

## TIDAL TURBINE FOUNDATION OPTIMISATION RAMBOLL ENERGY - RORY SINCLAIR



### **Presentation Contents**

- Introducing Ramboll
- Tidal Turbine Foundations
- Our Experience with Fatigue in:
  - Gravity Bases
  - Floating
  - Bottom-Fixed (Jacket/Monopile/Duopod)
- Looking Ahead
- Summary



INTRODUCING RAMBOLL

### **INTRODUCING RAMBOLL**

- Ramboll: leading engineering consultancy company founded in Denmark in 1945
- Today, we employ more than 13,000 expert engineers and consultants

- 300 offices in 35 countries
- EUR 1.1 billion revenue
- Owned by Ramboll Foundation





### **INTRODUCING RAMBOLL**

- O&G employees began first offshore wind project in 2001
- Since then...70% of <u>all the world's</u> offshore wind turbines now rise from foundations engineered by Ramboll
- Separate wind/tidal department set up 10 years ago
- 5 offshore offices: Denmark, Germany & UK
- London office next to waterloo











## TIDAL TURBINE FOUNDATIONS

### **TIDAL FOUNDATIONS**

- Tidal energy faces huge challenges:
  - Installation costs
  - High current speeds
  - Rocky seabed
  - Uneven seabed
  - Limited access
- At present foundations are trials and so are not suitable for mass production
- The next stage is a repeatable structure













### **TIDAL FOUNDATIONS**

#### General Comments

- Progress your foundation design at earliest opportunity
- Design for fatigue, don't make it an afterthought
- Hire specialists if experience is not in-house
- Installation and foundation design are intertwined











