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On Method of Estimation of Acoustic Shadow Zone When Assessing Groundfish Stocks

by

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Abstract

Assessment of groundfish abundance has been a challenge since 1986 when the first Russian trawl-acoustic survey for demersal fish stocks in the Barents Sea was conducted. Because of specific physical characteristics, merely acoustic method of assessment can not give complete and objective estimation of distribution density of marine organisms near the seabed. A lot of papers are known to study interactons between sound wave and near-seabed fish and to estimate so-called acoustic shadow zone or deadzone (from other references). This paper looks at the one of the practical ways of estimation of geometrical parameters of such shadow zone and corresponding correction coefficients K_{shad} for bottom channel of echo-integration system, irrespective of its type. Four equations are given to estimate effective values of acoustic shadow zone in dependence on fish distribution on the seabed, water parameters and specifications of equipment used.

Experimental approach to algorithms developed was made during trawl-acoustic survey for cod and haddock in the Barents Sea in October-December 1995 by RV "Professor Marti" using EK-500 echo-sounder and PC IBM 486 onboard. In these particular conditions of the survey, estimated values of correction coefficients of shadow zone varied in average from K_{shad}=1.5 to K_{shad}=20 relative to S_A values in the bottom channel of 2-m width integrator in dependence of the above listed conditions.

Introduction

At present, trawl-acoustic survey is accepted by the majority of experts in the world to be the only one more or less accurate way of groundfish stock assessment. Merely trawl or acoustic methods separately have their shortcomings and advantages but their integration in the whole process provide the most benefit.

The main aim of trawl-acoustic survey is to know the stock size in both pelagic and bottom layers. If method of assessment of pelagic fish has been sufficiently mastered by now, demersal and semi-demersal fish stock assessment involves some difficulties.

There are several factors preventing to obtain near seabed estimation with sufficient range of accuracy, the main of which are the effect of acoustic shadow zone of echo-sounder on possibility of fish detection and the response of fish themselves to the noise of the moving vessel. In different papers published earlier (Mitson, 1982, Mamylov et al., 1989, Ona and Mitson, 1995), those problems have already been arisen, therefore, in this paper we do not concern theoretical aspects of formation of echo-signals from fish distributed near seabed as well as problems related to " fish behaviour effects" during trawl-acoustic survey. In this paper we just consider one of the practical variants to "compensate" the acoustic shadow zone.

Materials and Methods

Ona and Mitson, 1995 in their paper gave minute description of practical aspects of signal processing from single objects near seabed using EK-500 echo-sounder as well as detailed description of acoustic dead zone (ADZ), integrator deadzone (IDZ) and zone determined by the distance of integration discontinuance above the seabed (BSZ), which extends from the depth detected as bottom. In the present paper when estimating geometrical parameters of the shadow zone, classic formulae of stereometry (Bronshtein, Semendyaev, 1986) were used. Besides, unlike the paper by Ona and Mitson, 1995, a very essential parameter such as the mean vertical development of near seabed concentrations of marine organisms - d, which can be determined with the accuracy not worse that 0.2-0.5 m when using an expander of the near seabed recording of echo-sounder were included into calculations and when integration interval is near one mile. As it is shown from the experience, it is precisely this parameter which has the most effect on the volume of the acoustic shadow zone and determines the optimum choice of operation regimes of bottom channels of echo-integration system in the particular conditions of the survey.

During calculations it was assumed that concentrations of marine organisms in the bottom layer of d-width were uniform in density and ground within the limits of directional diagram was even. Besides, equvalent 2-way beam angle of echo-integration system (under TVG - 20 lgR *regime*) was assumed to be constant and equal to the specification value of 10 lgψ, i.e.possible dependence ψ_{eff} *on* depth and threshold at weak echo-signals was excluded. It is known that acoustic survey is based on estimation of the mean density of marine organism distribution using a method of echo-integration. We are dealing with the bottom layer of d-width, where such distribution can be considered uniform in density. In this case, the value of echo-intensity measured is proportional to those part of the near seabed concentration which is accessible to the integration process V_1. The volume of V_2, the integrator shadow zone (IDZ according to Ona and Mitson, 1995), is proportional to those volume of echo-intensity from the concentration which is truncated by the low limit of the integrator or disguised by the echo-signal from seabed.

V_1 and V_2 values and methods of their estimation, respectively, depend on relationship between d-value, sea depth B, width of bottom channel, H, and backstep from the seabed, h.

Analysis shows that only four variants of such relatioships are possible, each having their own equation to calculate the shadow zone.

Assume, that fish distribution is that H+h>d (Fig. 1). By virtue of the fact that acoustic wavefront has spherical shape, V_1 volume is nothing more nor less than spherical segment and its numerical value can be evaluated by the following equation:

$$V_1=\frac{\pi a^2(3\times(B-h)-a)}{3} \tag{1}$$

where a - thickness of this segment can be calculated from

$$a=d-h \tag{2}$$

hence,

$$V_1=\frac{\pi\times(d-h)^2[3\times(B-h)-(d-h)]}{3} \tag{3}$$

Then after simple conversion we will come out to the following:

$$V_1=\frac{\pi\times(d-h)^2(3B-d-2h)}{3} \tag{4}$$

where

d - vertical development of the near seabed concentration of marine organisms, m h - backstep from the seabed, m

B - depth of the sea (from the transducer face to the seabed, m)

As Figure 1 shows, shadow zone coefficient relative to echo intensity in the bottom layer is a relationship

$$K_{shad}=\frac{V_1+V_2}{V_1}$$

Value of $V_1 + V_2$ can be determined as volume of frustum of a cone

$$V_1+V_2=\frac{\pi}{3}\,(d+\frac{c\tau}{2})\times tg^2\frac{\beta}{2}\,[\,(B+\frac{c\tau}{2})^2+(B-d)^2+(B+\frac{c\tau}{2})\,(B-d)\,] \qquad (5)$$

where,

β - beam angle to -3 dB points, °
c - sound velocity, m/sec
τ - pulse duration, sec

Hence,

$$K_{shad}=\frac{V_1+V_2}{V1}=\frac{(d+\frac{c\tau}{2})\times[\,(B+\frac{c\tau}{2})^2+(B-d)^2+(B+\frac{c\tau}{2})\,(B-d)\,]}{(d-h)^2\times(3B-d-2h)}\times tg^2\frac{\beta}{2} \qquad (6)$$

It should be noted that in formulae 5 and 6, the layer of $c\tau/2$ is included into V_2 volume to compensate the so-called "partial integration zone" (PIZ from Ona and Mitson, 1995) and that portion of fish which is distributed directly near the seabed and disguised by echo-signal from the seabed.

