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Head MM of atomic energy development
_____________ A.L. Lapshin
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Deputy minister

Ye. A. Reshetnikov

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Gosatomnadzor of Russia

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GUIDE

for identification of loads imposed on civil structures and equipment of nuclear power plants when cask of others objects drop to the pool filled with water

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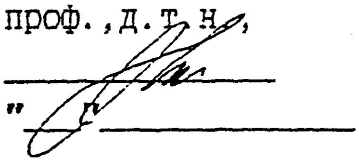

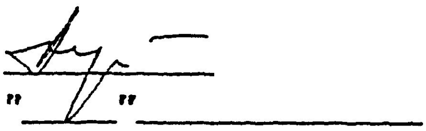

Work manager

MSCU head of department

Prof., Dr. Eng., academician

Зав.кафедрой МГСУ,

Chief engineer of the Institute Atomenergoproekt

академик

A.V.Mishuev

V. N. Krushelnitsky

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Remarks of Gosatomnadzor, Russia, (ref. 14-33/354 dated 25.07.94), Nizhegorodsky Institute "Atomenergoproekt" (ref. 21451/13-1172 dated 13.05.94), Russian Thermal Engineering Institute – VTI 70170 MO (ref.875 dated 21.12.96), All-Russian Research Institute of Hydraulic Engineering behalf B. E. Vedeneev - VNIIG" (ref. 2-29 dated 16.01.97) were taken into account while this study guide issuance

Guide for identification of loads imposed on civil structures and equipment of nuclear power plants when cask of others objects drop to the pool filled with water. Moscow State Construction University- M., MSCU, 1996

Methodologies have been developed in this "Guide ..." for identification of the parameters of the processes that produce the dynamic loads on the enclosing structures of the pool and calculations of these loads when emergency drop of a cask or other objects to the pool. Examples of calculating algorithms and the calculations themselves are given for the typical structures of the nuclear power plant pools.

This "Guide ..." is intended for use while nuclear power plants designing and cover the facilities of the Russian Federation Ministry of Nuclear Power.

The Guide was complied by - Acad., Professor, Doctor of Engineering. A.V. Mishuev,

associate professor, PhD in Engineering A.A. Gusev,

associate professor, PhD in Engineering V.D. Alexeenko

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LEGENDS

ΔP_f - pressure on shock wave front;

a_w - sound propagation speed in water;

a_c - sound propagation speed in the material of cask or dropping object;

ρ_w - water density;

ρ_c - cask or dropping object volume density;

$\tau_\perp$ - time of shock wave effect;

m_c - mass of cask or dropping object;

ω_p - cross sectional area of pool;

ω_c - midsection area (maximum sectional area perpendicular to the direction of drop) of cask or dropping object;

d_c - cask diameter;

h - height of cask (object) drop;

h_0 - water depth in pool;

ΔP - maximum permissible pressure increase on the bottom and walls of the pool after cask water surface impact (for $h_0 > d_c/2$);

t_p - time of pressure effect on the bottom and walls of pool after cask impact upon water surface;

V_w - shock wave front water velocity;

V_{max} - cask maximum immerse rate;

k - pressure release factor versus to shock wave front pressure;

β - attenuation factor of cask drop rate in water versus to drop rate in air;

$V_{w\ max}$ - maximum average water flow velocity between pool walls and immersing object;

h_{max} - maximum height of water splash from pool after emergency drop of cask to the pool;

$\mathbf{W}_{of}$ - water overflow volume from pool when cask drop into it;

W_c - volume of dropping object.

1.General provisions

1.1. Purpose of "Guide"

The purpose of the "Guide" is to calculate the force impacts from the side of liquid and dropping objects on the relative elements of civil structures of pools.

1.2. Application of "Guide"

Application scope of this "Guide" is limited by identification of the loads for the construction diagrams of pools, casks and slabs identical to those illustrated in Figure 2.1.

Application of design formulas is limited by the conditions specified in particular cases.

2. JUSTIFICATION OF NECESSARY PARAMETERS AND SEQUENCE OF CALCULATIONS OF HYDRODYNAMIC LOADS WHEN EMERGENCY DROP OF CASK OR OTHER OBJECTS (CARGO) TO NPP POOLS.

Investigations show that for different diagrams of pool (Figure 2.1) the below are the most dangerous processes following emergency drop of the cargo to the pool:

- process of cask impact on the pool surface resulting in initiating of the shock wave phenomena that cause considerable shock pressures on the bottom of the cask and, under the specific circumstances, the bottom of the pool too;
- process of cask immersing into the pool followed by:

a) general pressure increase in the pool (diagram 1);

b) possible impact of immersing cask on the ledge in the pool or its bottom;

c possible water splash from the pool resulting both from the cask (cargo) impact on the surface of the pool and cask immersing to the pool;

d) water overflow from the pool, since the volume of the dropping cask can exceed a water free volume of the pool (diagrams 1 and 2);

