UDC 627.24

***Doubrovsky M.P.**, DSc, Professor*
ORCID 0000-0003-1229-1717 doubr@tm.odessa.ua
***Dobrov I.Yu.**, post-graduate*
gidrotechnick@gmail.com
***Gerashchenko A.V.**, post-graduat*
andrey-david@mail.ru
Odessa National Maritime University
***Dubrovska O.M.**, Project Engineer*
ODubrovska@Deepoceangroup.com
DeepOcean, Norway

MODEL TESTING OF PILED CLUSTERS AND LARGE MONO-PILES OF IMPROVED DESIGN

When constructing piled clusters and structures supported by large mono-piles, piles designed are used to take up significant lateral and pressing-in loads. New effective and less resource-demanding design of piled cluster was considered before. At this paper some results of its model testing in laboratory conditions are analyzed and discussed. To increase energy-absorbing capacity of mooring/fender dolphins it was worked out and researched a new design of combined tubular mono-pile structure, incorporating internal flexible pile and damping element placed at the zone of pile head. This design has been tested by laboratory experiments using small scale model. Obtained results confirm its effectiveness and practicability.

***Keywords:** piled cluster, tubular mono-pile, bearing capacity, energy-absorbing capacity.*

***Дубровський М.П.**, д.т.н., професор*
***Добров І.Ю.**, аспірант*
***Геращенко А.В.**, аспірант*
Одеський національний морський університет
***Дубровська О.М.**, інженер проекту*
DeepOcean, Норвегія

МОДЕЛЬНІ ВИПРОБУВАННЯ ПАЛЬОВИХ КУЩІВ ТА ВЕЛИКИХ МОНОПАЛЬ УДОСКОНАЛЕНОЇ КОНСТРУКЦІЇ

Доведено, що при будівництві пальових кущів та споруд, що оперті на великі монопалі, використовують палі, запроектовані на великі бокові та вдавлюючі навантаження. Презентовано аналіз модельних випробувань у лабораторних умовах нової ефективної та економічної конструкції пальового куща. Для збільшення енергоабсорбційної здатності швартовно-відбійних палів розроблено та досліджено нову конструкцію комбінованої трубчастої монопалі, яка містить внутрішню гнучку палю й амортизатор, розміщений у зоні голови палі. Це рішення було перевірено лабораторними експериментами на моделі малого масштабу. Отриманими результатами підтверджено його ефективність та практичність.

***Ключові слова:** пальовий кущ, трубчата монопаля, несуча здатність, енергоабсорбируюча здатність.*

Introduction. When constructing piled clusters and structures supported by large mono-piles, piles are used to take up significant lateral and pressing-in loads [1].

Analysis of recent researches and publications. In particular it relates to deep-water sea structures piled foundations which need long piled supports of high bearing capacity [2 – 5]. It corresponds to one meets high level of stresses and significant deformations in such constructions. Some improved structures and technologies have been worked out to optimize stress-strain state of piled clusters and mooring/fender dolphin [6].

Identification of general problem parts unsolved before. To study peculiarities of these two innovative design solutions model testing in laboratory conditions have been produced in Odessa National Maritime University (Department «Sea, River Ports and Waterways»). Physical modeling was provided at two stages. The first one (preliminary experimental research) was simplified by testing of the model without soil media (instead of piles embedded into the soil piles' tips were fixed by special clamps (console scheme).

The aim of this first (simplified) stage was to determine the most appropriate calculation model and related software to be applied later at the second stage of experiment. The second stage was planned to test the same models in the soil box without artificial fixing of piles tips (piles were embedded into sandy soil).

In this paper we consider and discuss results of the first testing stage.

Basic material and results. 1) Model testing of pile cluster with shelled element. Developed is effective and less resource-demanding design when connection of all piles with large diameter casing provides their joint work and favorable distribution of stresses and deformations in pile cluster (Figure 1). Large diameter casing is installed both above and below sea bottom level relieving piles and then in decreasing stresses. Connection between casing and piles may be provided with similar sheet piles interlocks.

