STABILITY CONDITIONS OF ACCUMULATIVE FORMS OF SEDIMENTS ON SUBMARINE SLOPES

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Abstract

A lack of data representing natural phenomena, that give rise to transformation of the continental slope appears to be the most serious challenge in obtaining the full pattern of the process. The latest advanced instruments have insured more intensive, though not yet enough systematic observations of the submarine mass movement. Therefore, it seems reasonable to seek for indirect means of evaluation of sediment dynamics on the shelf and continental slopes by specially derived equations. An article deals with the study of statistical and dinamical conditions and some criterion of stability of the sedimentary forms on the submarine slope in deltaic areas.

Keywords: Mouth; Submarine slope; Sediment deposit; Stability conditions; Submarine slides.

1. Introduction

The major part of debris, washed down by river flow, accumulate on the mouth offshore submarine slope, stays there for some time (this period depends on seasonal conditions, hydro- and lithodynamic factors) in a stable condition and depending on the stability conditions for sediment deposits layer, either is gradually washed out by coastal currents, or is fallen down as discrete parts or blocks through underwater gorge channels.

Any forces acting upon the environment (the shelf and continental slope, in this particular case) in the long run induce dynamic equilibrium.This viewpoint is valid when the problem is considered at a time scale compatible with a geological epoch (without significant oscillations of the sea level and major tectonic movements). Each geological epoch with its contemporary orogenic processes – sea transgression and regression – had developed its own equilibrium conditions which were finally achieved by a unidirectional sediment flow under gravitational forces. Therefore, both the sedimentation and the shelf and continental slope erosion have been and still are a consequence of disturbance of the equilibrium. At a shorter time scale (decades, years, months, etc.) the shelf and continental slope surface can be obviously considered as a united system at unstable dynamic equilibrium, where the terrastrial river contribution appeared to be the basic "perturbarting" natural land-forming agent. The submarine gravity transport of sediments can be classified into stone falls, slides and slumps, material flows and turbidity flows depending on the sediment composition and motion (clastic, plastic, viscous), development of the motion (from sliding to suspension) and physical interaction between water and sediments. The forms of motion are frequently combined, e.g., land-slides, a viscous flows and turbidites form a gradational spectrum of allochtonous sediments in the cone (Allen 1971; Almagor 1982; Bagnold 1962; Bea

1983; Cochonat et al. 1993; Dill 1964; Einsele 1990; Hampton 1987; Lee 1986; Loginov 1971; Lowe 1982; Middleton 1966; Morgenstern 1967; Mulder et al. 1998; Nardin et al. 1979, Prior et al. 1978; Saphianov 1970; Savoey et al. 1991; Shepard et al. 1977; Syvitski et al. 1995; Terzaghi 1942). The stability conditions of submarine sediments are disturbed by changes in the tangential reaction between soil particles or blocks, increased pore pressures, storms, instability of the underlying rocks, structural motions, tsunamis, earthquakes. The most common motion stimulators are waves which induce different changes in the stability, from shifting a soil unit across the accumulative form surface to suspending the whole sediment load (under certain conditions). Analytical consideration of the question of stability of sediment accumulations on the submarine slopes of the mouth offshore was provided also by Voynich-Sianozhenski et al. (1969), Voynich-Sianozhenski and Bilashvili (1972), Bilashvili (1978, 1984, 1988).

2. Results and discussion

The results of these works where used for industrial needs in the Black Sea for assessment of possible mass withdrawal from the upperslope and destructive activity of submarine slides on the engineering structures etc.

Below we present further development of results, obtained in those works through envisaging adhesion forces in calculations.

Let us consider triangle configuration of sediment deposits, settled on the submarine slope, with horizontal upper plane, bottom, coincidental with the submarine slope plane and front plane, with angle of inclination, which is close to the angle of friction of the ground, under the water. On the basis of schematizing of this question, we have also assumed, that under influence of internal adhesive forces the mass is somehow cemented and on this basis it is possible to consider stability conditions for the sediment mass as a monolith body, instead of stability conditions for granular continuous medium(what actually corresponds to the sediment deposits).

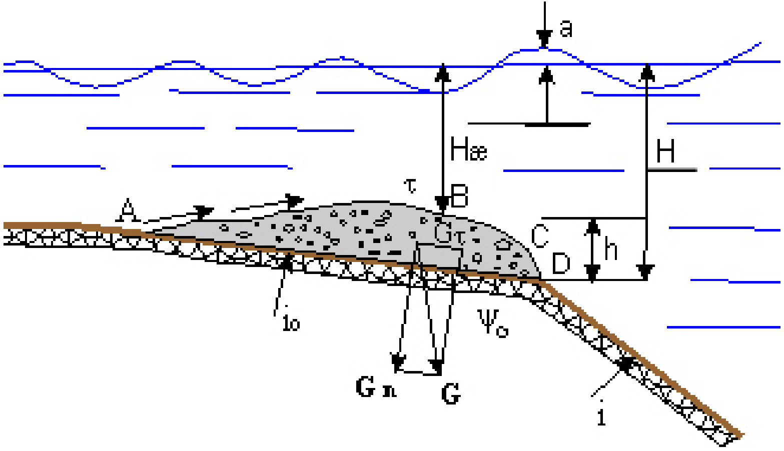

Figure.1

According to the assumed scheme, limit equilibrium condition for the described configuration of sediment accumulation body may be written as:

