

離岸風場海事工程 繫固分析探討



報告人：鍾承憲

財團法人船舶暨海洋產業研發中心
海洋產業處 處長

中華民國 107 年 8 月 3 日

葉片開發

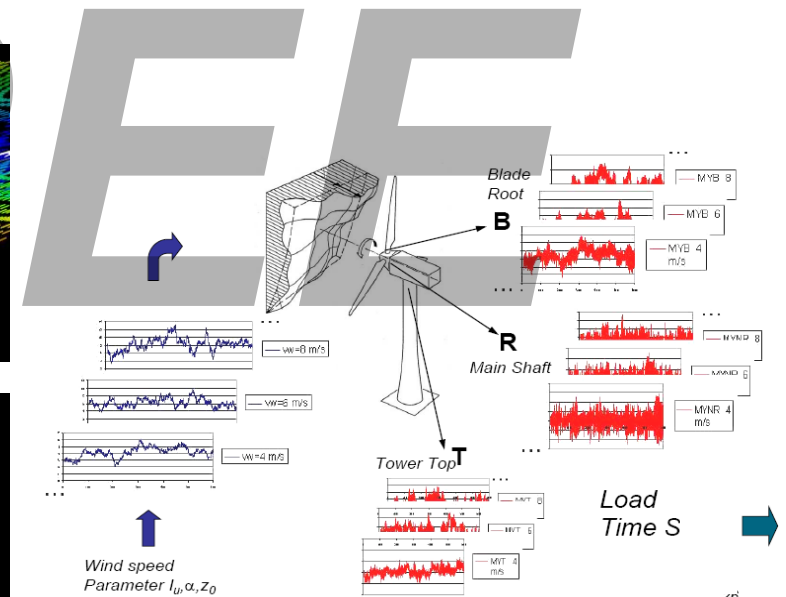
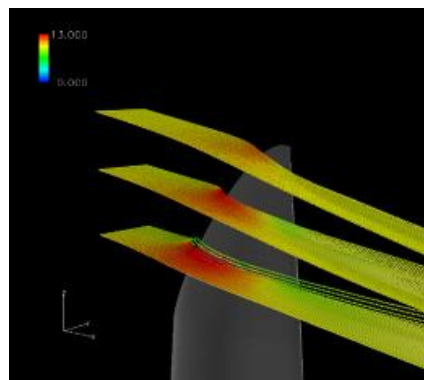
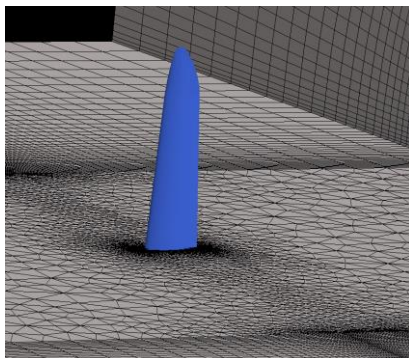
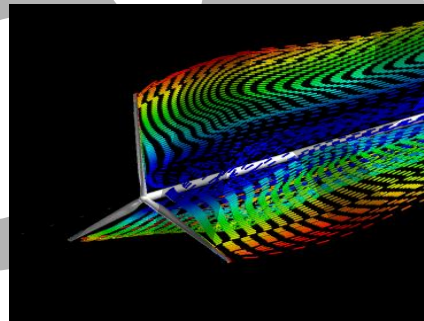
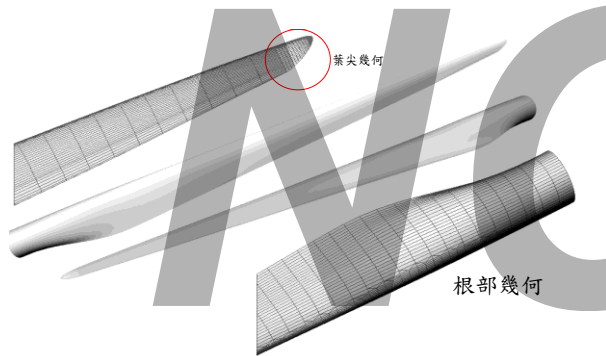
- 工研院機械所委託能專計畫

- 95.3-98.12
- 98.1-99.12
- 100.1-

2MW級高效能風力葉片技術開發

離岸風力機碳纖葉片初階設計及風場設置初步研究

海域型風力機葉片模擬分析與海上施工技術研究



負荷計算

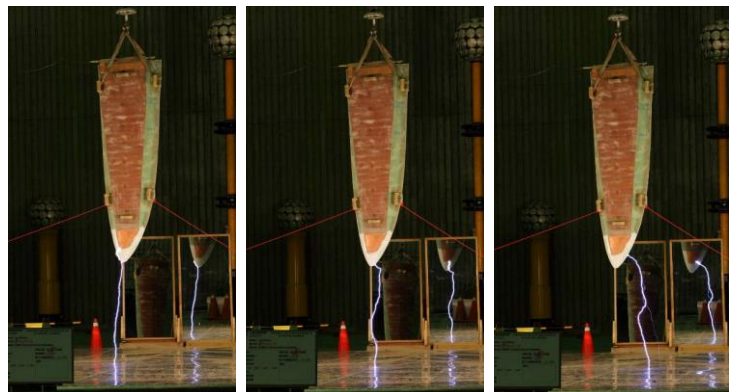
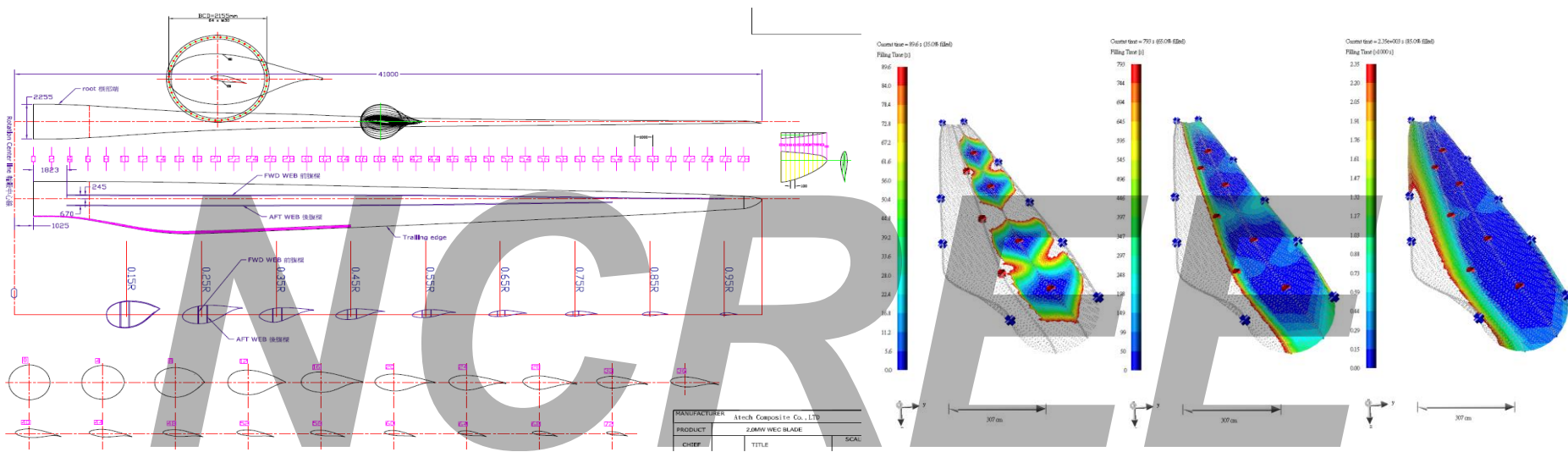
分析軟體 **FAST**、**AeroFLEX**、**GH Bladed**

氣動力幾何設計與流場模擬

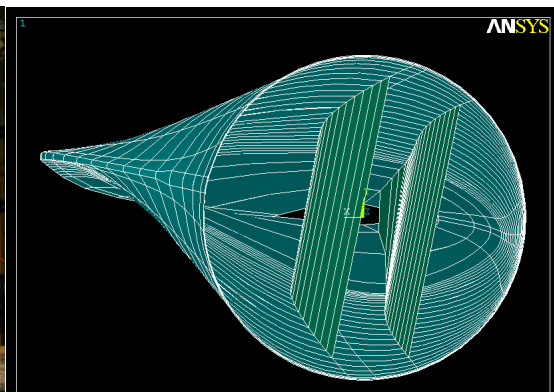
葉尖流線分析

葉片開發

- 工研院機械所委託能專計畫



葉片尖端雷擊試驗

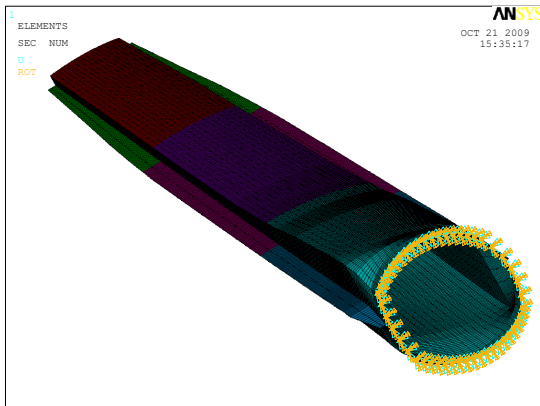
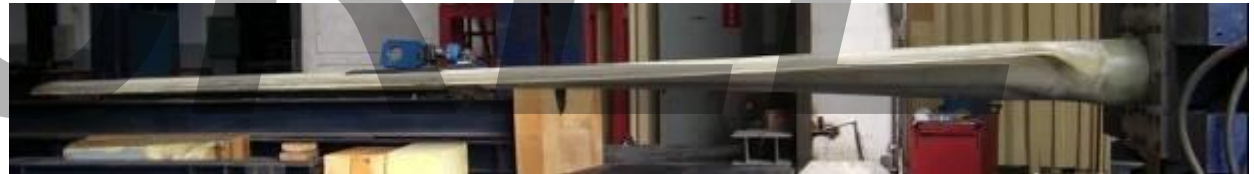
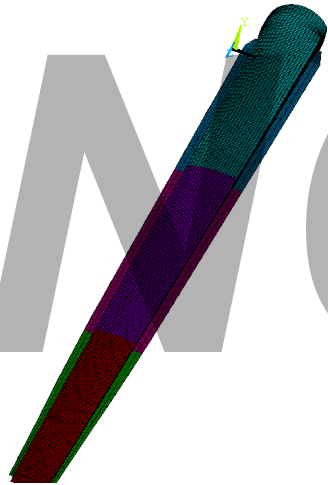
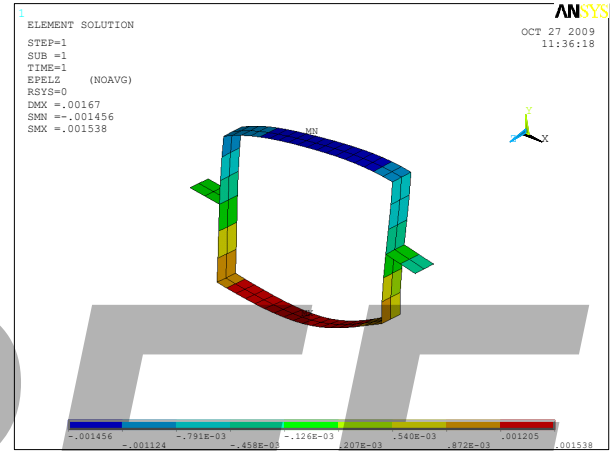


葉片結構設計與製造分析



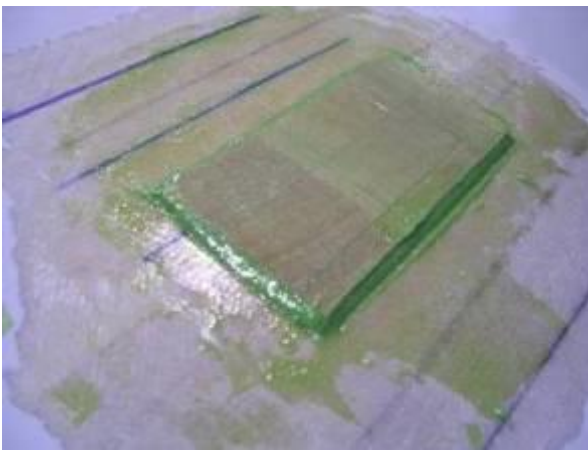
葉片開發

- 先進複材公司委託
- 6m水平軸碳纖維葉片積層設計



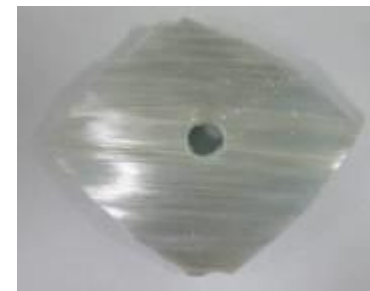
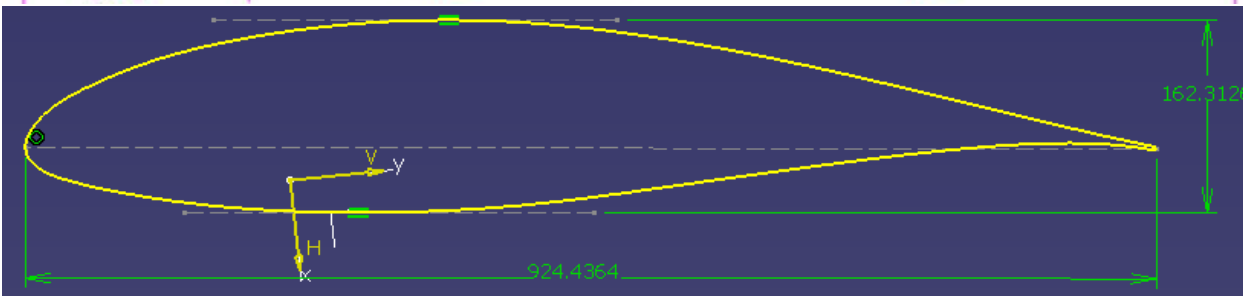
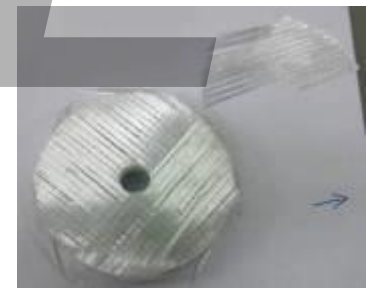
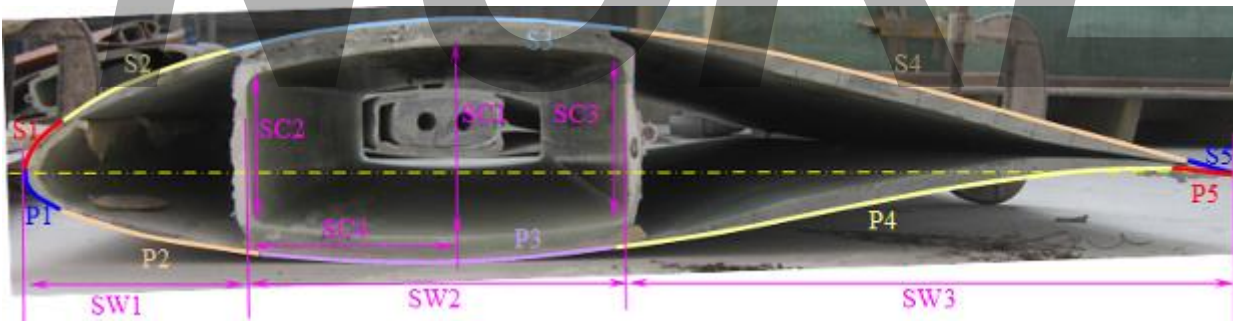
葉片維修