As it was shown above, concentration volume V_1 accessible to echo-integration is a spherical segment ("lens"). Let us introduce some angle α, tangent of which is determined from the following expression

$$tg\frac{\alpha}{2}=\frac{r}{B-d} \qquad (7)$$

where,

r is radius of sperical segment which can be calculated from

$$r=\sqrt{a\,(2B-a)}=\sqrt{(d-h)\times(2B-d-h)} \qquad (8)$$

Hence,

$$tg\frac{\alpha}{2}=\frac{\sqrt{(d-h)\times(2B-d-h)}}{B-d} \qquad (9)$$

Let us name α angle as angle of view in the bottom layer. Figure 1 shows that α angle is less than β angle, i.e. edges of "fish lens" are restricted to the limits of beam angle, β . In case of the same settings for bottom channel but at the higher value of d, i.e. at the higher vertical distribution of fish over the seabed, the situation will change somehow.

Fugure 2 shows that the upper boundary of the fish vertical distribution over the sea bed is still within the range of bottom channel, i.e. H+h>d. However, V_1 volume accessible to echo-integration has somewhat different form, and α, angle of view in the bottom layer, is already larger than the β, beam angle. It is clear that equation (6) is limited in use by situation when angle of veiw in the bottom layer, α, is less or equal to the beam angle, β. Volume of fish registered V_1 can be calculated as a difference between volume of spherical cone formed by the beam angle, β, and upper boundary of fish distribution in the bottom layer. The essence of geometrical manipulations with formulae are similar to the method described above, thus we give just a final variant of equation for the case presented in Figure 2.

$$K_{shad}=\frac{V_1+V_2}{V_1}=\frac{tg^2\frac{\beta}{2}(d+\frac{c\tau}{2})\times[(B+\frac{c\tau}{2})^2+(B-d)^2+(B+\frac{c\tau}{2})(B-d)]}{2(1-\cos\frac{\beta}{2})\times(B-h)^3-(B-d)^3\times tg^2\frac{\beta}{2}} \quad (10)$$

where variable legend is similar to that for equation (6).

Therefore, the above speculations suggest that in such vertical fish distribution in the bottom layer when its upper boundary is within the range of the bottom channel, value of angle of view in the bottom layer,α, and its relation to the value of beam angle, β, serve as criterion to choose equation (6) or (10) to estimate shadow zone coefficient. That is if

$$tg\frac{\beta}{2}\geq\frac{\sqrt{(d-h)\times(2B-d-h)}}{B-d},$$

equation (6) is used, but when

$$tg\frac{\beta}{2}<\frac{\sqrt{(d-h)\times(2B-d-h)}}{B-d},$$

equation (10) is applied.

Until now we have studied the situation, when the upper boundary of fish distribution in the bottom layer is within the range of bottom channel of echo-integration. Figure 3 suggests a variant, where the upper boundary of fish distribution on the seabed is already higher than the upper boundary of the bottom channel (i.e. $H+h\leq d$), but edges of the acoustic beam is even higher than the upper boundary of fish distribution (i.e.$\alpha<\beta$). If we compare this sutuation with that in Figure 2, it becomes evident that equation (10) is well suited for the calculation but its numerator and denominator are necessary to decrease by value of that fish volume which is situated higher than the range of bottom channel, i.e. V_3. Coming from Figure 3 legend and geometrical considerations, V_3 value is equavalent to the following expression:

$$V_3=\frac{\pi}{3}(d-H-h)^2\times(3B-2H-2h-d) \quad (11)$$

Hence, value of shadow zone coefficient for the variant of fish distribution presented in Figure 3 is determined from the following expression:

$$K_{shad}=\frac{V_1+V_2-V_3}{V_1-V_3}=$$

$$=\frac{tg^2\frac{\beta}{2}(d+\frac{c\tau}{2})\times[(B+\frac{c\tau}{2})^2+(B-d)^2+(B+\frac{c\tau}{2})(B-d)]-(d-H-h)^2\times(3B-2H-2h-d)}{2(1-\cos\frac{\beta}{2})\times(B-h)^3-(B-d)^3\times tg^2\frac{\beta}{2}-(d-H-h)^2\times(3B-2H-2h-d)}$$

(12)

In all the equations presented we are aware of keeping the restricting brackets in order to picture the geometrical essense of the equations more clearly. Figure 3 shows that equation (12) can be used merely in the case when the upper boundary of fish distribution near seabed is higher than the upper boundary of the bottom channel. However, by virtue of the fact, that the front of acoustic wave has spherical shape, it is more appropriate to say that the upper boundary of fish distribution near seabed should be situated between horizontal lines, one of which goes through the point of intersection of the back front of pulse and axis of acoustic beam, and another one connects the external edges of the pulse front, that is the following condition should be met:

$$H+h \leq d \leq B-(B-h-H)\times\cos\frac{\beta}{2}$$

As it was indicated above, d-parameter (vertical fish distribution over seabed) is determined visually by operator duty on echo recording of the extended bottom layer. We understand that the upper boundary of fish distribution near seabed can not be ideally even during a certain interval of integration and the use of some averaged value is admitted here.

And lastly, in our mind, one more variant of fish distribution on the seabed remains unpresented. This is the case, when the upper boundary of fish vertical distribution near the seabed is situated higher than the upper boundary of the bottom channel, that is $\alpha > \beta$ or

$$d > B-(B-h-H)\times\cos\frac{\beta}{2}\ (Figure 4).$$

The Figure and geometrical considerations show that equation (12) can be in use for estimation in such fish distribution, but d parameter is necessary to substitute with a following expression:

$$B-(B-h-H)\times\cos\frac{\beta}{2}.$$

Then, the complete equation for the situation showed in Figure 4 will take the following form:

$$K_{shad}=$$

$$=\frac{tg^2\frac{\beta}{2}(X+\frac{c\tau}{2})\times[(B+\frac{c\tau}{2})^2+(B-X)^2+(B+\frac{c\tau}{2})\times(B-X)]-(X-H-h)^2\times(3B-2H-2h-X)}{2(1-\cos\frac{\beta}{2})\times(B-h)^3-(B-X)^3\times tg^2\frac{\beta}{2}-(X-H-h)^2\times(3B-2H-2h-X)}$$

(13)

where

$$X=B-(B-h-H)\times\cos\frac{\beta}{2}$$

Thus, we presented four variants of estimation of shadow zone coefficient in dependence on fish vertical distribution near seabed, parameters of the acoustic instruments and settings of the bottom channel. Algorithm of choice of one or another of the estimaton methods are given in Figure 5.

Various coefficients of shadow zone in different situations are possible to be presented in both figures and tables. Table 1 give an array of such coefficients for certain parameters of the echo-sounder and integrator. It appear reasonable to renew data in this table when parameters vary during hydroacoustic survey. In our opinion, for this purpose it is convenient to use spreadsheets (Excel-type). Figure 6 and 7 show graphical representation of Table 1. Both table and plots are made using Excel 5.0. Figure 8 gives an example of estimation program of shadow zone coefficients. The program provides for automatic selection of one variant among the fourth variants necessary to estimate K_{shad} in dependence on relationship between d, B, H and h.

