

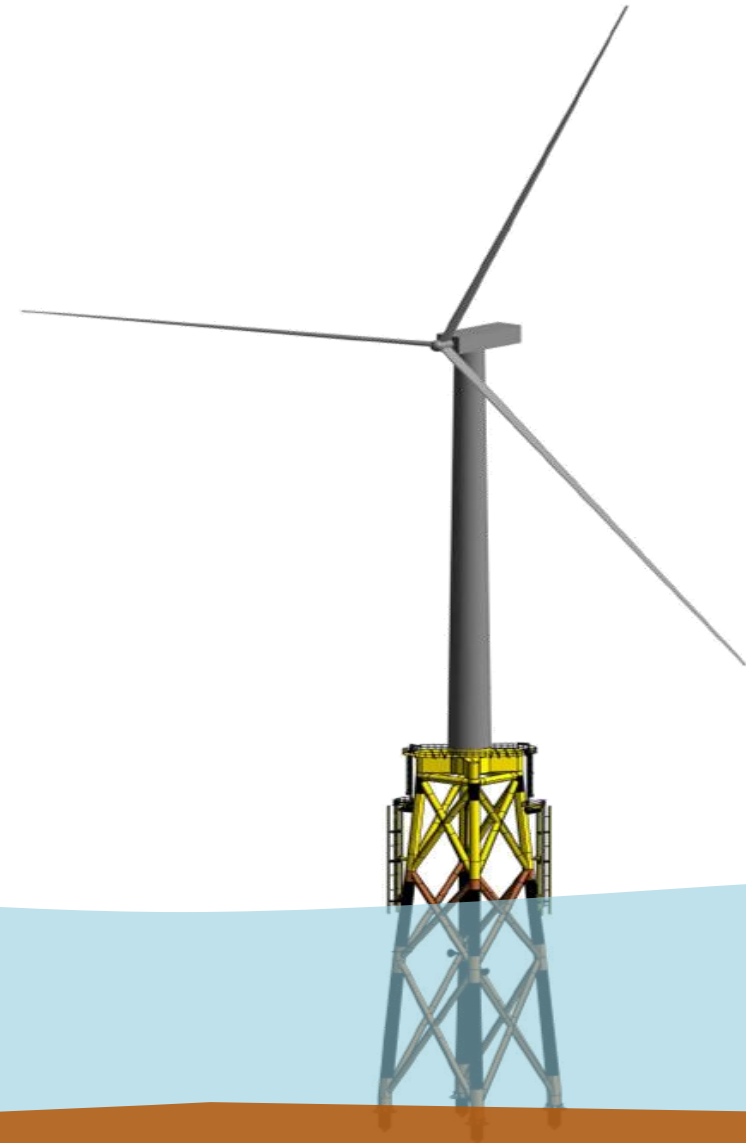
離岸風電工程設計本土化技術發展

主講人：徐偉朝 博士

中興工程顧問股份有限公司 電力及能源工程部

內容大綱

- 一、國內離岸風場開發經驗
- 二、離岸結構與陸域結構設計之差異
- 三、關鍵技術發展
- 四、結論



一、國內離岸風場發展經驗

• 台灣離岸風場與風機支撐結構主要基礎型式

2018年能源局分配5500MW風場開發案，另2013年台電及上緯示範風場分別獲110MW與128MW分配容量，共5738MW。

區域	開發商	風場	分配容量 (MW)	基礎型式
桃園	達德WPD	麗威	350	單樁
苗栗	上緯	海洋 (Formosa 1)	128	單樁
		海能 (Formosa 2)	378	套筒
彰化	沃旭(Ørsted)	大彰化東南	605.2	套筒
		大彰化西南	631.9	套筒
		大彰化西北	582.9	套筒
	玉山能源+北陸電力	海龍二號	532	套筒
		海龍三號	512	套筒
	哥本哈根基礎建設基金(CIP)	彰芳	552	套筒
		西島	48	套筒
	中鋼	中能	300	套筒
	台電	示範(一期)	110	套筒
台電(二期)		300	套筒	
雲林	達德(WPD)	允能	708	單樁



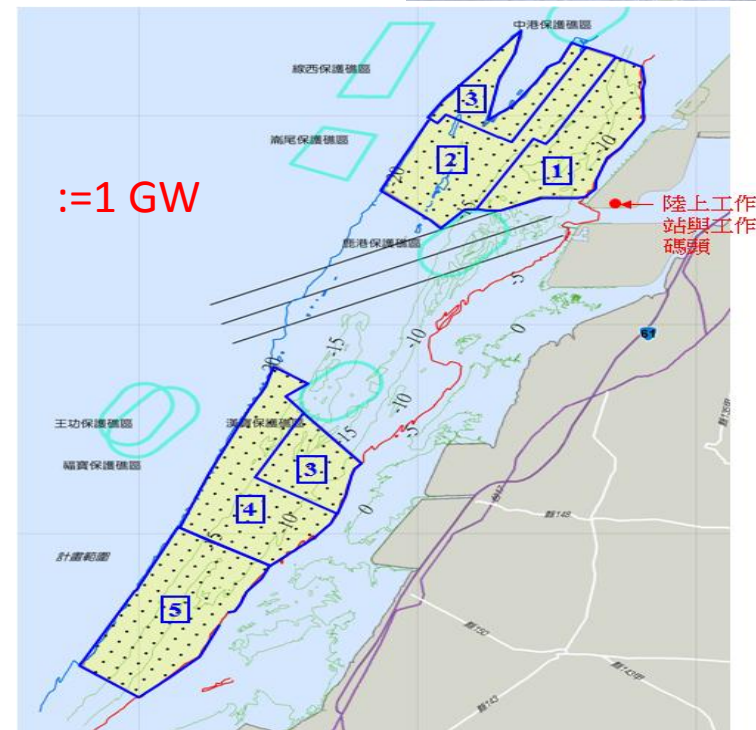
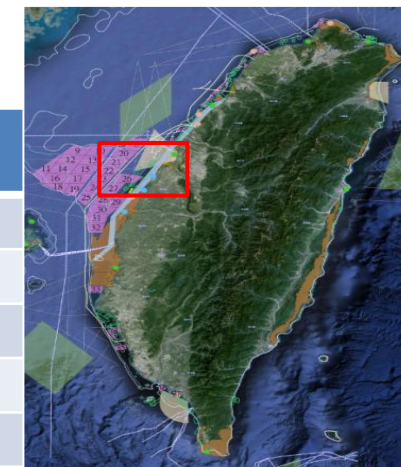
一、國內離岸風場發展經驗

➤ 台電彰化離岸風場可行性研究(2006~2007)

• 工作範圍

- 環境設計數調查與分析:
 - 海氣象資料
 - 海床變遷與淘刷
 - 海底地形
 - 地質
 - 生態
 - 當地社會與文化
- 風機選型
- 風能分析
- 風場佈置與發電量分析
- 風機支撐結構基本設計
- 施工計畫
- 籌設法規
- 營運計畫
- 成本分析
- 環境與社會衝擊
- 天然災害(含地震、颱風、沙波...)
- 船隻撞擊風險、安裝風險、營運風險...
- 計畫時程

Phase	No. of WTG (3.0~3.6MW)
1	56
2	63
3	56
4	71
5	81



一、國內離岸風場發展經驗

➤ 中興工程顧問公司辦理多件離岸風場可行性研究 (2007~2016)

• 工作範圍

● 環境設計數調查與分析:

- 海氣象資料
- 海床變遷與淘刷
- 海底地形
- 地質
- 生態
- 當地社會與文化

● 風機選型

● 風能分析

● 風場佈置與發電量分析

● 風機支撐結構基本設計

● 施工計畫

● 籌設法規

● 營運計畫

● 成本分析

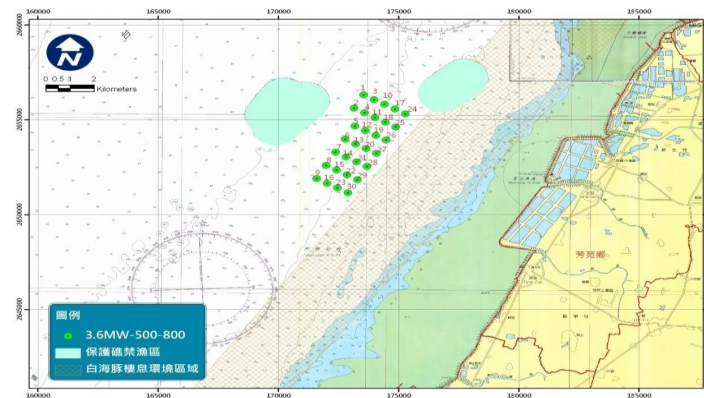
● 環境與社會衝擊

● 天然災害(含地震、颱風、沙波...)

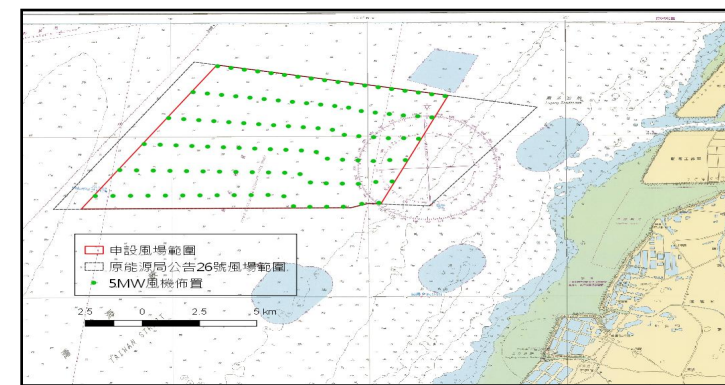
● 船隻撞擊風險、安裝風險、營運風險...

● 計畫時程

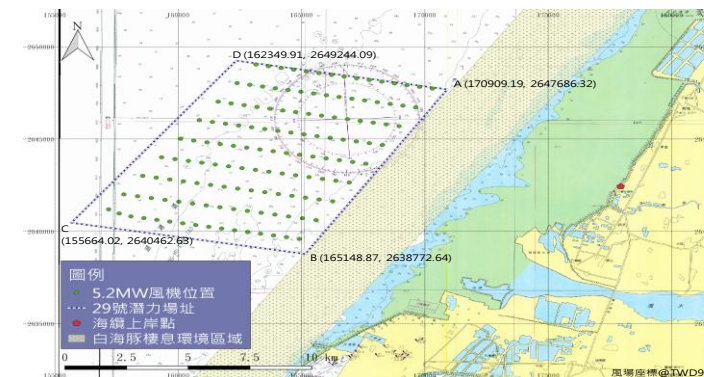
➤ 技術顧問: GL GH (Germanischer Lloyd Garrad Hassan) => DNV GL



TPC Phase 1 (108~110MW)



TPC Phase 2 (560MW ~ 720MW)



CSC (700MW)

一、國內離岸風場發展經驗

➤ 台電彰化離岸風場第一期計畫 (2016~2021)

• 準備階段

- 環境調查
- 離岸風機支撐結構基本設計
- 招標策略
- 計畫時程規劃
- 風險識別
- 風場佈置研究
- 價值工程

• 基本設計階段

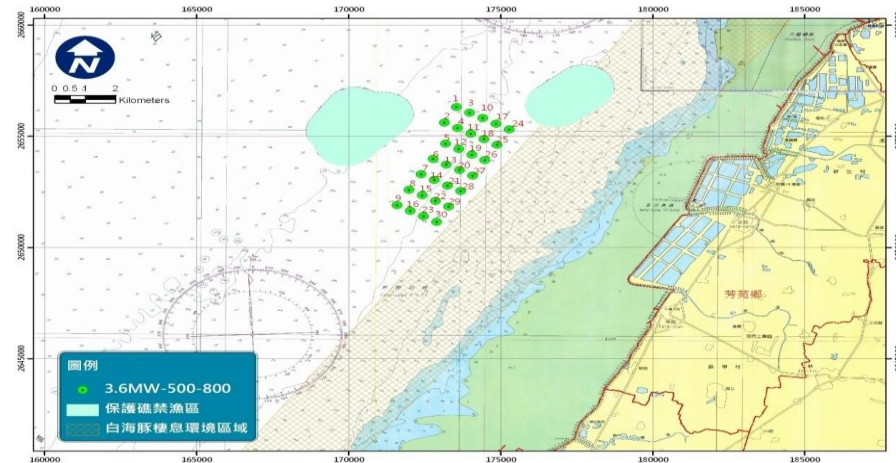
- 風機型式評估
- 離岸風機支撐結構基本設計
- 電力系統基本設計
- 海纜設計
- 成本評估
- 施工場地評估
- 監造計畫
- 營運計畫

• 招標階段

- 詳細成本評估
- 編製招標文件
- 審查投標廠商文件

• 建造階段

- 審查細部設計文件
- 審查施工文件
- 工地諮詢
- 教育訓練

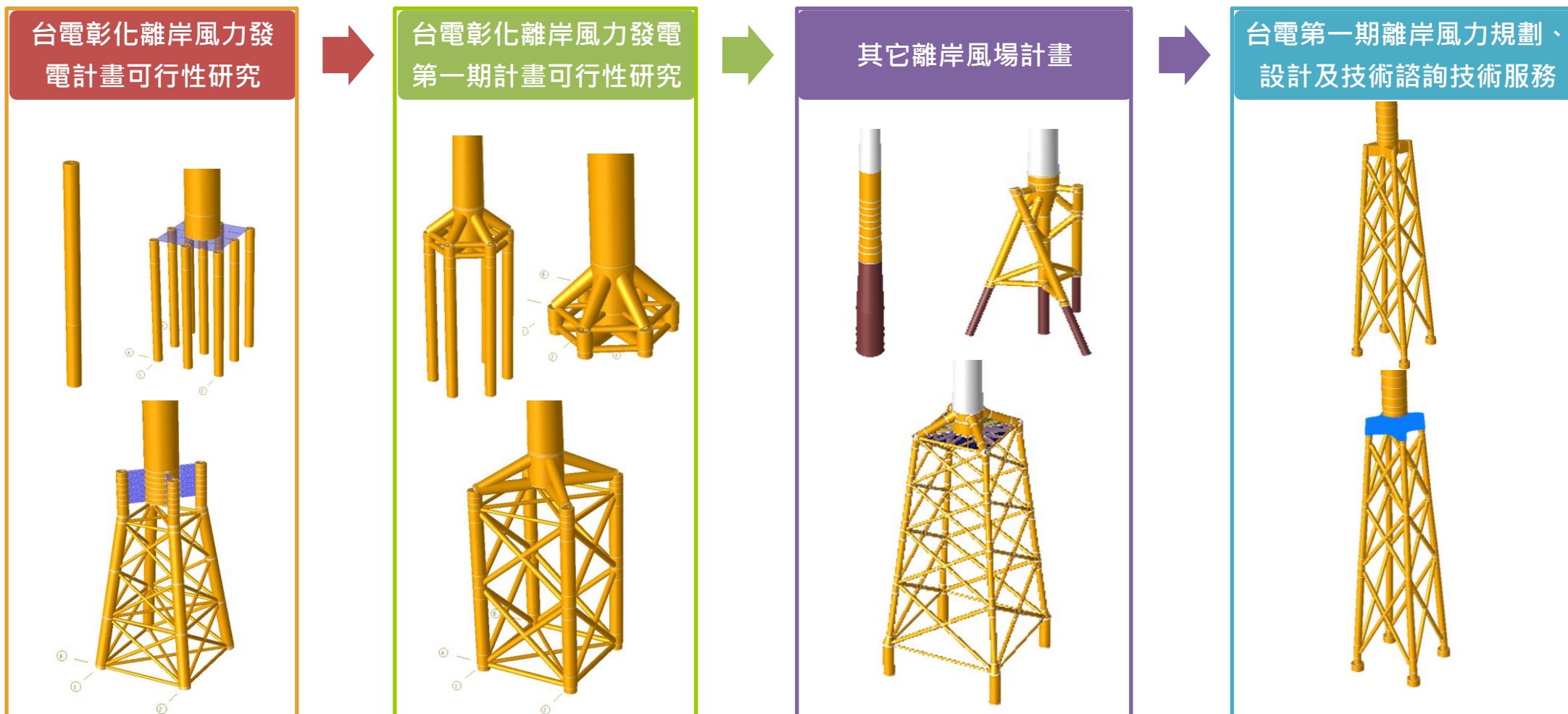


➤ 技術顧問: DNV GL與NIRAS

• (108 MW~110MW)

一、國內離岸風場發展經驗

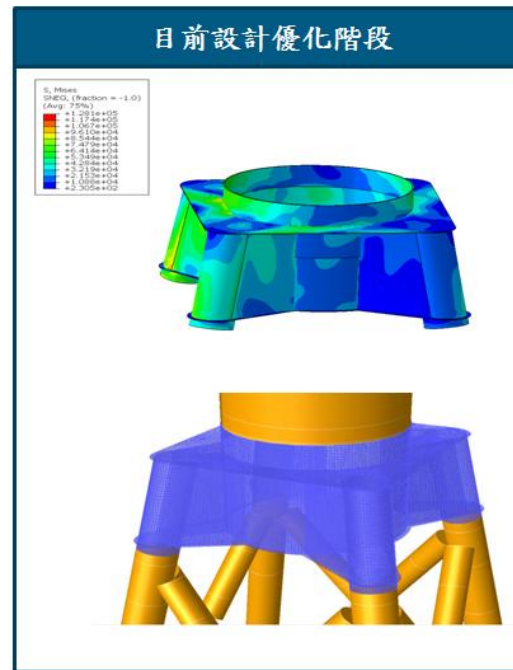
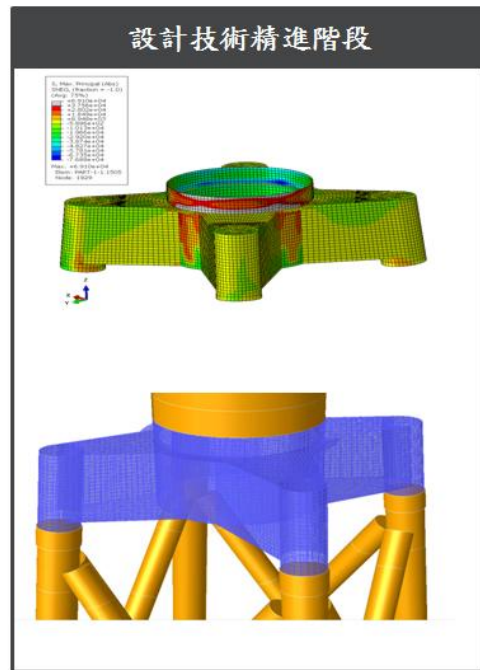
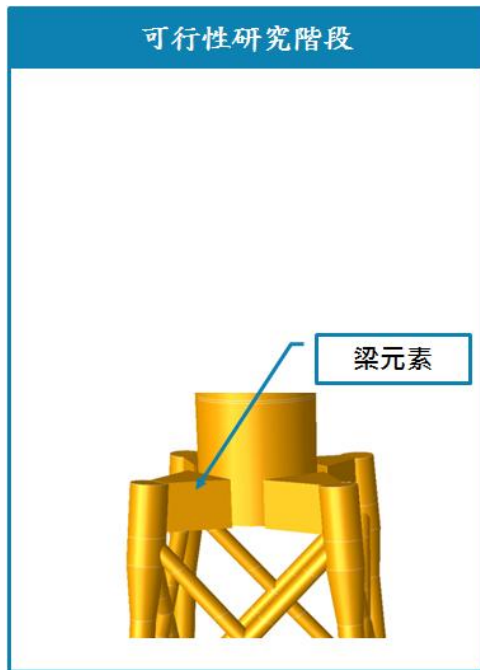
➤ 離岸風機支撐結構設計經驗(2006~2019)



一、國內離岸風場發展經驗

➤ 下部結構設計之經驗

- 中興公司曾於2008年完成並於2010年取得第三方認證機構 Bureau Veritas 所簽發之基礎與結構設計認證。
- 持續精進設計技術，並優化設計成果。



BUREAU VERITAS

ATTESTATION OF THIRD PARTY VERIFICATION
CLIENT: SINOTECH ENGINEERING CONSULTANTS, LTD.
SUBJECT: TAIPOWER – CHANG-HWA OFFSHORE WIND FARM
- FEASIBILITY STUDIES
BUREAU VERITAS REFERENCE: E&P/11216
ATTESTATION NR 1

The undersigned, acting within the scope of the General Conditions of Service of Bureau Veritas which regulate the interventions of the Society, hereby declares that, at the request of SINOTECH ENGINEERING CONSULTANTS, LTD., the appraisal of this Company's "Design of Foundations and Structures for Feasibility Study of Offshore Wind Farm at Chang-Hwa" – July 2008, has been performed.

After issuance of comments, all satisfactorily responded, the design (feasibility stage) has been found in conformity with the following applicable Code:

- API RP 2A-WSD 21st edition - Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms - Working Stress Design

Note: as international standard IEC 61400-3 - Wind turbines - Part 3: Design requirements for offshore wind turbines, was not published at the date of contract award to Bureau Veritas, above code had been selected as the most appropriate published code at this date. This certificate is issued on the basis of review of the technical report listed in Annex of this attestation.

Main particulars of this facility are:

- A farm of total 108 MW wind turbines offshore Western coast of Taiwan Island in water depth from 8 m to 22m – 25m.

Issued in Taiwan on 4th January, 2010 on behalf of Bureau Veritas Taiwan


Edward FAN
Manager of Industry & Facility Division



Jishun XING
Regional Chief Executive Greater China

Bureau Veritas Taiwan Branch 6F, No. 37, Zhongyang S. Rd., Sec. 2, Beitou District, Taipei 112, Taiwan R.O.C. TEL: 886-2-2997 6159 FAX: 886-2-2997 6258

二、離岸結構與陸域結構設計之差異

➤ 大量荷重情境

- 極端限制狀態(ULS, Ultimate Limit State)
 - 極端荷重事件(如颱風、地震、風力故障...)
- 疲勞限制狀態(FLS, Fatigue Limit State)
 - 檢核所有在壽齡期間發生之反覆荷重所造成銲接疲勞損傷。
- 服務限制狀態(SLS, Serviceability Limit State)
 - 風機正常運轉所需之結構變位限制，由風機廠商決定，通常要求海床基樁之永久傾斜角(含土壤塑性變形、安裝公差)在壽齡內不超過0.5度。
- 意外限制狀態(ALS, Accidental Limit State)
 - 受船隻撞擊之承受能力

Table 4-3 Design load cases

Design Situation	DLC	Wind Condition	Marine Condition				Other Conditions:	Type of Analysis		Partial safety factor
			Waves	Wind and wave directionality	Sea Currents	Water Level		Onshore	Offshore	
1) Power Production:	1.1	NTM $V_{in} < V_{hub} < V_{out}$	NSS $H_s = E[H_s V_{hub}]$	COD, UNI	NCM	MSL	For extrapolation of extreme loads (offshore - only RNA)	U	U	N (1.25)
	1.2	NTM $V_{in} < V_{hub} < V_{out}$	NSS Joint prob. distribution of H_s, T_p, V_{hub}	MIS, MUL	No Currents	NWLR or \geq MSL		F/U	F/U	F/N
	1.3	ETM $V_{in} < V_{hub} < V_{out}$	NSS $H_s = E[H_s V_{hub}]$	COD, UNI	NCM	MSL		U	U	N
	1.4	ECD $V_{hub} = V_r - 2 \text{ m/s}$, $V_r, V_r + 2 \text{ m/s}$	NSS $H_s = E[H_s V_{hub}]$	MIS, wind direction change	NCM	MSL		U	U	N
	1.5	EWS $V_{in} < V_{hub} < V_{out}$	NSS $H_s = E[H_s V_{hub}]$	COD, UNI	NCM	MSL		U	U	N
	1.6	NTM $V_{in} < V_{hub} < V_{out}$	SSS $H_s = H_{s,SSS}$	COD, UNI	NCM	NWLR		-	U	N
	1.7	NTM $V_{in} < V_{hub} < V_{out}$	NSS Joint prob. distribution of H_s, T_p, V_{hub}	MIS, MUL	No Currents	NWLR or \geq MSL	Ice formation	F/U	F/U	F/N

2) Power Production + occurrence of fault:

Table 4-3 Design load cases (Continued)

Design Situation	DLC	Wind Condition	Marine Condition				Other Conditions:	Type of Analysis		Partial safety factor	
			Waves	Wind and wave directionality	Sea Currents	Water Level		Onshore	Offshore		
3) Start up	3.1	NWP $V_{in} < V_{hub} < V_{out}$	NSS $H_s = E[H_s V_{hub}]$	COD, UNI	No currents	NWLR or \geq MSL		F/U	F/U	F/N	
	3.2	EOG $V_{hub} = V_{in}$, $V_r \neq 2 \text{ m/s}$, and V_{out} or ETM $V_{in} < V_{hub} < V_{out}$	NSS $H_s = E[H_s V_{hub}]$	COD, UNI	NCM	MSL	The timing of the gust and the start-up event chosen for minimum 4 distinct points	U	U	N	
	3.3	EDC	NSS	MIS, wind	NCM	MSL		U	U	N	
	2.1	2.2	2.3	2.3 altern	2.4	2.5					

Table 4-3 Design load cases (Continued)