$$G_\tau + T_\tau - fG_n - Cbl = 0 \tag{1}$$

It is clear, that projection of the weight of body is:

$$G = W_S(\gamma_S - \gamma) \tag{2}$$

Where W_S is total volume of the sediment configuration, γ_S and γ - correspondingly specific gravities of sediments and sea water. Projection of weight on the longitudinal (long) axis of sliding will be:

$$G_\tau = G\sin\psi_0 \tag{3}$$

Resistance to the shifting forces may be expressed by the sum of following forces: frictional $fG_n = fG\cos\Psi_0$, where $f = tg\varphi$ - is Coulomb friction coefficient, φ - angle of internal friction, Ψ_0 - angle of submarine slope and adhesive forces Cbl, where C is the adhesive coefficient, and bl - contact area of described form and underlying surface, which consists of bedrock.

Projection of the tangent stresses, which act along the upper surface under influence of water medium, generally may be expressed as:

$$T = \int_0^l \tau' b\,dl + \int_0^l \tau'' b\,dl \tag{4}$$

where $\tau' = k_f\rho(V^2_{orb})/2$ and $\tau'' = kf\rho(V^2_{cc})/2$ are average tangent stresses, caused by marine medium and affecting the accumulated form, on the account of orbital velocities of waves and velocities of countercurrent, correspondingly.

To determine average values of τ' and τ'', we shall use average, with respect to period, velocity Vorb and averaged with respect to depth, velocity Vcc. If we take their values according to Brovikov (1954), for the value of orbital velocity we obtain:

$$V_{orb} = \frac{2agthkH}{\pi C_k H} \tag{5}$$

where values of C and $k = 2\pi/\lambda$ are averaged with respect to depth H, in accordance with the changes of depth over upper contour of accumulated body of sediment deposits. Coastal countercurrent, directed to the sea, is accompanied by the current and flow of excess amount of water into the boundary zone, which is formed as a result of breaking of the waves, which come out to the coastal shallow.

As we know, whole specific discharge returns to the sea through cross-section, which is less than full depth H, i. e. through cross-section of χH depth, where $0<\chi<1$.

Therefore, according to the considerations, presented in Voynich-Sianozhenski et al. (1969), for the countercurrent velocity, which is conditioned by overturn of the water crest (ridge), we write Brovikov's formulas as:

$$V_{cc}^{1} = \frac{gh^2}{8HC}(1-th^2kH), \tag{6}$$

for the corresponding discharge it yields:

$$q' = \frac{gh^2}{8C}\chi(1-th^2kH) \tag{7}$$

for discharge of the current calculation expression will involve the product of average velocity of the wave current and the depth $H-\chi H=H(1-\chi)$, i. e.

$$q'' = \frac{gh^2}{8C'}(1-\chi) \tag{8}$$

If we divide summary magnitude ($q'+q''$) of total water discharge, flowing back, into the sea, by χ, for the velocity of the countercurrent we obtain:

$$V_{cc} = \frac{gh^2}{8C}\cdot\frac{\chi(1-th^2kH)+(1-\chi)}{\chi H} \tag{9}$$

or, taking into account, that $\chi=0{,}5$:

$$\bar{V}_{cc} = \frac{g\bar{h}^2}{8\bar{C}\bar{H}}(2-th^2\bar{k}\bar{H}), \tag{10}$$

Thus, for the values of average tangent stresses τ' and τ'':

$$\tau' = 2k_f\,\frac{\rho\bar{a}^2g^2th^2\bar{k}\bar{H}}{\pi^2\bar{C}^2\bar{k}^2\bar{H}^2}, \tag{11}$$

$$\tau'' = \frac{k_f\rho g^2\bar{a}^4(2-th^2\bar{k}\bar{H})^2}{8\bar{C}^2\bar{H}^2} \tag{12}$$

Consequently we obtain following expression for T:

$$T = \frac{k_f\gamma g\bar{a}^2bl}{\bar{C}^2\bar{H}^2}\left\{\frac{2th^2\bar{k}\bar{H}}{\pi^2\bar{k}^2}+\frac{\bar{a}^2}{8}(2-th\bar{k}\bar{H})^2\right\} \tag{13}$$