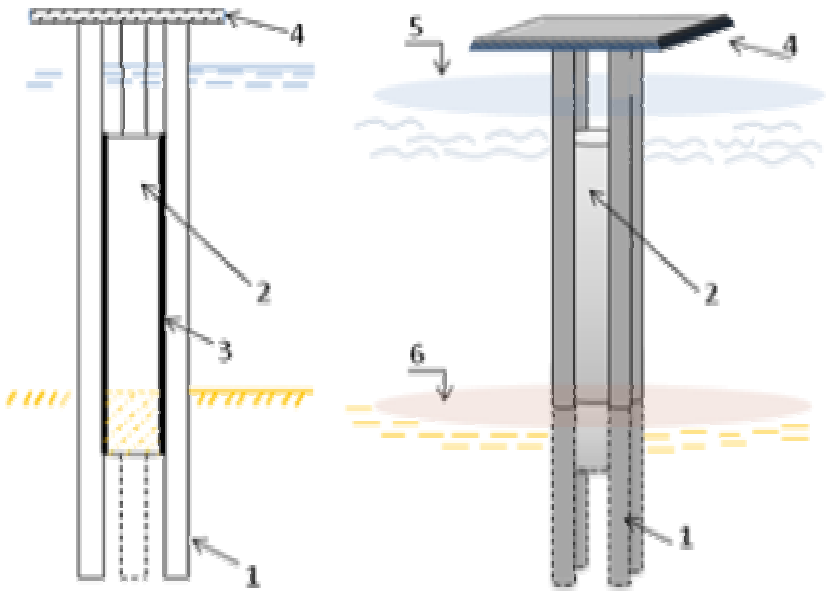

Figure 1 – Piled cluster of innovative design: a – cross-section; b – 3D view: 1 – bearing piles; 2 – steel cylindrical casing; 3 – interlock connections; 4 – superstructure; 5 – water level; 6 – bottom level

Such structure has been tested on 3-D physical model (scale appr. 1:100). Pile supports are fixed by special clamps to exclude their tips' displacements. Total length of the piles was preliminary determined according to the known recommendations of actual design codes (Figure 2).

a) b)

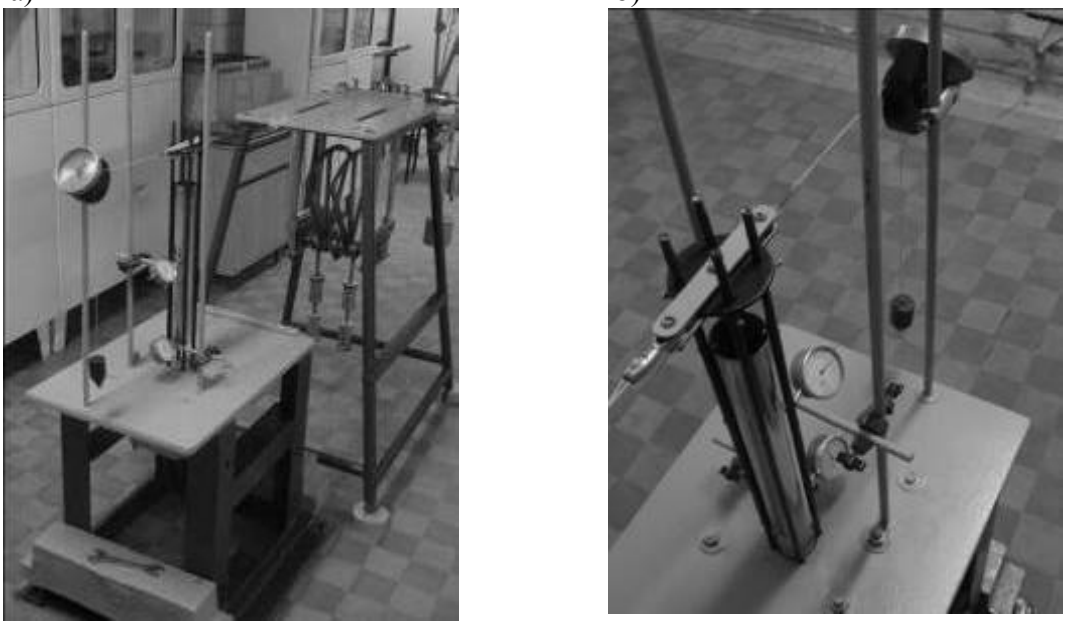

Figure 2 – Model testing of piled cluster model in laboratory
a – general view of the model; b – measuring and loading systems

The same model was analyzed by 3-D numerical simulation (FEM) using different programs in order to determine the most proper calculation model and software regarding peculiarities of the model and interaction between its elements. Three programs were applied to determine stress-strain state of the model: AxisVM, Lira-SAPR and Midas-Gen (calculation scheme is presented on the Figure 3).