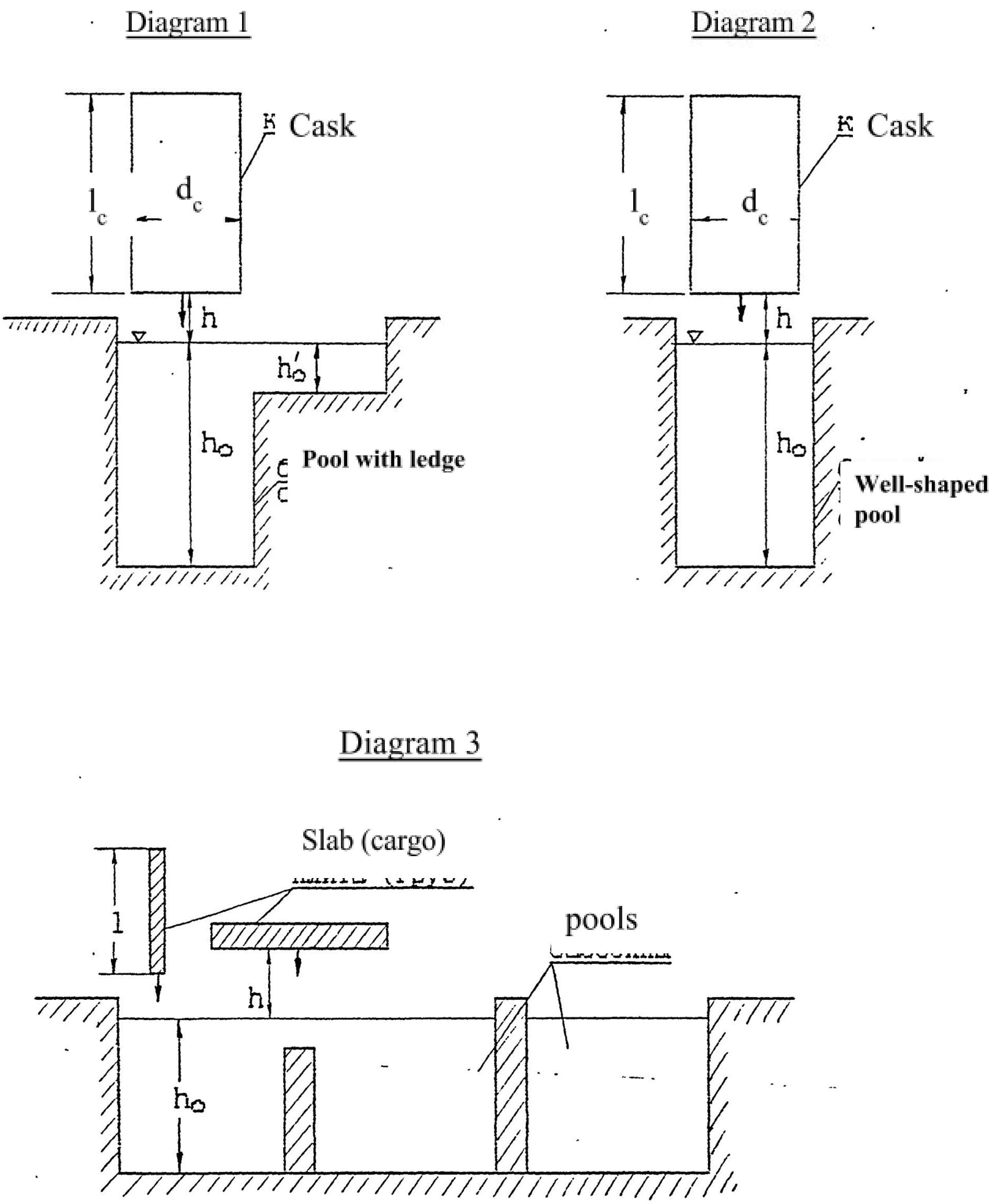

Figure 2 1. Possible diagrams of pools with dropping cargo

- process of cover slab or other objects sinking to the pool followed by a possible impact of cover slab, at its non-planar drop, or other dropping objects on the bottom of the pool (diagram 3).

Therefore, the below were referred to the parameters that require calculations to be made for identification of equivalent-statistic loads on the civil structures and equipment:

1) intensity of dynamic load occurring in water when cask (cargo) impact on the water surface in the pool;

2) intensity of dynamic load occurring with the process of cask sinking to the pool;

3) cask speed when pool impact;

4) nature and value of immerse speed change of the cask, cover slab or other objects to the pool;

5) maximum height of water splash from the pool when cask water impact or cask immersing into the pool;

6) ratio of the cask volume immersing into the pool and free volume of the pool before cask drop;

7) load intensity at cask, cover slab or another object impact on the bottom or ledge of the pool after penetration through the water column;

8) time and character of the change of the load occurring after the object impact on the bottom of the pool.

Design equivalent-static loads are identified by multiplication of the maximum dynamic load value by the dynamic factor $\mathbf{K_d}$**,** which is a function of dynamic load change character in time $\mathbf{\Delta P_d(t)}$ and circular frequency of self-induced vibrations of the structure $\Delta \mathbf{P}_{\mathbf{eqv}} = \mathbf{K}_{\mathbf{d}} \cdot \Delta \mathbf{P}^{\mathbf{max}}_{\mathbf{d}}$

3. IDENTIFICATION OF PARAMETERS OF THE PROCESSES THAT PRODUCE DYNAMIC LOADS ON THE POOL ENCLOSING STRUCTURES AND CALCULATIONS OF THESE LOADS WHEN EMERGENCY DROP OF CASK OR OTHER OBJECTS INTO THE POOL

3.1. Calculations of hydrodynamic loads when object impact upon water surface of the pool

3.1.1. Pressure on the shock wave front occurring in water after cask or another object impact upon the surface of the pool is determined as per the formula

$$\Delta \mathbf{P_f} = \mathbf{a_w} \cdot \boldsymbol{\rho}_\mathbf{w} \cdot \mathbf{V_w}, \qquad \text{Pa}$$

(3.1)

where

a_w - sound propagation speed in water ($a_w = \sqrt{E_w/\rho_w}$, where E_w – modulus elasticity of water; it can be accepted for calculations a_w= 1460 m/s), m/s;

ρ_w - water density (see table 1of appendix; it can be accepted for calculations ρ_w= 1000 kg/m^3), kg/m^3;

V_w - shock wave front water velocity (see i.3.1.2).

3.1.2.Water velocity after the shock wave front V_w (cask speed after impact) is determined as per formula

(3.2)

where
g - free fall acceleration, m/s^2;
h - height of cask (object) drop, m;

a_c - sound propagation speed in the material of cask (object), m/s;

ρ_c - cask or dropping object volume density; $\rho_c = m_c/W_c$, kg/m^3;

m_c - mass of cask or dropping object, kg;

W_c - volume of dropping object, m^3.

3.1. 3. Shock wave effect time τ_+ is determined as per formula

$$\tau_\perp = \frac{m_c}{\omega_c \cdot a_w \cdot \rho_w} \quad , \quad s \quad (3.3)$$

where ω_c- area of cask bottom, m^2;

3.1.4. Pressure change after the shock wave front in time is assumed as per the linear law and expressed by formula

$$\Delta P(t) = \Delta P_f \cdot \left(1 - \frac{t}{\tau_\perp}\right), \qquad \mathbf{Pa} \tag{3.4}$$

where t – current time within the range $0 \le t \le \tau_\perp$

Character of pressure change after the shock wave front is shown in figure 3.1.

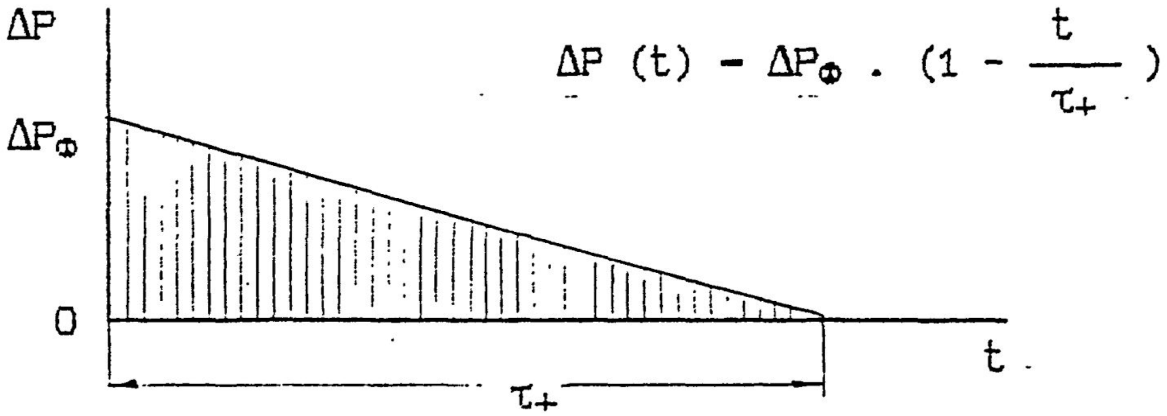

Figure 3.1. Relationship ΔP(t)

3.1.5. Identification of dynamic load on the walls and bottom of the pool when drop of the object with flat bottom.

3.1.5.1. Maximum possible increase of pressure on the bottom and walls of the pool after cask or another object with flat bottom impact upon the surface of water is determined by the formula

$$\Delta P = \left(\frac{m_c \cdot g}{\omega_c} + k \cdot \Delta P_f \right) \cdot \frac{\omega_c}{\omega_p}, \qquad Pa$$

(3.5)

where

m_c - weight of cask, kg;
g - free fall acceleration, m/s^2;
ΔP_f - pressure on shock wave front (see i. 3.1.1), Pa;
ω_c - cask midsection area, m^2;

ω_p - pool bottom area, m^2;

k - pressure release factor assumed as 0,082 (this value was experimentally obtained) for the below boundary conditions

$$0.4 \le \frac{\omega_c}{\omega_p} \le 0.7; \qquad 0 < h \le 4\ m; \qquad h_0 > \frac{d_c}{2};$$

This pressure is summarized with hydrostatic pressure in force before the cask drop.

