hitachi 5.2MW 下風型(Down-Wind Type)，相當特別也有別於大多數國際大廠如西門子(Siemens)公司、MHI-Vestas 等上風型(Up-Wind Type)。而在這次 GRE 2018，也注意到有 3 篇 Hitachi 5.2 MW 此離岸風機相關的論文發表，分別為(1) POWER CURVE MEASUREMENT OF HTW5.2-136 WIND TURBINE WITH DOPPLER LIDAR; (2) DEMONSTRATION RESULTS OF INDIVIDUAL BLADE PITCH ANGLE CONTROL: IMPROVING POWER PERFORMANCE OF FLOATING OFFSHOREWIND TURBINE;(3) DULABILITY TEST OF 5.2MW WIND TURBINE NACELLE 2ND REPORT。此有關 Hitachi 5.2MW 離岸風機為未來即將用於台電第一期離岸風場的預定風機系統，而以上相關論文主要為針對其風機系統的功率量測、葉片旋角控制改善整體發電效率以及風機機艙主要組件耐久性測試相關研究。其次，下風型風機系統結合轉向控制主要即對颱風環境劇烈變化的風速及風

向，降低風機系統整體受力，以維護風機結構系統的安全性及展現優良的發電效率。

(八) GRE 2018 再生能源國際研討會及展覽，每四年舉行一次，主要由日本國內再生能源產官學研與國際再生能源相關機構共同主辦，可謂相當大型的國際研討會並有展覽配合，以達產業及技術媒合。日本國內機構包括日本能源委員會、新能源及產業技術總合開發機構、國立產業技術總合研究所、日本科技代辦處、名古屋工業科學研究院、新能源基金會、日本太陽能協會和日本風能協會等，國際機構則如國際太陽能協會。專題演講邀請來自美國、德國、中國、英國、義大利、冰島、芬蘭、韓國、日本及台灣等各國專家學者，共計 15 位，分別針對包括政策和整合概念、光伏、太陽熱能應用、風能、生質能、氫能、燃料電池、地熱等不同領域，發表專題演講。而總計本項研討會議研究論文依據統計超過 900 篇的論文發表，為一相當盛大的再生能源國際研討會。

(九) 本次 GRE 2018 再生能源國際研討會特別邀請本所機械及系統工程專案主持人黃金城博士前往出席並擔任第五領域風能(Area 5 Wind Energy)技術的邀請講座，講題為「「THE DEVELOPMENT OF OFFSHORE WIND POWER IN TAIWAN: CHALLENGES AND PROSPECTS」。黃博士目前為本所風能技術團隊的負責人，也是科技部能源國家型離岸風力主軸計畫之「離岸風機固定式水下結構關鍵技術開發」整合型計畫的計畫主持人，整合目前國內台大、成大及慈濟大學技術團隊於離岸風機支撐結構健康診斷、支撐結構基礎工程及基礎與海床掏刷相關技術並落實應用於產業界。由於 GRE 2018 的主辦單位之一日本風能協會會長東京大學石原教授與黃研究員熟識，而石原教授過去也擔任國內標檢局相關顧問，熟悉國內於離岸風力技術研發的科研環境，因而透過石原教授的熱情邀請，本所黃研究員因而得以獲得此非常難得的機會，出席 GRE 2018 再生能源國際研討會及發表專題演講，向與會國際上的離岸風電學者專家及產業界說明目前國內的再生能源及離岸風力國家目標及政策，台灣海峽離岸風力資源及離岸風場預定場址的規劃現況，以及科研技術與產業鏈的建構及研發情形等。藉由本次機會於國際研討會正式場合的演講，相信對於台灣於國際上離岸風電建設可以大幅提升能見度，也對於未來離岸風力於國際上技術合作與國內離岸風力科研技術能量的提升，將有具體的助益。

四、建議事項

此次 ISOPE 2018 與 GRE 2018 研討會涵蓋議題廣泛，職等針對工作上的相關研究領域，蒐集其專業技術資料，以利綜理及規劃本所風能技術相關後續研發方向。綜合此次公差的心得，有如下建議。

（一)、未來計畫方向

政府為邁向 2025 年非核家園之目標，經濟部訂定再生能源發展策略，將於 2025 年完成再生能源裝置容量達 20%的目標，而離岸風電為其中最主要的項目之一。日前，經濟部已完成我國 2025 年完成離岸風電 5.5GW 裝置容量的規劃，其中第一階段遴選，總計 3.84GW 容量，德商達德能源核配容量最多，達 1.058GW；其次是沃旭為 0.9GW；CIP（丹麥哥本哈根基礎建設基金）的彰芳與西島則獲得 0.6GW；而台電、中鋼及海龍分別獲得 300MW。第二階段的競價，則由北陸電力與玉山能源、沃旭等 2 家開發商，共 4 個風場獲選 1.66GW 裝置容量。

其中第一階段遴選之主要目標在於加速離岸風電產業鏈的國產化與自主化，離岸風場區域性的環境條件，包含海流、波浪、風況、極端環境颱風、地震以及土壤條件等，顯著影響離岸風機系統與支撐結構的安全性與可靠度，台灣的地理氣候條件有別於歐洲，而離岸風機固定式水下基礎結構又為我國率先國產化之項目，因此在無法直接移植歐洲經驗作為我國借鏡的同時，應針對我國風場之特定條件進行安全影響評估，並協助國內相關業者逐步建立自主化設計之技術能力。本所過去 5 年已經建立相當的技術能力及成果，建議本所應持續投入經費與人力繼續擴大研究成果，與學校、產業界多方面合作，包含中鋼公司、世曦工程顧問公司、上緯新能源公司等。反觀國內離岸風電則尚在起步中，主要仍以 5MW 為工程及研發標的。故產官學有必要朝向大型化離岸風機進行相關技術研發如支撐結構與基礎及海事工程等，而離岸風機之水下支撐結構，不論是單樁、桁架式、重力式或是其他新穎形式的固定式水下結構，因應風機大型化趨勢皆面臨必須提升支撐材料強度與尺寸大小的挑戰，在鋼材的製造與施工上，將導致成本提高以及面臨鋼材難以製造組裝的問題；本所為政府國家級實驗室，應進行具目標性的整合技術研究開發，結合產業界合作，建構國內自主化的離岸風力發電技術，協助推動國內離岸風場之技術支援及產業發展。

（二）、技術團隊整合

離岸風力研究與發展涉及層面相當廣泛，國際間多以成立研究聯盟(Research Alliance)方式進行產、官、學研整合的研究專題，涵蓋包含風機設計分析、支撐結構工程設計分析、離岸風場場址評估、海事工程、甚至地質與地震及材料腐蝕等不同領域。目前本所已與台大、成大以及慈濟大學共同執行整合型計畫，主要應依循國家能源政策發展方向，持續向前擴展並加大力道。建議應繼續參照此模式以更具焦，並在有限的資源下整合相關領域技術團隊共同進行技術研發，以更符合產業界的實際需求。

（三）、增加國外技術交流

政府為解決能源短缺的問題，正積極推動國內離岸風電的發展。離岸風機水下結構須因應台灣海峽特殊海床條件以及颱風、地震等嚴格的自然環境條件，必須進行水下結構工程規劃以及建立適合台灣海域抗颱耐震之固定式基礎設計及標準或浮動載台的先期關鍵技術建置，經由此次研討會的參與，建議應增加與國內外不同團隊技術合作交流以取得最新的研發資訊。目前台灣離岸風電產業才正起步，藉著國外團隊的參與主導可加速離岸風電之研發，國內研發團隊或廠商亦可藉此練兵加速移植與建構技術學習曲線，俟建立自主的技術能量及產業聚落後，結合國際團隊向外拓展離岸風電之應用與開發。

（四）、促進產官學研合作

目前政府針對離岸風電於 2025 年前達成 5.5GW 裝置容量已全部規畫完成，各年度開發業者及建置風場皆已確定，以推動國內離岸風電及產業發展。而科技部也透過能源國家型科技計畫之離岸風力主軸計畫結合產官學研各界能量持續推動，以協助建立必要的鍵本土化離岸風力技術及學習曲線。近期政府公布遴選及競價結果，每家獲選開發商也已與多國內廠商各自簽署合作備忘錄，以逐步落實離岸風機零組件在地化發展為目標。建議本所未來仍應加強凝聚產官學研之能量，持續協助廠商加速填補產業鏈技術缺口，並藉由推動國際合作關係，促成產業發展的良好環境，為台灣未來離岸風電產業應用及技術研發做出更大貢獻。

五、附　錄

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Experimental Study of Surface Tension Influence on Sloshing Impact Loads [Oral presentation]
M Frihat, L Brosset, Gaztransport & Technigaz; J-M Ghidaglia, ENS Paris-Saclay, France

