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Dynamic Calculation of the Pile Supported Wharf

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The article deals with the issues of designing and operating marine pile supported wharf in the seismically hazard areas considering various superstructures and overload equipment influence. Analysis of hydraulic structures seismic resistance erected in seismic regions of Ukraine shows that the actual seismic load on buildings significantly exceeds the estimated loads that are determined by the normative documents before 2006. Design of hydraulic structures should be done considering berths of reloading complexes, with proper scientific support. Berth construction calculationsof the ship repair yard No. 2 of the «Ilichevsk Ship Repair Plan» are given.

Keywords: hydrotechnical structures, seismic, ice and wave loads

Динамічні розрахунки причальних споруд естакадного типу

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Розглянуто питання проектування й експлуатації морських гідротехнічних споруд з урахуванням впливу різних надбудов і перевантажувального обладнання у сейсмічно небезпечних районах України. Сейсмічні впливи можуть задаватися як лінійно-спектральним методом, так і прямим динамічним методом, за розрахунковими акселерограмами землетрусу, які являють собою трикомпонентну функцію прискорення коливань у часі. Необхідність обліку спільної роботи комплексу «основа – споруда», обліку різних навантажень та впливів призводить до ускладнення розрахункового обґрунтування споруд. Аналіз сейсмостійкості гідротехнічних споруд, зведених у сейсмічних районах України, показав, що фактичні сейсмічні навантаження на споруди значно перевищують розрахункові навантаження, які були визначені нормативними документами до 2006 року. Наведено аналіз можливих видів руйнувань причальних споруд естакадного типу під час землетрусу, для аналізу використовувалися вітчизняні та іноземні літературні джерела. На основі аналізу визначено основні види руйнувань як окремих елементів, так і всієї конструкції, побудовано блок-схему та матрицю для визначення ймовірності безвідмовної роботи конструкції як для нормативних значень забезпечення надійності окремого елемента за окремими видами руйнувань, так і розрахункових. З’ясовано, що проектування гідротехнічних споруд повинно здійснюватися з урахуванням перевантажувальних комплексів за належного наукового супроводу. Наведенно можливі розрахункові схеми причалів естакадного типу, а саме: одномасову систему, двовимірні системи та загальний випадок просторової системи.

Ключові слова: гідротехнічні споруди, сейсміка, льодові та хвильові навантаження

Introduction. Ports development is one of the most important components of state economy development. In the era of globalization, the transformation of cargo flows, changes in their structure, port development planning issue, which implies port facilities balanced development, namely: sea zone development, port zone, and land zone, becomes especially important. In connection with the change in the normative intensity of seismic impact in DBN 1.1-12: 2014 in relation to SNiP II-7-81, for 4 marine ports in Ukraine, now the normative ball of the construction area is more by one ball on the MSK-64 scale, and 7 of the 13 ports are in areas with a glide above 7. It should also be noted that the territories, where ports are located, are characterized by complex engineering-geological conditions with a wide spread of highly porous loam and loamy sandy sediments related to the III-IV categories of seismic properties. According to the requirements of DBN B.1.1-12:2014 the calculated seismicity for ground conditions of this type should increase by one point relative to the normative one. Considering the fact that seismic impact can lead to destruction of port hydraulic structures that lead to disruption of port functioning, seismic impact assessment along with port upgrading is an important and urgent task.

Characteristic types of pile mooring structures destruction supported wharf with seismic actions *Port of San Fernando, Philippines*. On July 16, 1990, the Luzon earthquake in the Philippines with magnitude of M = 7.8 damaged the wharf № 1 in the port of San Fernando. Pier on reinforced concrete piles of a square section is 200 m long and 19 m wide. Vertical and inclined piles were used (Fig. 1).