Design Situation	DLC	Wind Condition	Marine Condition				Other Conditions:	Type of Analysis		Partial safety factor			
			Waves	Wind and wave directionality	Sea Currents	Water Level		Onshore	Offshore				
4) Normal shutdown	4.1	N											
	4.2	E											
5) Emergency stop	5.1	N	7) Parked and fault conditions:	7.1	EWM $V_{hub} = V_1$	ESS $H_s = H_{s,1}$	MIS, MUL	ECM $U = U_1$	NWLR	Fault that produces deviations from the normal turbine behaviour while parked; including loss of electrical network	U	U	A
	6.1	E		7.2	NTM $V_{hub} < V_{out}$	NSS Joint prob. distribution of H_s, T_p, V_{hub}	COD, MUL	No currents	NWLR or \geq MSL		-	F/U	F/N
6) Parked (standing still or idling)	6.2	E	8) Transport, installation, maintenance and repair	8.1	NTM $V_{hub} = V_r$, to be stated by the manufacturer	NSS $H_s = H_{s,r}$, to be stated by the manufacturer	COD, MUL	No currents	NWLR	Design conditions shall be stated by the manufacturer	U	U	N
	6.3	E		8.2	EWM $V_{hub} = V_1$	ESS $H_s = H_{s,1}$	COD, MUL	No currents	NWLR	Transport, installation, maintenance and repair	U	U	A
	6.4	N		8.3	EWM $V_{hub} = V_1$	ESS $H_s = H_{s,1}$	COD, UNI	ECM $U = U_1$	NWLR	Vortex-induced vibrations due to wind, waves or	F/U	F/U	F/N
	6.5	N								g installation	-	F/U	F/N
	8.6	NTM $V_{hub} = V_r$	ESS $H_s = H_{s,r}$	COD, MUL	ECM $U = U_1$	NWLR	Supply vessel impact - abnormal event			al impact and ads - normal	-	U	N

須考慮成千上萬荷載情境

二、離岸結構與陸域結構設計之差異

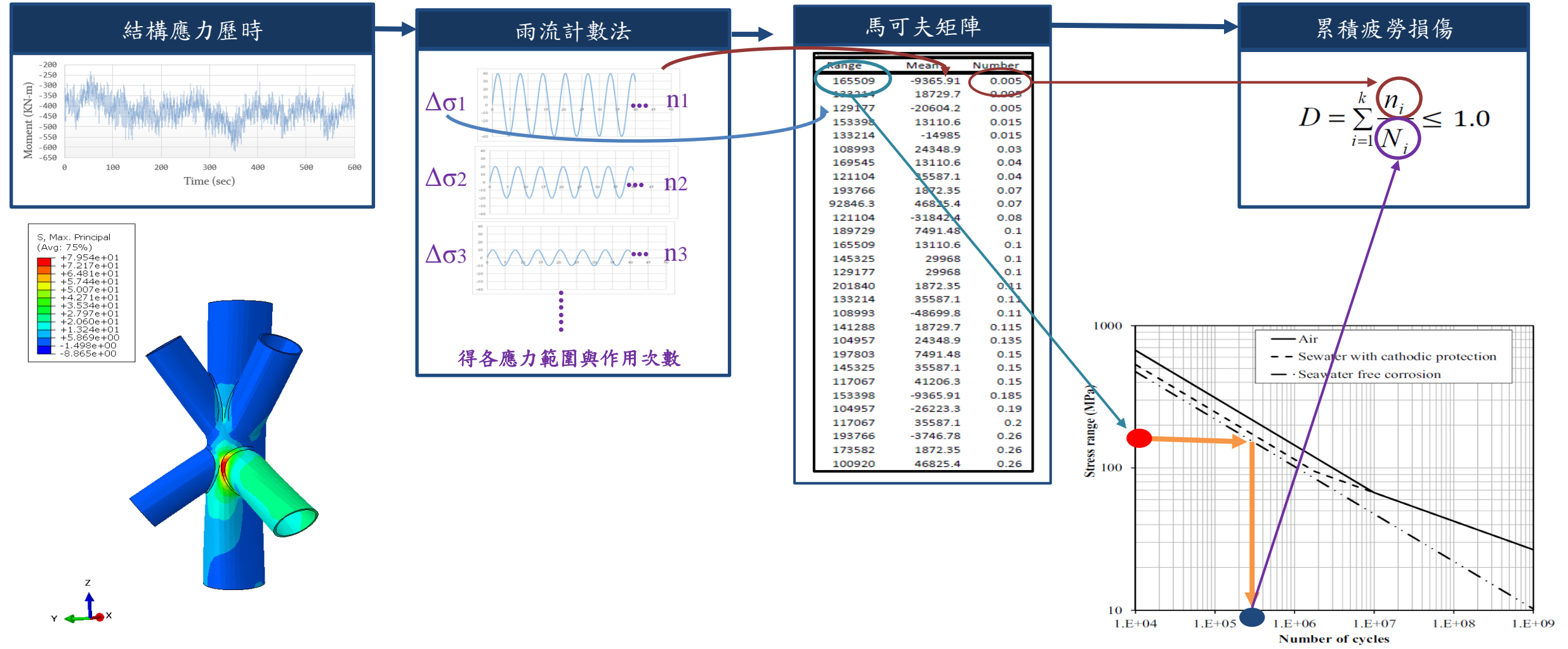
➤ 國內陸域(含近岸)結構設計與離岸風電支撐結構設計差異

	陸上(含近岸)	離岸風機支撐結構	比較
波浪/海流 (ULS)	有	有	方法相同。
風力 (ULS)	有	有	方法相同。 但風機荷重由供應商分析，較陸上結構設計更簡單。
疲勞 (FLS)	幾乎無	有	陸上結構設計幾僅橋梁需考慮疲勞設計。
地震 (ALS)	有	比照陸上	方法相同。
意外撞擊 (ALS)	可	有	陸上結構設計幾不考慮意外撞擊，但可依一般結構分析方法考慮。
服務性 (SLS)	有	有	方法相同。
設計規範	美規/日規	歐規	分析方法相同，強度檢核公式不同，但設計程式可依選用規範檢核。

二、離岸結構與陸域結構設計之差異

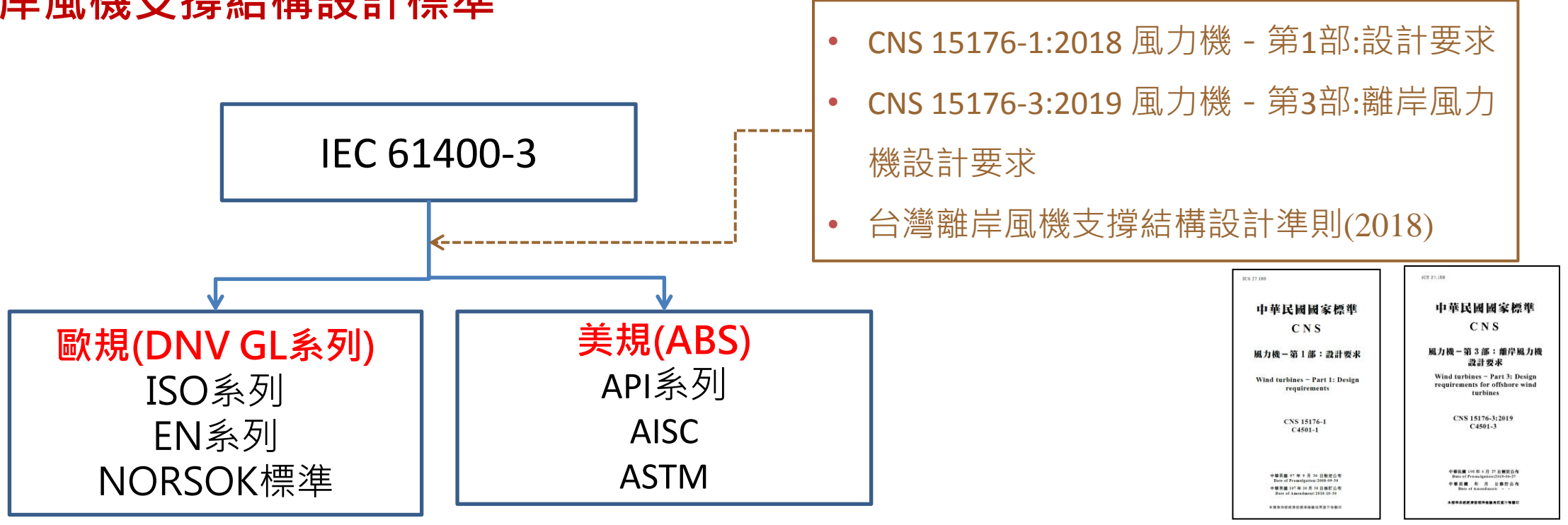
➤ 疲勞設計

- 發生於應力集中處，通常為形狀變化處，亦為銲接處。
- 瑕疵 -> 細微裂縫 -> 擴大 -> 破裂



二、離岸結構與陸域結構設計之差異

➤ 離岸風機支撐結構設計標準

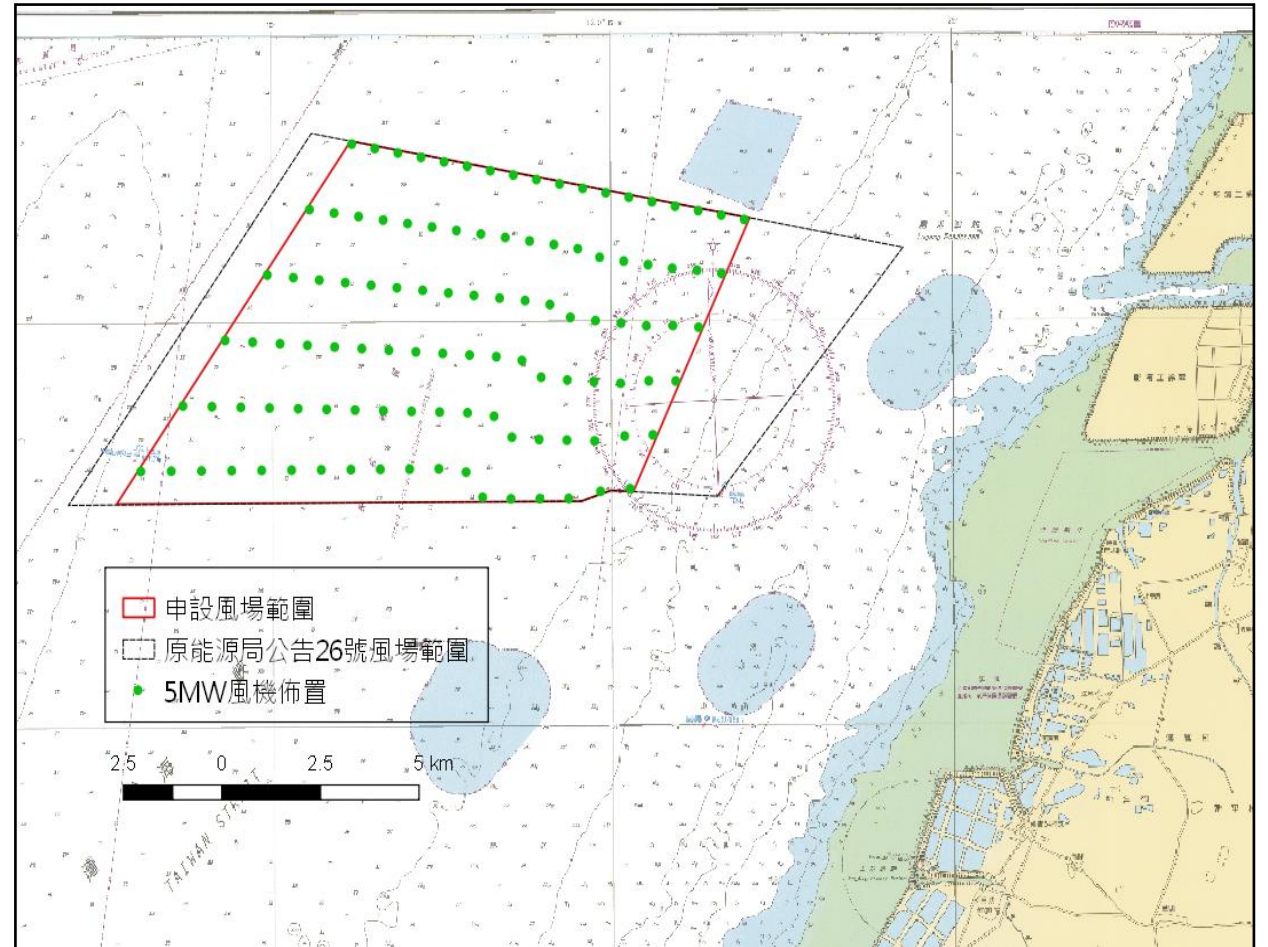
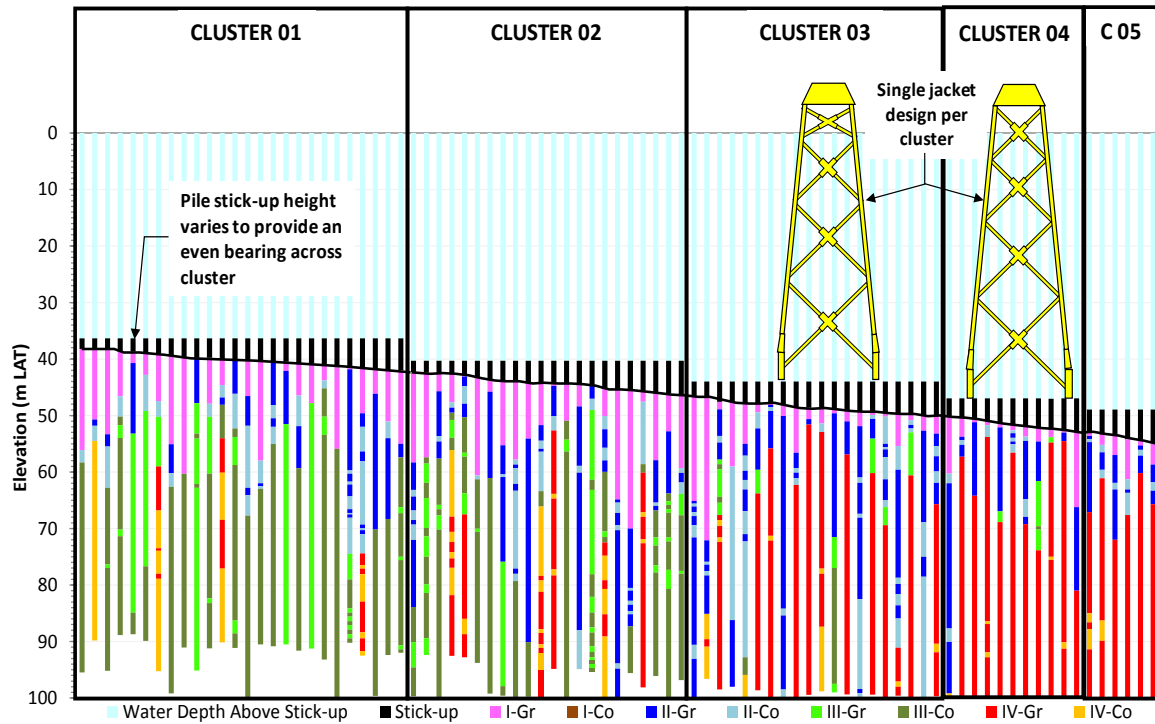


- DNVGL離岸風電結構設計標準發表於2004年，現與GL標準合併成DNVGL標準，內容涵規劃、調查、設計、製造、檢驗、與施工等細節。為目前為全世界離岸風電產業最廣泛採用之標準。
- 美國離岸風電發展很晚，ABS於2015年發佈設計與施工準則，2016年底才建立第一座風場(5部6MW)。
- 離岸風機結構與海上鑽油平台設計標準不太相同，前者受疲勞影響較後者更嚴重，故疲勞相關要求更高，但在極端環境荷重標準較低。

二、離岸結構與陸域結構設計之差異

➤ 大量風機支撐結構

- 水深
- 土壤條件



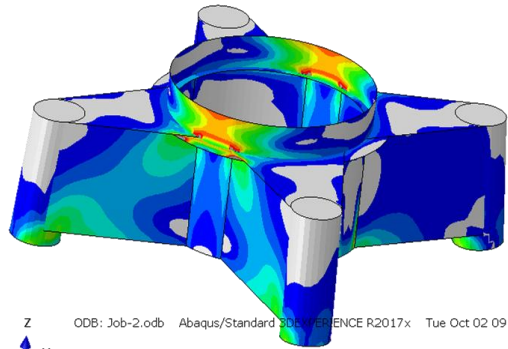
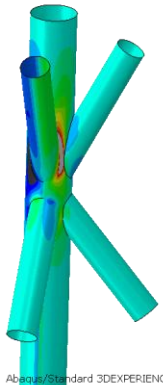
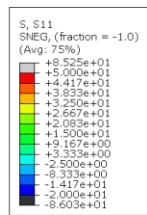
三、關鍵技術發展

➤ 環境設計參數

- 風: 速度、風向、機率...
- 波: 波高、週期、波向、機率
- 流: 流速、流向、機率
- 土壤: 凝聚力、摩擦角、剪力波速、地震...

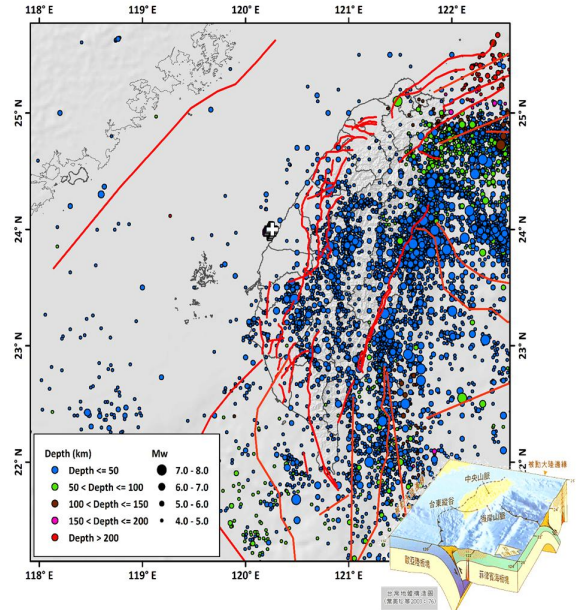
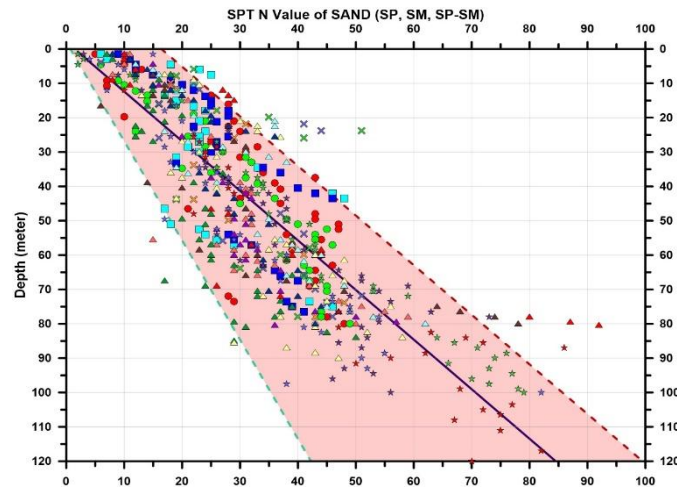
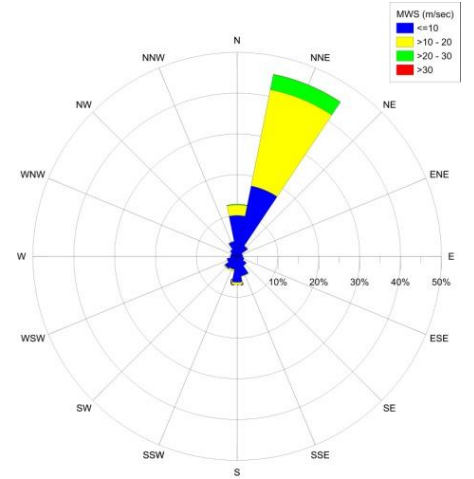
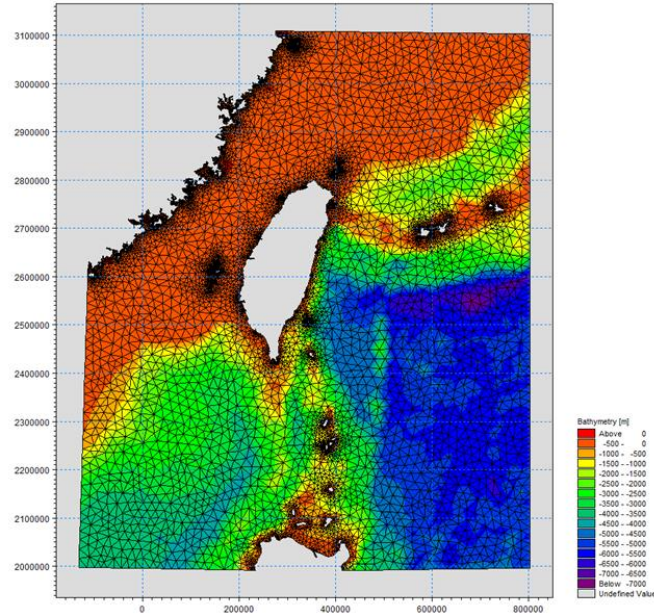
➤ 結構設計技術

- 大量荷載情境
- 疲勞設計



Step: Step-2
Increment: 1: Step Time = 1.000
Primary Var: S, Mises

Step: Step-1
Increment: 1: Step Time = 1.000
Primary Var: S, S11



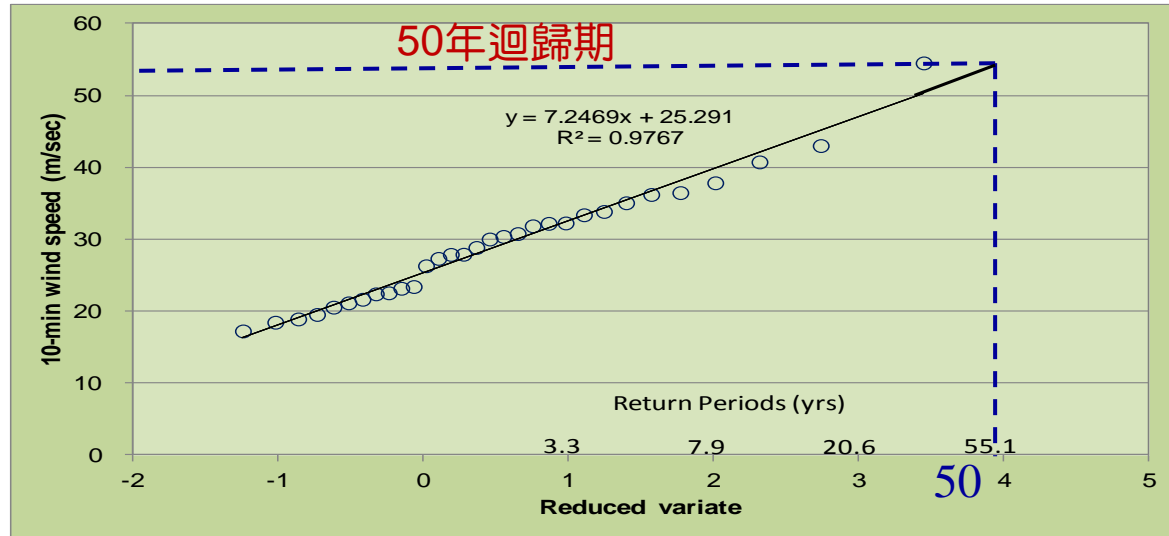
三、關鍵技術發展

➤ 風況設計參數

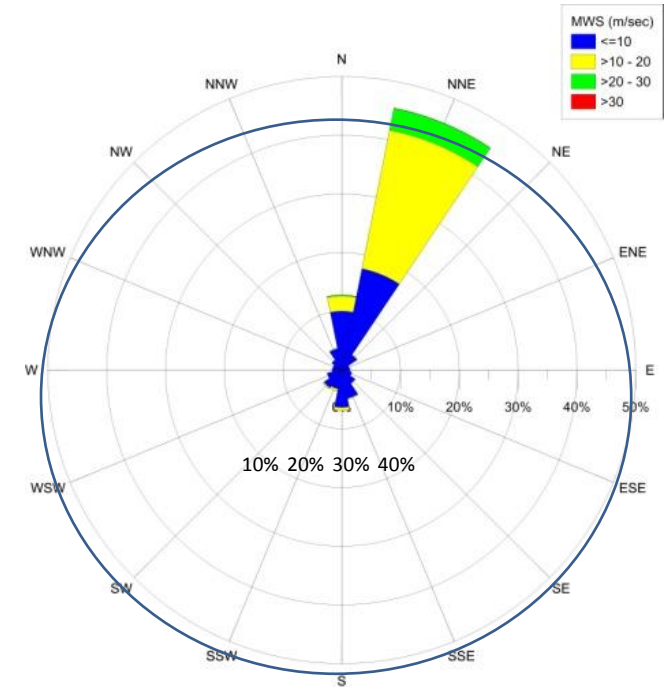
- 極端情境
- 疲勞情境

➤ 極端風速

10分鐘平均風速



➤ 年平均風花圖



三、關鍵技術發展

➤ 風能評估

- 完成符合台灣及國際規範(CNS 15176-1/3 & IEC 61400-1/3)及業界通用規定
- 使用先進風能分析軟體WAsP, WindFarmer及其他自行研發軟體
- 運用台灣及國際常用之海氣象及大氣環流模式(GCMs) 進行分析
- 本公司為台灣惟一通過國際知名風能分析公司DNV GL簽署認可風能分析程序及結果之本土顧問公司
- 離岸風電實蹟：台電離岸一期、二期、其他台灣離岸風電計畫

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R.O.C.

