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Publication date:
1990

Document Version
Tidlig version også kaldet pre-print

Link to publication from Aalborg University

Citation for published version (APA):
Jensen, J. L. (1990). *Full-Scale Measurements of Offshore Platforms*. Dept. of Building Technology and Structural Engineering, Aalborg University. Fracture and Dynamics Bind R9002 Nr. 17

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AALBORG UNIVERSITETSCENTER · AUC · AALBORG · DANMARK

FRACTURE AND DYNAMICS
PAPER NO. 17

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FULL-SCALE MEASUREMENTS OF OFFSHORE PLATFORMS
JANUARY 1990
ISSN 0902-7513 R9002

Full-Scale Measurements of Offshore Platforms

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Abstract

This paper is an extract of Jensen [49] and has been made since the contents may be of general interest when the dynamic properties of offshore platforms are considered.

During the seventies and the eighties the number of performed measurings and subsequent system identifications increased with the explosive increase in the number of offshore platforms. A survey has been performed to obtain information about how system identification is performed in practice and what practical results have been obtained. The survey includes offshore structures which have been experimentally investigated during the seventies and the eighties in international journals and conference proceedings.

An extensive survey of the available literature on the topic has been performed on the basis of more than 40 references corresponding to the experimental investigation of 34 offshore platforms. The number of investigated platforms is no doubt much larger, but a lot of the obtained information is not publicly available. E.g. the major part of all Norwegian platforms is instrumented due to authority regulations, but the number of references on those has been limited.

The performed survey is believed to reveal the typical results which can be expected from a system identification. It has not been possible to give an extensive final conclusive comment on the survey because the purpose of each instrumentation and analysis has been varying. The quality and quantity of the available references have also been very different, and furthermore, the presentation of the practical experiences varies considerably in form.

The survey has resulted in two sets of tables, the first set, tables 1 to 3, concerns the instrumentation and general information while the second set, tables 4 to 6, deals with the performed system identification methods and the obtained results. The two sets of tables are closely related but it has been necessary to divide the results of the survey into two sets of tables due to practical considerations. Anyway in the following, section 1 contains comments on mainly the first set of tables while the second set of tables is considered in section 2. A general discussion on the estimates of eigenfrequencies and damping ratios is given in sections 3 and 4, respectively.

1 The Performed Measurings: Tables 1-3

In tables 1a and 1b the performed instrumentations of jacket structures are given, and in table 2 and 3 the reported instrumentations of gravity and other platforms types are shown. The latter includes monopiles (monotower, tripod etc.) and different sorts of hybrid platforms. The typical instrumentation consists of $10 - 20$ sensors which measure the ambient excitation and the response due to ambient excitation.

The first column of the tables refers to the instrumented structure, the name of the structure, the number of legs in the case of jacket structures, the water depth and the location of the structure are given. The locations considered are mostly the North Sea and the Mexican Gulf.

The second column refers to the period in which the structure has been instrumented. From the references attempts have been made to determine whether the structure is permanently instrumented or whether it just includes a short period. Permanent platform instrumentation is typically due to authority regulations while short periods often are directed in relation to research projects organized in joint industrial and research programmes. A short period may mean just a couple of days.

The third column gives the reported ambient excitation H_s for which measurements have been analyzed and also tells whether an external excitation has been applied. The ambient excitation is the most frequently applied excitation source for the measured response since it is cheaper than applying an external excitation. Furthermore there will always be an extra risk with respect to the structural integrity when external excitation is applied.

The fourth column gives information about the sensors applied, the numbers and the principal types. This information is quite uncertain due to unprecise references. The following abbreviations have been applied:

- acc: accelerometers.
- mov.acc.: movable accelerometers.
- vel: velocity transducers (geophones).
- displ: displacement transducers.
- str.gau.: strain gauges.
- memb.forces.: strain gauges set-up to measure member forces.
- shock.tr.: shock transducers (typical for the response due to wave slamming).
- pres.trans.: pressure transducers (wave load).
- curr.m.: current meter.
- anom.: anometers (wind).