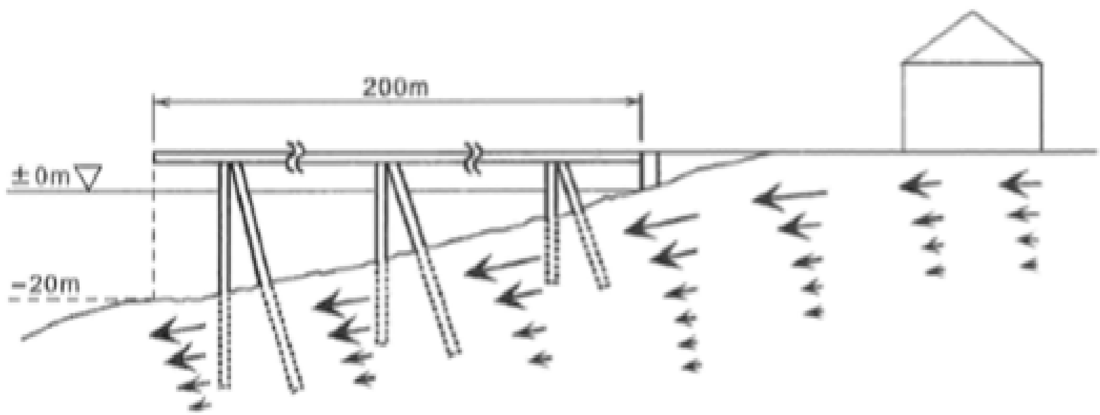

Figure 1 – Port of San Fernando, Philippines [10, 13]

The pier has received longitudinal displacements towards the sea [13, 14] as a result of shifts and bearing soil deformations. A lot of cracks arose in the longitudinal direction of the upper structure. The maximum opening of the cracks is 1.5 m. Also, cracks and fractures of pile heads were observed .

Port of Eilat, Israel. Earthquake on November 22, 1995 in Israel, the size of M = 7.2. The port of Eilat was at a distance of 100 km from the epicenter of this earthquake. The main berth had a total height of 13 m and a water depth of 10.5 m (Fig. 2). This open-type berth consists of prefabricated slabs and grillage on octagonal prestressed ferroconcrete piles with a diameter of 46 cm. After the earthquake, the pile was not damaged, but constant movements in the range of 5 to 15 mm led to jonts opening [5,10].

Port of Auckland, USA. The Loma Prieta earthquake in 1989, with a magnitude of 6.9 in California, caused serious damage to the terminal facilities in the port of Auckland [10, 13], which was 90 km north of earthquake epicenter. Acceleration in the Port of Auckland is 0,25 – 0,3g.

The most serious damage was inflicted on the Terminal in the vicinity of 7th Street (Fig. 3). The rarefaction of the backfill resulted in subsidence, coating lateral expansion and cracking over a large area. The nature of the damage was related to the fracture under tension as a result of embankment external pressure, indicating that liquefaction and accompanying transverse deformations were decisive factors.

Based on the analysis of trestle type moorage structures destruction during earthquakes, three main causes of trestle type moorage structures destruction during earthquakes can be identified [13]:

1. For berths built on strong ground it is the perception of inertia forces from the upper structure by piles (Fig. 3, a)

2. The maximum bending moment occurs in the headers of piles in the rear zone, since they have the smallest free length. In the event of significant shifts in the backfill, there may be movements of the upper structure towards the sea, which in turn lead to destruction, as shown in Fig. 3, b;

3. For berths built on weak soils, the appearance of piles movement towards the sea is characteristic, as shown in Fig. 3, c.

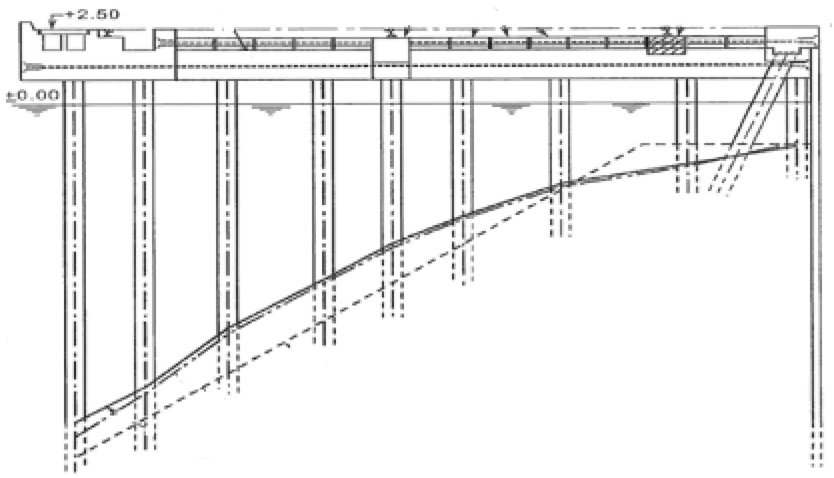

Figure 2 – Port of Eilat, Israel [10]