If **$h_0 \le d_c/2$**, dynamic load on the pool bottom is determined similar to that when cask impact without water effect taken into account, load is imposed therewith in the "spot" of impact (i. 3.3.3).

3.1.5.2. Character of pressure change after cask impact upon the surface of the water is assumed to be linear diminishing from the value ΔP (i. 1.2.1) to the value of hydrostatic pressure before the cask drop P.

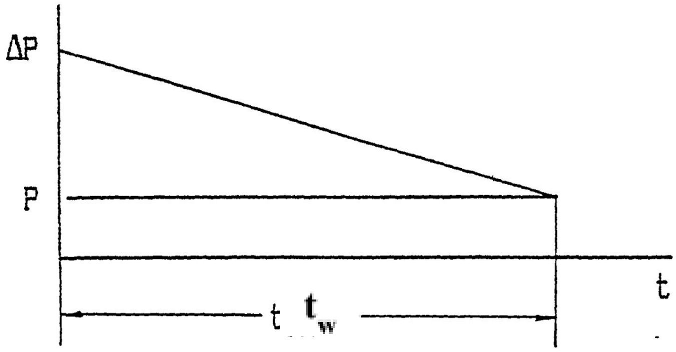

Figure 3.2. Relationship $\Delta P(t)$

τ_+ - is determined in i.3.1.3., (3.6)

3.1.5.3. Time of pressure change on the bottom and walls of the pool after cask impact upon the water surface is determined by the empirical formula

3.1.6. Identification of dynamic load on the walls and bottom of the pool when object drop at an angle α to the water surface (Figure 3.3)

ω_o

Figure 3.3

3.1.6.1. Critical angle of object impact upon water surface (maximum angle when shock wave is generating under the object) is determined by the formula

$$\alpha_{cr} = \mathrm{arctg}\frac{\sqrt{2gh}}{a_w}, \quad \text{degree}$$

(3.7)

where h - object drop height, m;

a_w - sound speed in water, m/s.

3.1.6.2. Maximum possible pressure increase on the bottom and walls of the pool after an object coming into the water ΔP

where $\alpha \le \alpha_{cr}$ (i.3.1.5.1),- in so doing a shock wave is generating under an object

$$\Delta P = \left(\frac{m_c \cdot g}{\omega_c} + k \cdot \Delta P_f\right) \cdot \frac{\omega_c}{\omega_\rho}$$

where ω_o- midsection area of the object;

for $\alpha > \alpha_{cr}$ at this no shock wave is generating under the object, but the calculation is made identically to that in i.3.1.5.1,

where the midsection area ω_o is assumed as the area of object effect on water.

(3.8)

3.2. Identification of the overflow value and height of water splash from the pool at emergency drop of cask to the pool

3.2.1. Volume of water overflow from the pool when a cask (cargo) drop into the pool $\mathbf{W_{of}}$

$$\mathbf{W_{of}=W_c-\acute{W}_p} \quad (3.9)$$

where $\mathbf{W_c}$ - cask (cargo) volume;
$\mathbf{\acute{W}_p}$ - volume of water free part of the pool.

3.2.2. Maximum height of water splash from the pool resulting from cask (cargo) impact upon the water surface in the pool

(3.10)

where - free fall acceleration, m/s^2;
$\mathbf{V_w}$ - shock wave velocity (i.3.1.2).

For the objects with non-flat bottoms with the water entrance angle (Figure 3.3.),

for $\boldsymbol{\alpha > \alpha_{cr}}$ (i.3.1.6.1), no splash value is determined.

3.2.3. Maximum possible rate of cask immersing into the pool $\mathbf{V_{max}}$

$$V_{max} = \beta \cdot \sqrt{2g \cdot \left(h + \frac{h_o}{2}\right)} \quad , \quad m/s$$

(3.11)

where h - cargo drop height, m;

h_o - water depth in the pool, m;

- attenuation factor of cargo drop rate into the water;

$$0{,}4 \leq \frac{\omega_c}{\omega_\rho} \leq 0{,}7; \qquad 0 < h < 4\ m; \qquad (3-4) \quad l_c > h_o > l_c$$

3.2.4. Maximum average water flow velocity between the walls of the pool and the immersing cask $\mathbf{V}_{w\ max}$

$$V_{wmax} = \frac{V_{max}}{\frac{\omega_\rho}{\omega_c} - 1}, \qquad m/s \quad (3.12)$$

where V_{max} - maximum rate of cask immersing (see i. 1.3.3);

ω_ρ - pool cross section area;

ω_c - midsection area of cask (cargo).

3.2.5. Maximum height of water splash from the pool when a cask (cargo) immersing into it

(3.13)

where $\mathbf{V}_{w\ max}$ - maximum average water flow velocity (see i.3.2.4);

g - free fall acceleration.

for $\omega_c / \omega_\rho \leq 0{,}4$ no splash height is determined.

$\boldsymbol{\beta}$ = 0,5 for the below boundary conditions

3.3. Identification of dynamic loads on ledge or bottom of the pool when object penetration through the water column after its emergency drop (P)

3.3.1. Object drop rate at the moment of impact upon the bottom or ledge of the pool when water depth being commensurable to the height of the dropping object

(3.14)

where h - object drop height before impact upon the pool surface;

- pool depth in the place of the object drop.

3.3.2. Object drop rate at the moment of impact upon the bottom or ledge of the pool when water depth being more than the height of the dropping object

3.3.2.1. Average rate of object motion in water $\mathbf{V_{av}}$ (for the objects which midsection area $\boldsymbol{\omega_o}$

$$\frac{\omega_o}{\omega_\rho} < 0{,}4)$$ is equal to

$$V_{av} = \frac{V_o + V_h}{2}, \qquad m/s$$

(3.15)

$$V_h = \sqrt{2g\left(h + \frac{h_o}{2}\right)} \quad , \quad m/s$$

(3.16)

- object motion rate on the depth $h_o/2$ with no account of water resistance

воды

3.3.2.2. Number Re for the water flowing around the object with velocity $\mathbf{V_{av}}$:

where $\mathbf{V_o}$ **-** rate of object when approaching the water surface

$$R_e = \frac{V_{av} \cdot l}{\nu} \quad , \qquad (3.18)$$

where $\mathbf{V_{av}}$ - average rate (i. 3.3.2.1);

l - length of object in the direction of drop;

ν - kinematic coefficient of water viscosity (see table 1 of enclosure; for practical calculations the below can be assumed

ν=0,01 m²/s), m²/s

3.3.2.3. Resistance coefficient of object motion in water C_x:

- for the **object** in case $\omega_c/\omega_p \le 0{,}4$ is determined by the graph in Figure 1 or approximately by Table 2 submitted in enclosure;

in case and $\mathbf{h_o > l_c}$ cask impact load is not determined due to its small size;

if $Re_l \leq 5 \cdot 10^5$, $\quad \mathbf{C_x = \frac{1{,}37}{\sqrt{Re_l}}}$,

(3.19)

if $Re_l > 5 \cdot 10^5$, $\quad \mathbf{C_x = 0{,}03 \cdot \left(\frac{k_{eq}}{l} + \frac{83}{Re_l} \right)^{0,2}}$, (3.20)

- for the **slab** dropping not linearly but vertically

where $\mathbf{k_{eq}}$ - equivalent roughness coefficient of the cover slab surface (at high quality of concrete slab surface $\mathbf{k_{eq}}$ - 0,55 mm; at mean quality of slab surface $\mathbf{k_{eq}}$ - 2,5 mm; at rough surface - $\mathbf{k_{eq}}$ - (3-9) mm);

$\mathbf{Re_l}$ - number of Reynolds for the water flowing around the slab (i.3.3.2.2).