After substitution of presented expressions for T into the equation (1) and some transformations, we obtain stability condition for sediment deposits, accumulated on the submarine slope of mouth offshore, as

$$f+\frac{2c'}{h(\gamma_s-\gamma)\cos\psi_0}=tg\psi_0+\frac{k_f}{\sigma_s\cos\varphi_0}\left\{\frac{\bar{a}_1^2A_1\cos\varphi}{\bar{k}_1\bar{H}_1^2th\bar{k}_1\bar{H}}+\frac{a_2^{-2}A_2l_2\cos\varphi_2}{\bar{k}_2l_2\bar{H}_2^2th\bar{k}_2\bar{H}_2\cos\psi_1}\right\} \tag{14}$$

Let us introduce following designations:

$$Ai=\frac{2}{\pi^2}th^2\bar{k}_i\bar{H}_i+\frac{\bar{a}_i^2\bar{k}_i^2}{8}(2-th\bar{k}_i\bar{H}_i)^2$$

$$\bar{H}_c=\frac{W_s}{bl}$$

Further, taking into account, that square of the wave steepness a^2k^2 always is less then one, by order of magnitude and $\varphi_0 \sim \psi_0$, and as upper plane may be assumed to be horizontal, on the basis of expression (14), stability criterion condition (>), condition of limit equilibrium (=) and instability condition (<) will be written, as:

$$f+\frac{2c'}{h(\gamma_s-\gamma)\cos\psi_0}=tg\psi_0+\frac{4k_f\cos\psi_0}{\pi^2\sigma l\bar{H}_c\sin\psi_0}\left\{\frac{\bar{a}_1^2th\bar{k}_1\bar{H}_1l_1}{\bar{k}_1\bar{H}_1^2}+\frac{\bar{a}_2^2th\bar{k}_2\bar{H}_2l_2}{\bar{k}_2\bar{H}_2}\cdot\frac{\cos\varphi_2}{\cos\psi_0}\right\} \tag{15}$$

It is clear, that after excluding parameters of the waves ($\alpha_1=\alpha_2=0$) from equation (15), we obtain static stability condition for the solid body or ground, which is characterized by adhesion on the inclined plane. At the same time it is necessary to point out number of conditions, which are required to correctly evaluate obtained equation (15). As we know, because of presence of orbital velocities of different directions in the scopes of wave length (in the area of wave foot towards the sea and under the wave crest towards the shore), and consequently tangent stresses of different directions at the upper limit of the accumulated form, when mass, being monolith quite enough, to resist breaking influence of the orbital velocities, factor of the waves for monolith body, with the length exceeding the wave length, become negligible, i. e. in this case we have:

$$f+c'bl=tg\psi_0 \tag{16}$$

3. Conclusion

Thus sea waves are an additional factor, which furthers loosing of sediment mass stability, only when the body of configuration is composed of weakly cemented blocks (what actually takes place in practice), or length of the deposit layer is less or equals to half length of the storm wave. As in natural conditions, as a result of inhomogenity of the deposit mass and action of differently directed breaking tangent stresses, it is likely, that sediment accumulations will have the structure, divided into the blocks and we found that it would be reasonable to evaluate degree of stability of entire mass, on the basis of stability conditions of the front block of the accumulated form In the case, when we consider body of deposits, which is not divided into separate sections, on the submarine slope of mouth offshore, effect of the waves on stability of sediment accumulation will be conditioned only by wave countercurrent, which is not periodical. Excluding the first component in the curly brackets in equation (13), for given case we yield:

$$T = \frac{k_f \gamma g a^4 bl}{8C^2 H^2}(2 - thkH)^2 \tag{17}$$

Substituting this expression in equilibrium equation (1)

$$G_\tau + T_\tau - fG_n - Cbl = 0$$

where

$$G = (\gamma_s - \gamma)W_s$$

we obtain:

$$f + \frac{2c'}{\gamma \overline{H}_c \cos\psi_0 \sigma_s} = tg\psi_0 + \frac{k_f \pi a^4 (2 - thkH)\cos\varphi_1}{4\sigma \overline{H}_c \lambda H^2 \cos\psi_0}, \tag{18}$$

where $\overline{H}_c = \frac{W_s}{bl}$ is average thickness of the sediment deposits and

$$\sigma_s = \frac{\gamma_s - \gamma}{\gamma}$$

From this inequality we can conclude, that wave amplitude is critical for stability of accumulated form of sediment deposits, with the length equal or more, than wavelength, as contribution of the wave factor in worsening stability conditions is proportional to the wave amplitude in the fourth degree. For the short waves thkH=1, factor in the brackets equals to one. As for long waves, when thkH=kH and λ>>H, member kH may be neglected in comparison with 2. This will lead to the fact, that second component becomes four times as greater for long waves, in comparison with the short waves. Though it is easy to see, that the role of bottom countercurrent for stability of body of sediment deposits is substantially less, than the role of tangent stress, conditioned by orbital velocities.

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