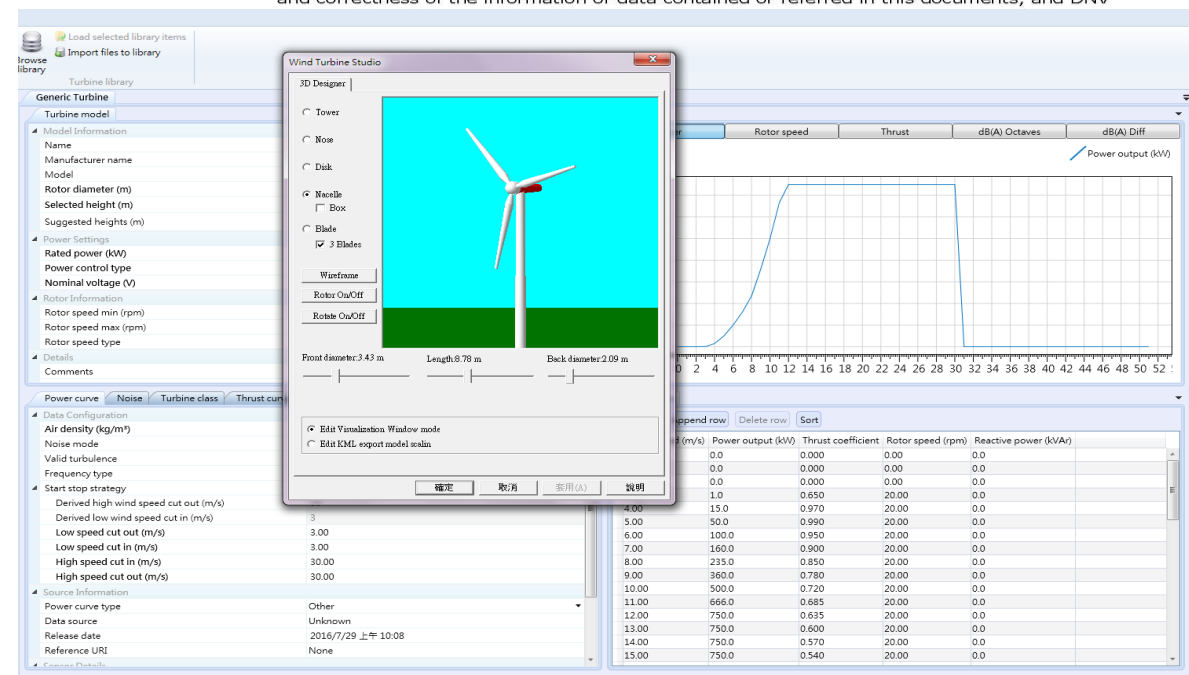
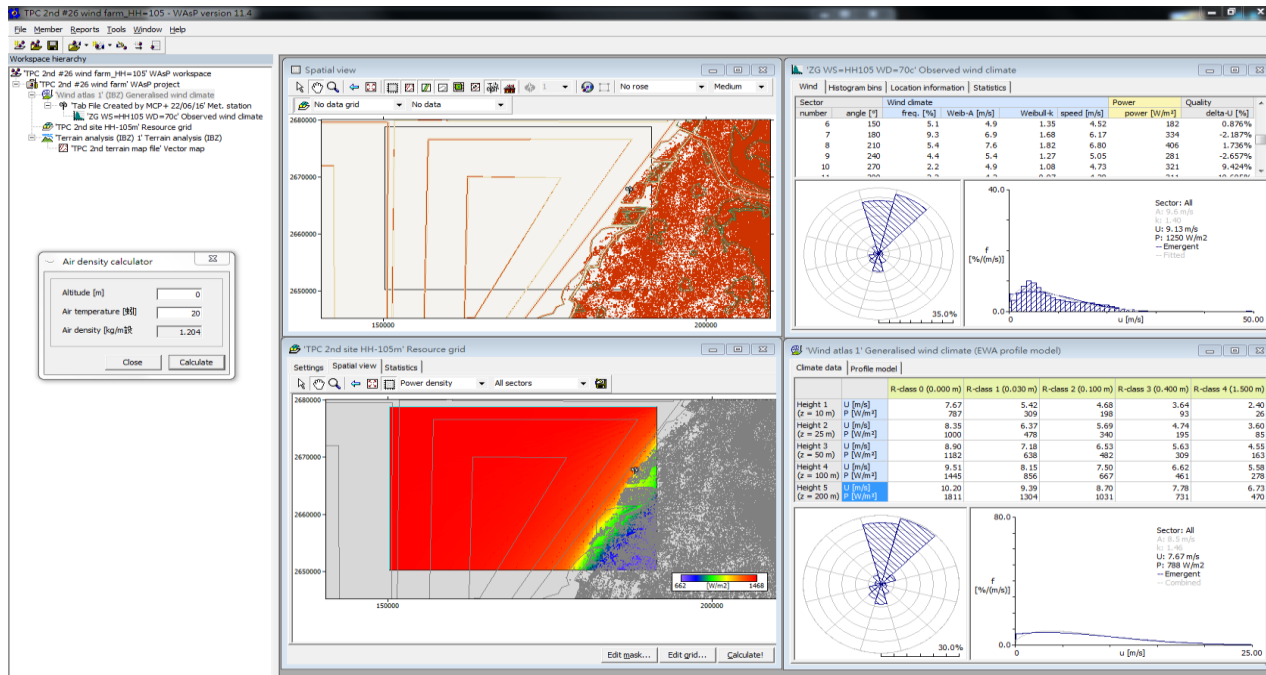
DNV GL Singapore Pte Ltd.
Renewables Advisory
Clean Technology Centre
16 Science Park Drive
Singapore
118227
Tel: +65 65083750

Date: 27/02/2017 **Our reference:** PP152788-WP3-02-A

Review of "Taipower Changhua Offshore Wind Farm Project - Phase 1 Wind Report (Rev 3)"
This document has been reviewed by DNV GL Singapore Pte. Ltd ("DNV GL") in accordance with DNV GL's own experience and knowledge and the good industry practice, which is part of our service with Sinotech Engineering Consultants ("Client") in accordance with the agreement signed between DNV GL and the Client in February 2016 ("Agreement").

For the avoidance of doubt, DNV GL hereby further clarify that:

1. The methodology of the data analysis is consistent with DNV GL's experience and good industry practice in wind resource assessment, subject to the inherent uncertainties of such analysis as specified within the report.
2. Our review of this document has been made based upon the information and/or data contained or referred to in this document. This review does not imply that any information or data is not subject to change. The Client shall be responsible for the accuracy, completeness and correctness of the information or data contained or referred to in this documents, and DNV

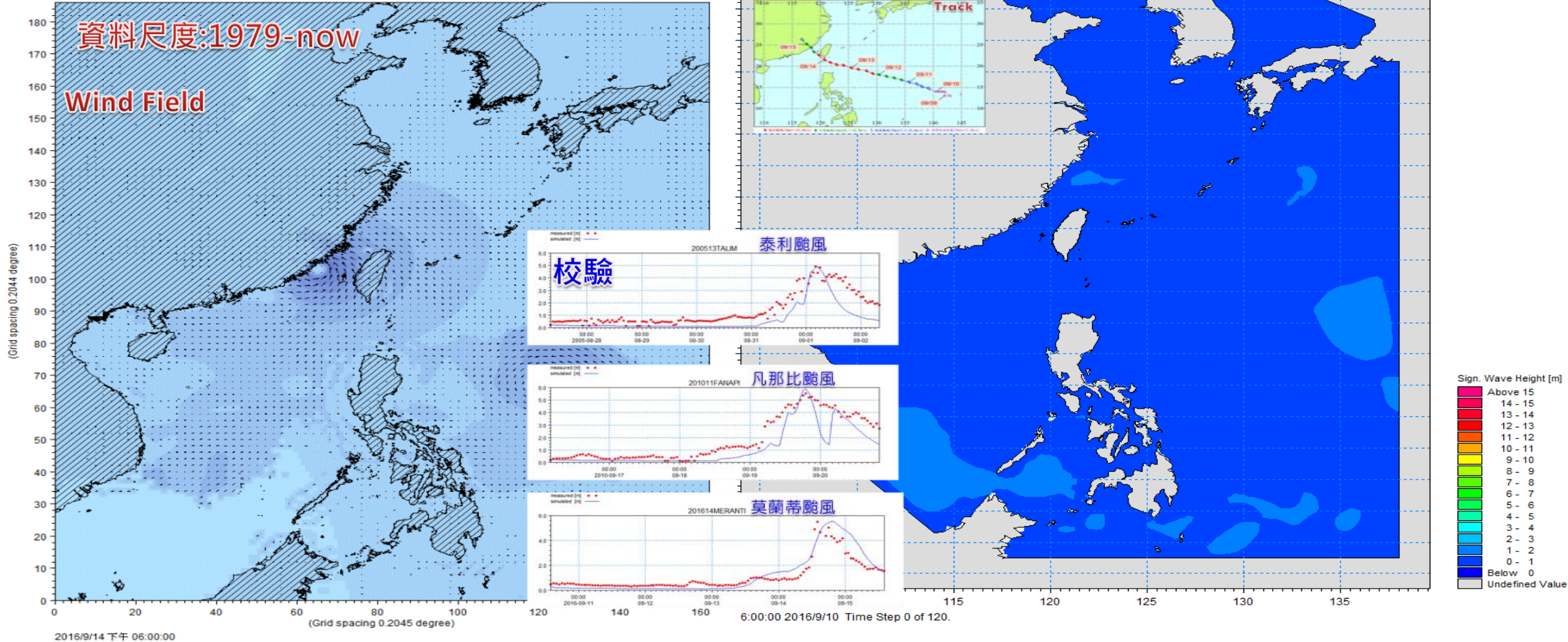


三、關鍵技術發展

➤ 波浪計算 Wave model M21 SW 結合 CFSv2 and JMA typhoon wind data

氣旋(Cyclone Wind)模組

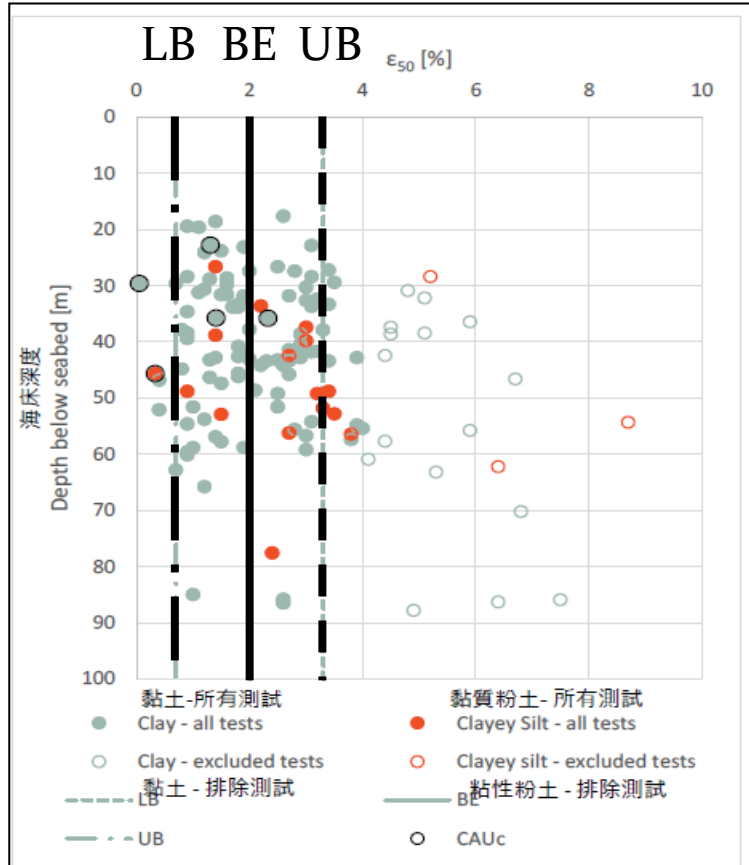
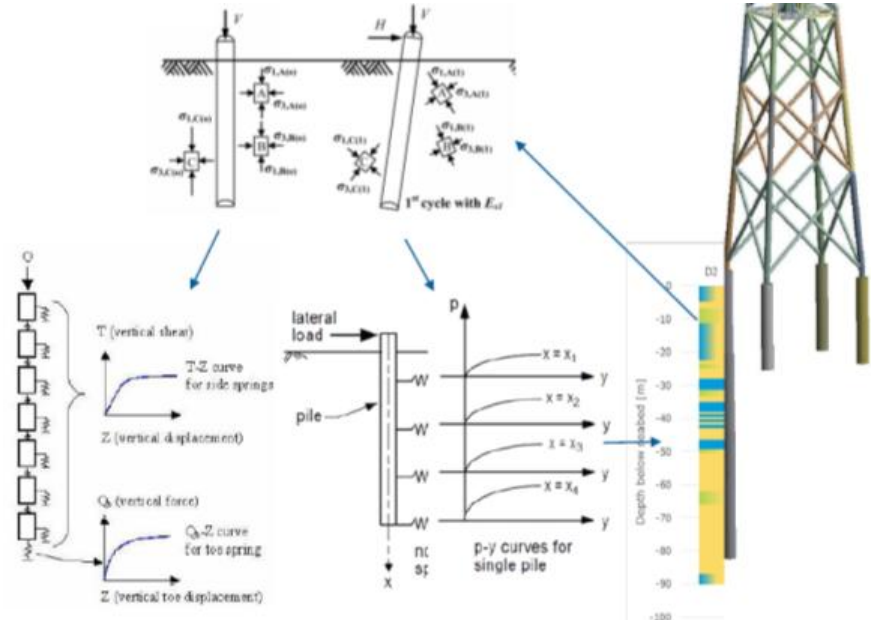
頻譜波浪(Spectral Waves, SW)模組



三、關鍵技術發展

➤ 土壤調查與基樁承載力評估

- 由現地與室內試驗決定設計參數
 - 推求p-y與t-z曲線
 - 計算基樁承載力

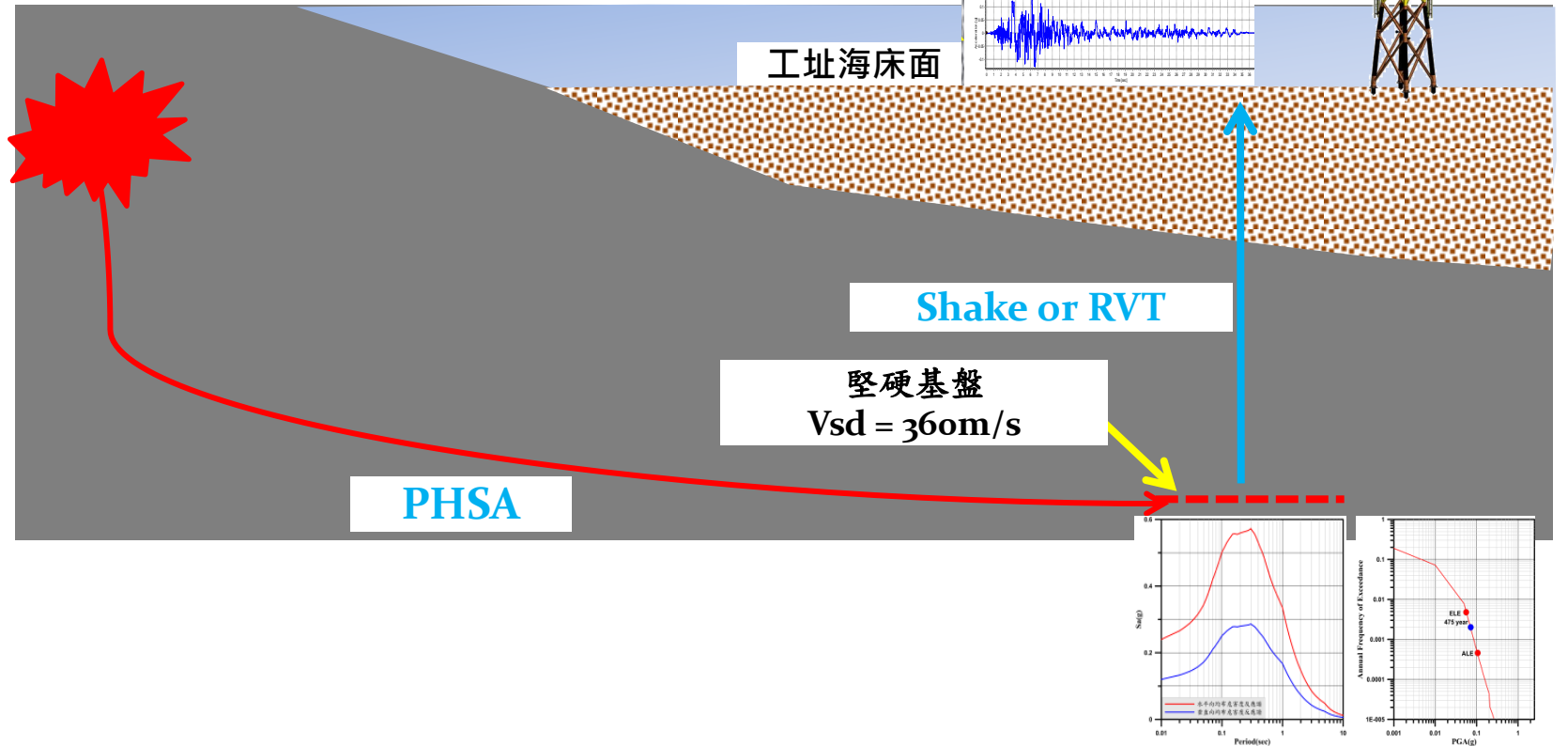
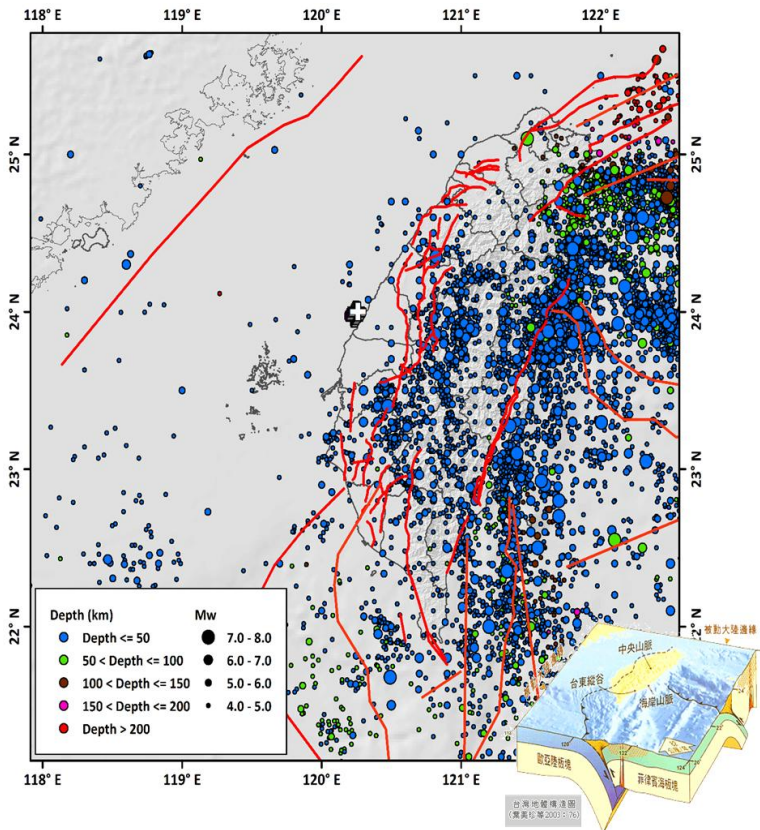


Depth (m)		soil type	γ' (kN/m ³)	Lower Bound						Best Estimate						Upper Bound					
from	to			ϕ (degrees)		S_u (kPa)		E_{50}		ϕ (degrees)		S_u (kPa)		E_{50}		ϕ (degrees)		S_u (kPa)		E_{50}	
				from	to	from	to	from	to	from	to	from	to	from	to	from	to	from	to		
0	2.8	Clay	3.9	-	-	6.8	11.1	0.02	0.02	-	-	13.7	19.1	0.02	0.02	-	-	23.2	29.5	0.007	0.007
2.8	8	Silt	6.3	30.3	30.4	11.1	21.1	0.02	0.02	31.8	31.9	19.1	31.5	0.02	0.01	32.8	32.9	29.5	44.0	0.004	0.004
8	13.1	Clay with sand	7.2	30.4	30.5	21.1	33.3	0.02	0.01	31.9	31.9	31.5	46.8	0.01	0.01	32.9	32.9	44.0	61.8	0.005	0.005
13.1	15.5	Sand	7.9	30.5	30.5	-	-	-	-	31.9	32.0	-	-	-	-	32.9	33.0	-	-	-	-
15.5	17.7	Clay	6.6	-	-	39.9	46.5	0.01	0.01	-	-	55.0	63.0	0.007	0.007	-	-	71.4	80.9	0.005	0.005
17.7	27	Sand	7.2	30.5	30.7	-	-	-	-	32.0	32.1	-	-	-	-	33.0	33.1	-	-	-	-
27	29.5	Clay	8.3	-	-	79.1	89.3	0.007	0.007	-	-	103.4	115.9	0.005	0.005	-	-	128.3	143.0	0.004	0.004
29.5	32.1	Sand with clay	8.8	30.7	30.8	89.3	100.5	0.007	0.005	32.1	32.2	115.9	129.7	0.005	0.005	33.2	33.2	143.0	159.2	0.004	0.004
32.1	39.3	Clay with silt	7.9	30.8	30.9	100.5	134.8	0.005	0.005	32.2	32.3	129.7	171.9	0.005	0.005	33.2	33.3	159.2	209.0	0.004	0.004
39.3	52.6	Sand	8.7	30.9	31.1	-	-	-	-	32.3	32.4	-	-	-	-	33.3	33.5	-	-	-	-
52.6	100	Sand	9.4	31.1	31.8	-	-	-	-	32.4	33.1	-	-	-	-	33.5	34.1	-	-	-	-

三、關鍵技術發展

➤ 設計地震評估

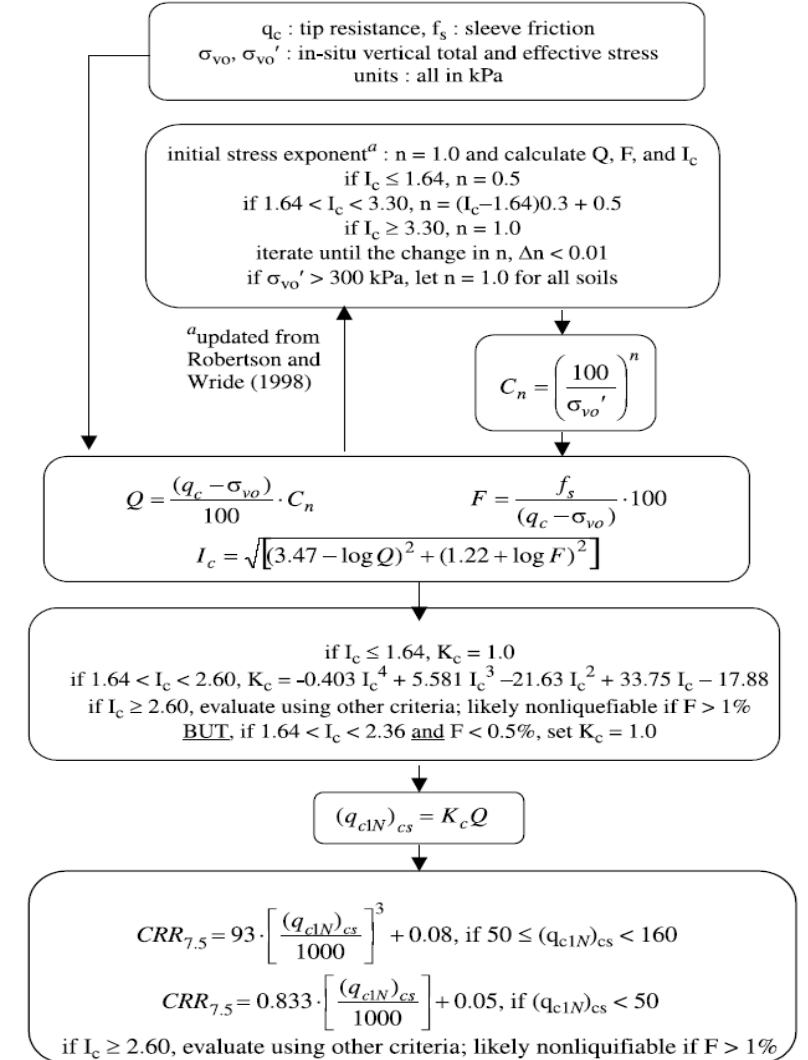
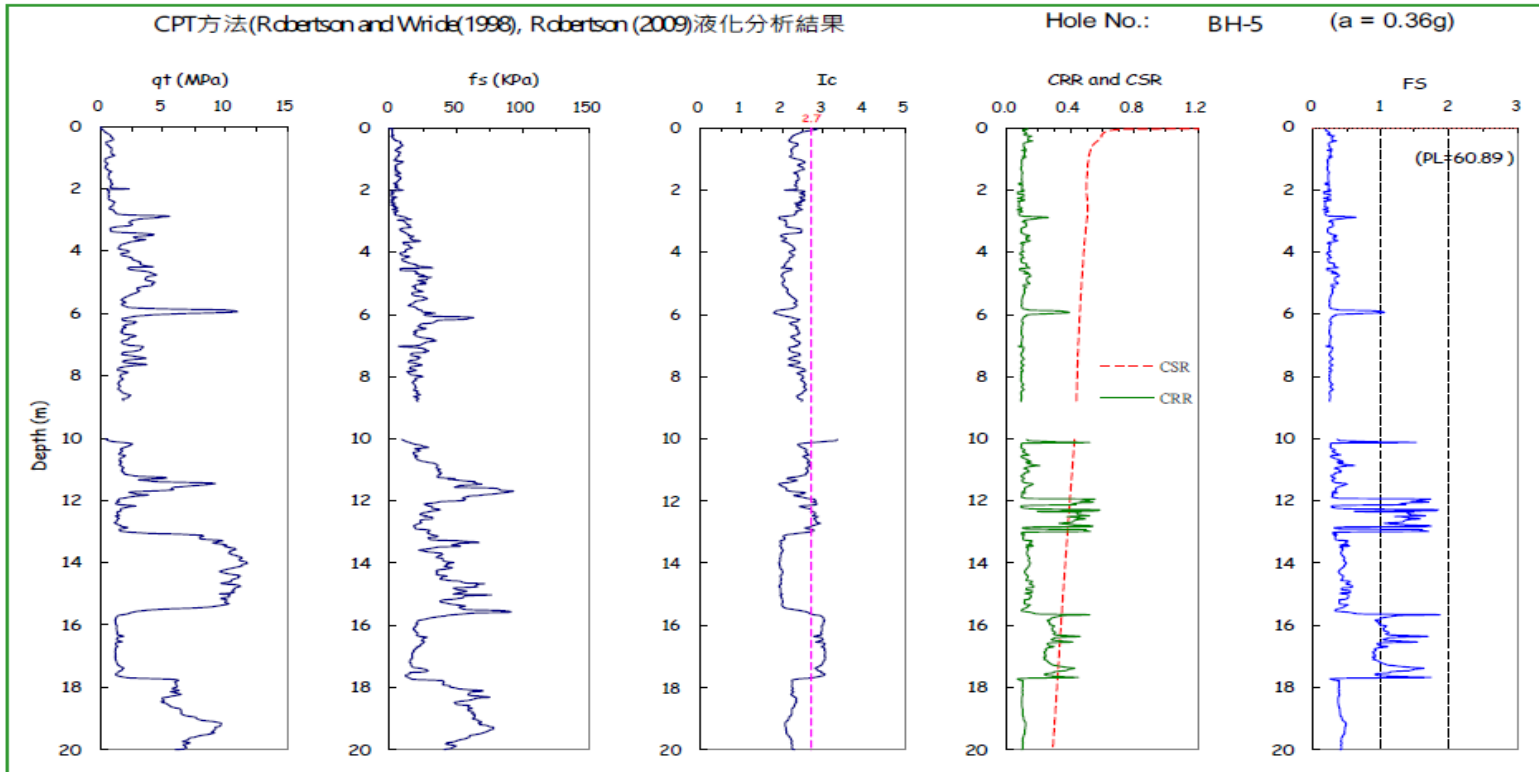
- 機率式危害度分析(Probabilistic Seismic Hazard Analysis, PSHA)
- 堅硬基盤(Vsd360 m/s)
- 地盤反應分析