3.3.2.4. Acceleration the dropping objects move with in water (a)

$$a = \frac{dV}{dt} - \frac{\rho}{m} \cdot \left(\frac{m}{\rho} \cdot g - gW - C_x \cdot \omega_o \cdot \frac{V^2{}_{av}}{2} \right), \quad m/s^2$$

(3.21)

where ρ - water density (1000 kg/m³);

m - weight of object;

W - volume of object;

V_{av} - rate of object sinking (i.3.3.2.1);

C_x - resistance coefficient (i.3.3.2.3);

ω_o - midsection area of the object (area of the object projection to the horizontal plane), area of lateral sides of the slab or area specific to the object.

3.3.2.5. Object drop rate at the instant of impact upon the bottom

- for the objects which midsection area (ω_o) $\omega_o \leq 0{,}4\omega_\rho$

$$V_t = \sqrt{V_o^2 + 2ah} \quad ,$$

(3.22)

where - rate of the object approach to water;

a - slab or object acceleration (i.3.3.2.4) in water.

where V_{max} is identified by i.3.2.3.

3.3.3. Dynamic load on ledge or bottom of the pool (F)

- for the objects which midsection area (ω_o) $0,4 < \frac{\omega_o}{\omega_\rho} \leq 0,7$

$V_t = 0,1V_{max}$

$$F = \left(m'_o V_t^2 - \rho g W'\right), \quad n \qquad (3.23)$$

where $m'_o = m_c/1m$ - localized mass of the object (object weight as if localized in the unit of length of cask or object), kg/m;

W' - volume of the immersed part of an object, m^3;

V_t - speed of the object at the moment of impact upon the ledge or bottom of the pool, (i.3.3.2.5), m/s;

ρ - water density, kg/m^3.

Dynamic load F is distributed over the area of dropping object impact upon the structure (in the "spot" of impact).

3.3.4. Time of effort F effect is determined as per formulas

(3.24)

(3.25)

where l_{min} - minimum linear size of dropping object (height of the object or its width in the place of impact upon the surface of the water), m;

δ_{min} - thickness of enclosing structure in the place of impact, m;

a_o , a_{st} - sound propagation speed in the material of object and structure, respectively, m/s.

While making calculations the least of the values $\tau_\perp$ is assumed.

3.3.5. Character of effort F change after an object impact upon the bottom is assumed as constant within the time τ_+

$$F (t) - F - const . \quad (3.26)$$

4. EXAMPLES OF CALCULATIONS ALGORITHMS AND CALCULATIONS THEMSELVES FOR TYPICAL STRUCTURES OF NUCLEAR POWER PLANT POOLS

4.1. Diagrams of typical structures of pools, initial data and design parameters

4.1.1. Pool with ledge. Diagram 1.

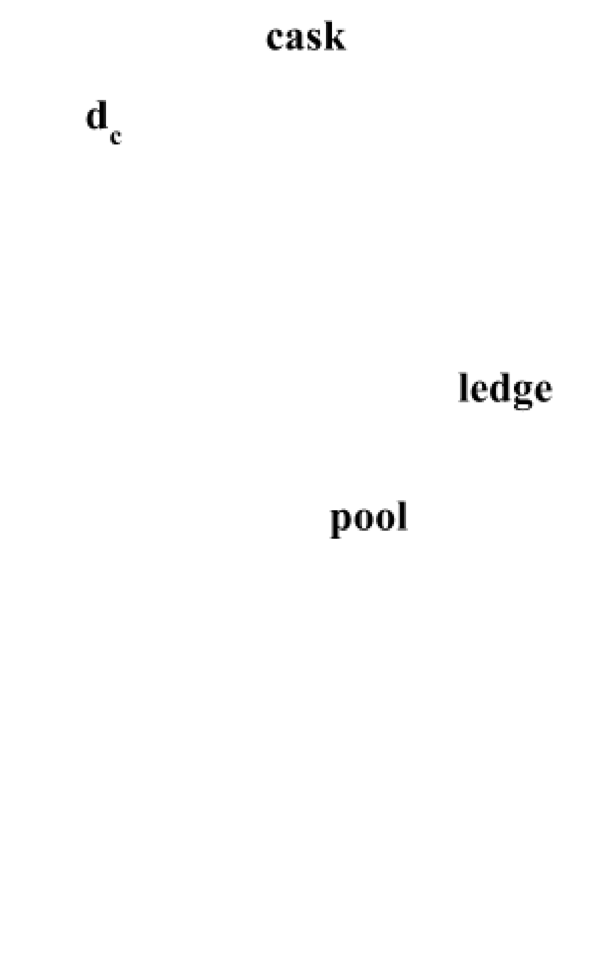

Figure 4.1

4.1.1.1. The most unfavorable cases that affect the pool structure and equipment after emergency drop of the cask from the hydrodynamic point of view are the case of loaded cask central hit to the well-shaped part of the pool in diagram 1 and cask impact upon the ledge bottom of the pool.

4.1.1.2. The below are referred to the design hydrodynamic parameters for this case:

- value of shock pressure on the bottom of the cask ΔP_f (i. 3.1.1);
- value of maximum possible pressure increase on the bottom and walls of the pool after cask impact upon the surface of the water

(i.3.1.5.1);

- time of shock wave effect (i. 3.1.3);
- pressure change time after cask impact upon the surface of the pool (i.3.1.5.3);
- volume of water overflow from the pool when cask drop into it (i.3.2.1);
- maximum height of water splash from the pool resulting from cask impact upon the water surface in the pool (i.3.2.2);
- value of load on the ledge bottom of the pool when cask impact upon it (i.3.3.3);
- time and nature of the load effect when cask impact upon the bottom of the pool (i.i. 3.3.4 and 3.3.5).

Figure 4.2

4.1.2. Well-shaped pool. Diagram 2

cask

$\mathbf{d_c}$

pool

4.1.2.1. The most unfavorable case that affects the pool structure and equipment after emergency drop of the cask from the hydrodynamic point of view is the case of central hit of loaded cask to the pool in diagram 2.

