Winter School at UACEG

Topic: Hydraulic structures. Dams and reservoirs

Task for Students #2:

Wind Wave, Freeboard and Dam crest calculations

Explanations and Example

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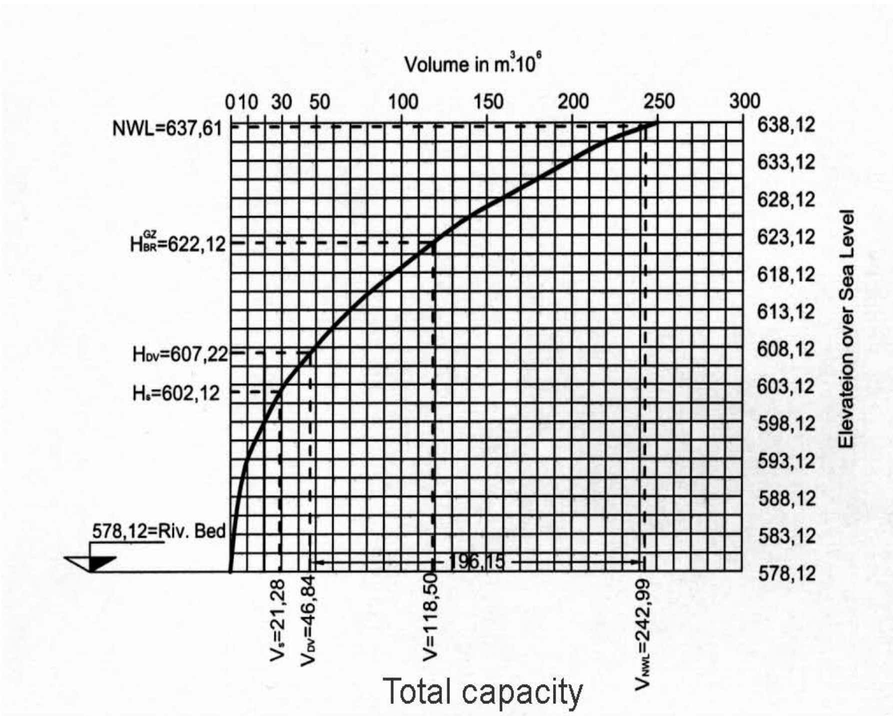
GIVEN DATA:

The catchment area topography of river X can be in general described as hilly and mountainous.

The wind speeds for the dam site are:

Name	wind speed, m/s for $APE_{50\%}$	wind speed, m/s for APE2%
Jovana	20	35
Alexander	25	42
Nikola	15	28

Storage Volume Curve of the Reservoir B



High flood level (*HFL*) is limited according to level NWL+H, where: *H=2[m]*, to keep an existing town from flooding.

PROBLEMS:

1. Compute the design wind wave parameters for a Dam of First class.
2. Design a suitable Embankment Dam Freeboard, elaborate the Dam Crest elevation against overtopping
3. Design a suitable Concrete Dam Freeboard. Compare the results from 2 and 3, give your explanation.

PROBLEM 1

WIND WAVE AND DESIGN WIND WAVE

Compute the design wind wave parameters for a Dam of First class.
We have to know the basic WIND WAVES patterns, height ***h*** *[m]*, period τ*[s]*, and length λ*[m]* to evaluate wind tide /wind set-up/ and wind wave run-up on the dam.