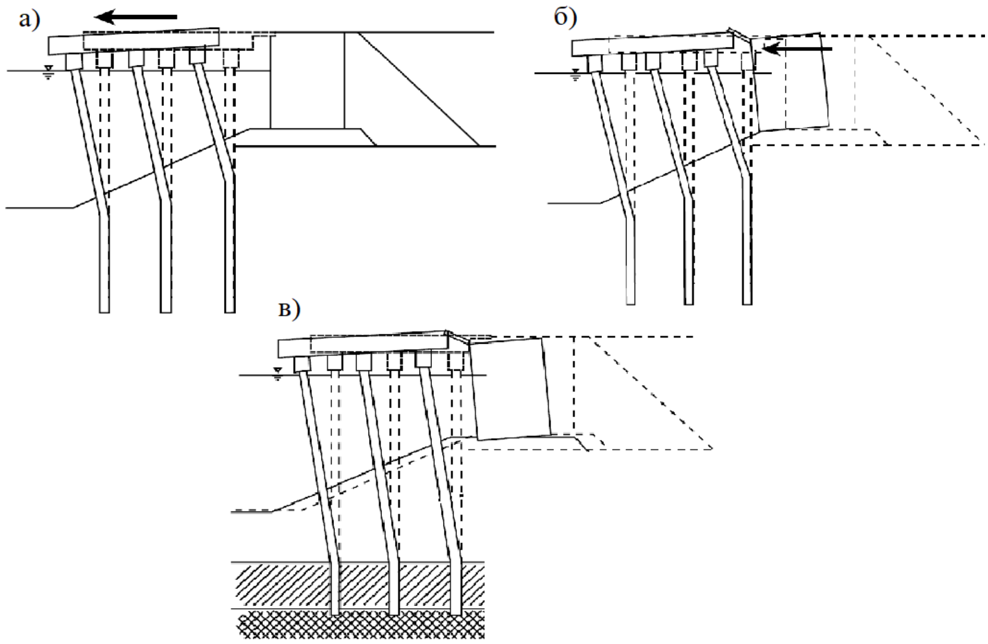

Figure 3 – Possible types of pile supported wharf during the earthquake destruction [13]:
a) deformation under the influence of inertia forces from the upper structure;
b) deformation in the event of significant shifts in the backfill;
c) deformation in weak soils

Design diagrams of pile supported wharf. Dynamic design schemes of pile supported wharf designed to determine seismic loads should be presented (Fig. 4, Fig. 5) [12, 16].

The most common and at the same time simple model is a single mass system (Fig. 4).

In modern design, a two-dimensional model is widely used to estimate the strength in the transverse direction-a multi-span frame (with rigid jamming and elastic springs modeling the base soil work (Figs 5, a, 5, b)) [13].

Recently, software complexes for the spatial calculation of complex structures have been developed. Figure 6 shows the calculated schemes of the pier:

– depending on the presence of links between sections, either as a chain of sections (see Figure 6 a), or as a separate section (see Fig. 6 b);

– depending on the presence of high-rise superstructures, or without add-ins (see Fig. 6a, b), or with superstructures (see Fig. 6 c, d) [13];

– depending on section upper structure deformation in the horizontal plane, or in the form of a hard disk (see Fig. 6, a, b, c), or in the form of a deformable structure (see Fig. 6, d), supported by elastic pile supports.

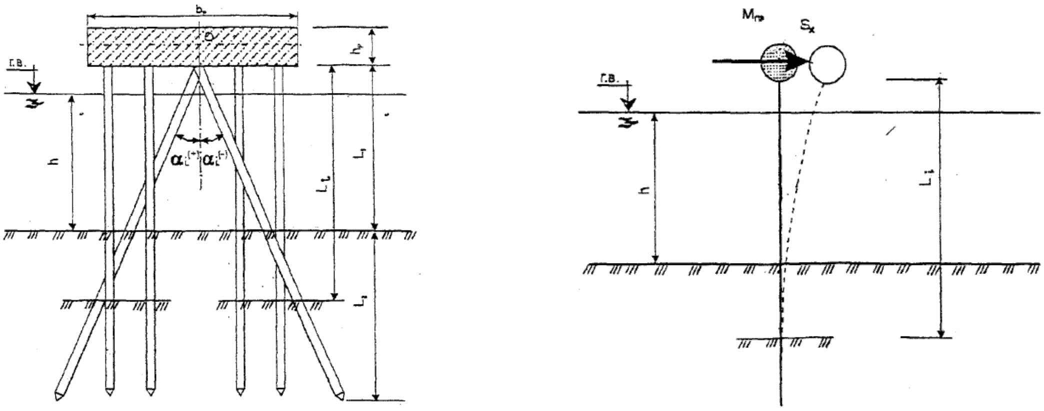

Figure 4 – Calculated (left) and reduced (on the right)

a) b)