- 台電修護處委託
- 葉片檢查制度與初階維修能力建置
 - 葉片檢查
 - 葉片損傷評估
 - 葉片初階修補



葉片維修

- 台電綜研所委託
- 風機葉片之逆向工程與修護評估技術之建立
 - Vestas v47 葉片逆向工程
 - 660kW
 - 23m
 - 葉片積層探討-斷面切割與檢視



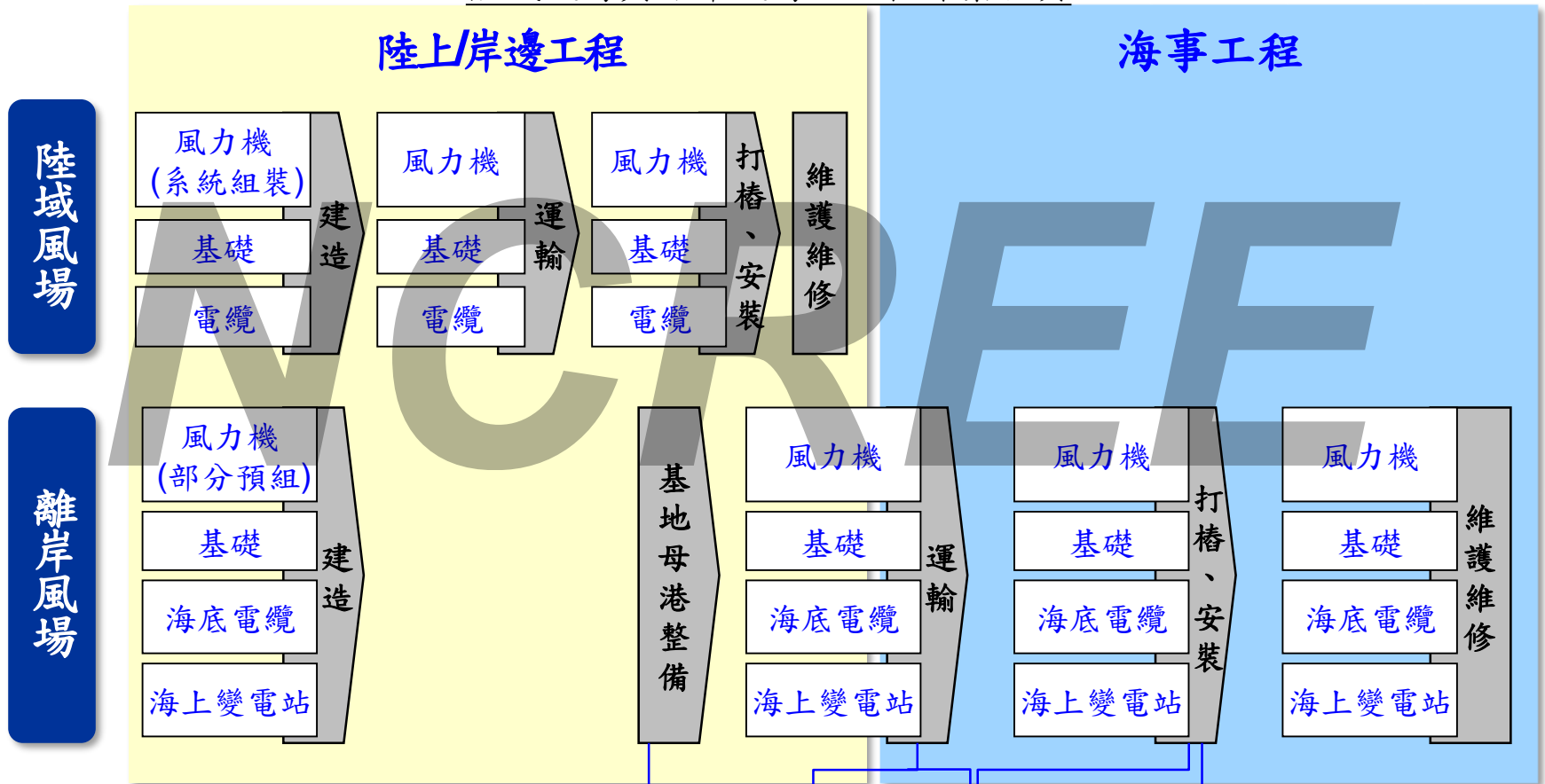
- 前言
- 安全評估項目
- 案例說明
 - 永傳海氣象觀測塔運輸
 - 上緯海纜運輸
- 結論

NORRE

離岸風場與陸域風場之差異

離岸風場開發工程近半在海上完成

陸域風場與離岸風場之工程作業差異



基地母港/專用港區



拖船



自升式平台/船



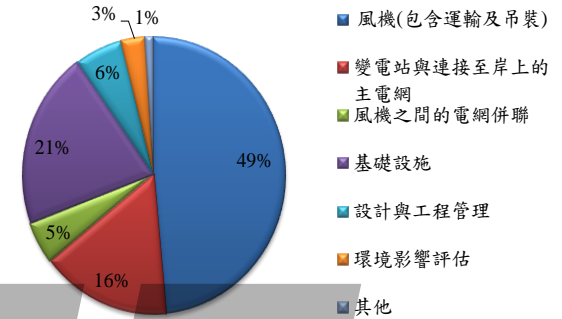
鋪纜船

離岸風場作業安全評估之背景

離岸風電開發作業安全評估之背景

在離岸風場之開發建置與營運過程中，除規劃設計外，其餘在運輸、吊裝、安裝施工及後續維護與營運階段均與海上作業有關，因而如何在安全之前提下，確保相關作業能如期如質完工，為相當重要的議題。

離岸風場成本結構



資料來源：丹麥國家永續能源實驗室，船舶中心整理，2013



運輸與吊裝



打樁與固著



維護與營運

安裝目標

>12 MW
(4架)

600 MW
(120架)

1.8 GW
(360架)

4 GW
(800架)

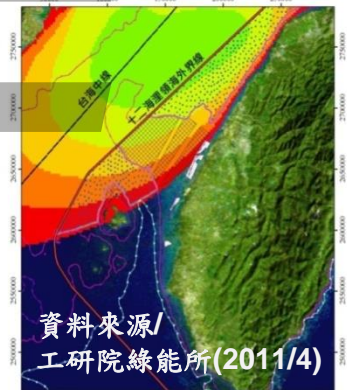
102年(2013)

105年(2016)

109年(2020)

114年(2025)

119年(2030)



需要本土化的離岸風電開發作業安全相關技術支應800架風機安裝工作

離岸風電海事工程安全風險高

離岸風電海事工程安全風險高



遭遇大浪事件



樁腿穿傾
(punch through)



吊裝穩度不足

- 離岸風電海事工程的複雜度遠超過陸上風電建置工程，無論是基礎或風力機組的運輸與安裝，均有其工程技術門檻，亦隱含安全上的隱憂。
- 近年全球風場意外事故中，以環境破壞、運輸損害、結構失效、火災、葉片失效、人員損傷等事故項目比重較大；離岸風電海事工程的運輸風險尤須控管。

離岸工程風險分析與對策

- 離岸工程之風險分析 (Risk Analysis)

- 風險來源識別
- 風險評估
- 緩解方式
- 評估結果

- 常見的風險對策4T

- 接受風險Take
- 應付風險Treat
- 轉換風險Transform
- 結束活動Terminate

	C1	C2	C3	C4	C5
L1	1	2	3	4	5
L2	2	4	6	8	10
L3	3	6	9	12	15
L4	4	8	12	16	20
L5	5	10	15	20	25

- 海上作業的風險，可洽第三方海事保證鑑定(Marine Warranty Survey-MWS)協助將之降低，或將此風險轉移，如找保險公司(Insurance Company)承保。

工程可保險之要求

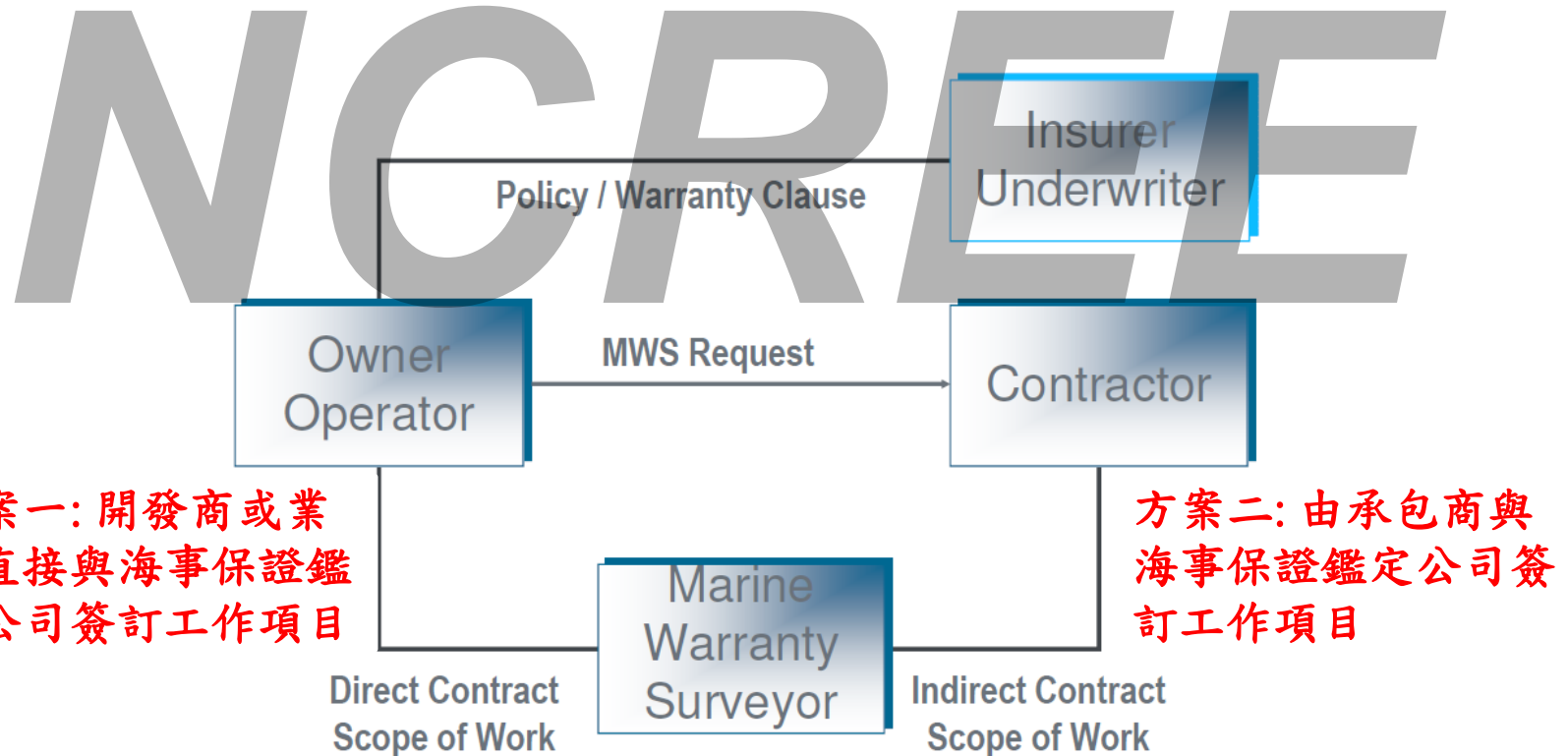
- 安排離岸風力發電專案工程保險前，必須完成項目
 - 核保報告書 (Underwriting Report)
 - 最大可能損失評估 (EML Study)
 - 海事保證鑑定 (Marine Warranty Surveying-MWS)
- 非品質保證，為針對海事操作之安全保證



來源：A2SEA

海事保證鑑定(MWS)

- 採用海事保證鑑定之避險作法
 - 海事保證鑑定 Marine+Warranty+Survey
=Supervision of Offshore Operations on behalf of the Client according to the **Insurer's interests**



海事保證鑑定(MWS)

- 歐洲現行通用之模式。
- 保險公司要求，確認重要的**海上施工作業**是**安全**的，其僅對「原則性」提出要求，要求某特定施工作業或步驟需要有MWS的事先確認及同意
 - 裝載(Loadouts)
 - 運輸(Transportation)
 - 安裝(Installation)
 - 海纜佈置(Cable Laying)
- MWS為客觀公正的第三方，評估與調查各海事操作(marine operation)是否符合保險公司**可承受風險**之標準，以確保保險公司與被保險人利益。
- 保險公司被保險人需對MWS提出的**改善建議進行處理**，以避免失去施工的保險保障。
- 受委託的MWS應提供最終的**審批證書**
 - Certificate of Approval (CoA)



<http://www.offshorewind.biz/wp-content/uploads/2014/09/AREVAs-Installed-Offshore-Wind-Capacity-Reaches-630MW.jpg>



https://i.vimeocdn.com/video/523361229_1280x720.jpg

- Marine Warranty Survey
有IAMWS聯盟組織，以海
事操作為主
- 國際再保險人指定之MWS
 - London Offshore
Consultants (LOC)
 - DNV GL
 - Mwaves
 - Cambridge Marine
 - TÜV Rheinland
 - Con4Mare
 - Global Maritime
 - ClassNK



來源：IAMWS





Certificate of Approval(CoA)



LONDON OFFSHORE CONSULTANTS (AUSTRALIA) PTY. LTD.
MARINE & ENGINEERING CONSULTANTS
7 Vantour Avenue, West Perth, WA 6005
PO Box 513, West Perth, Western Australia 6872
Telephone +61 (08) 9322 7943 Fax +61 (08) 9486 7860
email: loca@londonoffshore.com.au www.loc-group.com

Certificate of Approval

LOCA/5100/PB/C019

WOODSIDE ENFIELD AREA DEVELOPMENT PROJECT

LOAD-OUT OF RISER COLUMN

LAMPRELL FACILITY, JEBEL ALI, UNITED ARAB EMIRATES

This is to certify that this office, acting on behalf of Woodside Energy Ltd, has reviewed the procedures and witnessed the preparations for the load-out of the Enfield Area Development Project Riser Column onto the MV "FAIRPARTENER" at Lamprell Facility, Jebel Ali, U.A.E. for transportation to Exmouth Gulf, Western Australia.

This operation is hereby approved to proceed.

This Certificate of Approval is issued without prejudice to any insurance interests or to any or all parties concerned.

For and on behalf of
London Offshore Consultants
(Australia) Pty. Ltd.

[Surveyor's Name]

@ [time] on xx [month] 2005



DNV·GL

NOBLE DENTON MARINE ASSURANCE AND ADVISORY

CERTIFICATE OF APPROVAL

1/123456

LC12345/NDC/INITIALS OF SURVEYOR

SELF-ELEVATING OFFSHORE **DRILLING / CONSTRUCTION / ACCOMMODATION**
PLATFORM

TYPE: **RIG DESIGNER & MODEL NUMBER**

"RIG NAME"

LOCATION: **WELL NAME, BLOCK NUMBER, FIELD, SEA, COUNTRY**

THIS IS TO CERTIFY: that this office, acting on behalf of
RIG OWNER

has investigated the factors relating to the proposed location **WELL NAME, BLOCK NUMBER, FIELD, SEA, COUNTRY** and herewith approves the location subject to the limitations and recommendations appearing in the attached study.

This Certificate is issued subject to our **TERMS & CONDITIONS DETAILS**.

This Certificate is issued solely for the purpose of approving the location **WELL NAME, BLOCK NUMBER, FIELD, SEA, COUNTRY** for use by "RIG NAME" for **PROPOSED RIG OPERATIONS**, and is based on information provided to us by others as shown in the attached study, LC12345/NDC/INITIALS OF SURVEYOR, and without a survey having been made of the unit.

