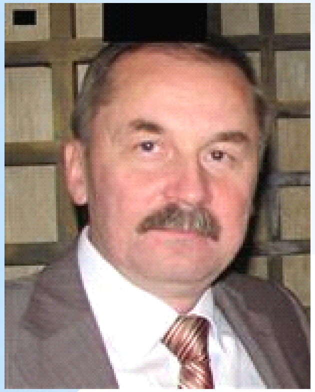
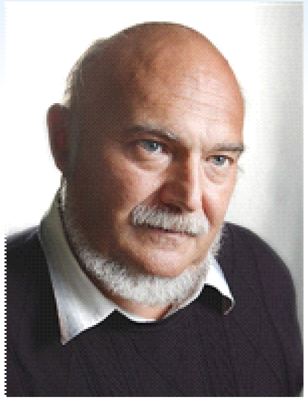
P.P. Shirshov Institute of Oceanology,
Russian Academy of Sciences
http://www.ocean.ru

A PROJECT OF CONCRETE STABILIZED SPAR BUOY FOR MONITORING NEAR-SHORE ENVIRONEMENT



Sergei I. Badulin
Wave theory



Andrey G. Zatsepin
Experimental oceanography

Dmitry V. Ivonin
Remote sensing

Dmitry G. Levchenko
Seismo-acoustics

Alexander G. Ostrovskii
Marine acoustics,
technique

Vladislav V. Vershinin
Civil engineering

Leopold I. Lobkovsky
Geodynamics, geotectonics

A sea buoy of our dream -

A stabilized research platform

in the right place, at the right time

(today, for the East near-shore of the Black Sea)

Durability (10 years min.)

Mechanical strength

Corrosion

…

Sustainability

Supportability

Multi-tasking

Upgradability

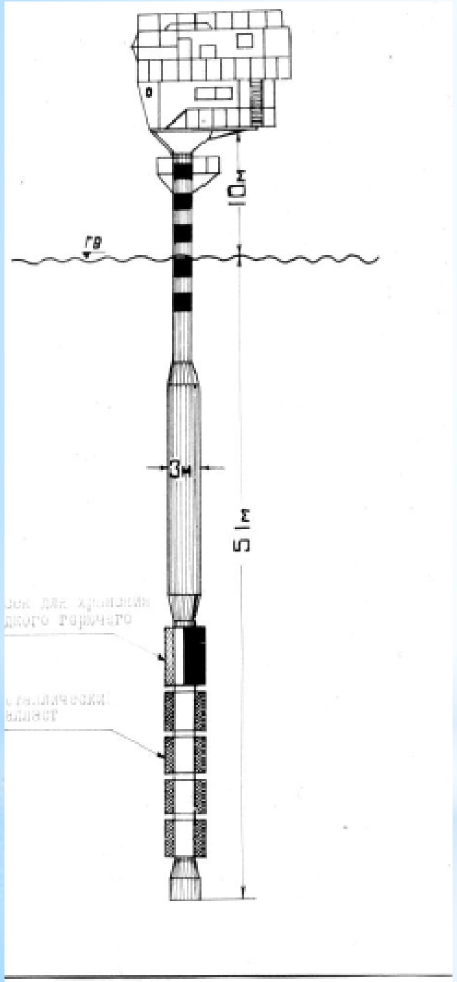
…

Reasonable cost of production, deployment and exploitation

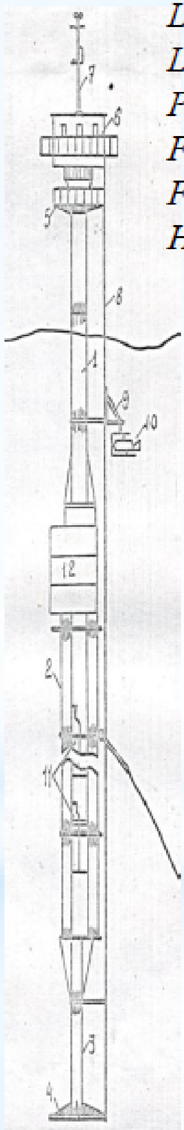
Mass production (?!)

Stationary research buoys

France, 1963,
H=2600 m



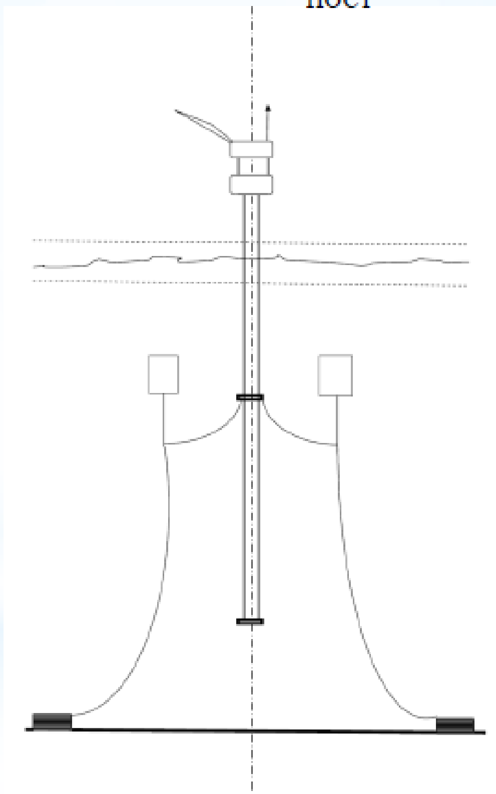
USSR, Institute of acoustics,1977



$L_{общ}$ = 64 м
$L_{подв}$ = 54 м
$P_{общ}$ = 62 т
$F_{верт}$ = 0,03 Гц
$F_{наклон}$ = 0,03 Гц
$H_{пост}$ = 70 – 300 м