Structure / Water Depth	Instr. Period	Ref.	H_s / Excitation	Sensors	Data Rec.	Comment
West Sole WE,4 legs 25m, N.Sea (UK)	1978 Aug	1	0.67m ambient	16 acc.	A	removal of struct. subj:damage detect.
Ekofisk, 8 legs 70m, N.Sea (N)	1979 Jun	2	1-2m ambient/ exciters	4 points acc,str.gau.	A	authority requirements /research
Ekofisk 2/4H,4 legs 70m, N.Sea (N)	1980-83	3	11.3m ambient	10 acc. 84 str.gau. wave radar etc	D+A	authority requirements
Valhall QP,4 legs 70m, N.Sea (N)	1980-83	3	10.8m ambient	?	?	
Frigg DP2, 8 legs 98m, N.Sea (N)	1978- permanent	4,5	1-13m ambient	8 acc str.gau. wave-radar	A+D /research	authority requirements
SP65A, 8 legs 103m, Me.Gulf (US) SP62C, 8 legs 103m, Me.Gulf (US) WD152A, 8 legs 124m, Me.Gulf (US) Eugene Island 331B, 8 legs, 82m, Me.Gulf (US)	1975-76	6	2-3m ambient/ Snap-Back /Impulse	acc. vel. wave staff water particle velocities were measured	A	research for ambient as well as forced excitation
MP296A , 8 legs 71m, Me.Gulf (US) SP62B, 8 legs 125m, Me.Gulf(US) SS274, 8legs 71m, Me.Gulf (US)	1978 + 1979	7,8,9	ambient	acc. at 7 variating points	D	Joint Industry Resarch Project case of damage detection
Forties Alpha,4 legs 133m,N.Sea(UK)	1980-82	13	ambient	8 acc.	D	integrity monitoring
Amorco Montrore Alpha,8 legs 100m,N.Sea (UK)	1980-82	13	ambient	10 acc. curr.m. wave staff	A	integrity monitoring

Table 1A. Performed measurings of jacket platforms with respect to the dynamic characteristic behaviour.

Structure / Water Depth	Instr. Period	Ref.	H_s / Excitation	Sensors	Data rec.	Comment
Occ.Claymero,8 legs 127m,N.Sea (UK)	1982 May-Aug	13	ambient	55 acc. 10 str.gau. 8 wave-pres.tr.	D	integrity - monotoring
4 legs 23m, (US)	1974 visites	14	ambient	3 acc.	A	damage detection due to impact
Light Station,4 legs 25m, NY Harb. (US)	1973 temporary	15	ambient	acc.	A	structural integrity
Bullwrinkle, 16 legs, 450m (US)	permanent	16	ambient	10 mov.acc. 11 str.gau. wave staffs	D (T)	
SP62C, 8 legs 100m, Me.Gulf (US)	temporary	10	4.5-5.5m /0.5-1m ambient	17 acc.	A	damage detection
	temporary	11	ambient	2 acc.	A	research on damping
Ocean Test Struct. 22m, Me.Gulf (US)	1976- permanent	12	3m ambient	92 sensors str.gau.,wave staff,curr.m.	D	research platform subject: hydrodynamic loading
4 legs 28m Abr.Gulf	1980 April	29	Exciter	mov.acc.	D	detection of of progressive damage(research)
Platform Hope 210m Cal.coast(US)	1969- permanent	30	ambient	6 acc.	A	earthquake instrumentation
Platfrom Grace,8legs 106m Cal.coast (US)	1981- permanent	31	ambient	23 acc.	D (T)	earthquake instrumentation
Midle Ground Shoal, Platform A,Alaska(US) ditto,Platform B West Delta,124m, Me.Gulf (US)	1971 (visites)	47	ambient	9 vel. (moveable)	A	research

Table 1B. Performed measurings of jacket platforms with respect to the dynamic characteristic behaviour.

Structure / Water Depth	Instr. Period	Ref.	H_s / Excitation	Sensors	Data	Comment
Gullfaks A,Condeep 134m,N.Sea (N)	1986- permanent	32,33	-9.5m ambient	16 acc.	D	authority requir. design verification, monitor. during. installation
TCP2,Frigg field 103m,N.Sea (N)	1979- permanent	34,35, 36,39	13.8m ambient	56 sensors: acc. str.gau. wave-radar 32 shock tr.	D	design verification, integrity, waves
Brent B,Condeep 140m,N.Sea (N)	1975- 77	37	10.3m ambient	10 acc., 24 str.gau. 3D-wave staff	D+A	integrity, design verification
Statfjord A,Condeep 145m,N.Sea (N)	1979- permanent	38,39	ambient	8 acc. (?) 16 shock tr. 2 wave staffs + more	D+A	authority req., design verification,
Statfjord Alp N.Sea (N)		39	ambient	acc,memb.forces		

Table 2. Performed measurings of concrete gravity platforms with respect to the dynamic characteristic behaviour.