三、關鍵技術發展

➤ 液化潛勢評估

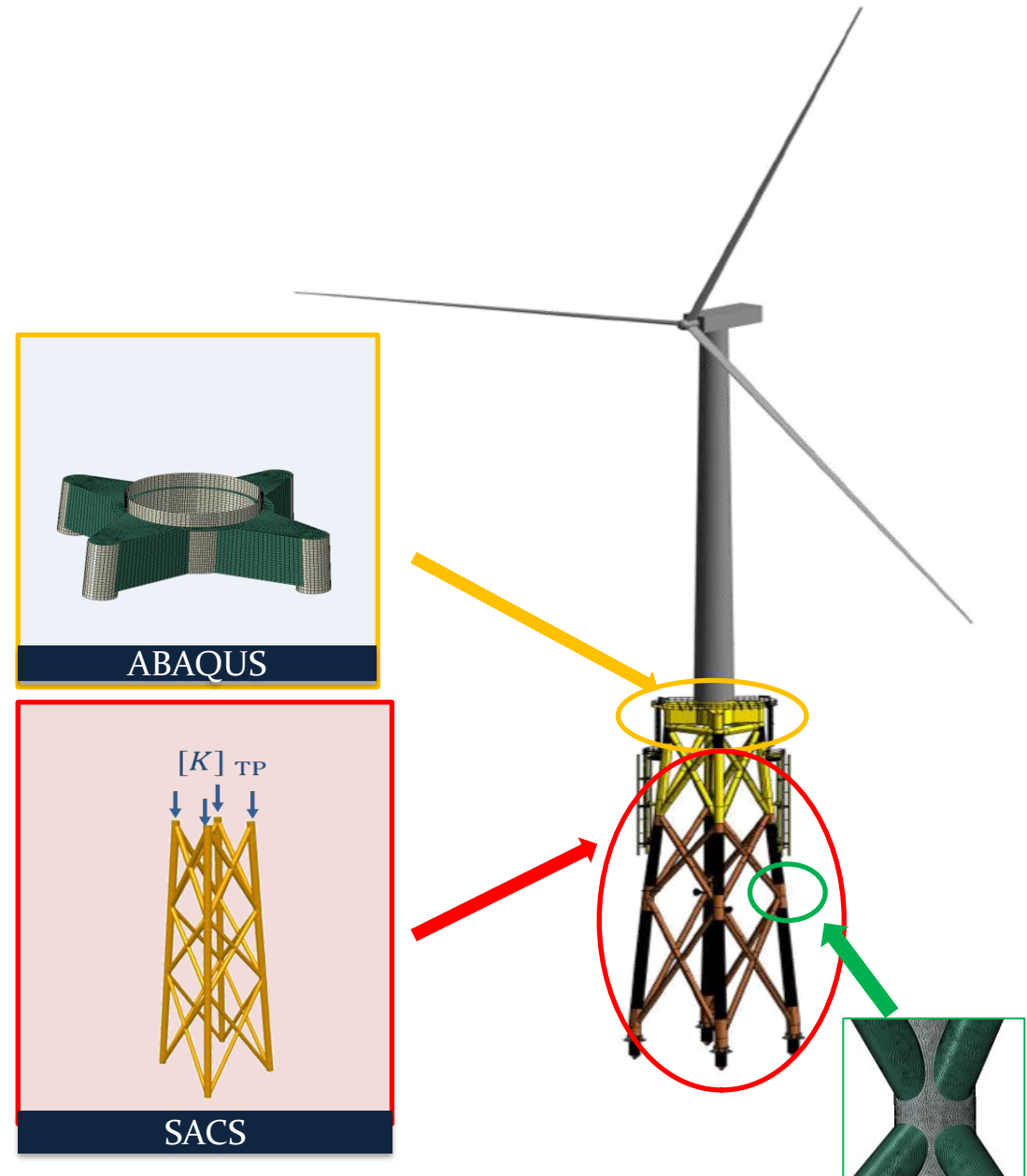
- 推求液化深度
- 結構分析
- 基樁設計



三、關鍵技術發展

➤ 結構設計

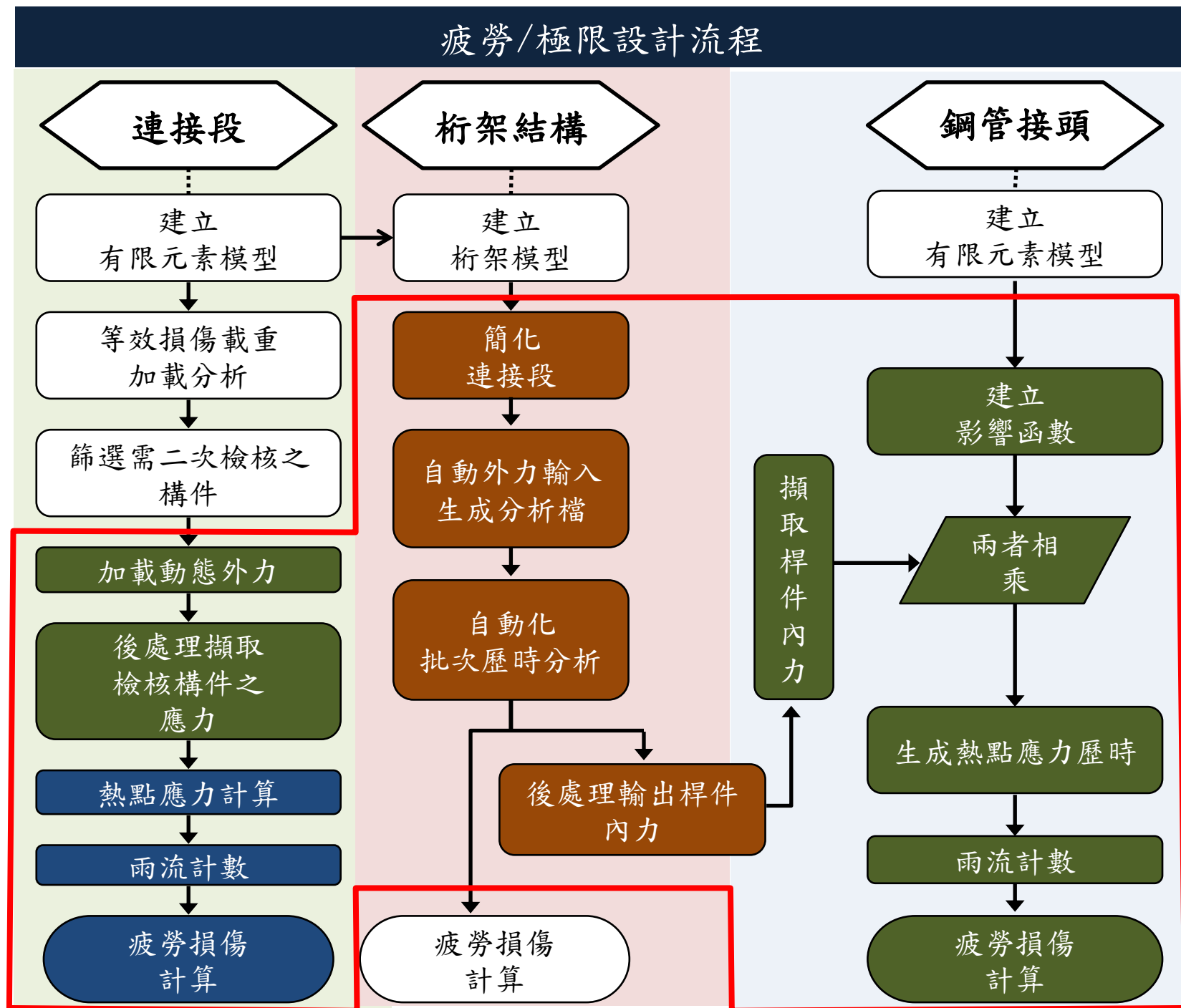
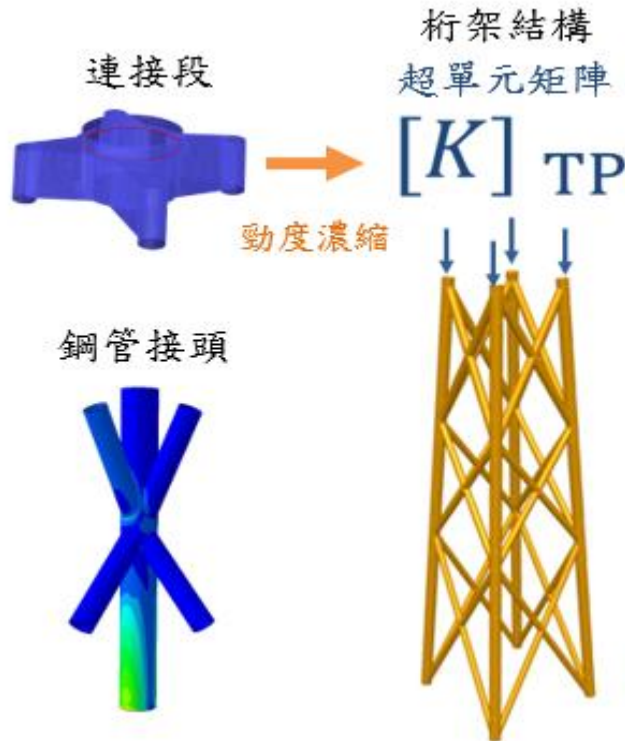
- 處理大量荷重情境
 - 極端情境 (max) vs 疲勞情境(sum)
 - 成千上萬組情境=>自動化
- 建立連接段設計方法
 - 應力分布複雜
 - 板殼元素數量龐大=>結構簡化技巧
- 從應力歷時計算得疲勞損傷
 - 設計標準之分析與設計檢核要求
 - 計算與資料處理=>自動化
- 建立細部設計流程
 - 耐震設計
 - 極限強度設計
 - 疲勞設計
 - :
 - :



三、關鍵技術發展

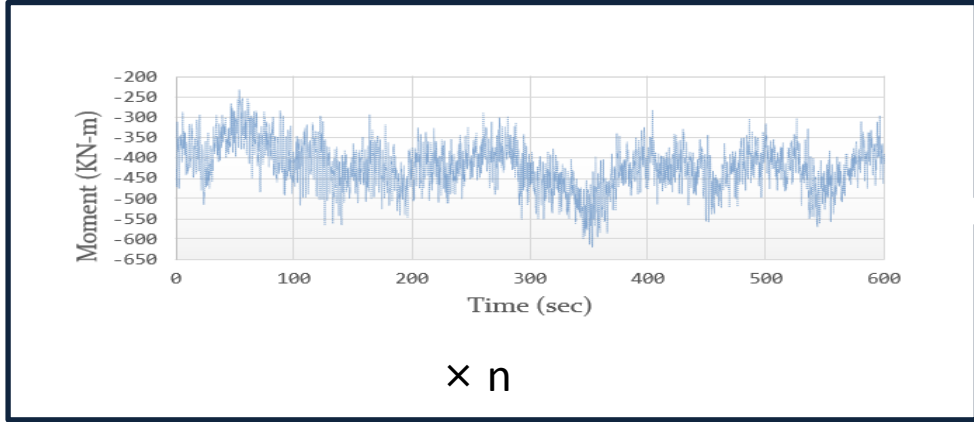
➤ 疲勞分析架構

- 以ABAQUS進行連接段和鋼管接頭局部有限元素分析
- 以SACS進行整體桁架結構分析
- 針對大量的分析資料及程序，以Python、Fortran、VBA、Matlab自撰程式自動化處理

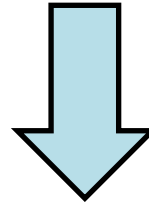
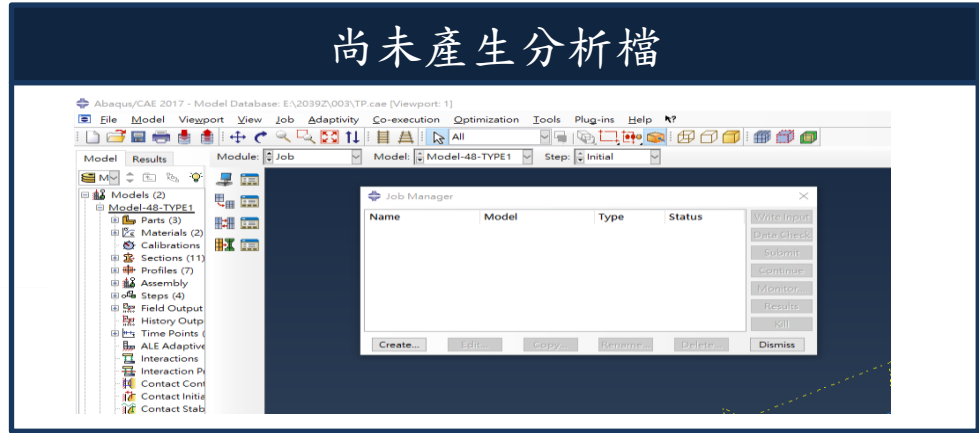
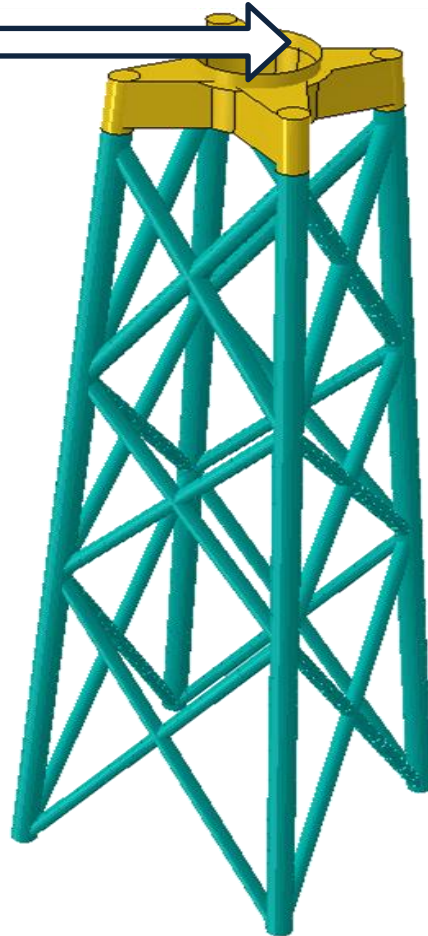


三、關鍵技術發展

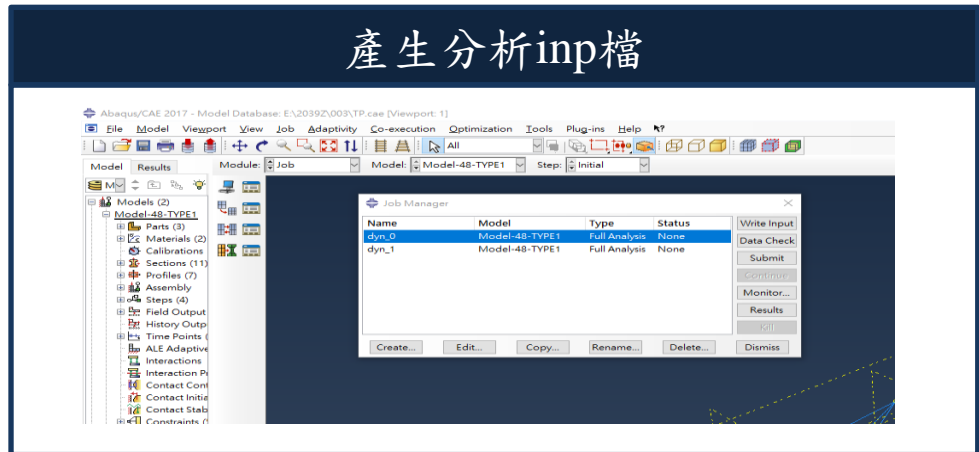
➤ 分析大量歷時情境(ABAQUS)



- 由於外力可能有數千組，因此須採用自動化加載以節省操作時間
- 後處理擷取元素應力也須以自動化進行資料處理並計算疲勞損傷



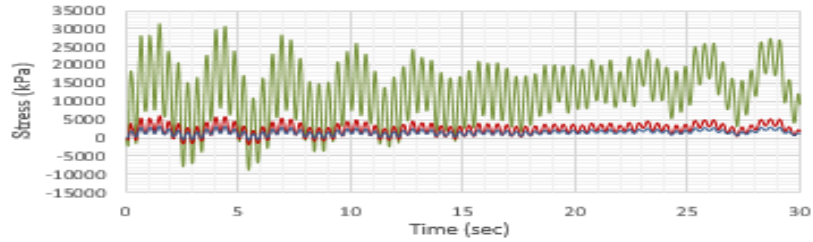
使用Python
撰寫自動化程式



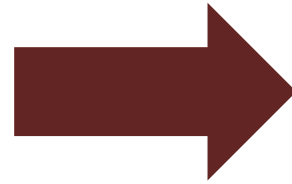
三、關鍵技術發展

➤ 自動擷取檢核元素應力歷時，計算疲勞損傷(ABAQUS)

擷取特定元素之正向與剪應力歷時

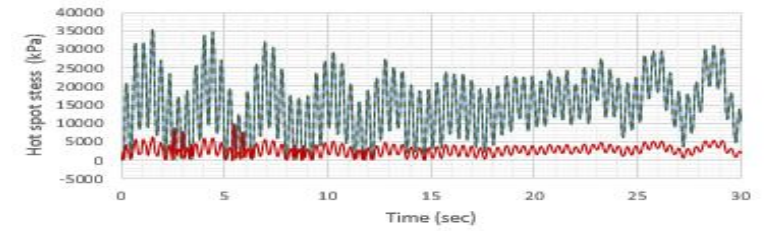


千組載重+數量眾多之元素



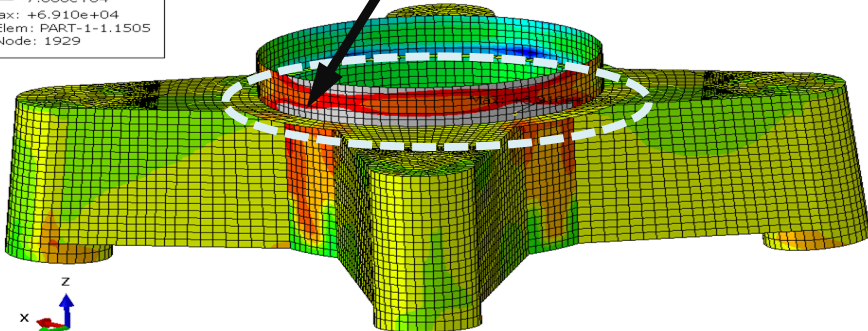
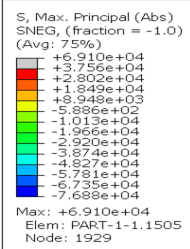
根據
DNVGL-RP-C203

特定元素之有效熱點應力歷時

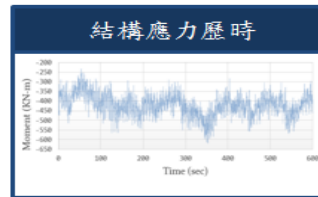


千組載重+數量眾多之元素

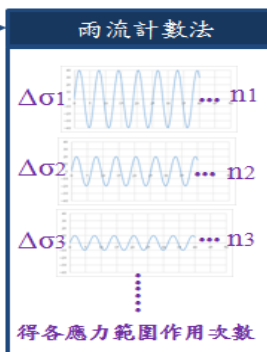
需詳細檢核之元素



結構應力歷時



兩流計數法



整理

馬可夫矩陣

Range	Mean	Number
165509	-9365.91	0.005
133214	18729.7	0.005
129177	-20604.2	0.005
153398	13110.6	0.015
133214	-14985	0.015
108993	24348.9	0.03
169545	13110.6	0.04
121104	35587.1	0.04
193766	1872.35	0.07
92846.3	46825.4	0.07
121104	-31842.4	0.08
189729	7491.48	0.1
165509	13110.6	0.1
145325	29968	0.1
129177	29968	0.1
201840	1872.35	0.11
133214	35587.1	0.11
108993	-46999.8	0.11
141288	18729.7	0.115
104957	24348.9	0.135
197803	7491.48	0.15
145325	35587.1	0.15
117067	41206.3	0.15
153398	-9365.91	0.185
104957	-26223.3	0.19
117067	35587.1	0.2
193766	-3746.78	0.26
175582	1872.35	0.26
100920	46825.4	0.26