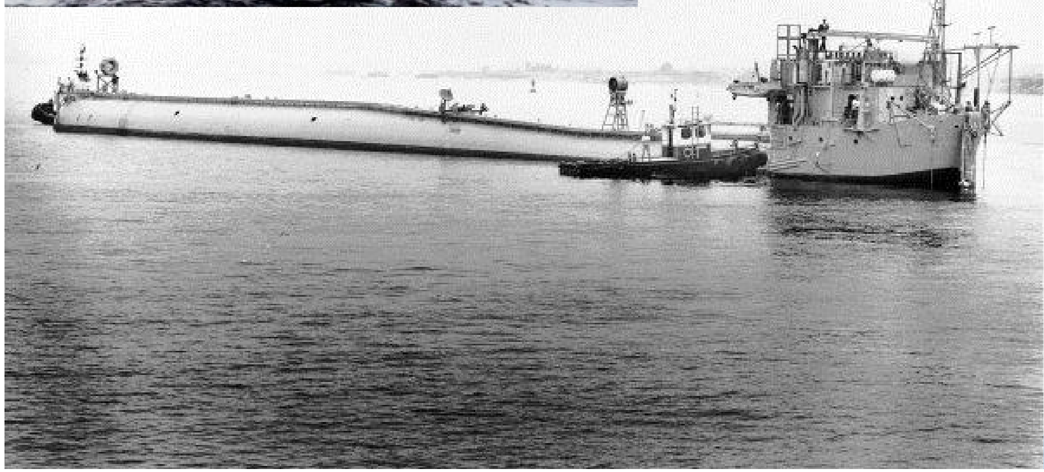
USSR, P.P.Shirshov Institute, 1974-1982

$L_{общ}$ = 63 м
$L_{подв}$ = 55 м
$P_{общ}$ = 64 т
$F_{верт}$ = 0,07 Гц
$F_{наклон}$ = 0,03 Гц
$H_{пост}$ = 70 м

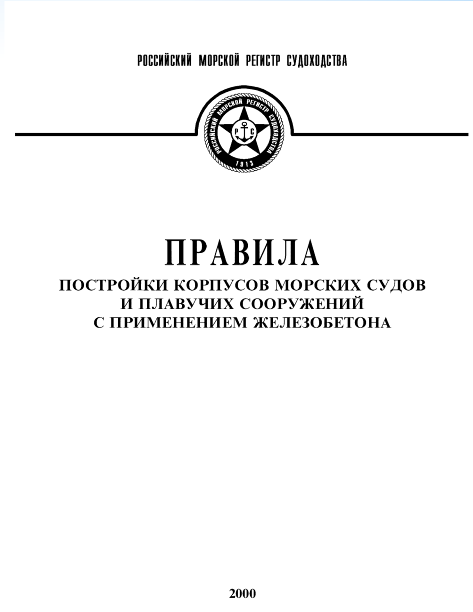


Stabilized research platform FLIP
USA, 1962-today

L_{tot}=105m
L_{sub}=90m
P_{tot}=2200 tonnes
$\Delta\alpha=2^{o}$
$\Delta h=0.1\ H_s$
W=2*100 kWt
Crew - 12 men



Concrete (ferrocement) vessels (decision)



РОССИЙСКИЙ МОРСКОЙ РЕГИСТР СУДОХОДСТВА

ПРАВИЛА

ПОСТРОЙКИ КОРПУСОВ МОРСКИХ СУДОВ
И ПЛАВУЧИХ СООРУЖЕНИЙ
С ПРИМЕНЕНИЕМ ЖЕЛЕЗОБЕТОНА

2000

Static of the buoy: buoyancy to weight aspect

Parameters:

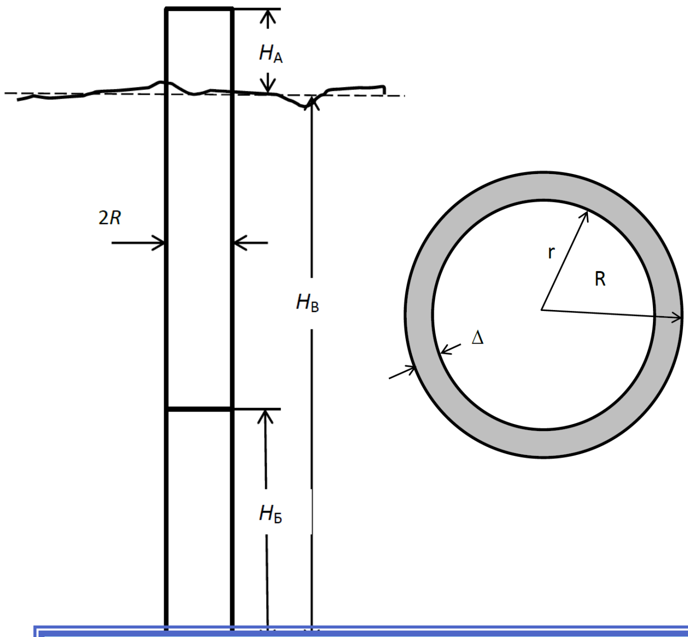
Concrete specific weight: $\rho = 2.4$ t/m^3