Structure / Water Depth	Instr.	Ref. Period	H_s / Excitation	Sensors	Data rec.	Comment
Amoco, Monopile 30m, Me.Gulf (US) (single well)	1980 Mar 1 week visite	17-22	0.3 -2.7m ambient	2 mov.acc. 1 wave staff 1 anom. 1 curr.m.	A	research authority requir. ?
Europlatf.,Monopile 32m, N.Sea (NL) (meterological st.)	1983 +1985 (2months)	23	ambient	4 acc. Wave staffs anom.,Curr.m.	D (T)	vibration problems
Monopile 18m,Cameroon Africa,(conduct)	1982 Jun-Jul	24	<2m ambient	3 acc. 4 str.gau. wave staff,curr.m.	D	verification of design
Lena Guyed Tower 193m Me.Gulf (US) (guided tower)	1984- permanent	25	ambient	41 load cells,13 acc. 3 displ.,16 anom. 2 wave staffs	D+A (T)	installation, integrity monotor., research
Nordsee 30m,N.Sea (D) (hybrid)	1975 Nov. + ?	26,27	Shaker, Snap-Back with H=1.4m	> 6 acc. 18 str.gau.	A	structure for research
Christchurch Bay Tow. 8m, S.Coast (UK) (hybrid)	visites	28	Exciter	acc.	-	research struct., tested offshore and onshore

Table 3. Performed measurings of other platform types with respect to the dynamic characteristic behaviour.

The fifth column refers to the recording of the data: D for digital records, A for analog records and (T) for transmission of data from the platform to the main centre, typical onshore. Transmission of data has only been applied in the case of instrumentation over a long period. Transportable equipment has usually been applied when the measurings were performed during short visits. In the case of long periods of instrumentation, minicomputers are applied to control the sampling, i.e. when and for how long to sample. A current check of the sea state is applied in the case of automatic sampling. In the case of permanent instrumentation a typical sampling rule in the Norwegian sector of the North Sea seems according to Holand et al [39] to be something like:

- Storm: Complete set of records of 20 minutes every 3 hours plus a reduced set of records of 20 minutes every hour.
- Normal sea: Complete set of records of 20 minutes every 24 hours plus a reduced set of records of 20 minutes every 3 hours.

A reduced set of records means here enough data to obtain a set of key numbers such as mean values, variance, maxima, minima, check of trends in data, etc. obtained from measured signals of the response and environmental data.

The minicomputer usually includes an A/D-conversion and subsequent storage, too. However, it is not unusual also to let the minicomputer control a synchronous analog sampling since information is lost forever by the digitalization, and as backup copy which can be sampled and filtered in alternative ways.

The sixth column includes the main purpose of the instrumentation according to the given references. The purpose of the instrumentation has typically been the motives given in the previous chapter, namely an interest to improve the general knowledge about the dynamic performance and/or to monitor the integrity of the structure by observing any changes in its response. In USA permanent vibration monitoring has especially been used due to risk of earthquakes. Besides monitoring the structural behaviour it has also been a general purpose to improve the knowledge of the wave and wind loading.

2 The Performed Identifications: Tables 4-6

The results of the identification and interpretation of the measured data are shown in tables 4 to 6. The tables provide important structural knowledge of offshore platforms and they give a review of the possibilities of system identification.

The first column gives the information of the given structure, the water depth, d and the applied excitation either being ambient excitation or a kind of external excitation. The number of the reference, in which the results and the method for system identification have been presented, is given in brackets. From the platform name it is possible to compare the instrumentation of the platform described in tables 1 to 3 with the identification results.

Struct./d/ref. excitation	f_i Hz	ζ_i	$\overline{\Phi}_i$ no.	T/f_s min./Hz.	Analysis type	Comment
West Sole WE,25m (1)	1.365 (1)	-	none	20-45	FFT	peak
ambient, H_s=0.7m	1.44 (2)	-		/ ?		frequencies
1978	3.95 (6)	-				
	±1%					
West Sole WE,25m ( )	1.375 (1)	-				
ambient	1.375 (2)	-				
1975	4.00 (6)	-				
Ekofisk,70m (2)	0.66 (1)	0.035(1)	none	? /	FFT	peak freq.
shakers	0.70 (2)	0.028(2)		f_{max}=15		damping by
1979	5.41(13)	0.026(3)				peak value
		±43%				
ditto	-	0.018(1)				damping by
	-	0.011(2)				bw.
	-	0.028(3)				
	-	±9%				damping by
ambient H_s=1−2m	-	0.014(1)				bw.
Ekofisk 2/4H,70m (3)	0.51(1)	-	none	-	FFT	peak freq.
ambient H_s=11m	0.55(2)	-				no influence
	0.67(3)	-				of sea state
Frigg DP2,98m (4)	0.625(1)	-	none	20	FFT	response
ambient H_s=1−13m	0.68 (2)	-		/6.25		vs. waves, peak
	0.90 (3)	-				frequencies
	-	0.01		40/	FFT	damping vs.
ditto (5)	-	-0.03		16.67		wave height
SP65A,103m(6)	0.56(1)	0.027(1)	none	20/	FFT	zero cross.
snapback/impulse	0.59(2)	0.022-			50 av.	freq. +log.
	0.83(3)	0.027(2)			0.0037Hz	dec.
SP62C,103m (6)	0.66(1)	0.026-0.029(1)	none	ditto	ditto	ditto
snapback/impulse	0.66(2)	0.034-0.042(2)				
	0.96(3)					
ambient		0.010(1)				damp. by bw.
ambient		0.021-0.051				damp. by sp.mom.
WD152A,124m (6)	0.61(1)	0.022(1)	none	ditto	ditto	zero cross.
snapback/impulse	0.62(2)	-				freq. +log.
	1.03(3)	-				dec.
ambient		0.031(1)				damp. by bw.
ambient		0.024-0.049(1)				damp. by sp.mom.
Eugene Isl.,82m (6)			none	ditto	ditto	
	0.52(1)					
	0.54(2)					