4.1.2.2. The below are referred to the design hydrodynamic parameters for this case:

- value of shock pressure on the bottom of the cask $\mathbf{\Delta P}_f$ (i. 3.1.1);
- value of maximum possible pressure increase on the bottom and walls of the pool after cask impact upon the surface of the water (i.3.1.5.1);
- time of shock wave effect (i.3.1.3);
- pressure change time after cask impact upon the surface of the pool (i.3.1.5.3);
- volume of water overflow from the pool when cask drop into it (i.3.2.1);
- maximum height of water splash from the pool resulting from cask impact upon the water surface in the pool (i.3.2.2);
- maximum height of water splash from the pool when cask immersing into it (i.3.2.5).

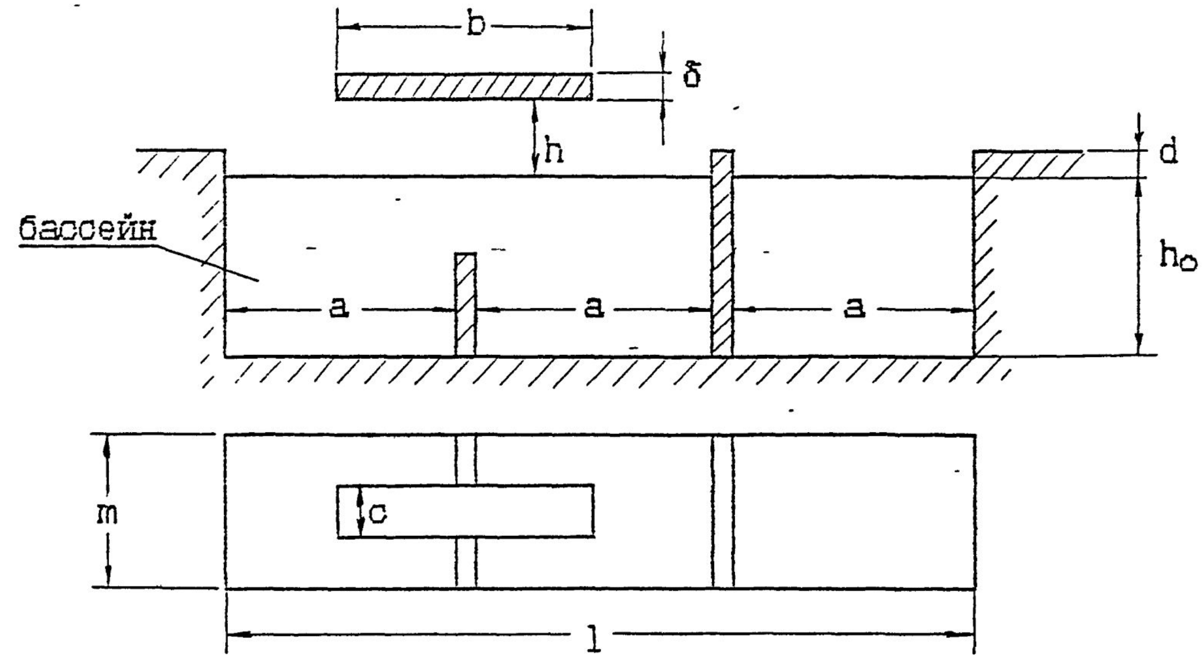

Figure 4.3

4.1.3. Three section pool whereto the cover slab drops. Diagram 3.

pool

4.1.3.1. The most unfavorable cases that affect the pool structure and equipment from the hydrodynamic point of view are the case of flat, parallel to the surface of the pool, cargo drop in the form of slab into one of the sections of the pool and case of vertical penetration of the slab through the water column with the face end impact upon the bottom of the pool.

4.1.3.2. The below are referred to the design hydrodynamic parameters for this case:

- value of shock pressure on the bottom of the slab (i. 3.1.1);
- intensity of load on the pool bottom in case of the cover slab impact upon it when vertical drop and penetration through the water column (i. 3.3,3);
- time of shock wave effect (i.3.1.3);
- time and nature of the load effect when the slab impact upon the pool bottom (i.i. 3.3.4 and 3.3.5).

4.1.4. The below are the initial data for calculations

- Geometrical dimensions of the pools (Fig.2.1, 2.2, 2.3) and dropping objects.
- Weights of dropping casks (cargo).
- Average densities of dropping casks (cargo)

$$\boldsymbol{\rho_c = m_c / W_c} \; ,$$

where $\mathbf{m_c}$ - cask (cargo) weight, kg;

$\mathbf{W_c}$ - cask volume, m^3.

$\boldsymbol{\rho_w}$ - water density in the pool, kg/m3.

$\mathbf{a_w}$ - sound speed in the water of the pool, m/s.

$\mathbf{a_c}$ - sound speed in the material of cask (cargo), m/s.

4.2. Identification of hydrodynamic parameters and loads for diagram 1 (i.4.1.1)

4.2.1. Identification of distributed load on the bottom of the cask of any type when it drops to the pool (case of parallel contact of the cask bottom and water surface).

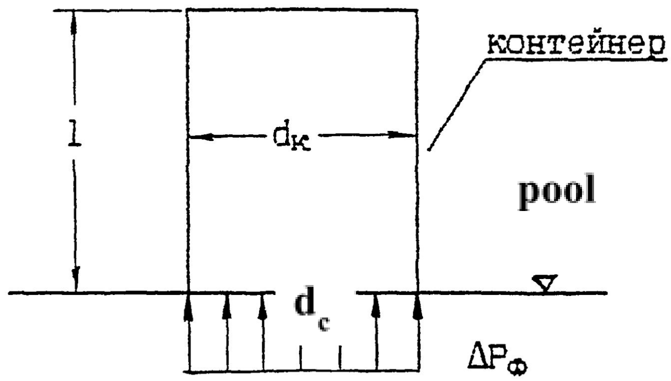

Figure 4.4

ΔP_f

4.2.1.1. Water flow velocity after the shock wave front $\mathbf{V_w}$ (i.3.1.2)

$$V_w = \frac{a_c \cdot \rho_c}{(a_w \cdot \rho_w + a_c \cdot \rho_c)} \sqrt{2gh} \quad , \quad m/s$$

4.2.1.2.Intensity of distributed load on the bottom of the cask $\Delta \mathbf{P_f}$ (i.3.1.1)

$$\Delta P_f = a_w \cdot \rho_w \cdot V_w \quad , \qquad Pa$$

4.2.1.3. Time of distributed load effect (i.3.1.3)

$$\tau_\perp = \frac{m}{\omega_c \cdot a_w \cdot \rho_w}, \qquad s$$

4.2.1.4. Character of distributed load change in time τ_+

(i.3.1.4).

4.2.2. Identification of maximum possible pressure increase on the bottom and walls of the pool after cask impact

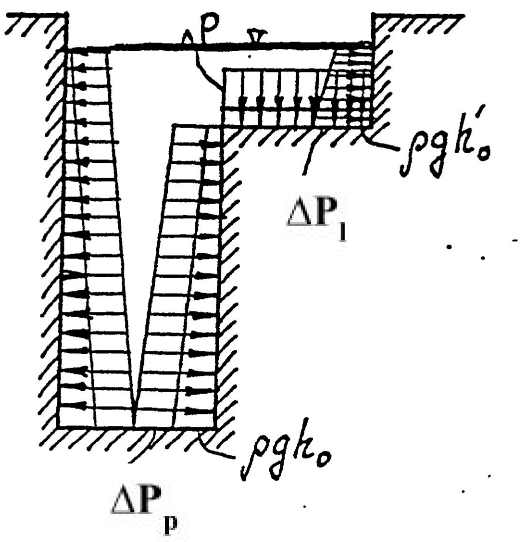

Figure 4.5

4.2.2.1. Additional load to the hydrostatic load on the bottom and walls of the well-shaped part of the pool (i.3.1.5.1, Figure 3.2)

$$\mathbf{\Delta P_p = \left(\frac{m_c \cdot g}{\omega_c} + k \cdot \Delta P_f\right) \cdot \frac{\omega_c}{\omega_p},} \qquad \mathbf{Pa}$$

where $\boldsymbol{\omega_p}$ - area for well-shaped part of the pool, $\boldsymbol{\omega_p = a \cdot b}$, m^2.