For: NOBLE DENTON CONSULTANTS LTD

SIGNATURE

Surveyor Name
Surveyor Title

Dated: Day Month Year

取得CoA之條件

- 所有相關文件均被審查通過
 - SoA(Statement of Acceptability)
- 現場與船舶準備已確實執行
- 海事操作相關裝備已被確認(survey)過
- 行前準備會議已召開過
- 氣候條件符合預設海事操作之條件

Page | 1

DNV·GL

Technical Review Note
Marine Warranty Survey

To: _____ STATUS **Acceptable with Comments**

Copy: _____ TRN No. _____

Module: _____

Document Title: TRANSPORTATION REPORT

Document Number: -

Revision Number: _____ Revision Date: _____

Additional Docs _____

Document Reviewed by: _____

Transmittal Details:

Date Received: _____ Date Sent Out: _____

Comment Class:	
R	Document / Item rejected has to be revised according to the mentioned requirements
H	Document / Item not acceptable / on hold - clarification, response or re-submission needed
A/C	Document / Item acceptable in principle, with comments for MWS site inspection
A	Document / Item is acceptable without any critical comments
I	Comments for information - by this class DNV GL office acknowledges certain data receipt or requires further clarifications (for non-critical MWS purposes or QA/QC related issues)
Nota Bene:	Above classes are displayed in descending severity order. The general STATUS of the document is to be defined by the most severe class of all below comments

- 前言
- 安全評估項目
- 案例說明
 - 永傳海氣象觀測塔運輸
 - 上緯海纜運輸
- 結論

NORRE

海事保證鑑定程序與項目

- 文件審閱與核准(Review and Approval of Documents)
 - 現場作業
 - 裝載
 - 運輸
 - 安裝程序
 - 鋪設作業
- 海事元件與設備狀況調查
(Condition surveys of marine units and equipment)
 - 船舶、吊車、錨機、其他設備、安全設施
- 海事操作作業現場監督(On-site surveillance during each marine operation)
 - 依據審核文件內容現場確認監督



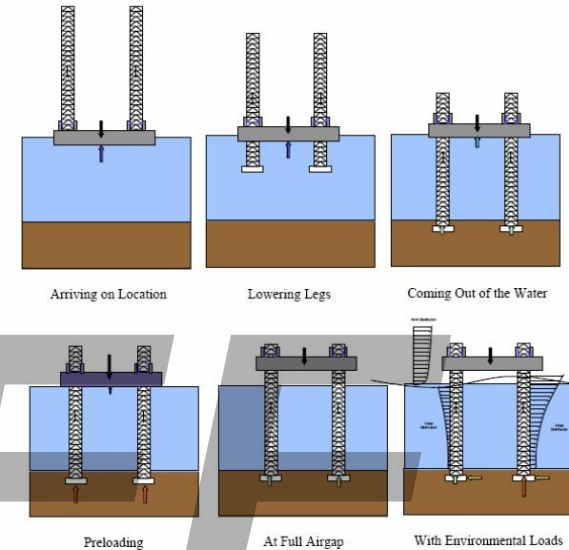
安全評估項目

- 含裝載/卸載、運輸、元件保全、安裝等海事操作行為
 - Load out, Float out, Float on/off
 - Towed and Self Propelled Transport
 - Launching, Upending, Positioning of Jackets
 - Setting, Piling, Grouting of jackets and subsea structures
 - Marine Lifting, Lift-off or Mating Operation



安全評估項目

- 含裝載/卸載、運輸、元件保全、安裝等海事操作行為
 - Transit and Positioning of Jack-ups and semi-submersibles
 - Rigid Pipe & Flexible/cable lay.
 - Pipe/cable crossing & Trenching
 - Subsea structures Installation operations
 - High value, Project Critical or Long lead Item
 - Cargo Shipments on general cargo vessels
 - Road, air or rail transportation of cargos en-route to shipment load out location



<http://image.slidesharecdn.com/finalproject-110415112423-phpapp02/95/final-project-37-728.jpg?cb=1302867436>



https://qph.ec.quoracdn.net/main-qimg-6e4a3ee35ee913428a8a8cb9f2653718-c?convert_to_webp=true



<http://subseaworldnews.com/wp-content/uploads/2014/04/dsc06646.jpg>

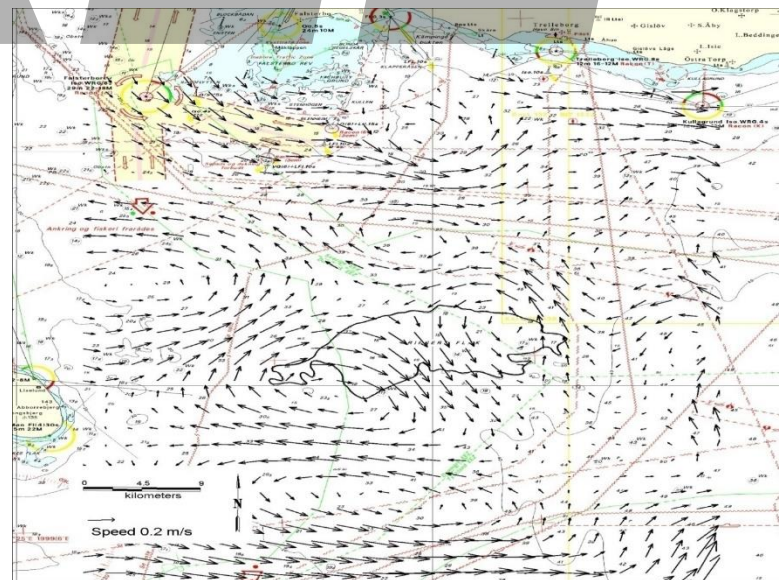
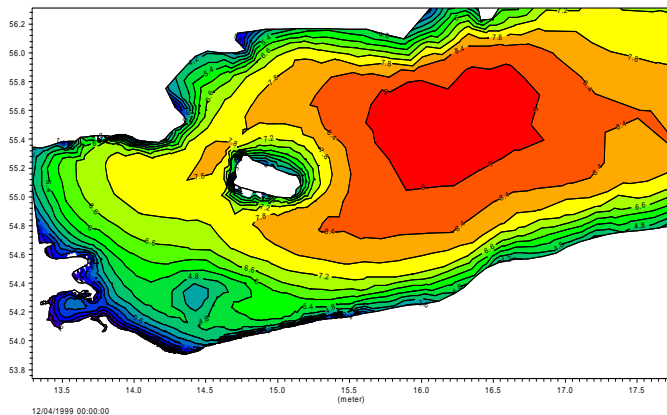
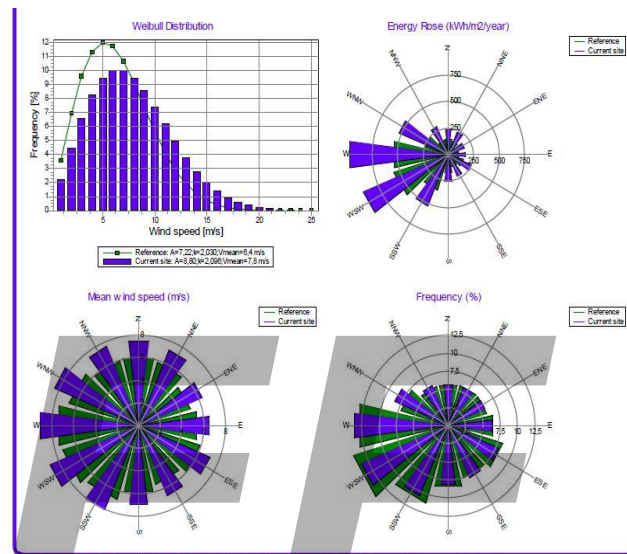
DNV GL Guideline



Title	GL Noble Denton	DNV GL
General guidelines for marine projects	0001/ND Rev 1.1	DNVGL-ST-N001
Guidelines for load-outs	0013/ND Rev 8.1	
Guidelines for concrete gravity structure construction & installation	0015/ND Rev 5.1	
Guidelines for marine lifting & lowering operations	0027/ND Rev 11.2	
Guidelines for steel jacket transportation & installation	0028/ND Rev 6.2	
Guidelines for marine transportations	0030/ND Rev 6.1	
Guidelines for float-over installations/removals	0031/ND Rev 3	
Guidelines for moorings	0032/ND Rev 2.1	
Guidelines for offshore wind farm infrastructure installation	0035/ND Rev 1.1	

環境條件

- 設計環境條件 (design environmental condition)
 - 該海事操作期間遭遇之波高、風速、流速與其他相關環境條件。
- 操作標準 (operational criteria)
 - 海事保證鑑定機構准許該海事操作各階段可進行之極限海氣象標準。
 - 需考慮設計環境條件與海事操作相關條件，如人員運輸、關聯船機等。
- 氣候限制操作 (weather restricted operation) v.s. 非氣候限制操作 (weather unrestricted operation)



非氣候限制性操作

Table 7-1 Metocean return periods – unrestricted operations

Operational reference period	Wind	Wave and Current
Up to 3 days ^[1]	5 year return, seasonal	3 month return, seasonal.
3 to 7 days	10 year return, seasonal	1 year return, seasonal
7 days to 1 month	25 year return, seasonal (or $10\text{yr} + 0.7 \cdot (50\text{yr} - 10\text{yr})$)	10 year return, seasonal
7 days to 1 month	For transportation, use reduced exposure towage /transportation computation (as defined in Section 3) with a minimum of the 1 year seasonal return	For transportation, use reduced exposure towage /transportation computation (as defined in Section 3) with a minimum of the 1 year seasonal return
1 month to 1 year	75 year return, seasonal (or $50\text{yr} + 0.7 \cdot (100\text{yr} - 50\text{yr})$)	50 year return, seasonal
More than 1 year	100 year return, seasonal	100 year return, seasonal

氣候限制操作

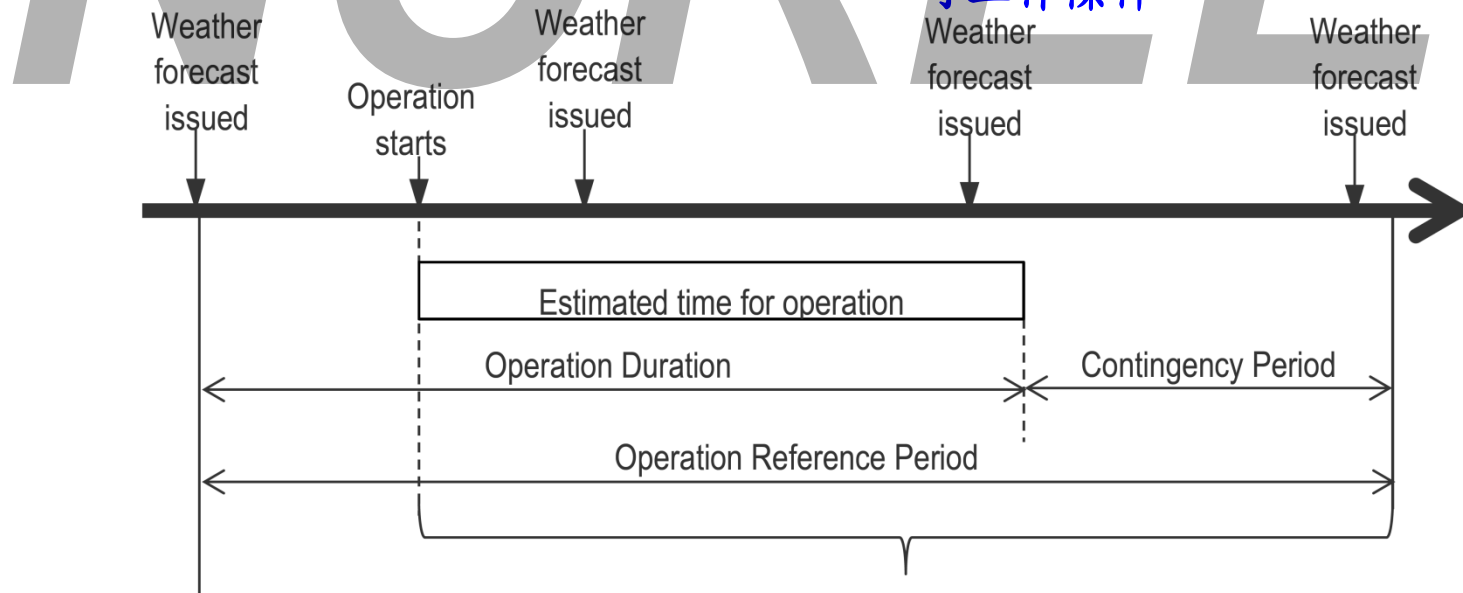
- 操作參考期間(operational reference period)低於72小時之海事操作通常被類歸為氣候限制操作。
 - 可不用極端環境統計值
 - Alpha factors α
 - 需有可靠之氣象預報

Required weather window with

$$OP_{WF} = \alpha \times OP_{LIM}$$

載具或設備的可工作條件

載具或設備的工作極限條件



Alpha Factor

Table 7-3 Forecast Requirement Classes

Forecast Requirement	A1	A2	B1	B2	C
Wave Alpha Factor	Table 7-8	Table 7-7	Table 7-6	Table 7-5	Table 7-4
Wind Alpha Factor	Table 7-9				
For weather sensitivity	HIGH		MODERATE		LOW
Typically required for the following examples. (These may vary depending on the value of the structures and complexity /weather sensitivity of the operations)	Major , e.g. Mating Offshore float-over Offshore installation GBS Float-out or tow		Significant , e.g. Offshore lifting Subsea installation Sensitive barge towing Jack-up move		Routine , e.g. Inshore /onshore lifting Load-out (without tidal restrictions) Standard towage
Dedicated meteorologist	YES		Not required [1]		Not required
Meteorologist on site	YES	NO	Not required		Not required
Environmental monitoring & feedback to meteorologist	YES	NO	YES	NO	Not required
Independent weather forecasts required [2]	2		2		1

Alpha Factor

Table 7-4 Alpha Factors for Waves - Forecast Requirement C (Low Sensitivity)

Operation Duration	Operational Significant Wave Height			
	Hs ≤ 1 m	Hs = 2 m	Hs = 4 m	Hs ≥ 6 m
≤ 12 hours	0.58	0.68	0.70	0.71
≤ 24 hours	0.56	0.65	0.68	0.69
≤ 36 hours	0.55	0.63	0.65	0.68
≤ 48 hours	0.53	0.61	0.63	0.66
≤ 72 hours	0.49	0.56	0.61	0.64

Table 7-7 Alpha Factors for Waves - Forecast Requirement A2 (High Sensitivity)

Operation Duration	Operational Significant Wave Height (No monitoring)			
	Hs ≤ 1 m	Hs = 2 m	Hs = 4 m	Hs ≥ 6 m
≤ 12 hours	0.64	0.75	0.77	0.78
≤ 24 hours	0.61	0.71	0.75	0.77
≤ 36 hours	0.61	0.69	0.71	0.75
≤ 48 hours	0.59	0.67	0.69	0.72
≤ 72 hours	0.54	0.61	0.67	0.70

Table 7-8 Alpha Factors for Waves - Forecast Requirement A1 (High Sensitivity)

Operation Duration	Operational Significant Wave Height (With monitoring)			
	Hs ≤ 1 m	Hs = 2 m	Hs = 4 m	Hs ≥ 6 m
≤ 4 hours	0.80	0.85	0.89	0.89
≤ 12 hours	0.69	0.81	0.85	0.85
≤ 24 hours	0.64	0.75	0.77	0.80
> 24 hours	As for Table 7-7 above			

- 前言
- 安全評估項目
- **案例說明**
 - 永傳海氣象觀測塔運輸
 - 上緯海纜運輸
- 結論

NORRE

海氣象觀測塔運輸

- 福海風場海氣象觀測塔運輸作業
 - 船舶適航條件
 - 構件海上繫固 (sea fastening)



