

1 GIBANJA MORA

Razlikuju se dvije vrste gibanja mora:

- pokreti cijele morske mase – morske struje
- pokreti dijelova morske mase – morski valovi.

Realni morski valovi su prirodni proces periodičkog kolebanja neke granične plohe u moru udružen s osciliranjem vodenih čestica pod djelovanjem pobuđujućih i umirujućih sila.

Pobuđujuće sile dolaze od:

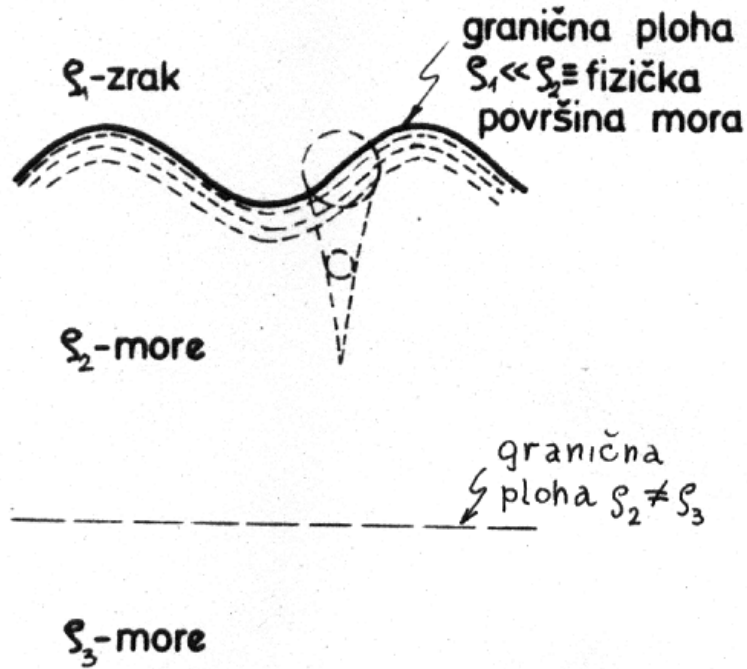
- vjetra,
- brodova.
- gibanja meteoroloških sustava,
- seizmičkih i tektonskih poremećaja,
- zvijezda.

Umirujuće sile su:

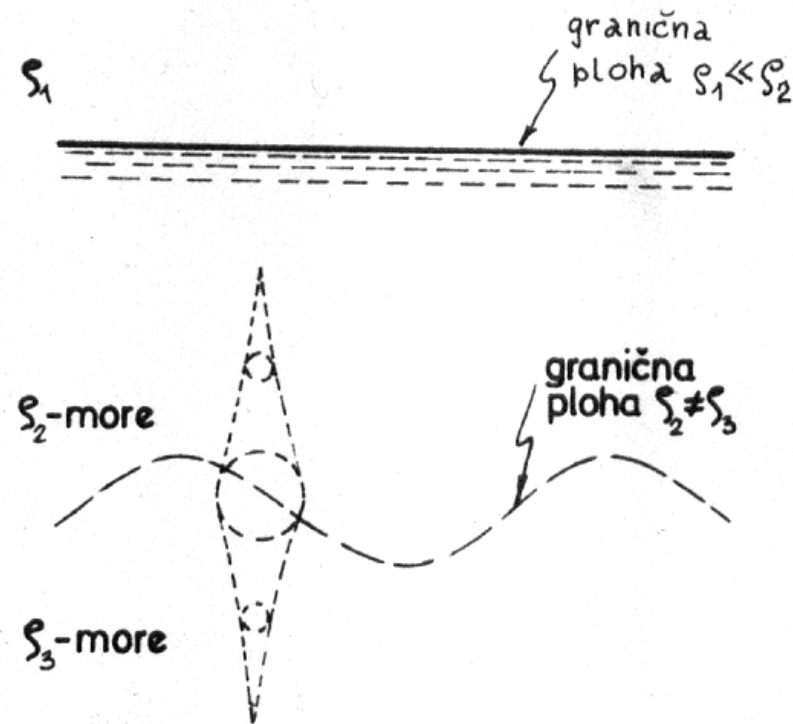
- površinska napetost,
- gravitacija,
- Coriolisova sila

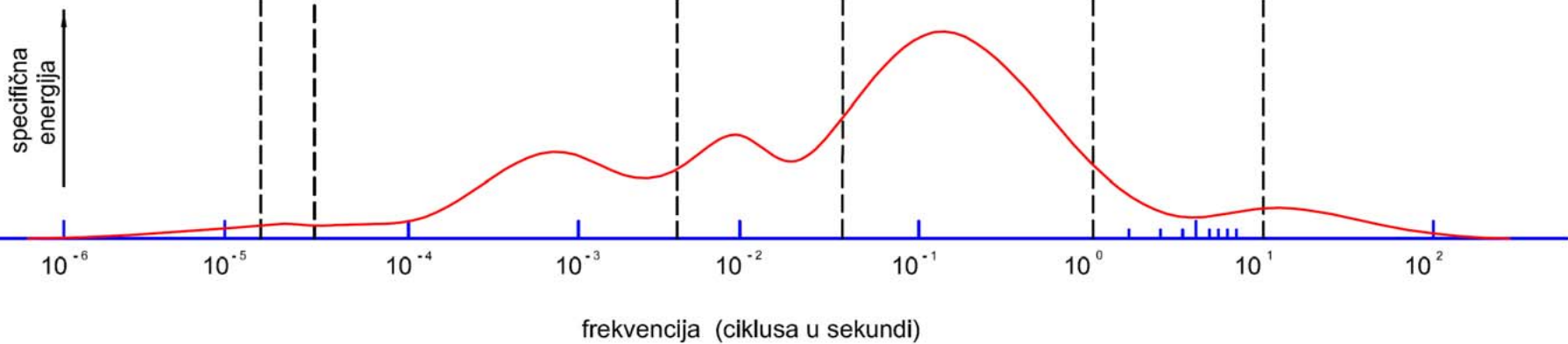
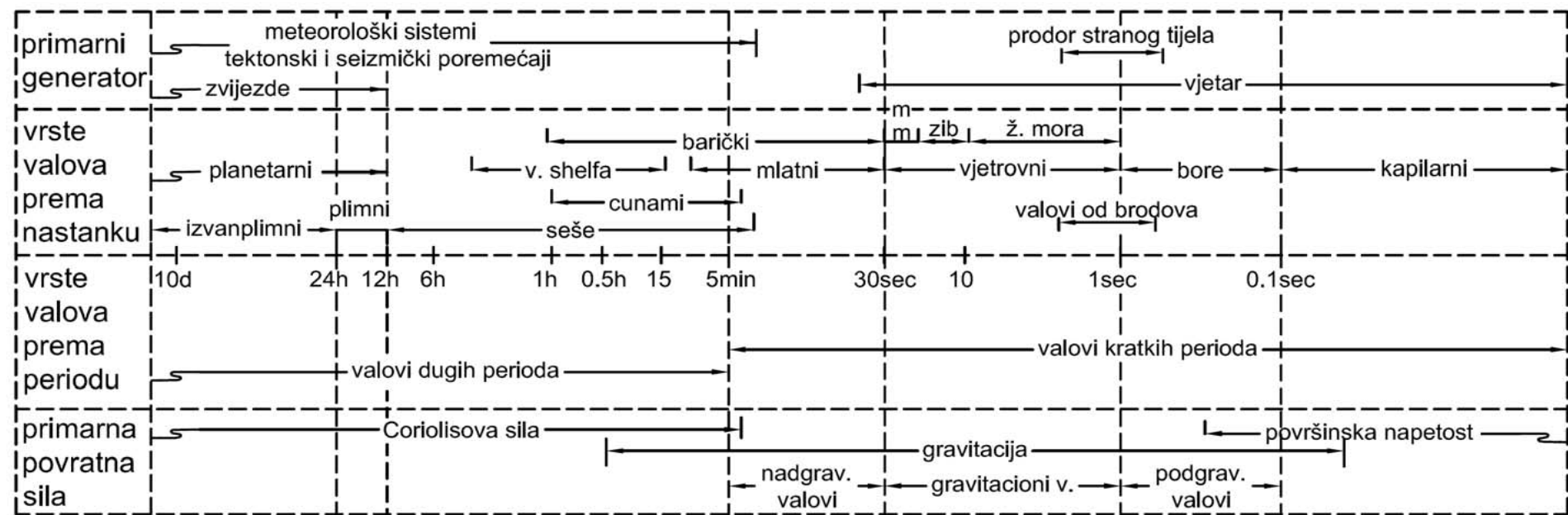
UNUTARNJI I POVRŠINSKI VALOVI

(a)

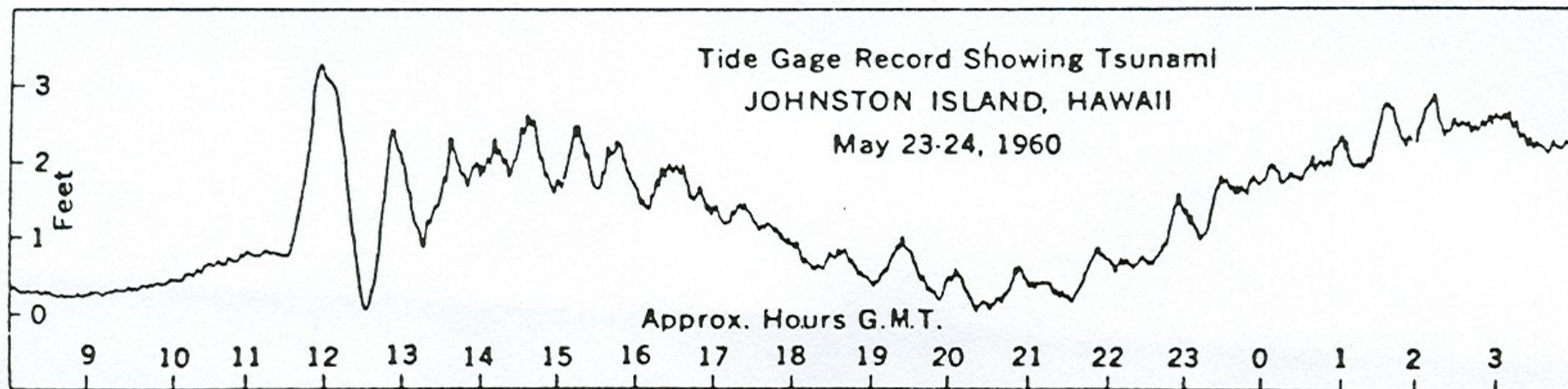
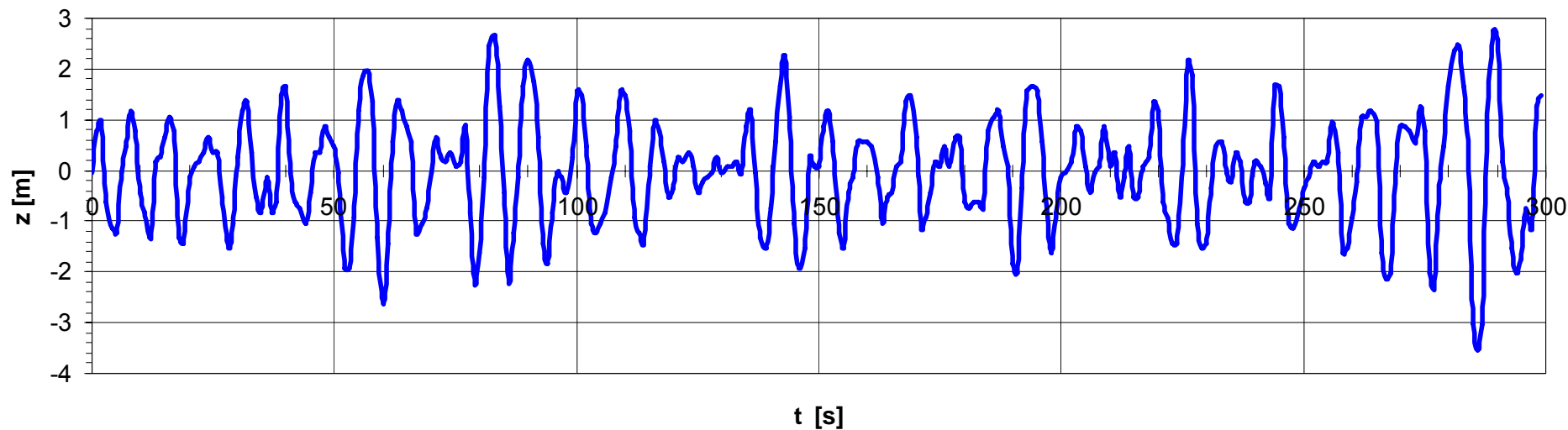


(b)





VALOVI KRATKIH I DUGIH PERIODA



2 IDEALNI VALOVI

Svaki opis morskih valova sadrži dvije stvari:

- opis valnog profila i
- opis gibanja vodnih čestica

Povijesno gledano i po složenosti, razvijena su tri načina opisa morskih valova:

- -deterministički,
- -statistički i
- -spektralni.

METODE ZA OPIS POVRŠINSKIH MORSKIH VALOVA

DETERMINISTIČKA

pravilni valovi:
- idealni valovi,
- valovi mrtvog mora

analitički modeli

PROBABILISTIČKA

neppravilni realni
valovi

probabilistički
modeli u domeni
vjerojatnosti

SPEKTRALNA

neppravilni realni
valovi

spektralni modeli u
frekventnoj domeni

2.1 DEFINICIJA IDEALNOG VALA

Idealni val je veoma restriktivan model realnog vala. Fizikalni model je restriktivan u toliko što je:

- dvodimenzionalan,
- monokromatski,
- jednostavan (opisan jednom ili više cikl. funkc.),
- konstantne visine.

Matematički model lje još restriktivniji od fizikalnog jer sadrži još i restrikcije vezane za idealni fluid i idealizirane rubne uvjete.

2.2 Vrste idealnih valova

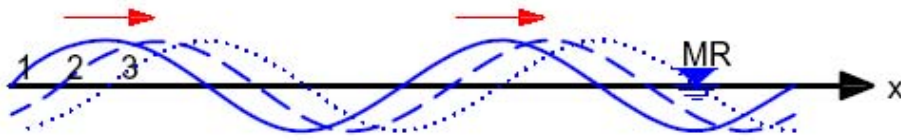
Osnovna je podjela idealnih površinskih valova prema veličini njihovog perioda:

- valovi kratkih perioda (period manji od 30 sek)
- valovi dugih perioda (period veći od cca 5 min.).

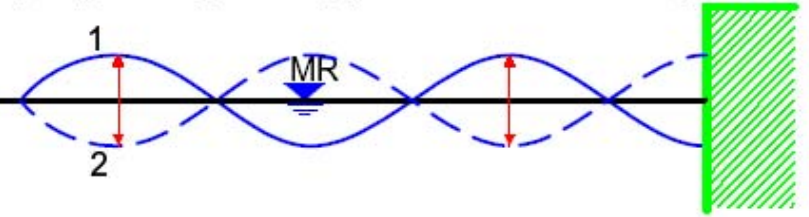
Podjele po načinu gibanja:

- *Gibanja valnog profila*
- *Gibanje vodnih čestica*

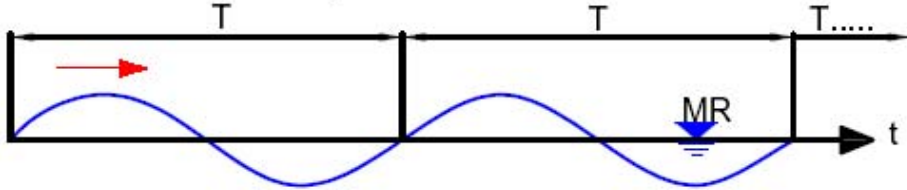
progresivni (pomikanje valnog profila u trenucima 1, 2 i 3)



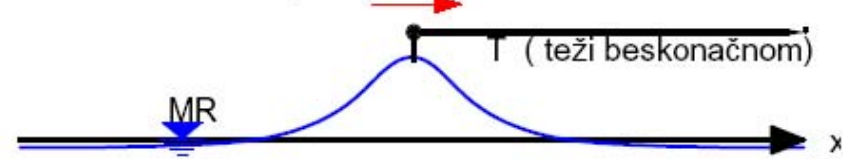
stojni (pomikanje valnog profila u trenucima 1 i 2)



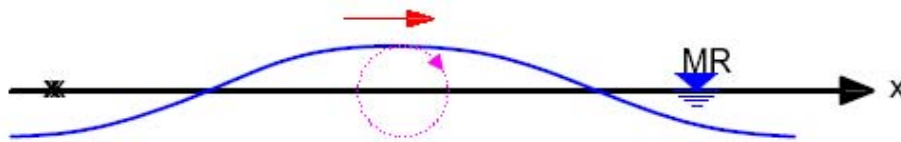
periodički



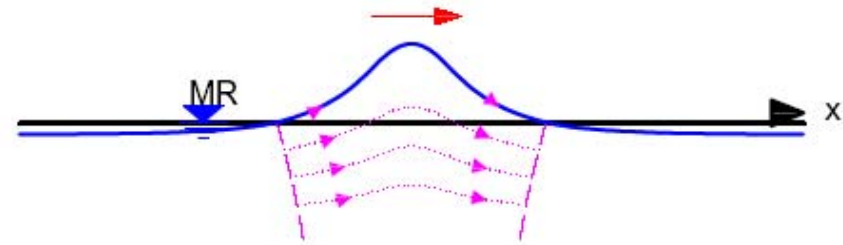
neperiodički



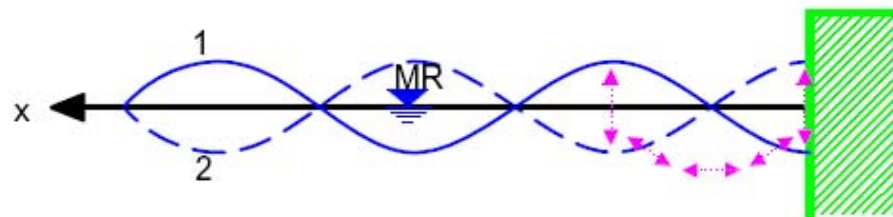
oscilatorni



translatorni



oscilatorni



2.3 DETERMIN. OPIS I VALNA OSNOVA

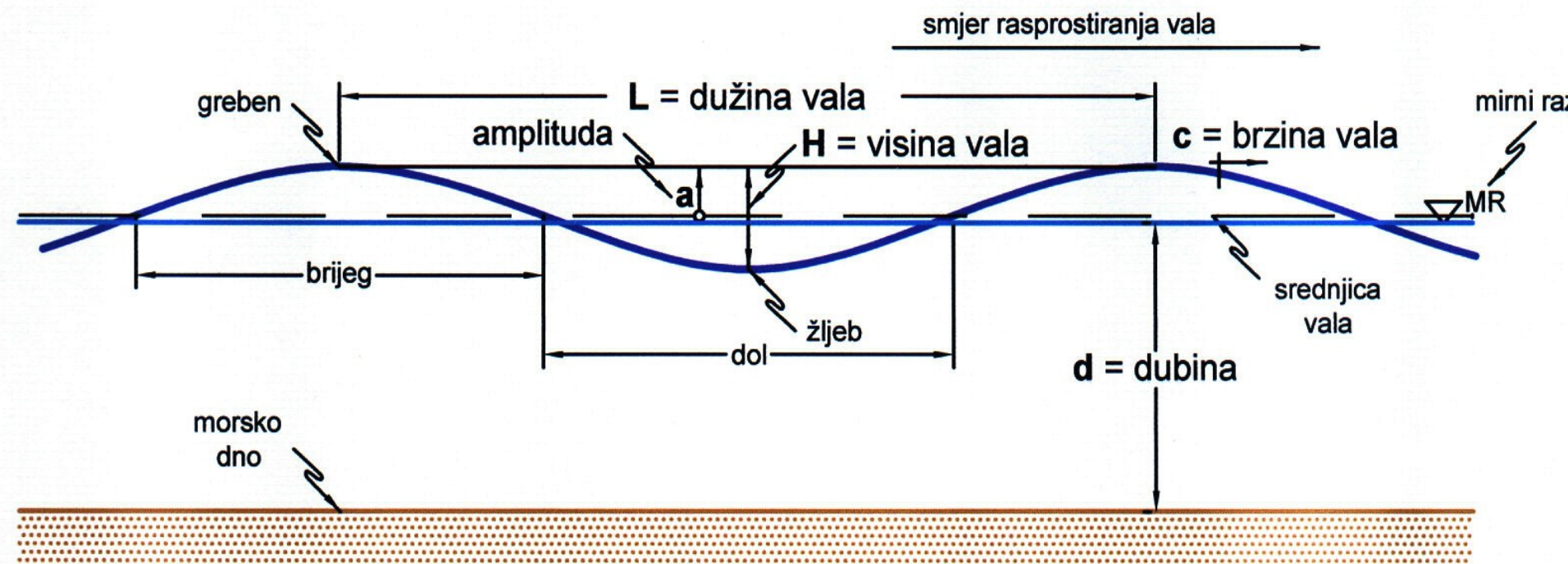
Determinističkim načinom daju se opisati samo idealni valovi.

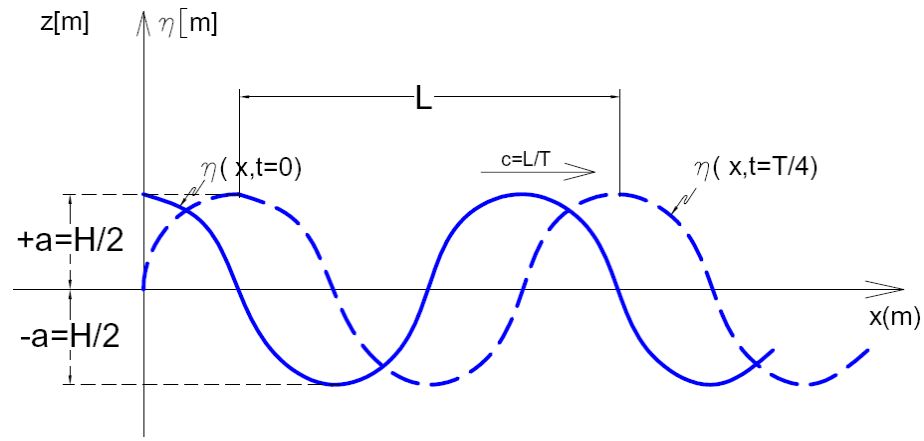
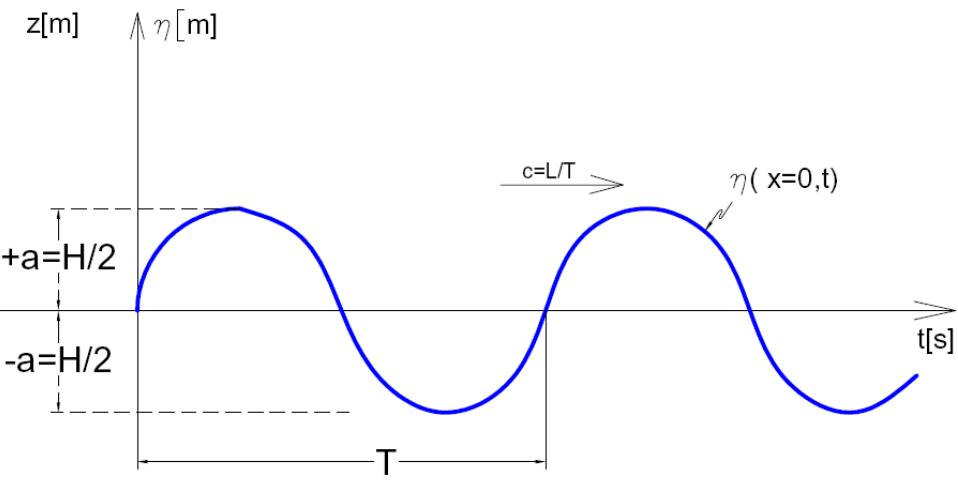
Deterministički opis sadrži 2 grupe parametara:

- za *valni profil* i
- za *gibanje vodnih čestica*.

Glavni dijelovi valnog profila

SI 2.3::1





$$\eta = \frac{H}{2} \cos\left(\frac{2\pi}{L}x - \frac{2\pi}{T}t\right)$$

VALNI PROFIL

Valni profil $\eta(x,t)[m] \equiv z(x,t)[m]$

visina $H[m]$,].

amplituda $a[m]=H/2$

dužina $L[m]$

period $T[s]$

strmost vala $H/L[1^\circ]=1/7$ do $1/200$
(ž. m. $1/10$ $1/25$)

samo brzina vala, $c[m/s]$

VODNE ČESTICE

Brzina vodne čestice $v[m/s]$

$u[m/s] \equiv v_x$

$w[m/s] \equiv v_z$

Ubrzanje vodne čestice
 $a[m/s^2]$, a_x i a_z .

