

## ARCHITECTURE AND CONSTRUCTION

## THE REACTIVE CAPACITY OF THE SOIL BASES OF GRAVITY-TYPE QUAY WALL

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## ABSTRACT

The results of studies of the reactive capacity of the soil base of a gravity-type quay-wall on the basis of the method developed for calculating the “structure - soil base” system are considered. The method proposed allows determining the reactive capacity of the soil base in conditions of mixed stress state model (limit and sublimit stress state of the soil base) under and around of the base of the foundation structure in a wide range of loads of lateral earth pressure. The transformation of limit and sublimit stress state zones of the soil base on the basis of numerical modeling is presented which shows an increase of the sizes of limit stress state and a decrease of the sizes of sublimit stress state.

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**Introduction.** Gravity-type quay-walls are the most common type of walls used for harbor berths. Reliability of the soil bases is one of the main factors in the design and the reconstruction of gravity-type quay-walls. Maritime transport development considerate the task of cargo complexes modernization and change their specialization including change of their operating condition. Thus, the studies of the reactive capacity of the soil base of a gravity-type quay-wall are importance and up-to-date.

The limit loads produced an effect on gravity-type quay-walls are of interest in the design or reconstruction of mentioned structures. It should be noted that the increase limit loads cause the loss of the reactive capacity of the soil base under the base of the foundation structure. Most often disturbance of stability of the soil base leads to a large settlement, to the rise from under the foundation and to the displacement of the structure. Significant displacement is dangerous for most of the aforementioned structures. Therefore, it is important to determine the maximum possible load on the soil base that won't disturb its stability.

**Purpose of the study:** to present the study's results of the reactive capacity of the soil base of gravity-type quay-wall on the basis of developed calculation method “structure – soil base” system [1] taking into consideration features work of the structure and soil backfill. The method proposed determines the reactive capacity of the soil base in the conditions of mixed stress state model. The model considers limit and sublimit stress state of the soil base under and around the foundation structure.

**Research results.** Calculation model of the “structure – soil base” system has been developed and numerical modeling has been performed in a wide range of loads of soil backfill pressure for studying of the system considered.

Occurrence issues of limit state zones of the soil base, determination of limit load causing their formation under the base of the foundation structure and influence of considered factors on the work

of the “structure – soil base” system have been discussed earlier by authors: M.V. Malyshev [2], P.I. Yakovlev [3], S.G. Kushner [4].

Currently, methods of calculation of the soil bases which are used in the design of berth structures don't take into consideration the presence and the transformation of the limit and sublimit stress state zones. Experimental studies conducted by Y.K. Zaretsky [5] have shown that the reactive capacity of the soil base depends not only on the strength properties of the soil base but also on the parameters which describe its behavior in sublimit stress state.

The calculation method of the reactive capacity of the soil base has been developed. It is based on the theory of the limit stress state. The method is different from other methods by the presence of two zones of soil stress state (limit and sublimit) in the soil base of the structure and by considering of the friction on the contact of rigid foundation structure and the soil base. The scheme of calculation of the reactive capacity of the soil base is shown in Fig. 1.

The model proposed of the interaction of a gravity-type quay wall with the soil base is based on the following presupposition:

1. The soil base interacting with the base of the foundation structure includes zones of limit and sublimit stress state.

2. The boundary of limit and sublimit stress state zones of the soil base (the width  $b_e$  of the contact zone of the soil base which is in limit stress state) is determined according to recommendations [1] and can be got from the expression

$$b_e = \frac{E - 0.5 \cdot B \cdot (f' + f_{np}^{mp})}{2 \cdot (f_{np}^{mp} - f')} \quad (1)$$

$b_e$  - the width of the contact zone of the soil base interacting with the base of the foundation structure in limit stress state;

$B$  - the width of the base of the foundation structure interacting with the soil base;

$f_{np}^{mp}$  - the intensity of the friction forces on the contact of the base of the foundation structure and the soil base within the width of limit stress state zone;

$f$  - the intensity of the friction forces on the contact of the base of the structure and the soil base within the width of the sublimit stress state zone;

$E$  - the resultant of lateral earth pressure (depends on an uniformly distributed load of intensity  $q$ ). It is defined as the vector sum of two components: limit  $E_e$  and sublimit  $E'$ , according to the recommendations [6] and may be expressed as

$$E = \left[ E_e^2 + E'^2 + 2 \cdot E_e \cdot E' \cdot \cos(\delta_e - \delta') \right]^{1/2} \quad (2)$$

3. Limit component of the reactive capacity of the soil base  $N_e$ . It conforms to the force acting within the width  $b_e$  of limit stress state zone. Sublimit component of the reactive capacity  $N'$ . It conforms to the force acting within the width  $B - b_e$  of sublimit stress state zone (see fig. 1).