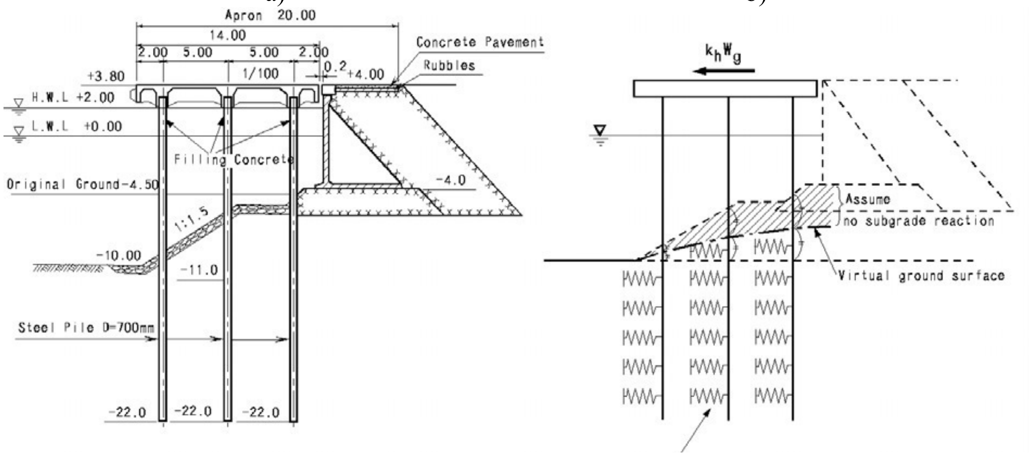

Figure 5 – Simulation of pile wharf:
a) rigid pinching; b) a system of elastic springs modeling the ground

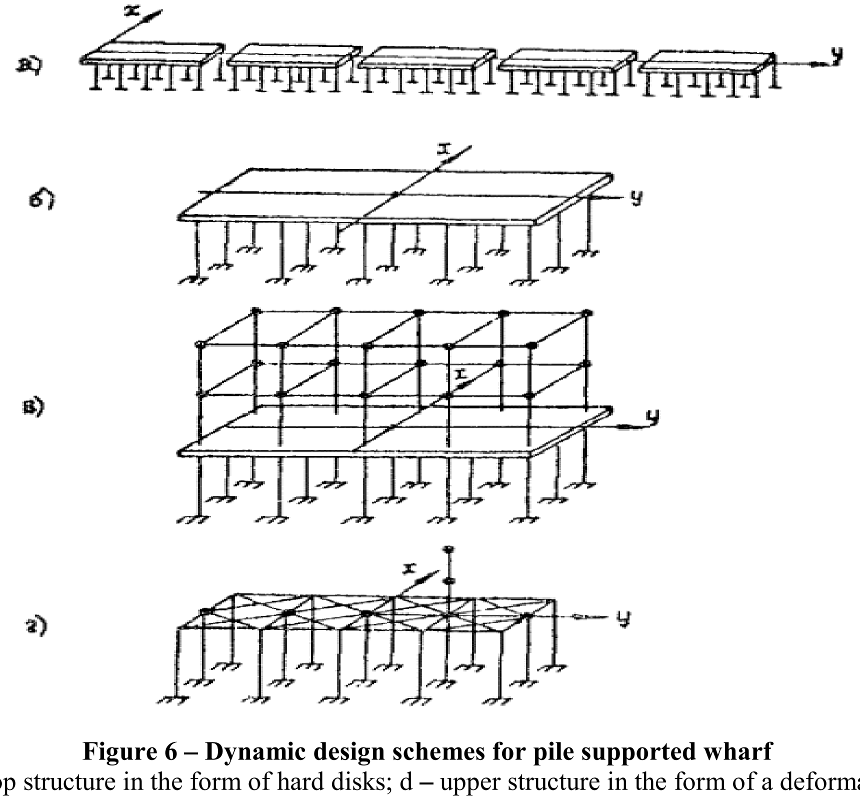

Figure 6 – Dynamic design schemes for pile supported wharf
a, b, c – the top structure in the form of hard disks; d – upper structure in the form of a deformable structure

The results of pile whatf calculation. Verification calculations were carried out for pier design of the ship repair pier No.2 « Ilyichevsky shipyard», considering design solutions for the reconstruction of the hydrotechnical part of the pier No.2 of the ISRZ for receiving Panamax type vessels for handling grain cargo. The calculation was carried out using the SCAD software, which implements the finite element method.