Radii (max): $R = 1.2$ m

Min. shell thickness: $\Delta = 0.12$ m

Section height: $H_A = 3$ m

Underwater part depth: $H_B = 30$ m



Estimates of buoyancy:

$P_B \leq Q_B$ (P_B и Q_B – weight and buoyancy)

Buoyancy condition: $k = \Delta/R < k_{lim}$ **= 0.236**

Ex. 1 (max. diameter Δ=20 cm)

$k = 0.166$, app.2/3 of max.

$R = 1.2$ m; $H_B = 30$ м; $H_A = 3$ м;

$Q_B = 37.8$ tonnes – buoyancy (payload)

$P_{sect} = 9.75$ t; $P_B = 97.5$ t – section, buoy weights

The ballast water column: $H_w \approx 10$ m, $P_w = 31.6$ t

Ex. 2 (min. shell thikness Δ=12 cm)

$k = 0.16$, app.2/3 of max.

$R = 0.75$ m; $H_B = 30$ м; $H_A = 3$ м;

$Q_B = 15$ tonnes – buoyancy (payload)

$P_{sect} = 3.3$ t; $P_B = 38$ t – section, buoy weights

The ballast water column: $H_w \approx 10$ m, $P_w = 12.3$ t

Solution: R>0.55 m Decision: R<1.25 m

Dynamics of the spar buoy

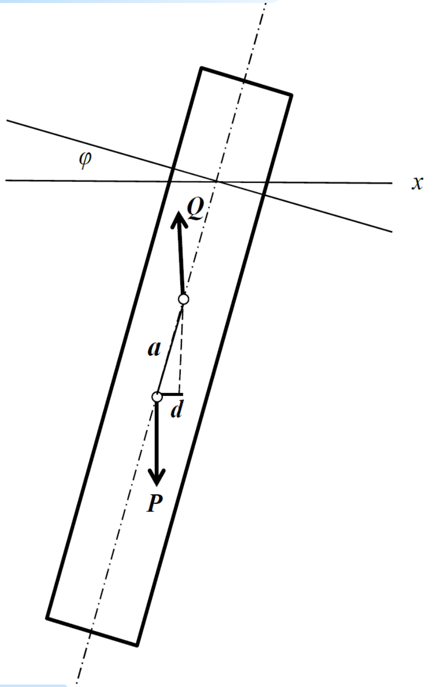
Centers of loads and buoyancy: $z_g = \frac{\sum_i^n p_i z_{gi}}{\sum_i^n p_i}; \quad z_b = \frac{\sum_i^n q_i z_{bi}}{\sum_i^n q_i}$

Righting moment: $M_B = Pa\sin\phi$

Equations of motion:

$$(m_b + m_a)\ddot{z} + K_d\dot{z} + g\rho S_w z = 0 \quad -\text{translation}$$

$$(J_b + J_a)\ddot{\phi} + k_d\dot{\phi} + gm_b a\phi = 0 \quad -\text{rotation}$$



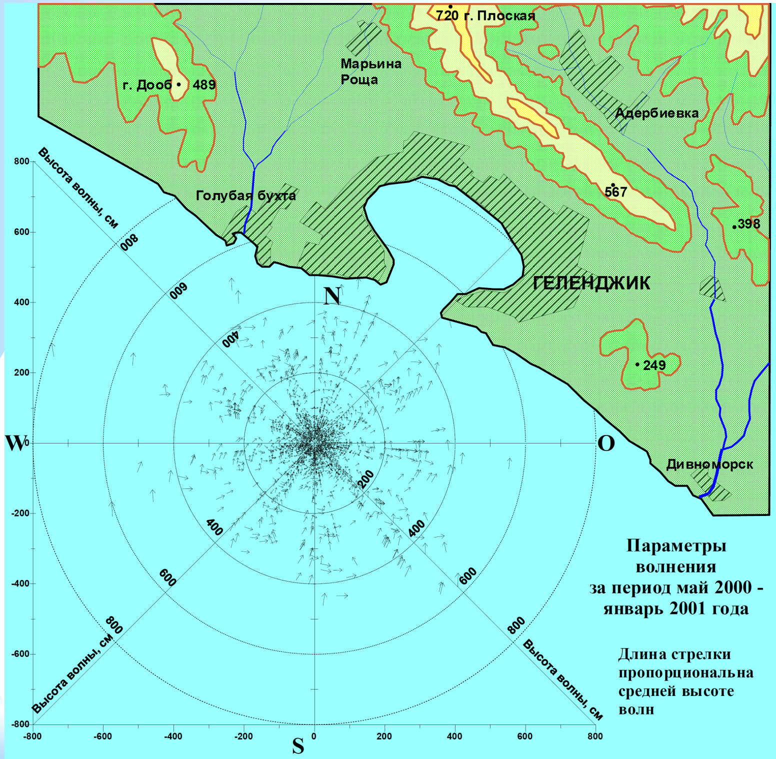
z - coordinate of the buoy center of loads; ϕ - angle
m_b, m_a - mass of the buoy, added liquid mass;
K_d, k_d - damping rates, J_a, J_b - inertia moments;
Sw - buoy cross-section, ρ – water density