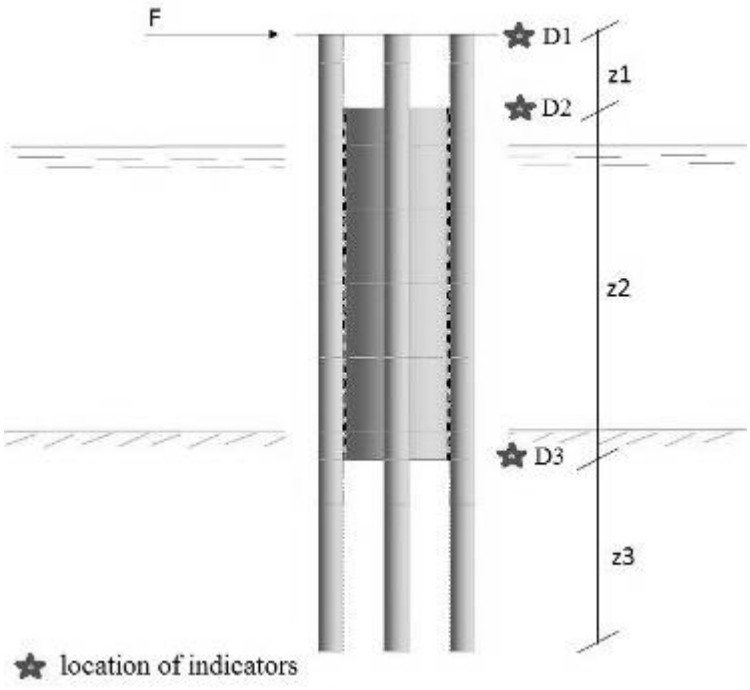

Figure 3 – Calculation scheme
(piles' tips are fixed, D1, D2 and D3 – locations of displacement indicators;
F – applied lateral force)

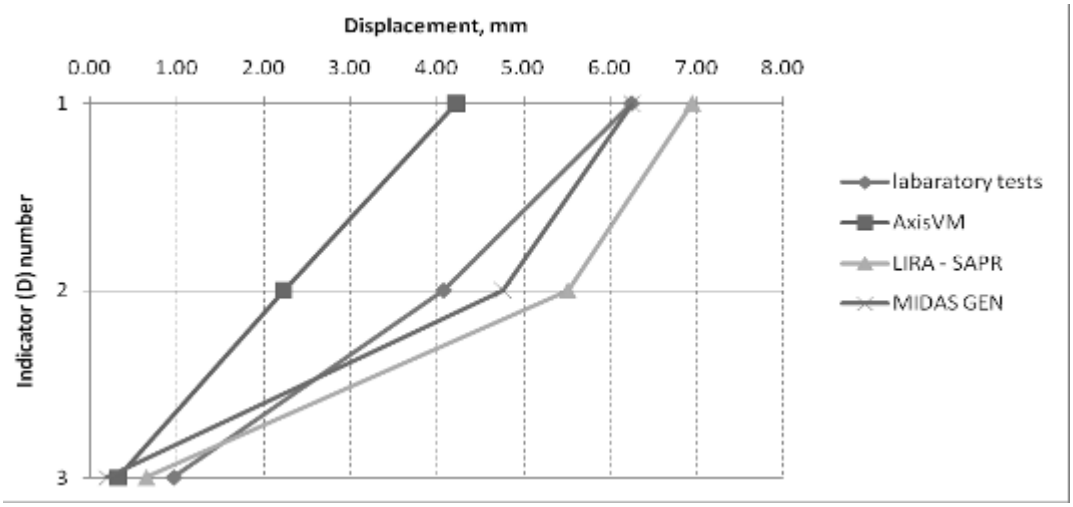

Figure 4 – Displacement diagrams obtained in experiment and calculated using different software (external lateral force F=350 N)

Program Midas-Gen demonstrates the most close results to experiment. So it will be applied further to describe more complex system «structure-soil».

2) Model testing of combined mooring/fender dolphin. To increase energy-absorbing capacity of mooring/fender dolphins it is worked out and researched a new design of combined tubular mono-pile structure. It incorporates internal flexible pile and damping element (cushion) placed at the zone of pile head (Figure 5). Work of damping element is correlated with bending strain parameters of combined mono-pile structure.