### **TIDAL FOUNDATION CONCEPTS**



### **CONCEPT ELIMINATION PROCESS**

#### Early-stage study of risk, cost and schedule

	- Cristina		13		1	12													
- 1					-11	1	-												
-		TO LET	contractor installed to be	BUC 1	test in the start		1.00												
			Carden and Andrew Contractor													-			
		TRACTOR OF THE OWNER	Contractor and in the lot of	-	ST COL	discussion in the second secon		ine .	THE PARTY OF	In Address of	man's suffrage (1)		THE REAL PROPERTY AND	-	increase.				
- 1		10000	and a contract of the local day of the	and the second second						01.846		-		Louis in	-				
			Carrow Carlot of the	Statistical and	an lower a	CARLANE			Lat	1.04	1000	3428	12508 1240 ML/01 15-08	Linuan In	Sector species (Sectors used and	-	1000 - 11 00 0 - 11		President and
-	Station in the	A	Careford Contraction of the local division o		tes for the	el nutral administrativa degrado		48	1.00	1.08	10,040	1008	HUM MAR		Tait New .	OV atter	201 200	104V 2012 200000000012121110020	1000 1001 1001 1001 1000 1000 1000 100
- 1			Conception of the last of the last			ntar Altimat			1.00	1.06	11380	1100	542-041 (6.30) 8,400	- 10	EP served - Paul metalled per pile solices skill		15/79/12 Wed 25/79/12	lav.	
- 3	Contraction in the	AND DESCRIPTION OF TAXABLE PARTY OF TAXA	Carlos and	100000-	and particular a	ni neu min				108	- 200	10.00	2500 UP	-	Multilication Installation 1	3 days	Max 03/07/13 Set 07/07/13 Set 03/07/12 Set 10/07/12	-	
- 1			Contraction of the local division of the loc	Based Columnity		Con Reduced								Lat	Stolog foundation template and d	# 12 911	Set 07/07/12 Set 07/07/12		
- 1			Construction of the local division of the lo	Same	an brandt	Color Brouge	1	181	-	138		_	200	10	Orling 1	12.80	Set EVENUE See 06/07/12	-	
			143/4010 W 11 10 10	and state of		TIP Y Sylving ratio Sultane:		8	100		-14		305.46 3.400 305.46 1.00		Access Intil	6 hrs	Sun 88/07/12 Sun 86/07/12	4	
I.			TRUNCTOR OF A TAXABLE PARTY	STATISTICS.	we have been a	Politica.	1	1	- 12	Det	Law		- <u>68</u> - 17	18	Grouing	24.95	Sar-08/07/12 Man.08/07/12	7	
- 1		Services.	CATALON W WIND W	Provide La		Contracting and an article			- 16	-			1007	-	Graphicy drift to res. 3	610	Sar 68,00013 Sar 08,00713	4	
- 4	1111 C	with the second	Concentration of the law of the l	Contraction of the local division of the loc	and burnleft	Construction International Academic State		8		- 15			- 200	1	Asscret & E	12 104	Man 09/00/23 Man 09/00/23	2	
	All have at some	Sold Party Sector	A MORTHUM PRIME OF THE	- Inguistance	an hander	A DAY BOLSON REAL STREET, CO.		181-	- 10	- 2			100	32	<ul> <li>Insert prophetic</li> <li>Growther</li> </ul>	Girs .	Man 09/07/12 Tan 35/07/12 Man 09/07/12 Tan 35/07/12	4	
and the second second	The second second	CTOPINST'	The last diversion of the Party	I I I I I I I I I I I I I I I I I I I	THE LET	icade -				-	- Lun	145	1.00	34	Deploy drill to res. 3	oho	Ter 10/07/12 Ter 10/07/12	1	
·	Sector Sector	Married T		A DECK THE PARTY		n Ann Inte		-	1.00	100	TOR	10.00	18.00 8.00	7.6 34	Onling 8 Answer Anli	12 hrs	Tae 10/00/12 Tae 10/00/12 Tae 10/00/12 Wed 11/00/12	*	
- 1		·	To My Copy work I TO TO TO	Same and the second		ant. Collegenter		-	100	10	1,000		A.M. 100	1 21	insert propile.	útm.	Wed 11/07/12 Wed 11/07/12	1	
- 1			THE OWNER OF THE			and the second s		-	18	- 10			100	10	Grouping Recapily from barge in Justicest	10 km	Weil20011 16120011		
			effetter tetter bei bei	and and a set		uning Tanah Aprilansa Sel	-		48	10		-	21,000		Incident V	415.64		-	
COLUMN 1	ALL DO NOT THE	CALCO V. G	12712121000 W 10 W 17	CONTRACTOR	all and	1 Trans		-	÷.	1.54	tie		100	11	installation 3	6.15 fire	The 18/87/12 Wed 15/97/11	-	-
			Maria and a state of the second state of the s			(NetFirst					.80	1	1 7		Installation 4	6.15 day	Weil 25/87/13 Weil 03/88/12 Weil 03/88/12 Tax 07/98/12		
			Carlos and		and to all 1	Town of land, which Timps, critics	1		-17	100		10.0	10.01 (0.01		Installation &	6.35 day	Tee 03/08/12 Man 13/06/12		
	Area carrier	THE CONSTRUCTOR			ALC: 100 100	Course of the second	1	1	14	14	100	Test		182	Installation 7 Installation &	6.15 day	Man 18/88/12 San 38/88/12 San 18/88/12 San 36/88/12		
1000			and the second s			Contraction of the Party of the	1		_		100		1 75		installation 9	6.15 649	San 35/28/13 Sat 00/99/12		
			STREET, STREET, ST.	HI	an praid	Number of Street			-	10,000	1.64	124	8.00 1.00	100 ptc	Denublication	J.15 day	Thu 06/09/12 Sut 08/09/12		
- 1			THE REPORT OF THE PARTY OF THE	1 manual and	and a series	CALCULATION	1	12	14	City	12	1/2	24.00 LOD 24.00 LOD		Saving 5des street time	414 005	Set 05/09/12 Wed 15/05/12		s
-	State Statement	Contrast of	Two are 1 - primiting	TTT I	THE T - THE	unity Courteer		-	20	1.54	1.00	1.06	75.48 LNE 75.49 LNE	15		0.000	*	4t.1	
	and the state of t	and the second	MARTIN TO THE O						16.05	86,891	14,46	tal.an	Laborat Values	-					
Statement of the local division of the local	CALCO.	Contract of	Construction of the lot of the lo	and the second second			-				•		1.55	- internal					
-	wine set	AND DESCRIPTION OF	ACCOUNTS OF A DATE OF	Contrast states			100												
							1000												
	the string weak start	other states	Contraction of the local division of the	Brank attac		-	100												
	at fright.	Toronaum.	1100 100 101 10 No. 1 DK 11	CONTRACTOR OF STREET	an n 100		-												
	Station and	ALEAS	STraves a set		ALL ALL DR.		100												
		-	CONTRACT BEI FIRE F			-	-												
-	THE LOCK		Contractor of the second	-			-												
R. 1	HALL NO.	a section	COLUMN TWO IS NOT	101		-	-35												
-	Carlo and	WEITer.	22	Place Weighting	EI - 10-14		-												
				and the second se															



## **GRAVITY BASE**

### **GRAVITY BASE**

#### Problems:

- Substantial ballast mass required v. expensive
- Carbon footprint large for ingots of steel/concrete
- Sensitive to seabed slope
- Bathymetry of tidal sites rarely flat







# FLOATING

### **FLOATING**

#### Pro's:

- Removes significant installation cost hugely attractive solution economically
- Obvious O&M benefits

#### Other Thoughts:

- Still requires fixation by seabed anchor or rock socket (fixed)
- Introduces additional complexity:
  - Dynamic platform impact on turbine efficiency
  - Dynamic export cable
  - Additional spacing requirements due to cables







# MONOPILE

### **MONOPILE – DESIGN**

#### <u>General</u>

- Simple design, proven concept
- Simple fabrication, weld automation

#### Fatigue Considerations

- Material thickness/diameters governed by fatigue
- ULS utilisation ratios are low
- No fatigue sensitive joints
- Pile diameter at upper limit of drilling capability...