Results and Discussion

Methods of estimation of shadow zone coefficients presented in this paper, in our mind, describe adequately the majority of possible combinations of fish vertical distribution near seabed and technical characteristics and settings of hydroacoustic equipment. However, if fish are distributed too close to the seabed (d<h), then merely a physical restriction of a possibility to receive echoenergy occurs, and correction of echo-intensity in the bottom channel using this way is impossible. Such cases are a cause to estimate S_A from results of bottom tows, considering that a bottom trawl catchability is known (Mamylov et al., 1989).

The method described was tried when carring out trawl-acoustic survey for groundfish in October-December 1996 in the Barents Sea by RV

"Professor Marti".

During the survey, the recordings were made by EK-500 38 kHz echo-sounder using β=6.91° split-beam transducer. Pulse duration was 1 ms at 3.8 kHz bandwidth and -75 dB SV threshold. An increased influence of noise from the running vessel (depth more than 300-400 m, weather deterioration etc.) was a cause to make recordings at 3 ms pulse duration, 1 kHz bandwidth and -80 dB.

During the survey, in the most cases, density of cod, haddock and redfish distribution in 1-2 m bottom layer could be considered uniform in depth. Therefore, taking into account that vertical development of the bottom trawl used constituted nearly 8 meters, the two bottom channels of EK-500 was set as follows: the first one from 8 to 2 m above the seabed, the second one from 2 m down. Discontinuance of integration in the second bottom channel was determined by h-value (backstep from the seabed) which was usually set at 0.5 m. In some cases (fairly even ground, lack of rolling and pitching etc.), it was possible to decrease h down to 0-0.2 m, which, respectively, increased the accuracy of acoustic estimation of bottom organisms distribution.

When processing the survey results, S_A in the second bottom channel in each integration interval was multiplied by K_{shad}, value of which was taken from Table 1 in dependence on particular averaged d and B. During the survey, such estimation of d and B in the integration intervals was made "by hand", from echogram images, however, in principal, it is not unduly difficult to make this process automatic using EK-500 potentialities and developing appropriate software.

During the trawl-acoustic survey of redfish, cod and haddock in the Barents Sea in 1995, the particular values of K_{shad} varied between 1.5 (when H=2 m, h=0 m, d>1 m, τ=1 ms) and 20 (when H=1.5 m, h=0.5 m, d<1 m, τ=3 ms), when average K_{shad}=2-3 for the main survey regime.

During bottom tows, S_A values were compared in 8-m bottom layer estimated from the catch size (Mamylov et al., 1989) and by acoustic method using estimation algorithm for K_{shad} described above.

Preliminary analysis of the results from 215 bottom tows made during the survey, taking into account the known restrictions in principal applicability of acoustic method for fish recognition in the bottom layer (Ona and Mitson, 1995) shows rather satisfactorily compliance of acoustic and trawl data. In near seabed concentrations of cod, polar cod, redfish, haddock and herring, the difference between S_{Atr} and $S_{Aacoust}$ in the most cases did not exceed 20-30%. However, it should be noted that if, when estimating S_{Atr}, one considers trawl catchability to be constant and independent of size-species composition of fish, in some cases this leads to essential differences between S_{Atr} and $S_{Aacoust}$. For example, for fish 10-13 cm long and shorter (including capelin) $S_{Aacoust}$ sometimes exceeded S_{Atr} several times, while when fishing for large haddock or redfish the opposite situation occurs when S_{Atr} >> $S_{Aacoust}$. In our mind, such inconsistencies are primarily related to some uncertainty in estimation of trawl catchability coefficient as well as its dependence on size-species composition of fish and effects of their behaviour near towed trawl.

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Table 1. The shadow zone coefficients for various d and τ.

$h = 0.5$ m, $c = 1470$ m/sec, $H = 1.5$ m, $\beta = 6.91°$

Bottom	τ=1.0 ms						τ=3.0 ms					
depth, m	d=1.0	d=1.5	d=2.0	d=4.0	d=6.0	d=8.0	d=1.0	d=1.5	d=2.0	d=4.0	d=6.0	d=8.0
20	3.84	2.43	1.97	1.96	1.96	1.96	7.63	4.34	3.27	3.25	3.25	3.25
40	3.86	2.39	1.93	1.91	1.91	1.91	7.40	4.12	3.08	3.04	3.04	3.04
60	3.98	2.42	1.93	1.90	1.90	1.90	7.53	4.10	3.05	2.98	2.98	2.98
80	4.12	2.45	1.95	1.90	1.90	1.90	7.76	4.14	3.05	2.96	2.96	2.96
100	4.29	2.49	1.97	1.91	1.91	1.91	8.05	4.19	3.07	2.95	2.95	2.95
120	4.48	2.54	1.99	1.92	1.92	1.92	8.38	4.26	3.09	2.95	2.95	2.95
140	4.70	2.58	2.01	1.93	1.93	1.93	8.77	4.33	3.13	2.95	2.95	2.95
160	4.93	2.64	2.04	1.94	1.94	1.94	9.19	4.41	3.16	2.95	2.95	2.95
180	5.19	2.69	2.06	1.95	1.95	1.95	9.67	4.50	3.20	2.96	2.96	2.96
200	5.48	2.75	2.09	1.96	1.96	1.96	10.21	4.59	3.24	2.97	2.97	2.97
220	5.81	2.81	2.12	1.97	1.97	1.97	10.81	4.69	3.28	2.98	2.98	2.98
240	6.19	2.87	2.15	1.98	1.98	1.98	11.50	4.79	3.32	2.99	2.99	2.99
260	6.61	2.94	2.18	1.99	1.99	1.99	12.28	4.90	3.36	3.00	3.00	3.00
280	7.09	3.01	2.21	2.00	2.00	2.00	13.17	5.02	3.41	3.01	3.01	3.01
300	7.60	3.09	2.24	2.02	2.02	2.02	14.11	5.14	3.46	3.02	3.02	3.02
320	8.11	3.17	2.27	2.03	2.03	2.03	15.04	5.27	3.51	3.03	3.03	3.03
340	8.61	3.25	2.31	2.04	2.04	2.04	15.98	5.41	3.56	3.04	3.04	3.04
360	9.12	3.33	2.34	2.05	2.05	2.05	16.91	5.55	3.61	3.05	3.05	3.05
380	9.62	3.43	2.38	2.06	2.06	2.06	17.85	5.70	3.67	3.06	3.06	3.06
400	10.13	3.52	2.42	2.07	2.07	2.07	18.78	5.86	3.73	3.07	3.07	3.07
420	10.63	3.63	2.45	2.09	2.09	2.09	19.71	6.03	3.79	3.08	3.08	3.08
440	11.14	3.74	2.49	2.10	2.10	2.10	20.65	6.22	3.85	3.09	3.09	3.09
460	11.65	3.85	2.54	2.11	2.11	2.11	21.58	6.41	3.91	3.10	3.10	3.10
480	12.15	3.98	2.58	2.12	2.12	2.12	22.52	6.61	3.98	3.12	3.12	3.12
500	12.66	4.11	2.62	2.13	2.13	2.13	23.45	6.83	4.05	3.13	3.13	3.13
520	13.16	4.25	2.67	2.15	2.15	2.15	24.39	7.07	4.12	3.14	3.14	3.14
540	16.37	4.40	2.72	2.16	2.16	2.16	25.32	7.32	4.19	3.15	3.15	3.15
560	14.18	4.56	2.77	2.17	2.17	2.17	26.26	7.58	4.27	3.16	3.16	3.16
580	14.68	4.73	2.82	2.18	2.18	2.18	27.19	7.85	4.35	3.17	3.17	3.17
600	15.19	4.89	2.87	2.19	2.19	2.19	28.13	8.12	4.43	3.19	3.19	3.19
620	15.69	5.05	2.93	2.21	2.21	2.21	29.06	8.39	4.51	3.20	3.20	3.20
640	16.20	5.21	2.99	2.22	2.22	2.22	29.99	8.66	4.60	3.21	3.21	3.21
660	16.71	5.38	3.05	2.23	2.23	2.23	30.93	8.93	4.69	3.22	3.22	3.22
680	17.21	5.54	3.11	2.24	2.24	2.24	31.86	9.20	4.79	3.23	3.23	3.23
700	17.72	5.70	3.17	2.25	2.25	2.25	32.80	9.47	4.89	3.24	3.24	3.24
720	18.22	5.87	3.24	2.27	2.27	2.27	33.73	9.74	5.00	3.26	3.26	3.26
740	18.73	6.03	3.31	2.28	2.28	2.28	34.67	10.01	5.10	3.27	3.27	3.27
760	19.24	6.19	3.39	2.29	2.29	2.29	35.60	10.28	5.22	3.28	3.28	3.28
780	19.74	6.35	3.47	2.30	2.30	2.30	36.54	10.55	5.34	3.29	3.29	3.29
800	20.25	6.52	3.55	2.31	2.31	2.31	37.47	10.82	5.46	3.30	3.30	3.30
820	20.75	6.68	3.63	2.33	2.33	2.33	38.41	11.09	5.59	3.32	3.32	3.32
840	21.26	6.84	3.72	2.34	2.34	2.34	39.34	11.36	5.73	3.33	3.33	3.33
860	21.77	7.01	3.82	2.35	2.35	2.35	40.28	11.64	5.88	3.34	3.34	3.34
880	22.27	7.17	3.91	2.36	2.36	2.36	41.21	11.91	6.03	3.35	3.35	3.35
900	22.78	7.33	4.02	2.38	2.38	2.38	42.14	12.18	6.19	3.36	3.36	3.36