DUBINE MORA

	d/L	$2\pi d/L$	$\tanh(2\pi d/L)$
duboka voda	$> 1/2$	$> \pi$	1
prelazno područje	$1/25$ do $1/2$	$1/4$ do π	$\tanh(2\pi d/L)$
plitka voda	$< 1/25$	$< 1/4$	$2\pi d/L$

Tab. 2.3::I

2.4 MEHANIKA VALOVA KRATKIH PERIODA

2.4.1 Vrste i osnova teorija valova kratkih perioda

Eulerov princip:

gibanje svih v. č. preko brzinskog potencijala Φ

$$u = \frac{\partial \phi}{\partial x} \quad w = \frac{\partial \phi}{\partial z}$$

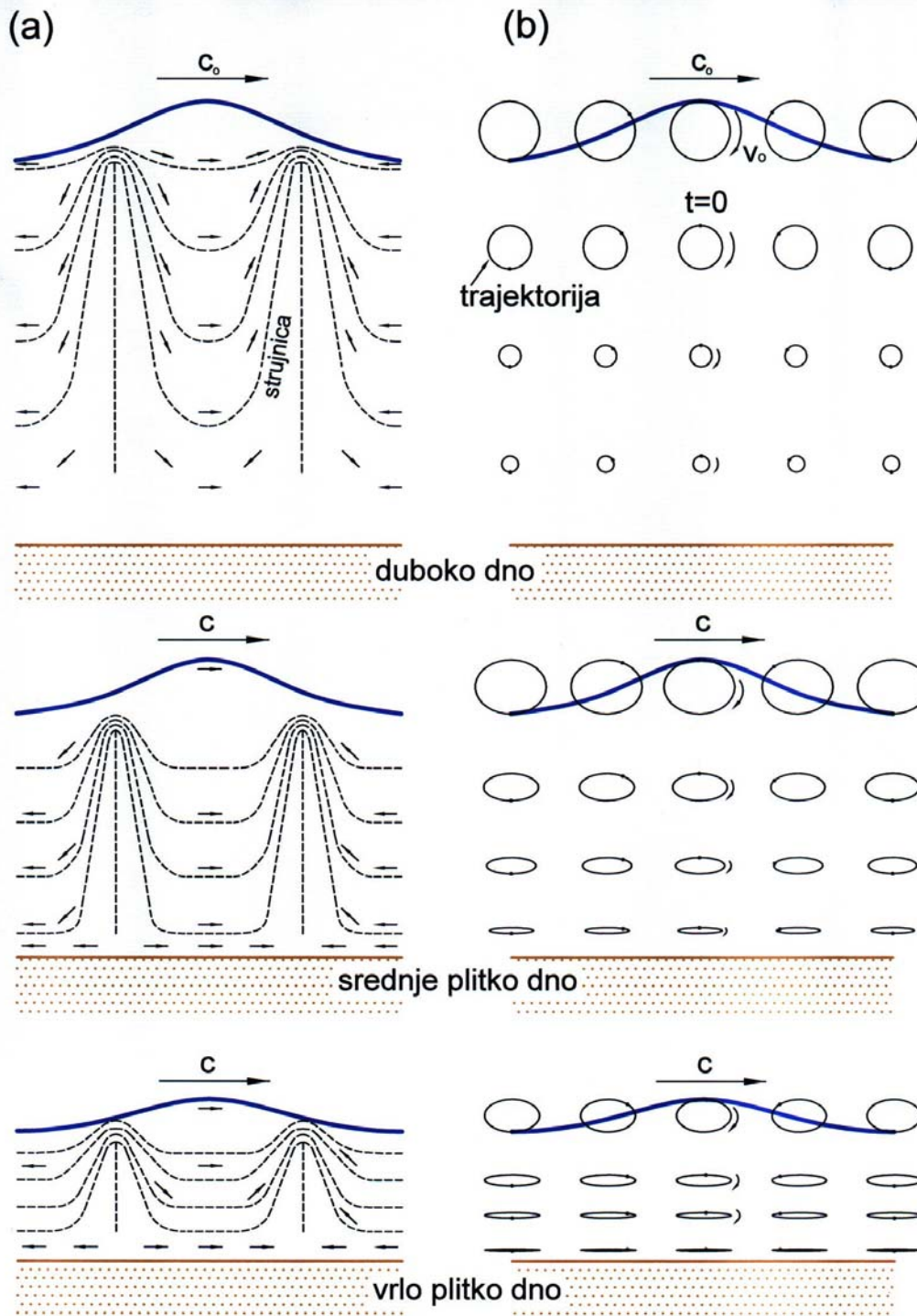
Lagrangeov princip:

gibanje pojedinih v. č. preko trajektorije v. č.

$$x = x(x_0, z_0, t) \quad \text{i} \quad z = z(x_0, z_0, t)$$

$$u = \frac{dx}{dt} \quad a_x = \frac{d^2 x}{dt^2}$$

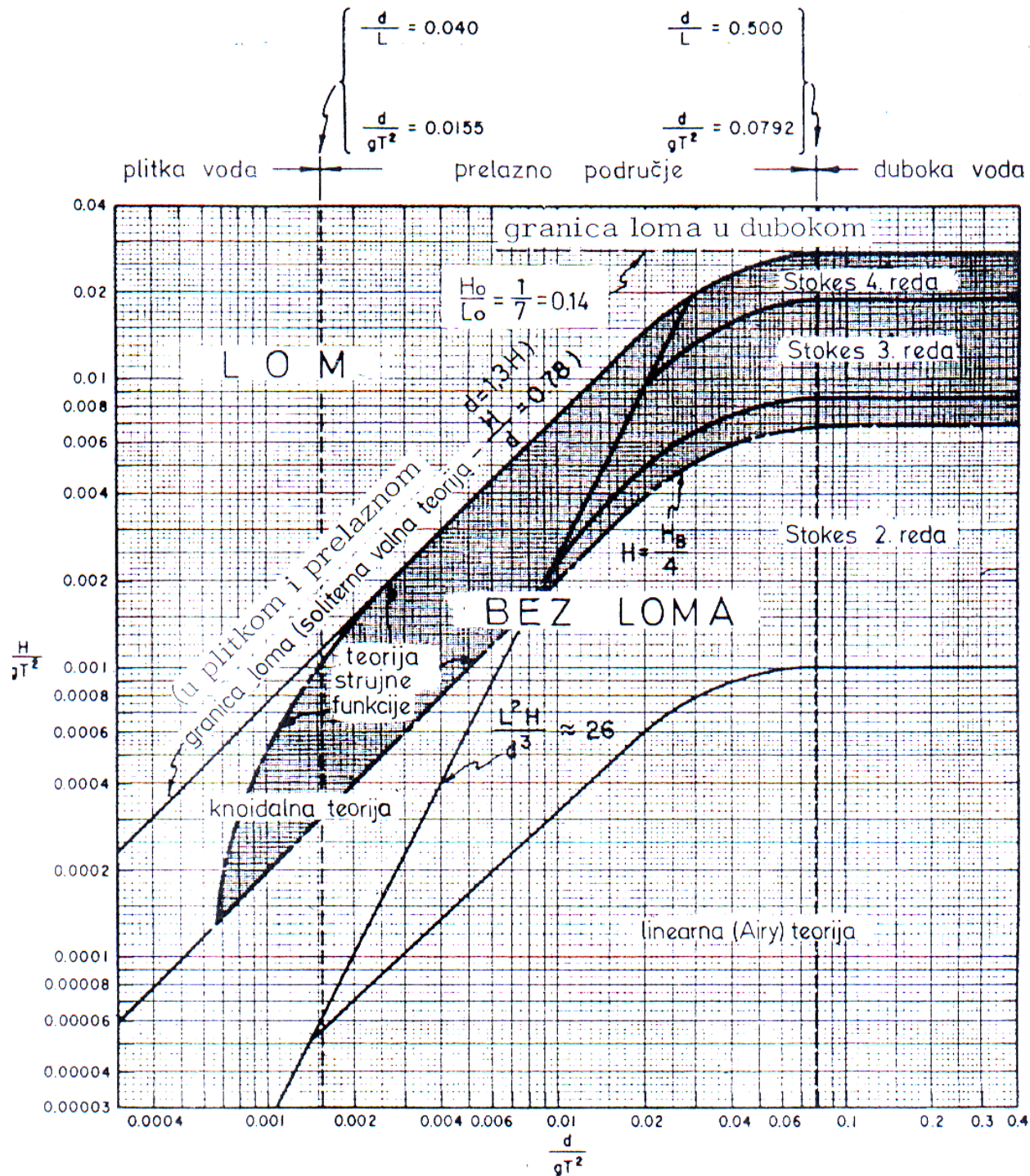
$$w = \frac{dz}{dt} \quad a_z = \frac{d^2 z}{dt^2}$$



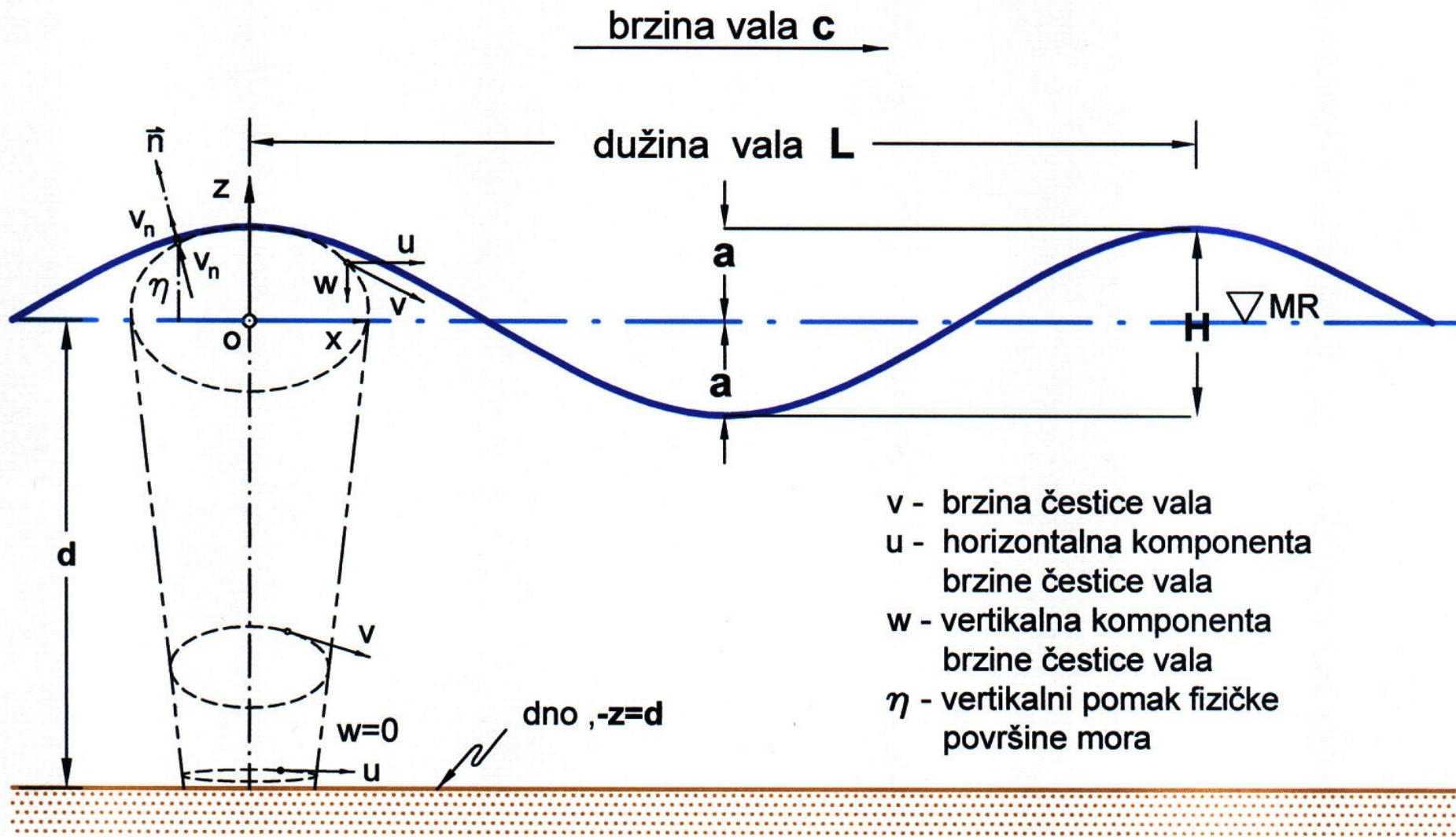
Sl.2.4-1::1

Veličina amplitude	Red teorije	Naziv i autor teorije
1 Valovi malih amplituda $H/L < 1/150$; $L > 150 H$	Prvog reda ili linearna	Airy (1845)
2 Valovi konačnih amplituda	Prvog reda ili linearna i višeg reda ili nelinearna	Trohoidalna, Gerstner (1802.), Stokes 2. reda (1880.), Stokes 3. reda Stokes 4. reda Stokes 5. reda Konoidalna 1. reda, Korteweg i De Vries (1895.), Konoidalna 2. reda, Hiperbolična (1968.) Iwagaki, Soliterna (1872.) Businessque, Teorija strujne funkcije (1973.) Dean

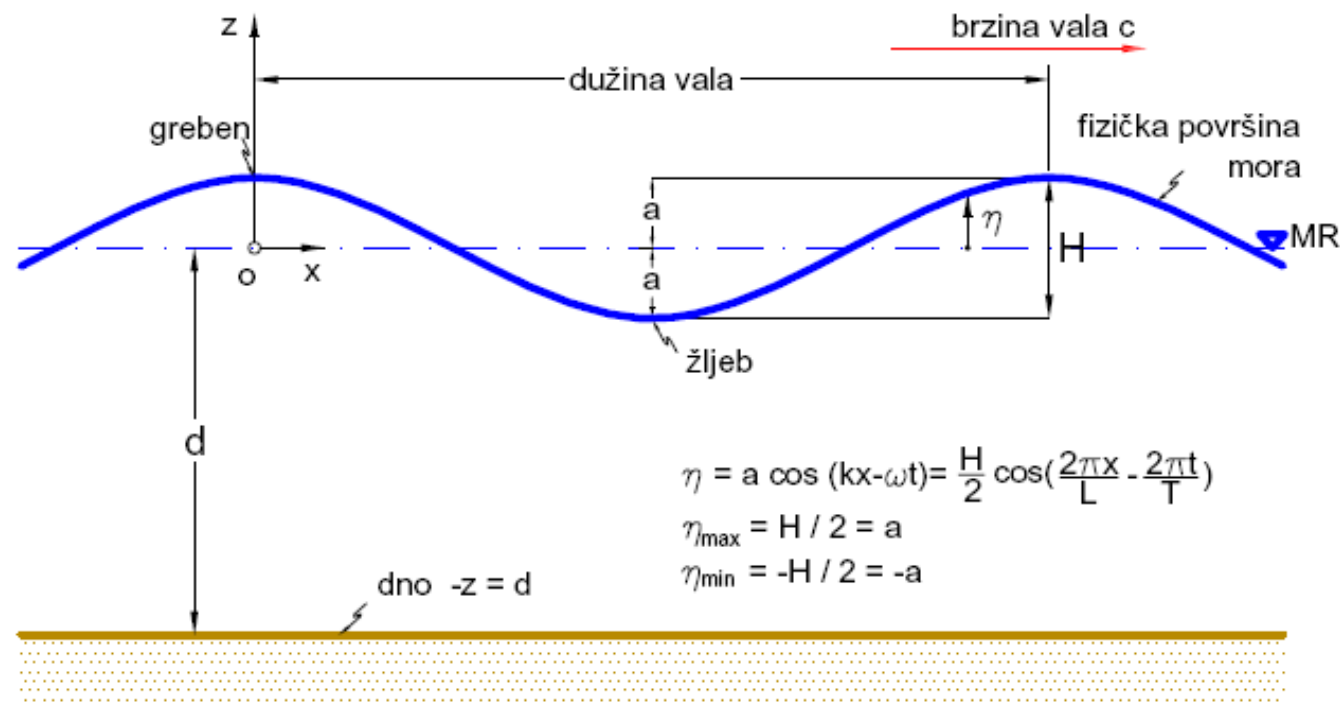
Tab.2.4-1::I



SI.2.4-1::2



2.4.2 LINEARNA TEORIJA. TVMA, AIRY-eva



$$\eta = a \cos(kx - \omega t) = \frac{H}{2} \cos\left(\frac{2\pi x}{L} - \frac{2\pi t}{T}\right)$$

$$\eta_{\max} = H / 2 = a$$

$$\eta_{\min} = -H / 2 = -a$$

η = pomak fizičke površine mora [m]

H = visina vala = $2a$ [m]

a = $H / 2$ = amplituda [m]

k = valni broj = $2\pi / L$ [rad/m]

L = dužina vala

ω = frekvencija vala = $2\pi / T$ [rad/s]

T = period vala = L / c [s]

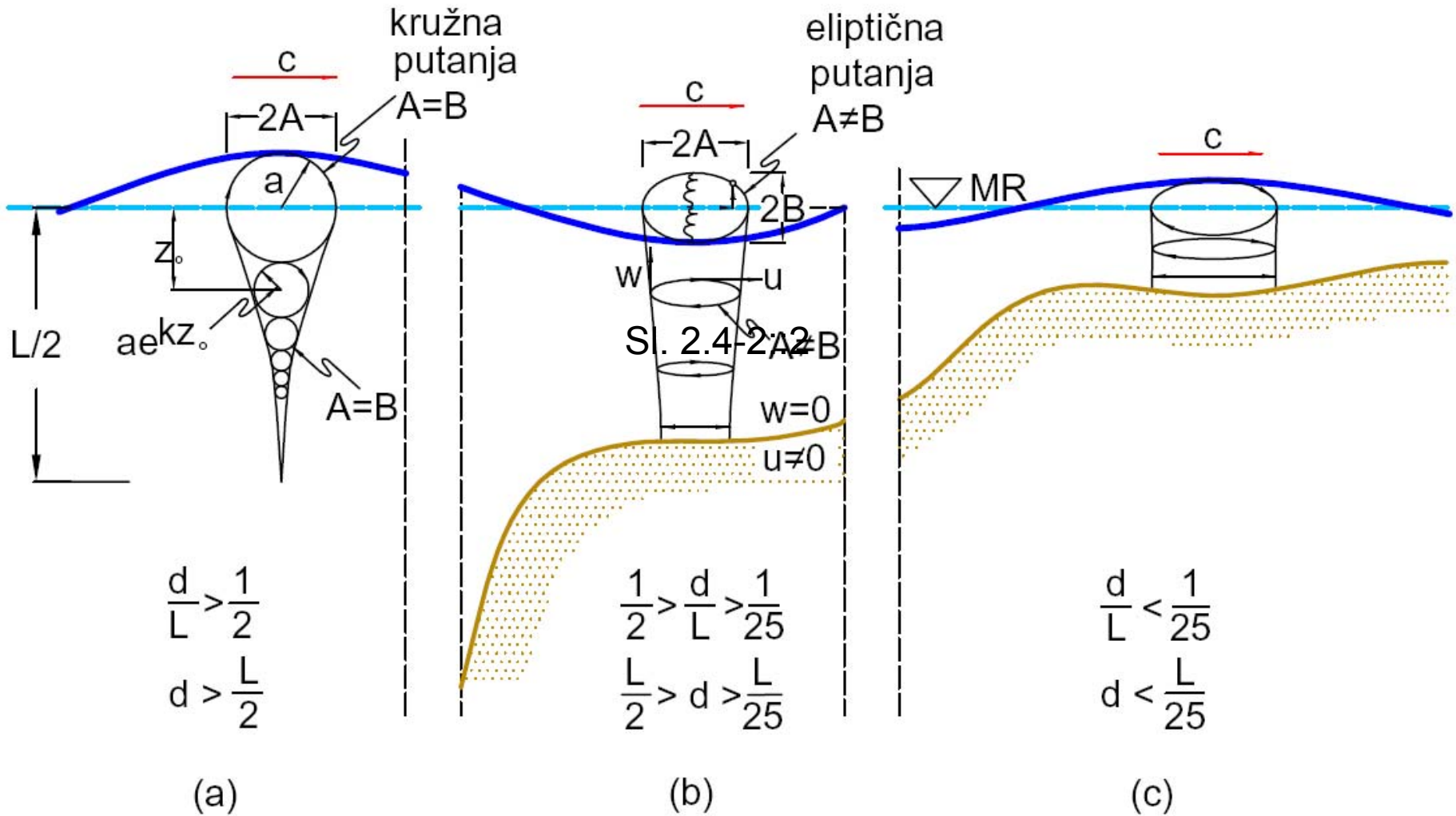
c = brzina rasprostiranja vala [m/s]

x, z = koordinate [m]

t = vrijeme [s]

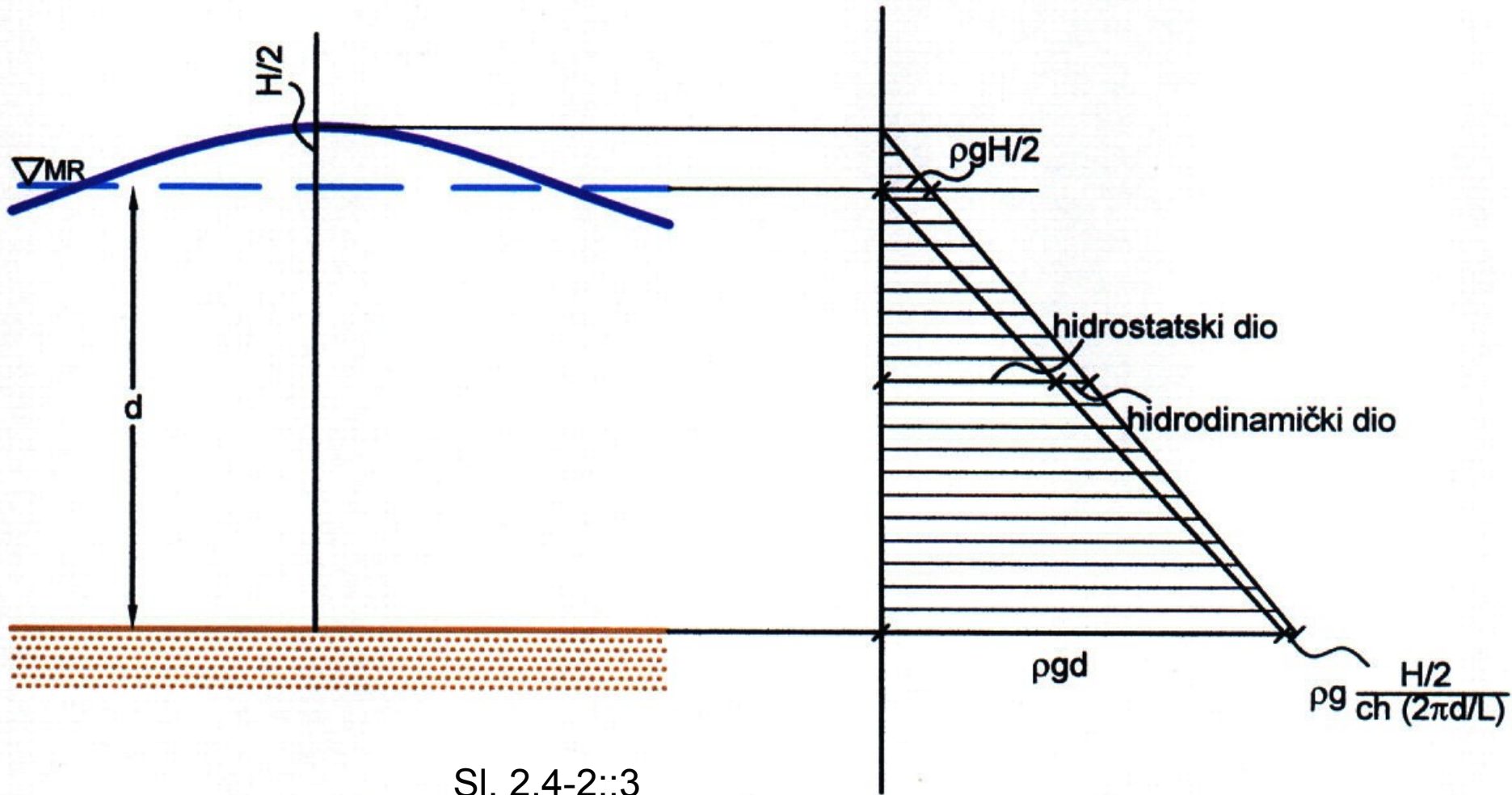
d = dubina vode [m]

POMACI VODNIH ČESTICA U LIN. T.