Phenomenological Study of the Initial Stages of Liquid Impacts Through a Simplified Liquid Impact Scenario [Oral presentation]
N Couty, Y Jus, HydrOcean; P-M Guilcher, NextFlow Software; L Brosset, Gaztransport & Technigaz, France

An Investigation on and Determination of Damping of Sloshing in a Tank around Resonance Frequency
Yusong Cao, Fuwei Chang, C-Z Marine Technology, USA; Jingzhe Jin, SINTEF Ocean, Norway

Two-Phase Particle Simulation of Violent Sloshing Flows with Large Density Ratios
Sang-Moon Yun, Jong-Chun Park, Pusan National Univ, Korea; Abbas Khayyer, Kyoto Univ, Japan; Se-Min Jeong, Chosun Univ, Korea

4. RENEWABLE ENERGY I: Support Structures (V. 1)

Monday **June 11** **10:30** Regent, 2F

Chair: Renata Archetti, Univ of Bologna, Bologna, Italy

Uncertainty Modeling and Fatigue Reliability Assessment of Concrete Gravity Based Foundation for Offshore Wind Turbines
Joey Velarde, Claus Kramhøft, COWI A/S, Denmark; John Dalsgaard Sørensen, Aalborg Univ, Denmark

A New Model for Fatigue Load Sequence Effects in Offshore Wind Turbine Substructures and its Implications for Design Life
R.C. Dragt, S.T. Hengeveld, J. Maljaars, Netherlands Inst for Applied Scientific Research (TNO), Netherlands

Fatigue Damage on Offshore Wind Turbines by a Cell Mapping Method
Odd Eiken, Michael Muskulus, NTNU, Norway

Sampling Methods for Simplified Offshore Wind Turbine Support Structures Load Case Assessment
Lars Einar S Stieng, Michael Muskulus, NTNU, Norway

Markov Approach to Estimate Fatigue Damage for Monopile-based Offshore Wind Turbines
Christina Capdevila Choy, Polytechnic University of Catalonia, Spain; Sebastian Schafhirt, Michael Muskulus, NTNU, Norway

Numerical Fatigue Analysis for Jacket-type Substructure of Offshore Wind Turbines under Local Environmental Conditions in Taiwan
Ting-Yu Fan, Chin-Yu Lin, Chin-Cheng Huang, Tung-Liang Chu, Inst of Nuclear Energy Research, Taiwan China

Study on Fragility Curves for Support Structures of Wind Turbines under Earthquake in Taiwan

Hsien-Chou Lin, Chin-Cheng Huang, Hsiung-Wei Chou, Inst of Nuclear Energy Research, Taiwan China

Modeling Uncertainty in Extrapolated Extreme Loads for Offshore Wind Turbine Support Structures [Proceedings only]
Lars Einar S. Stieng, Michael Muskulus, NTNU, Norway

5. VORTEX-INDUCED VIBRATIONS I (V. 3)

Monday **June 11** **10:30** Highness, 2F

Chair: Jin S Chung, ISOPE, USA
Co-Chair: Decheng Wan, Shanghai Jiao Tong Univ, China

Development of Prediction Model for Vortex-Induced Motion of Multi-Column Floating Structure
Seiya Shiiba, Shinichiro Hirabayashi, Hideyuki Suzuki, Rodolfo Trentin Gonçalves, Univ of Tokyo, Japan

Vortex Shedding and its Impacts on the Motions of a Paired-Column Semi-Submersible
Weiwen Zhao, Decheng Wan, Gang Chen, Shanghai Jiao Tong Univ, China

Experimental Study about Vibration Interference of Dual Pipe Systems
Yaowei Xuan, Shiqiang Li, Hanping Li, Hai Zheng, Dahong Fu, Guozhi Chen, Zhejiang Electric Power; Zhen Liu, Xiaoxia Zhang, Ying Zhang, Ocean Univ of China, China

Vortex-Induced Vibrations of Two Flexible Cylinders in Tandem Arrangement with Discrete Vortex Method
Ke Lin, Jiasong Wang, Jianliang Zhou, Liangbin Xu, Leixiang Sheng, Shanghai Jiao Tong Univ, China

Experimental Study on Flow-Induced Motion of an Array of Three Cylinders with Circular, Square and Diamond Sections
Rodolfo Trentin Gonçalves, Univ of Tokyo, Japan; Maria Eduarda Felippe Chame, Univ of Sao Paulo; Nicole Hepp Hannes, Federal Univ of Santa Catarina; Pedro Paludetto Silva de Paula Lopes, Univ of Sao Paulo, Brazil; Shinichiro Hirabayashi, Hideyuki Suzuki, Univ of Tokyo, Japan

6. ASSET INTEGRITY I:
Fracture, Fatigue Management (V. 4)

Monday **June 11** **10:30** Crystal A, 2F

Chair: Robert E Melchers, Univ of Newcastle, Australia
Co-Chair: Ali Reza, Exponent, USA

Risk-based Approach for Fatigue Integrity Assessment of Offshore Piping in the Arctic Environment
Arvind Keprate, DNV GL; R.M. Chandima Ratnayake, Univ of Stavanger, Norway

Asset Integrity and Site Investigation for Water Ingress to Flexible Elastomeric Foam (FEF) Thermal Insulation
Abe Nezamian, Armin Pilehforoushha, Suraj Kishnani, Asset Management Advisory, Aurecon, Australia

Van Minh Nguyen, Tien Thua Nguyen, Juwon Seo, Hyeon Kyu Yoon,Changwon National Univ; Yeon Gyu Kim, KRISO, Korea

The Analysis of Optimal Oscillation Angle of Fin in Propulsion Device of Wave Glider Based on Quasisteady Hydrodynamic Method
Zhongqiang Zheng, Zhenjiang Yu, Zongyu Chang, Xiujun Sun, Zhanxia Feng, Jiakun Zhang, Haoran Zhao, Ocean Univ of China, China

43. SLOSHING V: Sloshing Mitigation (V. 3)

Tuesday **June 12** **10:30** Empress, 2F

Chair: Andre Baeten, Augsburg Univ of Applied Sciences, Germany
Co-Chair: Mirek Kaminski, Delft Univ of Technology, Netherlands

Slosh Mitigation of LNG: New Challenges
Erik Jeroen Eenkhoorn, Hengelo (O), Netherlands

Slosh Mitigation Applications in LNG Containment Systems
Erik Jeroen Eenkhoorn, Hengelo (O), Netherlands

Effects of Internal Cylinders on Natural Sloshing Frequencies of a 3D Rectangular Tank
Chongwei Zhang, Peng Su, Dezhi Ning, Dalian Univ of Tech, China

Active and Passive Sloshing Mitigation in Tanks
Philipp Behruzi, Francesco De Rose, ArianeGroup GmbH, Germany

Numerical Simulation of Liquid Sloshing with Multiple Flexible Baffles Using a Coupled SPH with Smoothed Point Interpolation Method
Shuangqiang Wang, Guiyong Zhang, Boqian Yan, Dalian Univ of Tech, China; Zhiqian Zhang, Inst of High Performance Computing, Singapore; Zhi Zong, Dalian Univ of Tech, China

Incompressible SPH for Simulating Violent Sloshing in Tank with Different Baffles
Yi You, Xing Zheng, Harbin Engineering Univ, China; Qingwei Ma, City Univ London, UK; Gang Ma, Harbin Engineering Univ, China

44. RENEWABLE ENERGY V: Offshore Wind Simulations (V. 1)

Tuesday **June 12** **10:30** Regent, 2F

Chair: Decheng Wan, Shanghai Jiao Tong Univ, China

Study of Free Vortex Wave Method with Curved Filament Correction
Yi Lin, Lei Duan, Ye Li, Shanghai Jiao Tong Univ, China

3D Fully Nonlinear Beam Dynamics of Offshore Wind Turbines
Carsten Corte, Baustatik – Baudynamik – Numerische Modellierung, Germany

Comparison of Integrated and Sequential Design Approaches for Fatigue Analysis of a Jacket Offshore Wind Turbine Structure
Ana Glisic, Leibniz Univ Hannover; Ngoc-Do Nguyen, DNV-GL; Peter Schaumann, Leibniz Univ Hannover, Germany

Simulation of Topograpical Change in an Offshore Wind Farm
Hsing-Yu Wang, Hui-Ming Fang, Sung-Shan Hsiao, National Taiwan Ocean Univ; Yun-Chih Chiang, Tzu Chi Univ; Jung-Chang Su, Chun-Sen Lu, Sinotech Engineering Consultants, Taiwan China

Application of a New OpenFOAM Tool to Design a Pilot Floating Wind Farm Offshore Mazara del Vallo (Italy)
Agnese Paci, Renata Archetti, Univ of Bologna, Italy

A Regression Analysis for Fatigue Damage Estimation on Offshore Wind Turbine Using Artificial Neural Network
Hyeon-Jin Kim, Beom-Seon Jang, Seoul National Univ, Korea