Table 4A. Performed analysis of jacket platforms with respect to the dynamic characteristic behaviour.

Struct.,d,ref excitation	f_i Hz	ζ_i	$\overline{\Phi}_i$ no.	T/f_s sec/Hz	Analysis type	Comment
SS274,71m (7) ambient	0.65-0.66(1) 0.68-0.70(2) 4.57-4.60(10)	-	(1)- (10)	240/ ?	FFT 60 av.	peak freq.
ditto (8,9)			(1) -(12)			shape vect.
Amorco Mont.Alpha 100m (13) ambient	0.516(1) 0.535(2) 0.666(5) ±1%	-	none	15-50 /7.66- 61.3	FFT (1024) /MEM	peak freq. MEM equals FFT results
Forties Alpha 133m (13) ambient	0.486(1) 0.569(2) 2.562(8) ±1−2%	-	none	60/ 10.24	FFT (1024) /MEM	peak freq. MEM equals FFT results
?(US),23m (14) ambient	0.985(1) ±0.5%	0.01	none		FFT	
Light St.,25m,(15) ambient	1.12(1) 1.46(3)	- -	none		FFT	
SP62C,100m,(10) ambient H_s=0.5−5.5m	0.646(1) 0.658(2) 2.62(11) ? (24) ±0.8%	-	none		FFT	peak freq. f_i : ±1−2% due to sea state
ditto,(11)		0.0114(1) 0.0045(2) 0.0027(3)		32 / 6.4	FFT	damp. by bw.
		0.020(1) 0.021(2) 0.013(3) ±15%			MEM	damp. by bw.
ditto,(42)	0.642(1)	0.0322(1) ±62%	none	16.7/ 6.4	Ran. dec.	zero cross., log.dec.
(41)		0.0165(1) 0.0172(2) 0.0120(3)			Time	damp. by log.dec.

Table 4B. Performed analysis of jacket platforms with respect to the dynamic characteristic behaviour.

The second column gives the two lowest estimated eigenfrequencies plus the highest eigenfrequency which has been identified corresponding to three rows per performed identification session. The number of the mode is given in brackets. This presentation shows how close the two lowest eigenfrequencies were located, and further, the highest identifiable eigenfrequency. At a fourth row the magnitude of the coefficient of variation of the eigenfrequencies is given. The uncertainty includes in general the statistical uncertainty on the data, uncertainty of the identification method, and uncertainty due to time-varying characteristics of the structure, e.g. correlation with the sea state.

In analogy with the second column the third column gives the estimated damping ratios corresponding to the two lowest eigenmodes plus the ratio for the highest identified mode. At the fourth row the coefficient of variation is given if it has been estimated.

The fourth column gives the number of mode shapes which has been estimated. In general it is seen from the tables that eigenfrequencies are almost always identified while mode shapes rarely seem to be estimated. However, the interest in estimating the damping ratios and the mode shapes seems to be increasing. The typical case is that the three lowest eigenmodes have been identified since only those modes are sufficiently excited. In a single case up to 40 modes have been claimed to have been identified but, this is an exception where external excitation due to a shaker was applied.

Struct./d/ref. excitation	f_i Hz	ζ_i	$\overline{\Phi}_i$ no.	T/f_s min./Hz.	Analysis type	Comment
Midle Grou.Sh.Pl. A (47), ambient	0.90(1) 1.00(2) 1.20(3) ±2−3%	0.037(1) 0.037(2) 0.036(3) ±5%	none	? / 31.25	FFT 15 av.	peak freq. damping by bw.
Midle Grou.Sh.Pl. B (47), ice	0.98(1) 1.09(2) 1.41(5) ±1%	0.037(1) 0.033(2) 0.035(5) ± 5%	none	? / 31.25	FFT 15 av.	peak freq. damping by bw.
West Delta ,124m (47), ambient	0.24(1) 0.25(2) 0.40(3) ±2−3%	0.038(1) 0.038(2) 0.035(3) ±-5%		? / 31.25	FFT 15 av.	peak freq. damping by bw.
Ocean Test Struct. 22m, (12) ambient	-	-	-	-	-	estimation of C_D and C_M, member forces etc.
Abr.Gulf,28m,(29) shaker	0.85- 5.0		(1)- (40)		FFT	
Platf. Hope,210m, (30),earthquake	0.59(1) 0.61(2) ±1%	0.020-0.037(1) 0.026-0.028(2) ±10−25%	none		FFT	peak freq. damp. by. sp.mom.