<http://www.eewow.com/photo/2015/7/21367a.jpg>



<http://www.energyedu.tw/column.php?action=detail&cid=5&id=67>



<http://img5.cna.com.tw/www/WebPhotos/800/20150802/31165858.jpg>

海事繫固

- 海事繫固(Sea Fastenings)(簡稱海固)
 - 係工作船裝載運輸構件的安全設施，隨船、貨而變化
 - 從Load Out開始、Transportation接續、Lifting結束
 - 非商品，以功能、安全、可行為優先考量，經濟次之
 - 針對允許天候海況產生之船況進行設計、計算及執行
- 海固對象
 - 風力機基礎
 - 風力機構件
 - 作業機具及配合措施
- 海固出航型式
 - 產地至基地母港
 - 基地母港至風場場址
- 認證及投保：申請第三者認證，取得保險，分攤風險及成本



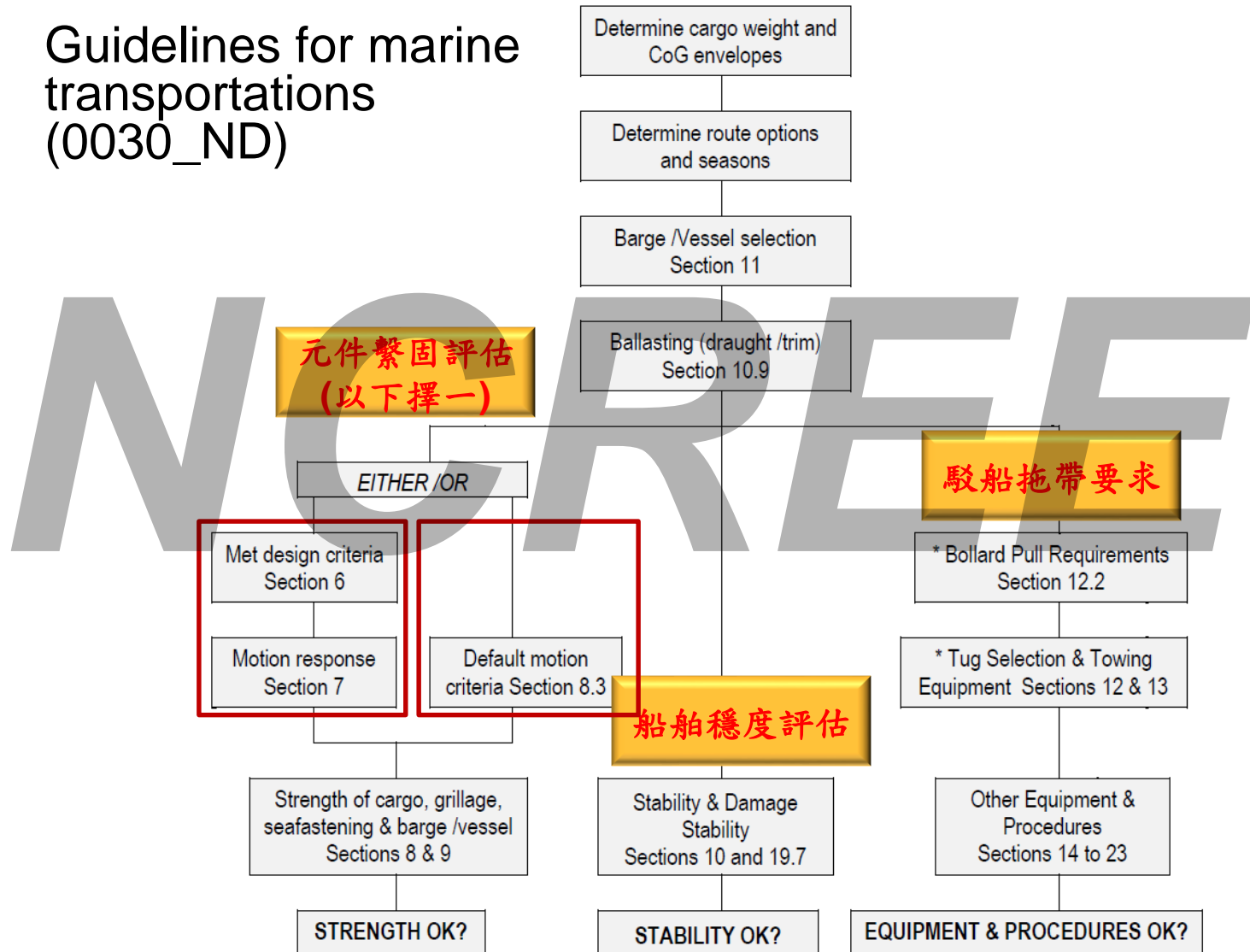
離岸風電之海事繫固



Fred Olsen之Brave號自升安裝船裝載風力機構件的側視照片，針對安裝風力機作業，Fred Olsen整理出很均稱之排列，重件繞著吊車，遠端放葉片。

GL Noble Denton 運輸評估認證流程

- Guidelines for marine transportations (0030_ND)



* = Delete box for transportations

船舶選擇



船級證書

載重線證書



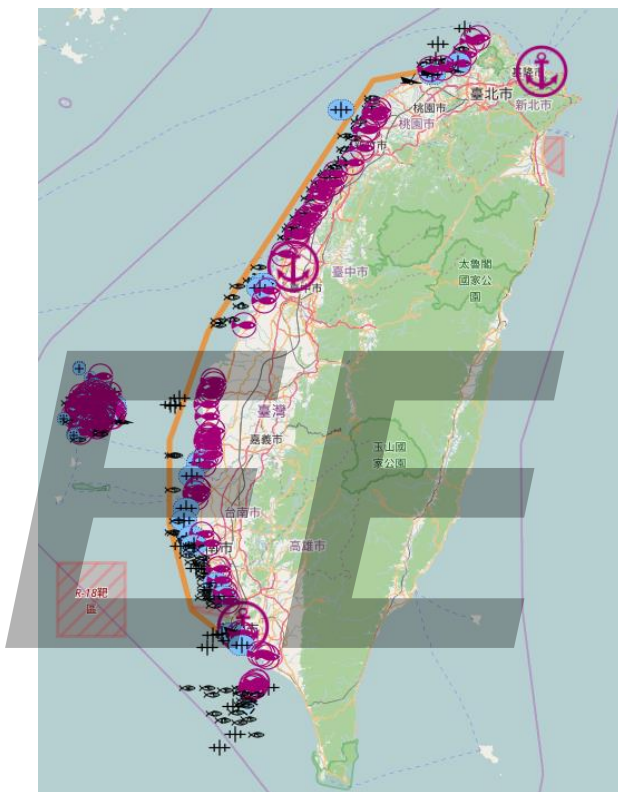
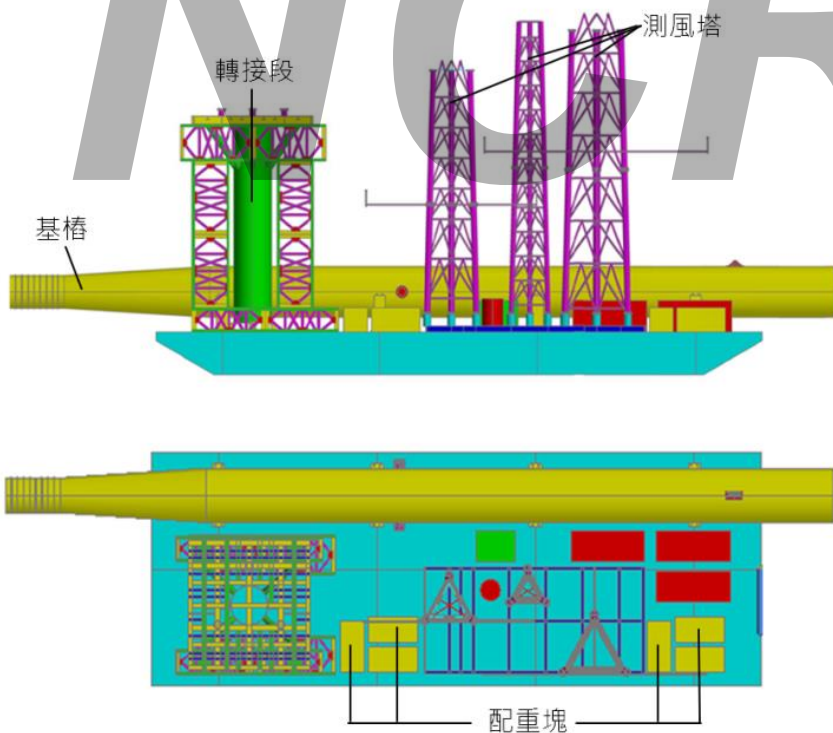
<http://www.yagcishipping.com/mustafa/asetifika/Classification-Crt.jpg>

https://upload.wikimedia.org/wikipedia/commons/5/51/Load_Line_Certificate.jpg

Document	Cargo vessels (Note 1)	Tugs (Note 1)	Barges (Note 2)	FPPO /FPU etc towages	Demolition towages	Other towages
Certificate of registry	✓	✓	✓		*	*
Certificate of class (hull)	✓	✓	✓	✓		*
Certificate of class (machinery)	✓	✓	✓			*
Tonnage certificate	✓	✓	✓	*		*
Cargo ship safety construction certificate	✓	✓	✓	*		*
Cargo ship safety equipment certificate	✓	✓	✓	*		*
Certificates for navigation lights & shapes			✓	✓	✓	✓
Certificate for Civil Liability for Bunker Oil Pollution	✓	✓	✓	✓	✓	✓
Load line certificate or load line exemption	✓	✓	✓	*	✓	
Load line exemption (if unmanned)				✓	*	✓
Air Pollution Prevention (IAPP) certificate	*	*	*	*	*	*
IOPP Certificate	✓	✓	✓	✓	*	
Safety Management Certificate (SMC)	✓	✓	✓			
Customs clearance	✓	✓	✓	✓	✓	✓
Ship Sanitation Control Certificate or exemption	✓	✓	✓	✓		✓
Radio certificate, including GMDSS	✓	✓				
Trim and Stability booklet	✓	✓	✓	✓		
Bollard pull certificate		✓				
Certificates for bridle, tow wires, pennants, stretchers and shackles		✓	✓	✓	✓	✓
Suez or Panama Canal documentation (if relevant)	✓	✓	✓	✓	✓	✓
Transportation or Towing manual	✓	✓	✓	✓	✓	✓
Manned towed objects						
Load line or Load Line Exemption	✓	✓	✓	✓	✓	✓
Certificates for life saving appliances	✓	✓	✓	✓	✓	✓
Crew list	✓	✓	✓	✓	✓	✓
Radio Certificate	✓	✓	✓	✓	✓	✓

路線與船舶選擇

- 海氣象觀測塔構件
 - 基樁、轉接段、三段塔架
- 使用船舶
 - 台船五號：全長50米非自身式推進駁船
- 運輸路線
 - 滿載狀況下從台北港至高雄



全長	50	(m)
水線長	45.7	(m)
最大船寬	18	(m)
船深	3.5	(m)
設計吃水	1.546	(m)
輕船重	288.8	(ton)
裝載重	932.3	(ton)

船舶穩度安全評估

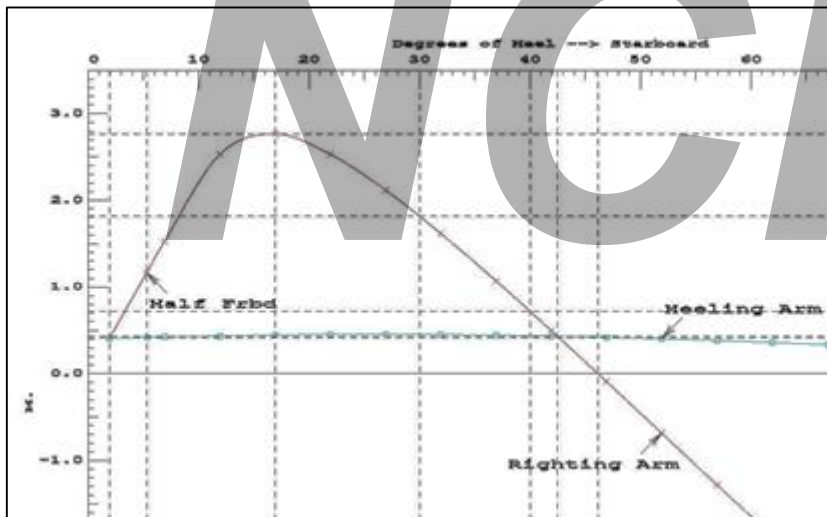
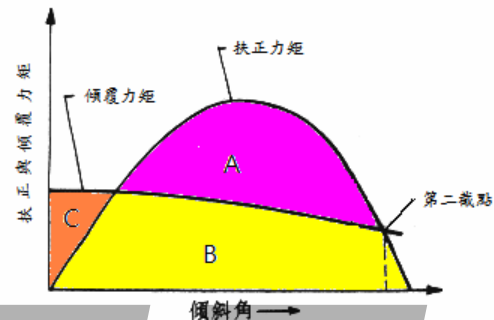


- 形心及質量資料
- 尺寸重量表

- 船體穩度評估規範
- ✓ IMO 2008 IS CODE
- ✓ GL Noble Denton

穩性評估

- 台船五號:
- ✓ 測風塔裝載狀況穩度



基樁先行單獨裝載時之傾角計算結果為5.2度，港邊裝載過程中，現場量測得到相當接近之結果。

IMO 2008 IS CODE之駁船完整穩度準則

項目	要求	計算
正穩度曲線下到最大復原力矩角度，面積不小於0.08 rad-m。	>0.08 rad-m	1.04 rad-m
受風速30米/秒之靜橫傾角度應小於在負載狀況下之一半乾舷角度。	<5.3°	7.9°
穩度最小範圍應不小於20°。	>20°	57.46°

GL Noble Denton之駁船完整穩度準則

項目	要求	計算
完整穩度範圍應不小於36度。	>36°	57.46°
有效的GM ₀ 值大於1米。	>1m	29m
完整穩度情況，正穩度(Intact GZ)曲線下的面積應大於風傾力矩(Wind Overturning Arm)曲線下面積的1.4倍。	>1.4	1.9

海事繫固力計算法規定義

- 預設值的資料來源主要基於歐洲的北海，波浪週期為10秒屬於長浪，在台灣並不常見，此數據在台灣幾乎等同颱風來襲時的海況，換言之非限制氣候條件(Unrestricted)預設值計算對台灣地區而言趨於保守。

Nature of Transportation	Case	LOA (m)	B ^[1] (m)	L/B ^[1]	Block Coeff	Full cycle period (secs)	Single amplitude		Heave
							Roll	Pitch	
Unrestricted (these values to be used unless any of the following apply)	1	> 140	and > 30	n/a	< 0.9	10	20°	10°	0.2 g
	2	> 76	and > 23	n/a	any	10	20°	12.5°	0.2 g
	3	≤ 76	or ≤ 23	≥ 2.5	< 0.9	10	30°	15°	0.2 g
	4	≤ 76	or ≤ 23	≥ 2.5	> 0.9	10	25°	15°	0.2 g
	5	≤ 76	or ≤ 23	< 2.5	< 0.9	10	30°	30°	0.2 g
	6	≤ 76	or ≤ 23	< 2.5	≥ 0.9	10	25°	25°	0.2 g
Weather restricted operations in non-benign areas for a duration <24 hours (see Section 7.9.2 d. For L/B < 1.4 use unrestricted case.	7	any		≥ 2.5	any	10	10°	5°	0.1 g
	8	any		< 2.5, > 1.4	any	10	10°	10°	0.1 g
Weather restricted operations in benign areas ^[2] (see Section 7.9.2.e). For L/B < 1.4 use unrestricted case.	9	any		≥ 2.5	any	10	5°	2.5°	0.1 g
	10	any		< 2.5, ≥ 1.4	any	10	5°	5°	0.1 g
Inland and sheltered water transportations (see Section 7.9.2.f). For L/B < 1.4 use unrestricted case.	11	any		≥ 1.4	any	Static	Equivalent to 0.1 g in both directions		0.0
Independent leg jack-ups, ocean tow on own hull. For L/B ≥ 1.4 use unrestricted Cases 1 to 6	12	n/a	> 23	< 1.4	n/a	10	20°	20°	0.0
Independent leg jack-ups, 24-hour or location move. For L/B ≥ 1.4 use Case 7 or 8 as applicable	13	n/a	> 23	< 1.4	n/a	10	10°	10°	0.0
Mat-type jack-ups, ocean tow on own hull. For L/B ≥ 2.5 the pitch angle may be reduced to 8°	14	n/a	> 23	< 1.4	n/a	13	16°	16°	0.0
Mat-type jack-ups, 24-hour or location move.	15	n/a	> 23	n/a	n/a	13	8°	8°	0.0