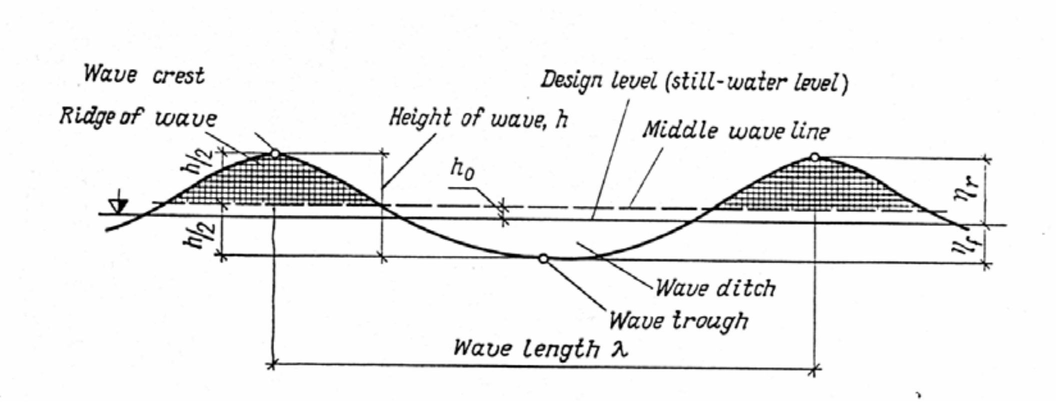


Figure 1. Wind waves

Wave patterns, height ***h,*** period ***t*** and length λ (fig.2) depend on wave inducting factors, i.e. wind speed **W**, duration **t,** on the fetch ***D*** and depth ***H*** of reservoir. The height is determined by analyzing the fetch and most undesirable wind speed combination on the design storm.

- Wind fetch D is a straight distance from the bank to structure;
- Wind speed **W** in the direction of fetch is determined by wind rose.

By wind fetch, the reservoir field of wave can be divided into **Zones**

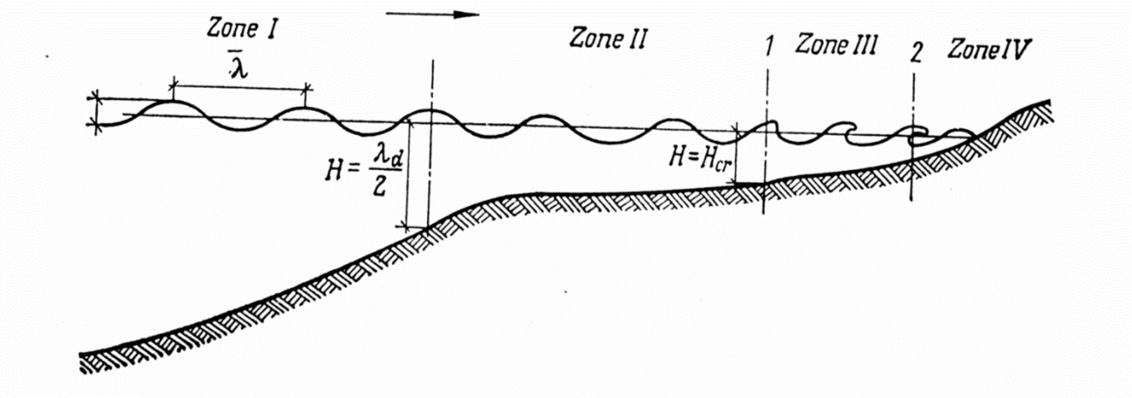


Figure2. Division of water area into zones by depth
I—deep-water zone; *II*—shallow-water zone; *III*—zone of surfs; *IV*—zone located near the shore line; *1*—section line of first fall of waves; *2*—final fall

- I-deep zone $H \rangle \frac{\lambda}{2}$,where the depth has no bearing on wave parameters;
- II- shallow zone
- III- zone of surfs
- IV-zone, where waves break out and run up ashore.

For large dams we start the calculation of the design wind wave usually with evaluation of the

regular wave into deep zone. Because of bad accuracy in the determination of inducting factors: wind speed in particular, the wave parameter calculations are not accurate either.
For the determination of the height of a wave, there are a number of empirical formulae. The best known is the formula of Stephenson, modified by Molitor. In the formula of Stephenson and Molitor the time duration of the wind (t, [h]), which is also an essential factor, is not taken into account.