Dynamic Loading Comparison between Fully Coupled and Simplified Model on Offshore Wind Turbines with Jacket Support Structures under Seismic Condition
Wen-Jeng Lai, Wei-Nian Su, Chin-Cheng Huang, Inst of Nuclear Energy Research; Yi-Mei Huang, National Central Univ, Taiwan China

45. SUBSEA, PIPELINES, RISERS I:
Flexibles, Umbilicals (V. 2)

Tuesday **June 12** **10:30** Highness, 2F

Chair: Yijun Shen, Rose Group, UK

Burst Tests of Pipeline Containing Colonies of Metal Loss Defects with Different Sizes
Chenliang Su, Dalian Univ of Tech; Ying Li, Zhejiang Univ of Sciene & Tech; Xin Li, Dalian Univ of Tech, China

An Overall and Safe Design Method for Subsea Production System
Jing Ma, Xiaohan Yan, Yongtu Liang, Haoran Zhang, Bohong Wang, China Univ of Petroleum-Beijing; Zhongliang Huang, CNPC Offshore Engineering, China

Analysis on Nonlinear Hysteresis Characteristic of Unbonded Flexible Pipes
Wei Wang, Hexiao wang, Liping Sun, Harbin Engineering Univ, China

Numerical Simulation of Nonlinear Vibration of Flexible Riser Conveying Fluid
Jianjie Niu, Jiangsu Univ of Sci & Tech; Xiaomin Li, Ocean Univ of China; Jiajia Shen, Li Zhou, Jiangsu Univ of Sci & Tech, China

Study of Mechanical Performance of New-type Non-metallic Composite Flexible Riser Offshore Environment
Lin Zhao, Yanju Yin, Ocean Univ of China, China

Global Analysis of Flexible Riser with Internal and External Pressure Load Effects
Jeong Du Kim, Beom-Seon Jang, Lan Hee Yoon, Seoul National Univ, Korea

Influence of Gap Span Creep Behaviour of Polymer Barrier Layer on Service Life in the HPHT Deepwater Unbonded Flexible Risers
Yijun Shen, Andrew Burton, Paul Birkinshaw, Roland Palmer-Jones, ROSEN Group, UK

A Procedure for Assessment of Umbilical Fatigue Damage [Proceedings only]

附錄二　ISOPE 2018 本所論文摘要

Numerical Fatigue Analysis for Jacket-type Substructure of Offshore Wind Turbines under Local Environmental Conditions in Taiwan

Numerical Fatigue Analysis for Jacket-type Substructure of Offshore Wind Turbines under Local Environmental Conditions in Taiwan

Ting-Yu Fan, Chin-Yu Lin, Tung-Liang Chu, Chin-Cheng Huang*

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*TEL /886-3-4711400 Ext.3349：Fax/ 886-3-4711452

Abstract

This paper is to perform a series of fatigue analyses for reference offshore wind turbine (OWT) under Taiwan local environmental conditions to investigate the potential design load cases (DLCs) which could affect the overall calculation procedure and improve the design calculation efficiency. Based on sequentially coupled approaches, NREL FAST and ANSYS software are employed to analyze the dynamic responses of offshore wind turbine system and jacket-type substructure under various DLCs defined in the international standard IEC 61400-3. The stress distributions around the intersection of tubular joints under the axial, in-plane and out-of-plane loads are computed to determine the stress concentration factors. Using conventional Rainflow counting algorithm, the cumulative fatigue damage (CFD) factors for tubular joints can be thus calculated with S-N curves and Palmgren-Miner’s rule. The computed results show fatigue damage caused by power production design scenario is more dominant and accounting for the ratio of total cumulative fatigue damage up to 90%. This work with more efficient load calculation procedure (LCP) in preliminary design will be helpful for cost assessment and selection of adequate types of substructures to be utilized in future offshore wind farms in Taiwan.

Keywords: Fatigue Analysis, Offshore Wind Turbine, Jacket-type Substructure, Load Calculation Procedure

附錄三　ISOPE 2018 本所論文摘要

Study on Fragility Curves for Support Structures of Wine Turbines under Earthquake in Taiwan

Study on Fragility Curves for Support Structures of Wine Turbines under Earthquake in Taiwan

Hsien-Chou Lin*, Chin-Cheng Huang, Hsoung-Wei Chou
Institute of Nuclear Energy Research, Atomic Energy Council, Taiwan, R.O.C.
juy@iner.gov.tw

Abstract

The paper presents the estimation process of seismic fragility curves and the seismic reliability assessments for a wind turbine support structure. At first, the Nation Renewable Energy Laboratory (NREL) 5MW reference wind turbine finite element model is built by beam and shell elements using ANSYS finite element package to conduct seismic response spectrum analysis. The realistic earthquake data reported from Pacific Earthquake Engineering Research Center (PEER) ground motion database are taken into account. Totally 500 earthquake response spectra derived by 100 Taiwan Chi-Chi earthquake data combined with magnification factors of 1, 2, 4, 7 and 10 are imposed on the wind turbine support structure model as the loading conditions. Through Monte Carlo simulations the peak displacements and peak stresses are regarded as the damage measures (DMs). The fragility curves could be thus numerically derived from DMs and the earthquake peak ground acceleration (PGA) using maximum likelihood estimator (MLE). In addition, the Taiwan probabilistic seismic hazard maps in terms of 475 and 2475 years return period are further considered to estimate the statistical parameters for annual maximum PGA distribution function. Finally, the annual reliability index of the wind turbine support structure can be obtained from the fragility curves and the annual maximum PGA distributions.

Keywords: Fragility Curve, Reliability, Earthquake Response Spectrum.

附錄四　ISOPE 2018 本所論文摘要

Dynamic Load Comparison between Fully Coupled and Simplified Models on Offshore Wind Turbines with Jacket Support Structures under Seismic Conditions

Dynamic Load Comparison between Fully Coupled and Simplified Models on Offshore Wind Turbines with Jacket Support Structures under Seismic Conditions

Wen-Jeng Lai[1,2], *Wei-Nian Su1, Chin-Cheng Huang1, Yi-Mei Huang*[2]
[1]Mechanical and System Engineering Program, Institute of Nuclear Energy Research, Taiwan, R.O.C.
[2]Department of Mechanical Engineering, National Central University, Taiwan, R.O.C.

Abstract

The dynamic load calculation of offshore wind turbine is an important technology in the future development of wind turbine industry in Taiwan. This paper presents a simplified equivalent-monopile model of reducing the dynamic load simulation time for offshore wind turbines with jacket support structures under seismic conditions. The FAST v7 code that only simulates monopile substructure is chosen as the analysis tool and is further recompiled to include the effect of seismic-pile-soil interaction in the simplified model. The numerical analysis results are then validated by comparing with the results from the fully coupled model, calculated by Bladed software, in a NREL 5MW offshore wind turbine. Two seismic load scenarios, operational and idling conditions, are studied in this work. The results show that usage of simplified model may offer advantages in preliminary support structure design. The advantages are apparent in seismic simulation since the simplified equivalent-monopile modeling allows current FAST v.7 code constraints relaxed for simulating jacket structures and leads to quicker and more convenient dynamic load calculation. The influence of earthquake and soil flexibility is especially important in design considerations since Taiwan is located in a seismically active region. Thus, the developed simplified numerical model will be helpful to shorten the simulation time of a series of seismic design load cases in the preliminary design phase.

KEY WORDS: Dynamic Load, Seismic Condition, Simplified method

附錄五　GRE 2018 本所邀請演講議程

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Area2	Photovoltaics	Area6	Biomass Utilization and Conv.	Area10	Energy Network
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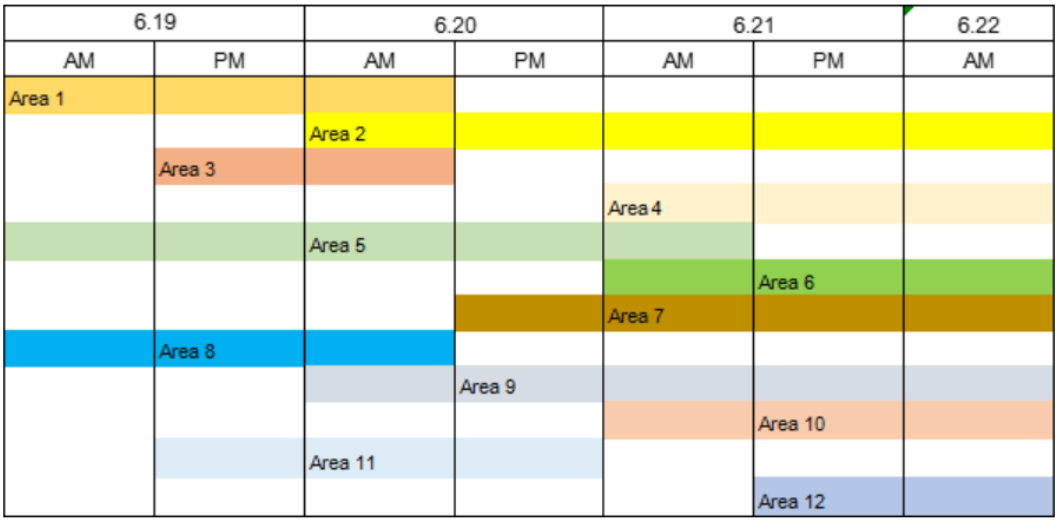

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		Area 2	■	■	■	■
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				■	Area 10	■
	■	Area 11	■			
					Area 12	■

AREA 5
Wind Energy

Dr. Hannele Holttinen is Principal Scientist at VTT Technical Research Centre of Finland (MSc and PhD from Helsinki Technical University). She has worked for VTT for more than 20 years in different fields of wind energy research, with main interest on the impact of wind and PV on power systems and electricity markets. She acts as Operating Agent of the IEA international collaboration on wind integration (IEA WIND Task 25), chaired IEAWind in 2011-12, and has been active in European Wind Energy Platforms ETIP and TPWIND as well as in Nordic energy research.