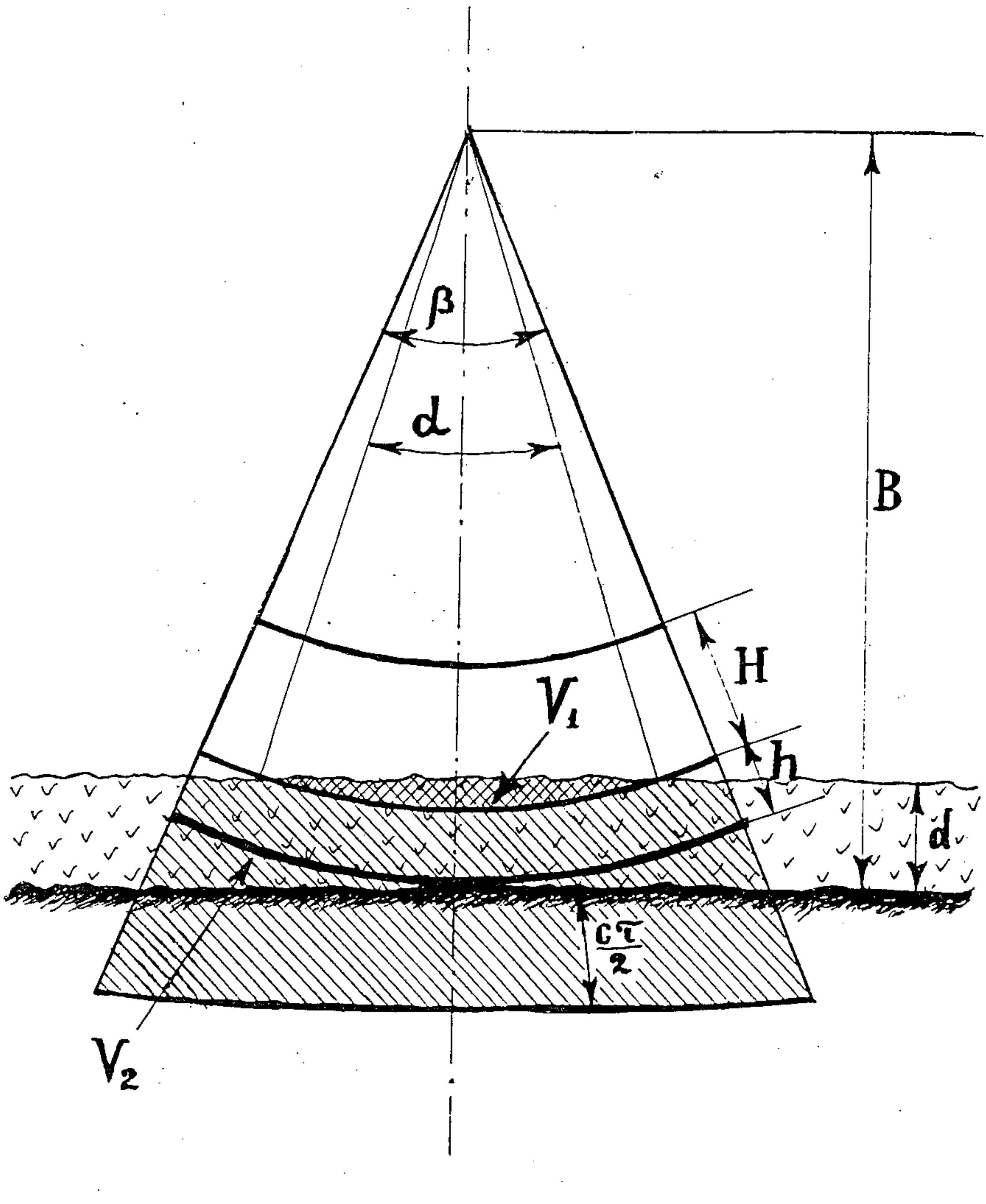

Figure 1. Algorithm of estimation K_{shad} at $H+h>d$ and $\alpha<\beta$

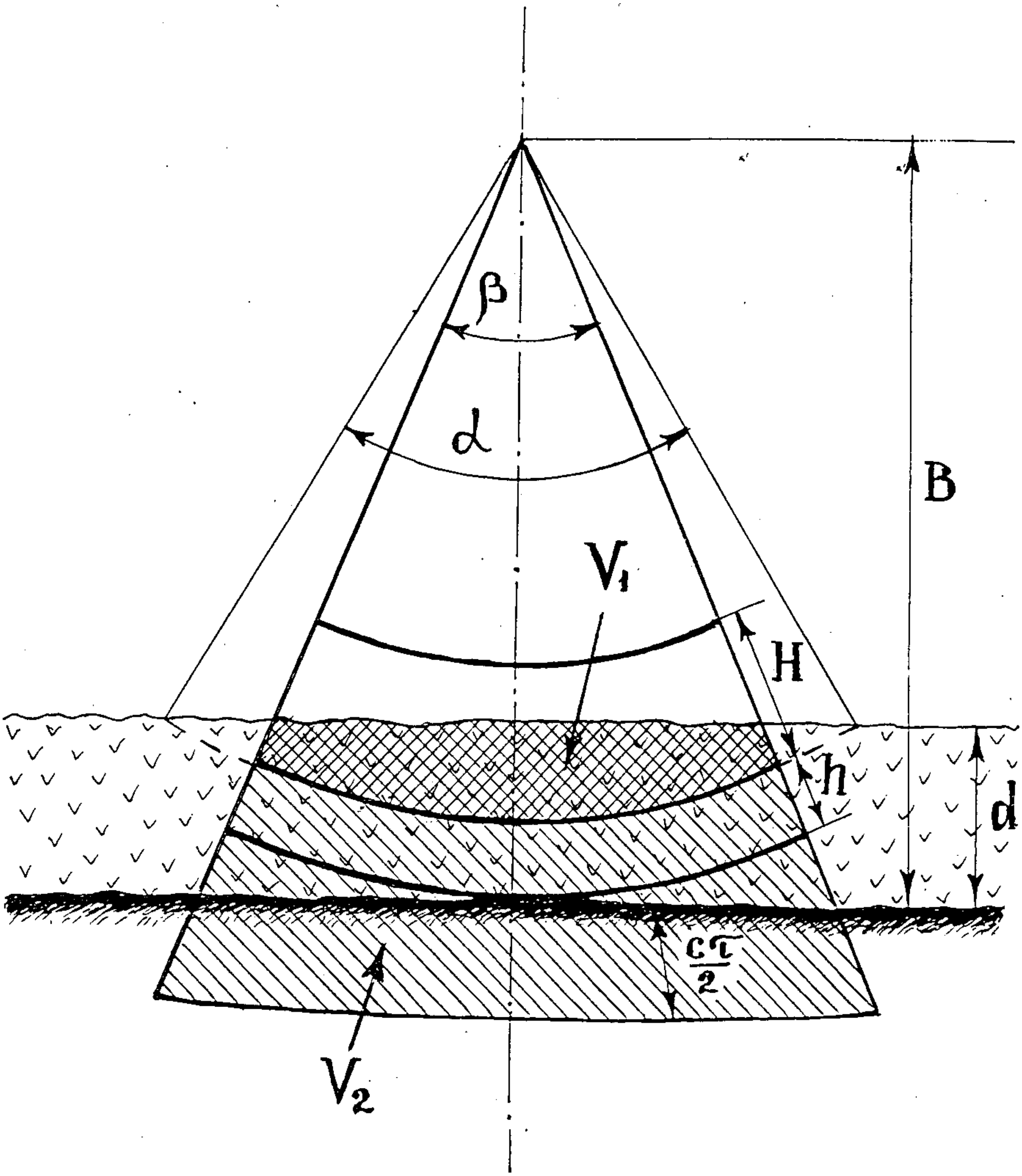