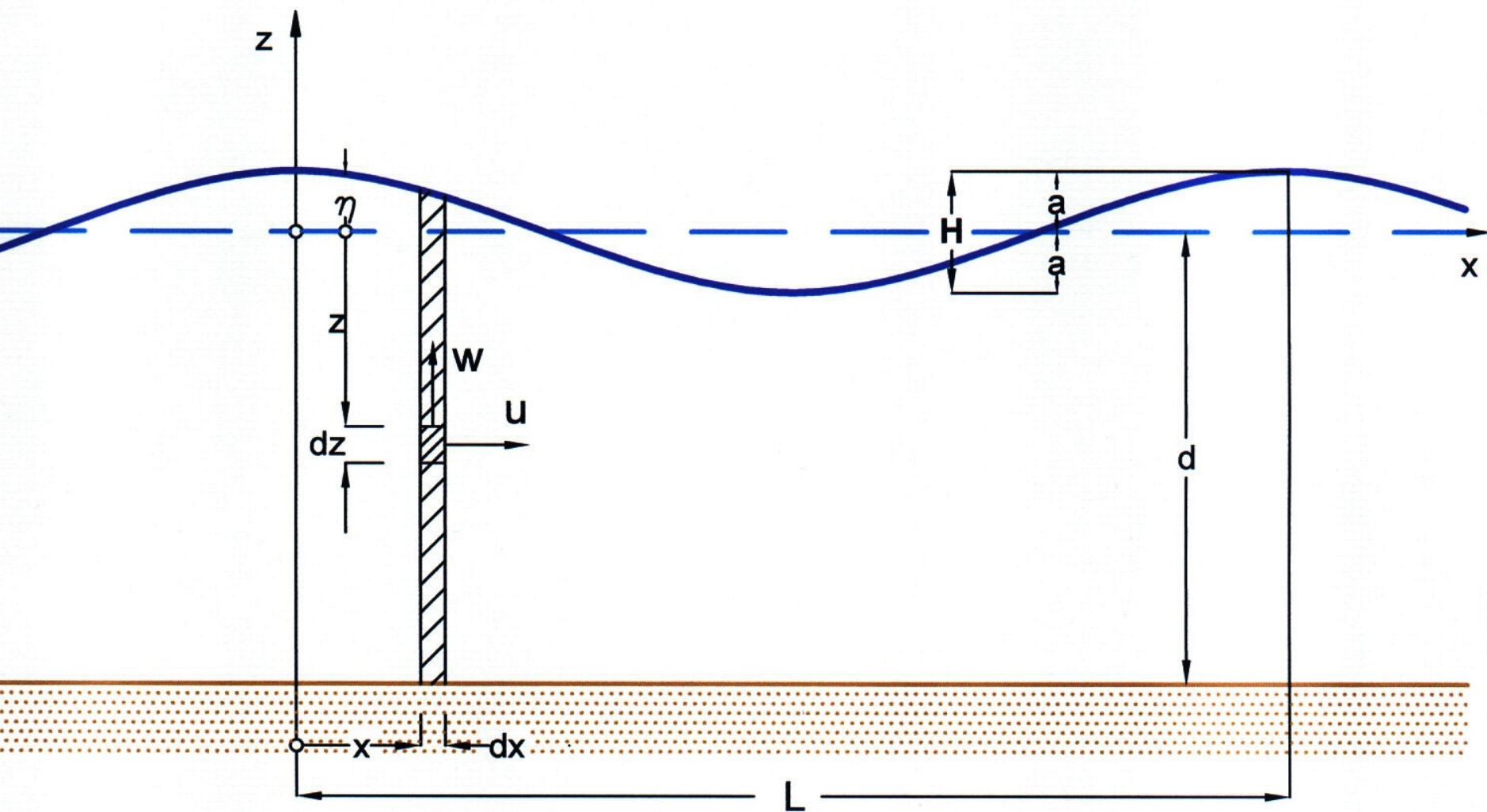
Relativna dubina	Duboka voda $\frac{d}{L} > \frac{1}{2}$	Prelazno područje $\frac{1}{25} < \frac{d}{L} < \frac{1}{2}$	Plitka voda $\frac{d}{L} < \frac{1}{25}$
<p>1. Profil vala</p> <p>2. Brzina vala</p> <p>3. Dužina vala</p> <p>4. Brz. grupe valova</p> <p>5. Brzine čestica a) horizontalna b) vertikalna</p> <p>6. Ubrzanja čestica a) horizontalna b) vertikalna</p>	<p>isto</p> $C = C_o = \frac{L}{T} = \frac{gT}{2\pi} = \sqrt{\frac{gL}{2\pi}}$ $L = L_o = \frac{gT^2}{2\pi} = C_o T, T = \sqrt{\frac{2\pi L}{g}}$ $C_g = \frac{1}{2} C = \frac{gT}{4\pi}$ $u = \frac{\pi H}{T} e^{2\pi z/L} \cdot \cos \theta$ $w = \frac{\pi H}{T} e^{2\pi z/L} \cdot \sin \theta$ $a_x = 2H \left(\frac{\pi}{T}\right)^2 e^{2\pi z/L} \cdot \sin \theta$ $a_z = -2H \left(\frac{\pi}{T}\right)^2 e^{2\pi z/L} \cdot \cos \theta$	<p>$\eta = \frac{H}{2} \cos \left[\frac{2\pi x}{L} - \frac{2\pi t}{T} \right] = \frac{H}{2} \cos \theta$</p> $C = \frac{L}{T} = \frac{gT}{2\pi} \tanh \left(\frac{2\pi d}{L} \right) = \sqrt{\frac{gL}{2\pi} \tanh \frac{2\pi d}{L}}$ $L = \frac{gT^2}{2\pi} \tanh \left(\frac{2\pi d}{L} \right)$ $C_g = nC = \frac{1}{2} \left[1 + \frac{4\pi d/L}{\sinh(4\pi d/L)} \right] \cdot C$ $u = \frac{H g T}{2 L} \frac{\cosh[2\pi(z+d)/L]}{\cosh(2\pi d/L)} \cos \theta$ $w = \frac{H}{2} \frac{g T}{L} \frac{\sinh[2\pi(z+d)/L]}{\cosh(2\pi d/L)} \sin \theta$ $a_x = \frac{g \pi H}{L} \frac{\cosh[2\pi(z+d)/L]}{\cosh(2\pi d/L)} \sin \theta$ $a_z = -\frac{g \pi H}{L} \frac{\sinh[2\pi(z+d)/L]}{\cosh(2\pi d/L)} \cos \theta$	<p>isto</p> <p style="text-align: right;">Tab. 2.4-2::1</p> $C = \frac{L}{T} = \sqrt{gd}$ $L = T \sqrt{gd} = CT$ $C_g = C = \sqrt{gd}$ $u = \frac{H}{2} \sqrt{\frac{g}{d}} \cos \theta$ $w = \frac{H \pi}{T} \left(1 + \frac{z}{d}\right) \sin \theta$ $a_x = \frac{H \pi}{T} \sqrt{\frac{g}{d}} \sin \theta$ $a_z = -2H \left(\frac{\pi}{T}\right)^2 \left(1 + \frac{z}{d}\right) \cos \theta$
<p>7. Pomaci čestica a) horizontalni b) vertikalni</p> <p>8. Putanje čestica</p>	$\xi = -\frac{H}{2} e^{2\pi z/L} \cdot \sin \theta$ $\xi = \frac{H}{2} e^{2\pi z/L} \cdot \cos \theta$ <p style="text-align: center;">kružnica</p>	$\xi = -\frac{H}{2} \frac{\cosh[2\pi(z+d)/L]}{\sinh(2\pi d/L)} \sin \theta$ $\xi = \frac{H}{2} \frac{\sinh[2\pi(z+d)/L]}{\sinh(2\pi d/L)} \cos \theta$ <p style="text-align: center;">elipsa</p>	$\xi = -\frac{HT}{4\pi} \sqrt{\frac{g}{d}} \sin \theta$ $\xi = \frac{H}{2} \left(1 + \frac{z}{d}\right) \cos \theta$ <p style="text-align: center;">elipsa</p>

TLAK ISPOD VALA MALE AMPL.



Sl. 2.4-2::3

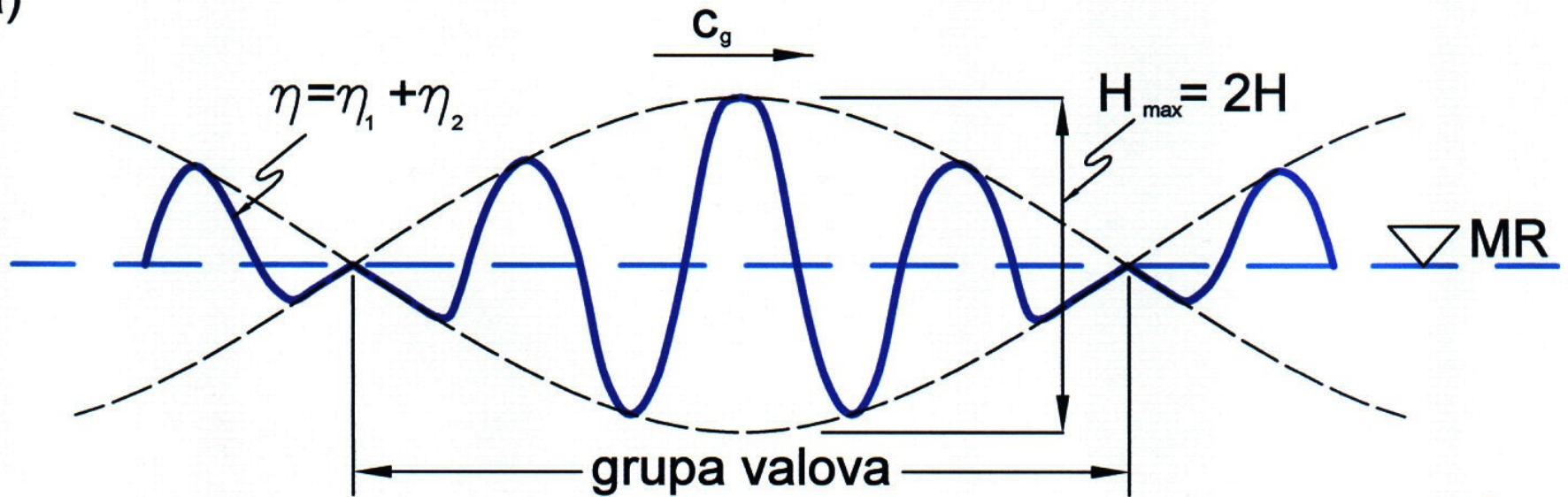
2.4.2.1 ENERGIJA VALA M. A.



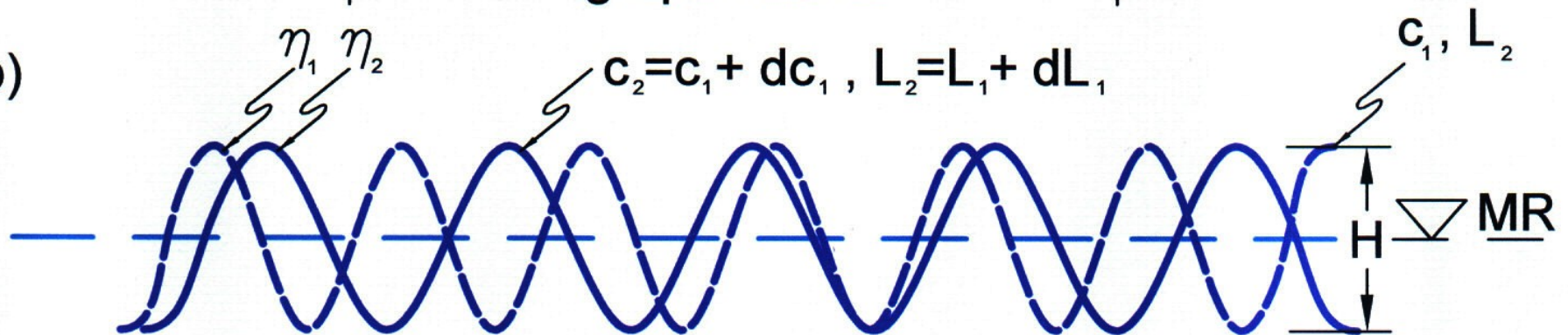
2.4.2.2 BRZINA GRUPE VALOVA

Sl. 2.4-2.2::1

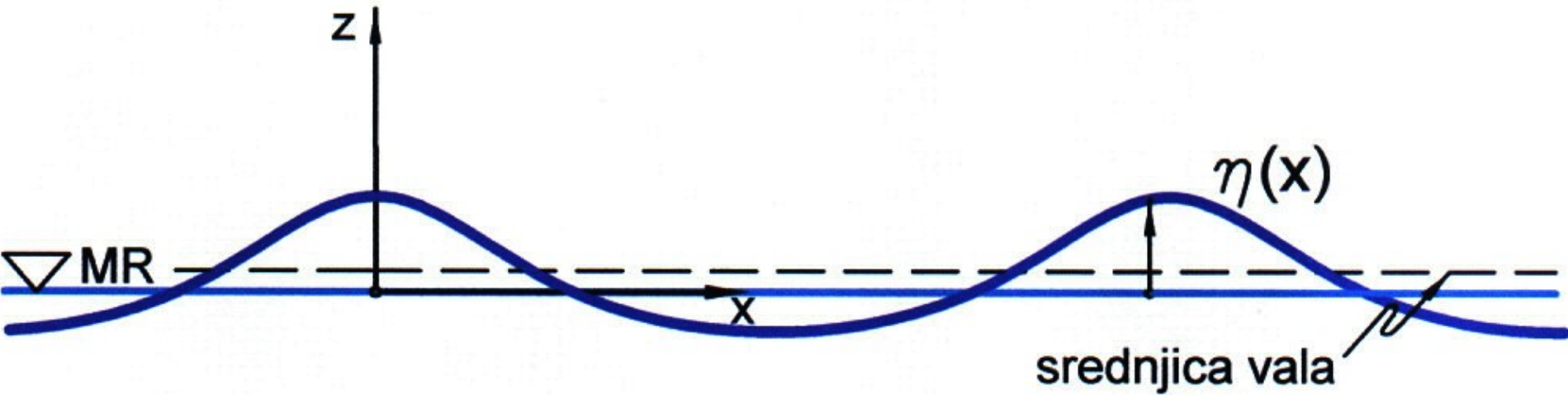
(a)



(b)

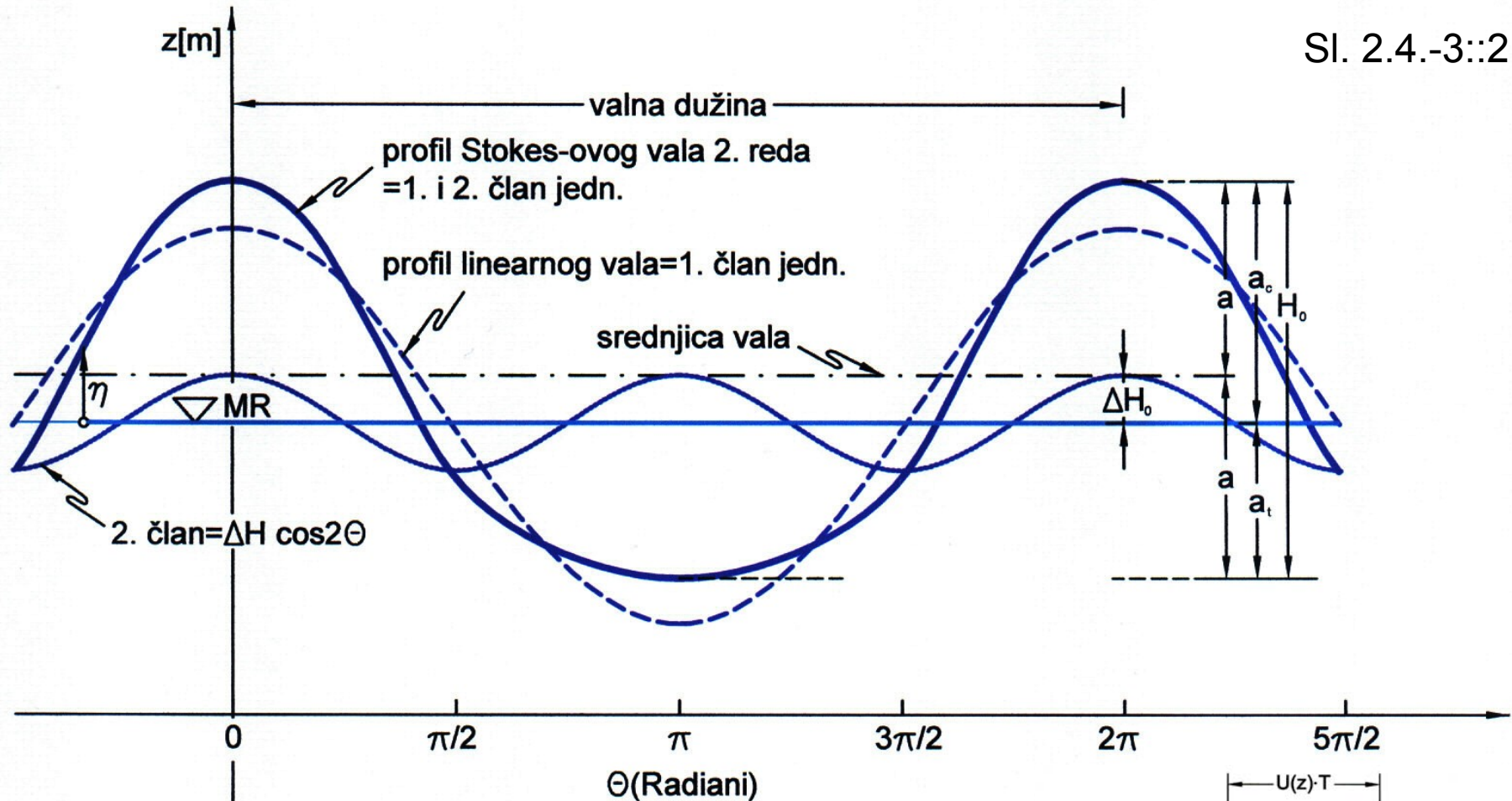


2.4.3 TEORIJE VALOVA KONAČNIH AMPLITUDA



STOKES-OVA TEORIJA 2. REDA

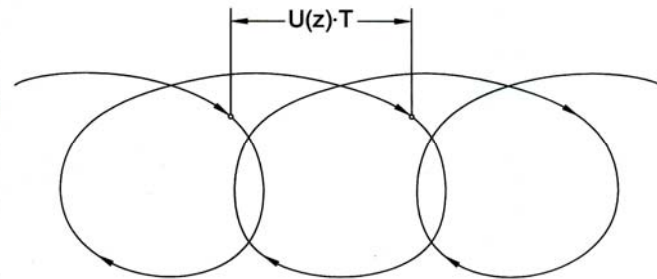
Sl. 2.4.-3::2



Profil Stokes-ovog vala 2. reda u dubokoj vodi:

$$\eta = \frac{H_0}{2} \cos\left(\frac{2\pi}{L_0}x - \frac{2\pi}{T}t\right) + \frac{\pi H_0^2}{4L_0} \cos\left(\frac{4\pi}{L_0}x - \frac{4\pi}{T}t\right)$$

$$\eta = \frac{H_0}{2} \cos\Theta + \Delta H_0 \cos 2\Theta ; \Delta H = \frac{\pi H_0^2}{4L_0}; \Theta = \frac{2\pi}{L_0}x - \frac{2\pi}{T}t$$

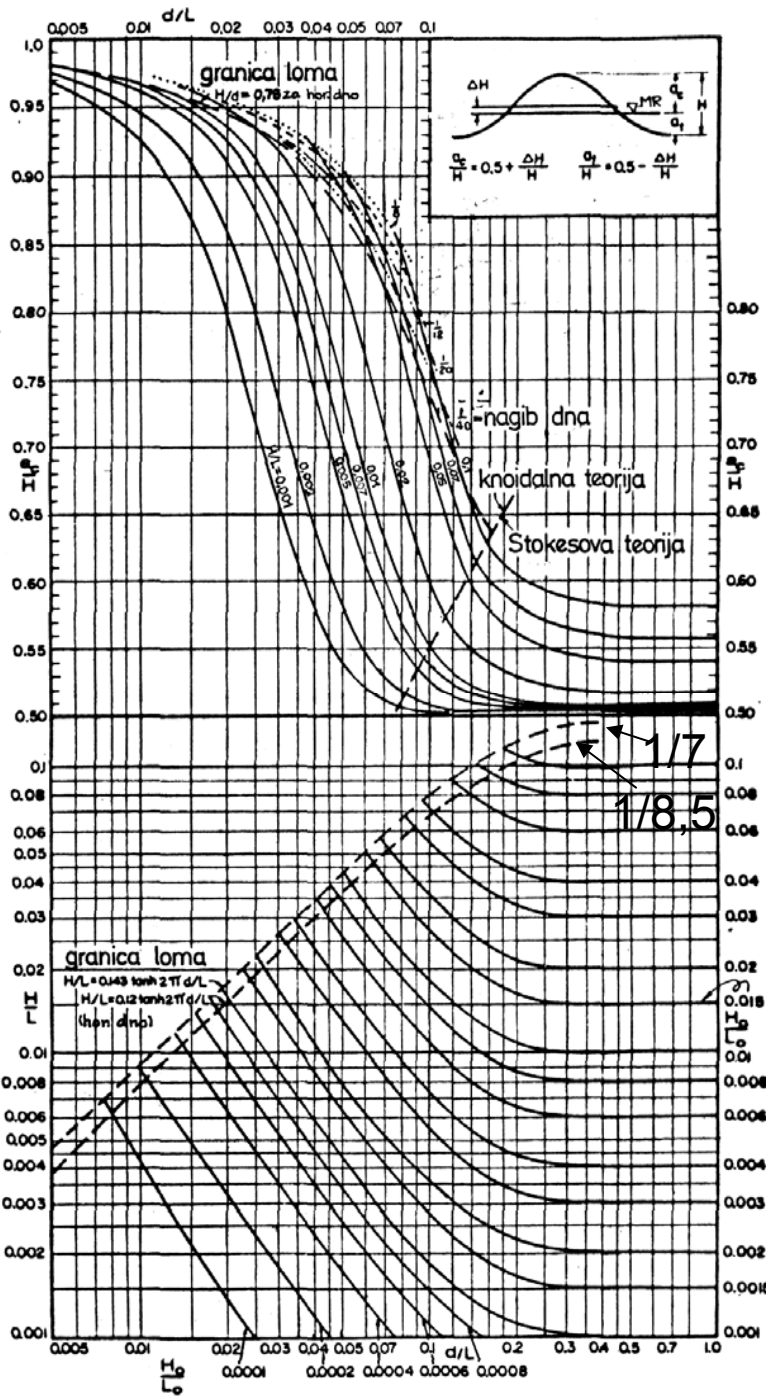


Predmet: PLOVNI PUTEVI I LUKE
Studij: diplomski
Smjer: H
Semestar: II
Fond sati: 45+45
Godina: 2010.

Gradivo za I. test, .ut. 16.03.2010.

- 1 GIBANJA MORA
- 2 IDEALNI VALOVI
- 2-1 Def.
- 2-2 Vrste teorija idealnih valova
- 2-3 Deterministički opis valova
- 2-4 Mehanika valova kratlih perioda
- 2-4.1 Vrste i osnova teorija v. kr. perioda
- 2-4.2 Teorija valova malih amplituda
- 2-4.3 Teorije valova konačnih amplituda

STRMINA VALA



$$\left(\frac{H}{L}\right)_{\max} = \left(\frac{H}{L}\right)_b = \left(\frac{H_0}{L_0}\right)_{\max} \operatorname{th}\left(\frac{2\pi d}{L}\right) = 0,143 \operatorname{th}\left(\frac{2\pi d}{L}\right)$$

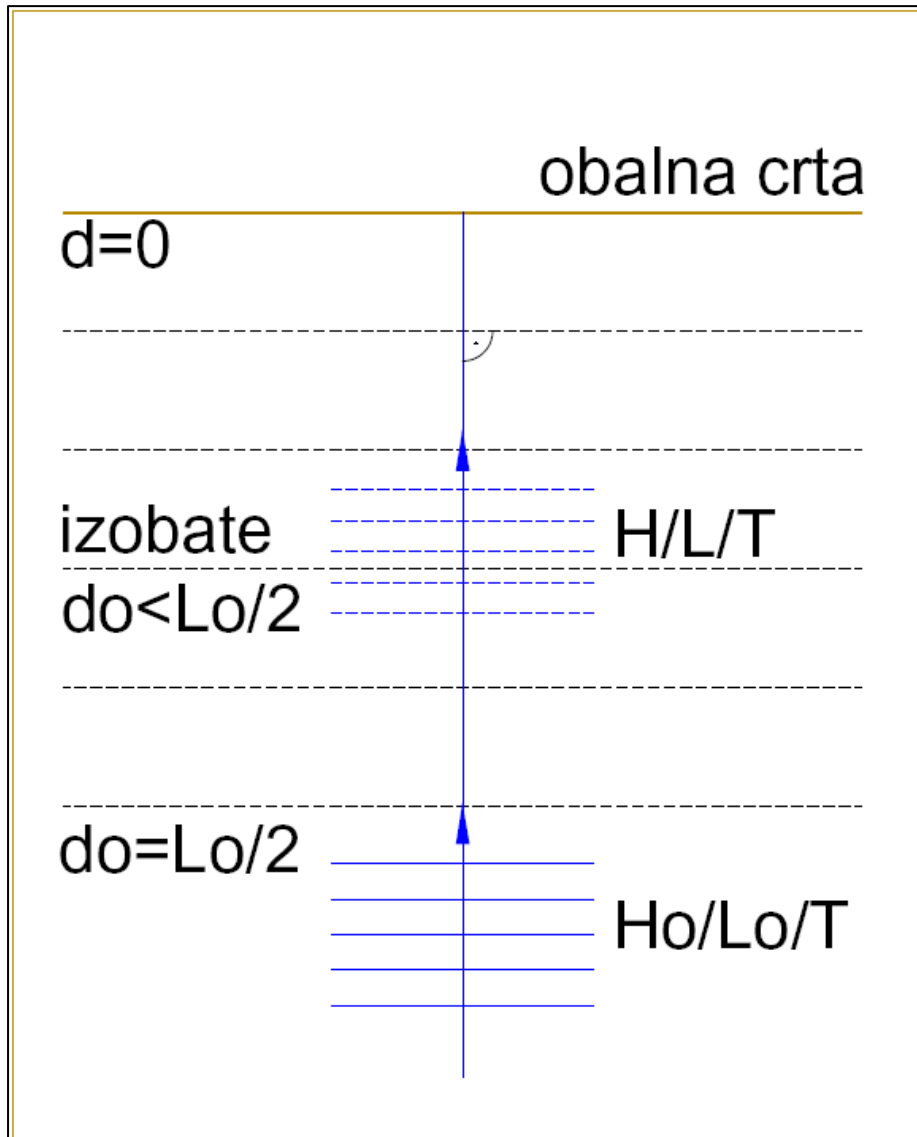
$$\left(\frac{H}{L}\right)_{\max} = \left(\frac{H}{L}\right)_b = \left(\frac{H_0}{L_0}\right)_{\max} \operatorname{th}\left(\frac{2\pi d}{L}\right) = 0,12 \operatorname{th}\frac{2\pi d}{L}$$

Sl. 2.4.-3::3

ZDIZANJE
SREDNJICE

u dubokom ... $\Delta H_0 = \frac{\pi H_0^2}{4 L_0}$

2.4.4 DEFORMACIJE VALOVA KRATKIH PERIODA

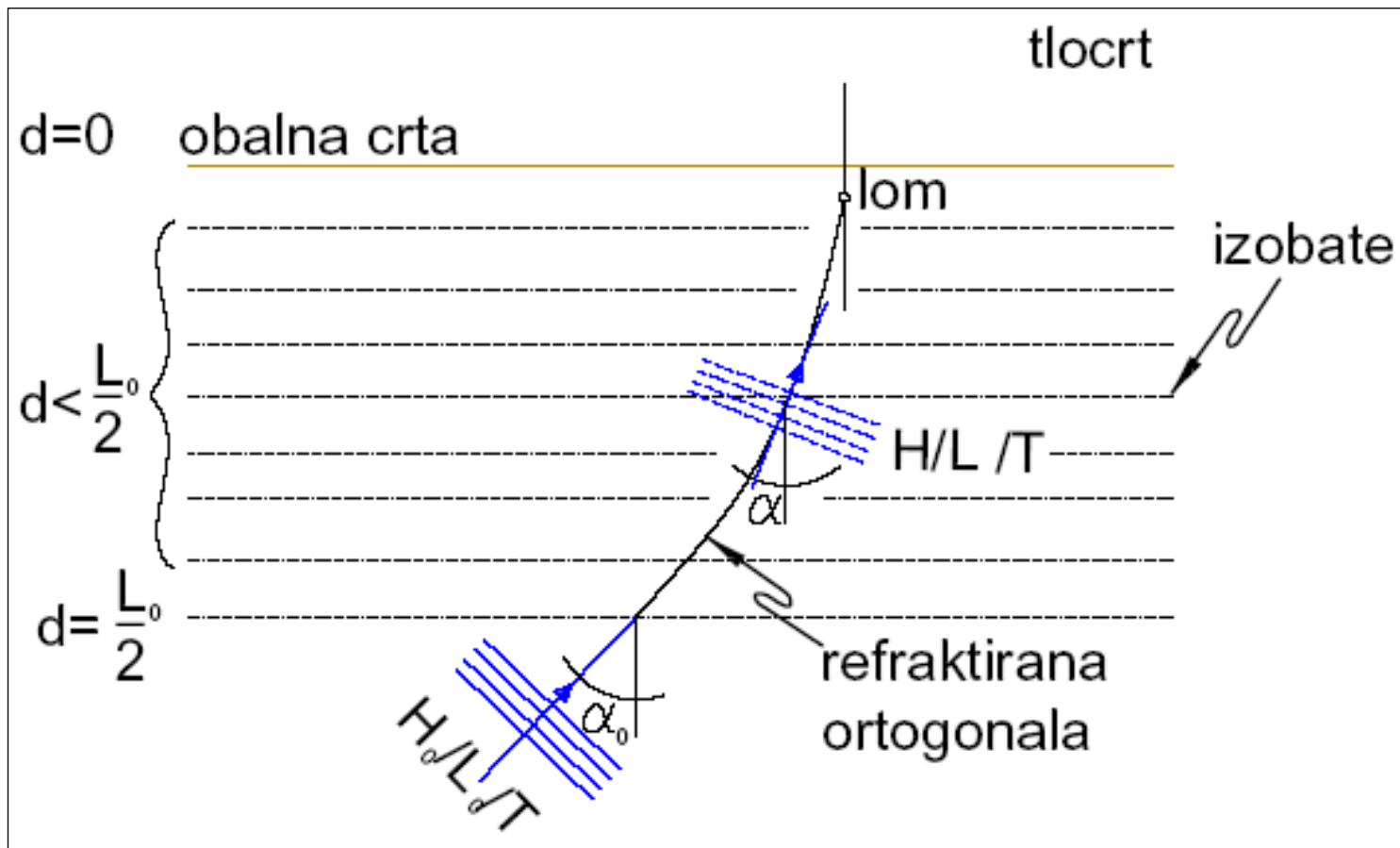


DEFORMACIJE NA NAGNUTOM DNU :

- *deformacija uslijed plićine ili "Shoaling efekt",*
- *deformacija uslijed trenja s dnom,*
- *odbijanje ili refleksija na nagnutom dnu i*
- *lom valova,*

Sl. 2.4.4::1.