Dr. Chin-Cheng Huang is currently the Scientist and Director of Mechanical and System Engineering Program at the Institute of Nuclear Energy Research(INER) which is a national laboratory in Taiwan. He is a senior research scientist with over 26 years of experience in the area of engineering analysis and structural integrity assessment for energy systems involving both nuclear power plant systems and wind power systems. Since 2013, Dr. Huang has been leading a research project on offshore wind power sponsored by the National Energy Program. His recent researches on offshore wind aim to develop techniques for verification and validation of offshore wind turbines with support structures under extreme external conditions specially for typhoons and earthquakes.

附錄六　GRE 2018 會議研討主題

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2. Photovoltaics

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- Module Reliability
- Performance Characterization Method
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- Operation and Maintenance
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3. Solar Thermal Applications

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- Solar based heat pump technology
- Solar Cooling
- Solar-fired power generation
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- Thermal Energy Storage
- Solar-thermally driven chemical processes
- Solar thermal utilization for hydrogen or fuel production
- Solar desalination
- Solar cooker
- Solar thermal detoxification

4. Innovative Bioclimatic Architecture

- Vernacular Architecture / Passive Design
- Zero Energy House/ Zero Energy Building
- Zero Net Carbon
- Affordable Green Housing
- Building Stock Activation / Refinement
- Smart City / ICT
- Comfort and Indoor Climate
- Energy Management System /Commissioning
- Elements and Materials
- Building Evaluation Index/Tool

5. Wind Energy

- Offshore Wind Energy
- Advanced Wind Turbine Technology
- Grid Connection and Electrical Systems
- Site Assessments and Forecasting
- Plant Design and Management
- Operation and Maintenance
- Tower and Foundation
- Measurement and Monitoring Techniques
- Acoustics and Noise Issues
- Small/Distributed Wind Power
- COE of Wind Power
- Social and Environmental Issues

6. Biomass Utilization & Conversion

- Biofuels (Bioethanol, BDF including BTL)
- Biomaterials
- Gasification and combustion
- Biomass Refinery
- Marine Biomass including freshwater biomass
- Pyrolysis and carbonization including torrefaction
- Anaerobic Digestion
- Carbon Neutrality
- Forestry
- Hydrothermal Technology
- Sustainability

7. Hydrogen & Fuel Cell

- Hydrogen Energy Systems
- Hydrogen Production
- Hydrogen Transportation and Storage
- Hydrogen End-Use Technology
- Technology and Fabrication
- Fuel Cell for Transportation
- Fuel Cell Power Plants
- Fuel Cell for Co-generation

8. Ocean Energy

- Wave Energy
- Tidal Current Energy
- Ocean Current Energy
- OTEC
- Offshore Wind Energy
- Utilization with Aquaculture
- Resource Assessment and Monitoring
- Economic Assessment
- Ocean Resources for Energy
- Ocean Marine Biomass
- Deep Sea Water Application

9. Geothermal Energy & Ground-Source Heat Pump

- Power generation
- Direct use
- Enhanced Geothermal Systems (EGS)
- Social and environmental aspects
- Exploration
- Geochemistry (erosion, corrosion and scaling)
- Induced seismicity
- Numerical modeling
- Monitoring
- Thermal conductivity
- Saving energy
- Ground-source heat pump

10. Energy Network

- Smart Grid
- Micro-grid
- Energy Network
- Distributed Energy Resources
- Power Storage and System
- Vehicle to Grid
- Demand Response
- Power Electronics
- Superconductor and System
- Advanced Electric Car

11. Energy Conservation & Heat Pump

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- Thermal Energy Technology and Storage
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12. Small Hydro & Non-Conventional Energy

- Hydropower Development and Utilization
- Practical Examples and Field (Model) Tests
- Micro & Pico System
- Undeveloped Energy for Human Life
- Unused Energy Recovery

附錄七　GRE 2018 本所專題演講摘要：
The Development of Offshore Wind Power in Taiwan
Challenges and Prospects

THE DEVELOPMENT OF OFFSHORE WIND POWER IN TAIWAN: CHALLENGES AND PROSPECTS

Chin-Cheng Huang
Institute of Nuclear Energy Research, Longtan, Taoyuan City 32546, Taiwan

SUMMARY: This presentation is to introduce the development of offshore wind power in Taiwan with some challenges and prospects. To mitigate global warming and climate change, the offshore wind has become one of major renewable energy alternatives over the past years. In Taiwan, **The Incentive Program of Offshore Wind Power Demonstration System** was announced in 2012. Recently, the Taiwan government further announced the **Four-year Wind Power Promotion Plan** to boost the offshore wind power deployment. With the applied researches and developments under National Energy Program(NEP), the technical resources from academia, research institutes and offshore wind sectors are integrated to build up the learning curve of offshore wind power development in Taiwan. To adapt offshore wind turbines to local extreme external conditions as typhoons and earthquakes, an integrated dynamic load analysis of offshore wind turbine and support structure combination is important and needs to be paid special attentions. The technique has been developed at the INER which is a national laboratory in Taiwan. It will be helpful for adoption of international standards and increase of reliability with reasonable cost to facilitate the national offshore wind power projects in Taiwan in the future.

Keywords: offshore wind power, design verification, local extreme condition

INTRODUCTION

Utilization of renewable energy has been regarded as one of the most important actions that people can take to mitigate the global warming and climate change. Over the past decades, the wind power has been one of the most promising renewable energy sources. As of 2017, total installed capacity of wind power in the world is 540 GW. Among them, the offshore wind power accounts for 18.8 GW in installation. Many countries including the UK, Germany and Denmark, etc. in the Europe, China in Asia have success stories. The America also had its first offshore wind farm, the Block Islands wind farm, in 2016. The offshore wind has become one of the fast-growing renewable energy sectors.

Following the Fukushima nuclear accident in Japan in 2011, nuclear power faced very severe challenges from public primarily on design safety, operation and nuclear waste management, etc. Some of countries with nuclear power began to strengthen nuclear power safety, regulation and operation. Some of countries also examined and evaluated the state nuclear policy. In Taiwan, new government stepped on in May of 2016 and announced the nuclear-free homeland national policy. The renewable energy will become one of important and necessary alternatives for future national energy target of Taiwan.

OFFSHORE WIND DEVELOPMENT IN TAIWAN

To speed up offshore wind deployment, Taiwan government announced **The Incentive Program of Offshore Wind Power Demonstration System** in 2012 to financially support three offshore wind farm developments including two private offshore wind developers, Swancor and TGC, and one national offshore wind developer, Taiwan Power Company. In October of 2016, two offshore wind turbines were successfully built at Formosa-I wind farm located in Taiwan Strait near northern Taiwan. Further, the Energy Bureau formulated a **Four-year Wind Power Promotion Plan** to run from 2017 to 2020. Its short-term goal is to solidify industry foundations and increase installed onshore wind capacity to 814 MW and offshore wind to 520 MW, respectively. For national medium and long-term targets, the plan is to improve the installation environments and increase total installed capacity to 4.2 GW (1.2 GW onshore and 3 GW offshore) by 2025. These efforts will promote energy diversification and self-sufficiency, stimulate domestic job growth and demonstrate Taiwan’s commitment to renewable energy.

RESEARCH AND DEVELOPMENT OF OFFSHORE WIND

To develop the learning curve of offshore wind technology in Taiwan, a National Energy Program was formed under the Ministry of Science and Technology(MOST) to integrate academia, research institutes and offshore wind sectors to move the national wind power development forward. One of the important research projects is to develop technology of design analysis and verification of dynamic loads for adaptation of offshore wind turbine system to local extreme external conditions as typhoons and earthquakes. This work has been performed at the INER which is a national laboratory in Taiwan, It will be helpful for adoption of international standards of design, operation and maintenance of offshore wind and increase of reliability with reasonable cost to facilitate the national offshore wind power project in Taiwan in the future.