Figure 2. Algorithm of estimation K_{shad} at $H+h>d$ and $\alpha>\beta$

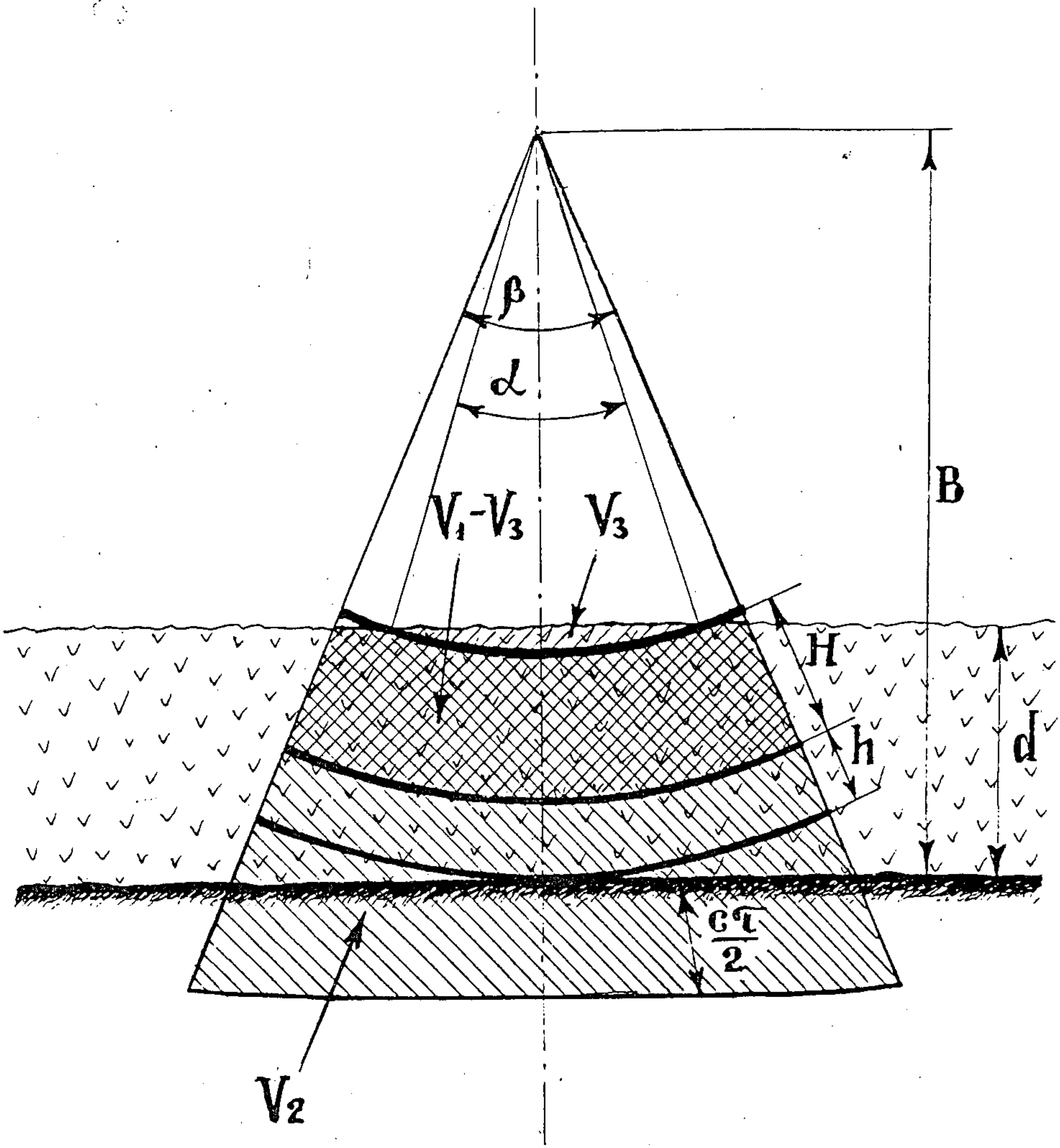

Figure 3. Algorithm of estimation K_{shad} at H+h<d and $\alpha<\beta$