Loads and actions taken to calculate structures correspond to DBN B.1.2-2: 2006 «Loads and impacts» and SNiP 2.06.04-82 «Loads and impacts on hydraulic structures (wave, ice and ships).» [3]. Seismicity of the area for the proposed hydroengineering facility of responsibility class for the failure in operation of CC2-2 - 7 (seven) points.

It is supposed to perform a partial reconstruction of the berth, namely: to keep the depth on one side of the pier while installing the dredging on the other side, with the device of a subprime slope with a laying close to 1: 4, with matting of the BONTEX type. The settlement vessel of the type CH-50 (Panamax), the depth at the berth is 12.5 m from the «O» port. For the perception of mooring forces with reinforced concrete existing piles altered due to dredging, on feast two sides, the pallet openings, which are monolithic reinforced concrete superstructures, 1550 mm thick, joining 4 newly arranged piles of steel rolling profiles «Stainless Steel Pipes» along GOST 10704-91, with a diameter of 1020 mm, with a wall thickness of 14 mm. With the berth section standart length of 46.5 m, there are four slots for one section (2 on each side symmetrically). The pallets are joined in pairs by a monolithic reinforced concrete superstructure due to the promontory of the existing superstructure, including rubbing, 1550 mm thick. In the middle part of the joining plate, a pair of inclined piles are arranged, symmetrical to the longitudinal axis of the section, from pipes of the same diameter, with a 3: 1 laying. The mark of the piles bottom lowering corresponds to the roof of the IGE «Sand clayey» (abs-30.5), which corresponds to the length of the vertical element of 31.55 m and 33.26 m – the sloping one.