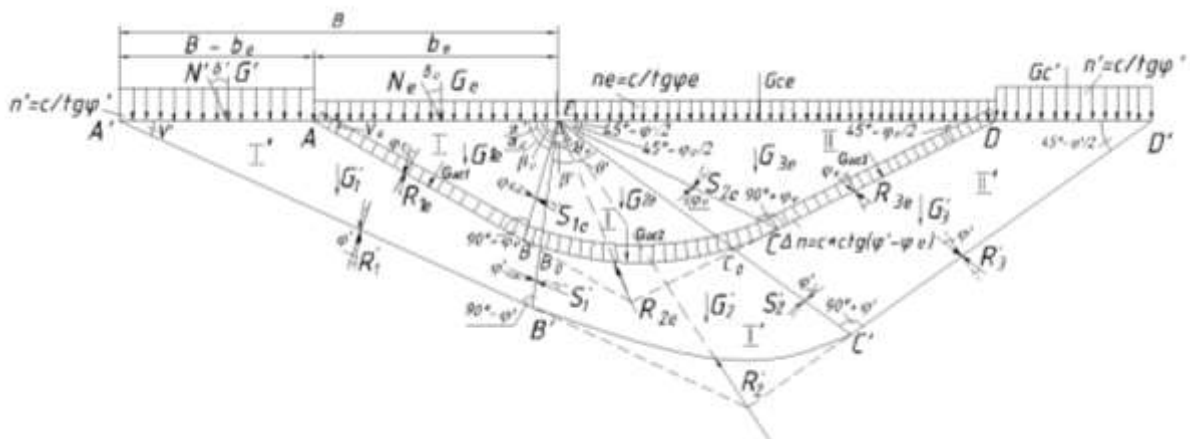


Fig. 1. The sliding surface and the outlines of limit and sublimit stress state zones of the soil base

4. The components' deflection angles  $N_e$  and  $N'$  and the resultants of reactive pressure of the soil base along the sliding surface from the normal to the boundary of this surface are accepted for limit stress state zone  $\delta_e, \varphi_e$  and for sublimit stress state zone accordingly  $\delta', \varphi'$ . It should be noted that the angle  $\varphi'$  is determined according to the recommendations [6] and may be expressed in form  $\varphi' = \varphi_o + n(\varphi - \varphi_o)$ .

Based on the design scheme (see Fig. 1) it can be obtained followed characteristics:

- the angles  $\delta'$  and  $\delta_e$ , determine as  $tg\delta' = E'/G'$  and  $tg\delta_e = E_e/G_e$  where  $E_e, G_e$  and  $E', G'$  horizontal and vertical components of the resultants  $N_e$  and  $N'$  accordingly in the range of limit and sublimit stress state zones;

- the parameter  $n$  is depended on the sizes of limit and sublimit stress states zones of the soil base and is determined by the ratio  $n = V_e/V$  where  $V_e$  - the volume of the area of the soil base being in limit stress state;  $V$  - volume of whole soil mass interacting with the base of the foundation structure.  $V_e$  and  $V$  can be determined from geometrical consideration of the design scheme;

- the angle  $\varphi_o$  conforms to the earth pressure at rest and can be taken according to the recommendations [7].

5. The resultant of the reactive capacity of the soil base  $N$  can be determined for each current deformed state of the structure as the vector sum of two components: limit  $N_e$  acting within the wide  $b_e$  and sublimit  $N'$  acting within the wide  $B-b_e$ . In this case, the resultant of the reactive capacity of the soil base  $N$  can be expressed by the equation

$$N = \left[ N_e^2 + N'^2 + 2 \cdot N_e \cdot N' \cdot \cos(\delta_e - \delta') \right]^{1/2} \quad (3)$$

6. The cohesive soil characterized by specific cohesion  $c$  can be taken into consideration by loading of an uniformly distributed load acting downward on the top surface of the soil backfill. The intensity of the load within limit stress state  $n_e = c/tg\varphi_e$  and the intensity of the load within sublimit stress state  $n' = c/tg\varphi'$  as shown in fig. 1.

The resultants of uniformly distributed loads in the first case  $G_{ce}$  and in the second case  $G'_c$ . It should considerate the increment of the cohesive pressure  $\Delta n$  on the boundary of limit and sublimit stress state zones which can be calculated as follows:  $\Delta n = c \cdot ctg(\varphi' - \varphi_e)$ .

The balance conditions of limit and sublimit strain stress zones of the soil base are considered consistently for determination of limit  $N_e$  and sublimit  $N'$  reactive capacity of the soil base. In this case, it considers force interaction of the aforementioned zones.

Some results of numerical modeling of the "structure – soil base" system are considered. It should be emphasized that there are two phases of the interaction of gravity-type quay wall and the soil backfill: the phase of structure construction which includes the process of formation of the soil backfill; the phase of operation when an uniformly distributed load  $q$  effects on the structure. The paper studies the second phase of the interaction of gravity-type quay wall and the soil backfill. In this case, soil backfill lateral pressure will increase depending on the loading and the increase of an uniformly distributed load  $q$ .