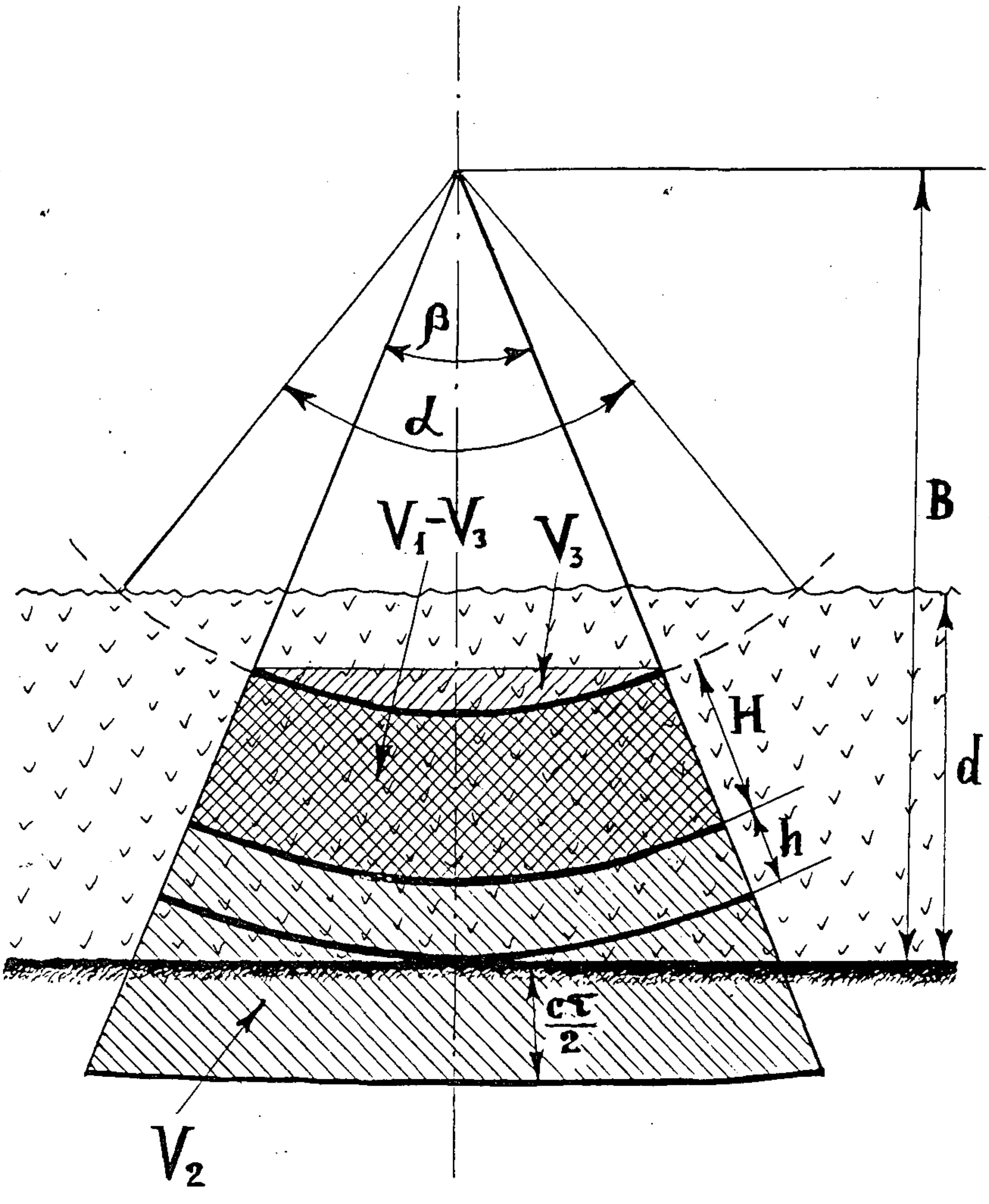

Figure 4. Algorithm of estimation K_{shad} at $H+h<d$ and $\alpha>\beta$

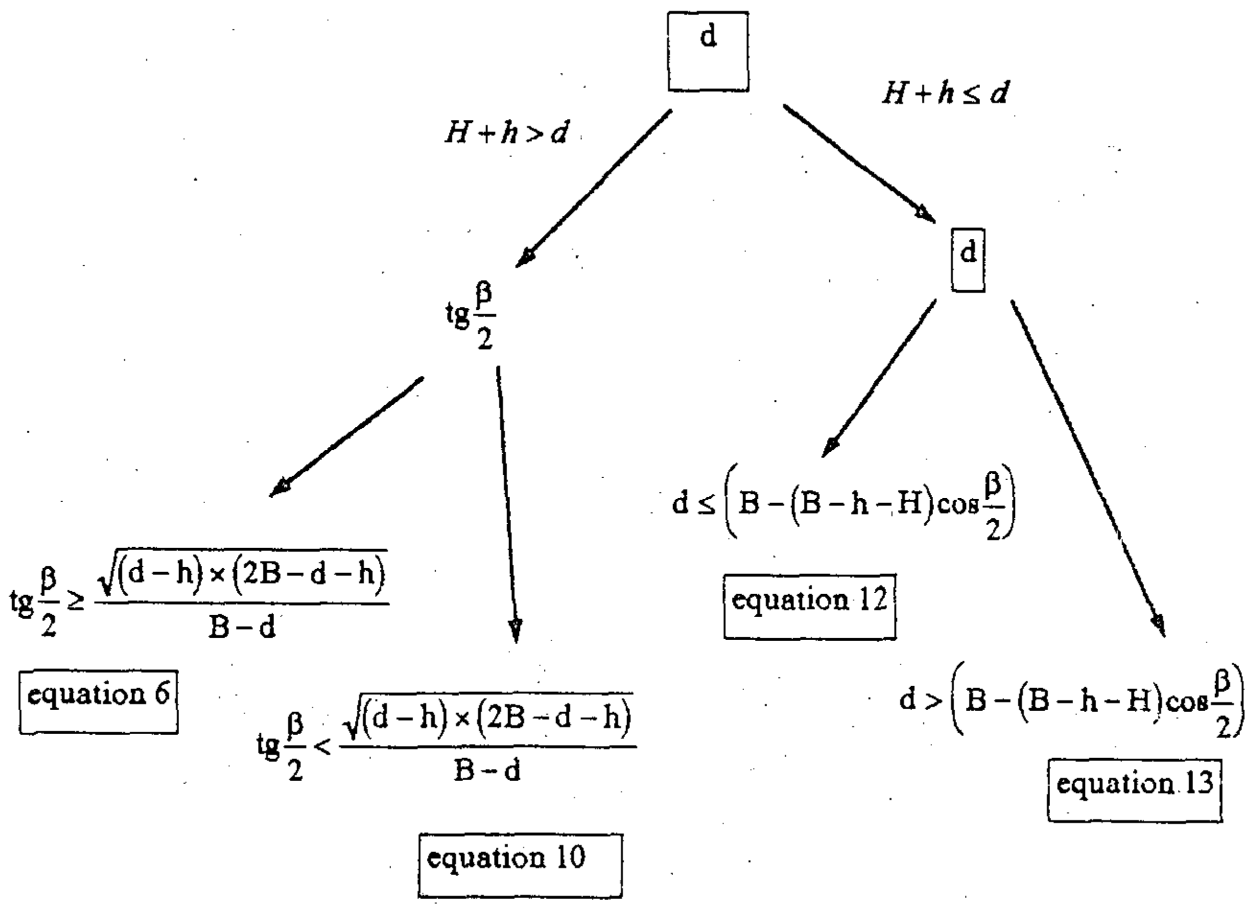

Figure 5. Algorithm of choice of a method of estimation K_{shad}