4.2.2.2. Additional load to the hydrostatic load on the bottom and walls of the ledge after the cask drop to the pool ledge area

(i.3.1.5.1, Figure 3.2)

$$\Delta P_l = \left(\frac{m_c \cdot g}{\omega_c} + k \cdot \Delta P_f \right) \cdot \frac{\omega_c}{\omega_l} \quad , \qquad Pa$$

where ω_l – area of ledge, ω_l=**a·c, m²; k=0,082** with $h_o \leq d_k/2$ (if dynamic load on the bottom of the pool is identified similar to that when cask impact without water effect taken into account (see i.3.3.3).

4.2.2.3. Time of additional distributed load effect t_w (i.3.1.5.3)

4.2.2.4. Character of additional distributed load change (ΔP_p **and** ΔP_l) within time t_w (i.3.1.5.2).

4.2.3. Volume of water overflow from the pool when cask drops into it.

4.2.3.1. Cask volume (Figure 2.1)

4.2.3.2. Volume of water free part of pool (Fig.4.1)

$$W_c = \omega_c \cdot l - \frac{\pi d_c^2}{4} \cdot l \quad , \quad m^3$$

$$W_p' = (b + c) \cdot a \cdot d \quad , \quad m^3$$

4.2.3.3. Volume of water overflow from the pool when cask drops into it W_{of} (i. 3.2.1)

$$W_{of} = W_c - \acute{W}_p \quad , \quad m^3$$

4.2.4. Maximum height of water splash over the surface of the pool resulting from cask impact upon water h_{max} (i.3.2.2) where $\mathbf{V}_w$ see i.3.1.2.

4.2.5. Intensity of load on the ledge bottom of the pool when cask impact upon it. (i.3.3).

$$V_t = \sqrt{2g(h + h'_o)} \quad , \qquad m/s$$

4.2.5.1. Cask drop rate at the moment of impact upon ledge (i.3.3.1)

4.2.5.2. Dynamic load on the ledge of the pool (i.3.3.3)

is identified similar to that for impact of two absolutely rigid objects

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$$F = m'_c \cdot V_t^2 - \rho g W' , \qquad N$$

where - volume of immersed part of cask;

m'_c - localized mass of cask.

4.2.5.3. Time τ_+ of load effect (F): (i.3.3.4)

- is the least of the values:

where δ_l - ledge bottom thickness;

a_l - sound speed in material of ledge bottom structure.

4.2.5.4. Character of load change after impact within time

(i.3.3.5)

F=const

4.2.6. Example of calculation of intensity of dynamic load on ledge when cask impact on it.

Identify dynamic load on the pool ledge when cask impact for the below initial data:

- pool diagram as per Fig.4.1;
- cask mass $\mathbf{m_c}$=120000 kg;
- cask bottom area $\boldsymbol{\omega_c}$=4,15 m^2;
- cask length **l**= 5,6 m;

- cask diameter $\mathbf{d_c}$=2,3 m;
- cask volume $\mathbf{W_c}$=23 m^3
- water density $\boldsymbol{\rho_w}$=1000 kg/m^3;
- sound propagation speed in concrete $\mathbf{a_p}$=3000 m/s
- ledge concrete slab thickness $\mathbf{V_l}$=1,0 m
- cask drop height **h**=1,2 m
- water depth above ledge $\mathbf{h_0}$=3,45 m
- sound propagation speed in cask material $\mathbf{a_c}$=5000 m/s

1) Identify the cask motion speed on the ledge level taking into account that $h_o<l_c$ (3,45m <5,6m), (i.4.2.5.1)

2) Identify the effort on the pool ledge (i.4.2.5.2). Assume that the structures of slab and ledge are absolutely rigid

$$\mathbf{F = (120,000 \cdot 9,8^2 - 1000 \cdot 9,81 \cdot 3,45 \cdot 4,15) = 11,5 \cdot 10^6} \quad \text{N.}$$

While identifying the value $\mathbf{W'_c}$ it was accounted that the cask was only immersed to the height $\mathbf{h_o}$**= 3,45** m.

3) Identify the time of effort F effect (i.4.2.5.3)

$$\tau_{\perp,1} = 0,00023 \text{ s}$$ **is taken into account.**

4) Character of effort (load) change within the time is assumed as constant, i.e. $F(t) - const$ (i.4.2.5.4).

4.3. Identification of hydrodynamic parameters and loads for diagram 2 (i.4.1.2)

4.3.1. Identification of distributed load on the bottom of the cask of any type when it drops to the pool (case of parallel contact of the cask bottom and water surface).(See Fig. 3.1)

4.3.1.1. Water flow velocity after the shock wave front (i. 3.1.2)

$$\mathbf{V_w = \frac{a_c \cdot \rho_c}{a_w \cdot \rho_w + a_c \cdot \rho_c}\sqrt{2gh}\ , \quad m/s}$$

4.3.1.2. Intensity of distributed load on the bottom of the cask $\mathbf{\Delta P_f}$

(i.3.1.1.) - $\mathbf{\Delta P_f = a_w \cdot \rho_w \cdot V_w}$, Pa

4.3.1.3. Time of distributed load effect (i.3.1.3)

$$\mathbf{\tau_\perp = \frac{m_c}{\omega_c \cdot a_w \cdot \rho_w}, \qquad s}$$

4.3.1.4. Character of distributed load change in time (i.3.1.4)

4.3.2. Identification of maximum possible pressure increase on the bottom and walls of the pool after cask impact (see Fig.2.2)

Fig.4.6

$$\Delta P = \left(\frac{m_c g}{\omega_c} + k \cdot \Delta P_f\right) \cdot \frac{\omega_c}{\omega_p}, \qquad \text{Pa}$$

4.3.2.1. Additional load to the hydrostatic load on the bottom and walls of the well-shaped part of the pool (i. 3.1.5.1)

4.3.2.2. Time of additional distributed load effect $\mathbf{t_w}$ (i.3.1.5.3)

$$t_w = 15\tau_\perp, \quad s$$

4.3.2.3. Character of additional distributed load (**ΔP_p and ΔP_l**) change within time $\mathbf{t_w}$ (i.3.1.5.2)

4.3.3. Volume of water overflow from the pool when cask drops into it.

4.3.3.1. Cask volume (see Fig.2.2)

4.3.3.2. Volume of water free part of pool (see Fig.2.2)

$$W_p = a \cdot b \cdot d, \qquad m^3$$

4.3.3.3. Volume of water overflow from the pool when cask drops into it $\mathbf{W_{of}}$ (i.3.2.1)

$$W_{of} = W_c - W'_p, \qquad m^3$$

4.3.4. Maximum height of water splash over the surface of the pool resulting from cask impact upon water h_{max} (i. 3.2.2)

$$\mathbf{h_{max} = \frac{1{,}12 \cdot V_w^2}{g}, \quad m}$$

where $\mathbf{V_w}$ see i.4.1.1.