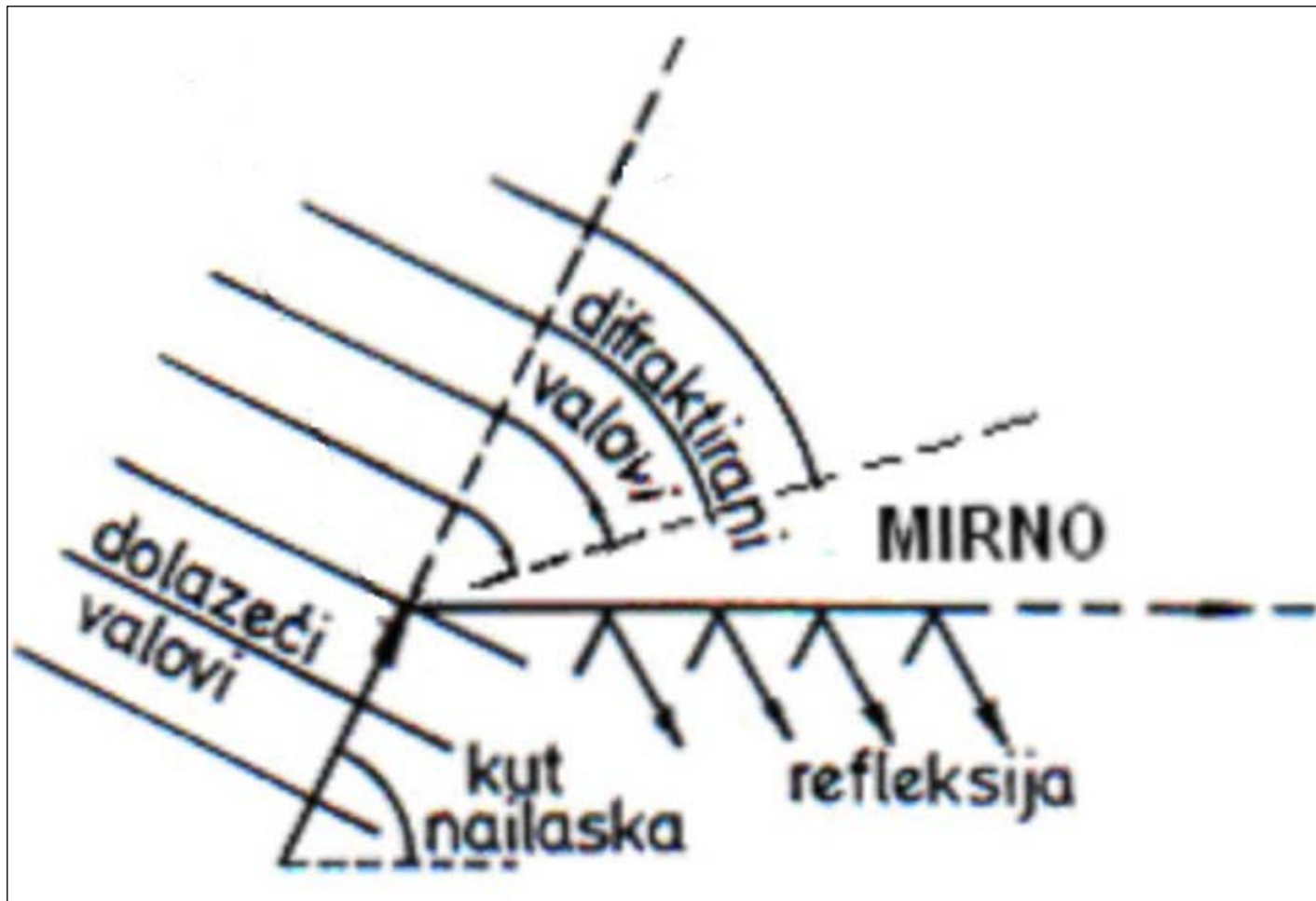
DEFORMACIJA NA NAGNUTOM DNU KOSO NA KONTURU DNA: *refrakcija vala*



Sl. 2.4.4.:2

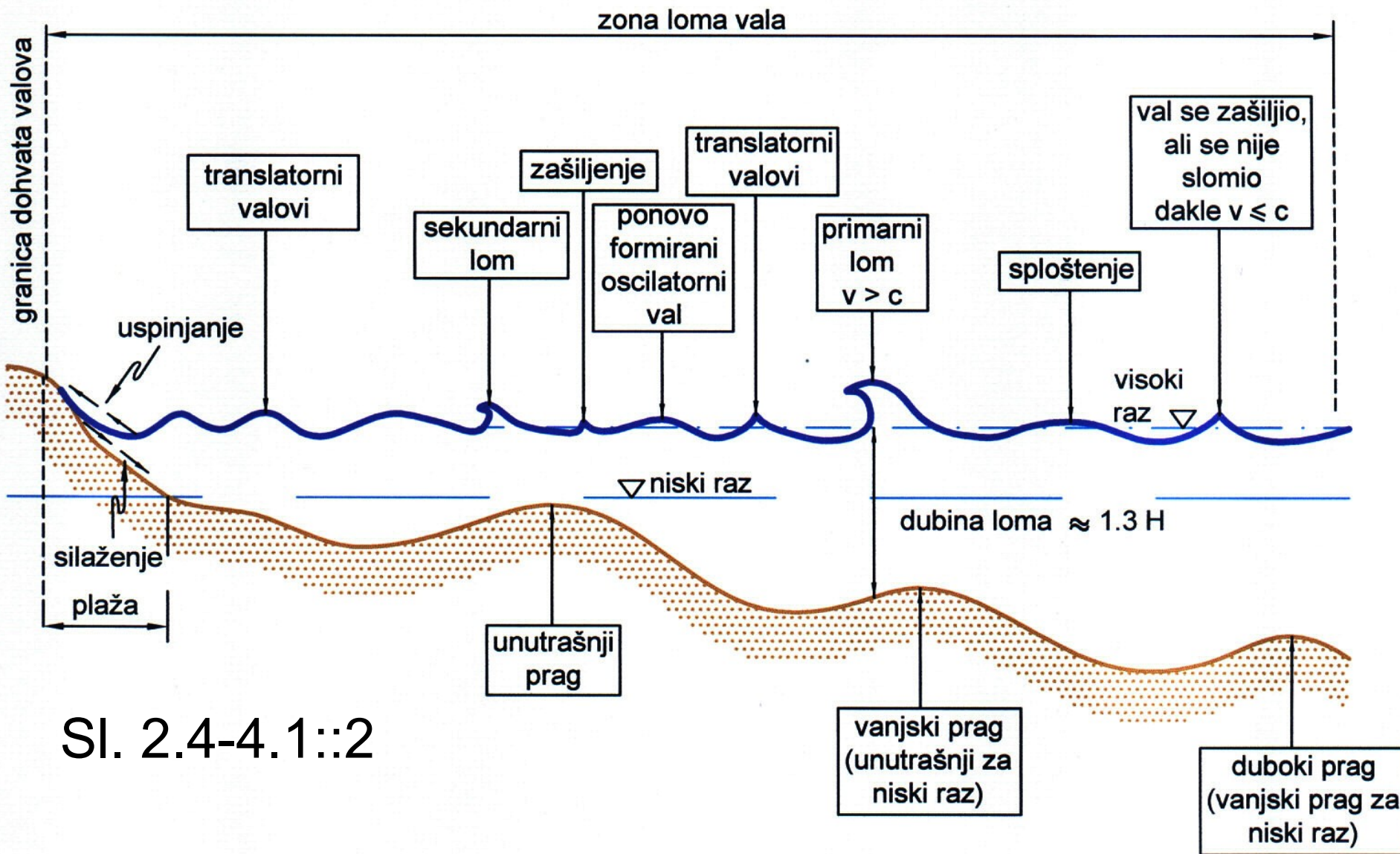
DEFORMACIJA OKO I NA VERTIKALNOJ PREPRECI:

- *ogib ili difrakcija vala, odbijanje ili refleksija vala*



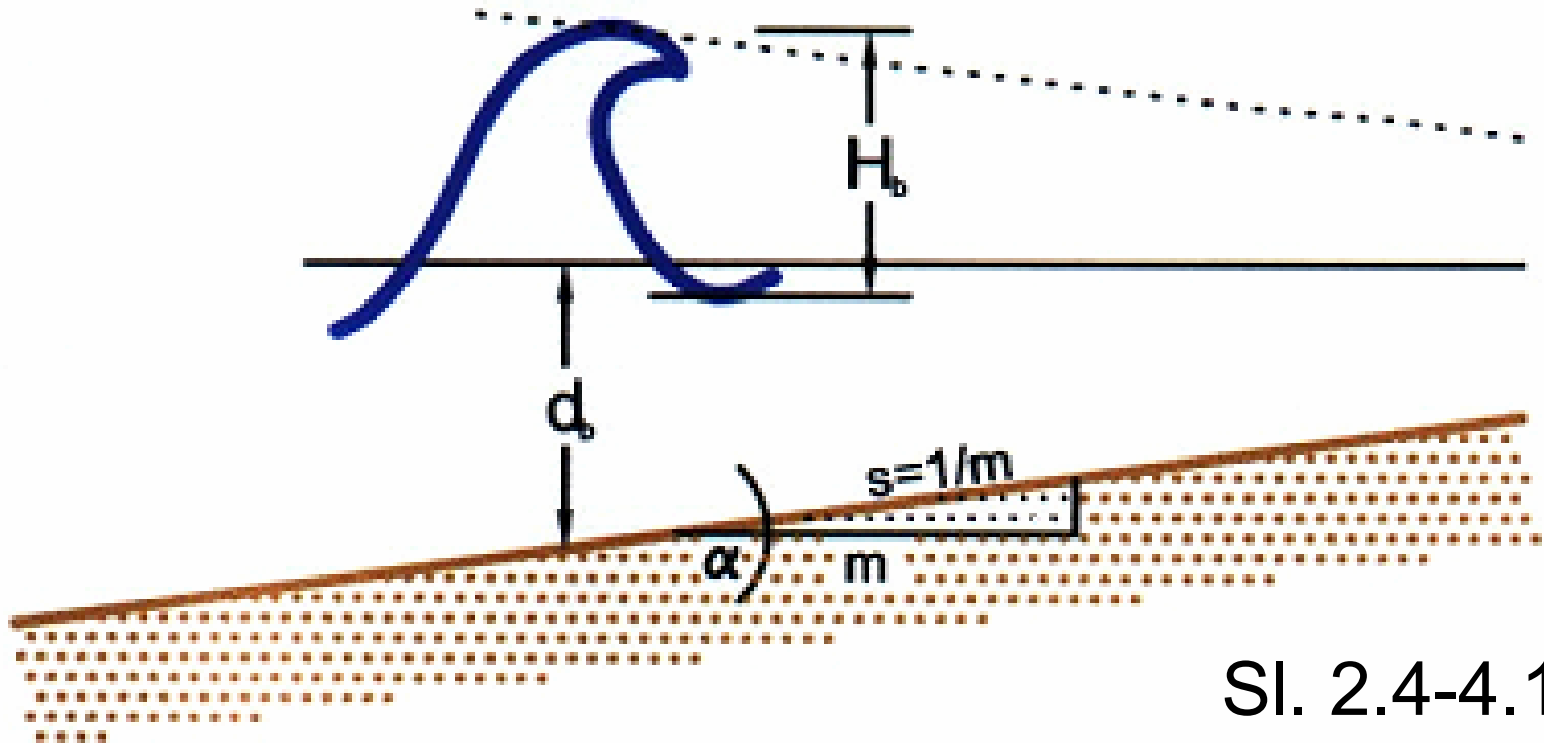
Sl. 2.4.4::3

2.4.4.1 LOM VALOVA



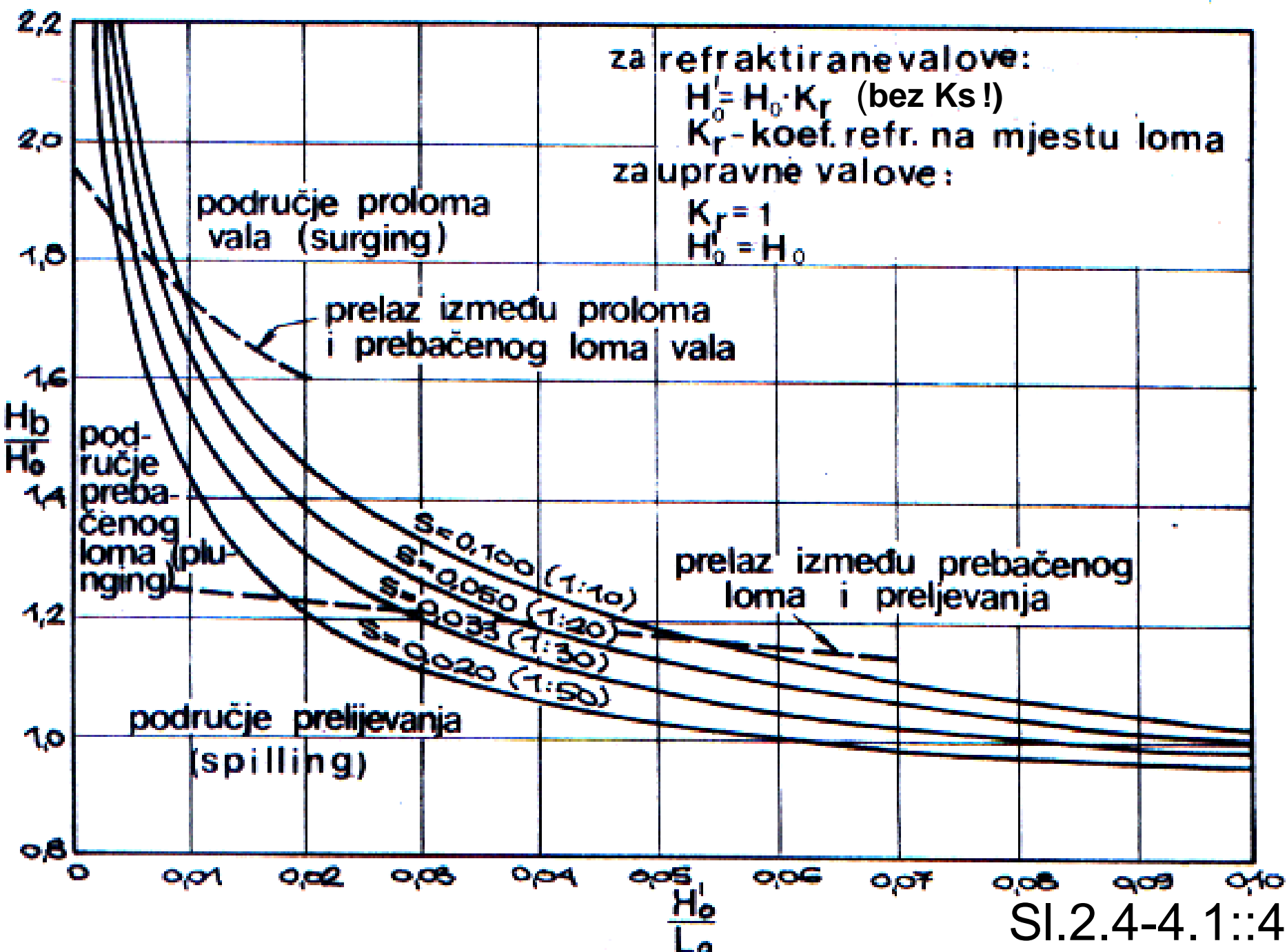
Sl. 2.4-4.1::2

Mjesto loma i visina lomljenog vala



Sl. 2.4-4.1::3

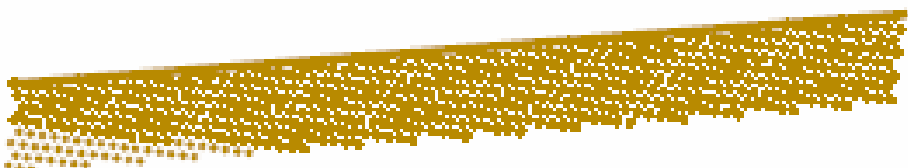
$$\frac{H_b}{d_b} = 0,78 \quad \frac{d_b}{H_b} = 1,28 \approx 1,3 \quad d_b \approx 1,3 H_b$$



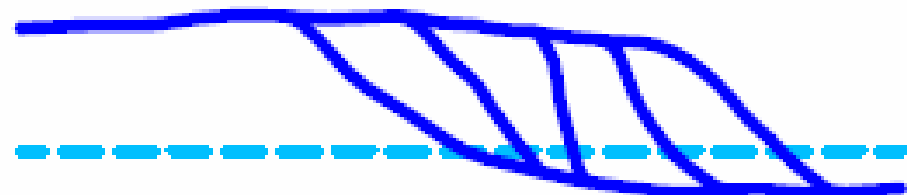
TIPOVI LOMA VALA



prelijevanje (spilling)



prebačeni lom (plunging)



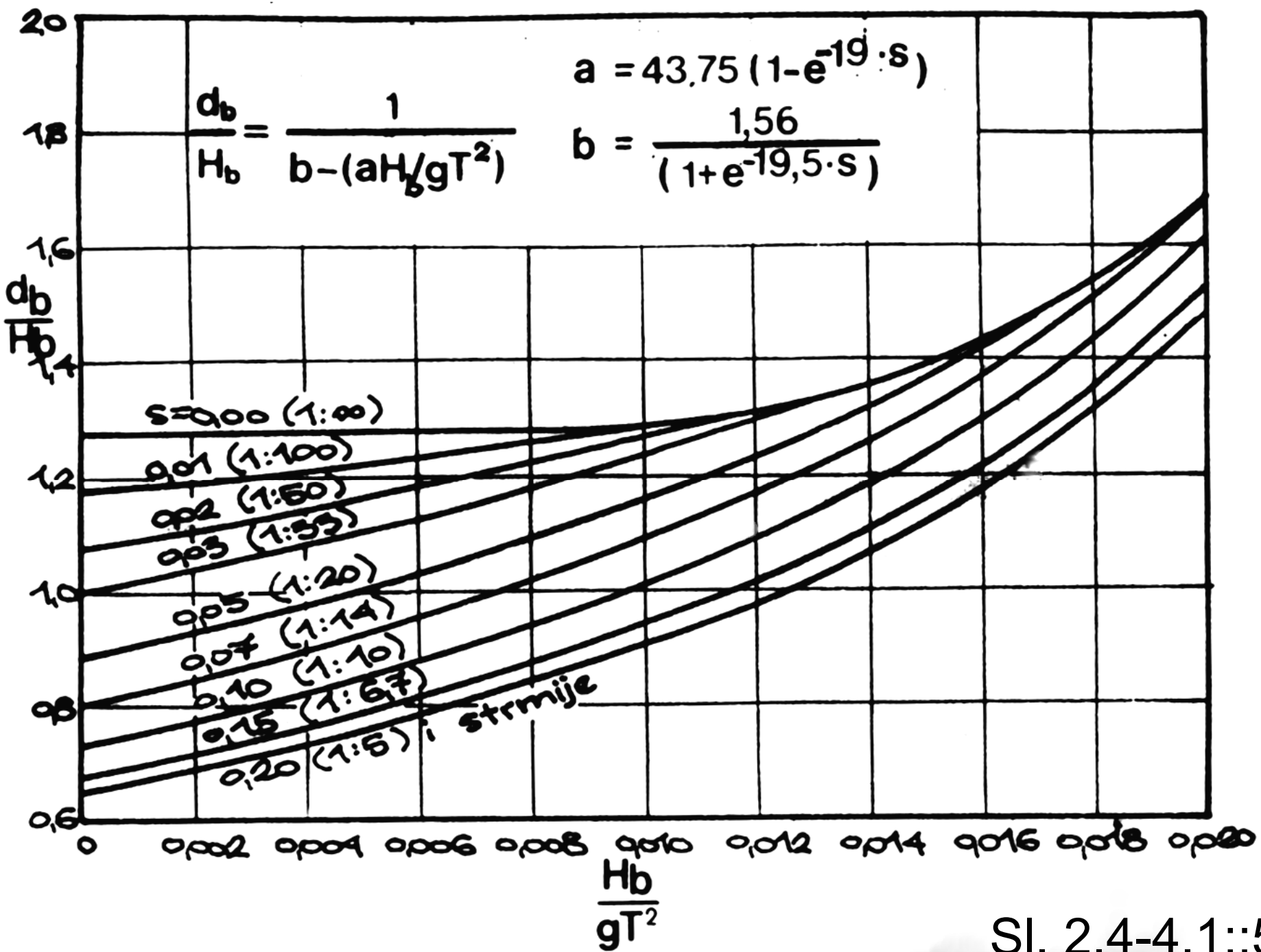
rušenje (collapsing)



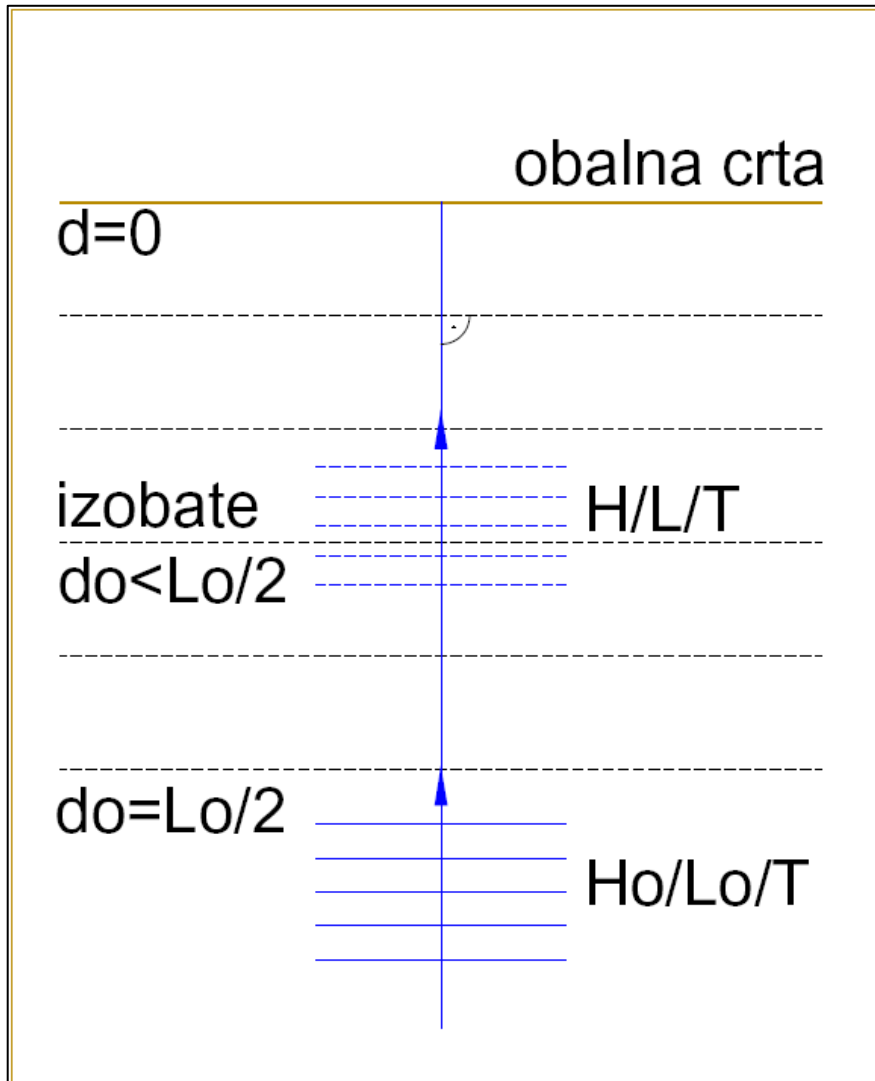
prolom vala (surging)