Table 4C. Performed analysis of jacket platforms with respect to the dynamic characteristic behaviour.

Struct.,d,ref. Excitation	f_i Hz	ζ_i	$\overline{\Phi}_i$ no.	T/f_s sec./Hz	Analysis type	Comment
Gullfaks A,134m,(33) ambient	0.438(1) 0.533(2) 0.753(4) ±2%	0.015(1) 0.014(2) 0.021(4) ±8−30%	(1)- (4)	20/ 2.3-11.4	ARMA	identific. from ARMA-model
TCP2,103m,(34) ambient,H_s<13.8m 1979	0.647(1) 0.760(2) 1.07(3) ±2−3%	-	none	20/	FFT	peak freq. + response vs. waves
extra deck mass(31%)	0.593(1) 0.675(2)					
ditto, (35) 1980,storm	0.605(1) 0.645(2) 0.765(3)	-		20/	MEM	peak freq. identific. of
ditto, (35) 1981,storm extra deck mass(31%)	0.605(1) 0.600(2) 0.670(3)			20/	MEM	stiffness and mass
(36) H_s<12m				20/ 4	FFT	member force vs. waves
Brent B,140m,(37) ambient,H_s<10.3m	0.56(1) 0.58(2) 0.84(3)	-	(1)- (3)	20/	FFT	peak freq. +identfic. of stiffness
Statfjord A,145m,(38) ambient,H_s<10.7m	0.43(1) 0.43(2) 1.58(8)	0.015(1) 0.02(2) ±50%	(1)- (3)	20/ 8	ARMA	identific. by ARMA, estimates vs. waves stifn. identific.

Table 5. Performed analysis of concrete gravity platforms with respect to the dynamic characteristic behaviour.

If possible the fifth column gives the basic length of the applied time series plus the sampling frequency or alternatively the maximum frequency kept in digitally converted signals.

The most typical record length seems to be 20 minutes. This record length is thought to be due to the need for limiting the amount of data when measurings are performed over a longer period. Furthermore, the record length is also limited by the fact that system identification in general assumes data due to stationary random processes. The wave excitation process will only be quasi stationary within shorter periods of time. The sampling frequency has to be sufficiently high to ensure an accurate representation of the continuous signals on digital form. On the other hand, the amount of data must be limited. The result is that filtering and synchronous sampling with different sampling frequencies are widely applied for the purpose of getting information about a given frequency region in the measured response and excitation processes.

Struct.,d,ref. Excitation	f_i Hz	ζ_i	$\overline{\Phi}_i$ no.	T/f_s sec./Hz	Analysis type	Comment
Monopile,30m,(19)	0.3234(1)	0.0104(1)	none	32/	MEM	curvefit
ambient	0.3237(1)	0.0111(1)		6.4		peak freq.+
						damp.by bw.
ditto	0.3228(1)	0.0227(1)		32/	FFT	curvefit
	0.3234(1)	0.0244(1)		6.4		peak freq.+
						damp.by bw.
ditto, (18,21)	0.32(1)		(1)-	80/	MEM	peak freq.
	1.20(2)		(2)	6.4		
	3.06(3)					
ditto, (17,20)	0.325(1)	0.011(1)	none		MEM	peak freq.,
H_s=0.3−1m	0.327(2)	0.013(2)				damp. by
		±<14%				bw.
ditto, (17,20)	0.323(1)	0.010(1)	none		MEM	ditto
H_s=1.7−2.7m	0.328(2)	0.014(2)				
		±<20%				
ditto, (17,20)	0.323(1)	0.009(1)	none		MEM	ditto
H_s=0.7−1.3m	0.327(2)	0.011(2)				
		±<27%				
ditto, (22)						identific. of
						mass+stiffness
ditto, (43)	0.326(1)	0.0095(1)	none		Ran.-	Ibrahim time
		±<9%			dec.	domain method
Monopile(NL),32m	0.382(1)	0.015(1)	none		FFT	peak freq.,
(23),ambient						damp. by bw.
Monopile(Africa)	0.41(1)	-	(1)-	40/	FFT	shape vect.
18m,Cameroon	2.58(2)		(5)	20		
ambient,H_s=2m	5.00(5)					C_D and C_M
						estimated
Nordsee,hybrid ,30m	2.22(1)	0.028(1)	none	75	FFT	curvefit,
(26,27)	3.34(2)	-			(0.02Hz)	also mass
shakers and	4.03(3)	0.023(3)				estimation
H=1.4m	±<3.5%	±<30%				
Christch.Bay,hybrid	2.3-2.4(1)	0.02-0.04(1)	none		FFT	peak freq.,
8m,(28)	3.3-4.9(2)	0.01-0.03(2)				damp. by bw.
shakers						off-/onshore