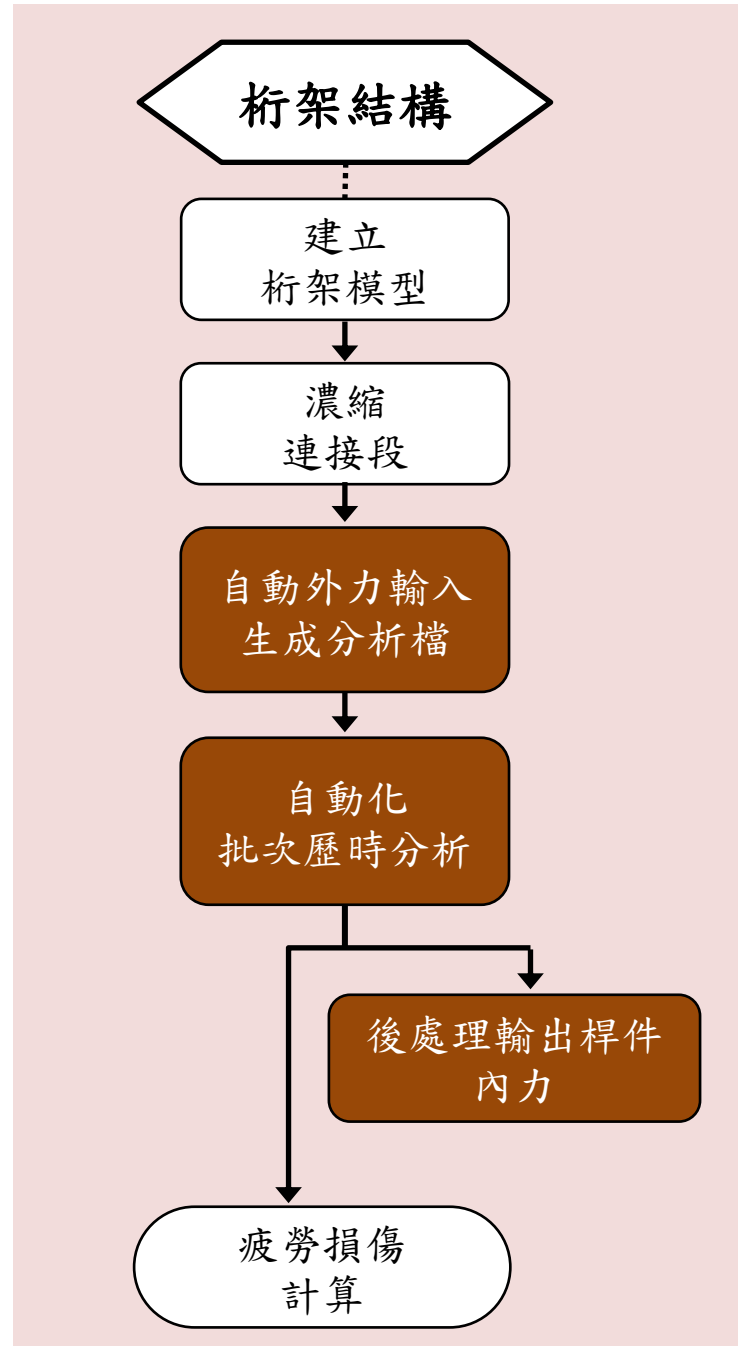
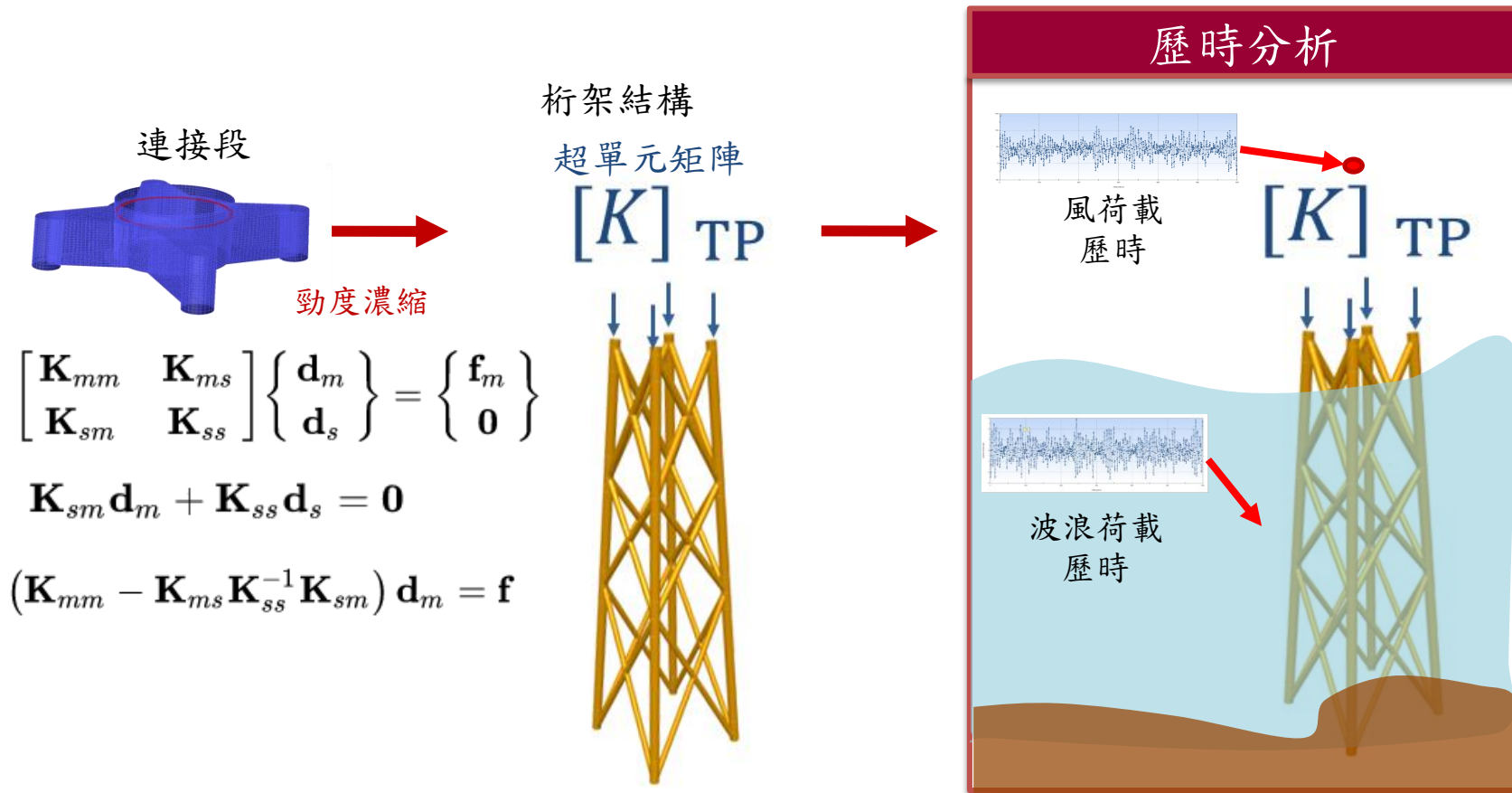
累積疲勞損傷

$$D = \sum_{i=1}^k \frac{n_i}{N_i} \leq 1.0$$

三、關鍵技術發展

➤ 自動化分析程序(SACS)

- 於SACS軟體中減少連接段模型自由度，**加速分析效率**
- 針對上千組載重組合，**自動生成**SACS分析所需之輸入檔
- 使用SACS Wind Turbine Process功能**自動化**進行**歷時分析**
- **自動化輸出**各載重組合分析結果之**桿件內力**供鋼管接頭分析使用



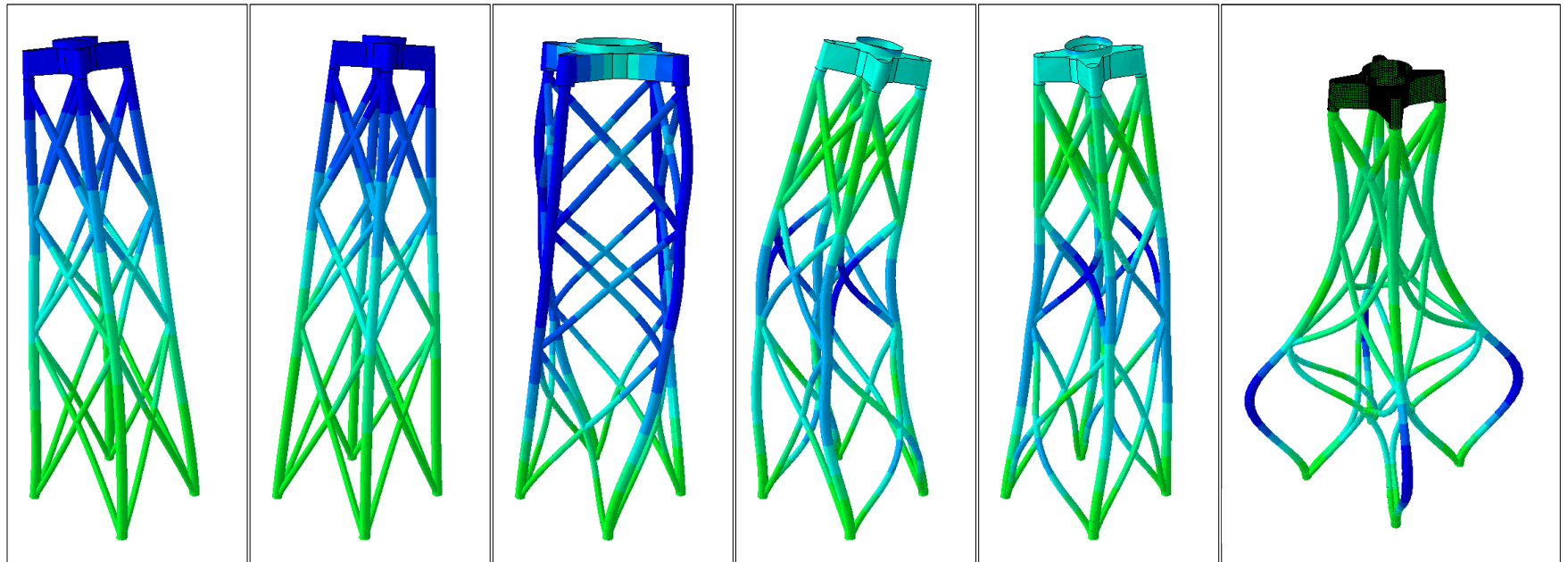
三、關鍵技術發展

➤ 簡化模型驗證

模態分析 (SACS v.s. ABAQUS)

Mode	X (1 st)	Y (1 st)	Torsion (1 st)	X (2 nd)	Y (2 nd)	Z (1 st)
SACS - Freq.(Hz)	2.48	2.49	5.22	7.96	7.96	8.99
ABAQUS - Freq.(Hz)	2.48	2.48	5.14	7.75	7.75	8.55

(無塔架)



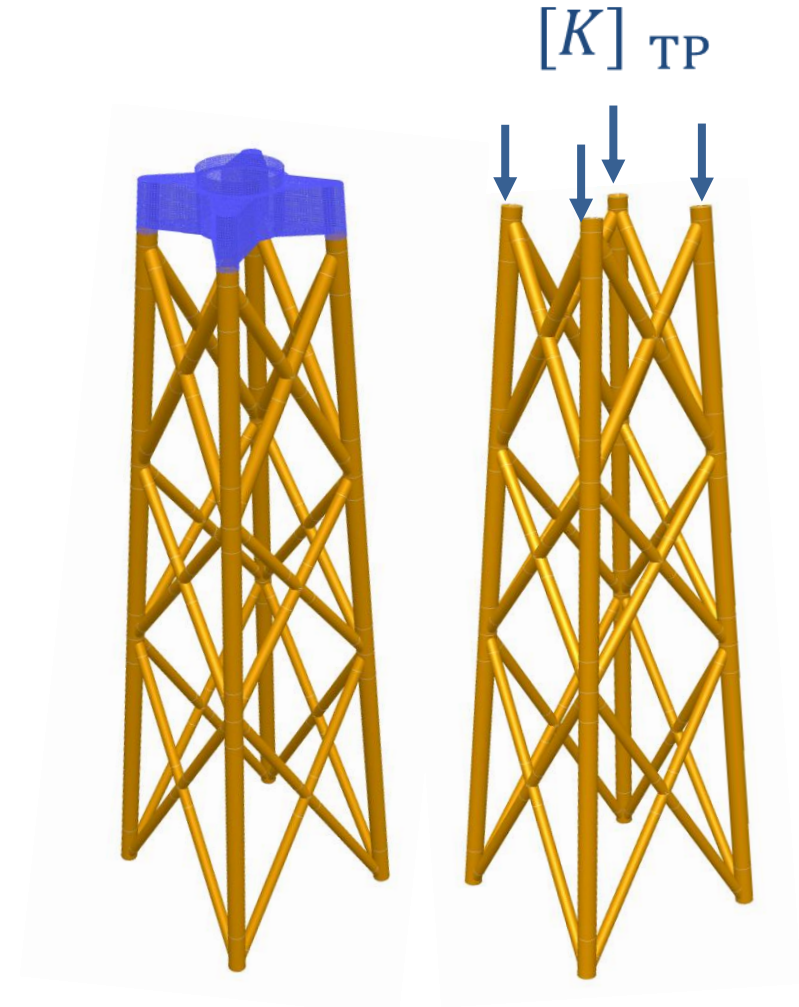
三、關鍵技術發展

➤ 簡化模型驗證

模態分析 (有限元素模型 v.s. 簡化模型)

Mode	Freq. (Hz)	
	Plate Element - TP	Superelement - TP
X (1st)	2.48	2.48
Y (1st)	2.49	2.48
Torsion (1st)	5.22	5.22
X (2nd)	7.96	7.93
Y (2nd)	7.96	7.93
Z (1st)	8.99	8.99
Z (2nd)	11.85	11.86

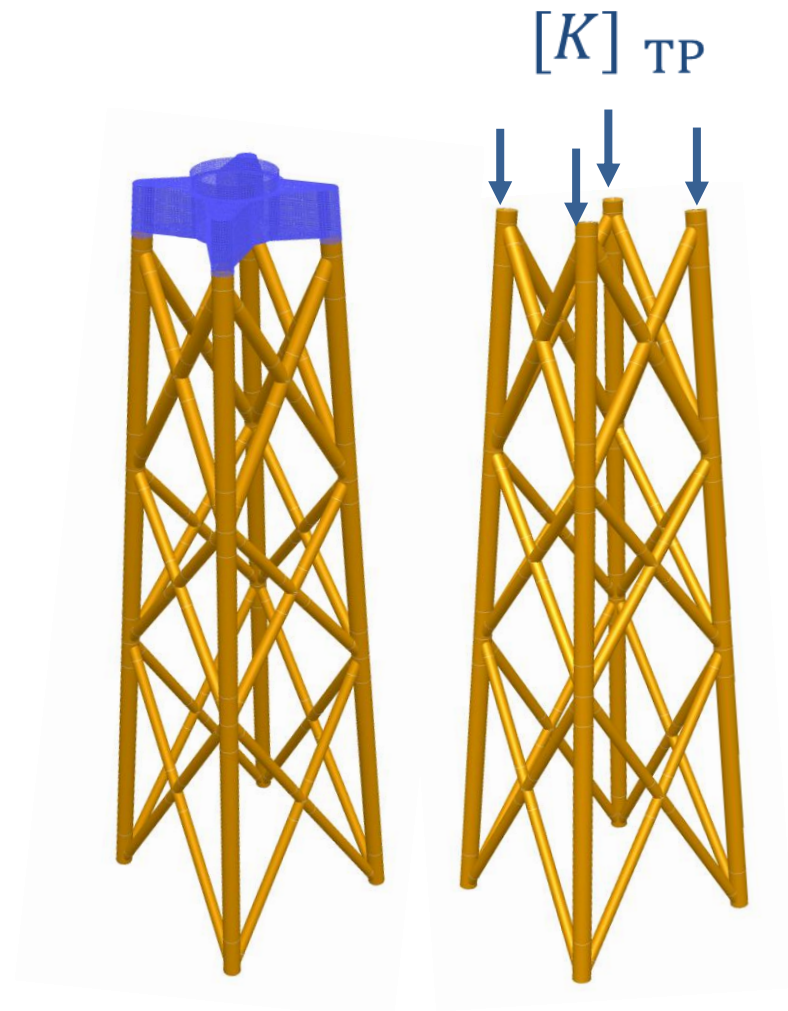
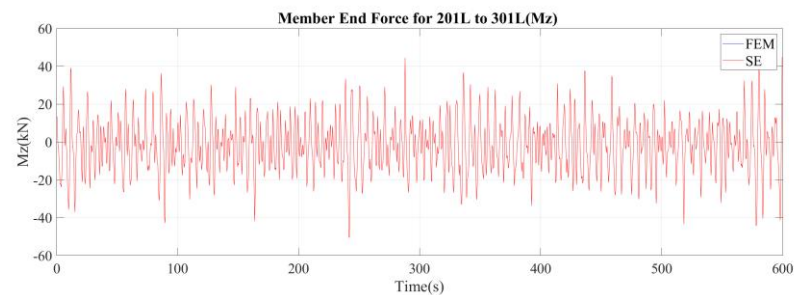
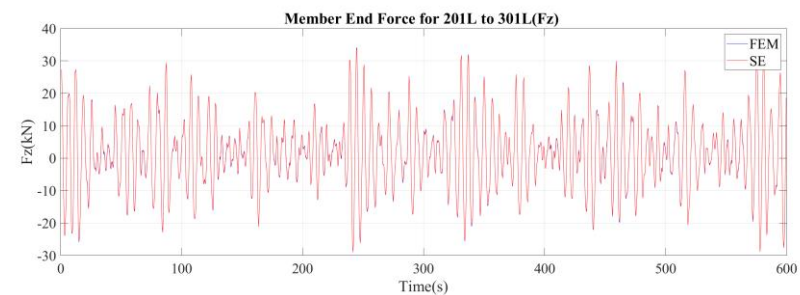
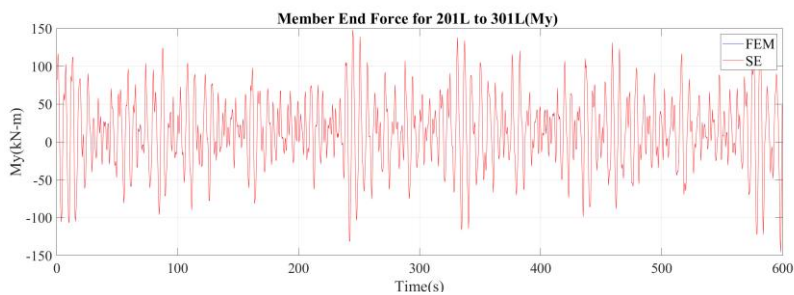
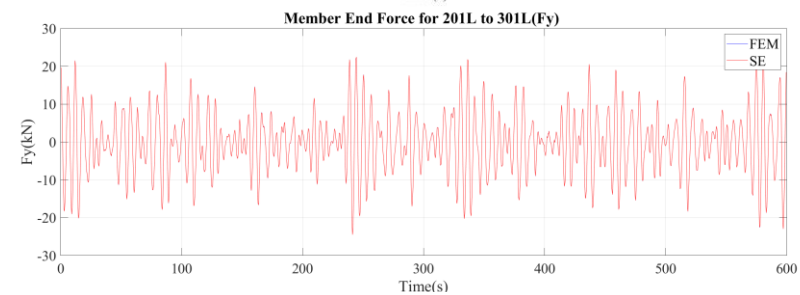
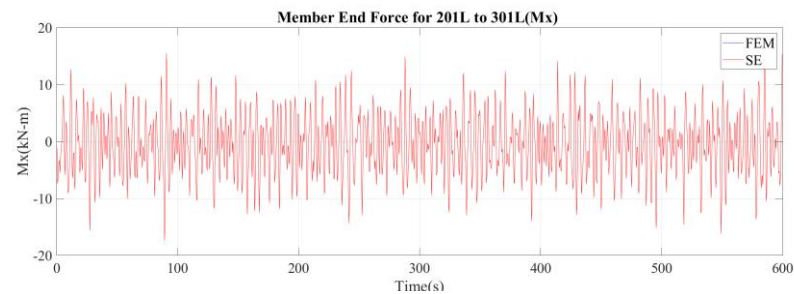
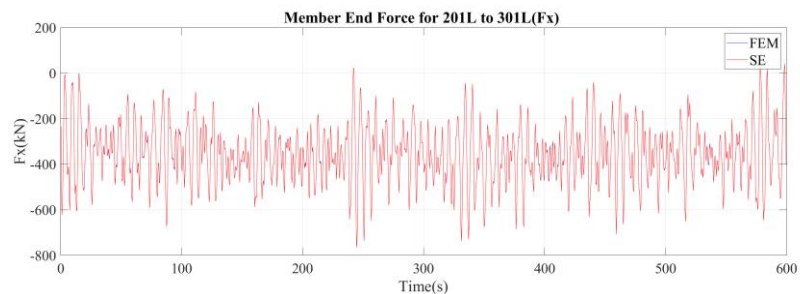
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三、關鍵技術發展

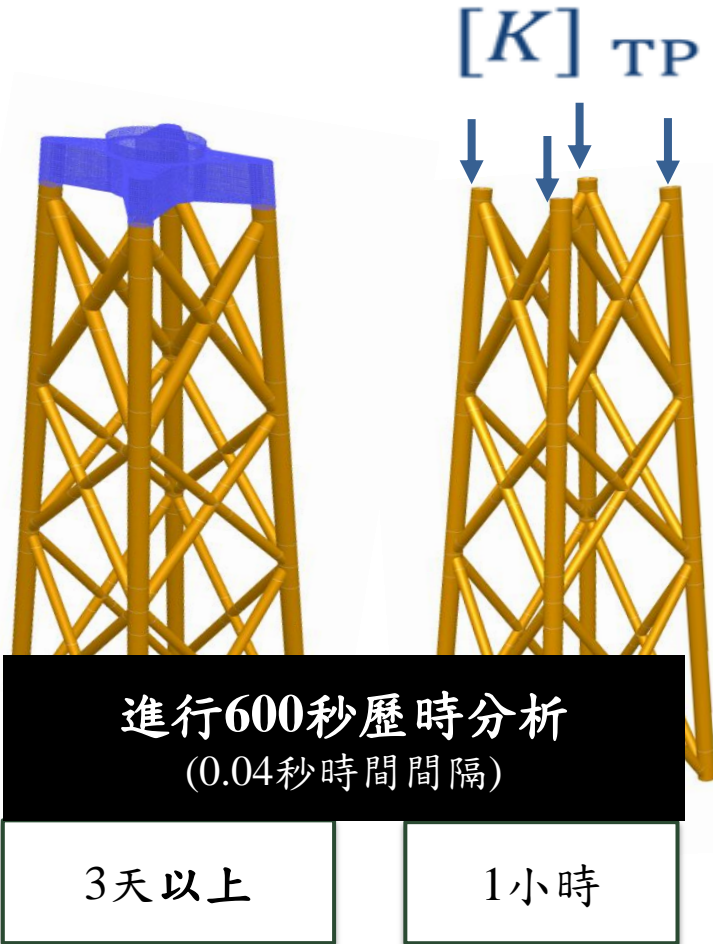
➤ 簡化模型驗證

歷時分析(有限元素模型 v.s. 簡化模型)



三、關鍵技術發展


➤ 比較連接段FE模型和超單元模型之計算效率



- 對於一座離岸風電下部支撐結構，完整的疲勞分析可能須經歷4000組歷時分析，一台8核心的電腦可同時進行8組分析，則分析時間為：

1500天以上 V.S. 20天

(以電力部工作站效能估計)

記憶體(RAM)	128GB	
中央處理器(CPU)	Intel Xeon Gold 6134 Processor	
核心數目	8	
時脈頻率	3.2GHz	

節省98.7%計算時間!!!!!!!

三、關鍵技術發展

➤ 自動建立輸入檔—VBA自撰程式自動化生成載重組合輸入檔(SACS)

- 依據DNVGL-ST-0437定義之風況、海況、方向條件.....等建立載重組合
- Excel介面操作，勾選欲分析載重組合，一鍵生成各載重組合資料夾、SACS歷時分析所需之input檔及自動化操作指令檔

Design Situation	DLC	Wind Condition		Marine Condition				Other Conditions:	Type of Analysis		Partial safety factor	
				Waves	Wind and wave directionality	Sea Currents	Water Level		inshore	offshore		
Load case type	Case No.	Wind condition										
<input type="checkbox"/> 執行	1.1	NTM	A	N	COD	UNI	NCM					
<input checked="" type="checkbox"/> 執行	1.2	NTM	A	NS	PROB	MIS	MUL	No				
<input type="checkbox"/> 執行	1.3	ETM	A	NSS	E	COD	UNI	NCM				
<input type="checkbox"/> 執行	1.4							MSL		U	N	
<input type="checkbox"/> 執行	1.5							MSL		U	N	
<input type="checkbox"/> 執行	1.6							NWLR		U	N	
<input checked="" type="checkbox"/> 執行	1.7	NTM	A	NSS	PROB	MIS	MUL	No	NWLR >=MSL	F/U	F/N	
<input type="checkbox"/> 執行	2.1	NTM	A	NSS	E	COD	UNI	NCM	MSL		U	N
<input type="checkbox"/> 執行	2.2	NTM	A	NSS	E	COD	UNI	NCM	MSL		U	A
<input type="checkbox"/> 執行	2.3	EOG	B	NSS	E	COD	UNI	NCM	MSL			
<input type="checkbox"/> 執行(替代)	2.3C2	NTM	A	NSS	E	COD	UNI	NCM	MSL			
<input type="checkbox"/> 執行	2.4	NTM	A	NSS	E	COD	UNI	No	NWLR >=MSL			
<input type="checkbox"/> 執行	2.5	NWP	A	NSS	E	COD	UNI	NCM	MSL			
<input type="checkbox"/> 執行	3.1	NWP	A	NSS	E	COD	UNI	No	NWLR >=MSL			
<input type="checkbox"/> 執行	3.2	EOG	D	NSS	E	COD	UNI	NCM	MSL		U	N
<input type="checkbox"/> 執行(替代)	3.2C2	ETM	A	NSS	E	COD	UNI	NCM	MSL		U	I
<input type="checkbox"/> 執行	3.3	EDC	D	NSS	E	MIS	direction c	NCM	MSL		U	N
<input type="checkbox"/> 執行	4.1	NWP	A	NSS	E	COD	UNI	No	NWLR >=MSL		F/U	F/N
<input type="checkbox"/> 執行	4.2	EOG	D	NSS	E	COD	UNI	NCM	MSL		U	N
<input type="checkbox"/> 執行(替代)	4.2C2	ETM	A	NSS	E	COD	UNI	NCM	MSL		U	N
<input type="checkbox"/> 執行	5.1	NTM	D	NSS	E	COD	UNI	NCM	MSL		U	N

依據載重組合中考慮之風浪方向生成資料夾

勾選欲分析載重組合

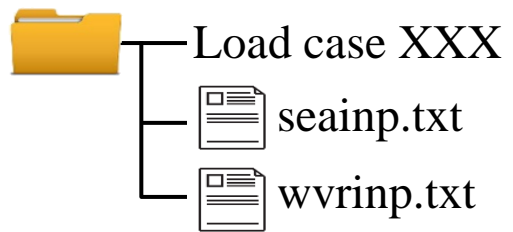
生成SACS自動化操作指令檔

一鍵生成分析檔 操作簡單

各載重組合資料夾

- F_Load case1.2_WiD0_WiVout_WaD0
- F_Load case1.2_WiD0_WiVout_WaD30
- F_Load case1.2_WiD0_WiVout_WaD60
- F_Load case1.2_WiD0_WiVout_WaD90
- F_Load case1.2_WiD0_WiVout_WaD120
- F_Load case1.2_WiD0_WiVout_WaD150
- F_Load case1.2_WiD0_WiVout_WaD180
- F_Load case1.2_WiD0_WiVout_WaD210
- F_Load case1.2_WiD0_WiVout_WaD240
- F_Load case1.2_WiD0_WiVout_WaD270
- F_Load case1.2_WiD0_WiVout_WaD300
- F_Load case1.2_WiD0_WiVout_WaD330
- LOAD CASE Function.xlsm
- SacsFatigueCheck.txt