Sl. 2.4-4.1::6

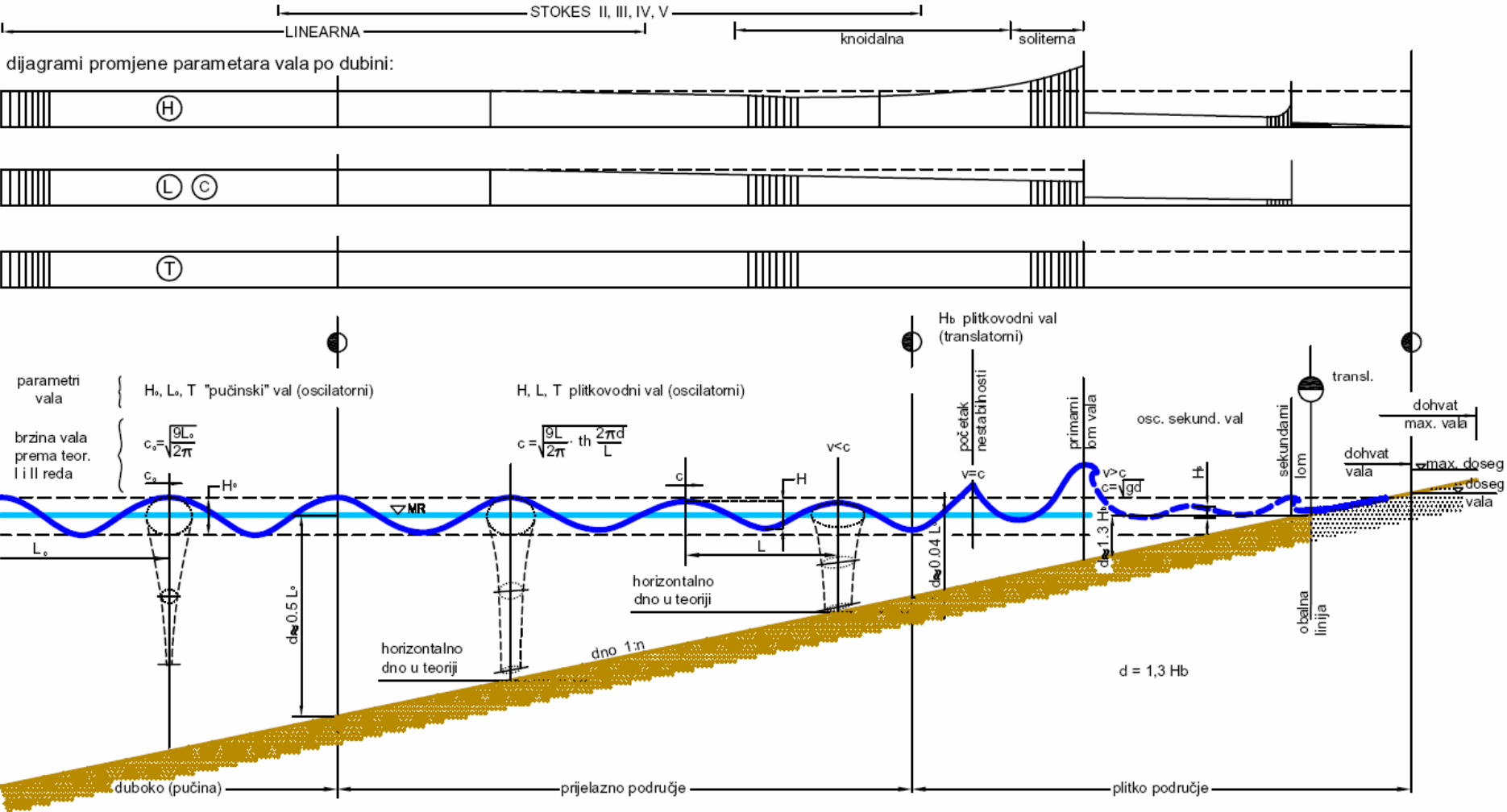


2.4.4.2 DEFORMACIJE VALOVA NA NAGNUTOM DNU USLIJED SMANJENJA DUBINE; UČINAK PLIĆINE - SHOALLING EFEKT

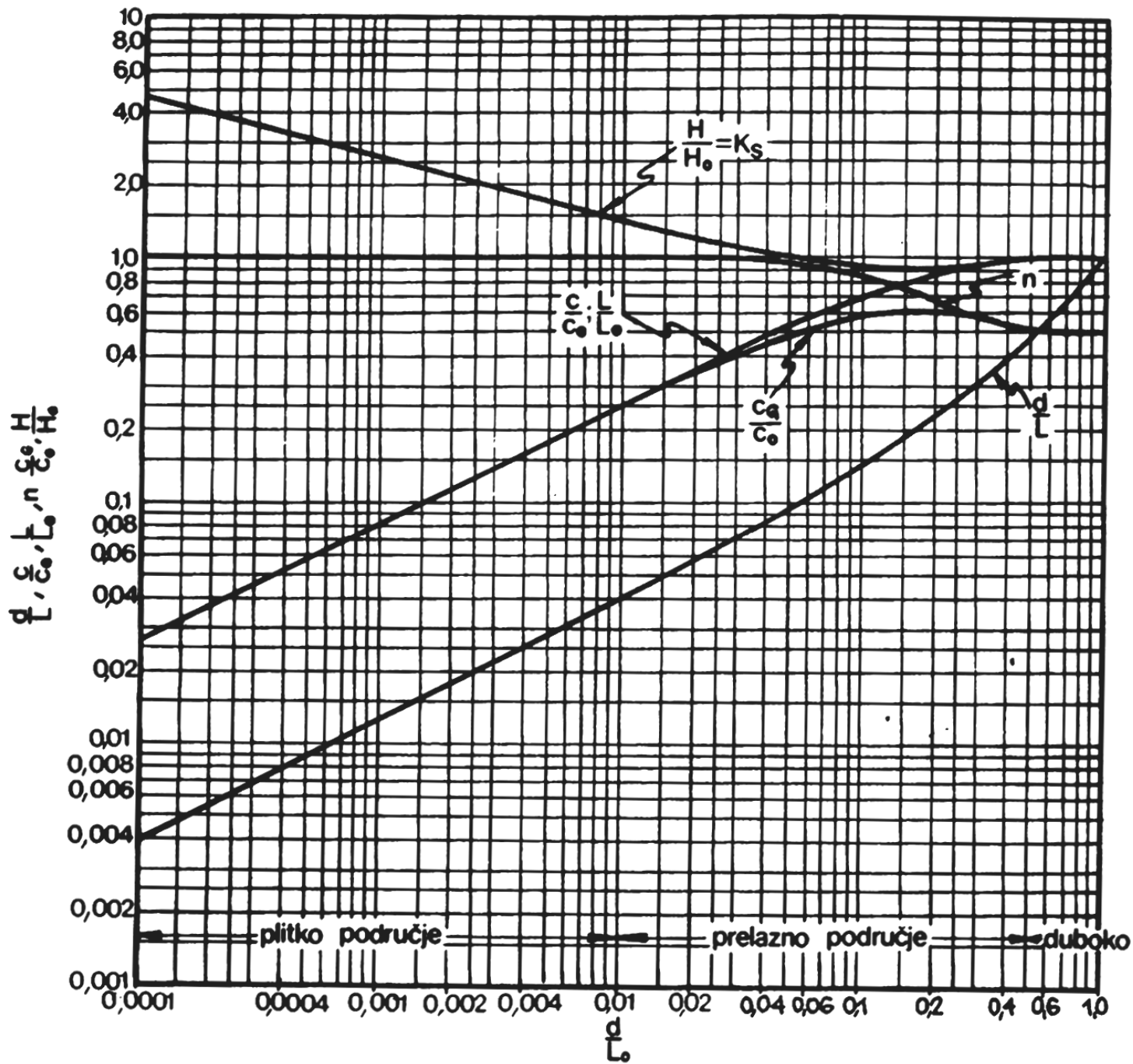


Sl. 2.4-4.2::1

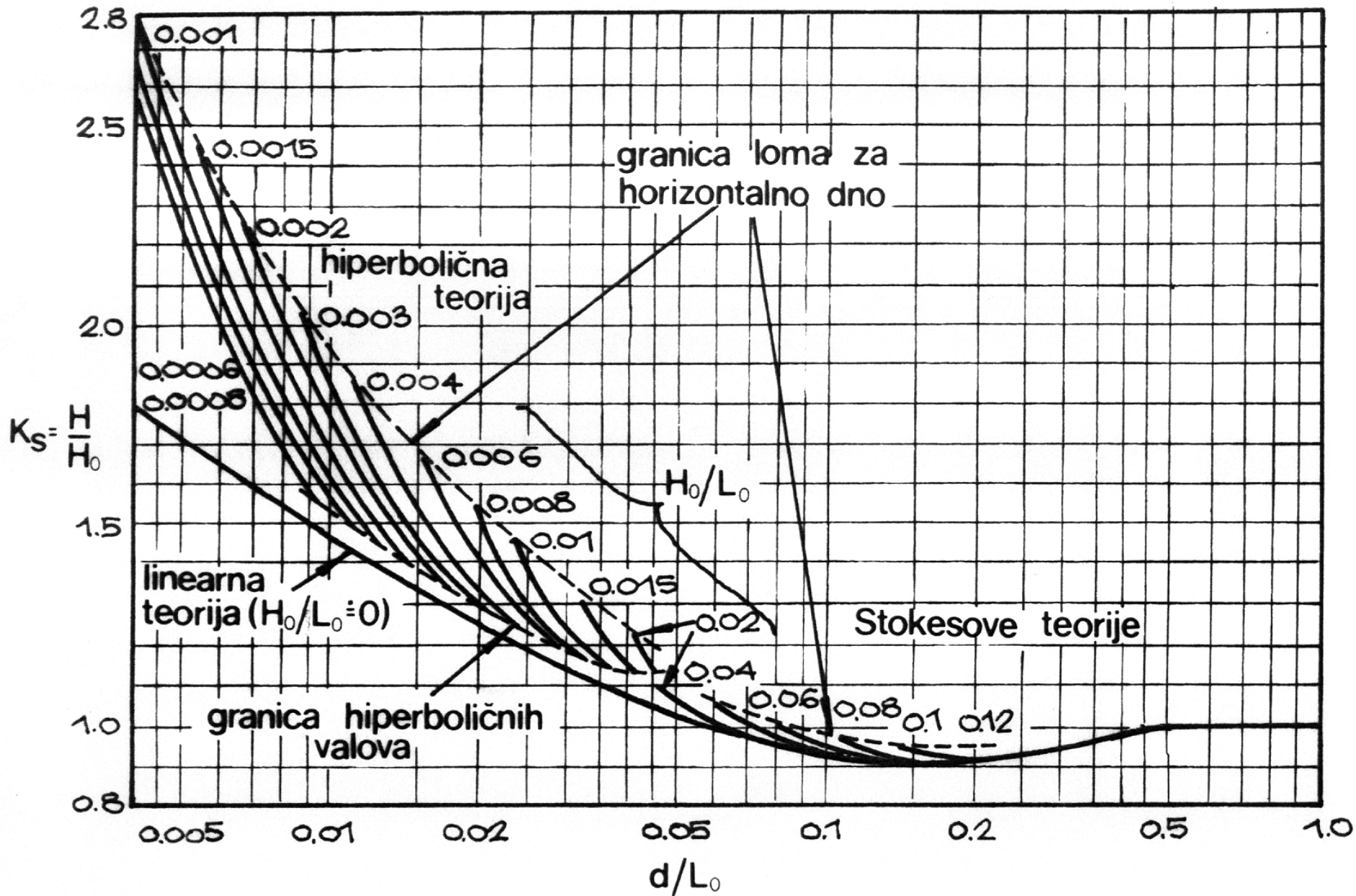
Orijentacijski izbor meritorne valne teorije u slučaju konačnih valova:



SI. 2.4-4.2::2



2.4 -4.2::3



Sl. 2.4-4.2:::4

2.4.4.3 DEFORMACIJA VALOVA USLIJED TRENJA S DNOM

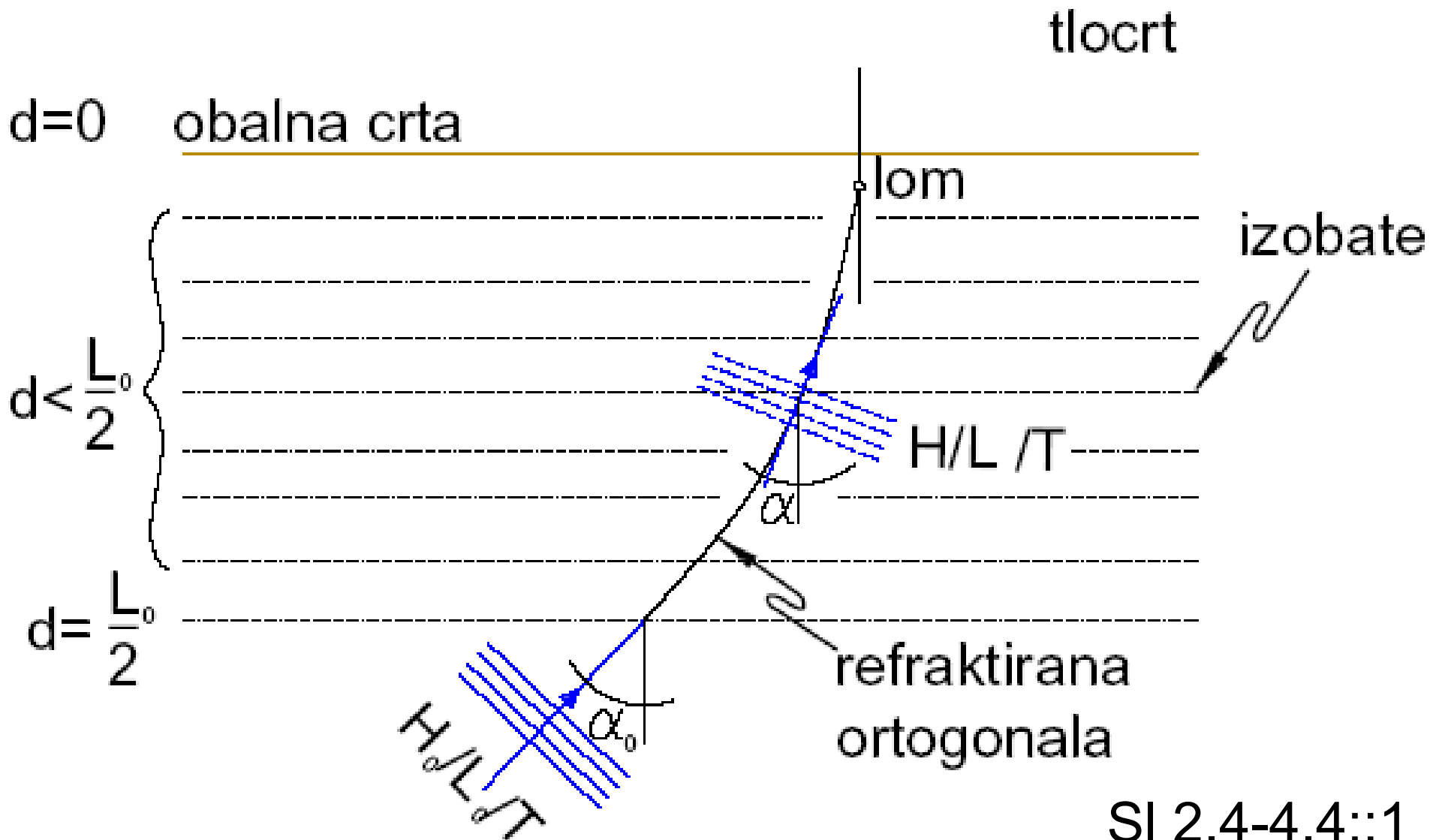
$$H_2 = K_f H_1$$

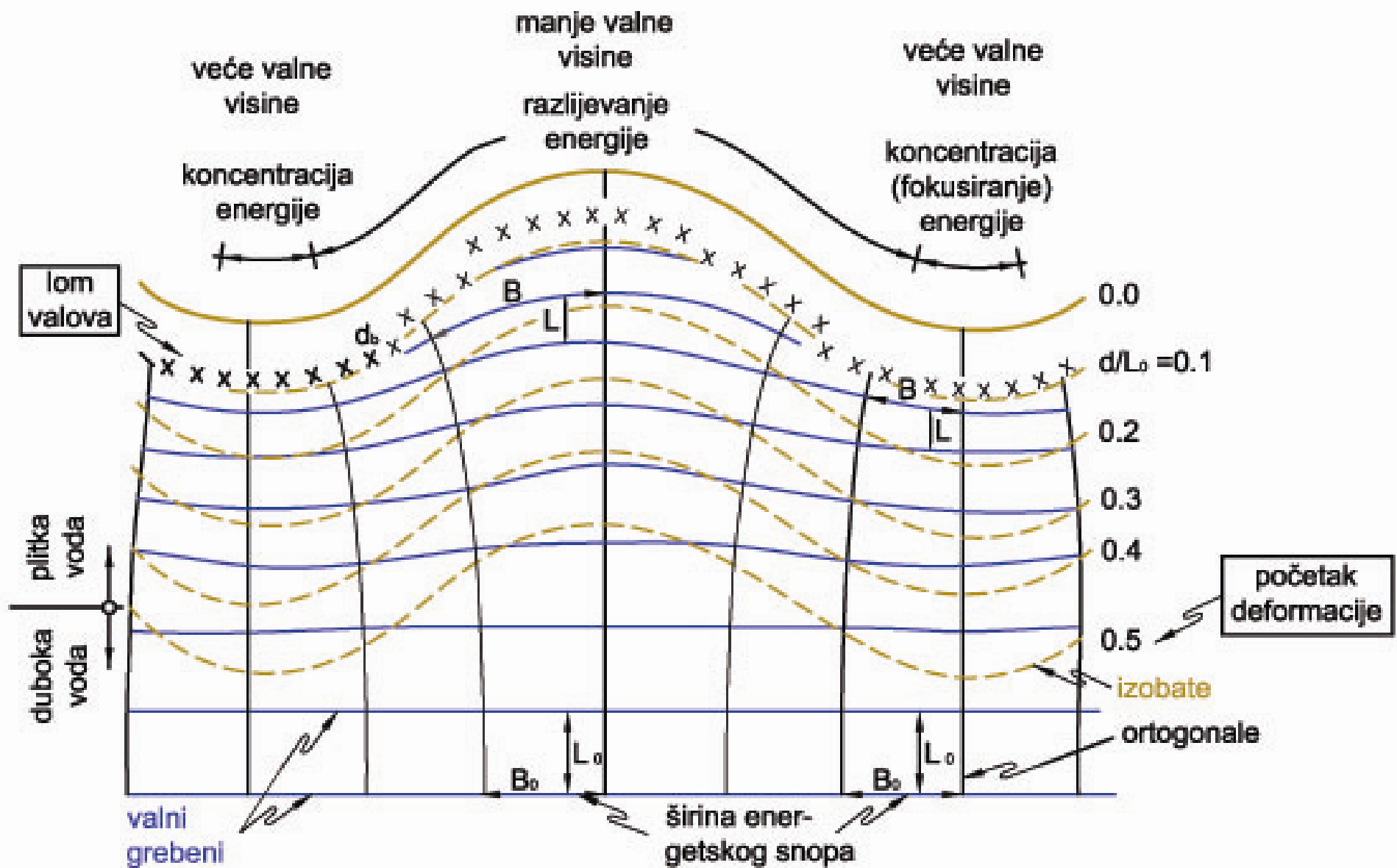
H_2 valna visina u plićem

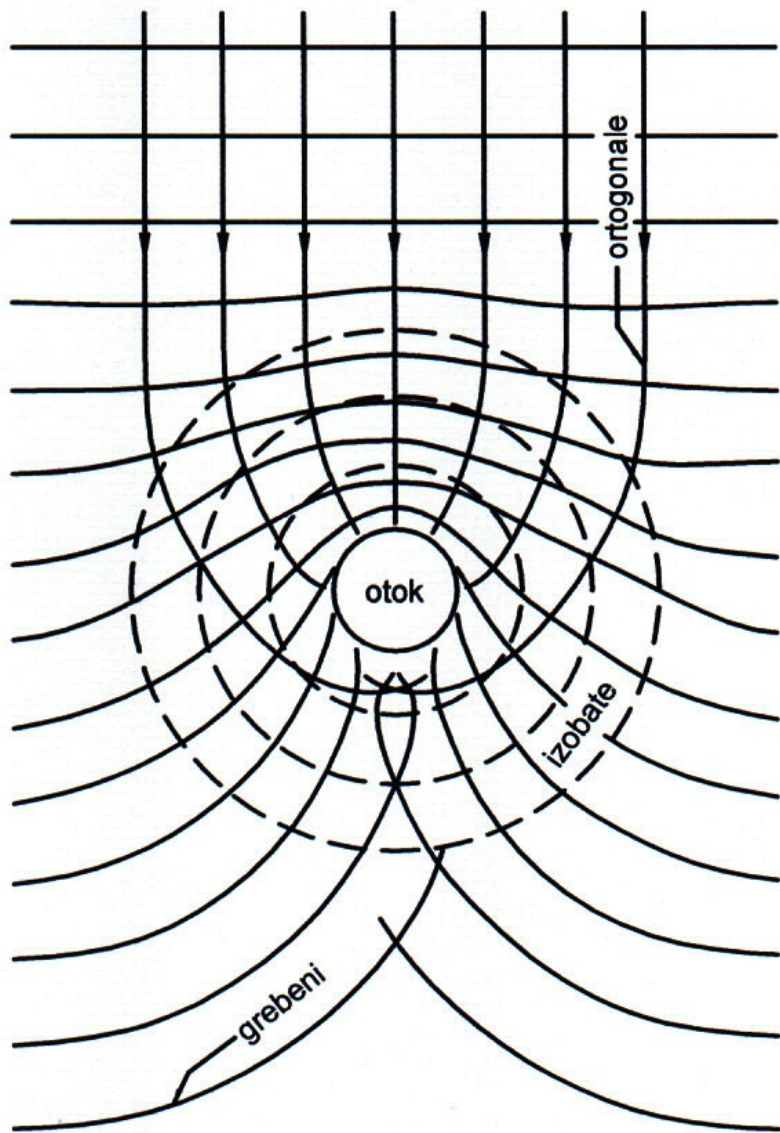
H_1 valna visina u dubljem

$$H_2 < H_1$$

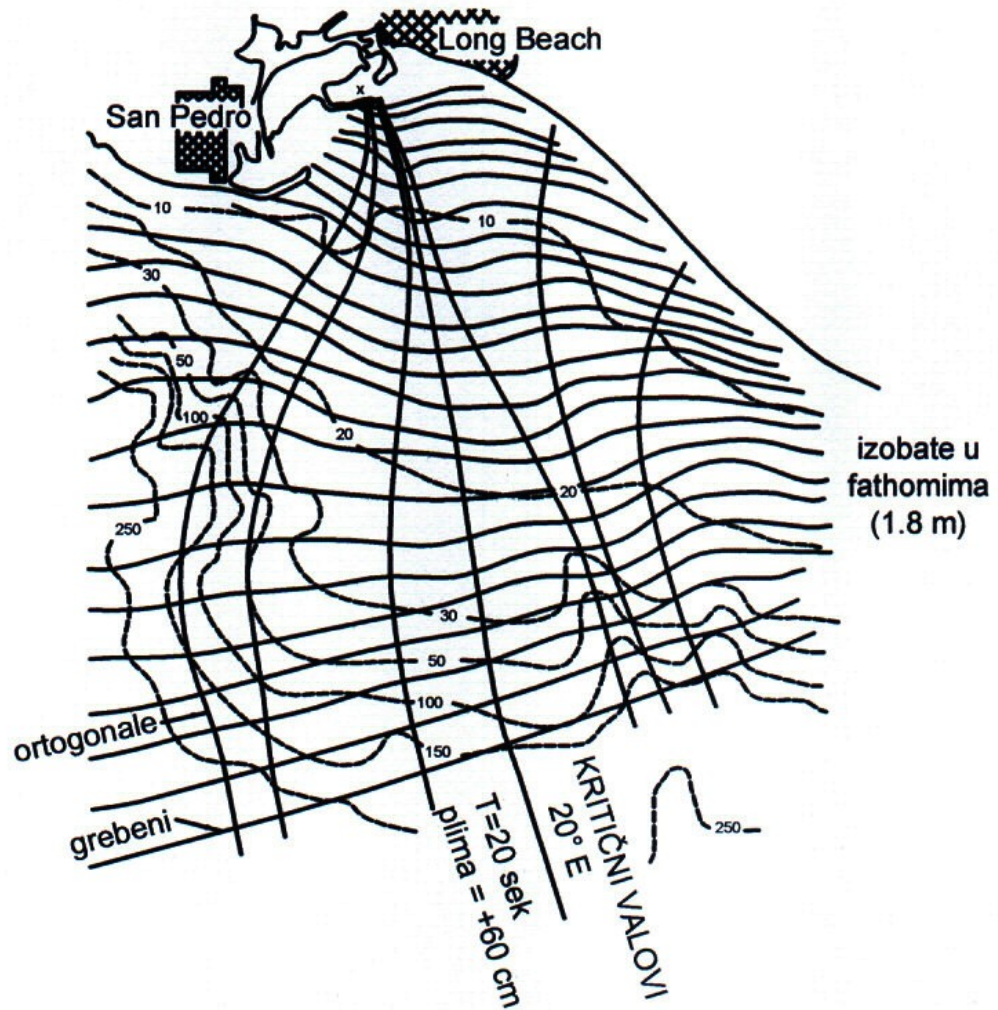
2.4.4.4 ZALOMLJAVANJE ILI REFRAKCIJA VALOVA



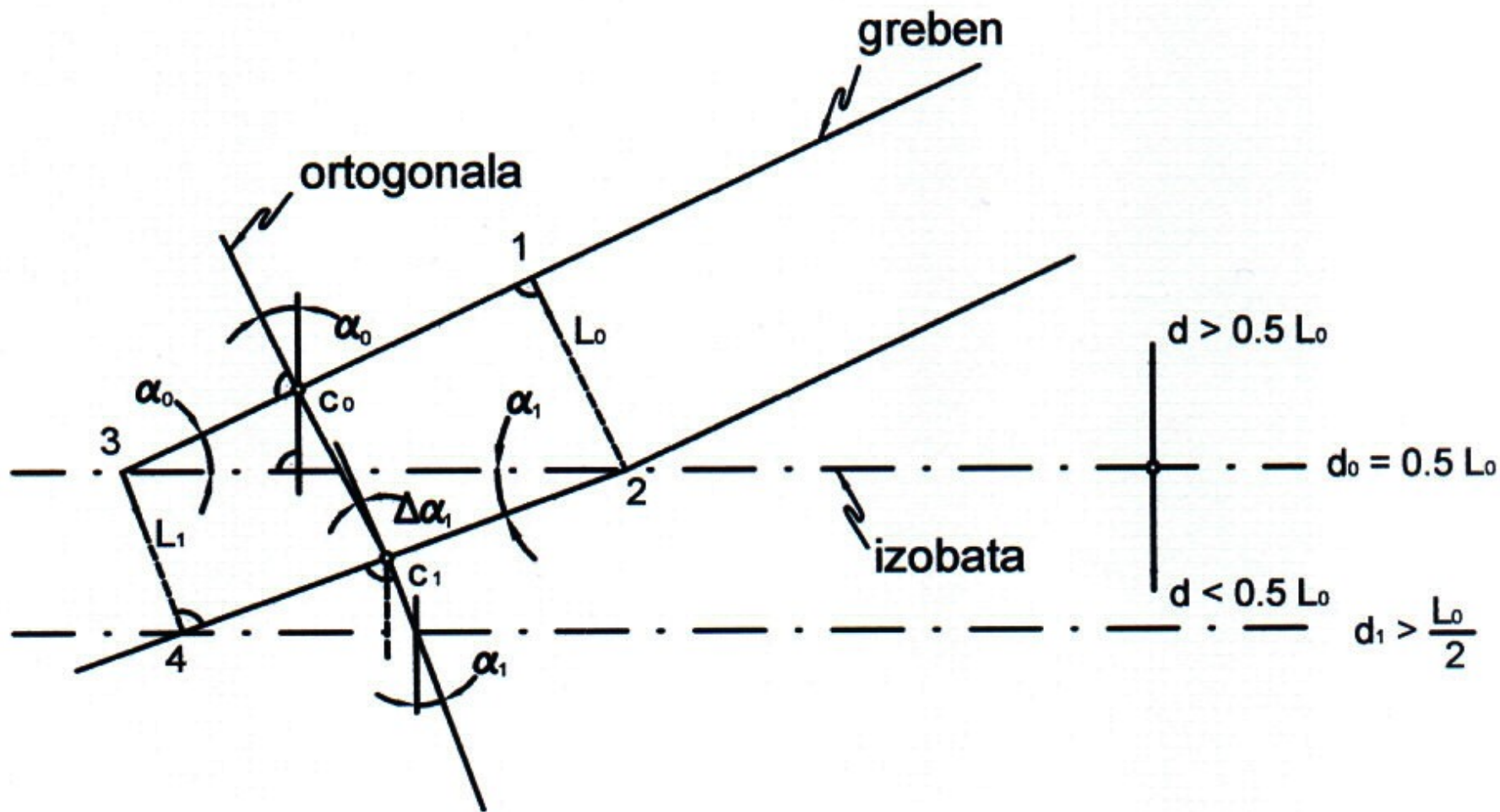




Sl. 2.4-4.4::3

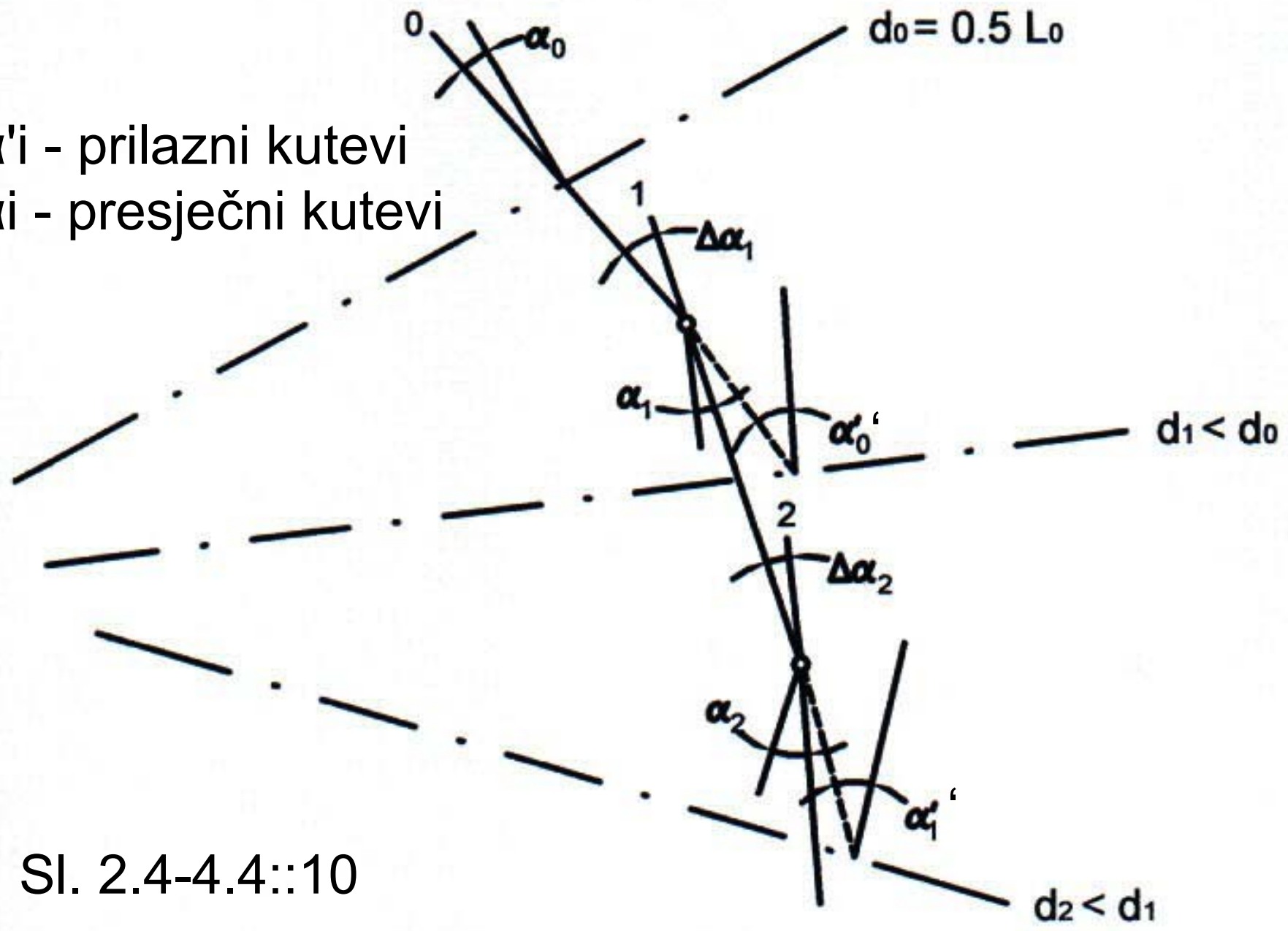


Sl. 2.4-4.4::4



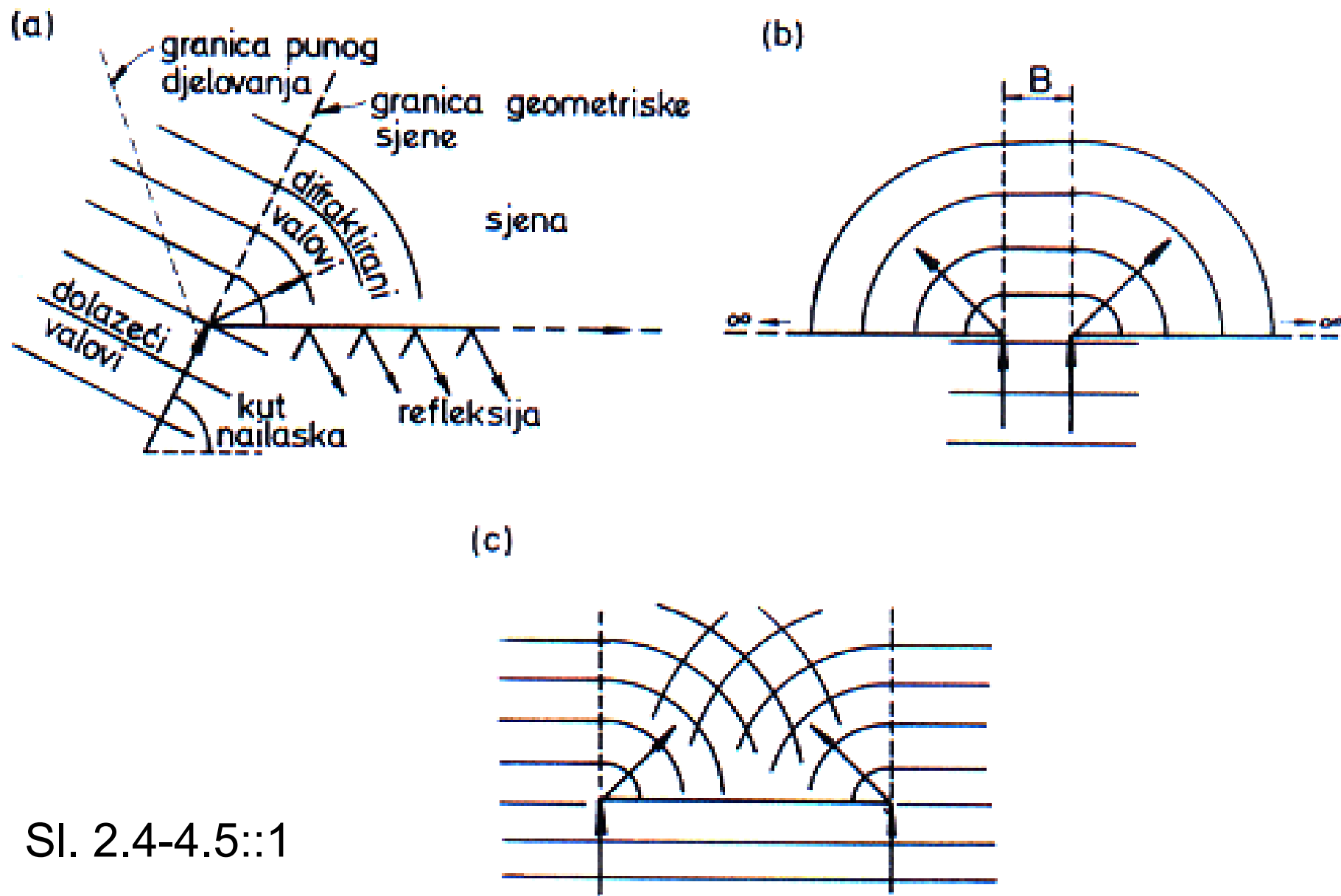
Sl. 2.4-4.4::6

α'_i - prilazni kutevi
 α_i - presječni kutevi

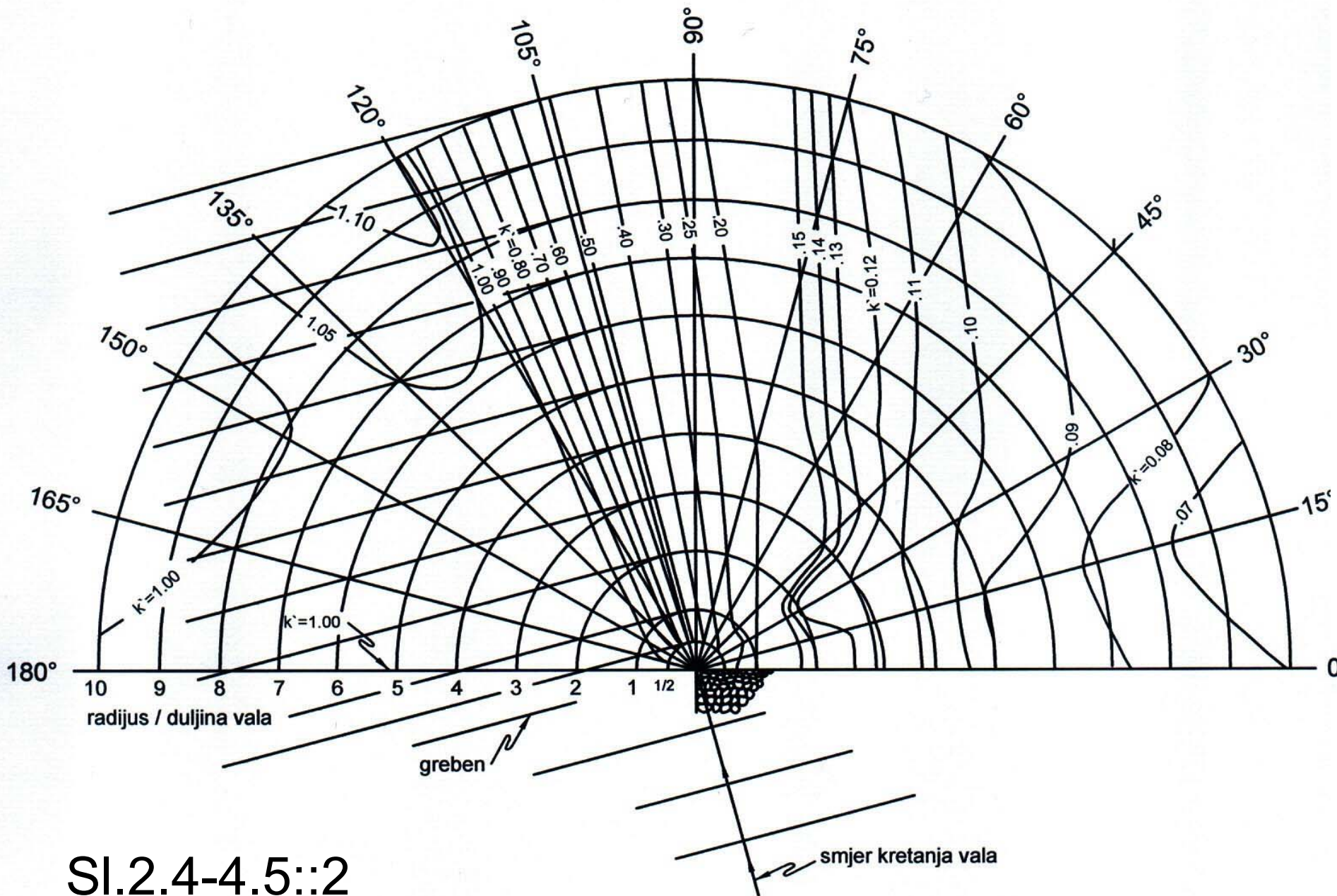


Sl. 2.4-4.4::10

2.4.4.5 OGIB ILI DIFRAKCIJA VALOVA

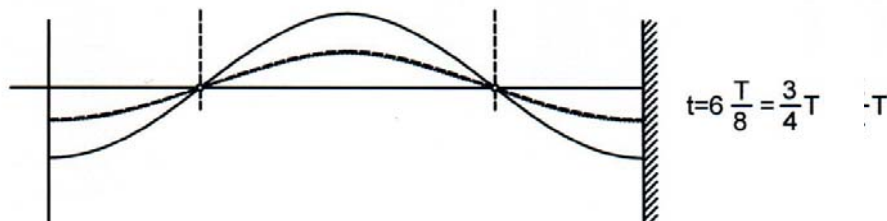
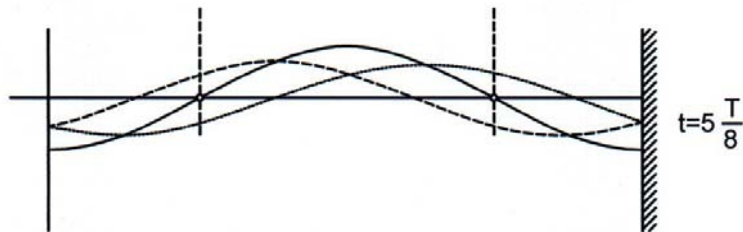
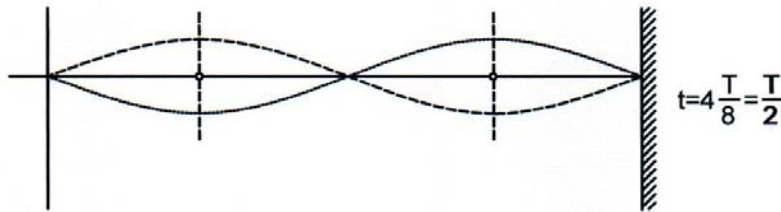
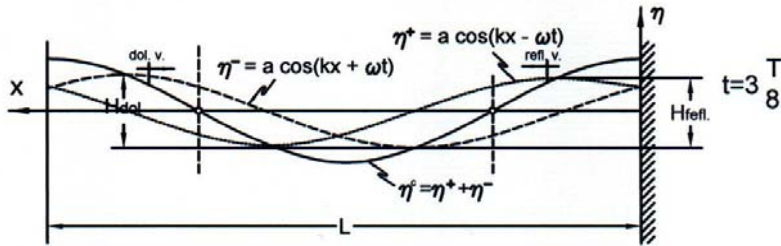
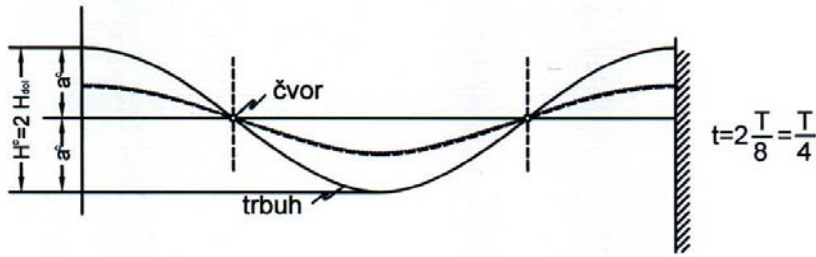


Sl. 2.4-4.5::1



SI.2.4-4.5::2

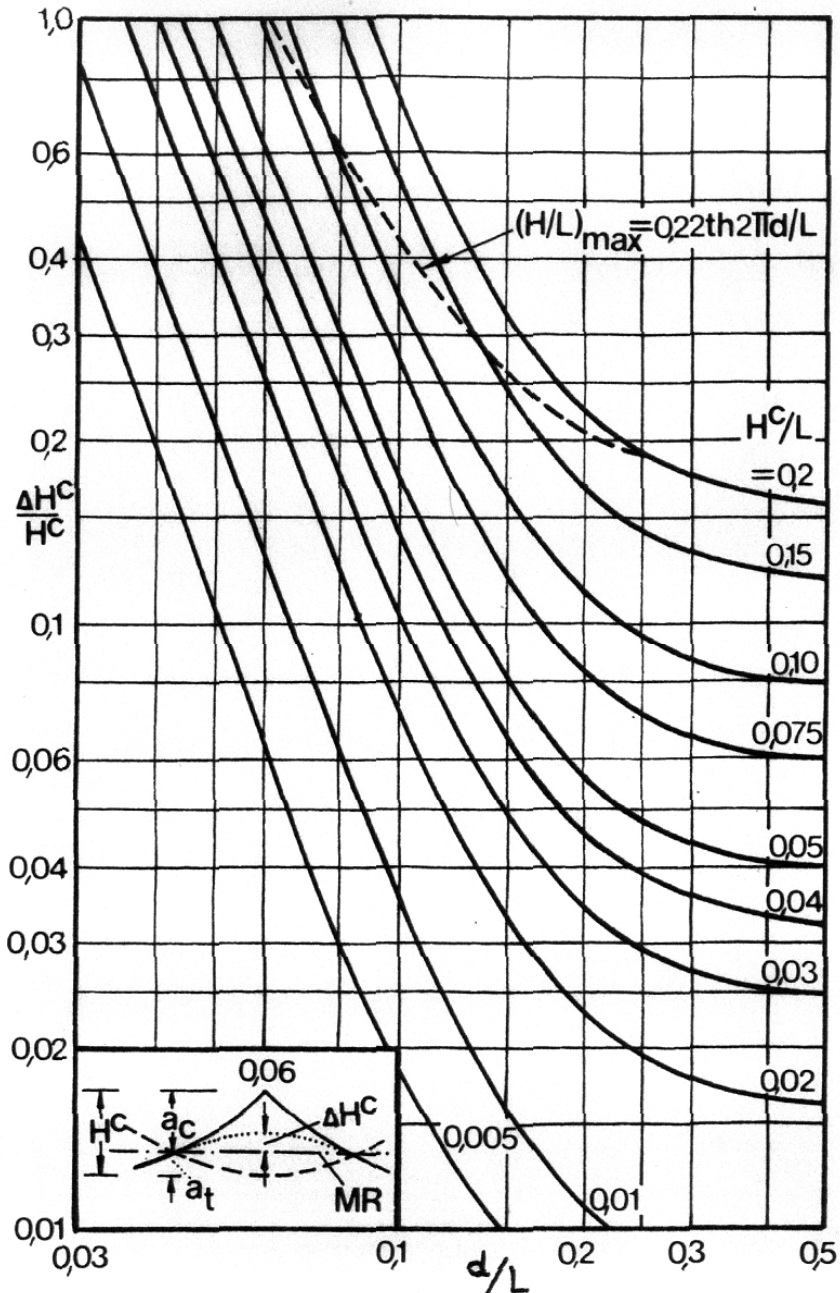
2.4.4.6 ODBIJANJE ILI REFLEKSIJA VALOVA



SI.2.4-4.6::1

SI.2.4-4.6::2

Izdizanje srednjice stojnog vala



$$H_{sup} = 2H_{dol} = H^c$$

$$a_{sup} = 0,5 H_{sup} = H_{dol} = 0,5 H^c$$

$$a_c = 0,5 H^c + \Delta H^c$$

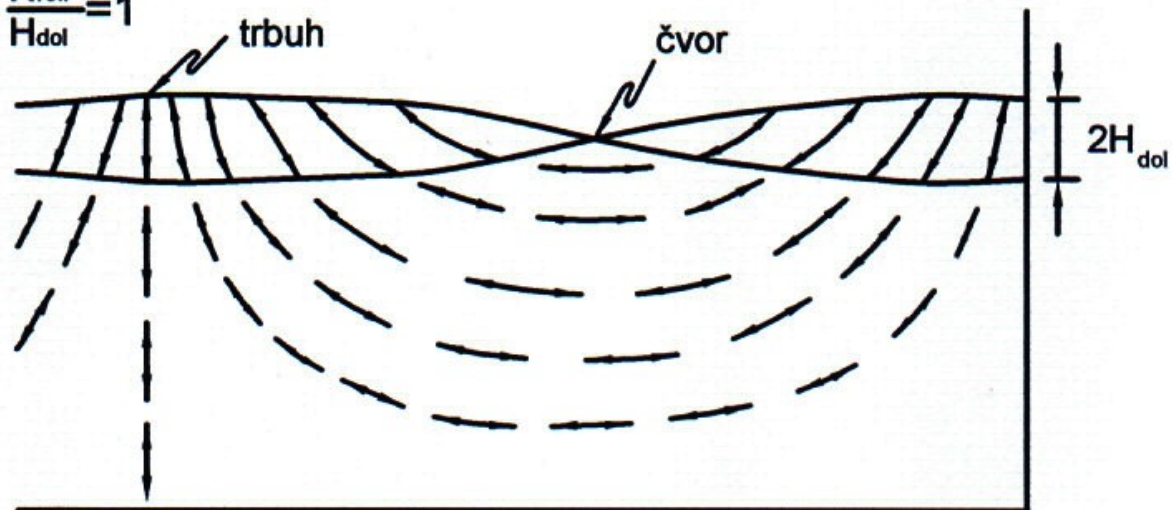
$$a_t = 0,5 H^c - \Delta H^c$$

$$\Delta H^c = \frac{\pi (H^c)^2}{4L} \text{cth} \frac{2\pi d}{L} \times$$

$$\left[1 + \frac{3}{4 \text{sh}^2 \frac{2\pi d}{L}} - \frac{1}{4 \text{ch}^2 \frac{2\pi d}{L}} \right]$$