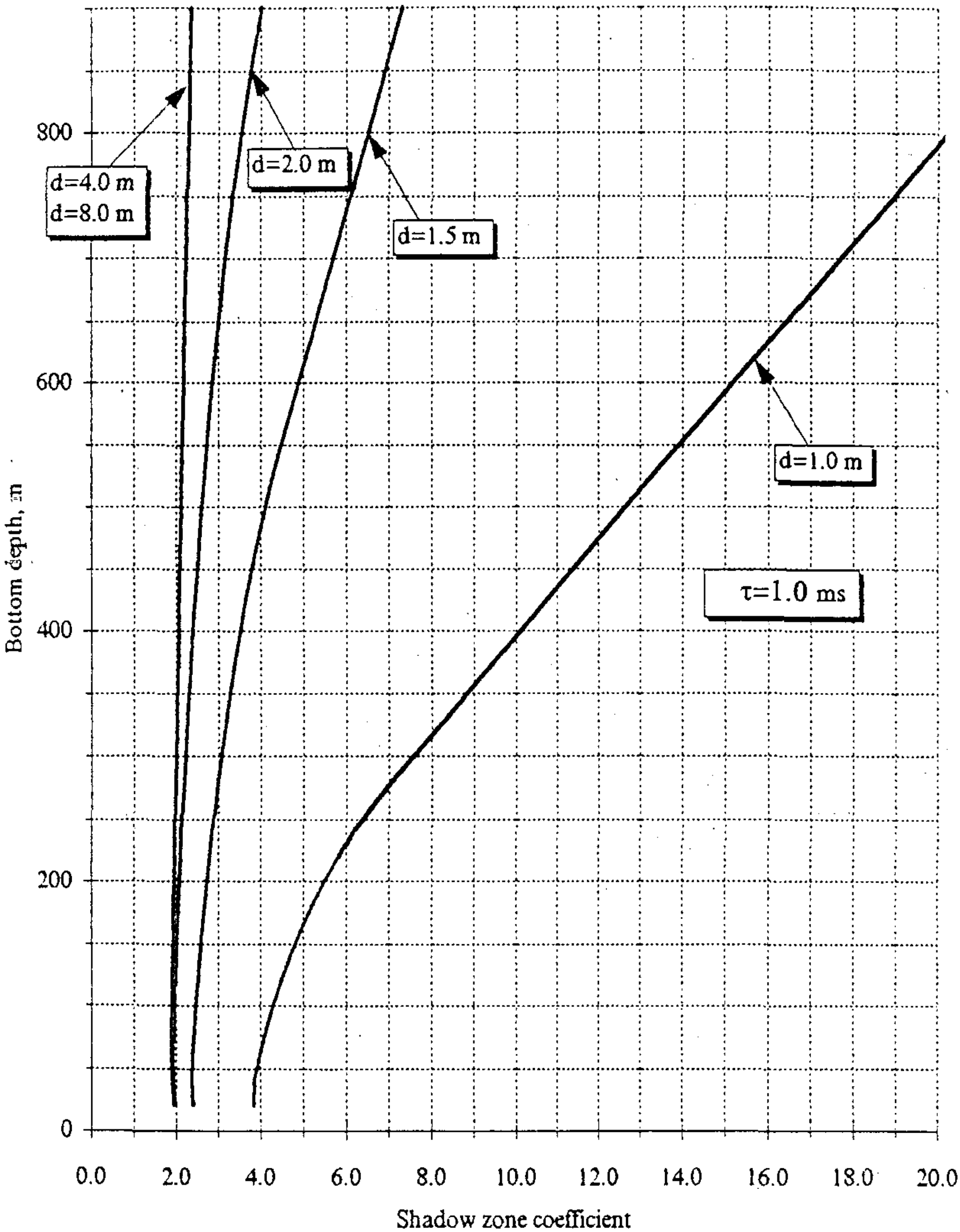

Figure 6. Depenendences of the shadow zone coefficients for τ= 1,0 ms

(h= 0.5 m, c= 1470 m/s, β= 6.91°, H=1.5 m)