離岸風電
船舶常用
情境

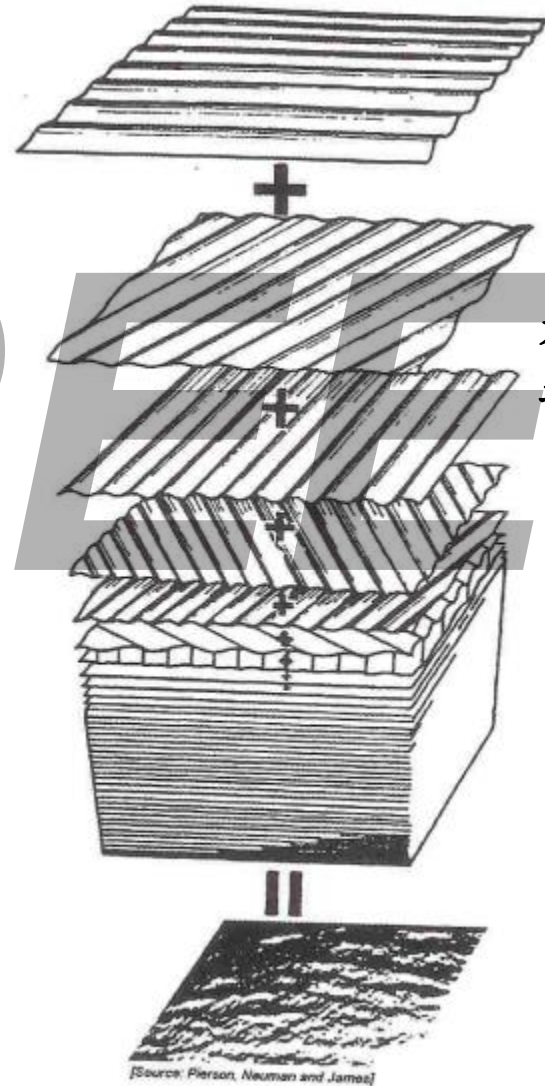
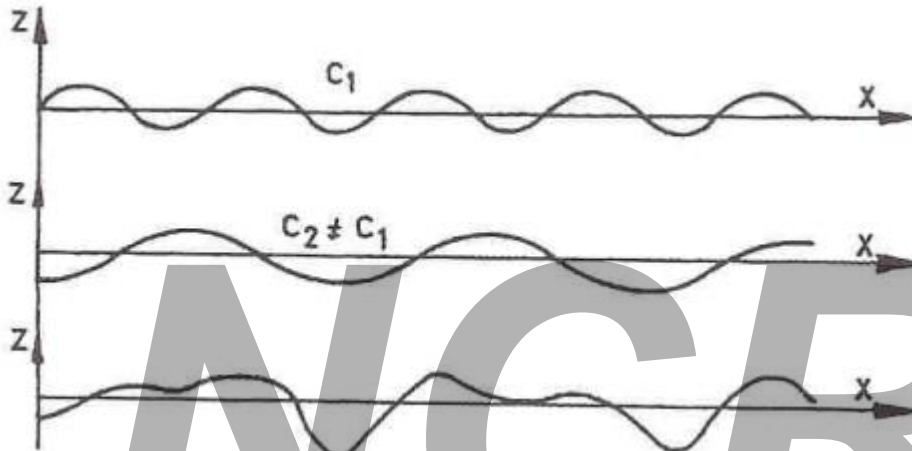
赤道無風
帶外

港內避風

鑽井平台

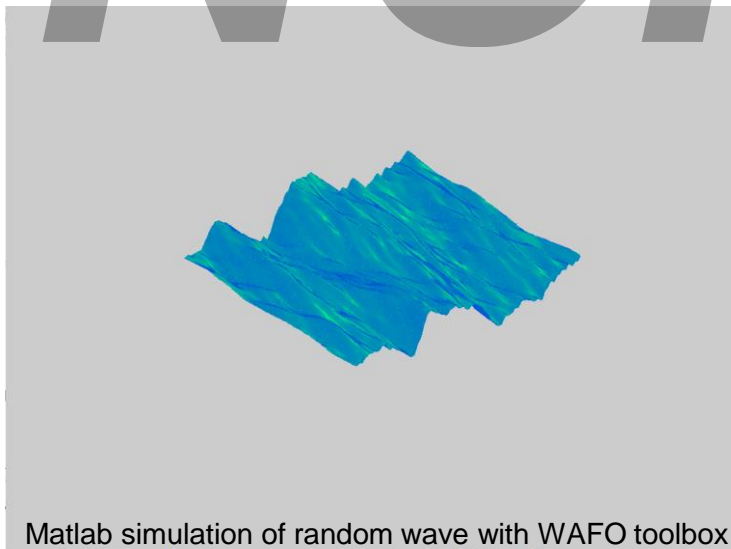
根據海上作業
時間訂
定選用

波浪



不同頻率
之規則波

非規則波



Matlab simulation of random wave with WAFO toolbox

水動力分析船體運動

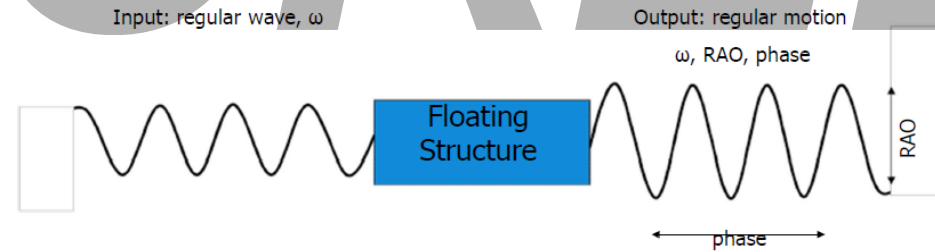
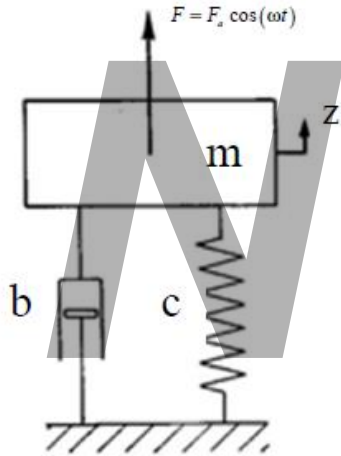
船體受波浪的影響，假設為線性(linear)的情況，單一自由度可以簡化成一種彈簧質量系統(Spring Mass System)如下：

$$mz'' + bz' + cz = F_a \sin(\omega t)$$

如外部力為規則波，穩態解可以寫成：

$$z(t) = z_a \sin(\omega t + \varepsilon)$$

式中， z_a 是振幅， ω 是波浪頻率， ε 是相角(phase angle)。



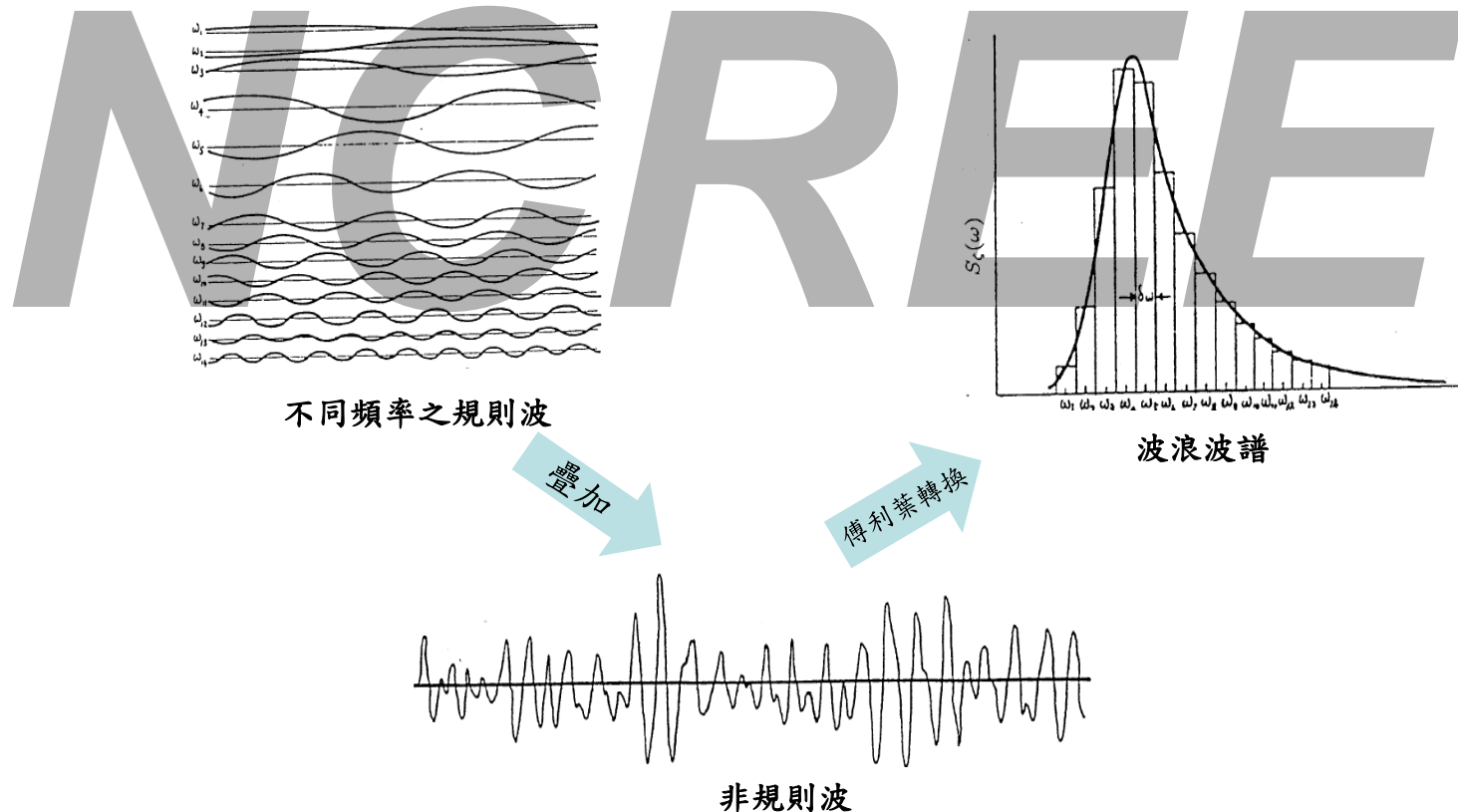
將所得運動的振幅/波的振幅即為反應振幅運算子 RAO(Response Amplitude Operator)。

$$RAO = \frac{z}{z_a}(\omega)$$

RAO的含意為『規則波的情況下，波浪的單位振幅造成船體運動振幅，其與頻率有關』。

波浪頻譜(wave spectra)

- 將不規則波形以傅利葉轉換，將波浪時間域訊號轉換至頻率域中，如波浪波譜所示。
- 波浪能譜曲線底下之積分面積(均方值: m_0)，即代表該海域當時海象所包含的能量。



使用波譜

- 國際上常用之波譜
 - 單參數波譜：Pierson-Moskowitz波譜、ITTC波譜
 - 雙參數波譜：Bretschneider波譜、ISSC波譜、JONSWAP波譜
- JONSWAP波譜(Joint North Sea Wave Project)(1973,1987)
 - 主要針對峽灣或有限風區非充分成長海域之波譜，與台灣近岸海況特性相近，故常被使用。
 - γ 為Peak-shape 參數，一般平均為3.3。x為海峽寬度(km)。

$$S(\omega_0) = \alpha \frac{g^2}{\omega_0^5} \exp\left[-\frac{5}{4}\left(\frac{\omega_m}{\omega_0}\right)^4\right] \cdot \gamma \exp\left[-(\omega_0 - \omega_m)^2 / 2\sigma^2 \omega_m^2\right]$$

$$\alpha = 0.076(\bar{x})^{-0.22}$$

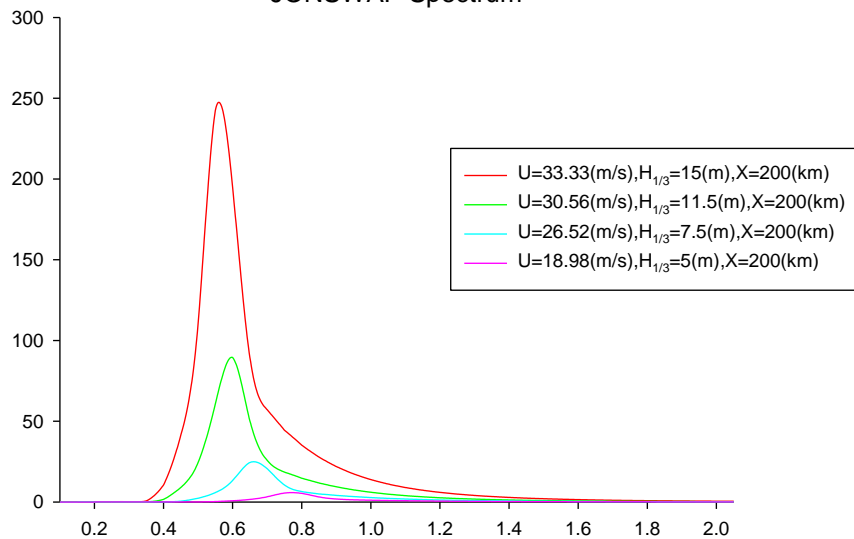
$$\sigma = 0.07(\omega_0 \leq \omega_m)$$