附錄八　GRE 2018 本所專題演講簡報：

The Development of Offshore Wind Power in Taiwan : Challenges and Prospects

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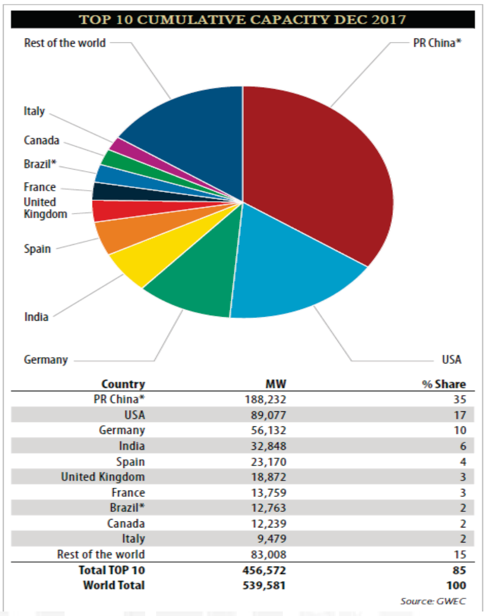
June 20, 2018

核能研究所

Outline

- Status of wind power in the world
- Wind resources and Taiwan wind power policy
- Status of offshore wind development in Taiwan
- Research activities on offshore wind in Taiwan
- Offshore wind turbine structural system under typhoon and earthquake
- Summary

Status of wind power in the world



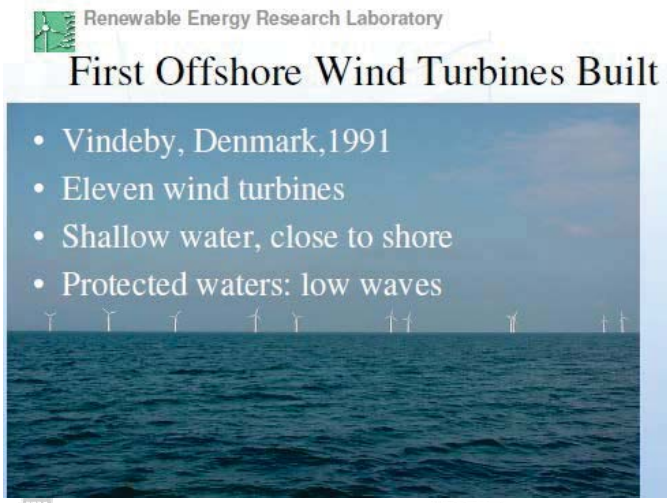
TOP 10 CUMULATIVE CAPACITY DEC 2017

Country	MW	% Share
PR China*	188,232	35
USA	89,077	17
Germany	56,132	10
India	32,848	6
Spain	23,170	4
United Kingdom	18,872	3
France	13,759	3
Brazil*	12,763	2
Canada	12,239	2
Italy	9,479	2
Rest of the world	83,008	15
Total TOP 10	**456,572**	**85**
World Total	**539,581**	**100**

Source: GWEC

- According to GWEC, 52GW of global new installed wind power in 2017, global cumulative wind power has been 540 GW as of 2017.
- China, leading country of wind power, installed 19 GW of wind power in 2017. Cumulative wind power has been up to 188 GW as of 2017.

First modern offshore wind farm



Renewable Energy Research Laboratory

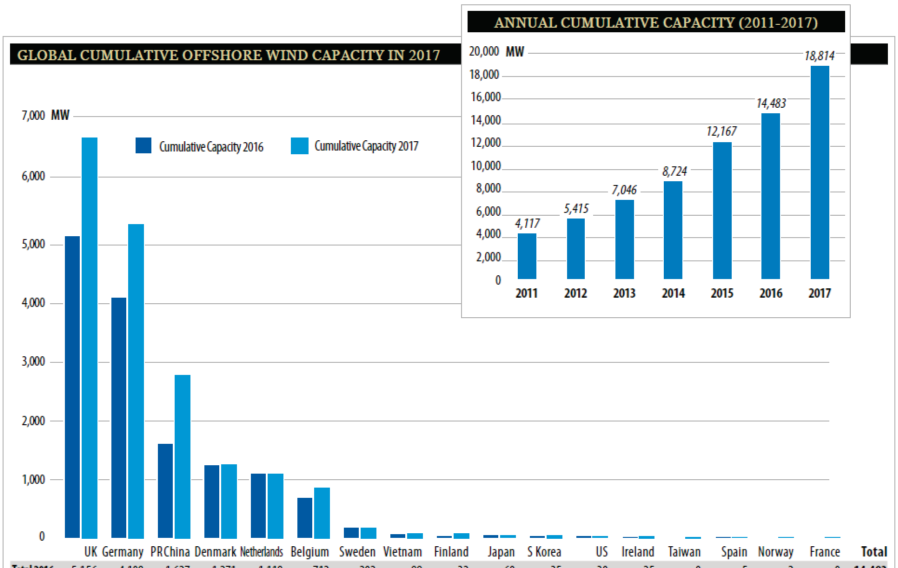
First Offshore Wind Turbines Built

- Vindeby, Denmark,1991
- Eleven wind turbines
- Shallow water, close to shore
- Protected waters: low waves

Source:UM/RERL

11 X 450kW wind turbines. Decommissioned in 2017
Max water depth: 4m   Distance from shore: 2 km

Status of offshore wind power in the world



	UK	Germany	PR China	Denmark	Netherlands	Belgium	Sweden	Vietnam	Finland	Japan	S Korea	US	Ireland	Taiwan	Spain	Norway	France	**Total**
Total 2016	5,156	4,108	1,627	1,271	1,118	712	202	99	32	60	35	30	25	0	5	2	0	**14,483**
New 2017	1,680	1,247	1,161	0	0	165	0	0	60	5	3	0	0	8	0	0	2	**4,331**
Total 2017	6,836	5,355	2,788	1,271	1,118	877	202	99	92	65	38	30	25	8	5	2	2	**18,814**

Source: GWEC

Wind resources for offshore wind development in Taiwan

Shallow Water (5-20 m)

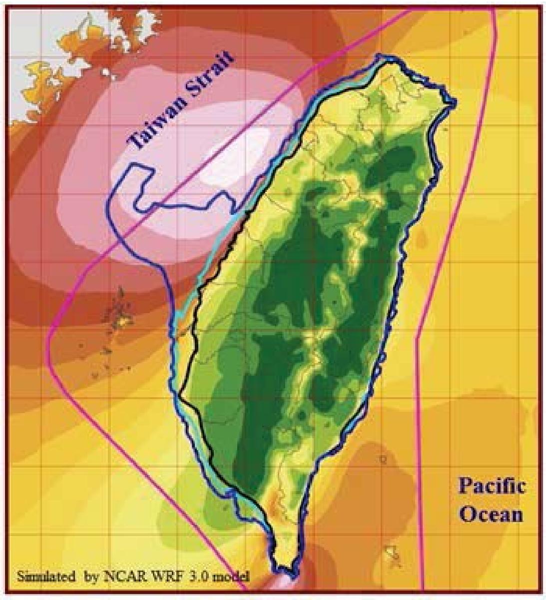
- **Area:** 1,779.2 km²
- **Potential:** 9 GW
- **Feasible:** 1.2 GW

Deep Water (20-50 m)

- **Area:** 6,547 km²
- **Potential:** 48 GW
- **Feasible:** 5 GW

Deeper Water (> 50 m)

- **Potential:** 90 GW
- **Feasible:** 9 GW



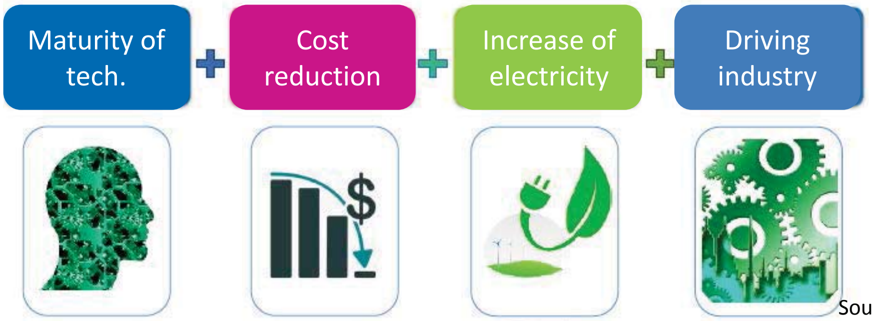
Wind Power Density(W/m2)

< 100	400 - 500	800 - 900	1,200 - 1,300
100 - 200	500 - 600	900 - 1,000	1,300 - 1,400
200 - 300	600 - 700	1,000 - 1,100	1,400 - 1,500
300 - 400	700 - 800	1,100 - 1,200	> 1,500

Source: ITRI

Taiwan wind power policy

- To achieve the nuclear free homeland policy in Taiwan by 2025, wind power especially offshore wind is one of major renewable energies.