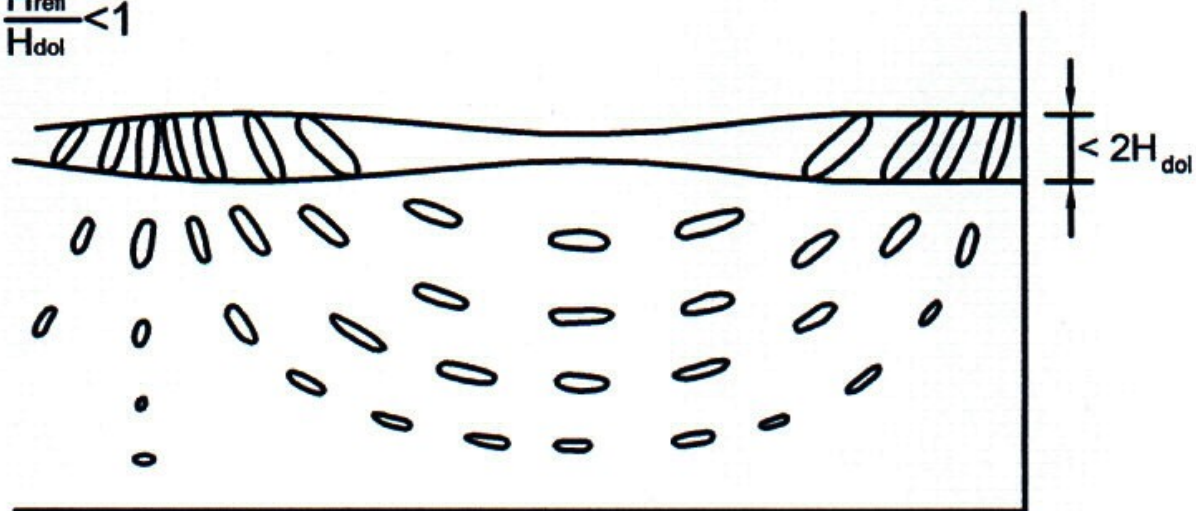
(a) potpuna refleksija (gladak nepropusan zid)

$$K_r = \frac{H_{ref}}{H_{dol}} = 1$$



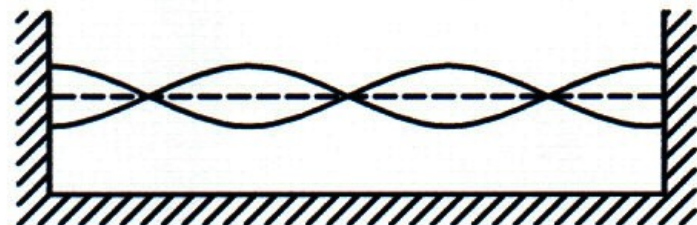
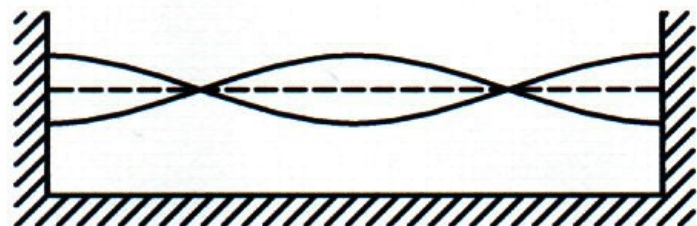
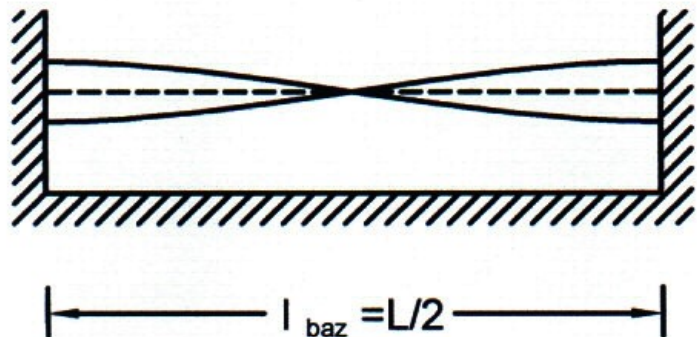
(b) djelomična refleksija (hrapav i propustan zid)

$$K_r = \frac{H_{ref}}{H_{dol}} < 1$$

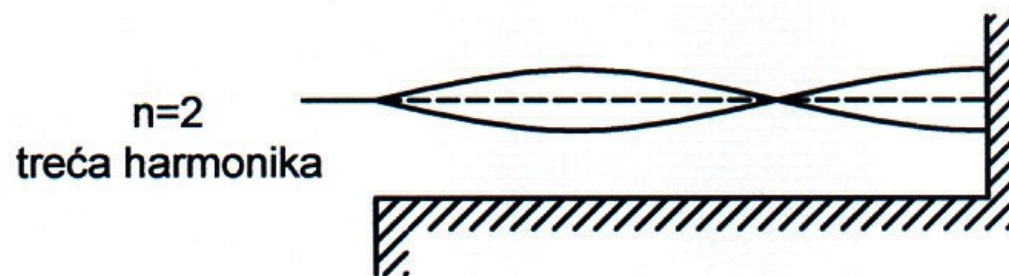
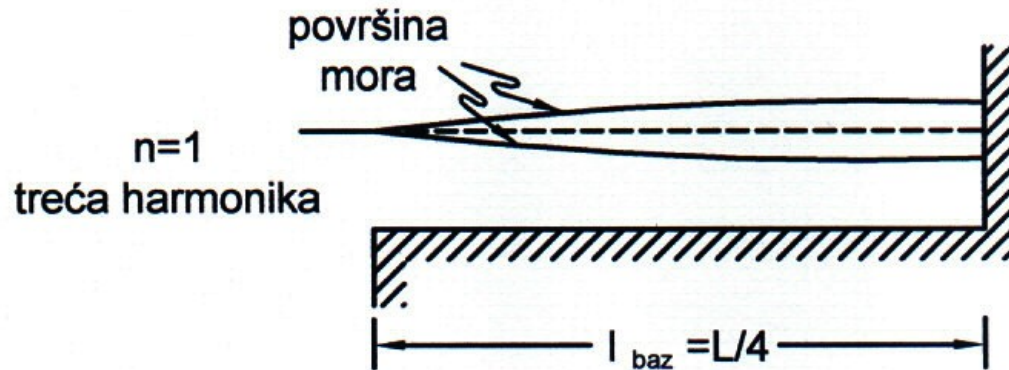


Sl. 2.4-4.6:::3

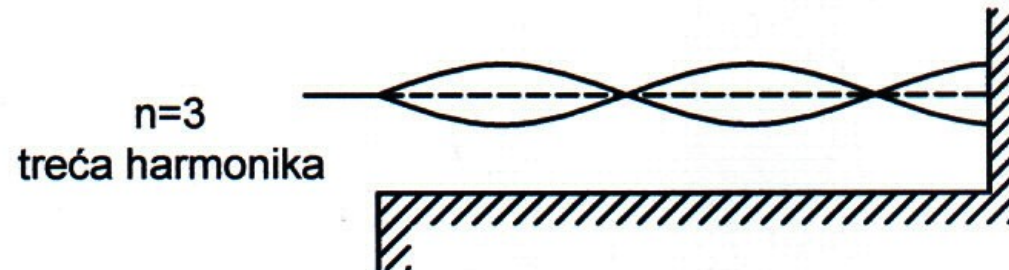
ZATVORENI BAZEN

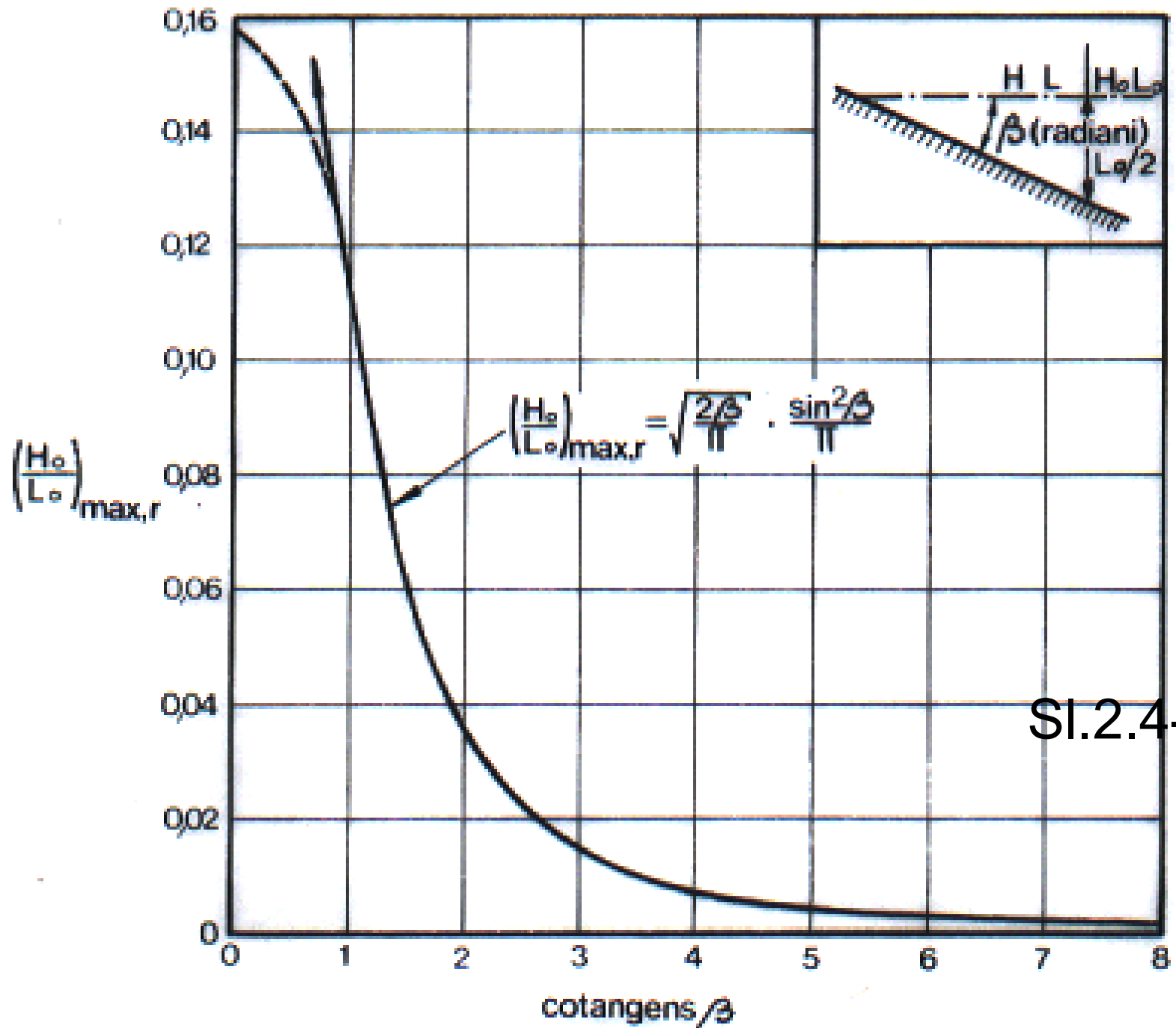


OTVORENI BAZEN



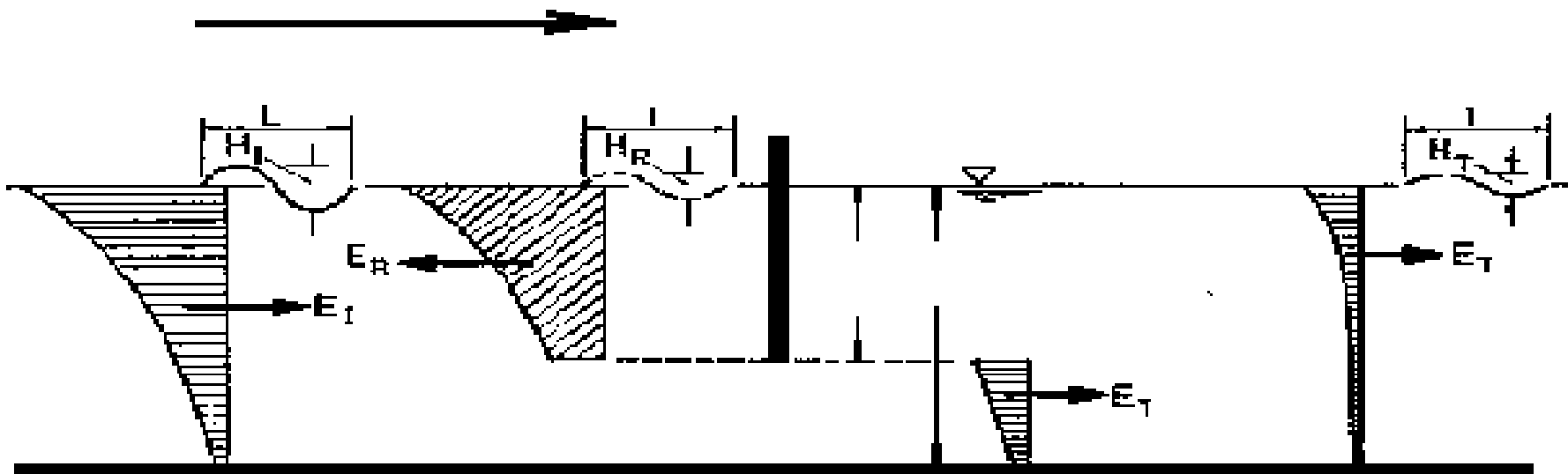
Sl.2.4-4.6::4



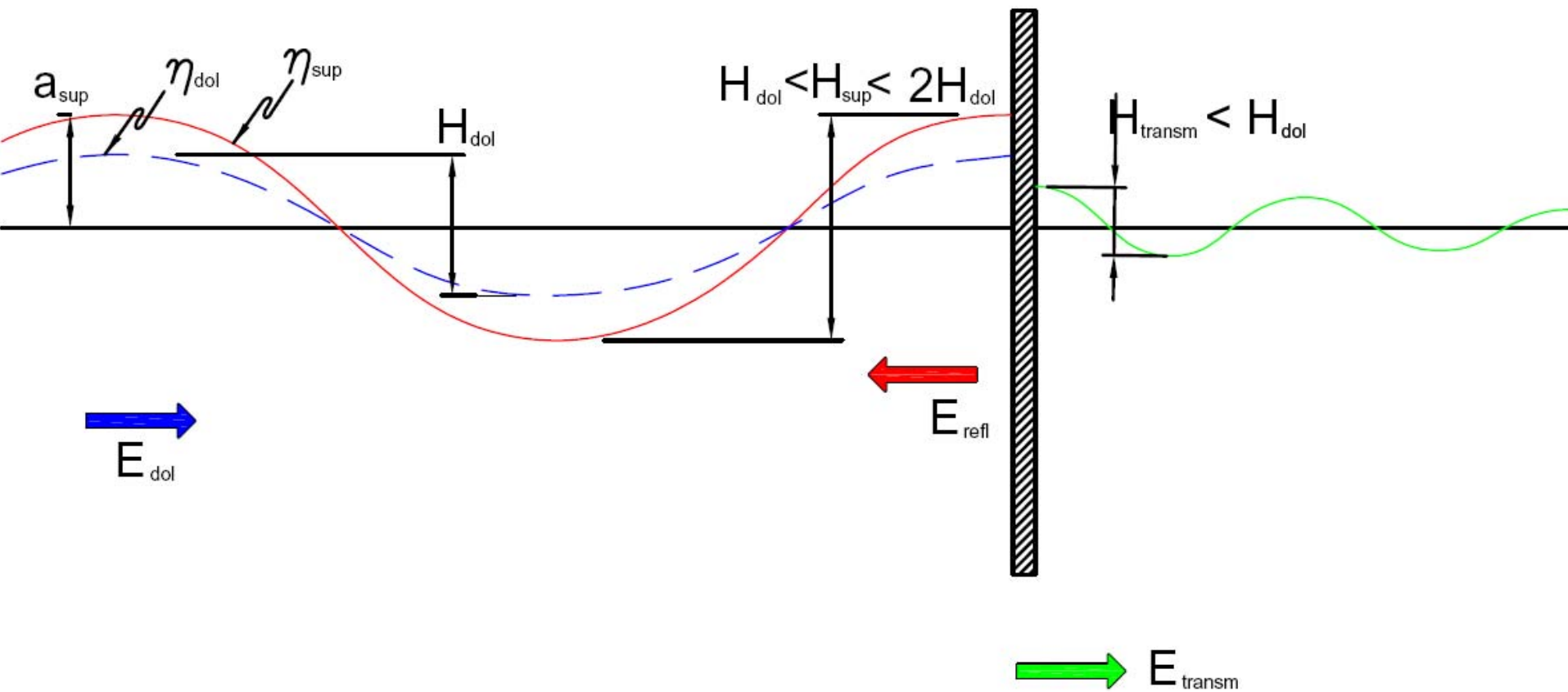


SI.2.4-4.6::6

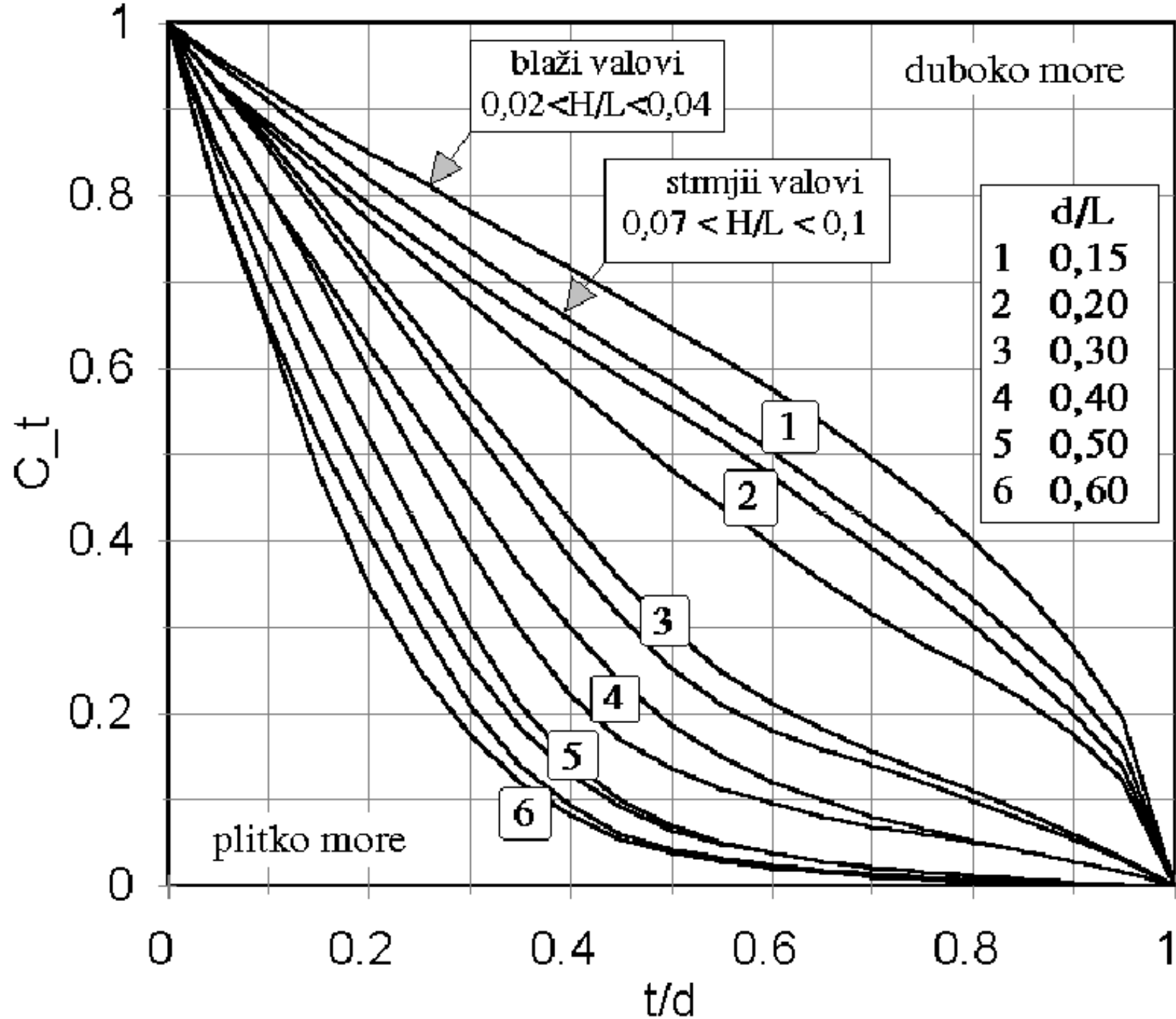
2.4.4.7 Propuštanje ili transmisija valova



Sl. 2.4.4.7::1



SI. 2.4.4.7::2



Predmet: PLOVNI PUTEVI I LUKE
Studij: diplomski
Smjer: H
Semestar: II
Fond sati: 45+45
Godina: 2010.

Gradivo za II. test, ut. 30.03.2010.

2-5 Deformacije valova kratkih perioda

2.4.5 VALNO OPTEREĆENJE FIKSNIH POMORSKIH KONSTRUKCIJA

FIKSNE POMORSKE KONSTRUKCIJE		
VOLUMSKE		VITKE
$D/L \geq 1$ sila tlaka vala	$1 > D/L > 0,2$ sila difrakcije	$D/L \leq 0,2$ sila otpora i inercije (Morrisonova jednadžba)

Tablica 2.4.5::I

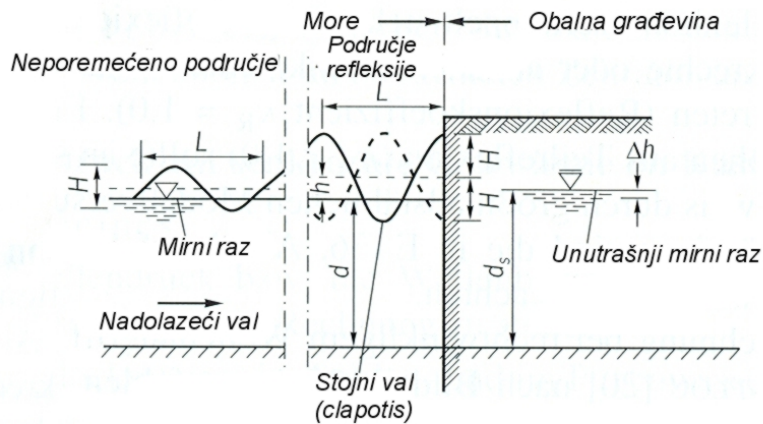
2.4.5.1 SILA TLAKA VALA

2.4.5.1.1 SILA TLAKA TOTALNO REFLEKTIRANOG VALA - Sainflou

2.4.5.1.2 SILA TLAKA PARCIJALNO REFLEKTIRANOG VALA - Goda

Primjenjiva za sve slučajeve od nelomljenog do lomljenog vala.

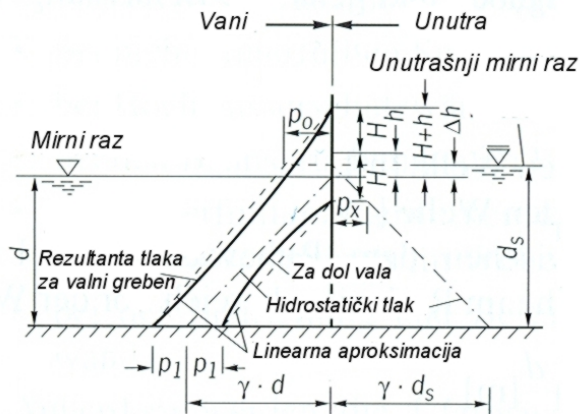
2.4.5.1.3 SILA TLAKA LOMLJENOG VALA -



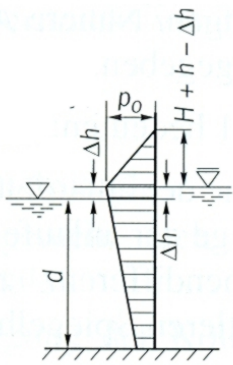
a) Prikaz valnih parametara reflektiranog vala

$$p_1 = \frac{\rho_w \cdot g \cdot H}{\operatorname{ch}\left(\frac{2\pi d}{L}\right)} = \frac{\gamma_w \cdot H}{\operatorname{ch}\left(\frac{2\pi d}{L}\right)} \quad \left[\text{N/m}^2\right]$$

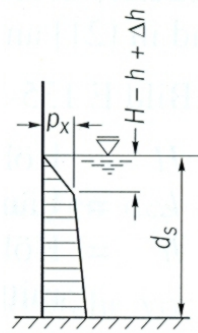
$$p_{st} = \rho_w \cdot g \cdot d = \gamma_w \cdot d \quad \left[\text{N/m}^2\right]$$



b) Raspodjela hidrostatskih i dinamičkih tlakova

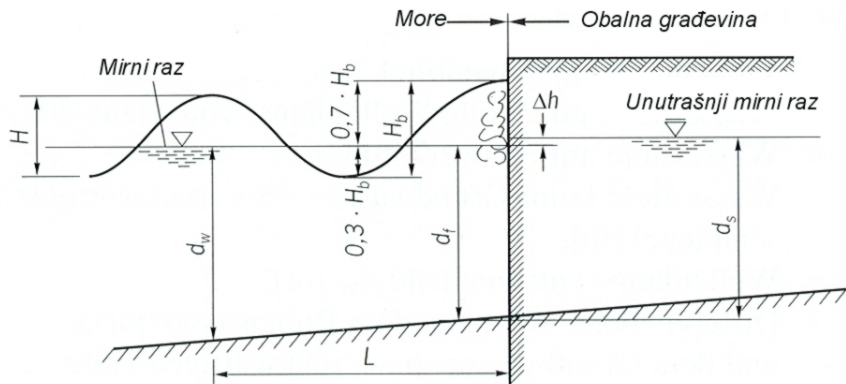


c) Maksimalni valni tlak - greben vala

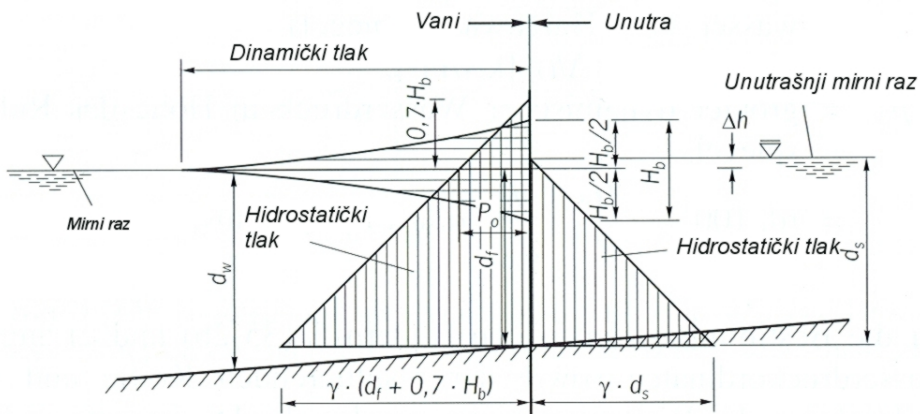


d) Minimalni valni tlak - dol vala

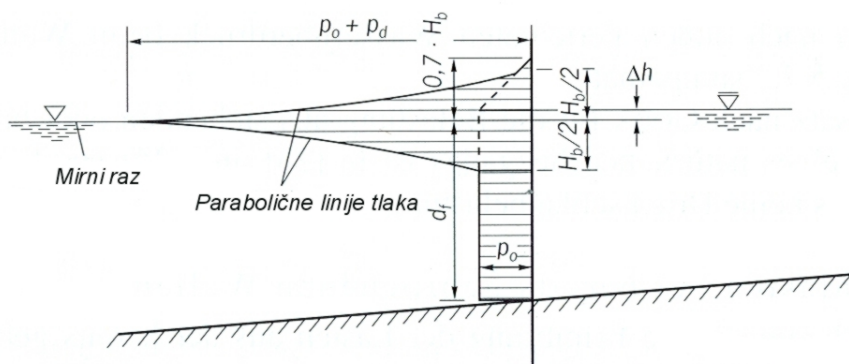
Sl. 2.4.5.1.1:::1
Sila tlaka nelomljenog vala - Sainflou