For example, the Average parameters of wind waves in deep water can be determined by using Bulgarian guidelines and these graphs:

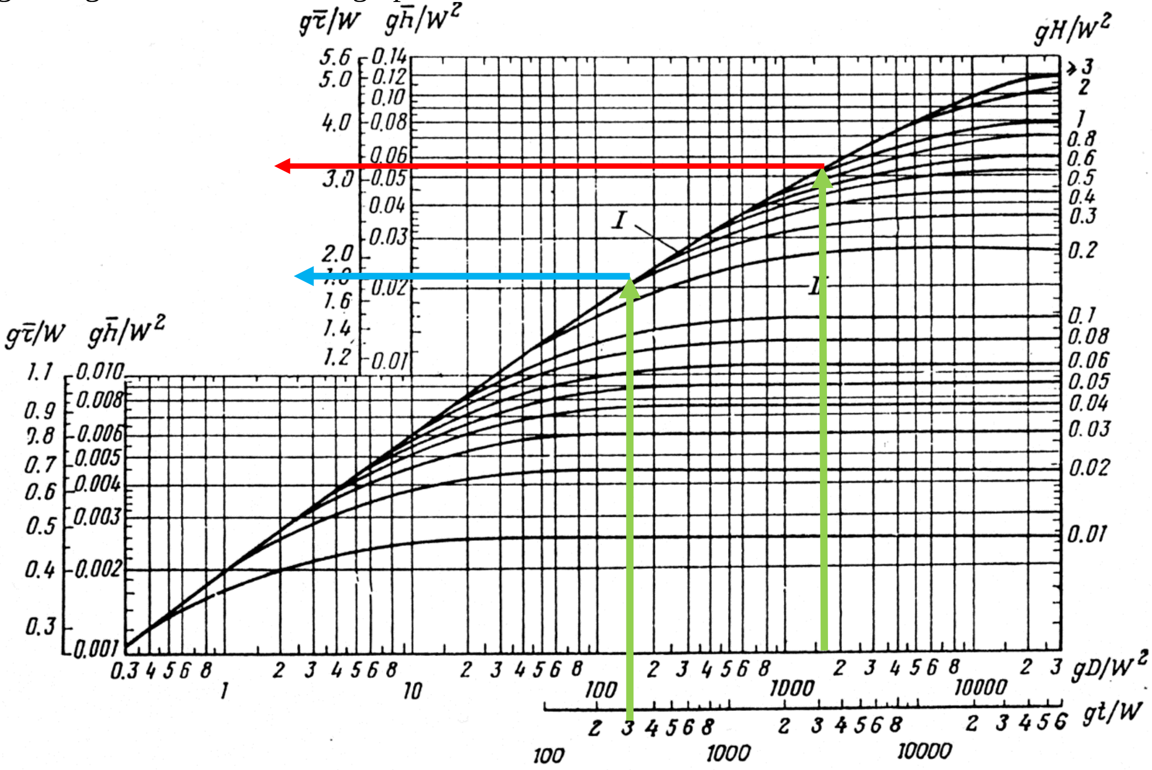


Figure3. Graphs for the determination of average parameters of wind-induced waves in deep-water (*I*) and shallow-water (*II*) zones (for a slope of bed *i* ⩽ ⩽ 0.001)

The figure presents diagrams from which it is possible to determine mean values of the height ***h*** and the period ***τ*** depending upon: wind speed ***W*** *[m/s];* fetch ***D*** *[km];* time ***t*** *[h](**t**=6h)* and depth ***H*** *[m].*

These diagrams have been drawn by means of empirical formulae, derived by means of using the methods of mathematical statistics, and the spectral theory of waves caused by wind. On the abscissa-axis on separate scales, there are applied the non-dimensional values ***gt/W*** and ***gD/V²***, in which ***g*** *[m/s2]* is the earth acceleration. On the ordinate-axis on separate scales, there are applied the non-dimensional values ***gh/W²*** and ***gτ/W***. If for some non-dimensional values W, D and t, the value of ***gt/W*** is found to the left of the value ***gD/W²***, the wave develops, i.e. grows along with the increase in time duration of the wind. In such a case, the parameters of the wave are determined from the time duration of the wind, which is to say from the value ***gt/W***. If the value of ***gt/W*** is situated to the right of the value of ***gD/W²***, then the wave is completely developed, so the increase in t does not cause an enlargement of the wave's dimensions. In such a case, the wave parameters are determined from the value of ***L***. As soon as a governing scale on the abscissa-axis has been selected for a deep zone, the values ***gh/W²***and **gτ/W** will be determined along the envelope of the family of curves with determined values of ***gH/W²***, so that mean values of ***h*** and ***τ*** are obtained.