一個載重組合資料夾內含 SACS分析input檔



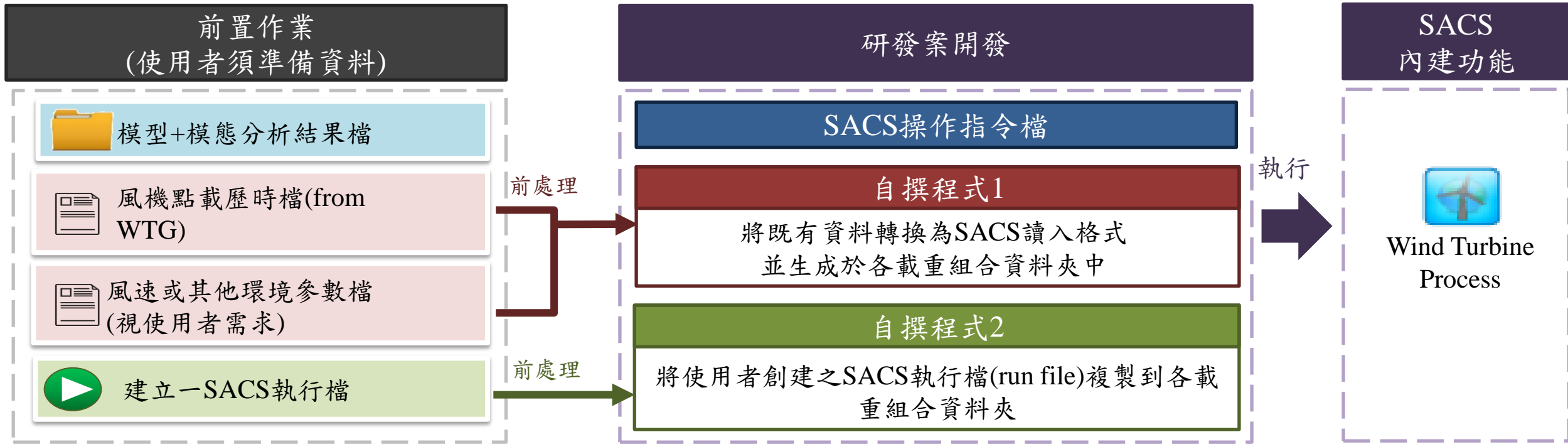
強度分析 LOAD CASE 生成

疲勞分析 LOAD CASE 生成

三、關鍵技術發展

➤ 自動執行 - SACS自動化執行

- 上一步驟生成之SACS自動化操作指令檔+SACS內建整合分析程序「Wind Turbine Process」→自動執行上千組歷時分析



同時處理多組歷時分析

Runfile Name	Analysis Type	Current Module	Status	Module Time	Total Time
wvrd... wvrdat.runx	Time History Wave an...	Wave Response	TIME 565.120 SECS SEED 1	00:17:27	00:17:28
wvrd... wvrdat.runx	Time History Wave an...	Wave Response	TIME 564.160 SECS SEED 1	00:17:26	00:17:28
wvrd... wvrdat.runx	Time History Wave an...	Wave Response	TIME 549.640 SECS SEED 1	00:17:27	00:17:28
wvrd... wvrdat.runx	Time History Wave an...	Wave Response	TIME 568.800 SECS SEED 1	00:17:27	00:17:28
wvrd... wvrdat.runx	Time History Wave an...	Wave Response	TIME 577.760 SECS SEED 1	00:17:26	00:17:28

自動化歷時分析

三、關鍵技術發展

➤ 自動擷取輸出 - 自動化輸出桿件內力歷時

- 完成歷時分析後自動化執行多筆後處理分析，輸出各桿件內力，以供鋼管接頭分析使用

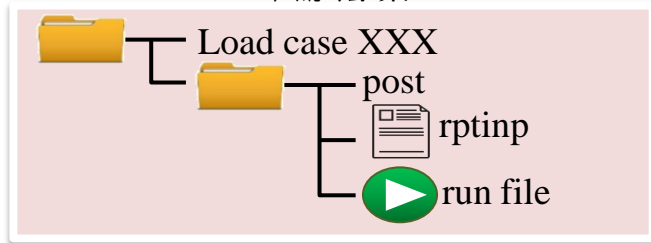
依順序執行MATLAB自撰程式

自撰程式1

讀取載重組合資料夾名稱，並表列於一txt檔供其他自撰程式應用

自撰程式2

於各載重組合資料夾中生成SACS後處理資料夾及所需檔案

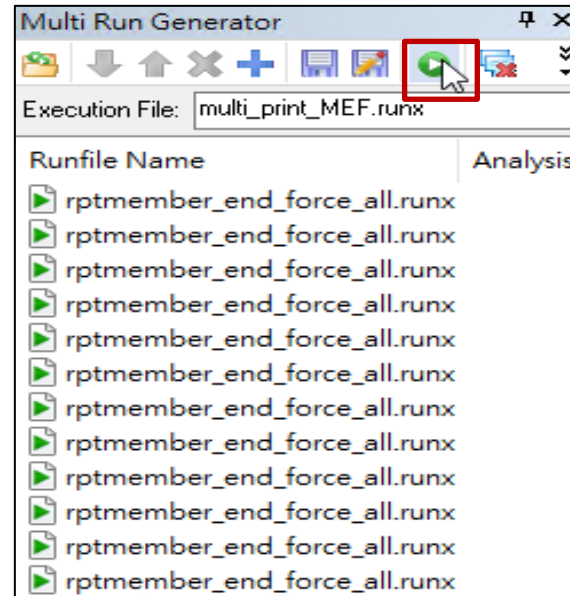


自撰程式3

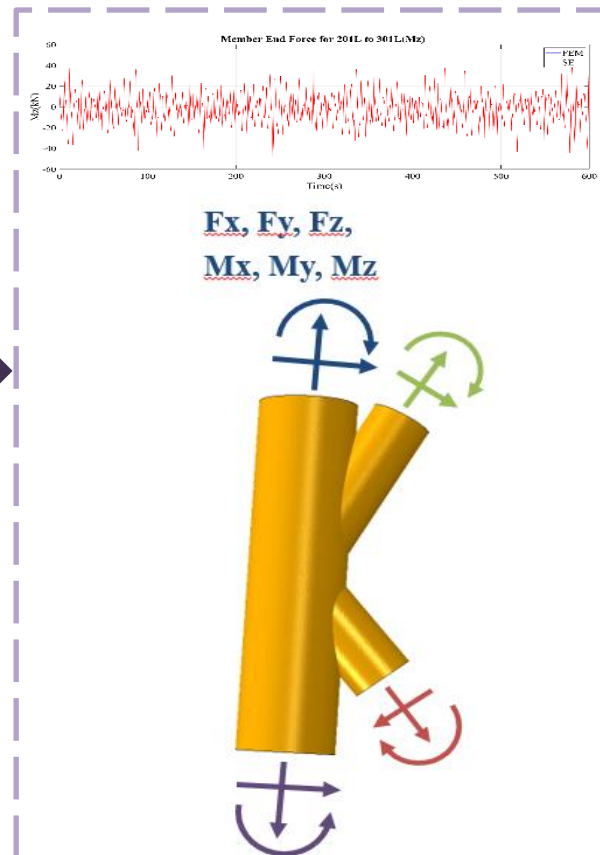
生成SACS多核處理執行檔(multi run file)，則可於SACS中一次呼叫各載重組合資料夾中後處理分析執行檔

於SACS中開啟多核處理執行檔

自動載入各後處理分析執行檔，則可一鍵執行多組後處理分析



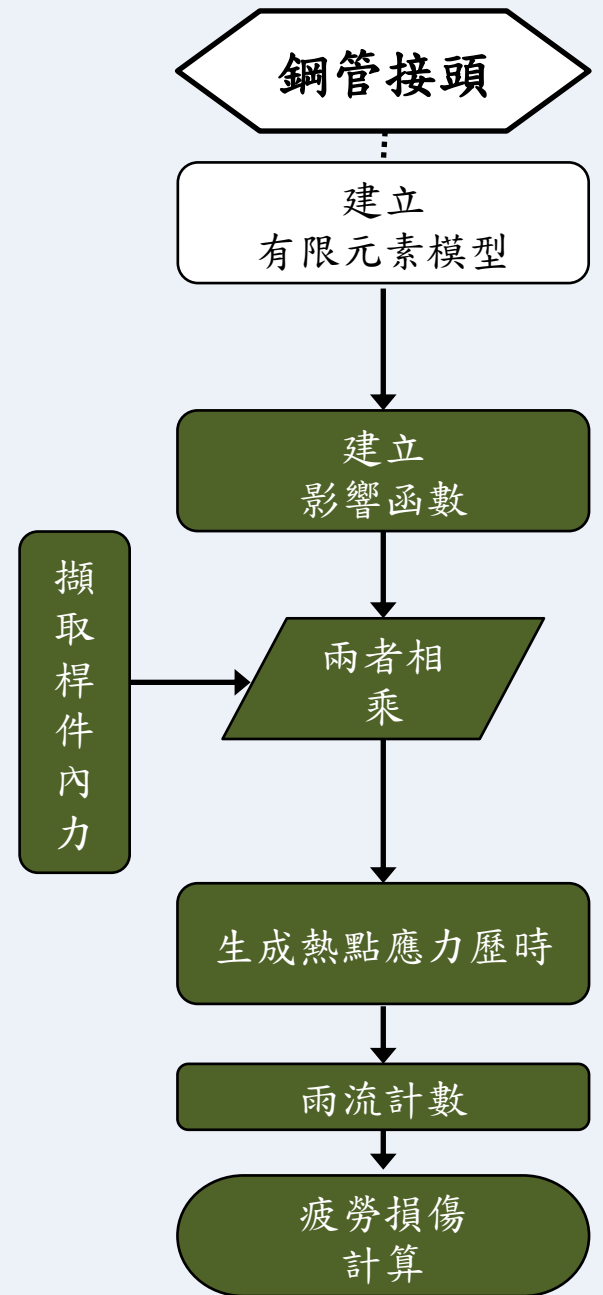
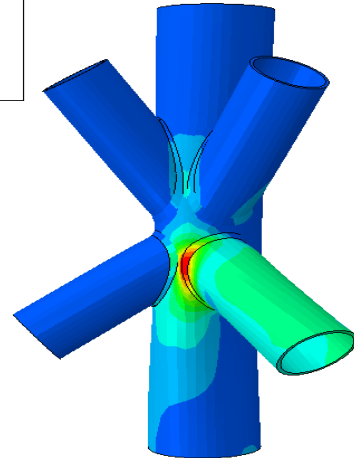
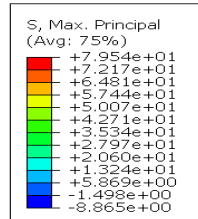
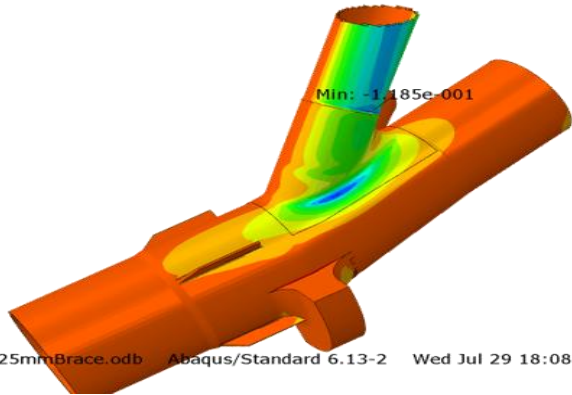
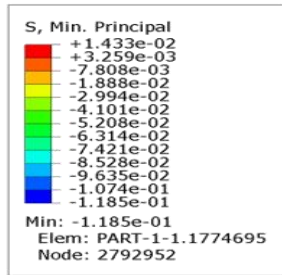
輸出桿件內力歷時供後續分析使用



三、關鍵技術發展

➤ 鋼管接頭疲勞分析

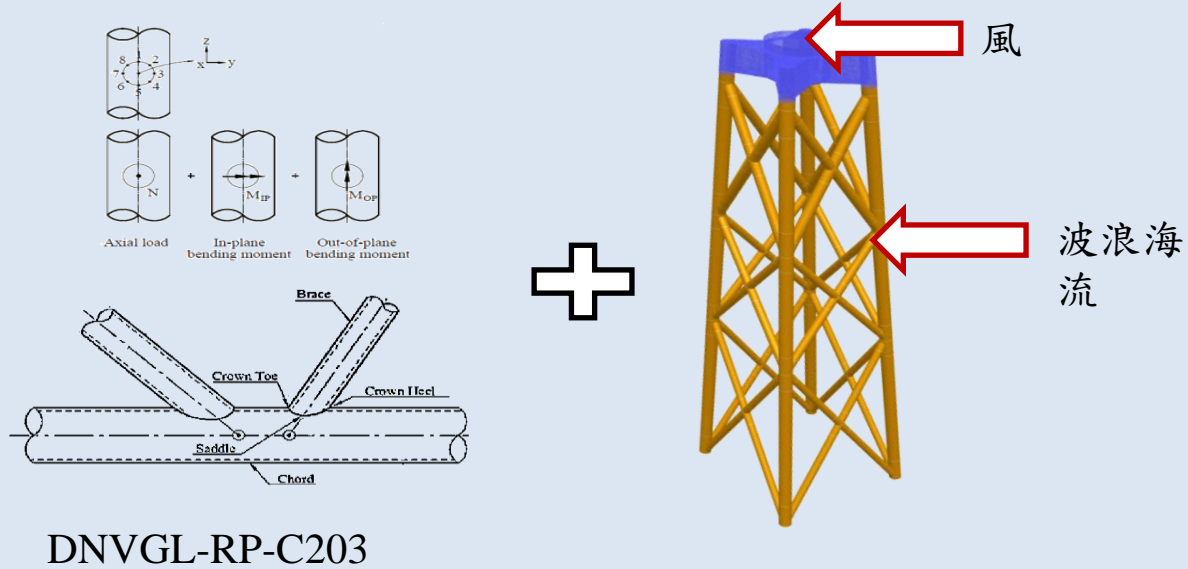
- 接頭計算可採Eftymiou公式法或有限元素法
- Eftymiou公式法有其幾何限制，無法計算特殊形式接頭
- 有限元素法無幾何限制，且可提供額外的驗證
- 採用有限元素法運算，下列因素將導致計算量龐大，因此須建立自動化分析以加速運算
 - ✓ 元素數量眾多
 - ✓ 多組時間歷時



三、關鍵技術發展

➤ 鋼管接頭疲勞分析流程(Efthymiou公式法 vs. 有限元素法)

Efthymiou公式法



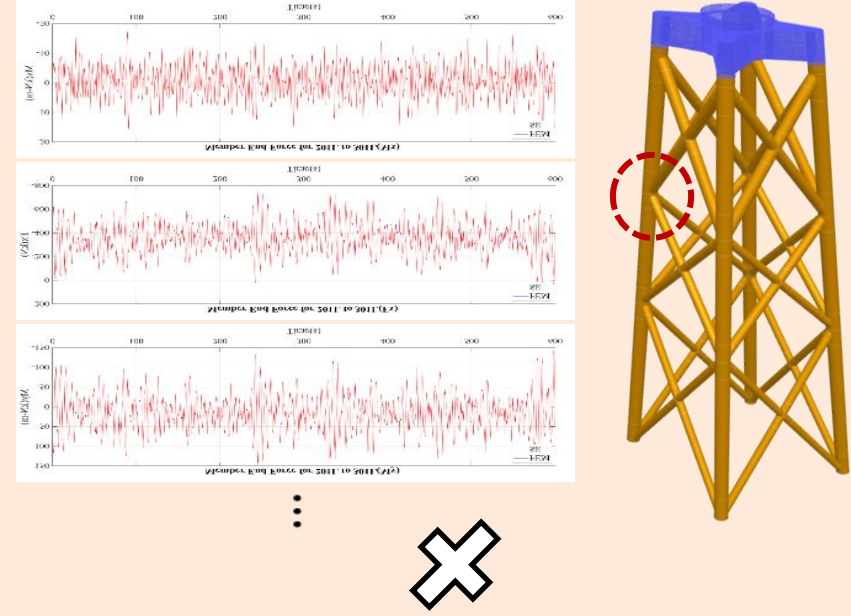
SACS分析成果

*** INTERMEDIATE MEMBER FATIGUE REPORT ***

MEMBER	GRUP	DISTANCE FROM END M	OUTSIDE DIAMETER CM	WALL THICK. CM	STRESS CONC. FACTORS		** FATIGUE RESULTS **		
					AXIAL	BENDING	DAMAGE	LOC	SUC LIFE
101L-0000	BR1	2.000	100.000	4.500	1.500	1.500	.72384-3	L	34538.05
		2.000	100.000	4.000	1.500	1.500	.10773-2	L	23206.39
		14.120	100.000	4.000	1.500	1.500	.43401-3	R	57602.41
		14.120	100.000	4.500	1.500	1.500	.29006-3	R	86188.63

Damage

有限元素法



	Rp1			Rp2			Rp3			Rp4			Rp5		
	σ_{xx}	σ_{yy}	σ_{zz}	σ_{xx}	σ_{yy}	σ_{zz}	σ_{xx}	σ_{yy}	σ_{zz}	σ_{xx}	σ_{yy}	σ_{zz}	σ_{xx}	σ_{yy}	σ_{zz}
F_x	-11.74	-1.83	-1.43	-2.79	-0.61	0.45	-1.07	-2.12	0.03	-1.49	-0.96	-0.66	2.86	7.99	-1.57
F_y	3.34	2.55	0.96	-2.09	-5.98	2.83	-5.54	-11.58	0.66	7.78	5.48	4.13	5.12	9.17	-1.29
F_z	25.37	6.12	-0.91	3.1	10.96	0.84	0.78	4.39	2.15	-4.1	1.36	1.94	-3.85	-8.92	1.94
M_x	62.51	20.63	-0.11	-15.93	-2.36	0.85	-3.16	-0.02	1.36	1.43	-0.12	-1.47	10.9	22.06	-4.23
M_y	14.87	13.17	1.84	6.42	5.25	0.07	1.47	1.48	0.05	-0.63	-0.35	-0.2	-1.92	-0.43	0.3
M_z	50.7	13.03	5.74	11.19	5.7	-0.75	2.15	5.01	-0.27	-5.76	-4.63	-1.49	11.38	20.4	-2.98

Rainflow counting

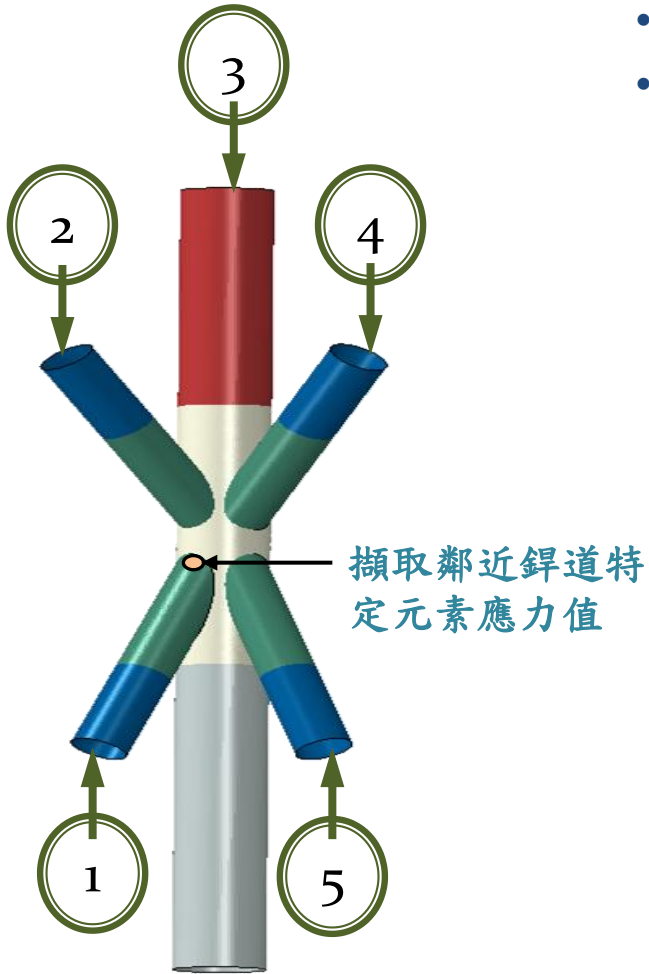
求得損傷

三、關鍵技術發展

➤ 鋼管接頭疲勞分析 - 利用有限元素模型建立影響函數

建立影響函數

- 建立鋼管接頭有限元素模型
- 分別加載單位力於5處桿端，各桿端加載6個自由度單位力，共30個自由度，即可建立特定元素之影響函數矩陣



	Location 1			Location 2			Location 3			Location 4			Location 5		
Fx	$\sigma_{xx,1x}$	$\sigma_{yy,1x}$	$\sigma_{zz,1x}$	$\sigma_{xx,2x}$	$\sigma_{yy,2x}$	$\sigma_{zz,2x}$	$\sigma_{xx,3x}$	$\sigma_{yy,3x}$	$\sigma_{zz,3x}$	$\sigma_{xx,4x}$	$\sigma_{yy,4x}$	$\sigma_{zz,4x}$	$\sigma_{xx,5x}$	$\sigma_{yy,5x}$	$\sigma_{zz,5x}$
Fy	$\sigma_{xx,1y}$	$\sigma_{yy,1y}$	$\sigma_{zz,1y}$	$\sigma_{xx,2y}$	$\sigma_{yy,2y}$	$\sigma_{zz,2y}$	$\sigma_{xx,3y}$	$\sigma_{yy,3y}$	$\sigma_{zz,3y}$	$\sigma_{xx,4y}$	$\sigma_{yy,4y}$	$\sigma_{zz,4y}$	$\sigma_{xx,5y}$	$\sigma_{yy,5y}$	$\sigma_{zz,5y}$
Fz	$\sigma_{xx,1z}$	$\sigma_{yy,1z}$	$\sigma_{zz,1z}$	$\sigma_{xx,2z}$	$\sigma_{yy,2z}$	$\sigma_{zz,2z}$	$\sigma_{xx,3z}$	$\sigma_{yy,3z}$	$\sigma_{zz,3z}$	$\sigma_{xx,4z}$	$\sigma_{yy,4z}$	$\sigma_{zz,4z}$	$\sigma_{xx,5z}$	$\sigma_{yy,5z}$	$\sigma_{zz,5z}$
Mx	$\sigma_{xx,1mx}$	$\sigma_{yy,1mx}$	$\sigma_{zz,1mx}$	$\sigma_{xx,2mx}$	$\sigma_{yy,2mx}$	$\sigma_{zz,2mx}$	$\sigma_{xx,3mx}$	$\sigma_{yy,3mx}$	$\sigma_{zz,3mx}$	$\sigma_{xx,4mx}$	$\sigma_{yy,4mx}$	$\sigma_{zz,4mx}$	$\sigma_{xx,5mx}$	$\sigma_{yy,5mx}$	$\sigma_{zz,5mx}$
My	$\sigma_{xx,1my}$	$\sigma_{yy,1my}$	$\sigma_{zz,1my}$	$\sigma_{xx,2my}$	$\sigma_{yy,2my}$	$\sigma_{zz,2my}$	$\sigma_{xx,3my}$	$\sigma_{yy,3my}$	$\sigma_{zz,3my}$	$\sigma_{xx,4my}$	$\sigma_{yy,4my}$	$\sigma_{zz,4my}$	$\sigma_{xx,5my}$	$\sigma_{yy,5my}$	$\sigma_{zz,5my}$
Mz	$\sigma_{xx,1mz}$	$\sigma_{yy,1mz}$	$\sigma_{zz,1mz}$	$\sigma_{xx,2mz}$	$\sigma_{yy,2mz}$	$\sigma_{zz,2mz}$	$\sigma_{xx,3mz}$	$\sigma_{yy,3mz}$	$\sigma_{zz,3mz}$	$\sigma_{xx,4mz}$	$\sigma_{yy,4mz}$	$\sigma_{zz,4mz}$	$\sigma_{xx,5mz}$	$\sigma_{yy,5mz}$	$\sigma_{zz,5mz}$

三、關鍵技術發展

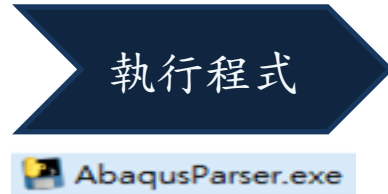
➤ 鋼管接頭疲勞分析自動化流程

1. 建立特定接頭之影響函數

輸入檔 (擷取ABAQUS輸出)

IF11.rpt	Element Label	Int Pt	S.S11 @Loc 1	S.S22 @Loc 1	S.S33 @Loc 1
IF11.rpt	1	1	331.866E-03	-280.543E-03	5.59509
IF12.rpt	2	1	1.70677	-400.368E-03	5.57744
IF13.rpt	3	1	-1.35519	-506.778E-03	4.96368
IF14.rpt	4	1	-606.781E-03	-247.704E-03	4.77960
IF15.rpt	5	1	-39.3687E-03	-163.574E-03	4.78305
	6	1	1.19686	-354.684E-03	5.34085
	7	1	297.617E-03	-1.18393	5.20318
	8	1	-3.68370	-2.03634	4.22660
	9	1	2.47278	162.715E-03	5.69412
	10	1	1.42576	-441.579E-03	5.47796
	11	1	-1.36956	-495.496E-03	4.98171
	12	1	-3.18250	758.256E-03	5.16531
	13	1	-348.415E-03	-199.427E-03	4.69457
	14	1	903.424E-03	-379.355E-03	5.25176

桿件應力擷取輸出檔



AbaqusParser.exe

輸出檔 (建立影響係數)