a) Parametri lomljenog vala

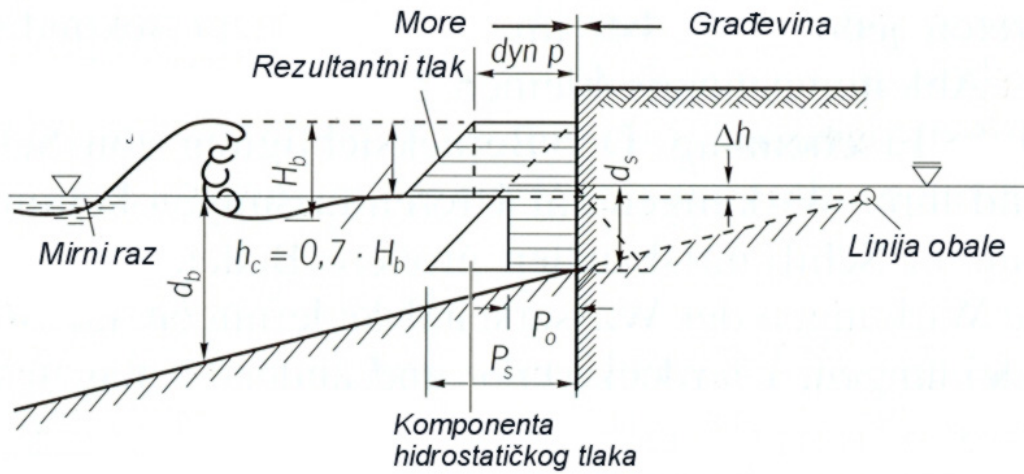


b) Hidrostatski i dinamički tlak na vertikalni zid

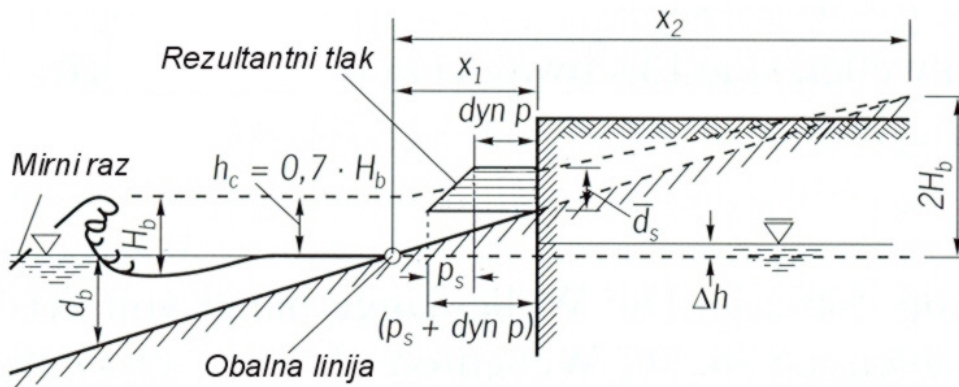


c) Rezultanta tlaka

Sl. 2.4.5.1.3::1
 Sila tlaka od vala lomljenog na mjestu vertikalnog zida (Minikin)



a) Obalna građevina ispred obalne linije



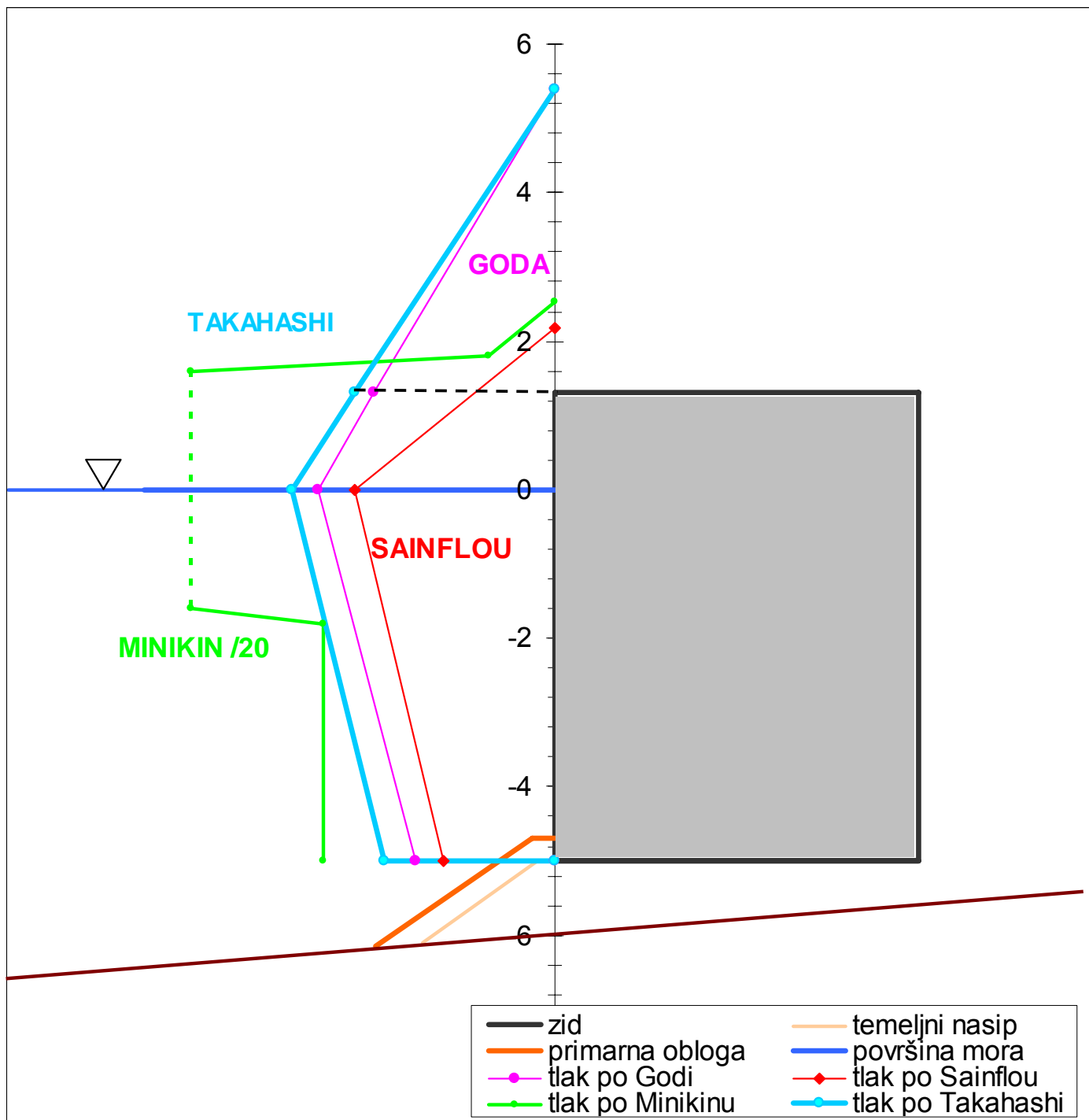
b) Obalna građevina iza obalne linije

$$d_s = h_c \cdot \left(1 - \frac{x_1}{x_2}\right) \text{ [m] ,}$$

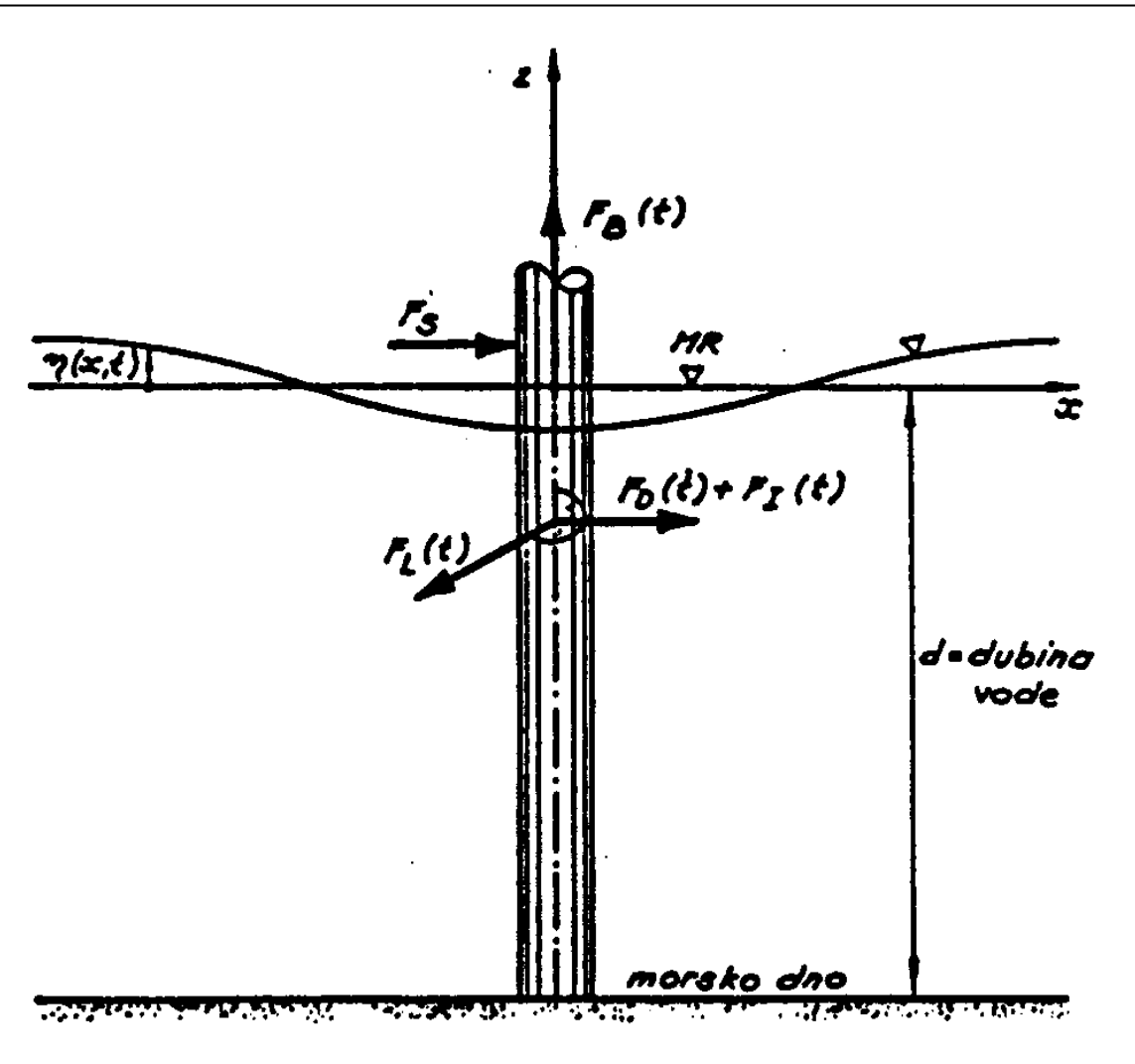
$$\text{dyn } p = 1/2 \cdot \gamma \cdot d_b \cdot \left(1 - \frac{x_1}{x_2}\right)^2 \text{ [kN/m}^2\text{] ,}$$

$$p_s = \gamma \cdot d_s = \gamma \cdot h_c \cdot \left(1 - \frac{x_1}{x_2}\right) \text{ [kN/m}^2\text{] .}$$

Sl. 2.4.5.1.3::2
Sila tlaka od vala lomljenog neposredno ispred vertikalnog zida (CERC)

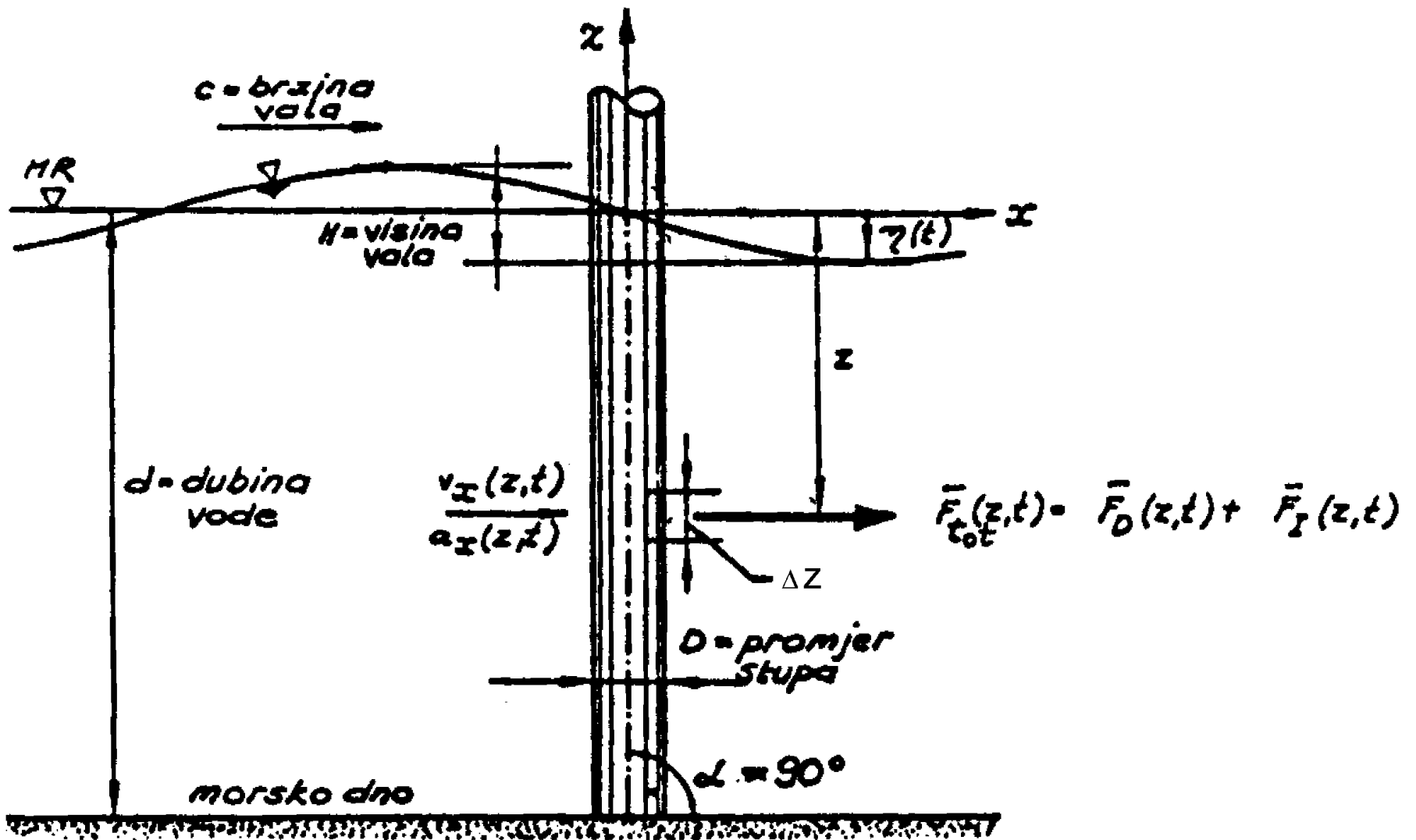


2.4.5.2 SILE OTPORA I SILE INERCIJE (MORISONOVA JEDNADŽBA)



- sile otpora $F_D(t)$ i sile inercije $F_I(t)$ hor.
- sile dinamičkog uzgona $F_L(t)$..vert.
- sile statičkog uzgona $F_B(t)$..vert.
- sile od udara vala F_S ...hor.

Sl. 2.4.5.2::1

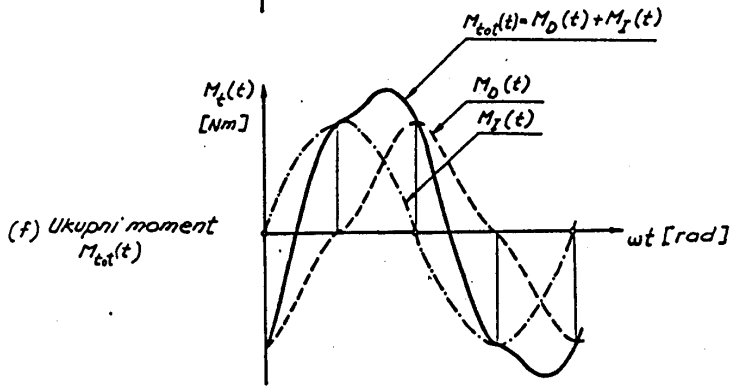
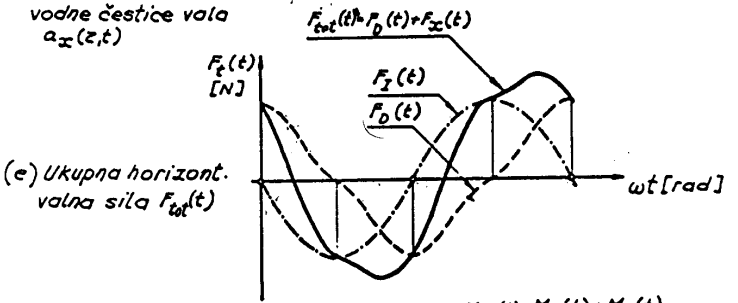
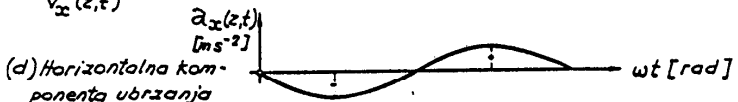
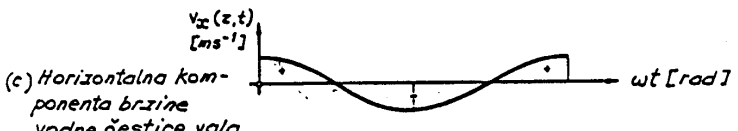
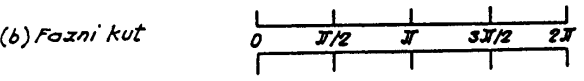
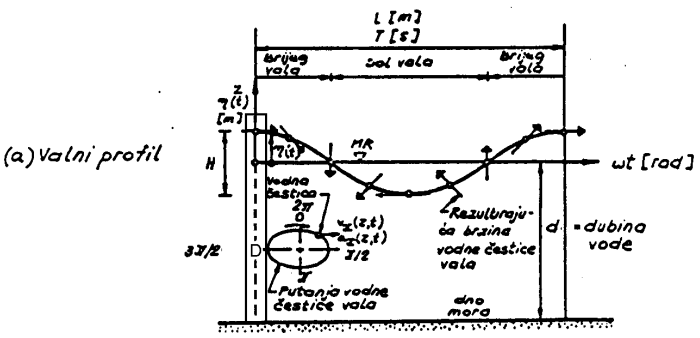


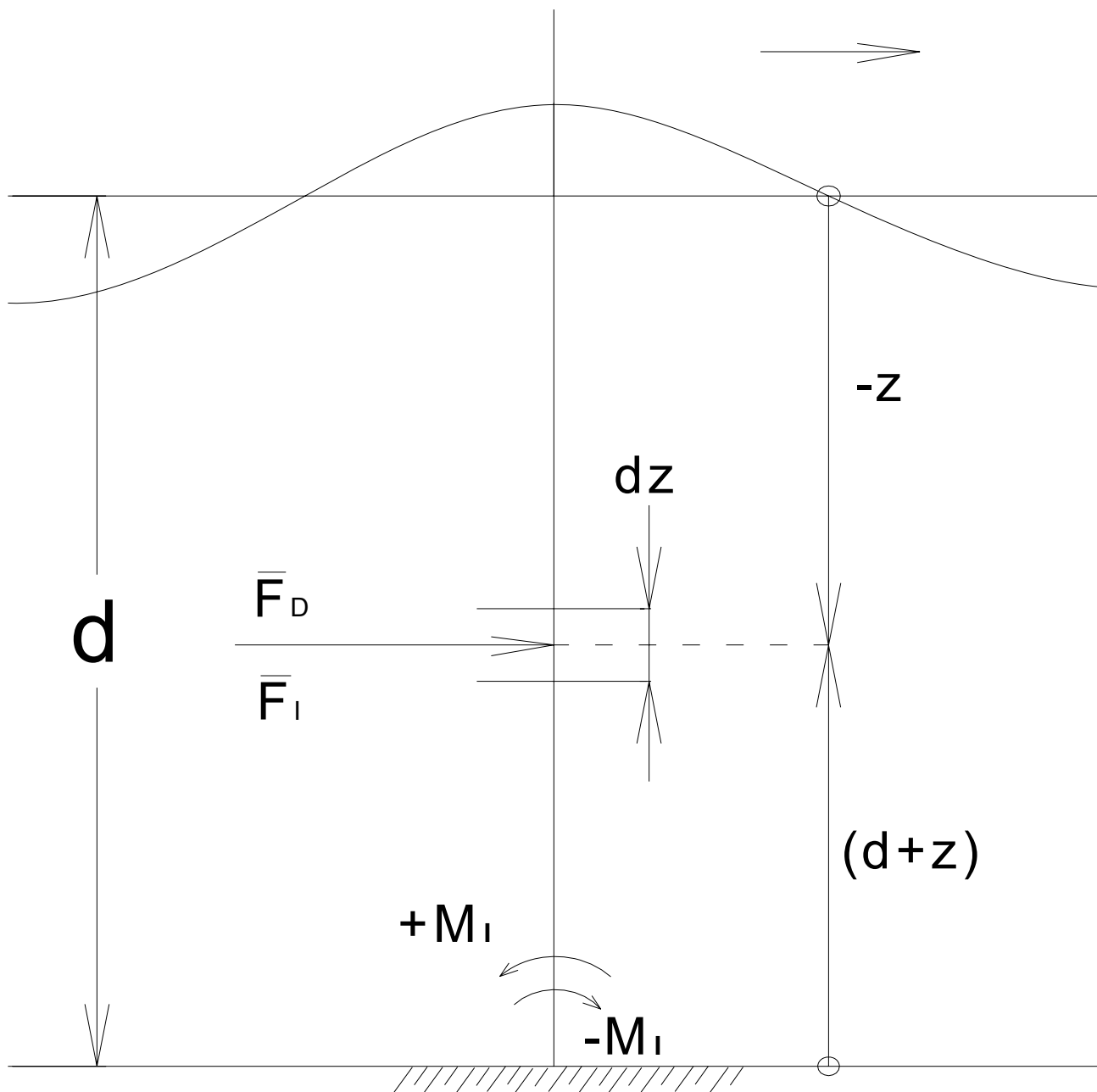
U slučaju linearne (Airyeve) valne teorije ukupna horizontalna valna sila $F_{\text{tot}}(t)$ je:

$$F_{\text{tot}}(t) = \frac{\pi\rho DH^2 LC_D}{16T^2} \frac{\{2k[\eta(t) + d]\} + \sinh\{2k[\eta(t) + d]\}}{\sinh^2(kd)} [\cos(\omega t)|\cos(\omega t)] - \frac{\pi^2\rho D^2 HLC_l}{4T^2} \frac{\sinh\{k[\eta(t) + d]\}}{\sinh(kd)} \sin(\omega t)$$

U slučaju linearne (Airyeve) valne teorije ukupni moment $M_{\text{tot}}(t)$ je:

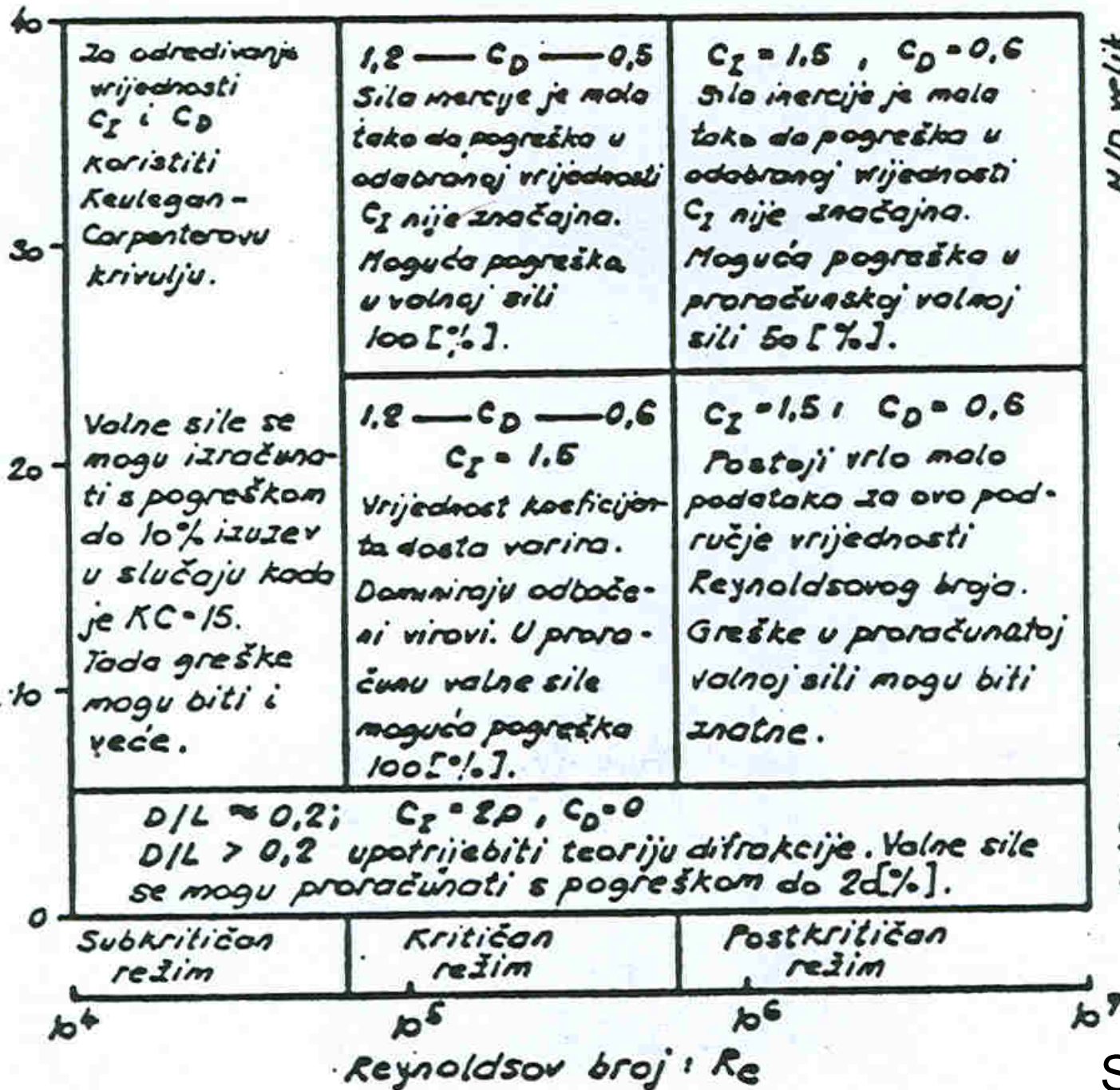
$$M_{\text{tot}}(t) = \left\{ -\frac{\rho DH^2 L^2 C_D}{64T^2} \frac{2k^2[\eta(t) + d]^2 + 2k[\eta(t) + d]\sinh\{2k[\eta(t) + d]\} - \cosh\{2k[\eta(t) + d]\} + 1}{\sinh^2(kd)} \right\} \times [\cos(\omega t)|\cos(\omega t)] + \left\{ \frac{\pi\rho D^2 HL^2 C_l}{8T^2} \times \frac{k[\eta(t) + d]\sinh\{k[\eta(t) + d]\} - \cosh\{k[\eta(t) + d]\} + 1}{\sinh(kd)} \right\} \sin(\omega t)$$





Slika
 2.4.5.2::4

Keulegan - Carpenterov broj: KC



Reynoldsov broj: Re