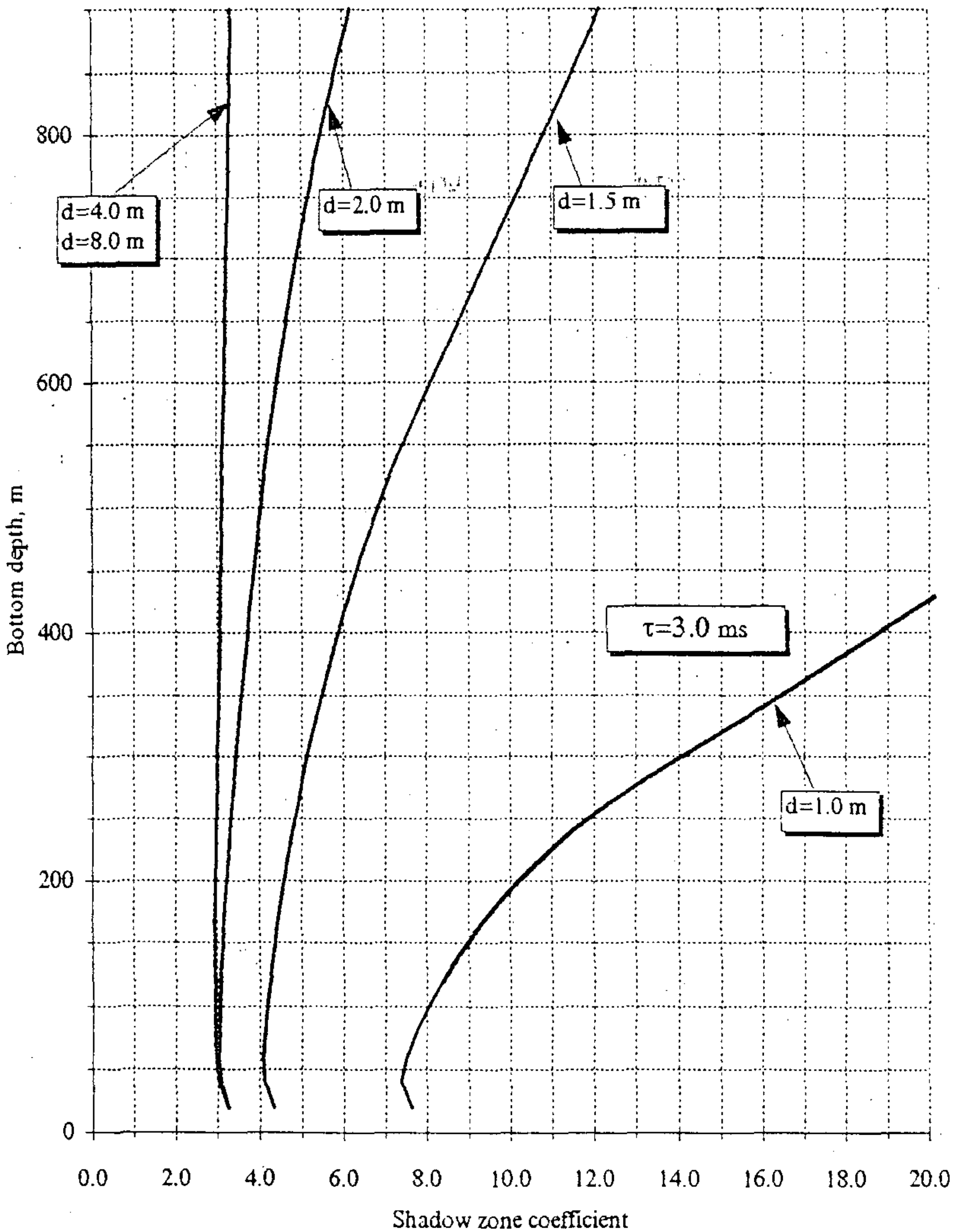

Figure 7. Depenendences of the shadow zone coefficients for τ= 3,0 ms

(h= 0.5 m, c= 1470 m/s, β= 6.91°, H=1.5 m)

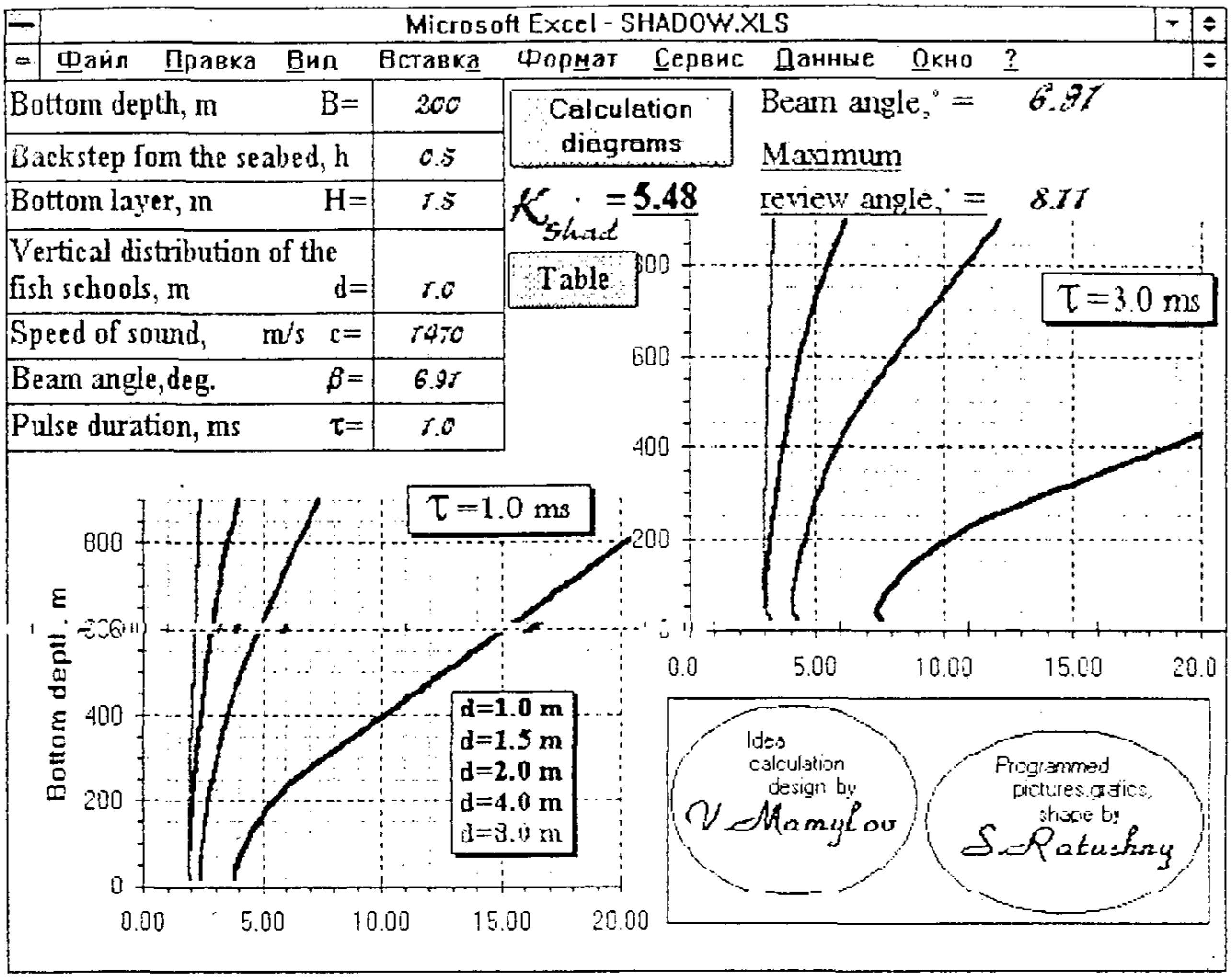

Figure 8. The MicroSoft Excel window with the activated program of estimation of the shadow zone coefficients