Table 6. Performed analysis of other platform types with respect to the dynamic characteristic behaviour.

The sixth column shows the kind of signal analysis which has been reported in each reference:

- FFT (Fast Fourier Transformation) which is further described in chapter 5 and partly also in chapter 7 in Jensen [49].
- MEM (Maximum Entrophy Method) which is described in chapter 8 in Jensen [49].
- Random dec. (random decrement technique) which is described in chapter 5 and partly in chapters 6 and 7 in Jensen [49].
- ARMA (Auto-Regresssive Moving Average) which is described in chapter 8 in Jensen [49].

The first two kinds of analyses are usually applied in the frequency domain while two latter are methods in the time domain. The first and the third method are methods which in system identification are combined with some kind of curvefitting algorithm, while the second and the fourth method are methods which provide parametric expressions for e.g. the eigenfrequencies and the damping ratios.

In the case of a performed FFT analysis any available information of the number of averages, the resolution or the number of frequency points is also given in the sixth column.

In the seventh column comments have been made on the system identification and any applied curvefitting algorithm. The applied curvefitting algorithms include:

- Peak freq. (frequency) which is identification of the eigenfrequencies from the peak frequencies of the measured response spectra.
- Damping by bw. (bandwidth) which is identification of the damping ratio from the width of the resonance peak in the measured response spectra, see chapter 7 in Jensen [49].
- Zero cross. freq. (zero crossing frequency) which is identification of the eigenfrequency from the zero crossing period of the measured response process, see chapter 7 in Jensen [49].
- Log. dec. (logarithmic decrement) which is identification of the damping from a free decay, see chapter 7 in Jensen [49].
- Damp. by sp.mom. (damping by spectral moments) which is identification of the damping ratio from the three lowest spectral moments of the response spectrum, see chapter 7 in Jensen [49].
- Shape vect. (shape vectors) which is identification of the eigenfrequencies and the mode shapes from a curvefit on a measured response spectrum, see chapter 7 in Jensen [49].
- Ibrahim time domain method which is a method for identification of the modal parameters from a free decay, see chapter 7 in Jensen [49].

The more general curvefitting algorithms which have been applied in some references are discussed in chapter 7 in Jensen [49].

3 The Eigenfrequency Estimates

From the estimated eigenfrequencies of jacket platforms it is seen that the first eigenfrequency is clearly correlated with the water depth, see figure 1. A similar observation can be made for tall buildings. Ellis [44] observed from a review of experimental and numerical analysis of 163 buildings that the most reliable calculated estimate of the first eigenfrequency was obtained from the expression $f_1 = \frac{46}{h}$ Hz obtained from a fit of the experimental estimated eigenfrequency. It was reported that the uncertainty of estimates obtained by numerical analysis by finite element methods were about 50%. The uncertainty of the identified eigenfrequency from measurements typical lies in the range of $1-2\%$. This case for tall buildings clearly illustrates the importance of the concept of system identification in structural design.

One reason for the uncertain prediction of eigenfrequency is probably that the mass distribution of structures is more uncertain than commonly expected. Snedden [45] has reported that already at the construction site of offshore structures there is an uncertainty of the masses of construction elements about $10-15\%$ in spite of a performed weight control. This source of uncertainty will tend to give an underestimation the total mass since modification of the design during construction will in general tend to give an increase of the steel consumption because steel is relatively inexpensive. This source plus the uncertainty of structural modification during the structural lifetime may mean an uncertain of the mass distribution of about 20% leading to an uncertainty prediction of the eigenfrequencies.