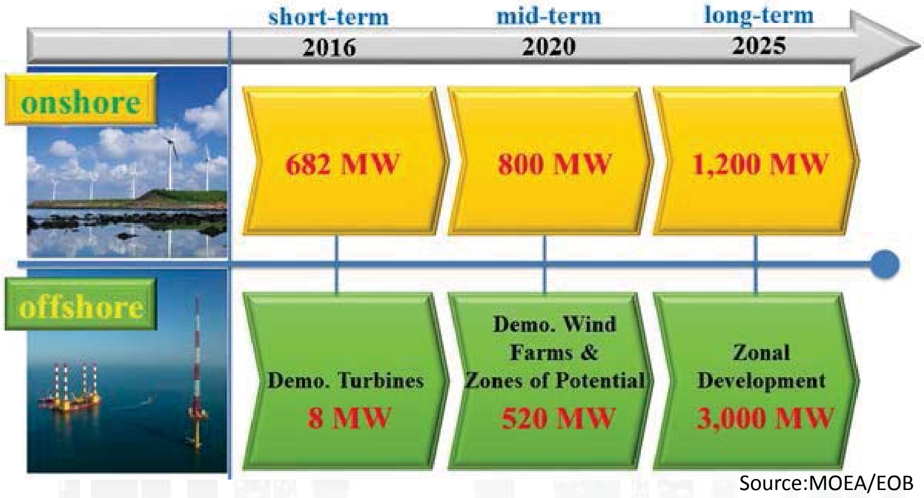
Maturity of tech. + Cost reduction + Increase of electricity + Driving industry

Source:MOEA/EOB

Maturity of tech.	Cost reduction	Increase of electricity	Driving industry
UK has 6.84 GW offshore wind since 2000 Germany has 5.36GW offshore wind since 2010	The cost is expected to be reduced. The LCOE for offshore wind is around 0.15 USD/kwh	In Taiwan, 12.6 Billions Kwh /yr based on 4.2GW and 35% capacity factor Is expected to increase.	Boost investment of 540 Billions NTD or more in offshore wind sector by 2025 in Taiwan

National target for wind power development

- Energy Bureau of Taiwan set national target for wind power development



	short-term 2016	mid-term 2020	long-term 2025
onshore	682 MW	800 MW	1,200 MW
offshore	Demo. Turbines 8 MW	Demo. Wind Farms & Zones of Potential 520 MW	Zonal Development 3,000 MW

Source:MOEA/EOB

Strategy for promoting offshore wind

DIP Incentives for Pioneers → **ZAP** Transition Period → **ZD** Self-sustaining Industry

- **[Phase 1] Offshore Demonstration Incentive Program** (示範獎勵辦法)
  - 4 Demonstration Turbines by 2017, 3 Demonstration Wind Farms by 2020
  - Government provides subsidy for both equipment & developing processes
- **[Phase 2] Directions of Zone Application for Planning** (場址作業要點)
  - 36 Zones of Potential revealed for preparation in advance of Zonal Development
  - Applicants must acquire EIA approval by 2017 and Preparation Permit by 2019
- **[Phase 3] Offshore Zonal Development** (區塊開發)
  - Zones will be released in stages by the government
  - Commercial scale for cost reduction
  - SEA has been approved by EPA

Source:MOEA/EOB;ITRI

Status of offshore wind development in Taiwan

- In 2013, three developers (Swancor, TGC and Taipower) were awarded as DIP players of offshore wind.
- Three met masts were installed at offshore wind candidate sites close to Miaoli and Changhua sites.

Met mast of Taipower OWF

Met mast of Formosa OWF

Met mast of Fuhai OWF

Source:Swancor/TGC/Taipower

Status of offshore wind development in Taiwan

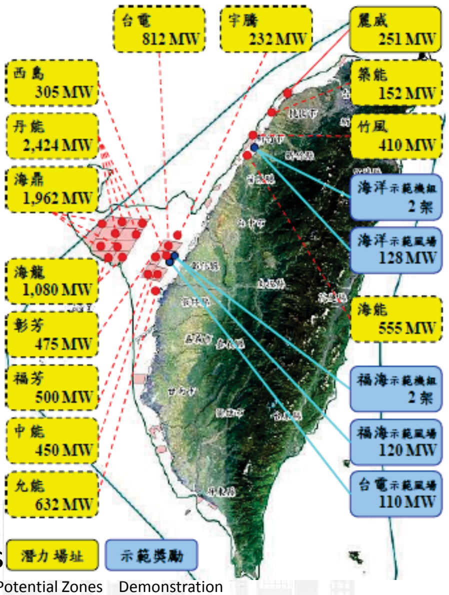
- In October of 2016, Swancor first completed 2 offshore wind turbines at Formosa-I offshore wind farm off the coast of Miaoli county(1~5 km) with 5~10 m of water depth.
- In Jan. of 2018, JDN and Hitachi won the contract of Taipower-I OWF at Changhua (110 MW)

Siemens SWT-4.0-120

Hitachi 5.2 Mw-127/136 Source: Hitachi

Status of offshore wind development in Taiwan

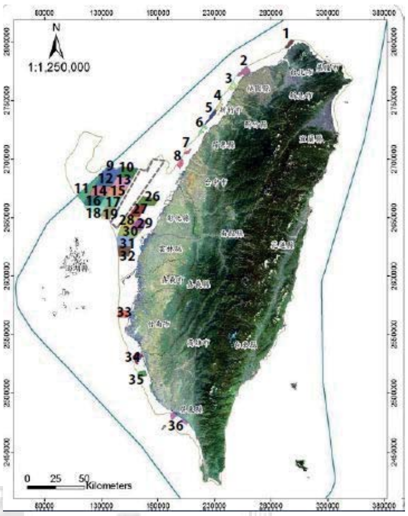
- National target for offshore wind
  - In 2016, 2 units of Formosa-I 8MW
  - In 2020, completion of DIP
  - and potential 520MW
  - In 2025, zonal development 3 GW
- 4-year plan of promotion for wind power
  - Announced in June 2017, 2017-2020
  - Three stages for offshore wind, from DIP>potential>zonal development.
  - 18 cases of offshore wind project applications. Some of them have obtained EIA approval including some international developers as Orsted, CIP, wpd,etc, and some local developers as Taipower, CSC, Swancor, ACC,TGP, etc.



Source:MOEA/EOB

Status of offshore wind development in Taiwan

- Announcement of " Directions for Allocating Installed Capacity of Offshore Wind Potential Zones“ in Feb of 2018.
- 3.5 GW is by selection and apply to incentive feed-in-tariff.
- Added 2 GW will be by auction.
- Achieving the 5.5 GW of offshore wind power installation by 2025 is the revised national target of offshore wind power in Taiwan.



Offshore wind potential Zones

Source:MOEA/EOB

Status of offshore wind development in Taiwan

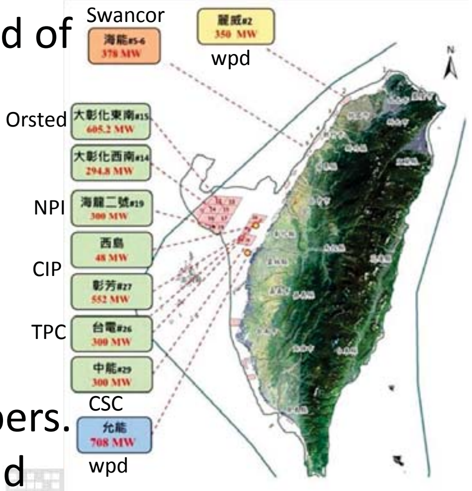
- Applications of offshore wind farms by selection ended at end of this March.
- In total, 18 OWF applications submitted by 9 local and international developers.
- International developers include Orsted, CIP, wpd, NPI.
- Local developers include Taipower, CSC, Swancor, ACC, TGP, etc.