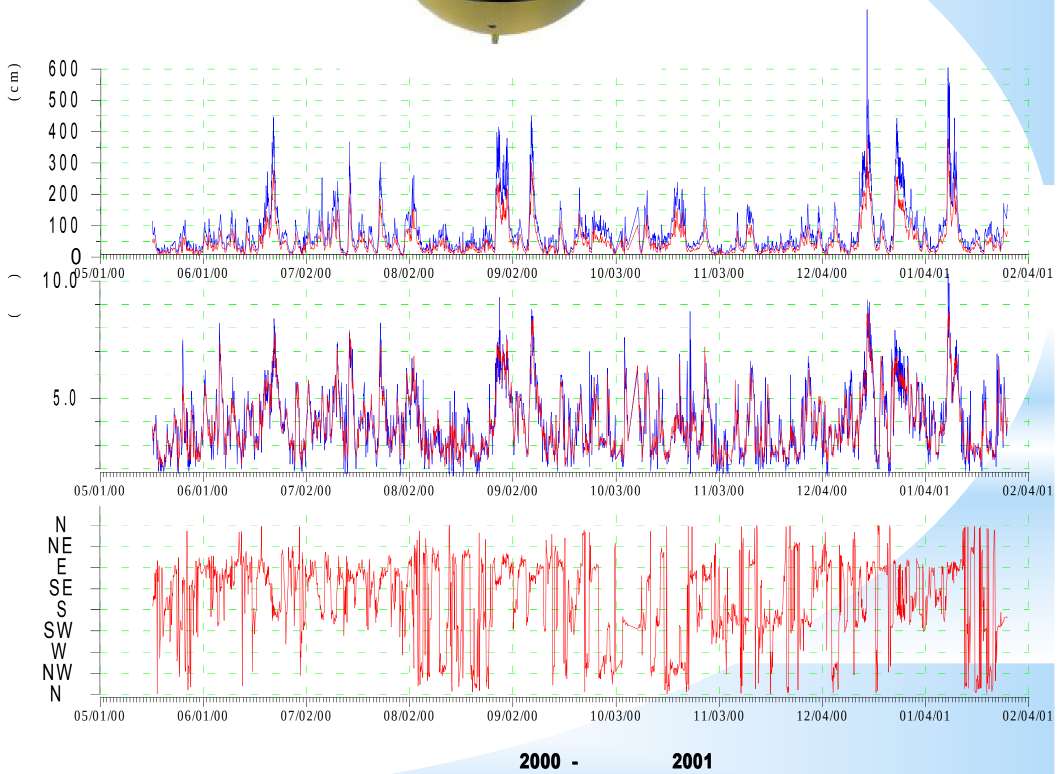
The buoy motion eigen frequencies (R=1.2 m, a=3 m; ma=136 t, Δ=15 cm):

f_{tr}=0.088 Hz
f_{rot}=0.051 Hz

The stabilization is reachable !
Solution: permanent ballast+adjusting water ballast

Monitoring of waves with Datawell buoy near the Gelendzik Bay (R. Kosyan, 1996 – 2003, NATO TU-WAVES Project)