4.3.5. Maximum height of water splash from the pool when cask immersing into it

4.3.5.2. Maximum average water flow velocity between pool walls and immersing cask (i.3.2.4)

4.3.5.1. Maximum possible rate of cask immersing into the pool

V_{max} (i.3.2.3)

$$V_{max} = \beta \cdot \sqrt{2g \cdot \left(H + \frac{h_o}{2}\right)}, \quad m/s$$

$$V_{w\,max} = \frac{V_{max}}{\frac{\omega_\rho}{\omega_c} - 1}, \quad m/s$$

where ω_ρ=**a·b** , m^2 (see fig.2.2)

(see fig.2.2)

4.3.5.3. Maximum height of water splash from pool when cask immersing into it (i.3.2.5)

$$h'_{max} = \frac{V^2_{w\,max}}{2g}, \quad m$$

4.3.6. Examples of calculations

Identify dynamic load on enclosing structures of the pool when fuel cask drops into it, as well as parameters of water overflow and height of water splash from the pool for the below initial data:

- assumption is made that the cask drops flat with its bottom on water;
- pool diagram as per version №2;

- sound propagation speed in cask material $\mathbf{a_c}$=5000 m/s;
- cask density $\boldsymbol{\rho_c}$= 5170 kg/m^3;
- cask mass $\mathbf{m_c}$= 120000 kg;
- cask cross section area perpendicular to its longitudinal axis $\boldsymbol{\omega_c}$= 4,15 m^2;
- cask diameter $\mathbf{d_c}$= 2,3 m;
- cask length $\mathbf{l_c}$= 5,6 m;
- sound propagation speed in water $\mathbf{a_w}$= 1460 m/s;
- water density $\boldsymbol{\rho_w}$= 1000kg/m^3;
- pool depth $\mathbf{h_p}$= 16,7 m;
- pool dimensions in horizontal projection $\mathbf{a_p \cdot b_p}$= 2,7·2,7 m;
- cross section area of pool $\boldsymbol{\omega_\rho}$= 7,3 m^2;
- water depth in pool $\mathbf{h_o}$= 15,7 m;
- height of unfilled part of pool $\mathbf{h^x}$= 1,0 m;
- cask drop height $\mathbf{h}$= 1,5 m;
- pool bottom thickness $\boldsymbol{\delta}$= 2,0 m.

1. Identify the water flow velocity after the shock wave front

$$\mathbf{V_w = \frac{a_c \cdot \rho_c}{a_w \cdot \rho_w + a_c \cdot \rho_c} \cdot \sqrt{2gh} = \frac{5000 \cdot 5170}{(1450 \cdot 1000 + 5000 \cdot 5170)} \cdot 2 \cdot 9{,}81 \cdot 1{,}5 = 5{,}15 \ m/s}$$

2. Identify pressure on the shock wave front

$$\Delta P_f = a_w \cdot \rho_w \cdot V_w = 1460 \cdot 1000 \cdot 5{,}15 = 7{,}5 \cdot 10^6 \quad Pa$$

3. Identify time of shock wave effect

4. Pressure response in the shock wave in the time range $\mathbf{0 \le t \le 0{,}02}$ s (see Fig. 3.1) is assumed to be linear.

5. Identify a summarized dynamic load on the enclosing structures of the pool from the cask impact and motion in water when it drops into the pool

$$\Delta P = \left(\frac{m_c g}{\omega_c} + k \cdot \Delta P_f \right) \cdot \frac{\omega_c}{\omega_\rho} = \left(\frac{120000 \cdot 9{,}81}{4{,}15} + 0{,}08 \cdot 7{,}5 \cdot 10 \right) \cdot \frac{4{,}15}{7{,}3} = 5{,}14 \cdot 10^5, \ \text{Pa}$$

6. Identify maximum speed of cask during its immersion after impact upon water

$$V_{max} = \beta \cdot \sqrt{2g\left(h + \frac{h_o}{2} \right)} = 0{,}5\sqrt{2 \cdot 9{,}81 \cdot \left(1{,}5 + \frac{15{,}7}{2} \right)} = 6{,}7 \quad m/s$$

7. Identify time of effect

$$t_w = 15\tau_\perp = 15 \cdot 0{,}02 = 0{,}3 \quad s$$

10. Identify the volume of water free part of pool

8. Pressure change in the time within the range $\mathbf{0 \le t \le t_w}$ is assumed to be linear (see Fig. 3.2)

8. Identify the volume of the cask

$$\mathbf{W = \omega_c \cdot l_c = 4{,}15 \cdot 5{,}6 = 23{,}2} \ \text{m}^3$$

$$\mathbf{W'_p = a \cdot b \cdot h^x = 2{,}7 \cdot 2{,}7 \cdot 1{,}0 = 7{,}3}$$

m^3

11. Identify the volume of water overflow from the pool when complete immersion of cask

$$\mathbf{W_{of} = W_c - W'_p = 23{,}2 - 7{,}3 = 15{,}9} \quad m^3$$

12. Identify maximum height of water splash resulting from cask impact upon water

13. Identify maximum water flow velocity in the clearances between the walls of the pool and cask when the cask immersion

$$V_{w\,max} = \frac{V_{max}}{\left(\frac{\omega_p}{\omega_c} - 1\right)} = \frac{6{,}7}{\left(\frac{7{,}3}{4{,}15} - 1\right)} = 8{,}8 \quad m/s$$

15. Identify the start time of the second water splash

14. Identify maximum height of water splash resulting from cask immersion

$$h'_{max} = \frac{V^2_{w\,max}}{2g} = \frac{8{,}8^2}{2 \cdot 9{,}81} = 3{,}95 \quad m$$

Thus, two water splashes will take place with the time interval of

1,17 sec. Calculated splash height refers to the surface of the water; height of water splash relative to the upper part of the pool, however, is less by the height of the unfilled part of the pool in our task h^x

1,0 m .

4.4. Identification of hydrodynamic parameters and loads for diagram 3 (i.4.1.3)

4.4.1. Load on the bottom of the pool from the impact of slab face end, when its emergency vertical drop and penetration through water column (i.3.3).