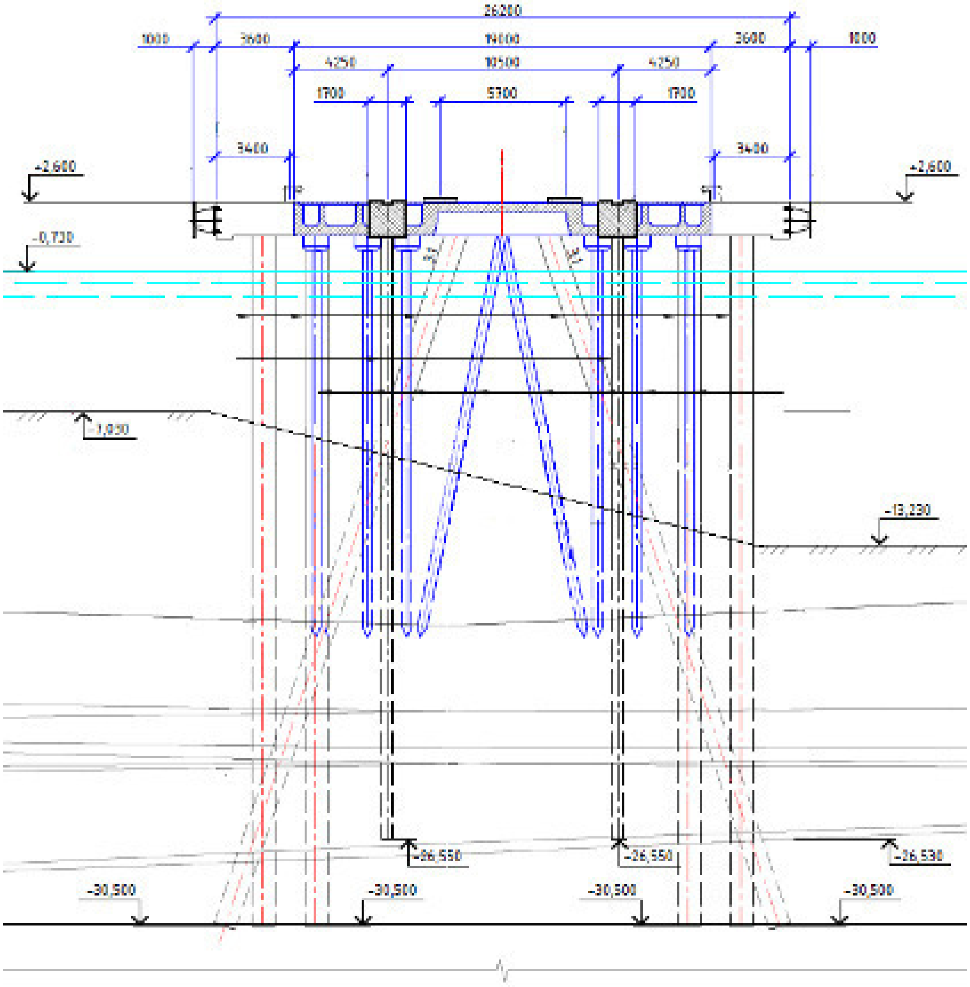

Figure 7 – Cross section

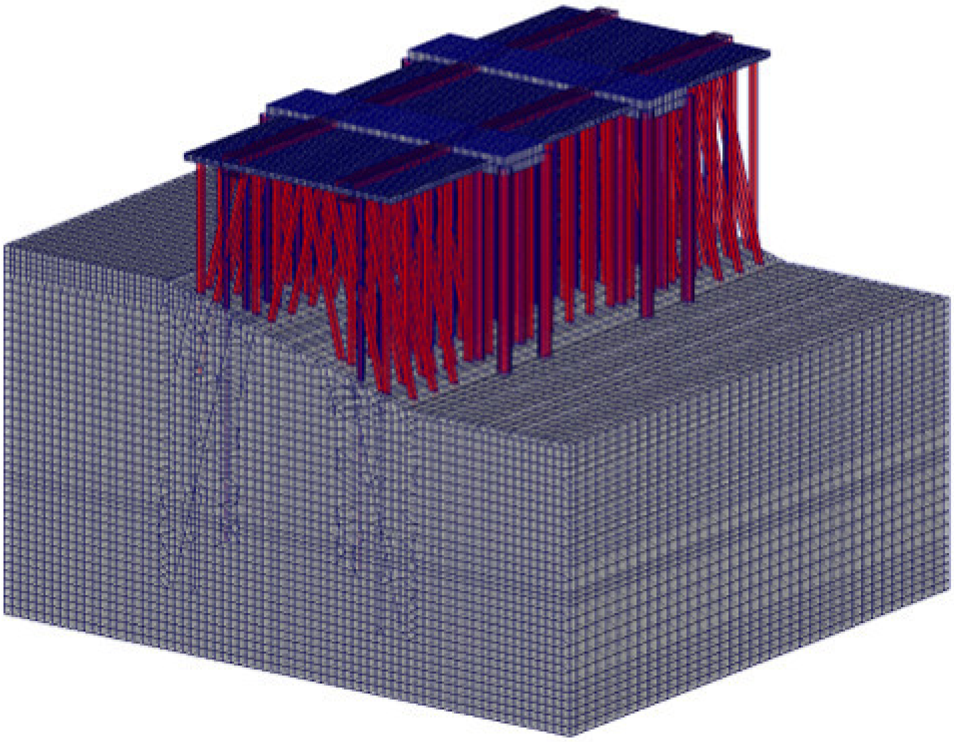

Figure 8 – three-dimensional design frame. General form

Re-profiling the berth for the processing of grain cargo provides for the installation of a loading machine with a capacity of 1200 t/h of the type «Neuero». The base is 10500 mm, the number of rollers is -4 (5), the load on the skating rink is up to 37 tons.

To absorb loads from the reloading machine, additional series of piles are arranged along the axis of crane beams from the steel rolling profile «Pipes made of straight steel» according to GOST 10704-91, with a diameter of 530 mm, with a wall thickness of 12 mm. The pile step corresponds to the 2.5 m moorage accepted for the original design.

The accepted cross-section of a monolithic reinforced concrete crane girder is 170x155 cm.

For cargo delivery to the reloading machine on the quay, a conveyer gallery assembly is provided. The gallery is made of metal structures. Supports pitch is vertical, in the longitudinal direction – 6 m, in the transverse direction - 5.7 m. The calculation scheme is shown in Fig. 8.

Considering feasibility study nature, the following loads and their combinations were used to assess structure performance:

– Load from the own weight of the structural elements (L1);
– Load from the ship loader (L2..L6);
– Load from transport conveyor gallery (L7);
– Load from mooring tension (L8);
– Payload on the berth territory (L9);
– Seismic impact intensity of 7 (seven) balls in the direction «perpendicular» to the longitudinal axis of the pier.