$$\sigma = 0.09(\omega_0 > \omega_m)$$

$$\omega_m = 2\pi \times 3.5\left(\frac{g}{U}\right) \bar{x}^{-0.33}$$

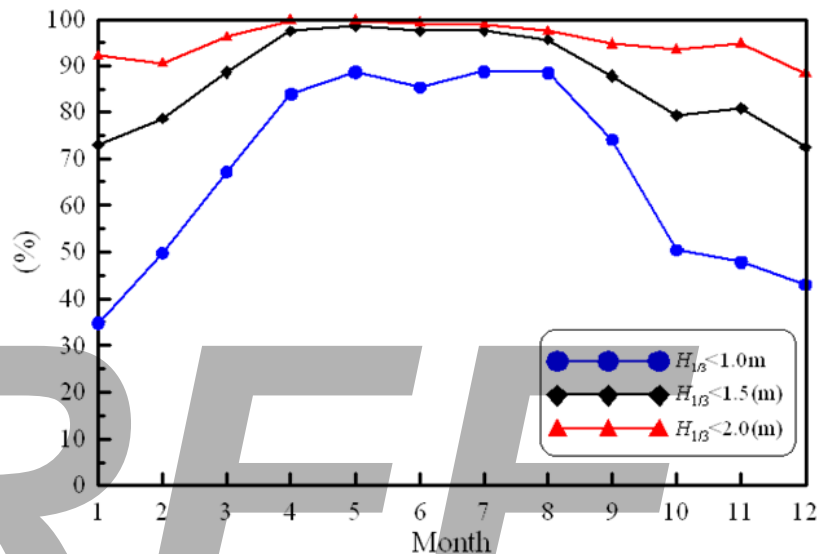
$$\bar{x} = \frac{gx}{U^2}$$

JONSWAP Spectrum



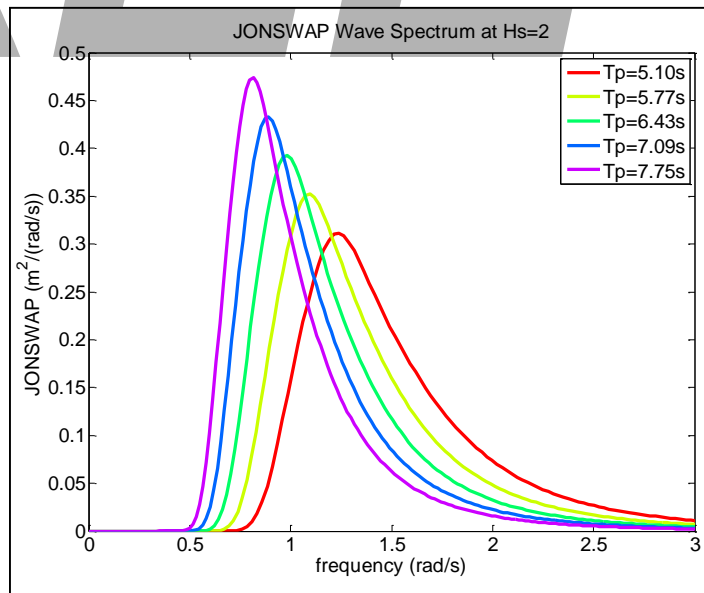
耐海性能分析-環境條件

- 依中央氣象局浮標資料進行相關統計分析之每月示性波高出現機率分佈。



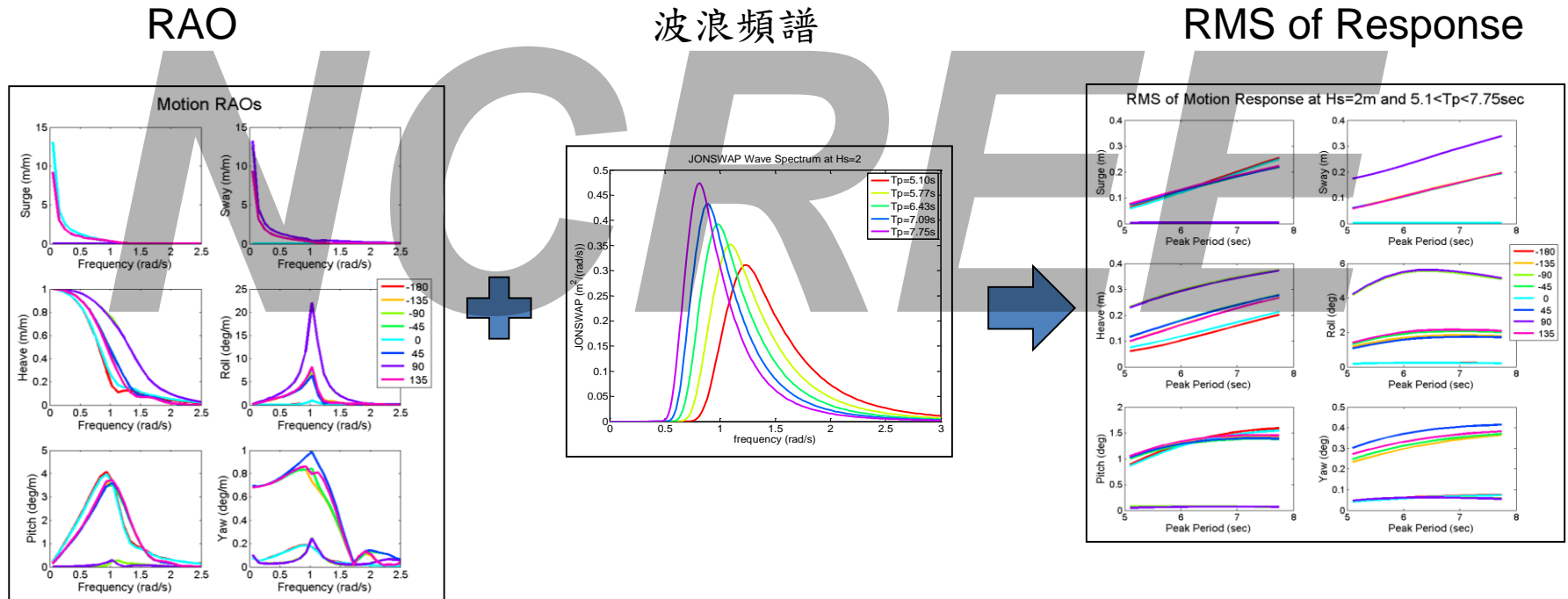
- 以示性波高2m為設計示性波高(H_s)，臺灣夏季(4~9月)即有95%以上時間為可工作狀態。

- 尖峰週期 (T_p)範圍
 - $\sqrt{13H_s} \leq T_p \leq \sqrt{30H_s}$
 - 可得JONSWAP設計波譜



船舶運動響應計算

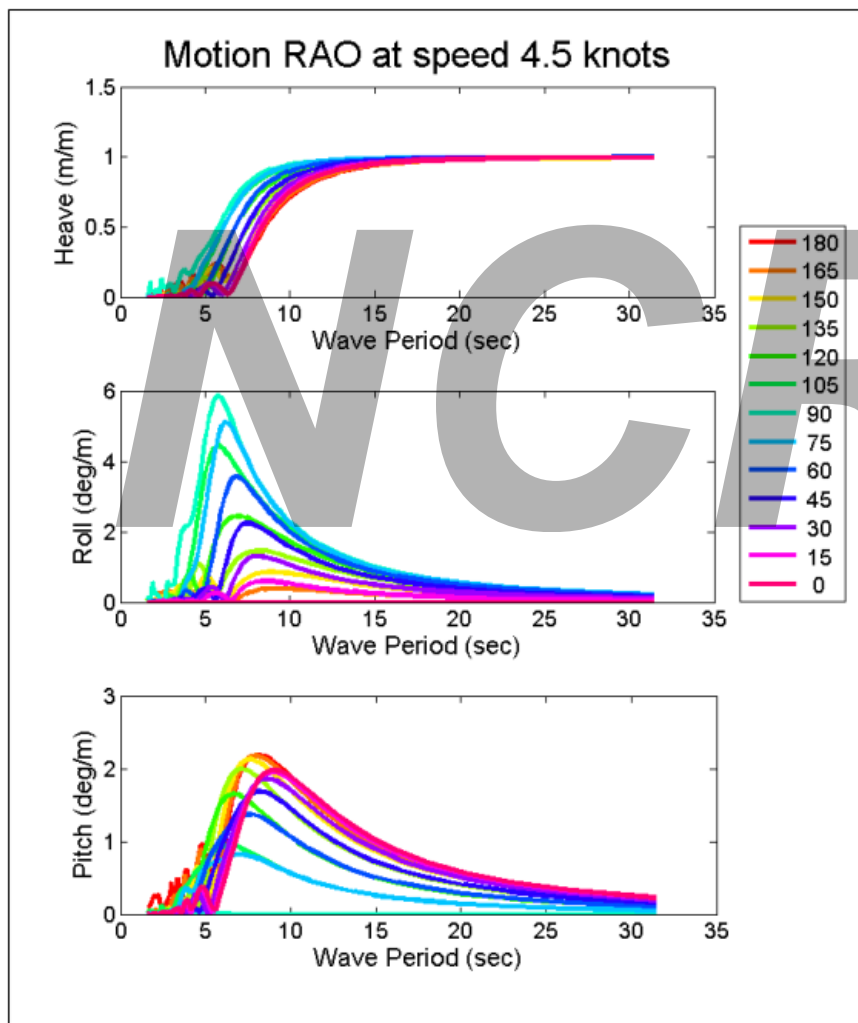
評估駁船之船體運動，經由水動力軟體計算船體之位移與加速 RAO，再與設計海況之波浪波譜結合，求取此海況下之位移與加速度響應。



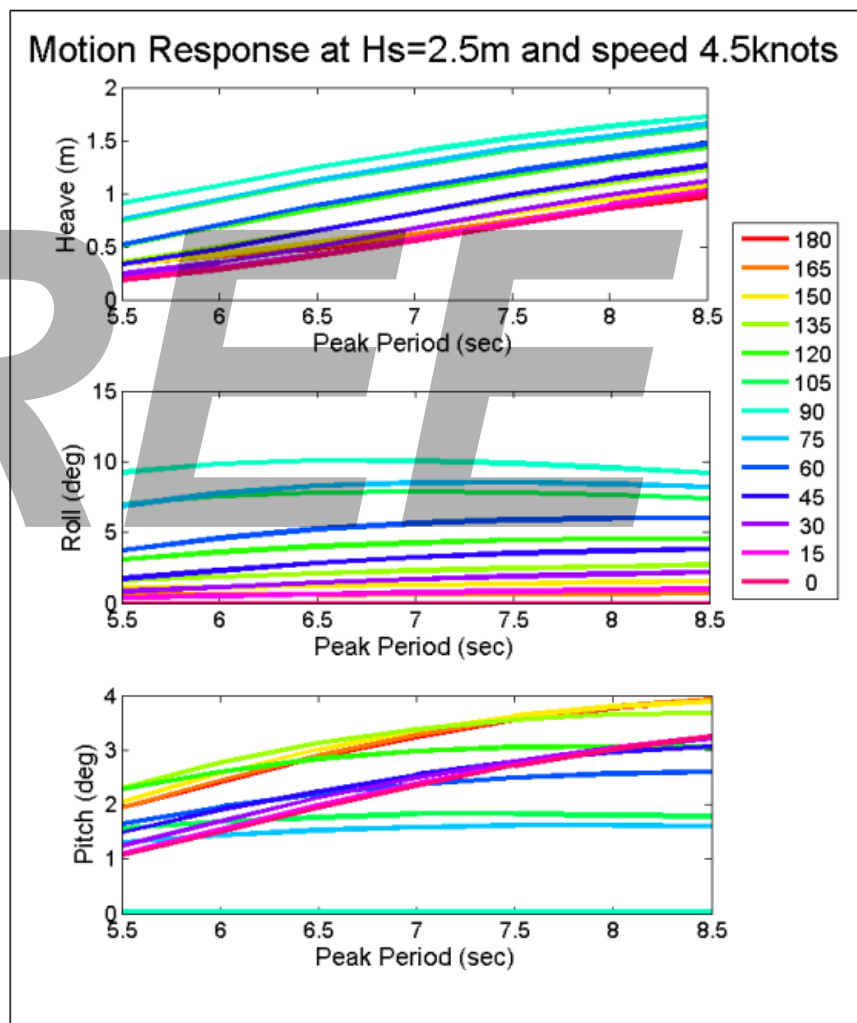
$$\int_{\omega} |\text{RAO}|^2 \cdot S_{\zeta}(\omega) d\omega = \text{RMS of Response}$$

船舶運動響應計算結果

RAO



MPM



耐海性能分析結果

- 無耐海性能分析資料或實驗資料時，GL Noble Denton準則以船舶全長、船寬、方塊係數區分，提供預設運動條件，以進一步計算繫固力分析。以工作船全長81米，船寬32米為例，為橫搖為25度、縱搖為15度且起伏加速度為0.2倍之重力加速度預設值。

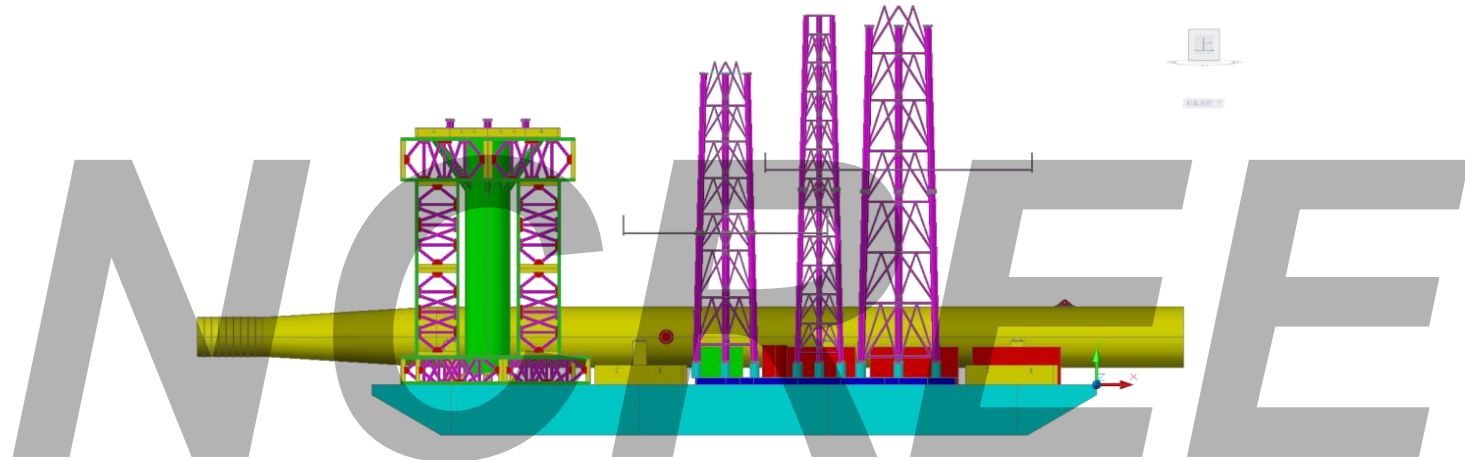
船體運動橫搖(Roll)較船體縱搖(Pitch)大！

計算結果	振幅		起伏加速度 ($g=9.81\text{m/s}^2$)
	橫搖(deg)	縱搖(deg)	
GL-ND準則預設值	20	12.5	0.2
SMP計算結果	10.12	3.95	0.167

- 準則之預設運動條件與耐海性能計算結果相比，預設運動條件為較保守，如使用耐海性能計算可降低準則之繫固力要求，減少繫固成本。
- 運動計算使用SMP(Ship Motion Program)

海事繫固力計算法規定義

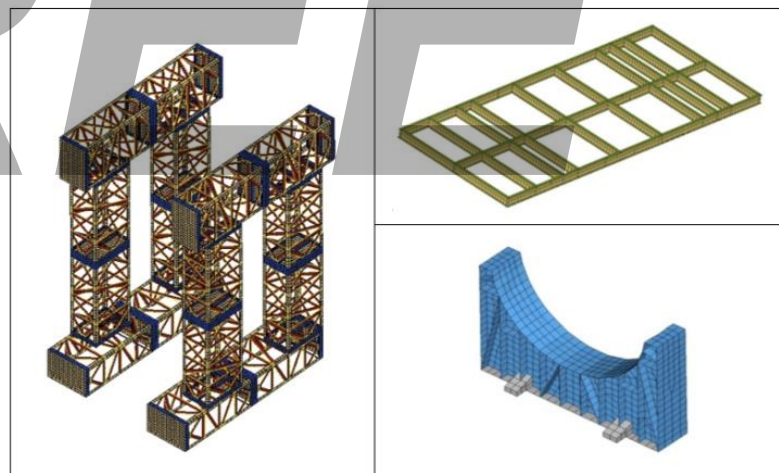
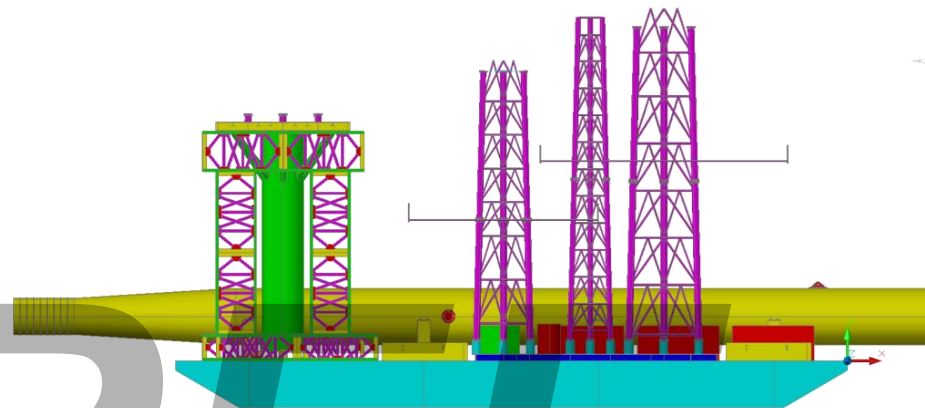
- Roll與Pitch最大值不會同時發生，採用預設值計算時，採用不同組合假設最嚴重的工作狀態為組合共八種的最大值帶入繫固計算。