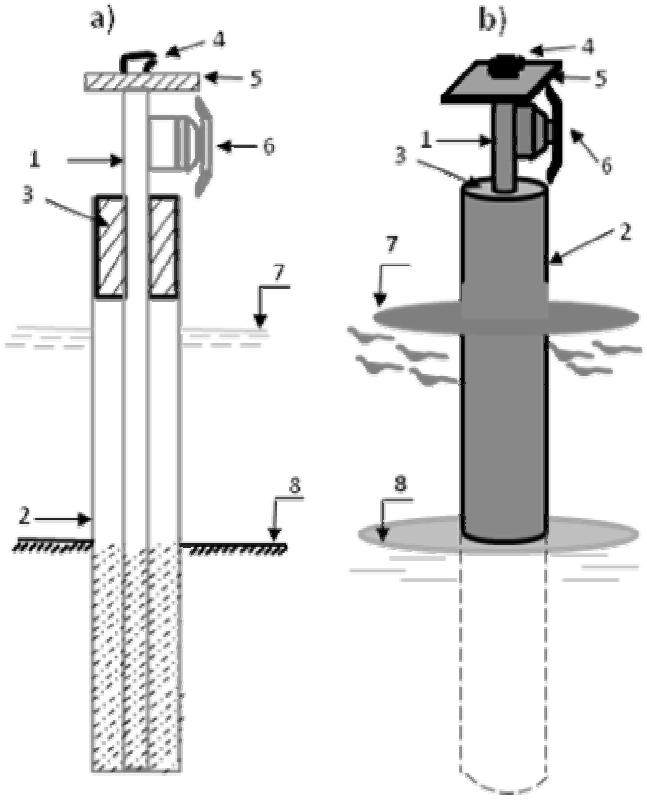

Figure 5 – Mooring/fender dolphin: a – cross-section; b – 3D view:
1 – internal pile; 2 – external tubular pile; 3 – damping element (cushion);
4 – bollard; 5 – superstructure; 6 – fender; 7 – water level; 8 – bottom level

External force provoked by ship mooring (either via bollard of via fender) initially is taken by internal pile. While bending the internal pile presses the damping element and through this cushion transfers the decreased force to the external tubular pile. Thus due to joint work of three elements (internal and external piles and damping cushion between them) the dolphin may take essential ship load. It makes needless use of large diameter (3-4 m) heavy-walled (40-60 mm) tubular pile of ruggedness strength (and, correspondingly, of high cost). In such a case combined dolphin made of two comparatively small diameter piles (of about 1 m for external pile and 0.5 m for core one) may be profitably applied to withstand large operational force.

This structure has been tested on physical model in laboratory (Figure 6). Pile supports (both internal and external) are fixed by special clamps to exclude their tips' displacements. Total length of the piles was preliminary determined according to the recommendations of actual design codes.

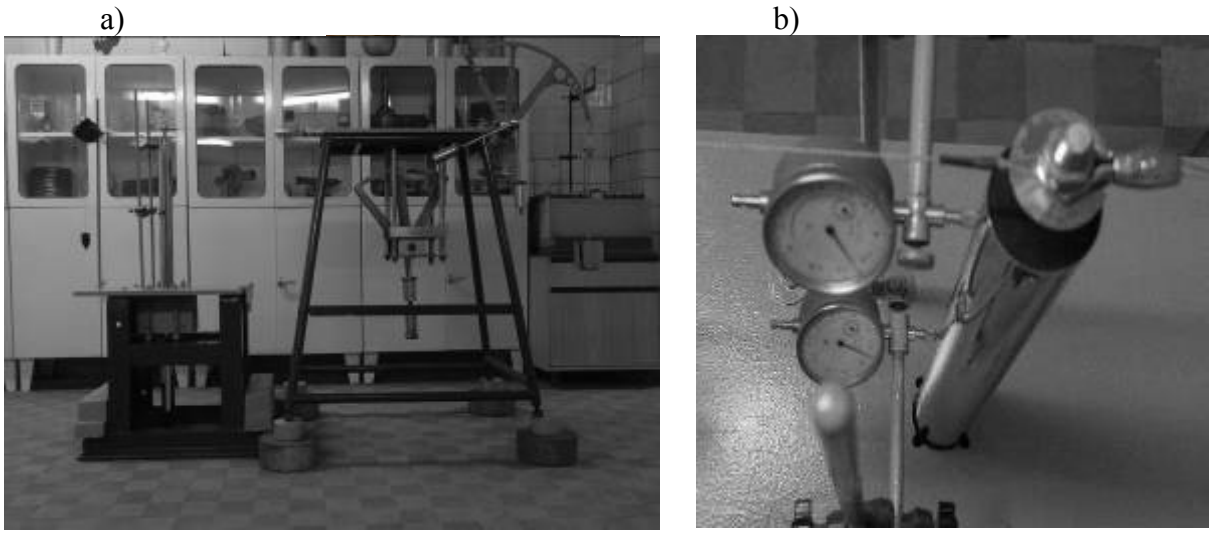

Figure 6 – Model testing of mooring/fender dolphin model in laboratory
a – general view of the system; b – measuring and loading facilities

The same model was analyzed by 3-D numerical simulation (FEM) using different programs (as above) in order to determine the most proper calculation model and software regarding peculiarities of the model and interaction among its elements. Calculation scheme is presented on the Figure 7, where points d1, d2, d3 and d4 correspond to the location of displacement indicators (to simplify external force application both tubes in this test were fixed horizontally).