4.4.1.1. Average speed of slab motion (i.3.3.2.1)

4.4.1.2. Number for the flow around the slab (i.3.3.2.2)

$$\mathbf{Re_l = \frac{V_{av} \cdot l}{\nu}}$$

4.4.1.3. Resistance coefficient of slab motion in water

(i. 3.3.2.3)

$$\mathbf{C_x = \frac{1{,}37}{\sqrt{Re_l}} \qquad for \quad Re_l \le 5 \cdot 10^5}$$

4.4.1.4. Acceleration the slab is moving in water with (i.3.3.2.4)

$$\mathbf{C_x = 0{,}03 \cdot \left(\frac{k_{eq}}{1} + \frac{83}{Re_l} \right)^{0,2} \qquad for \quad Re_l > 5 \cdot 10^5}$$

$$\mathbf{a = \frac{dV}{dt} = \frac{\rho}{m_{sl}} \cdot \left(\frac{m_{sl}}{\rho} \cdot g - gW - C_x \cdot \frac{\omega_{sl} \cdot V_{av}^2}{2} \right)}$$

$$\mathbf{\omega_{sl} = 2 \cdot b \cdot l}$$

4.4.1.5. Slab speed at the moment of impact upon the bottom (i. 3.3.2.5)

$$V_t - \sqrt{2\ (gh + ah_o)}$$

4.4.1.6. Load imposed on the pool bottom resulting from slab face end impact (i. 3.3.3)

$$\mathbf{F = m'_{sl} \cdot V^2 - \rho g W' b}$$

4.4.1.7. Time of load effect (i.3.3.4). The least value is assumed from

where $\boldsymbol{\delta_{sl}}$ - slab thickness;

$\boldsymbol{\delta_b}$ - pool bottom thickness;

$\mathbf{a_{sl}}$, $\mathbf{a_b}$ - speed of sound in the material of slab and pool bottom respectively.

4.4.1.8. Character of load change within the time τ_+ (i.3.3.5)

ENCLOSURE

1. Drag coefficient   for different objects

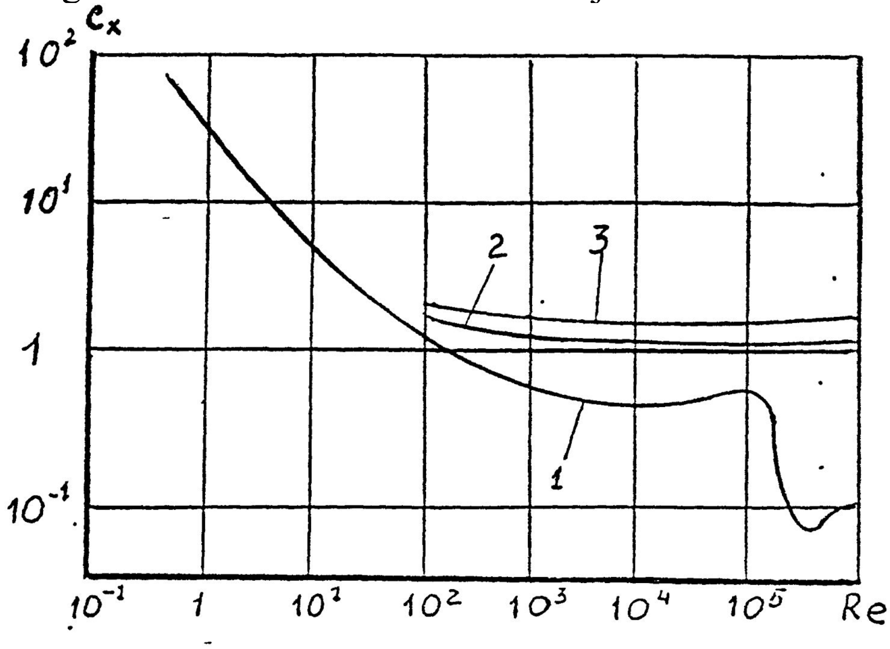


Fig.1. Drag coefficient – number Reynolds relationship

: 1-ball; 2-cylinder; 3-disc

2. Water density, kinematic -dynamic viscosity and temperature relationship

Table 1

Temperature ^0C	Water density ρ, kg/m³	Water kinematic Кинематическая viscosity $\nu \cdot 10^{-4}$, m²/s	Water dynamic иинамическая viscosity $\mu \cdot 10^3$, Pa·s
0	999,9	0,0179	1,79
4	1000	0,0152	1,57
20	998	0,0101	1,01
40	992	0,0066	0,65
60	983	0,0048	0,48
80	972	0,0037	0,36
90	965	0,0033	0,31

99	959	0,0028	0,27

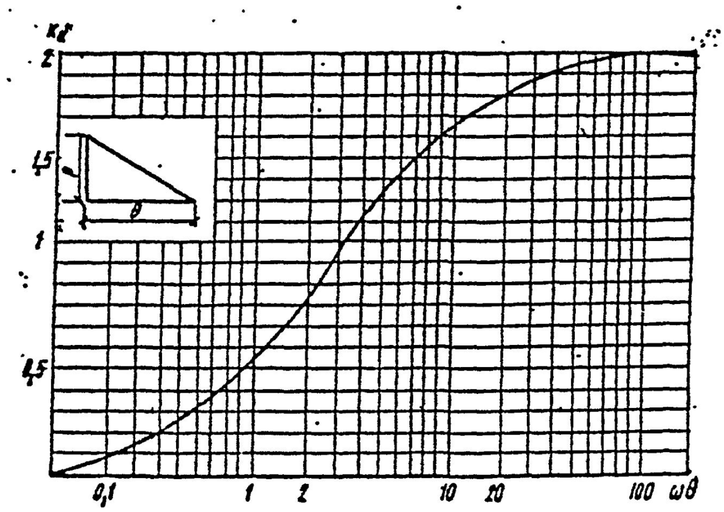
3. Averaged values for some objects

Table 2

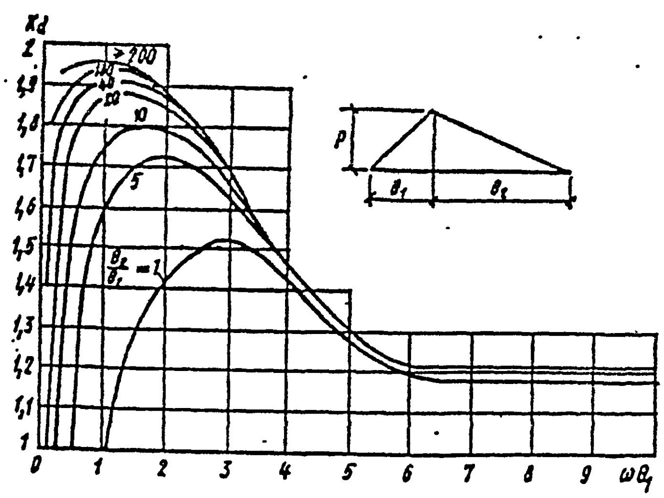
Form of the object	Value
Flat square plate put perpendicular to the flow direction	1,28
Round flat disc put perpendicular to the flow direction	1,1
Ball	0,45
Ellipsoid with a big axis directed perpendicular to the flow and axes ratio equal to 1,35	0,6
Ellipsoid with a big axis directed down flow and axes ratio equal to 1,8	0,075
Spindled object with front blunt and back sharped end (minimal resistance) when length to diameter ratio equals 4 and axis directed along flow	0,026
Cylindrical object having in section object configuration with best flow and axis directed perpendicular to the flow	0,090
Cylindrical object having in section object cycle configuration с осью, направленной перпендикулярно потоку	1,20

Cylindrical object having in section object rectangle configuration with axis directed perpendicular to the flow and facet directed perpendicular to the flow	2,0
The same, but with facets directed by angle 45 degree to the flow	1,50

4. Relation of dynamic factor for instantaneously growing load while calculation of the structure in the elastic stage of operation



5. Relation of dynamic factor for increment load while calculation of the structure in the elastic stage of operation



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