Load Case	Motion Combination
1	Gravity + Roll(to port) + Heave(downward)
2	Gravity + Roll(to port) - Heave(downward)
3	Gravity - Roll(to stbd) + Heave(downward)
4	Gravity - Roll(to stbd) - Heave(downward)
5	Gravity + Pitch(to stern) + Heave(downward)
6	Gravity + Pitch(to stern) - Heave(downward)
7	Gravity - Pitch(to bow) + Heave(downward)
8	Gravity - Pitch(to bow) - Heave(downward)

繫固力評估

- 各構件所需繫固力
 - 慣性力：由各裝載元件重心座標資料與 GL Noble Denton 預設運動值，計算此運動對裝載元件重心產生之加速度值，再乘上裝載零件重量。
 - 摩擦力。



項目	縱向力	橫向力	單位
基樁	89.861	253.441	[ton]
測風塔-上段	12.092	16.449	[ton]
測風塔-中段	12.22	17.886	[ton]
測風塔-下段	19.056	27.363	[ton]
轉接段	71.527	102.411	[ton]

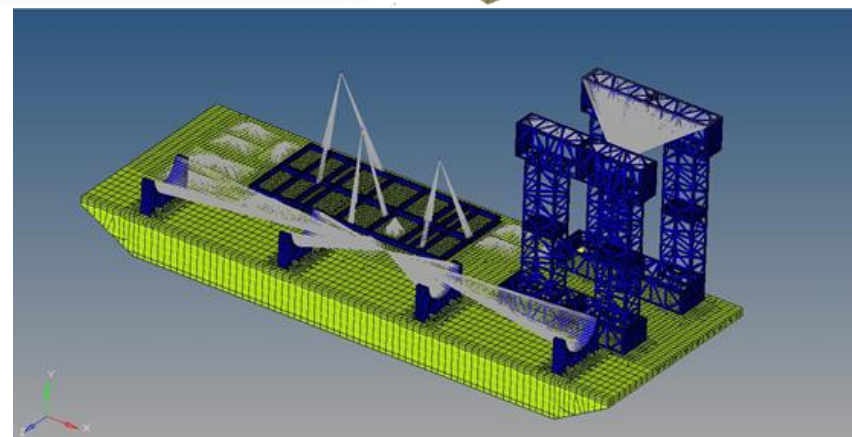
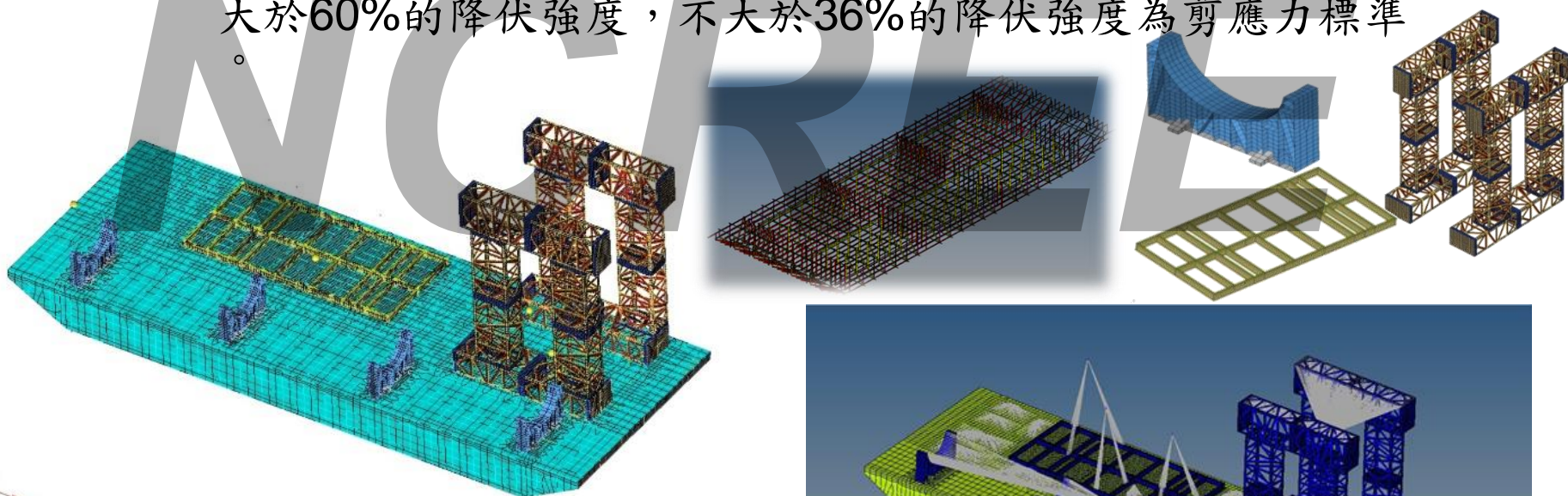
繫固結構分別為支撐轉接段之6米墩 (圖左)、與塔架焊接之Skid (圖右上)、支撐基樁之樁架(圖右下)。

水動力及法規預設值繫固力計算比較

法規及水動力繫固力計算值			
繫固力	GL-ND法規計算 (非氣候限制條件)	水動力模擬分析	相差比值
項目	Transverse [t]	Transverse [t]	法規/水動力
Pile	253.441	146.71	1.73
測風塔-上	16.449	3.841	4.28
測風塔-中	17.886	4.856	3.68
測風塔-下	27.363	5.502	4.97
配重塊1	26.943	18.673	1.44
配重塊2	25.273	18.673	1.35
配重塊3	26.288	18.726	1.40
配重塊4	26.943	19.074	1.41
配重塊5	25.273	19.074	1.32
配重塊6	26.288	19.127	1.37
TP	102.411	25.022	4.09

結構分析評估-建模

- 分析主體為繫固結構
- 支撐結構與全船有限元素模型
 - 甲板上之基樁、塔架、轉接件等裝載元件以集中質量元素模擬，將位置放置於重心上之節點，再連結至各支撐結構及甲板上。
 - 根據AISC鋼結構容許應力法，以最大容許von-Mises應力不得大於60%的降伏強度，不大於36%的降伏強度為剪應力標準。

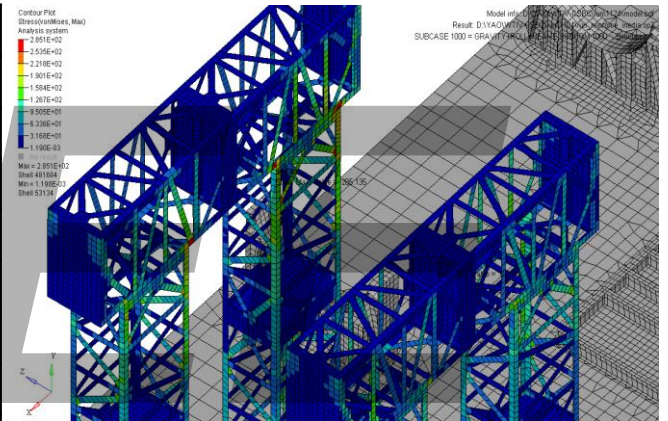


材料	密度 (tonne/mm ³)	楊氏係數 (MPa)	浦松比	降伏強度 (MPa)
軟鋼	7.83E-9	207000	0.3	245

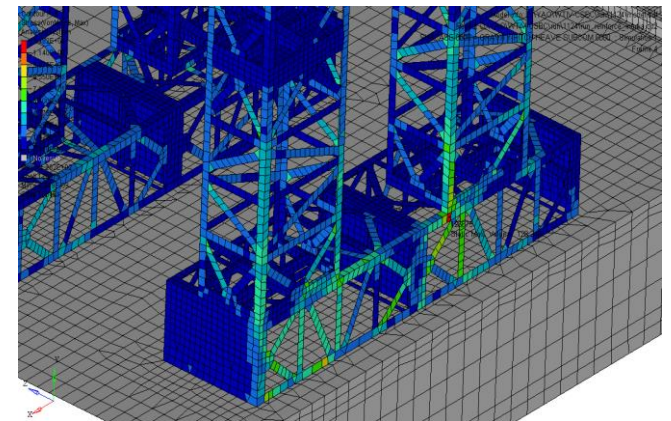
各繫固底座應力分布- 6米墩座

- 最大應力出現在LC1為 285.1 N/mm^2 ，位置坐落在六米墩座交接結構不連續處，除LC8外應力值皆超過容許應力，各case在六米墩座組成單元相接處皆出現過大應力，建議應有適當結構相連以利應力傳遞。

材料	降伏強度	檢核標準	
軟鋼	245 N/mm^2	165 N/mm^2	
各繫固底座應力分布			
六米墩座	補強前計算值	補強後計算值	計算結果
Load Case 1	285.1	需補強	
Load Case 2	217.9	需補強	
Load Case 3	283.79	需補強	
Load Case 4	217.89	需補強	
Load Case 5	254.17	需補強	
Load Case 6	193.33	需補強	
Load Case 7	172.05	需補強	
Load Case 8	128.25	不需補強	ok



Load Case 1



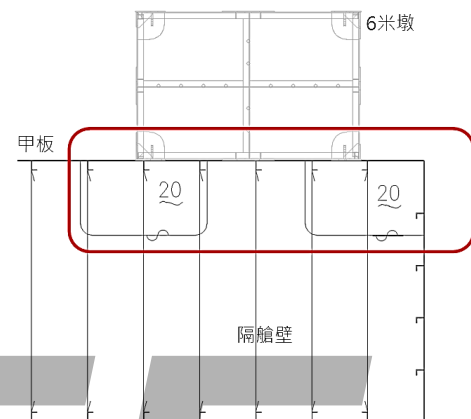
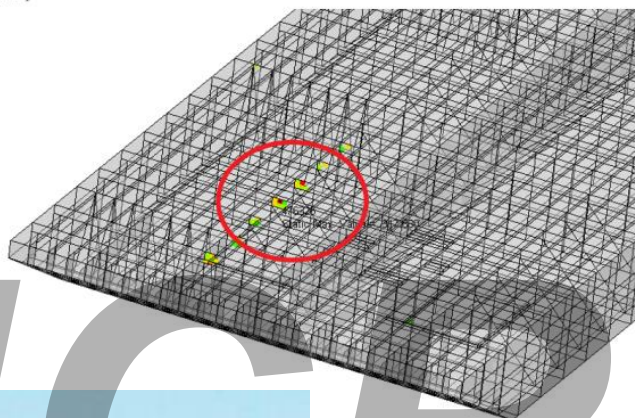
Load Case 8

結構局部補強與運輸作業

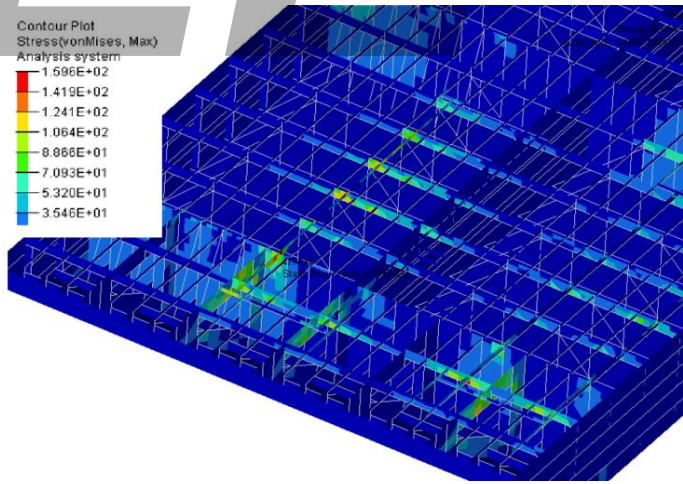
Contour Plot
Stress(vonMises, Max)
Analysis system

- 3.179E+02
- 2.826E+02
- 2.472E+02
- 2.119E+02
- 1.766E+02
- 1.413E+02
- 1.060E+02
- 7.064E+01
- 3.532E+01
- 0.000E+00

No result
Max = 3.179E+02
Shell 476326
Min = 0.000E+00
Shell 297155



補強方法為於相對應之隔艙壁及大肋骨加大板厚寸法

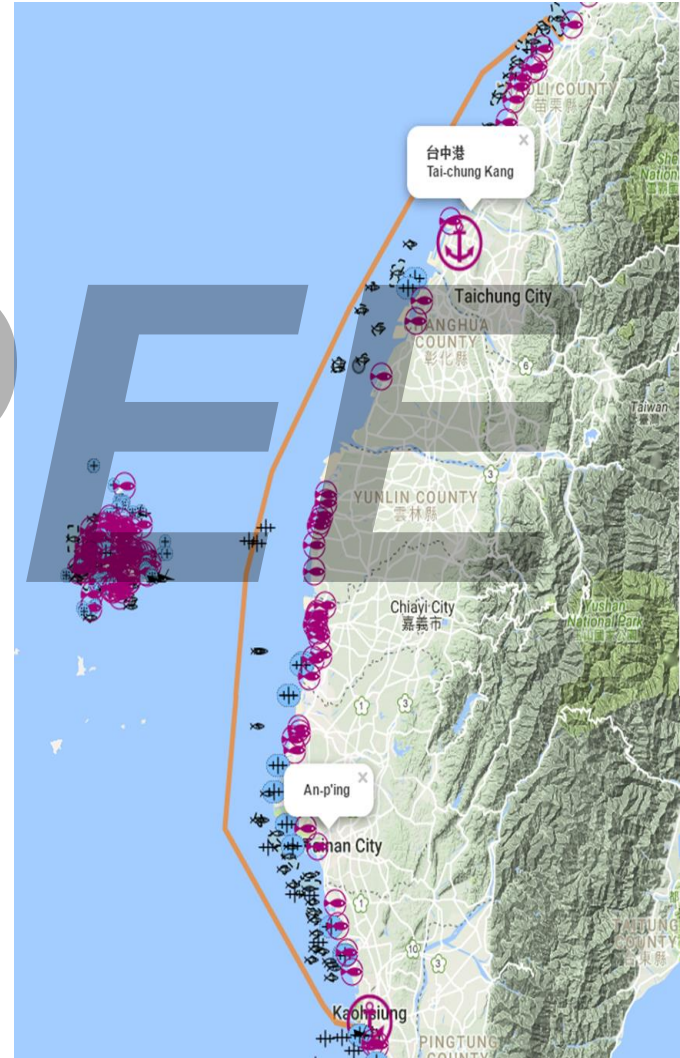


經由補強後之船體已可符合容許應力之要求整體應力分佈！

海纜運輸作業

- 使用船舶
 - 穩晉五號：全長 80 米、具 DP 之佈纜船
 - 拖船
- 運輸路線
 - 滿載狀況下從高雄至苗栗

NCR



拖船拖力與環境條件



風力負荷 F_{wind} : ABS MODU 2016 part 3

波浪力量 $F_{wavedrift}$: DNV-RP-H103

海流力量 $F_{CURRENT}$: Morrison's equation

拖力需求條件 $BP_{effective} > F_{wind} + F_{waveDrift} + F_{curr}$

拖船拖力與環境條件

- 拖船拖力 (Bollard Pull)
(0030_ND)