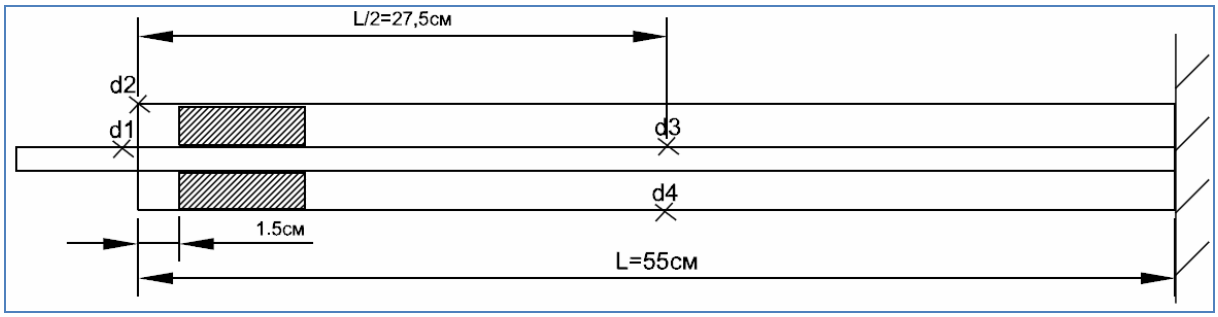

Figure 7 – Simplified scheme of the dolphin's model

The most appropriate results were obtained by use of program Midas-Gen when for description of damping element work elastic-plastic model of applied Druker-Prager (Figure 8 and Table 1).