The results of the calculation are presented in Table 1.

Table 1 – Periods of oscillation

Load	Form	Eigenvalues	Frequency		Periods (seconds)
			1/sec	Gz	
10	1	0,308	3,252	0,518	1,931
10	2	0,221	4,517	0,719	1,39
10	3	0,205	4,881	0,777	1,287
10	4	0,068	14,78	2,354	0,425
10	5	0,066	15,229	2,425	0,412
10	6	0,055	18,15	2,89	0,346

Proceeding from the experience of designing such structures and in accordance with [9], the period of port piers and pile embankments natural oscillations (including the inclined pile) is in the range T = 0.19 – 0.44. This leads to the need to take the coefficient of dynamism on the ground β = 2.5 that determines the maximum horizontal seismic force on the port overpass.

The period of pier natural oscillation in accordance with the manual calculation is T = 0.4481 sec, and in the three-dimensional model T = 1.931 sec, which leads to an underestimation of seismic forces.

The calculations showed that the berth was designed for loading from the windfall at a wind speed of 20 ms, a design vessel of the Panamamax type.

The horizontal force from the windmill is equivalent to the seismic force at 7 balls.

Analysis of research results. The significant change in the technical regulatory framework during the period of Ukraine's existence as an independent state led to the situation when most of the port infrastructure facilities commissioned before 1991 and currently operated nowadays do not meet the requirements of these standards. For example - with the implementation of DBN B.1-1-12: 2006 and revision B.1-1-12: 2014, formally, none of Odessa and Ilyichevsk ports hydraulic structures, built before 2006, do not provide the required responsibility class, since their calculation and design were carried out, including without consideration possible seismic event onset.

In the process of designing marine hydraulic structures, many natural factors should be considred including hydrological, hydrographic, engineering-geological, geomorphological, and meteorological conditions of the construction area. Hydrological conditions include: sea wind wave, ice regime, level fluctuations, sea currents, tsunami waves. The hydrographic conditions include water depth, seabed and adjacent coastline topography. Of particular importance are the engineering-geological and geomorphological data on seabed structure, bottom soils physical and mechanical properties, and sediments migration. The main meteorological factor is the wind regime (speed, direction and duration). Also, during the design of offshore structures, seismic calculations must be performed. In this case, it is necessary to consider structure structural features and construction area existing engineering and geological conditions [3, 4].

Calculations of hydraulic structures strength, landslide slopes stability, structures located on them and bank protection structures in Odessa region should be carried out considering seismic loads. These effects can be specified either by linear-spectral method or by direct dynamic method, according to the calculated accelerograms of earthquake which represent oscillation acceleration three-component function in time.

The need to consider joint work of the «foundation-construction» complex, taking into consideration the various loads and impacts, leads to design basis for the structures complication. Calculation of emergency (seismic) impact using calculated accelerograms, considering nonlinear physical properties, considering the stages of construction, complicating the task of calculating and designing marine hydraulic structures many times, and at the same time making it possible to obtain rational solutions that provide specified operational properties with regulated reliability and safety parameters.

Conclusions. The issues of port hydraulic structures calculations, design, maintenance, repair, inspection and reconstruction have traditionally been regulated by the departmental requirements (Ministry of the Maritime Fleet) regulatory documents. There are no updated versions of these documents that correlate with state building regulatory documents.

Regardless of the current strategy for the port industry development, a systemic state approach is required to create modern technical regulatory framework and effective methods for monitoring compliance, especially for strategic port infrastructure facilities.

When designing hydraulic structures, it is necessary to considere a number of factors and requirements; compliance with them ensures structure effective operation, reliability and durability.

Based on the analysis of surveys results and existing regulatory documents requirements, it is necessary to designate the design parameters of natural, including seismic, impacts on the designed structures, considering their service life.

Design of hydraulic structures should be carried out considering transshipment complexes at the berth, with proper scientific support.

The use of new constructive solutions requires appropriate experimental studies, including in-situ and laboratory conditions.

During project implementation, it is necessary to comply with the regulatory documents requirements that ensure construction and installation works proper quality.

At present, it is necessary to improve the methods for calculating the stress-strain state of the soil foundation under hydraulic engineering structures, considering alternating effects.

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