T_e : Tug Efficiency

- 拖力證書

$$T_e = 80 - (18 - 0.0417 LAO \sqrt{BP - 20})(H_s - 1) \quad \%$$

- 1% of BHP

- $BP_{\text{effective}} = BP * T_e$

F_{wind} : ABS MODU 2016 part 3

$$F_{\text{Wind}} = P A_{\text{wind}} \quad [N]$$

$$P = f V_k^2 C_h C_s \quad [N/m^2]$$

- 環境負荷

- Wind

$F_{\text{wavedrift}}$: DNV-RP-H103

$$F_{\text{WaveDrift}} = \frac{1}{8} \rho_w g R^2 B H_s^2 \quad [N]$$

- Wave Drift

- Current

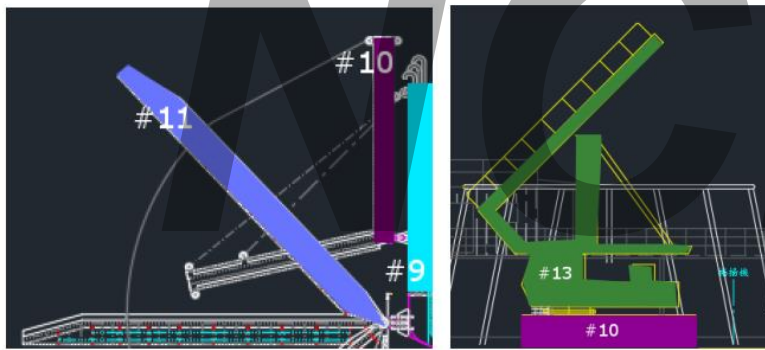
F_{CURRENT} : Morrison's equation

$$F_D = 0.5 \rho_w C_d A_{\text{current}} V_{\text{current}}^2$$

- 拖力需求條件

- $BP_{\text{effective}} > F_{\text{wind}} + F_{\text{waveDrift}} + F_{\text{current}}$

受風面積與風力計算



Item	N	Z0 m	W m	H m	Cs	Ch	Area (m2)	COAZ (m)	F (kgf)	M (kgfm)
Gantry Vertical	4	4.15	1.2	11.15	1.5	1	13.38	9.72	13240.7	137703.6
Gantry Vertical	4	15.30	1.2	11.06	1.5	1.1	13.27	20.83	14445.7	310698.3
Gantry Top	1	26.36	21.07	1.43	1.5	1.1	30.17	27.08	8208.3	227824.3
Deck House 1	1	4.15	10	9.10	1	1	91.00	8.70	15004.0	140635.0
Deck House 2	1	4.15	12.225	6.08	1	1	74.33	7.19	12255.1	96364.3
Deck House 3	1	4.15	18.345	6.40	1	1	117.41	7.35	19358.1	155313.6
Deck House 4	1	4.15	24.205	6.40	1	1	154.91	7.35	25541.7	204925.9
Cable Machine	1	4.15	6.71	4.82	1.5	1	32.34	6.56	7998.8	57857.0
Cable	1	4.15	18.4	1.00	1.5	1	18.40	4.65	4550.6	24224.0
Component	2	4.15	1.05	11.15	1.5	1	11.71	9.72	5792.8	60245.3
Component	2	15.30	1.05	0.85	1.5	1.1	0.89	15.72	483.6	7930.3
Cable Equipment 2	1	2.50	1.243	12.80	1.5	1	15.91	8.90	3936.0	37687.5
Cable Equipment 2	1	15.30	1.243	8.20	1.5	1.1	10.19	19.40	2771.7	55641.4
Cable Equipment 3	1	7.32	1.116	7.98	1.5	1	8.91	11.31	2203.5	26409.3
Cable Equipment 3	1	15.30	1.116	3.70	1.5	1.1	4.13	17.15	1122.3	20004.2
Crane pedestal	1	4.15	7	1.20	1.5	1	8.40	4.75	2077.5	11266.5
Crane	1	5.35	6.35	2.80	1.5	1	17.78	6.75	4397.3	32642.1
Hull	1	0.00	78.17166	4.15	1	1	324.13	2.07	53442.3	146966.2
Total										1754338.8

N = Amount of items

Z0 = Distance from waterline to bottom of item

W = Width of item

H = Height of item

Cs = Shape Factor

Ch = Height factor

Area = the wind area

COAZ = center of area

Alpha Factor

Table 7-3 Forecast Requirement Classes

Forecast Requirement	A1	A2	B1	B2	C
Wave Alpha Factor	Table 7-8	Table 7-7	Table 7-6	Table 7-5	Table 7-4
Wind Alpha Factor	Table 7-9				
For weather sensitivity	HIGH	MODERATE		LOW	
Typically required for the following examples. (These may vary depending on the value of the structures and complexity /weather sensitivity of the operations)	Major , e.g. Mating Offshore float-over Offshore installation GBS Float-out or tow	Significant , e.g. Offshore lifting Subsea installation Sensitive barge towing Jack-up move		Routine , e.g. Inshore /onshore lifting Load-out (without tidal restrictions) Standard towage	
Dedicated meteorologist	YES		Not required [1]		Not required
Meteorologist on site	YES	NO	Not required		Not required
Environmental monitoring & feedback to meteorologist	YES	NO	YES	NO	Not required
Independent weather forecasts required [2]	2	2		1	

Alpha Factor

Table 7-5 Alpha Factors for Waves - Forecast Requirement B2 (Moderate Sensitivity)

Operation Duration	Operational Significant Wave Height (No monitoring)			
	Hs < 1 m	Hs = 2 m	Hs = 4 m	Hs > 6 m
< 12 hours	0.61	0.71	0.74	0.75
< 24 hours	0.59	0.69	0.71	0.73
< 36 hours	0.58	0.67	0.69	0.71

Table 7-9 Alpha Factors - Wind (all Forecast Requirements)

Operation Duration	Design Wind Speed (V_d)	
	$V_d < 0.5 \times V_{10 \text{ year return}}$	$V_d > 0.5 \times V_{10 \text{ year return}}$
< 24 hours	0.71	0.76
< 48 hours	0.67	0.71
< 72 hours	0.62	0.67

$V_{10 \text{ year return}} = 29.38 \text{ m/s}$

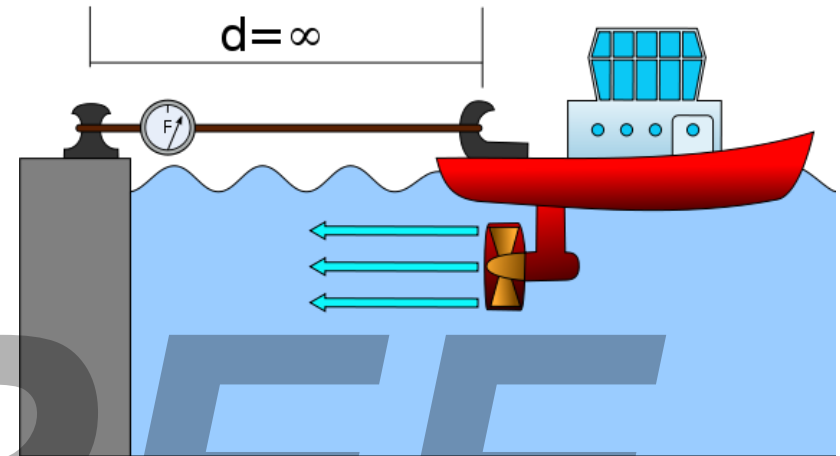
符合拖力標準之環境條件

- H_s : 實際作業之示性波高
- αH_s : 天氣預報之示性波高

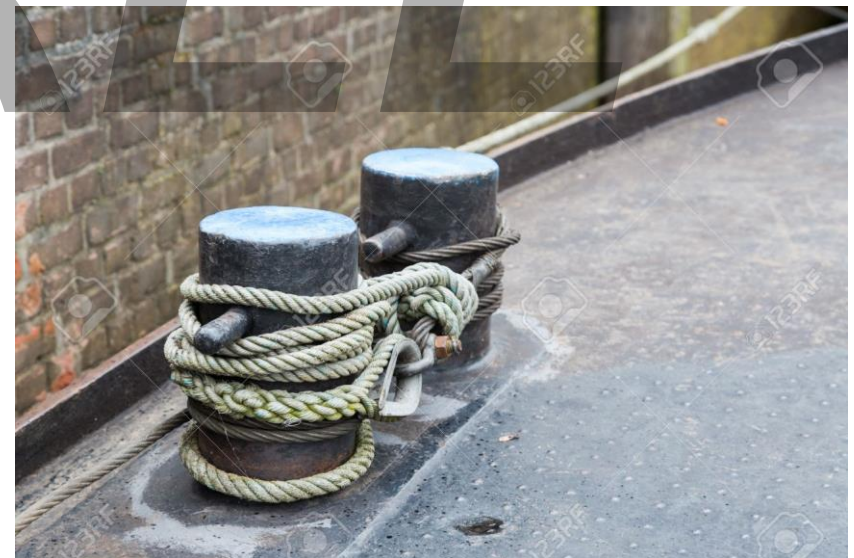
			V_{wind}	10	11	12	13	14	15	16	17	18	19	20	21	22
			α	0.67	0.67	0.67	0.67	0.67	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71
			αV_{wind}	6.7	7.37	8.04	8.71	9.38	10.65	11.36	12.07	12.78	13.49	14.2	14.91	15.62
H_s	α	αH_s														
1	0.61	0.61	5.76	6.46	7.23	8.07	8.97	9.95	10.98	12.09	13.26	14.50	15.81	17.18	18.62	
1.1	0.589	0.6479	6.14	6.85	7.62	8.46	9.36	10.33	11.37	12.48	13.65	14.89	16.20	17.57	19.01	
1.2	0.598	0.7176	6.57	7.27	8.04	8.88	9.78	10.76	11.79	12.90	14.07	15.31	16.62	17.99	19.43	
1.3	0.607	0.7891	7.03	7.73	8.50	9.34	10.24	11.22	12.25	13.36	14.53	15.77	17.08	18.45	19.89	
1.4	0.616	0.8624	7.52	8.23	9.00	9.84	10.74	11.71	12.75	13.86	15.03	16.27	17.58	18.95	20.39	
1.5	0.625	0.9375	8.06	8.76	9.53	10.37	11.27	12.25	13.28	14.39	15.56	16.80	18.11	19.48	20.92	
1.6	0.634	1.0144	8.63	9.33	10.10	10.94	11.84	12.82	13.86	14.96	16.13	17.37	18.68	20.05	21.50	
1.7	0.643	1.0931	9.24	9.94	10.71	11.55	12.45	13.42	14.46	15.57	16.74	17.98	19.29	20.66	22.10	
1.8	0.652	1.1736	9.88	10.58	11.35	12.19	13.10	14.07	15.11	16.21	17.39	18.63	19.93	21.31	22.75	
1.9	0.661	1.2559	10.56	11.26	12.04	12.87	13.78	14.75	15.79	16.89	18.07	19.31	20.61	21.99	23.43	
2	0.67	1.34	11.28	11.98	12.75	13.59	14.50	15.47	16.51	17.61	18.78	20.02	21.33	22.70	24.15	
2.1	0.671	1.4091	12.03	12.74	13.51	14.35	15.25	16.22	17.26	18.37	19.54	20.78	22.09	23.46	24.90	
2.2	0.672	1.4784	12.82	13.53	14.30	15.14	16.04	17.01	18.05	19.16	20.33	21.57	22.88	24.25	25.69	
2.3	0.673	1.5479	13.65	14.36	15.13	15.96	16.87	17.84	18.88	19.99	21.16	22.40	23.71	25.08	26.52	

拖力其他檢核項目

- 在拖船拖力下強度評估
 - 纜繩(Towline)
 - 卸扣(Shackle)
 - 繫船柱(Bollard)



https://upload.wikimedia.org/wikipedia/commons/thumb/6/6d/Bollard_pull_idealized-2.svg/568px-Bollard_pull_idealized-2.svg.png



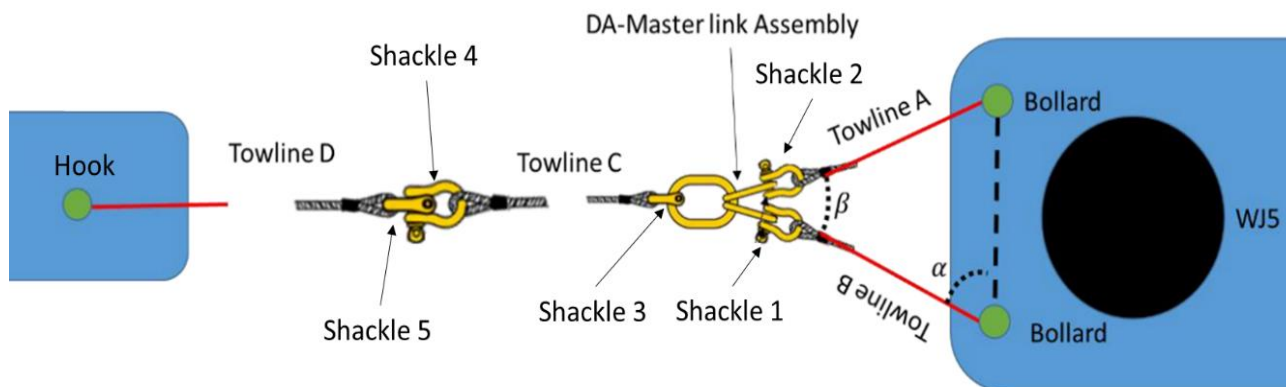
<http://previews.123rf.com/images/kruwt/kruwt1208/kruwt120800023/14677090-Rope-tied-to-steel-bollard-on-ship-deck-Stock-Photo.jpg>

拖力其他檢核項目

- 需求斷裂負荷(Required Breaking Load)
 - RTBL > 2BP
 - Towline(拖纜) MBL > RTBL
 - Shackle(卸扣) MBL > 1.3×RTBL
 - Bollard(繫船柱) MBL > 1.25×RTBL



	Comparison	Value
Towline C MBL>RTBL	89.1t>57.6t	TRUE
Towline D MBL>RTBL	110t>57.6t	TRUE
Shackle 1,2,3,4,5 MBL>1.3×RTBL	35 x 6 > 74.9t	TRUE
DA-master link assembly MBL>1.3×RSBL	38.3*5t>97.34t	TRUE
DA-master link assembly a > Shackle Pin Diameter	285mm>57mm	TRUE
DA-master link assembly b > Shackle Pin Diameter	155mm>57mm	TRUE
Towline hook	50 x 5 > 72t	TRUE
Bollards Min () > 1.25 x RTBL	72.17t > 72t	TRUE



- 前言
- 安全評估項目
- 案例說明
 - 永傳海氣象觀測塔運輸
 - 上緯海纜運輸
- **結論**

NORRE

結論

- 依循國際**海事保證鑑定**準則需求，建立相關**安全評估技術**，以提升國內海事工程作業安全性，並符合保險融資需求之風險標準。
- **穩度安全評估**由**IMO**與**GL Noble Denton**標準檢驗穩度要求，並藉由基樁先行裝載測試得知，在重量資料準確下，本評估方式能確實計算出穩度傾角。
- **耐海性能計算結果顯示預設運動條件較為保守**，可持續累積經驗，提升與驗證耐海性能計算可靠性，逐步使用耐海性能計算取代預設運動條件，可降低後續之繫固力計算要求，減少繫固成本。
- 實際作業中，氣象預報資料愈準確，**Alpha Factor**(為考慮氣象預報與實際差距之衰減因子)可採用較大之值，以增加 weather window。

敬請指教