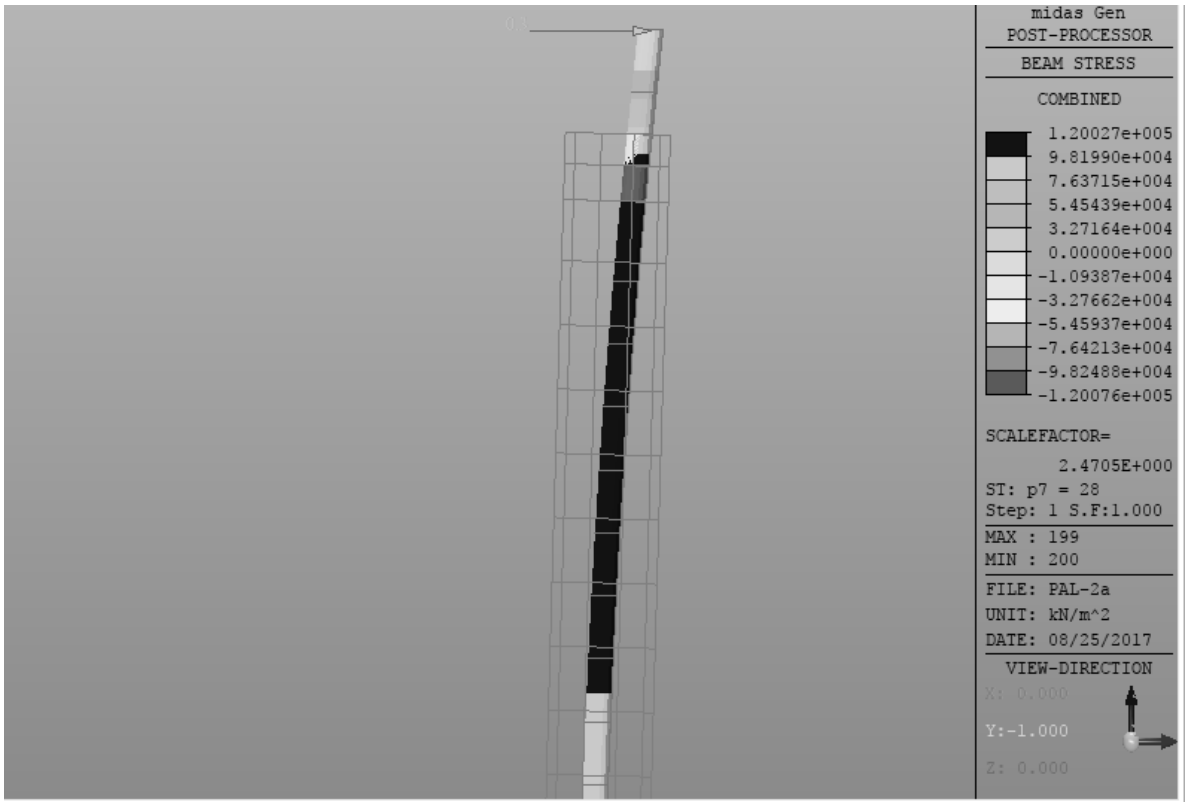

Figure 8 – Deformations of the dolphin under lateral force application (Midas-Gen)

Table 1 – Calculated and measured horizontal displacements of internal and external piles at points d1 and d2

Force, N	Indicator d1, mm			Indicator d2, mm		
	test	calculation	difference	test	calculation	difference
4	1,525	1,443	0,082	0,745	0,837	-0,092
8	2.310	2,880	-0,570	1,545	1,673	-0,128
12	3,200	4,320	-1,120	2,415	2,508	--0,093
16	5,050	5,760	-0,710	3,315	3,343	-0,028
20	7,050	7,190	-,0140	4,265	4,177	0,088
24	9,110	8,610	0,500	6,015	5,010	1,005
28	10,910	10,030	0,880	7,045	5,844	1,201
32	12,600	11,440	1,160	7,960	6,677	1,283

So discrepancy of test and calculations reaches up to 17 %. Therefore program Midas-Gen and above mentioned model may be applied for considered structure design for further more complicated stage of the system «dolphin – soil». Besides in general, results of tests demonstrated expected contribution of both piles (internal and external) and damping element either qualitatively or quantitatively.

Conclusions. Fulfilled experiments have given possibility to check effectiveness of innovative structural and technological solutions effectiveness of piled cluster and mooring / fender dolphin on combined mono-pile.

The first stage of the planned tests (experiments without soil with fixed piles' tips) occurred to be useful for study of proposed structural peculiarities of both new designs as well as for appropriate calculation program determination (by comparison of measured and calculated data).

Obtained results may be used as sufficient background for the second stage of planned experiments when both innovative structures will be tested in the sand box for detailed study of structure-soil interaction.

References

1. *Tomlinson M. G. Pile Design and Construction Practice: 4th Edition / M. G. Tomlinson // E&FN SPON. – An Imprint of Chapman & Hall, 1994. – 411 p.*
2. *Gerwick B. C. Construction of Marine and Offshore Structures / B. C. Gerwick. – CRC Press. Taylor & Francis Group, 2007. – 386 p.*
3. *Doubrovsky M. P. Marine Engineering and Geotechnique / M. P. Doubrovsky, M. B. Poizner. – Odessa: DRUK, 2000. – 163 p.*
4. *Doubrovsky M. P. Innovative development of coastal, port and marine engineering / M. P. Doubrovsky, M. B. Poizner. – Lambert Academic Publishing (Germany), 2016. – 125 p.*
5. *Морские шельфовые и речные гидротехнические сооружения / М. П. Дубровский, П. И. Яковлев, В. Т. Бугаев и др. – М.: Недра, 1997. – 370 с.*
   Morskie shelfovyie i rechnyie gidrotehnicheskie sooruzheniya / M. P. Dubrovskiy, P. I. Yakovlev, V. T. Bugaev i dr. – M.: Nedra, 1997. – 370 s.
6. *Дубровский М. П. Некоторые инновационные конструкторско-технические решения причальных сооружений и палов на свайном основании / М. П. Дубровский, И. Ю. Добров, А. Ю. Геращенко // Будівельні конструкції: міжвід. наук.-техн. зб. – К.: НДІБК, 2016. – Вип. 83, кн. 2. – С. 38 – 43.*
   Dubrovskiy M. P. Nekotoryie innovatsionnyie konstruktorsko-tehnicheskie resheniya prichalnyih sooruzheniy i palov na svaynom osnovanii / M. P. Dubrovskiy, I. Yu. Dobrov, A. Yu. Geraschenko // BudIvelnI konstruktsIYi: mIzhvId. nauk.-tehn. zb. – K.: NDIBK, 2016. – Vip. 83, kn. 2. – S. 38 – 43.

Received 13.09.2017