IF.txt 影響係數輸出檔，針對單一節點只會有一處

```

****
1.70677 -400.368E-03 5.57744 1.70677 -400.368E-03 5.57744 1.70677 -400.368E-03 5.57744 1.70677 -400.368E-03 5.57744
3.03935 240.267E-03 5.87062 3.03935 240.267E-03 5.87062 3.03935 240.267E-03 5.87062 3.03935 240.267E-03 5.87062
1.19686 -354.684E-03 5.34085 1.19686 -354.684E-03 5.34085 1.19686 -354.684E-03 5.34085 1.19686 -354.684E-03 5.34085
297.617E-03 -1.18393 5.20318 297.617E-03 -1.18393 5.20318 297.617E-03 -1.18393 5.20318 297.617E-03 -1.18393 5.20318
-3.68370 -2.03634 4.22660 -3.68370 -2.03634 4.22660 -3.68370 -2.03634 4.22660 -3.68370 -2.03634 4.22660
2.47278 162.715E-03 5.69412 2.47278 162.715E-03 5.69412 2.47278 162.715E-03 5.69412 2.47278 162.715E-03 5.69412
****
-1.35519 -506.778E-03 4.96368 -1.35519 -506.778E-03 4.96368 -1.35519 -506.778E-03 4.96368 -1.35519 -506.778E-03 4.96368
-3.57289 812.790E-03 4.99266 -3.57289 812.790E-03 4.99266 -3.57289 812.790E-03 4.99266 -3.57289 812.790E-03 4.99266
-39.3687E-03 -163.574E-03 4.78305 -39.3687E-03 -163.574E-03 4.78305 -39.3687E-03 -163.574E-03 4.78305 -39.3687E-03 -163.574E-03 4.78305
-3.18250 758.256E-03 5.16531 -3.18250 758.256E-03 5.16531 -3.18250 758.256E-03 5.16531 -3.18250 758.256E-03 5.16531
1.88571 96.4223E-03 5.57441 1.88571 96.4223E-03 5.57441 1.88571 96.4223E-03 5.57441 1.88571 96.4223E-03 5.57441
-1.32663 -431.552E-03 4.99377 -1.32663 -431.552E-03 4.99377 -1.32663 -431.552E-03 4.99377 -1.32663 -431.552E-03 4.99377
****
-606.781E-03 -247.704E-03 4.77960 -606.781E-03 -247.704E-03 4.77960 -606.781E-03 -247.704E-03 4.77960 -606.781E-03 -247.704E-03 4.77960
-2.96201 -1.82187 4.48510 -2.96201 -1.82187 4.48510 -2.96201 -1.82187 4.48510 -2.96201 -1.82187 4.48510
761.971E-03 -290.675E-03 5.07555 761.971E-03 -290.675E-03 5.07555 761.971E-03 -290.675E-03 5.07555 761.971E-03 -290.675E-03 5.07555
156.607E-03 -1.03694 5.26465 156.607E-03 -1.03694 5.26465 156.607E-03 -1.03694 5.26465 156.607E-03 -1.03694 5.26465
96.5573E-03 -925.242E-03 5.40488 96.5573E-03 -925.242E-03 5.40488 96.5573E-03 -925.242E-03 5.40488 96.5573E-03 -925.242E-03 5.40488
331.866E-03 -280.543E-03 5.59509 331.866E-03 -280.543E-03 5.59509 331.866E-03 -280.543E-03 5.59509 331.866E-03 -280.543E-03 5.59509
****

```

2. 輸出桿件元素應力歷時

輸入檔 (擷取SACS輸出)

- IF.txt 影響係數輸出檔
- linkOutput.txt SACS模型檔
- nodeListFile.txt 擷取處節點名稱檔
- SACStimeHistory.txt SACS時間歷時資料



StressCalculation.exe

輸出檔 (結合影響係數，計算應力歷時)

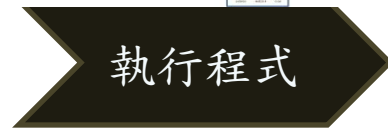
201L-element1.txt	σ_{xx}	σ_{yy}	σ_{zz}
201L-element1.txt	465	723	107
201L-element2.txt	390	157	716
	838	648	158
	440	931	382
	352	348	254

特定元素應力輸出歷時

3. 計算損傷值

輸入檔

- 201L-element1.txt 特定元素應力輸出歷時
- 303L-element1.txt :
- THfileListFile.txt 擷取元素歷時名稱檔



RCountingDCalculation.exe

輸出檔

damageOutput.txt

```

201L-element1-x: 0.00702
201L-element1-y: 0.00051
201L-element1-z: 0.00132
303L-element1-x: 0.00029
303L-element1-y: 0.00462
303L-element1-z: 0.00132

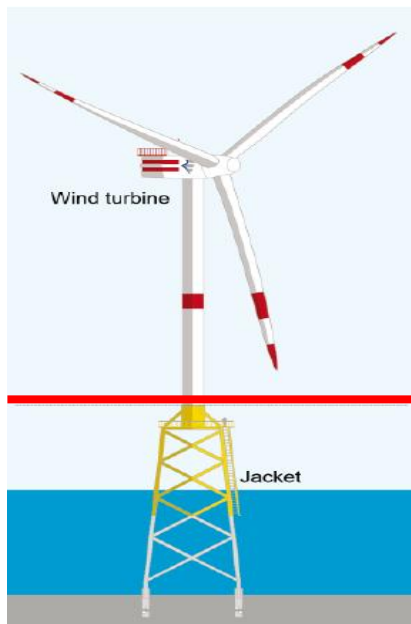
```

特定元素
各主應力損傷值

三、關鍵技術發展

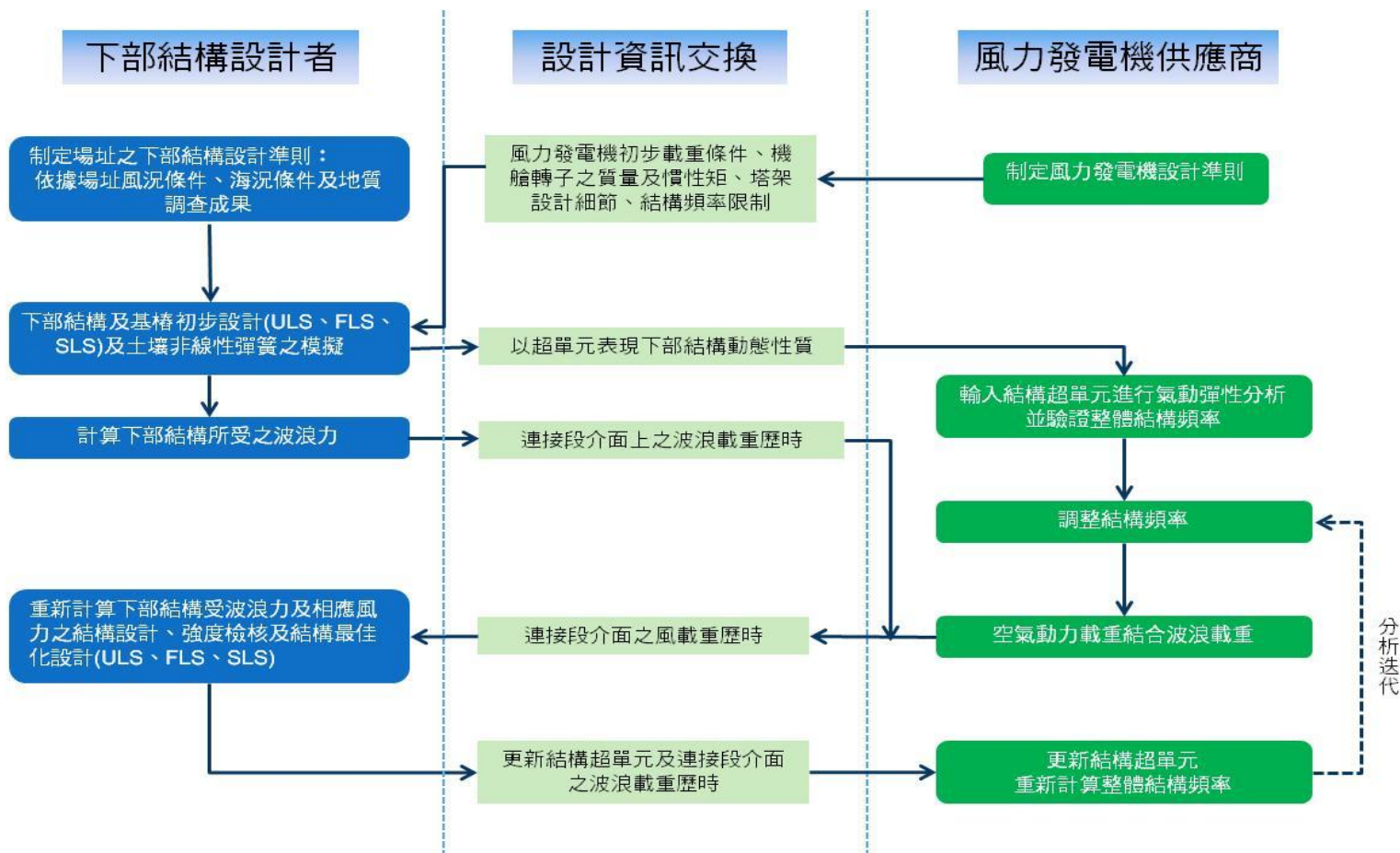
➤ 風機支撐結構細部設計分工

- 風機廠商責任
 - 提供風機塔架與下部結構間之介面荷重
- 工程顧問(下部結構設計者)責任
 - 提供場址風況
 - 提供下部結構之勁度、阻尼與質量矩陣或結構模型



風機廠商

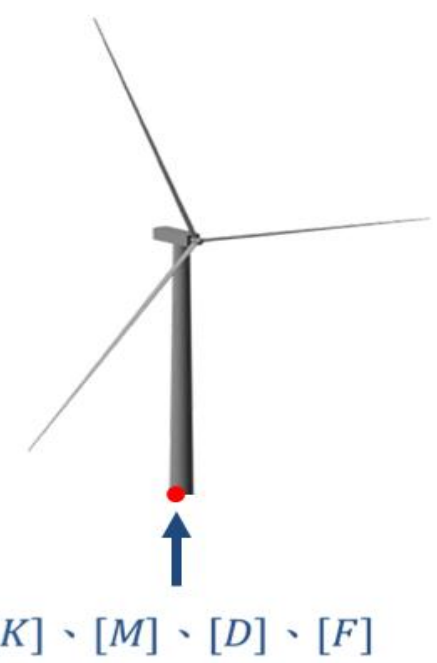
工程顧問



三、關鍵技術發展

➤ 提供下部結構動態參數予風機廠商，進行迭代分析

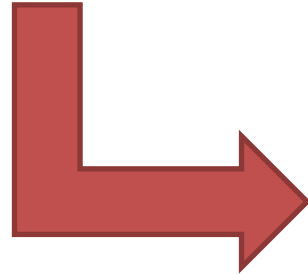
```
1 !Mass matrix
2 ! -- col 1 -- -- col 2 -- -- col 3 -- -- col 4 -- -- col 5 -- -- col 6 -- -- col 7 -- -- col 8 -- -- col n --
3 1.61E+06 -2.39E+00 8.40E+02 5.31E+01 -4.74E+07 -3.95E+05 -2.27E-07 ... 7.69E+00
4 -2.39E+00 1.61E+06 1.82E+03 4.74E+07 -3.97E+01 -3.27E+03 -7.65E+02 ... -4.02E+00
5 8.40E+02 1.82E+03 1.49E+06 3.76E+05 9.66E+03 -1.36E+01 -1.13E+01 ... 3.22E-01
6 5.31E+01 4.74E+07 3.76E+05 4.51E+09 6.46E+02 3.99E+03 -6.60E+04 ... 9.95E+00
7 -4.74E+07 -3.97E+01 9.66E+03 6.46E+02 4.50E+09 3.63E+07 1.95E-05 ... 0.00E+00
8 -3.95E+05 -3.27E+03 -1.36E+01 3.99E+03 3.63E+07 4.91E+07 1.71E-07 ... 0.00E+00
9 -2.27E-07 -7.65E+02 -1.13E+01 -6.60E+04 1.95E-05 1.71E-07 1.00E+00 ... 0.00E+00
10 ... ..
11 7.69E+00 -4.02E+00 3.22E-01 9.95E+00 -7.14E+00 6.57E+00 0.00E+00 ... 1.00E+00
12 !Stiffness matrix
13 ! -- col 1 -- -- col 2 -- -- col 3 -- -- col 4 -- -- col 5 -- -- col 6 -- -- col 7 -- -- col 8 -- -- col n --
14 8.74E+07 -2.52E+02 2.59E+05 5.55E+03 1.34E+09 -2.44E+05 0.00E+00 ... 0.00E+00
15 -2.52E+02 8.74E+07 2.07E+05 -1.34E+09 -4.91E+03 -2.86E+05 0.00E+00 ... 0.00E+00
16 2.59E+05 2.07E+05 2.38E+09 -3.96E+06 5.35E+06 -4.48E+03 0.00E+00 ... 0.00E+00
17 5.55E+03 -1.34E+09 -3.96E+06 7.55E+10 1.07E+05 -1.50E+07 0.00E+00 ... 0.00E+00
18 1.34E+09 -4.91E+03 5.35E+06 1.07E+05 7.55E+10 -2.24E+07 0.00E+00 ... 0.00E+00
19 -2.44E+05 -2.86E+05 -4.48E+03 -1.50E+07 -2.24E+07 1.78E+10 0.00E+00 ... 0.00E+00
20 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 3.94E+00 ... 0.00E+00
21 ... ..
22 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 ... 8.34E+03
23 !Damping matrix
24 ! -- col 1 -- -- col 2 -- -- col 3 -- -- col 4 -- -- col 5 -- -- col 6 -- -- col 7 -- -- col 8 -- -- col n --
25 7.01E+05 -1.91E+00 1.88E+03 4.21E+01 7.16E+06 -2.15E+04 -1.13E-08 ... 3.85E-01
26 -1.91E+00 7.01E+05 1.56E+03 -7.16E+06 -3.69E+01 -2.20E+03 -3.83E+01 ... -2.01E-01
27 1.88E+03 1.56E+03 1.70E+07 -9.34E+03 3.85E+04 -3.25E+01 -5.64E-01 ... 1.61E-02
28 4.21E+01 -7.16E+06 -9.34E+03 7.61E+08 7.93E+02 -1.06E+05 -3.30E+03 ... 4.98E-01
29 7.16E+06 -3.69E+01 3.85E+04 7.93E+02 7.61E+08 1.66E+06 9.75E-07 ... -3.57E-01
30 -2.15E+04 -2.20E+03 -3.25E+01 -1.06E+05 1.66E+06 1.29E+08 8.56E-09 ... 3.29E-01
31 -1.13E-08 -3.83E+01 -5.64E-01 -3.30E+03 9.75E-07 8.56E-09 7.80E-02 ... 0.00E+00
32 ... ..
33 3.85E-01 -2.01E-01 1.61E-02 4.98E-01 -3.57E-01 3.29E-01 0.00E+00 ... 5.92E+01
34 !Loading
35 ! --time (s)-- -- F 1 -- -- F 2 -- -- F 3 -- -- F 4 -- -- F 5 -- -- F 6 -- -- F 7 -- -- F n --
36 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 ... 0.00E+00
37 4.00E-02 4.64E+00 -7.20E-04 -7.45E-01 -1.11E+00 -2.32E+02 -2.06E-02 ... -4.33E-17
38 8.00E-02 1.82E+01 -2.87E-03 -2.48E+00 -3.94E+00 -9.09E+02 -8.00E-02 ... -1.69E-16
39 1.20E-01 3.97E+01 -5.96E-03 -4.42E+00 -7.62E+00 -1.99E+03 -1.75E-01 ... -3.67E-16
40 1.60E-01 6.80E+01 -8.99E-03 -5.76E+00 -1.10E+01 -3.40E+03 -3.02E-01 ... -6.24E-16
41 2.00E-01 1.01E+02 -1.05E-02 -5.73E+00 -1.27E+01 -5.07E+03 -4.56E-01 ... -9.20E-16
42 2.40E-01 1.37E+02 -8.67E-03 -3.60E+00 -1.12E+01 -6.86E+03 -6.35E-01 ... -1.23E-15
43 ... ..
44 6.00E+02 -9.86E+04 -1.58E+03 -2.87E+04 3.29E+06 4.41E+06 3.42E+03 ... 1.39E-12
```



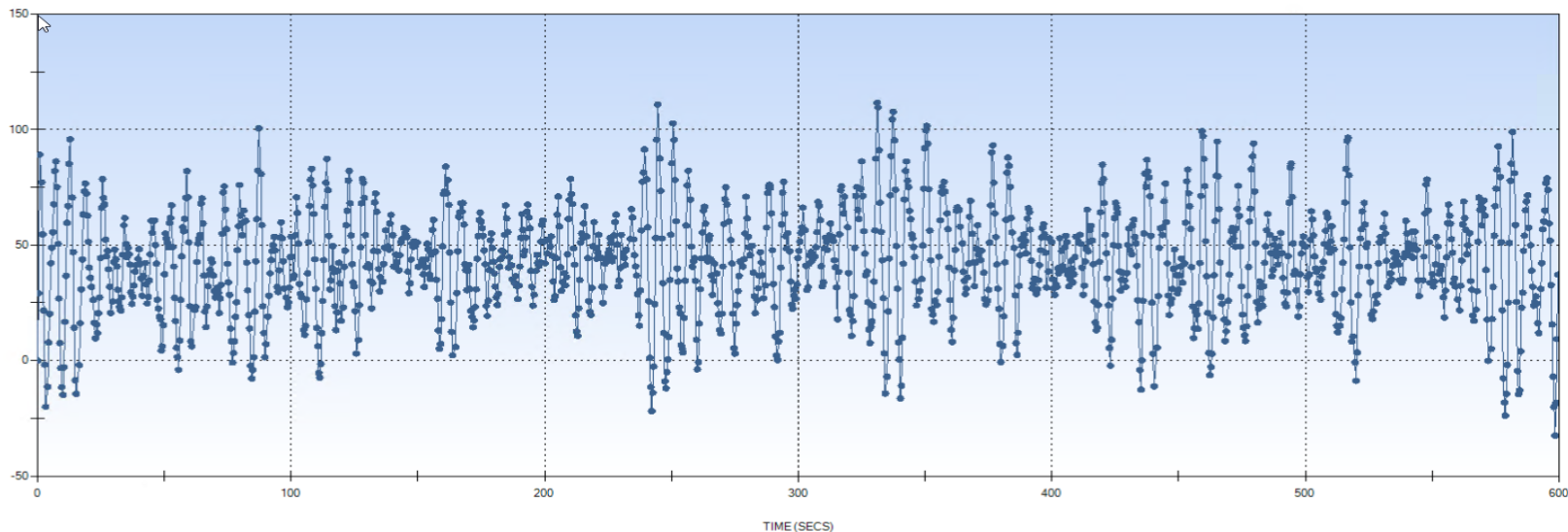
三、關鍵技術發展

➤ 風機廠商提供塔架底部介面作用力歷時，進行下部結構設計。

```
1 #DESCR,"FLEX 5 Interfaceloads"  
2 #DESCR,"Loads at interface height: 2.92E+01 "  
3 #DESCR,"Timestamps are given in ROSA time, matching wave input"  
4 #DESCR,"Time offset relative to VTS is 200.00s"  
5 #DESCR,"      time,- AX [m/s2] --,- AY [m/s2] --,- AZ [m/s2] --, -- FX [N] --, -- FY [N] --, -- FZ [N] --, -- MX [Nm] --, -- MY [Nm] --, -- MZ [Nm] --, -- eta [m] --"  
6 #TIMVAL, 200.000, 1.66467E-002, -1.30784E-002, 1.10408E-004, -2.57465E+005, 9.69048E+003, -7.77660E+006, -1.05972E+006, -1.52746E+007, -7.55938E+005, -1.78580E+00  
7 #TIMVAL, 200.040, 4.35646E-002, -1.39568E-002, 6.38229E-005, -2.59637E+005, 8.36669E+003, -7.77641E+006, -1.03293E+006, -1.49733E+007, -7.45420E+005, -1.77433E+00  
8 #TIMVAL, 200.080, 6.86024E-002, -1.45678E-002, 1.05786E-004, -2.61477E+005, 7.74304E+003, -7.77557E+006, -1.01520E+006, -1.46772E+007, -7.41573E+005, -1.76189E+00  
9 #TIMVAL, 200.120, 9.14894E-002, -1.59057E-002, 2.22926E-004, -2.62263E+005, 8.27431E+003, -7.77377E+006, -1.01215E+006, -1.43916E+007, -7.38327E+005, -1.74815E+00  
10 #TIMVAL, 200.160, 1.11213E-001, -1.58714E-002, 2.59937E-004, -2.61277E+005, 9.01934E+003, -7.77072E+006, -1.02335E+006, -1.41245E+007, -7.25736E+005, -1.72704E+00  
11 #TIMVAL, 200.200, 1.23269E-001, -1.24379E-002, 3.41876E-005, -2.57814E+005, 9.14189E+003, -7.76670E+006, -1.04290E+006, -1.38938E+007, -6.98161E+005, -1.71010E+00  
12 #TIMVAL, 200.240, 1.24461E-001, -8.16358E-003, 9.67337E-006, -2.52614E+005, 8.94395E+003, -7.76239E+006, -1.06183E+006, -1.37230E+007, -6.56884E+005, -1.70843E+00  
13 #TIMVAL, 200.280, 1.16161E-001, -5.61469E-003, -2.86659E-004, -2.47898E+005, 8.82205E+003, -7.75837E+006, -1.07356E+006, -1.36313E+007, -6.09863E+005, -1.68655E+00  
14 #TIMVAL, 200.320, 1.02590E-001, -5.03129E-003, -1.46006E-004, -2.44904E+005, 8.33805E+003, -7.75547E+006, -1.07513E+006, -1.36189E+007, -5.65368E+005, -1.66695E+00  
15 #TIMVAL, 200.360, 8.43763E-002, -3.35558E-003, -5.30496E-004, -2.42477E+005, 6.73892E+003, -7.75445E+006, -1.07016E+006, -1.36680E+007, -5.27984E+005, -1.65786E+00  
16 #TIMVAL, 200.400, 6.03746E-002, 1.02384E-003, -2.28735E-004, -2.38064E+005, 4.43948E+003, -7.75557E+006, -1.06715E+006, -1.37479E+007, -5.00050E+005, -1.64562E+00  
17 #TIMVAL, 200.440, 3.01367E-002, 5.95991E-003, -5.20274E-004, -2.30553E+005, 3.04791E+003, -7.75962E+006, -1.07426E+006, -1.38332E+007, -4.84191E+005, -1.62772E+00  
18 #TIMVAL, 200.480, -2.55032E-003, 8.29908E-003, 4.90003E-004, -2.21494E+005, 3.41596E+003, -7.76427E+006, -1.09307E+006, -1.39124E+007, -4.79922E+005, -1.61550E+00  
19 #TIMVAL, ... , ... , ... , ... , ... , ... , ... , ... , ... , ... , ...  
20 #TIMVAL, 800.000, -1.95225E-002, 4.21952E-003, 1.55053E-004, -2.56221E+005, -1.68656E+003, -7.77218E+006, -7.40881E+005, -1.55333E+007, 3.90183E+005, -1.56916E+00  
21 #EOF
```



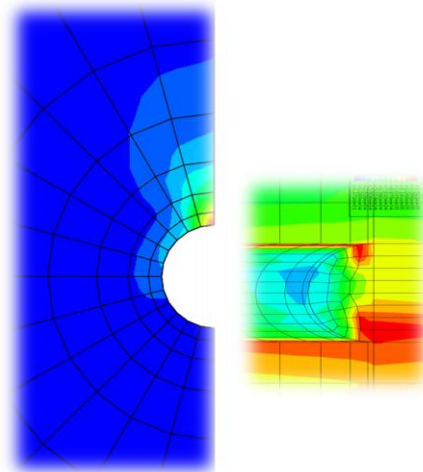
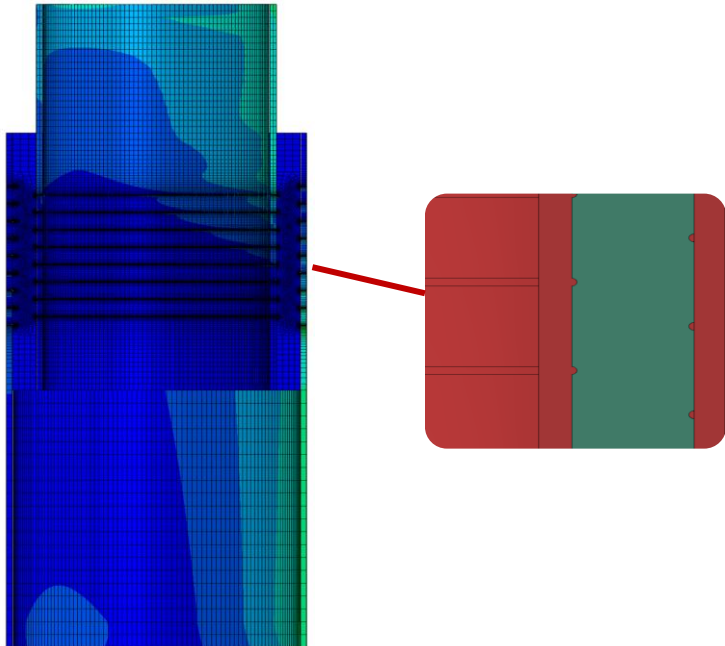
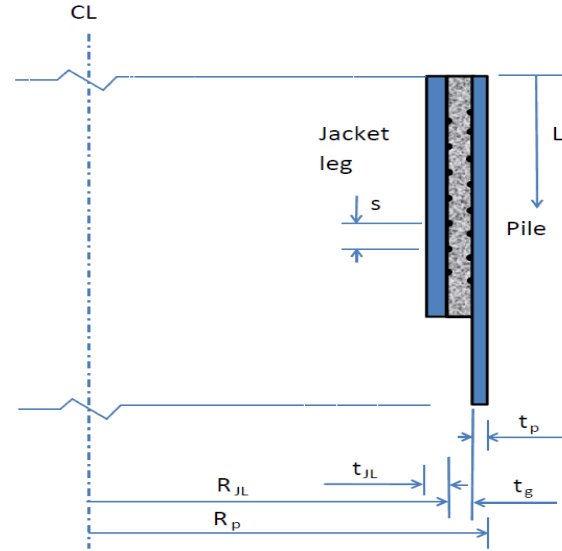
Enter in SACS