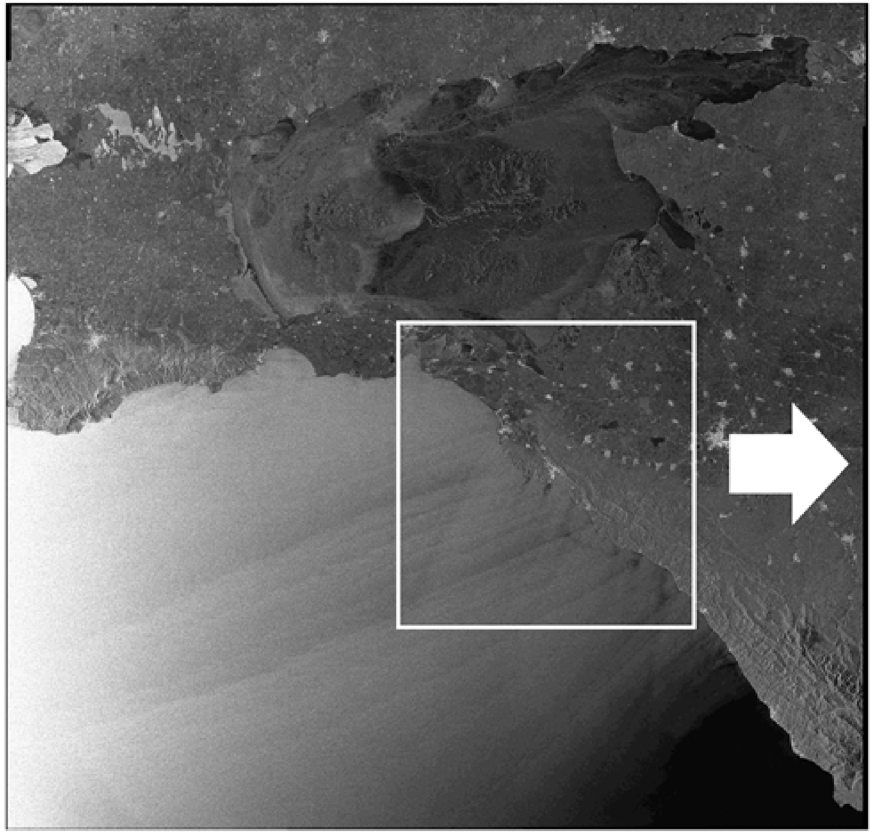


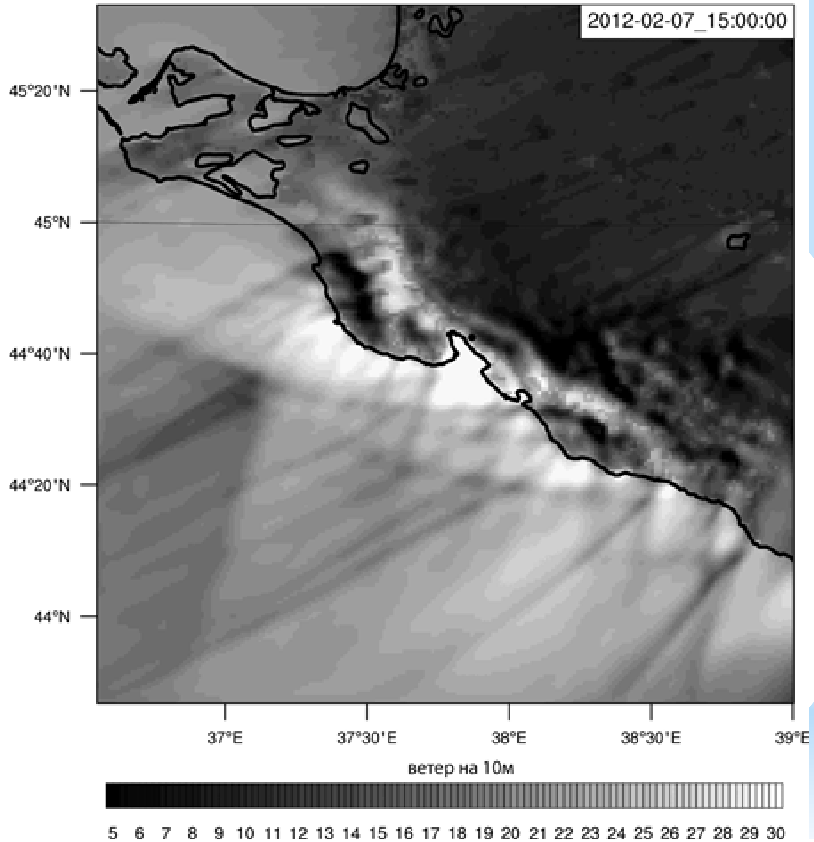
Intermittency of wind field

during the Novorossiysk bora February,7, 2012, 15.25 UTC

Left - Radarsat-1; Right - WRF-ARW model

A. Gavrikov & A. Ivanov, Izv. Atm. and Ocean. Phys., 2015, V. 51, N. 5, pp. 546–556





How to estimate sea state in absence of reliable measurements of wind field?

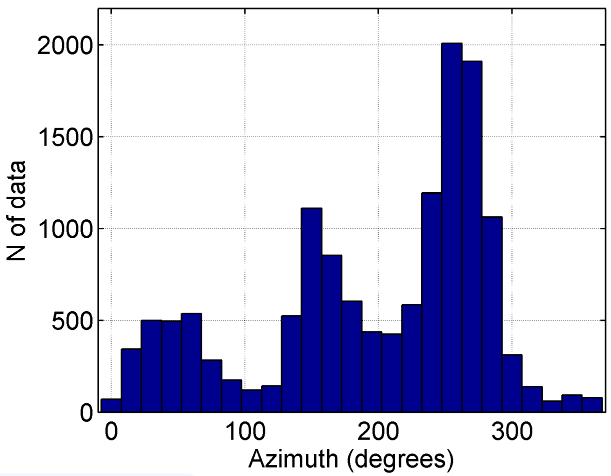
Wind-free method for the joint probability distribution of wave heights and periods (Solution)

Wind-free invariant (Zakharov et al., JFM,2015)

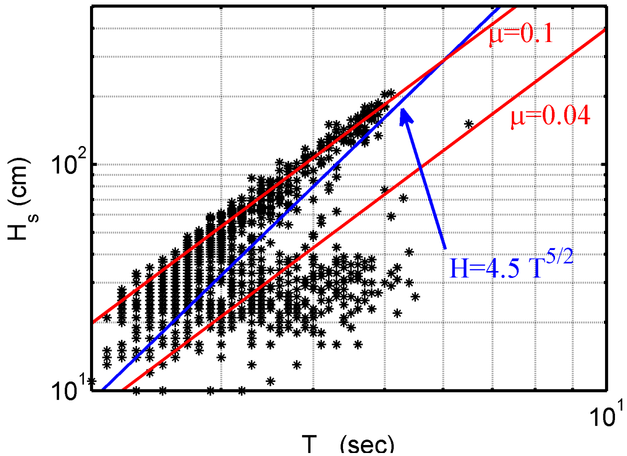
$$\mu^4 \nu = \alpha_0^3; \quad \alpha_0 \approx 0.62$$