Formosa-I offshore wind farm planning (source:Swancor)

Source:Siemens

Status of offshore wind development in Taiwan

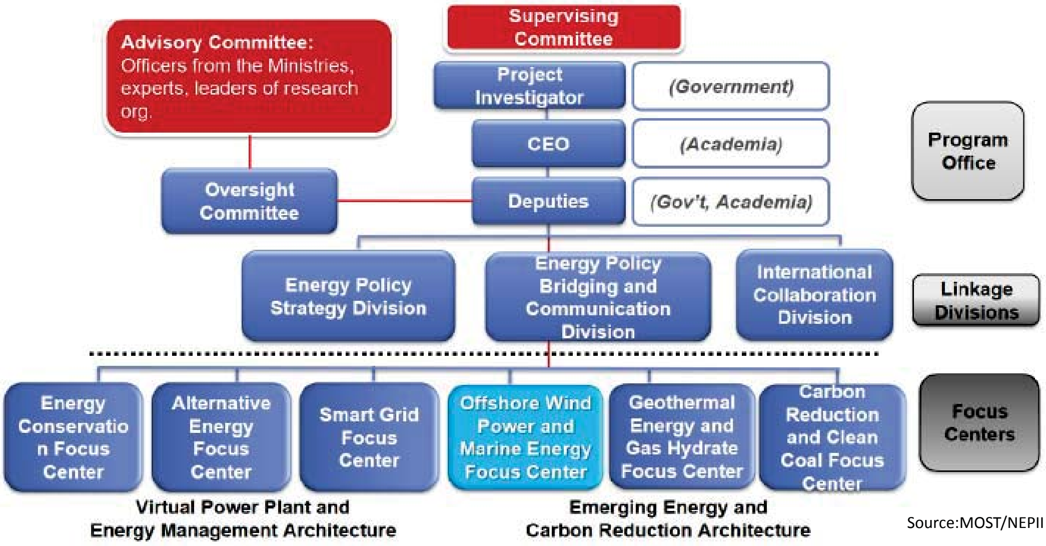
- Results of offshore wind farms site selection were announced at end of this April by MOEA/BOE.
- 7 international/local companies were awarded to develop 10 offshore wind farms .
- wpd, Orsted and CIP were big winners; Swancor, CSC and Taipower are main local developers.
- By 2020, adjusted to 738MW and add. 3098MW by 2025. In total, 3836MW by 2025.



Source:MOEA/EOB

NEP-II Execution Framework

- A National Energy Program(NEP) under Ministry of Science and Technology: NEP-I/II


Advisory Committee: Officers from the Ministries, experts, leaders of research org.

Supervising Committee

Project Investigator (Government)

CEO (Academia)

Deputies (Gov't, Academia)

Oversight Committee

Program Office

Energy Policy Strategy Division

Energy Policy Bridging and Communication Division

International Collaboration Division

Linkage Divisions

Energy Conservation Focus Center

Alternative Energy Focus Center

Smart Grid Focus Center

Offshore Wind Power and Marine Energy Focus Center

Geothermal Energy and Gas Hydrate Focus Center

Carbon Reduction and Clean Coal Focus Center

Focus Centers

Virtual Power Plant and Energy Management Architecture

Emerging Energy and Carbon Reduction Architecture

Source:MOST/NEPII

Offshore Wind Power and Marine Energy Focus Center(NEP-II, 2014~2018)

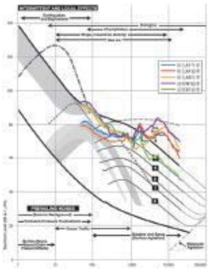
- Three areas for offshore wind power technology development.
- Integrate the resources from academia, research institutes and industry.

Offshore Wind Farm Development	Offshore Wind Turbine Localization and R&D	Marine Engineering and Underwater Structure	Marine Energy Generation System R&D
■ Identify wind field blocks ■ Field surveys ■ Environmental impact assessment, ■ Approval scheme ■ Financial / incentive mechanisms ■ Operation & Maint.	■ Establish domestic wind turbine industry supply chain ■ Offshore wind power industry parks ■ Offshore Wind Turbine design capability	■ Build the assembly harbors ■ Marine engineering fleet of support ships ■ Structure design	■ Wave energy generation system development and demonstrators ■ Ocean current energy generation system development and demonstrators

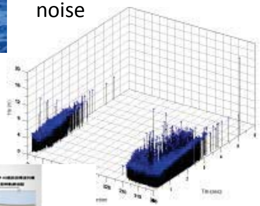
Source:MOST/NEPII

Some important research projects of offshore wind under NEP-II

- Measurement and simulation of underwater background noise at offshore wind farm
- Development of floating met-ocean lidar carriers
- Development of met-ocean observation and real time pre-warning system
- Development of Smart offshore wind farm surveillance and management system


Measurement of underwater background noise


Floating met-ocean lidar system

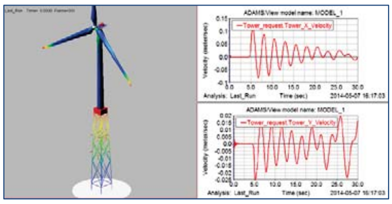

Wave height and wave direction plot

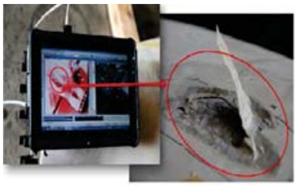

Scouring monitoring system development

Source:MOST/NEPII projects

Some important projects of offshore wind under NEP-II

- ➢ Integrated load analysis and verification for typhoon and earthquake resistant offshore wind turbine support structure
- ➢ Design and manufacture of diagnosis device for wind blade surface damage
- ➢ Risk assessment of offshore wind foundation stability


Integrated load analysis for offshore wind turbine


Surface damage detection of wind blade


Source: Marin

Bottom mounted substructure foundation

Forward-Looking infrastructure construction project-Green Energy

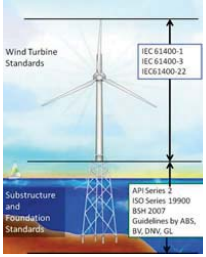
- ➢ The FLICP Project period is from 2017 ~ 2020, including 8 main categories as railway, water environment, digital infrastructure, etc. Green energy is one of them.
- ➢ Aims to increase energy security and help create green energy economy and promote environmental sustainability.
- ➢ Build up the domestic green energy infrastructure to strengthen local green energy sector integrity including wind and PV, etc.

Some important projects under FLICP-Green Energy

- Localization of engineering design guidance for offshore wind support structure
- Set up a center for third-Party accreditation and certification for renewable energy

DNV·GL

Source: DNV GL



Source: NREL

International design standards for OWT/support structure

Source: DNV GL

Design Assessment

Quality Management

Prototype Testing

Turbine Type Certificate

Site Assessment

Turbine Site Specific Certificate

Site Specific Design Assessment

Assessment of: Met Mast, Cabling, Power Station, Landfall

Project Certificate

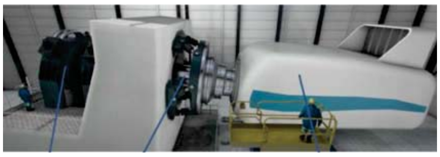
Transport & Erection Surveillance

Fabrication Surveillance

Commissioning & Witnessing

Typical offshore wind turbine/ farm certification scheme

Block Island offshore wind farm

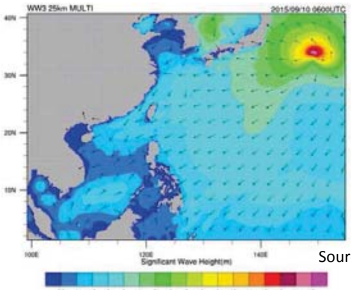


Nacelle equipment test platform

Source:Eric Thayer/Bloomberg

Some important projects under FLICP-Green Energy

- Applied service of meteorological Information for green energy development



Source:CWB

Wave data forecast

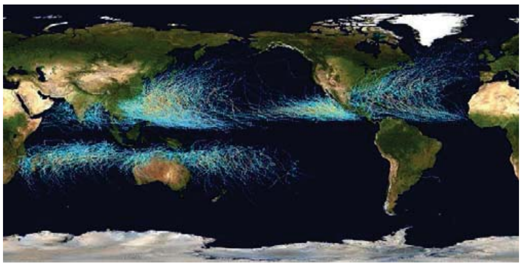
- Develop Offshore wind power industrial zone at Taichung Harbor

Source:TPC

Offshore wind power industrial zone

Typhoon and earthquake on offshore wind

- Geographically, typhoon is frequent in northeast Asian regions. In average, 6 typhoons hit Taiwan a year.
- Similarly, Japan and Taiwan are both located in earthquake active regions. Earthquake is one of important design factors for structural safety of buildings, wind turbines, etc.



Global tropical cyclone track (1985-2005)
(Source: NASA/Nilfanion)

Building and Wind turbine collapse under earthquake
(Source: windAction)

Offshore wind turbine structural system under typhoon and earthquake

- Not much European experience with typhoon and earthquake can be used for offshore wind design and operation in Taiwan.
- These extreme external conditions are not completely covered in international standards for offshore wind turbine design requirement.