三、關鍵技術發展

➤ 灌漿段設計

- DNVGL計算式
- 有限元素法



Input values			
Outer radius of pile (/jacket leg):	$R_p =$	1400	mm
Wall thickness of pile (/jacket leg):	$t_p =$	75	mm
Outer radius of sleeve (/pile):	$R_s =$	1750	mm
Thickness of sleeve (/pile):	$t_s =$	70	mm
Outer diameter of grout:	$D_g =$	3360	mm
Nominal thickness of grout:	$t_g =$	280	mm
Full length of grouted section:	$L =$	4000.00	mm
(C.1.1.2) Effective length of grouted connection:	$L_g =$	3440	mm
	$L_g/s =$	12.74	
Number of shear keys:	$n =$	8	
Height of shear key:	$h =$	12	mm
Width of shear key:	$w =$	24	mm
Vertical distance between shear keys:	$s =$	270	mm
Characteristic compressive strength:	$f_{ck} =$	73.3	N/mm ²
Young's modulus for grout:	$E_g =$	40000	N/mm ²
Young's modulus for steel:	$E =$	210000	N/mm ²
Moment of Inertia for the pile (/jacket leg):	$I_p =$	5.96E+11	mm ⁴
Design axial load:	$P_{ad} =$	40800000	N
Design bending moment:	$M_d =$	6117000	Nm
Design horizontal shear force:	$Q_d =$	4988000	N
6.4.1.2 Material factor:	$\gamma_{m,ULS} =$	2	
	$\gamma_{m,FLS} =$	1.5	

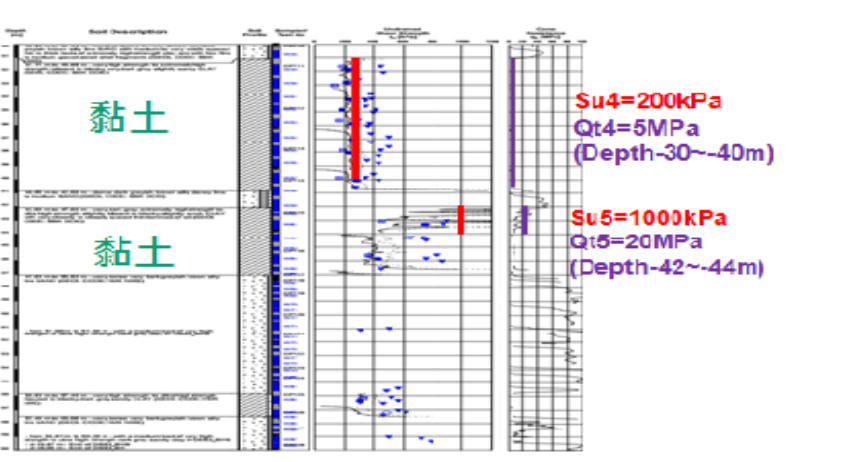
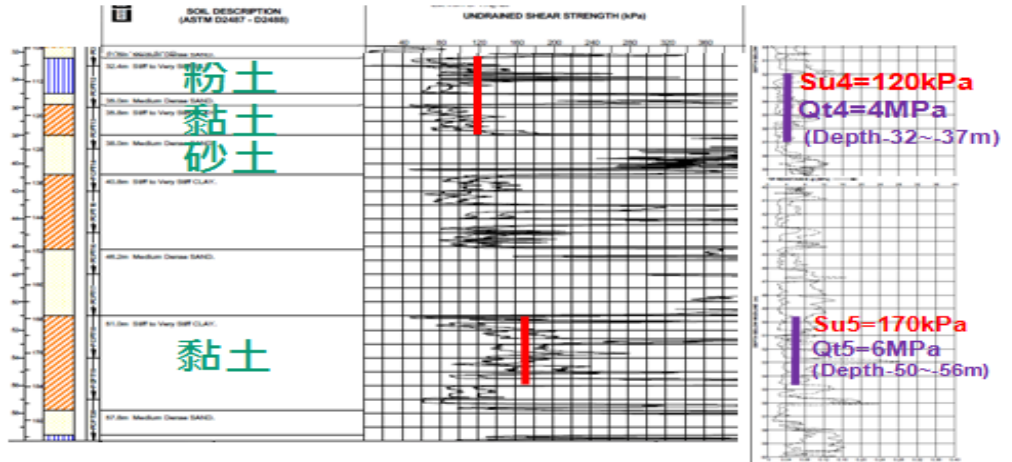
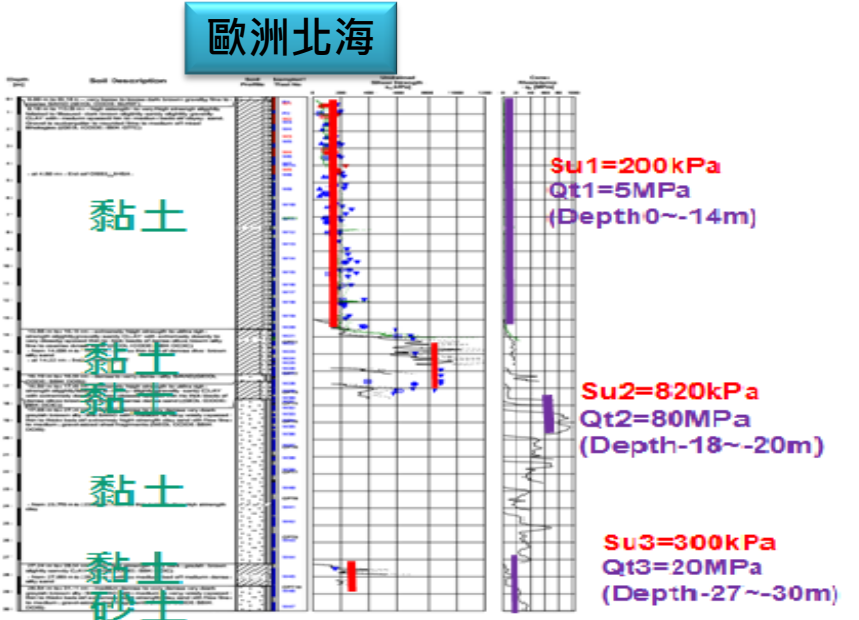
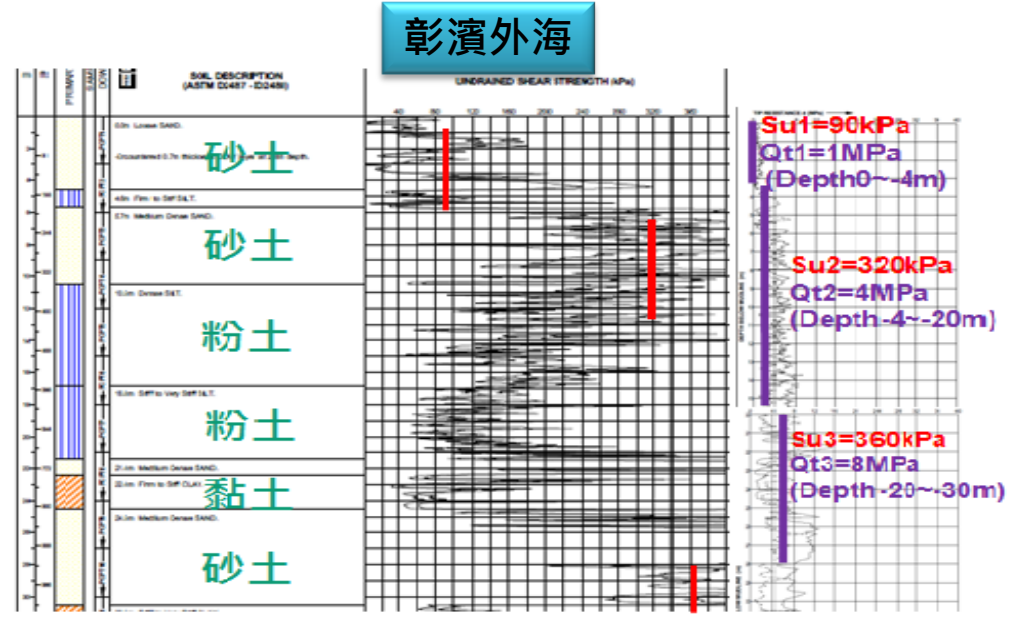
Calculations			
C.1.4.2	Design load per unit length:	$F_{V1Shkd} =$	579.779 N/mm
C.1.4.3	Radial stiffness parameter:	$k =$	0.027
C.1.4.3	Interface shear capacity:	$f_{bk} =$	4.971 N/mm ²
C.1.4.4	Characteristic capacity of one shear key:	$F_{V1Shkcap} =$	1342.045 N/mm
C.1.4.5	Design capacity of one shear key:	$F_{V1Shkcapd} =$	671.022 N/mm
C.1.4.14	Ratio of Young's modulus:	$m_e =$	5.25
C.1.4.14	Supporting spring stiffness:	$k_{rD} =$	16481 N/mm ²
C.1.4.12	Elastic length of the pile (/jacket leg):	$l_e =$	2348.06 mm
C.1.4.15	Max nominal radial contact pressure:	$p_{nom} =$	1.15 N/mm ²

四、國內工程設計之優勢

➤ 台灣與歐洲北海相異之環境條件—地質

彰濱外海之海床土壤剪力強度只有歐洲北海地區的1/3~1/6，國內工程師瞭解本土地質條件。

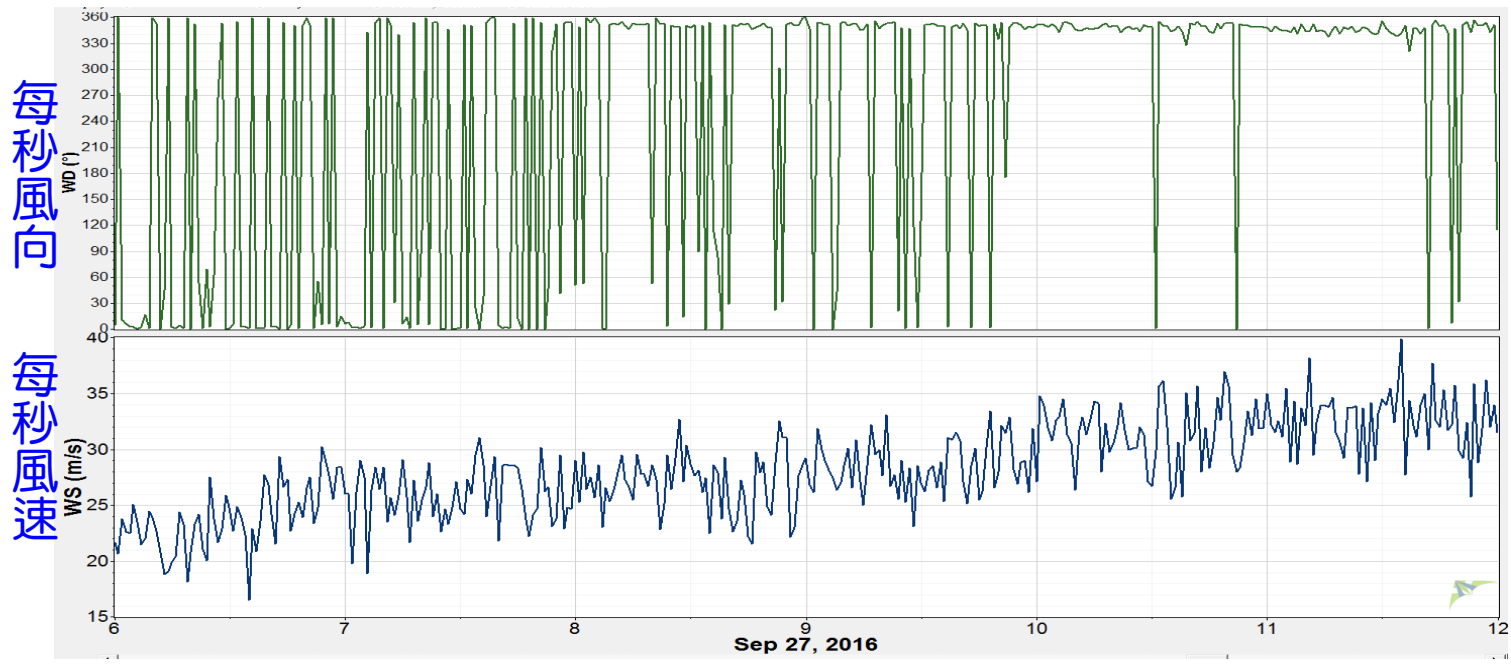
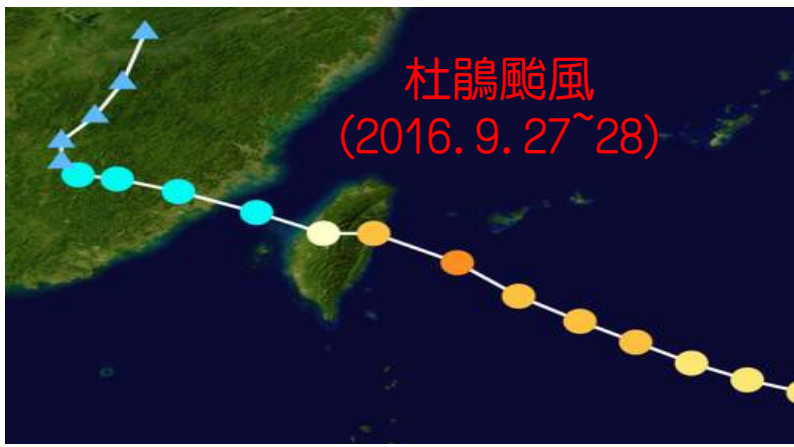
容易發生液化



四、國內工程設計之優勢

➤ 台灣與歐洲北海相異之環境條件 - 颱風

- 風速
- 風向變化速度



風向角度變化量之標準差

小時	9月26日	9月27日
12:00 AM	9.0	8.3
1:00 AM	8.6	5.7
2:00 AM	6.0	20.4
3:00 AM	7.0	17.8
4:00 AM	6.1	11.1
5:00 AM	7.1	13.0
6:00 AM	5.4	19.5
7:00 AM	3.3	19.1
8:00 AM	4.8	24.8
9:00 AM	4.5	25.9
10:00 AM	3.2	4.8
11:00 AM	3.7	15.8
12:00 PM	4.2	6.6
1:00 PM	3.5	5.1
2:00 PM	3.7	14.4
3:00 PM	3.7	4.6
4:00 PM	4.2	14.3
5:00 PM	3.6	
6:00 PM	5.0	
7:00 PM	5.1	
8:00 PM	4.4	
9:00 PM	4.6	
10:00 PM	4.6	
11:00 PM	5.7	15.6
All	8.5	20.3

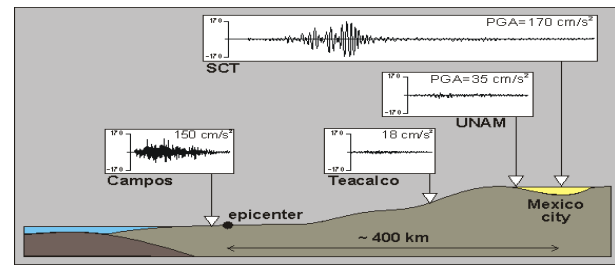
測風塔倒塌

四、國內工程設計之優勢

➤ 台灣與歐洲北海相異之環境條件 - 耐震設計

- 設計地震評析
- 液化潛勢分析
- 地盤受震反應分析
- 結構耐震設計

完整專業養成至少需1~2年。



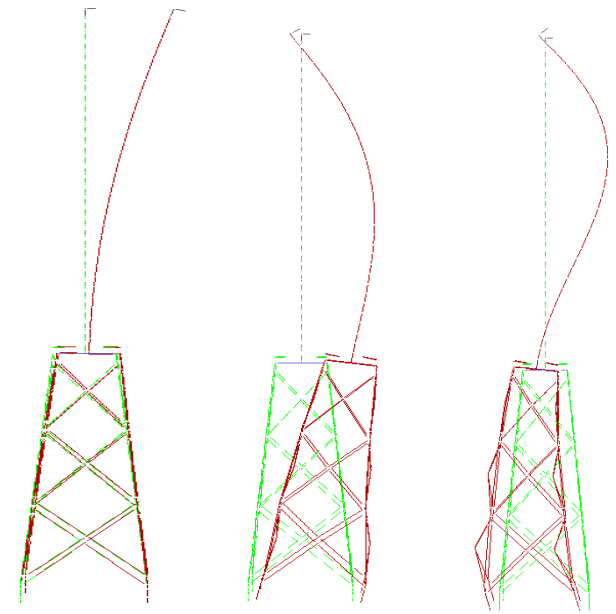
地盤受震反應分析

圖片來源
https://zh.wikipedia.org/wiki/%E5%A0%B4%E5%9D%80%E6%95%88%E6%87%89#/media/File:Site_effects_mexico_1985_recordings_v2.gif



液化災害

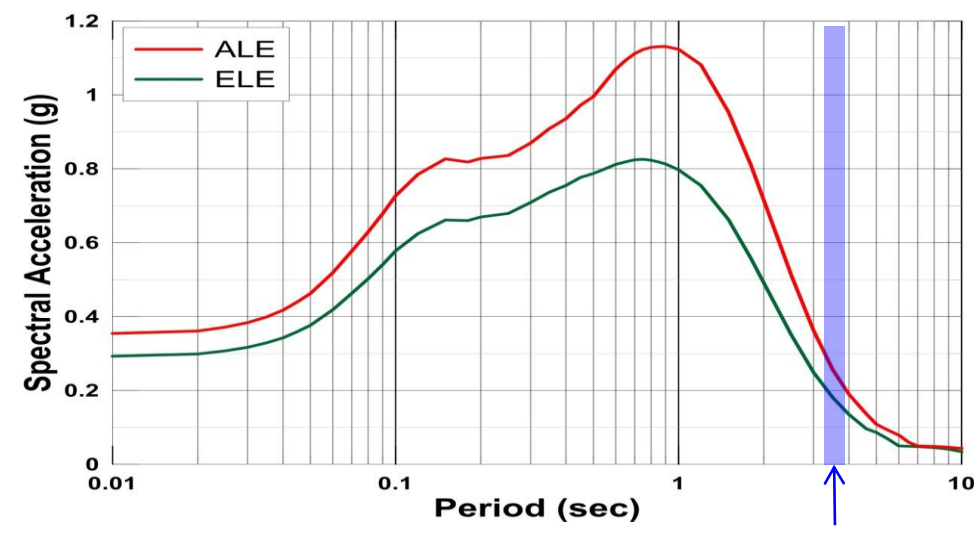
圖片來源：
<https://probaway.wordpress.com/tag/earthquake-new-zealand/>



1st 2nd 3rd

結構模態分析

地震不影響風機結構??



設計震譜

風機基本自然頻率

四、國內工程設計之優勢

- 全世界大學之工程技術類前百大排名，台灣佔5所。

# RANK	UNIVERSITY	LOCATION	COMPARE	QS STARS™
2018	University search	Taiwan	↓	<input type="checkbox"/> Rated only
19	National Taiwan University (NTU) More	Taiwan	<input type="checkbox"/>	
33	National Tsing Hua University More	Taiwan	<input type="checkbox"/>	
48	National Chiao Tung University More	Taiwan	<input type="checkbox"/>	
62	National Cheng Kung University (NCKU) More	Taiwan	<input type="checkbox"/>	
93	National Taiwan University of Science and Technology (Taiwan Tech) More	Taiwan	<input type="checkbox"/>	

台灣工程師擁有國際水準之專業能力



來源: https://zh.wikipedia.org/wiki/File:Taipei_101_from_afar.jpg



四、國內工程設計之優勢

➤ 本土調查、研究與法規資料幾為中文

- 中國大陸亦有相關資料，外國公司難以查找引用於設計。
- 國內相關設計法規要求(如地工、設計耐震要求)

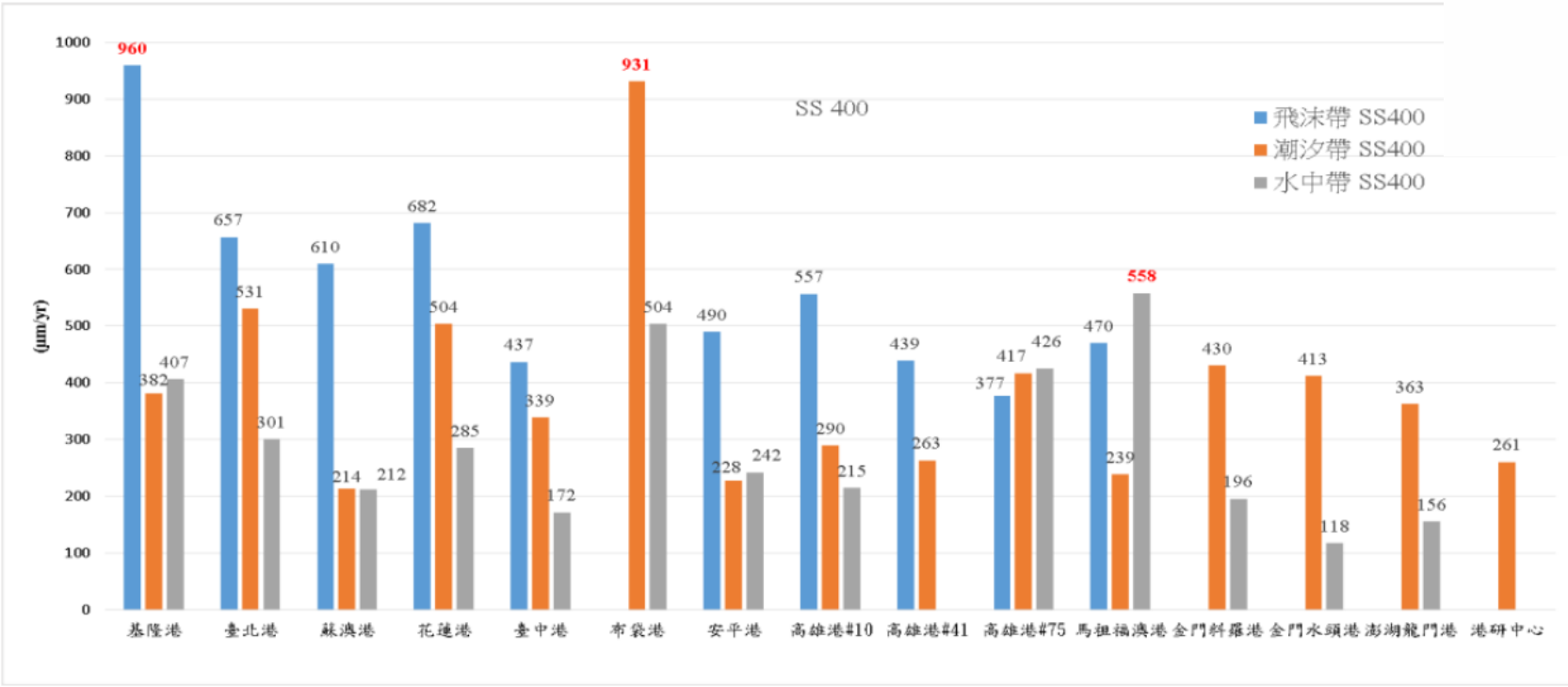


圖 8 各港區第一年底碳鋼金屬水下腐蝕速率分析

3.2 海生物附着厚度隨水深分布

有关研究表明：海生物生长受水温影响显著^[8]，同时也受海水中的营养盐影响。因而，海生物生长受水深影响，图 5 为海生物附着厚度随水深的散点图。从图 5 中可以看出，海生物附着厚度总体上随水深增加而厚度减小。根据海上平台的设计，在水深 0~25m 区域由于平台设有防海生物装置，使得海生物附着厚度比 25m~50m 水深处更小。

根据海生物厚度随水深的变化，可以将海生物厚度按分层进行研究，本文按 0~25m、25~50m、50~80m 和大于 80m 水深，分别开展海生物附着厚度研究。

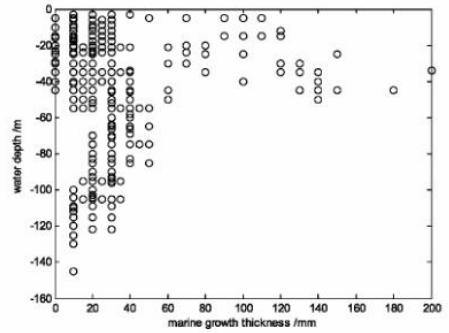


图 5 海生物附着厚度随水深变化的散点

六、結論

➤ 國內已具備離岸結構細部設計能力：

- 風況調查與風能分析。
- 海況調查與波浪分析。
- 地質調查與地工分析。
- 處理大量荷重情境與分析資料。
- 計算應力歷時之疲勞損傷，可承接各種分析軟體之應力歷時輸出，進行計算。
- 以結構學理論減少連接段之有限元素模型自由度，大幅減少計算時間。
- 研發接頭疲勞分析程式，可更精確計算其疲勞損傷。
- :
- :