μ – wave steepness; $\nu = 2k_p x$ – number of waves

Sea state (Hs,Tp) can be assessed for a given fetch without wind speed



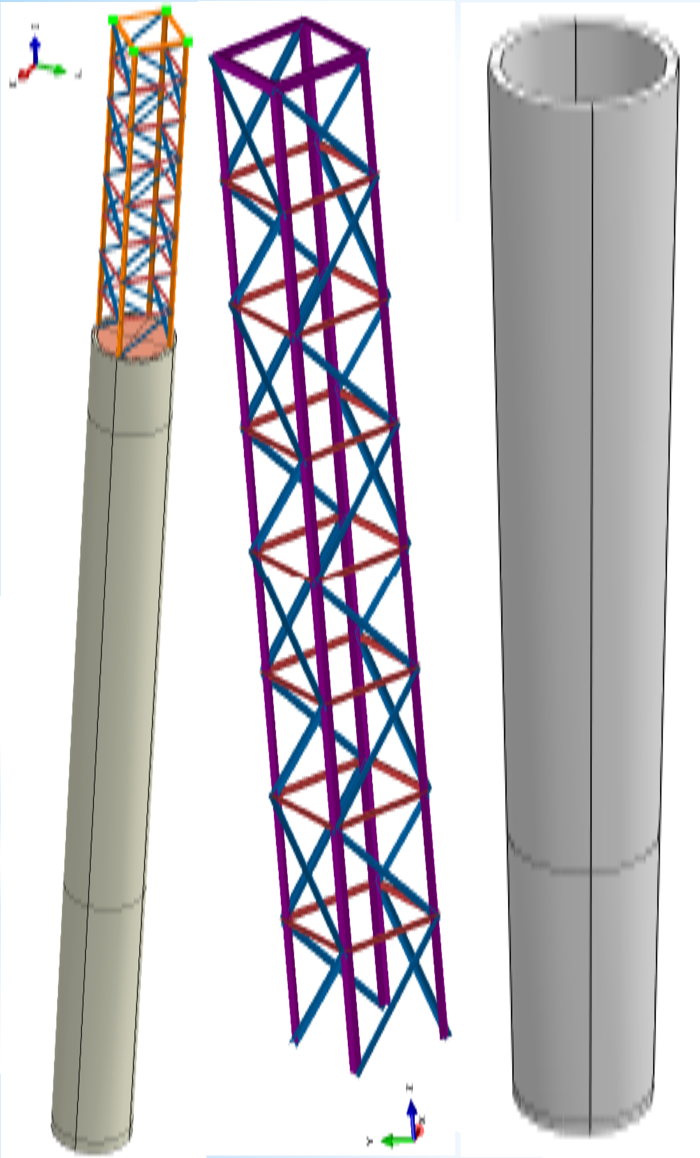
Number of measurements vs wave direction at the buoy site



Sea state estimate for offshore winds

Wave measurements are between the wind-free invariant and a limiting wave steepness

Strength of the buoy under effect of wind and waves



Concrete part

Prestressed concrete tube 33 (30+3) m length

Diameter 2.4 meters (manufacturing + transportation)

Shell thickness 15 cm (> 12 cm)

Bottom thickness 3 meters (permanent ballast)

Concrete C80 and higher (available everywhere)