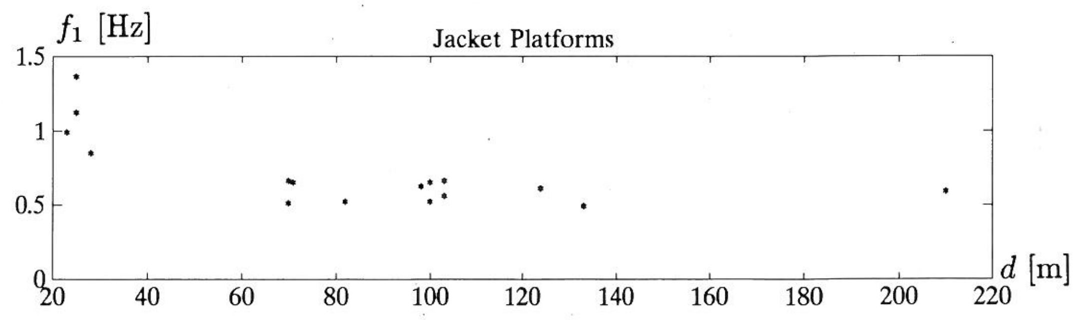

Figure 1. Identified first eigenfrequency of jacket platforms versus the water depth.

Only a small number of identified eigenfrequencies has been found on gravity platforms. However, the same correlation w.r.t. the water depth is expected to exist. The first eigenfrequency seems to lie in the range $0.30-0.65$ Hz for water depths $100-150$ m.

Offshore structures such as monopiles (monotowers, single standing conductors, tripods etc.) are becoming increasingly popular structural concepts for unmanned platforms, however, the number of such platforms are still small and thus also the number of performed measurings. However, some cases of system identification of such platforms have been found. At a water depth about 30 – 40 m, the first eigenfrequency will typically lie in the range 0.30 – 0.40 Hz.

Structural changes will also affect the eigenfrequencies. A practical example was given by the TCP2 condeep platform in the Norwegian part of the North Sea, see tables 3 and 5. Here, a 31% increase in the deck mass led to a 13% decrease in some of the lowest eigenfrequencies. Furthermore, during a period of 5 years some eigenfrequencies dropped about 10%. Thus an offshore structure cannot be considered to be a time independent system over several years.

For an SDOF system the first eigenfrequency is given by $f_0 = 2\pi\sqrt{\frac{k}{m}}$ which leads to the sensitivity relations of the eigenfrequency w.r.t. the mass and the stiffness:

$$\frac{df_0}{f_0} = -\frac{1}{2}\frac{dm}{m} \tag{1}$$

$$\frac{df_0}{f_0} = \frac{1}{2}\frac{dk}{k} \tag{2}$$

The observed decrease in the eigenfrequency in the Norwegian case is seen to have the same magnitude which was to be expected for an SDOF system. Thus, since it is the lowest eigenmodes which are excited in practice, significant stiffness and mass changes associated with the lowest eigenmodes will be observed as significant changes in the lowest eigenfrequencies, while structural changes affecting the performance of the higher modes will in general not be possible to detect, since those modes are not dynamically excited.

4 The Damping Estimates

The estimated damping ratios in the tables do not seem to be correlated with the water depth. Instead they seem to depend upon the type of structure. Neither does the damping ratio seem to depend upon the eigenmode considered. This means that in general offshore structures will not be proportionally damped.

An analysis of all identified damping ratios of jacket platforms for all modes shows that the damping typically lies between 1–3% with a mean of 2.1% and a coefficient of variation of 46%, see figure 2.

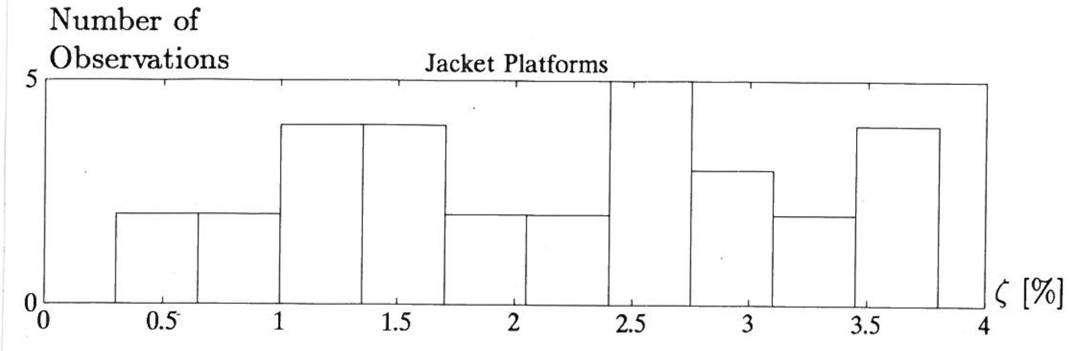

Figure 2. Histogram of identified damping ratios for jacket platforms including all identified modes.

For monopile structures the damping may be a little smaller with a mean of 1.3% and a coefficient of variation of 37%. For gravity platforms the damping seems to lie in the range $1.4 - 2.1\%$. However, only a few structures of the two structural types have been identified.