### **MONOPILE - INSTALLATION**

#### Subsea Drilling

- Most tidal sites have rock ground conditions this requires drilling
- Current drilling diameter limit of ~ >2.8m (installed pile less than that)
- For 1MW+ device, MP's may struggle to work in fatigue at this diameter





### **MONOPILE - INSTALLATION**

#### Topside Drilling

- No such diameter limits BUT requires a stable platform e.g. a jack up barge:
  - Successful application of jack ups in tidal races is limited (stability & VIV issues)
  - Jack up owners reluctant to deploy in tidal races
  - Susceptible to weather downtime
  - Expensive day rates
- Bottom line:
  - If "no" to jackups → it's a "no" to topside drilling
  - For  $1MW + \rightarrow$  very possibly a no to MP's







### **MONOPILE – A REVIVAL?**

#### Updated Scale Effect

- SN curves derived using test plate thickness 25mm
- Scale effect used to account for actual plate thickness (basically a factor applied to the stress term)
- Formulae changed to depend upon weld width









### **MONOPILE – A REVIVAL?**

#### Updated SN Curves

- Current SN Curves:
  - Based on decades old research
  - Questionable representation of modern materials
  - Questionable representation of advances in modern fabrication techniques
  - Questionable representation of current member geometries (7m + diameter!)
- Structural Lifetime Industry Collaboration (SLIC):
  - Joint-industry project
  - Develop the existing SN curves
  - New testing being carried out using modern materials/practices/geometries
- Potential for improvement in fatigue performance of MP (or otherwise...)



### **MONOPILE – VIABLE?**

#### Summary:

- Current diameter restrictions severely limits application of the MP
- < 1MW devices (prototype?) likely to be viable
- > 1MW devices potentially going to have fatigue issues
- Codes are changing as we speak, FLS failure not necessarily the case in the future...
- If MP's can be made to work in fatigue with OD limits they may be 'the solution'





### DUOPOD

- Significant reduction in pile diameter due to:
  - X2 load paths to support (soil)
  - Forces are more 'axial'
  - Capacity of soil to 'take' axial load greater than lateral load
- Problems:
  - Joints introduced suddenly much more complicated for fatigue
  - If significant out-of-plane bending loads at joints fatigue issues
  - More expensive to fabricate than MP
- Are there better solutions?







### **TRIPOD**





- Main advantage of duopod without going all the way to a jacket
- 3<sup>rd</sup> leg reduces out-of-plane bending forces in joints
- Potentially thinner sections than with duopod
- Advantage of on-bottom stability
- More expensive to fabricate than MP
- The solution we often settle upon



### **JACKETS**

#### Key Points

- Lever arm to load not sufficient to 'require' a jacket
- Multiple piles -> increased installation complexity
- Lots of members -> fabrication complexity & cost (very much)
- Probably not the economic answer
- May be deployed at deeper water sites in future





# LOOKING AHEAD

### **Super-Elements & Influence Matrices**

• Simple Beam Element Model (BEM) simplifies stiffness @ joints (below left)



- Local Joint Flexibility (LJF) introduced at simple joints as more accurate representation of joint stiffness
- Involves insertion of offset (very stiff element) and a spring to model joint stiffness
- EFTYMOI parametric equations empirically derived to determine LJF
- Generally (though not always!) results in improvement in fatigue performance



### **Super-Elements & Influence Matrices**

- Equations are not suitable/reliable for complex joints e.g. offshore substation girder joint
- We use super-elements instead!
- What is a super-element:
  - We create accurate model of our complex geometry in FE software
  - Extract stiffness & mass matrix and insert into same old (simple) beam element model
  - Seamless integration with BEM software





### **Super-Elements & Influence Matrices**

- Influence Matrices:
  - Relates forces in simple BEM with forces inside the super-element 'black box'
  - Basically a large matrix of numbers
- A few years ago influence matrices mainly used in very complex joints
- Their use is no-longer exceptional:
  - We're now inserting influence matrices wherever we see a benefit
  - Even within applicability limits of EFTYMOI equations
  - Getting joints to 'work' that we just couldn't get working





## SUMMARY

### **Summary**

- Foundation design and installation intertwinned, foundation design impacts installation – a major project cost driver
- Tidal foundations are almost always governed by fatigue
- There is no one foundation solution, we don't subscribe to the 'universal foundation' concept:
  - When you progress a detailed design at array scale, one size fits all isn't economic
  - Turbine & site-specific variables easily justify expense of optimised foundation
  - Cluster foundations at array scale
  - Our fee is negligible  $\ensuremath{\textcircled{\sc o}}$

