Steelwork

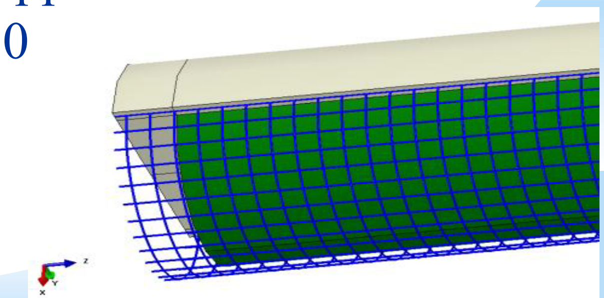
Steelwork height 12 meters

pointwise payloads: 4*50kg at 15 m height,

4*20 kg at 13.5 m, 4*20 kg at 12 m

Heavy equipment in the upper section

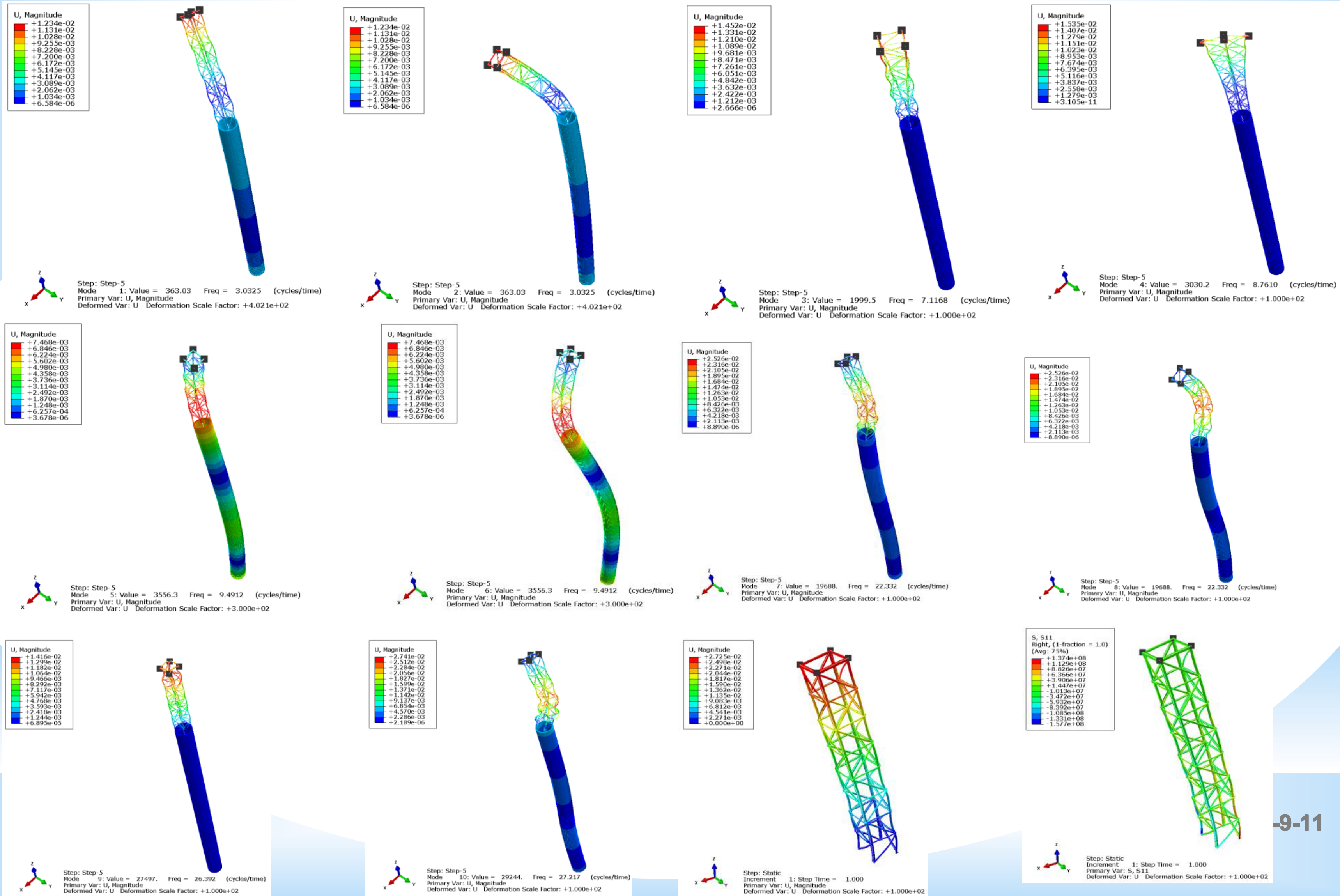
(batteries etc.) - totally 10



Eigenmodes of the buoy deformation

Frequencies are far from the wind wave range (>5Hz) !!!

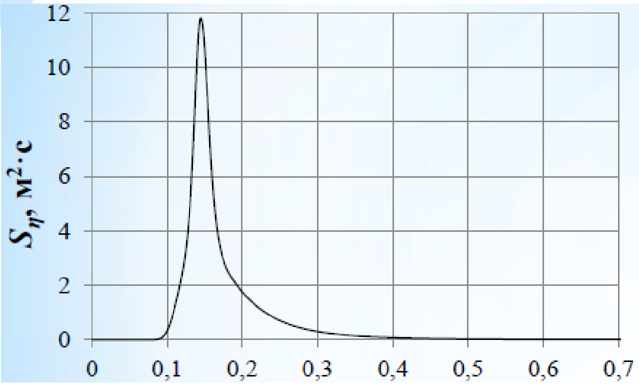
Loads are quasi-stationary



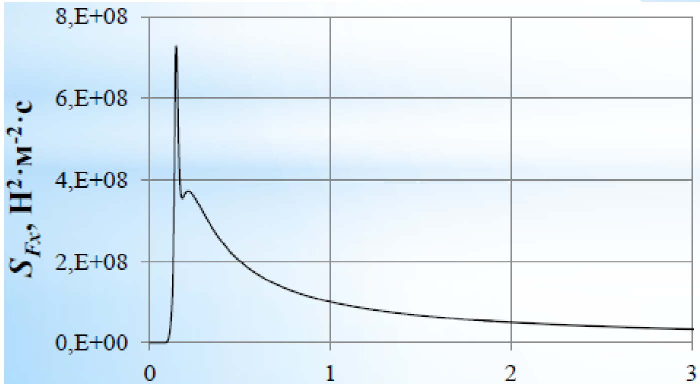
Wind and wave loads are alternating !!!
This is critical for the floating concrete structures !!!