The estimated magnitude of the damping ratios can be compared with the recommendation of Det Norske Veritas [48] as shown in table 7. The damping values from the Det Norske Veritas include only structural damping. A contribution of the magnitude $0.05 - 0.02$ may be added due to the surrounding water. The damping in the foundation is not explicit evaluated in the reference. It is seen that the obtained damping from the review is in general larger than the given values for the structural damping. The damping contribution from the foundation and water seems to be rather uncertain according to the rules of Det Norske Veritas and it is clear that the damping is in general underestimated if the design basis only includes the structural damping given by e.g. Det Norske Veritas. This will be a conservative element in the design basis and thus lead to less optimal structures.

Estimates due to	Jacket platforms	Monopile platforms	Gravity platforms
Review	2.1%	1.3%	1.4-2.1%
D.N.V.	1%	1%	1-2 %

Table 7. Damping ratios from the review and from the rules of Det Norske Veritas (D.N.V.) [48].

The review has shown that a priori knowledge of the damping ratios based upon the tables is coupled with a coefficient of variation of the damping ratio in the range of 50% while a performed identification on a given structure may reduce the uncertainty of the damping ratio down to a magnitude of about 10%. I.e. the case with a monopile platform shows that if a single analysis is disregarded the coefficient of variation due to different analysis is as low as 7% for the first damping ratio and 12% for the second damping ratio. Thus, a substantial reduction in the uncertainty of damping can be obtained by identification of a given structure.

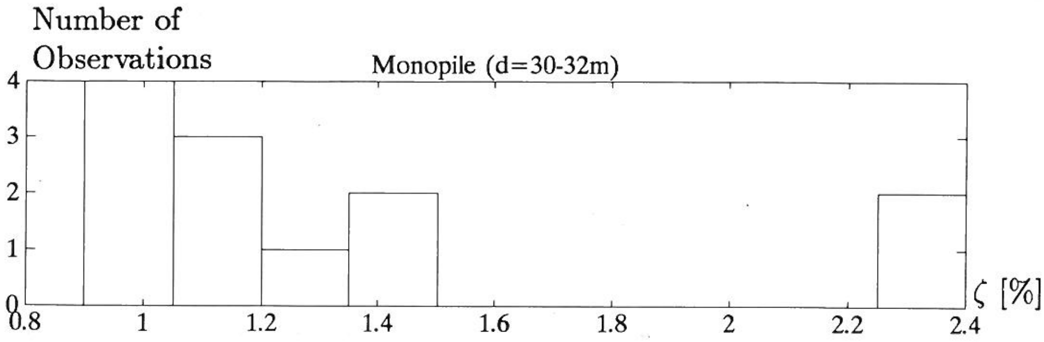

Figure 3. Histogram of the identified damping ratios of all modes for investigated monopile structures.

5 Conclusion

The performed survey has revealed the existing practice and stage of system identification of offshore platforms.

The results of the survey of performed system identifications show that the eigenfrequencies and the damping ratios can be estimated of a certain accuracy for a given offshore platform which will provide a much better basis than the general a priori knowledge that e.g. Det Norske Veritas' rules represent. The latter will typically be the knowledge which can be extracted from a survey of the performed kind which clearly illustrates how uncertain the a priori knowledge of especially damping is, and it is thus also pointed out how conservative the design basis must be to ensure the reliability of the structures.

The aspect has been illustrated by Jeary and Ellis [46] who have investigated the effect of reducing the uncertainty of predicted response by employing results of system identification. Considering an SDOF system harmonically excited by its eigenfrequency, the displacement amplitude is given by:

$$X(f_0) = \frac{F(f_0)}{4\pi^2 f_0^2 m 2\zeta_0} \tag{3}$$

which leads to a simple relation between the uncertainty of the predicted response and sources of uncertainty:

$$\frac{dX(f_0)}{X(f_0)} = \frac{dF(f_0)}{F(f_0)} - \frac{dm}{m} - \frac{d\zeta_0}{\zeta_0} - \frac{2df_0}{f_0} \tag{4}$$

Assuming the following uncertainties at the design stages:

$$f_0 : \pm 50\% \quad m : \pm 20\% \quad \zeta_0 : \pm 100\% \quad F(f_0) : \pm 20\%$$

the uncertainty of displacement amplitude at resonance becomes: ±240%, while a performed system identification, if it has led to the following reduced uncertainties:

$$f_0 : \pm 0.1\% \quad m : \pm 20\% \quad \zeta_0 : \pm 10\% \quad F(f_0) : \pm 20\%$$

leads to an uncertainty of ±50% of the predicted response.

This example illustrates together with the discussion in this and the previous chapter, what can be gained by system identification of offshore structures.

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