Offshore wind turbine under typhoon (Source: NREL)

DNV·GL

STANDARD

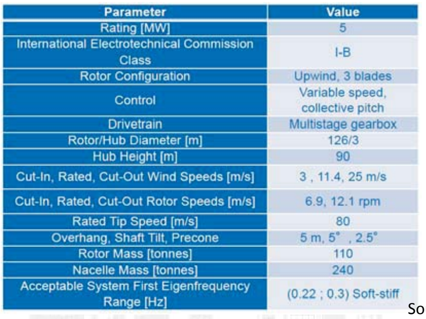
DNVGL-ST-0437 Edition November 2016

Loads and site conditions for wind turbines

DNVGL-ST-0437 standard (Source: DNVGL)

Integrated load analysis for offshore wind turbine and support structure

- With IEA Wind Task23/30, OC3/OC4, NREL 5MW reference offshore wind turbine was used to develop the domestic reference offshore wind turbine and support structure under typhoon and earthquake.
- INER also joined the IEA Wind Task30/OC5 as an observer in 2015.



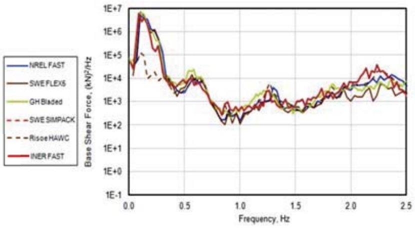
Parameter	Value
Rating [MW]	5
International Electrotechnical Commission Class	I-B
Rotor Configuration	Upwind, 3 blades
Control	Variable speed, collective pitch
Drivetrain	Multistage gearbox
Rotor/Hub Diameter [m]	126/3
Hub Height [m]	90
Cut-In, Rated, Cut-Out Wind Speeds [m/s]	3 , 11.4, 25 m/s
Cut-In, Rated, Cut-Out Rotor Speeds [m/s]	6.9, 12.1 rpm
Rated Tip Speed [m/s]	80
Overhang, Shaft Tilt, Precone	5 m, 5° , 2.5°
Rotor Mass [tonnes]	110
Nacelle Mass [tonnes]	240
Acceptable System First Eigenfrequency Range [Hz]	(0.22 ; 0.3) Soft-stiff

Source:NREL

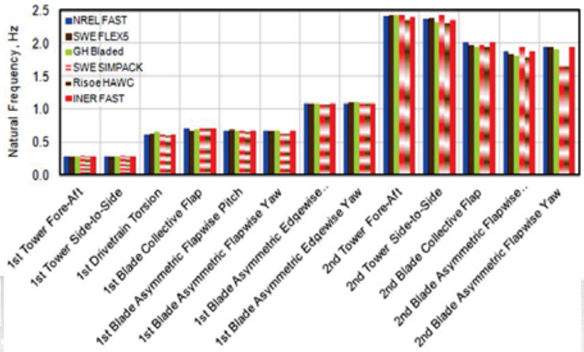
NREL 5MW reference offshore wind turbine

Load analysis model and results comparison with OC3

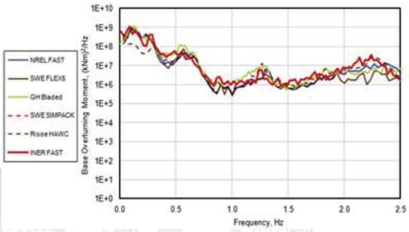
- Build load analysis model for combination of wind turbine and support structure, load cases of OC3 were analyzed and compared



Shear stress results at tower base



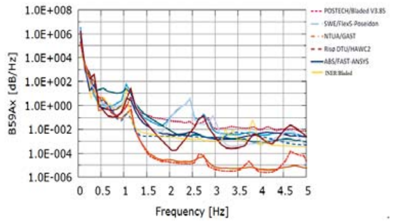
Comparison of natural frequencies



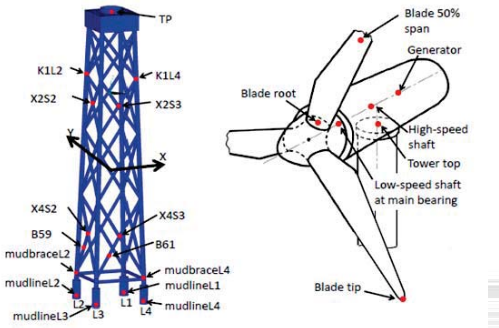
Overturning moment results at tower base

Load analysis model and results comparison with OC4

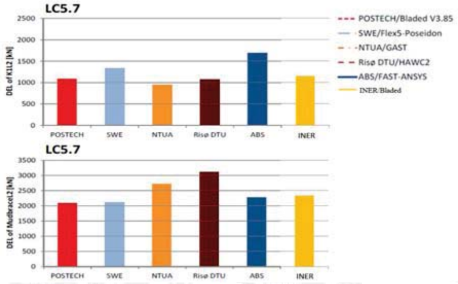
- Model for 5MW reference offshore wind turbine and jacket support structure with load cases defined in OC4



Tubular axial force at bottom of jacket structure



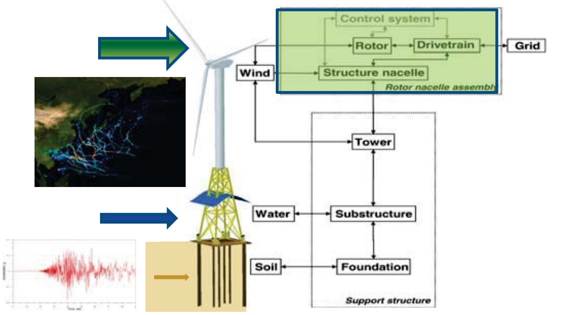
Jacket support structure used in OC4



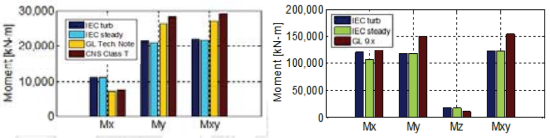
Damage Equivalent Load comparisons

Reference offshore wind turbine/support structure under typhoon and earthquake

- Collecting extreme wind data recorded for typhoons from 1977 to 2015 at Wuchi which is close to candidate sites of offshore wind farms.
- Design earthquake indicated in the technical specification document of Taipower offshore wind farm was used.
- GL Tech. Notes of design load cases with typhoon and earthquake were used for load analyses.

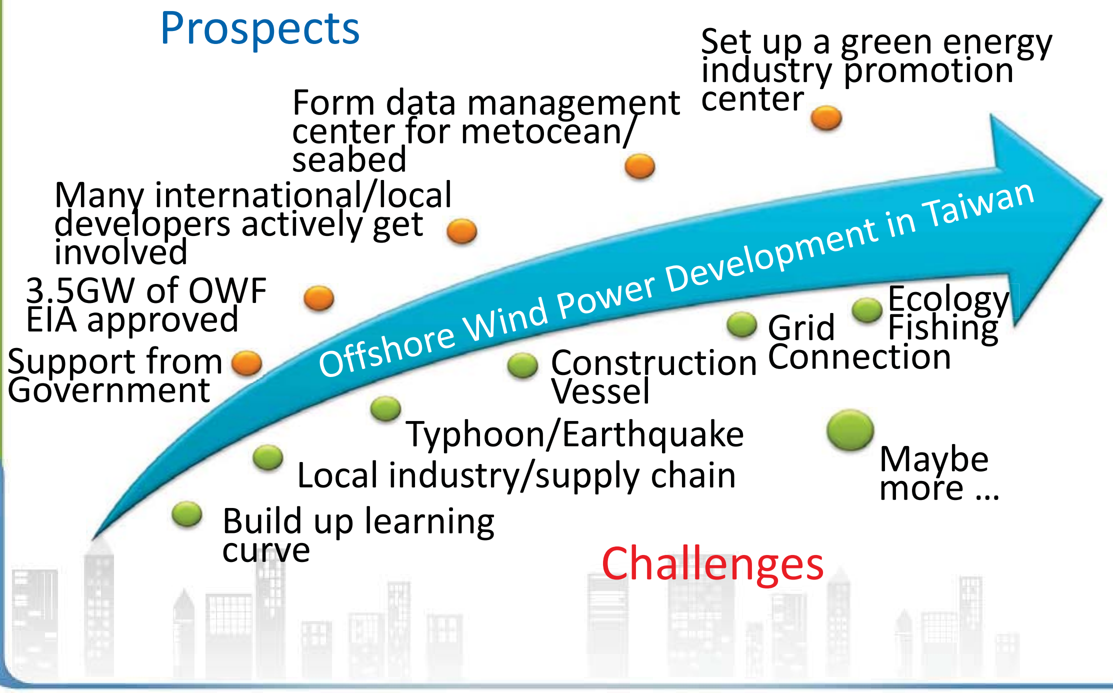


Load analysis for offshore wind turbine structural system Under typhoon and earthquake



Comparisons of load analysis results

Summary



Prospects

Support from Government

3.5GW of OWF EIA approved

Many international/local developers actively get involved

Form data management center for metocean/ seabed

Set up a green energy industry promotion center

Offshore Wind Power Development in Taiwan

Build up learning curve

Local industry/supply chain

Typhoon/Earthquake

Construction Vessel

Grid Connection

Ecology Fishing

Maybe more …

Challenges

Thank you for your attention