Limiting load for compression is more than 15 times higher that one for decompression (stretching)

A JONSWAP-like parameterization of wave spectra for pairs (H_s, T_p)



Spectral density of horizonal hydrodynamic loads



Prestressed concrete structure is a regular (unavoidable) solution

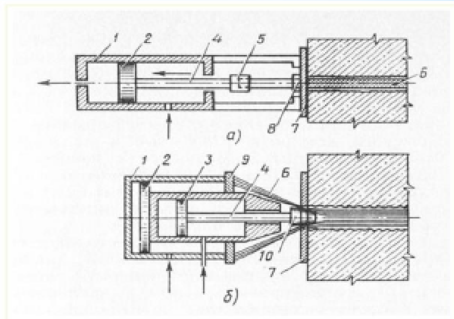


Рис. 4. Гидравлические домкраты одиночного (а) и двойного (б) действия: 1 — цилиндр, 2,3 — поршни, 4 — шток, 5 — захват, 6 — арматура, 7— прокладка, 8— шайбы, 9—обоймы для крепления арматуры, 10 — пробка

Regimes of alternating loads(Critical for the concrete structure)

Solution: different time-scale scenarios

Event	Duration	$H_{1/3}$, meters	T_m, sec	N cycles	n of σ for 99%
Max.storm-3	3 hrs	6.89	9.3	1 200	3.5
Max.storm-7	7hrs	6.00	9.06	2 800	3.9
Day	24 hrs	3.6	6.5	13 300	4.0
Weak	7 days	3.2/2.0	6.6/5.7	92 000	4.4
Month	30 days	2.6/1.4	6.0/4.7	430 000	4.9
Year	365 days	1.45	4.8	6 550 000	5.3
Decade	10 years	0.84	3.9	82 000 000	5.7

red - mean of daily (monthly) maxima
blue - maximal running mean for the whole duration

Conditions of structural health

$\sigma_c > \sigma_t$ compression is stronger than decompression

$\sigma_c + |\sigma_t| < R_b \Pi \gamma_i$ – all the stresses are weaker than the medium strength

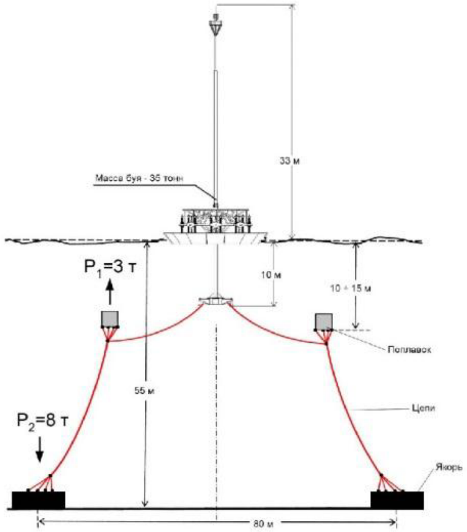
	MS-3	MS-7	Day	Weak	Month	Year	Decade
$\Pi \gamma_i$	-	0.84	0.86	0.75	**0.67**	0.71	0.70

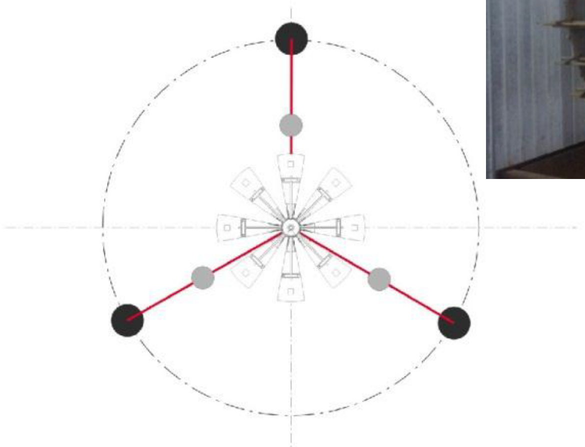
Regime ***Month*** is the most critical for assessment of the structural health

C80 and higher concrete grade - solution

Anchor system

- Buoy is fixed by three anchors and three submerged floatages (the same as the buoy sections)





Ladies are for scaling only

Anchors can be made on-site

Buoy deployment

The buoy is manufactured and transported to the place of deployment in the form of separate sections of about 3 m length. The buoy assembling is carried out on the shore. The stressed state of the structure is ensured by special jacks.

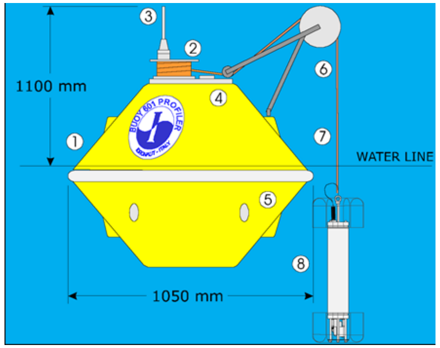
Equipment

Navigation systems

Structure control systems

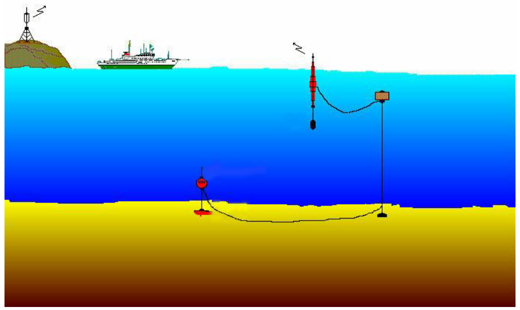
Radars

Sea
profilers



Telecommunication
systems

Seismic bottom
stations



etc.

Summary

1.The project of concrete stabilized spar buoy with the expected lifetime 10 years is presented for the Black Sea near-shore;

2.Strength and durability of the buoy are assessed. Specification of the concrete and metal constructions is formulated based on local wind sea conditions;

3.Specification of on-board instrumentation is sketched for monitoring the Black Sea near-shore.

Thank you

This work was supported by the Russian Science Foundation No. 14-50-00095.