The increase load  $q$  leads to the growth of the reactive capacity of the soil base (due to the appearance and development of limit stress zones in the soil base). This process can be continued while limit reactive capacity in the soil base won't be reached. Further increase of the external load may lead to loss of the structure stability due to the exhaustion of the bearing capacity of soil base.

The growth of an uniformly distributed load  $q$  leads to the increase of active earth pressure of the soil backfill and to the transformation of the areas of limit and sublimit stress states of the soil base. The transformation leads to the increase of the area of limit stress state and to the decrease of the area of sublimit stress state. An example of the transformation of considered zones as a result of the increase of the load  $q$  is given in fig. 2.

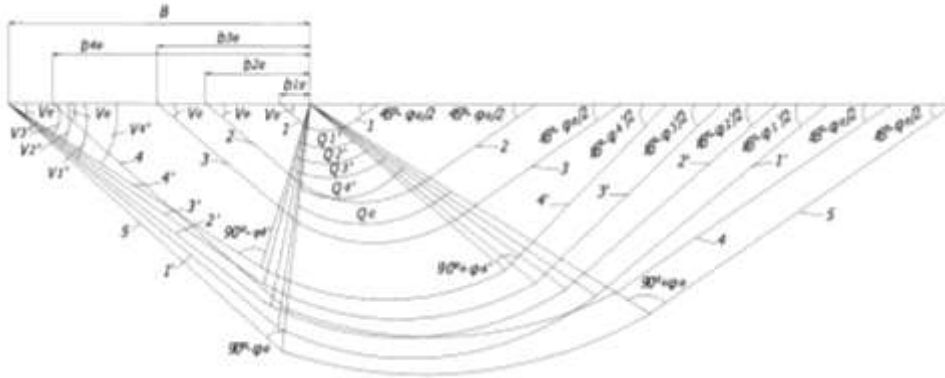


Fig. 2. The transformation of limit and sublimit stress state zones of the soil base:

- 1' – the boundary of sublimit strain stress zone in the case of the achievements of active pressure which leads to formation of limit strain stress zone 1;  
 2, 2'; 3, 3'; 4, 4' – the boundaries of limit and sublimit stress state zone of the soil base as a result of the increase of the load  $q$ ;  
 5 – the boundary of the soil mass in case of achievements of limit reactive capacity of the soil base

At the time of the transformation of the boundaries of limit stress state of the soil base 1, 2, 3 and 4 falls down remaining parallel due to the constancy of the angle  $V_e$ . The boundaries pointed pass through the points of the contact surface of the base of the foundation structure within the width  $b_1$ ,  $b_2$ ,  $b_3$  and  $b_4$ . The boundaries of limit stress state of the soil base 1, 2, 3 and 4 in the area located behind the foundation structure fall down remaining parallel due to the constancy of the angle  $45^\circ - \varphi_e/2$ .

The boundaries of limit stress state of the soil base 1, 2, 3 and 4 in the intermediate area (Prandtl zone) fall down due to the constancy of the angle  $\theta_e$  ( $\theta_e$  is the angle of the logarithmic spiral of considered area). At the same time the boundaries of sublimit stress state 1', 2', 3' and 4' under the base of the foundation structure change the slope to the horizon from angle  $V_1'$  to  $V_2'$ ,  $V_3'$  and  $V_4'$  as a result of the increase of active pressure in the range from  $E_a$  to  $E_{np}$ .

The boundaries of sublimit stress state 1', 2', 3' and 4' in the area located behind the foundation structure change the slope to the horizon from angle  $45^\circ - \varphi_1'/2$  to  $45^\circ - \varphi_2'/2$ ;  $45^\circ - \varphi_3'/2$ ;  $45^\circ - \varphi_4'/2$  in accordance with considered range of active pressure. The boundaries of sublimit stress state 1', 2', 3' and 4' in the intermediate area change the angle from  $\theta_1$  to  $\theta_2$ ,  $\theta_3$ ,  $\theta_4$ . Pointed boundaries are drowned by a logarithmic spiral as shown in fig. 2.

It should be noted that the growth of an uniformly distributed load  $q$  at the time of the formation of sublimit stress state zones reduces the sizes of sublimit stress state and changes the boundaries outline of the sliding surfaces. This process continues until the width of limit stress state zone won't reach of the value  $B$ .

**Conclusions.** The most important factor affecting on the assessment of the reactive capacity of the soil bases of gravity-type quay walls and on the determination of work of the “structure- soil base” system is lateral soil pressure. Thus, the study of the reactive capacity of the soil base on the basis of the calculation model proposed of the “structure-soil base” system is an important task. The findings of studies can be used in the design and the construction of considered structures and so for the analysis of the technical condition of the operation structures including rigid retaining walls.

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