Mean values of h and period can be determined through non-dimensional parameters:

The length of the wave is calculated from the expression

$$\bar{\lambda} = \frac{g\bar{\tau}^2}{2\pi};$$

<u>For the first class dams:</u>

Design Wind Wave height ***h*** has 1% APE (annual probability of exceedance), while **τ** and λ are derived as follows:

$h_{1\%} = 2.42\bar{h}$; $\lambda = \bar{\lambda}$ and $\tau = \bar{\tau}$.

You have to calculate Design Wind Waves for 2 scenarios:

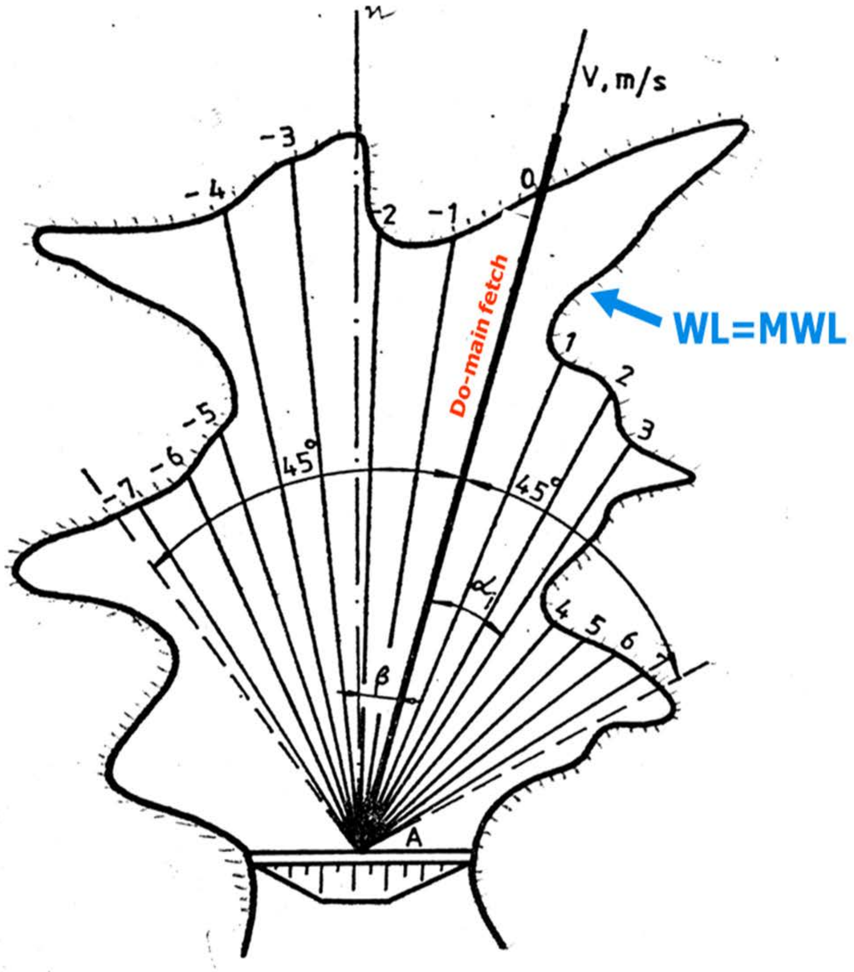
Scenario 1: WL=NWL, Wind with speed with APE=2%

Scenario 2: WL=MWL, Wind with speed with APE=50%

Use the reservoir layout in scale 1:100000, wind direction and values of wind speed attached.

<u>The effective fetch:</u> (2) $D_{Eff} = \frac{\sum_{-n}^{+n} D_i \cos^2 \alpha_i}{\sum_{-n}^{+n} \cos \alpha_i}$ m,

Where: Di - the fetch length on "i"direction



PROBLEM 2

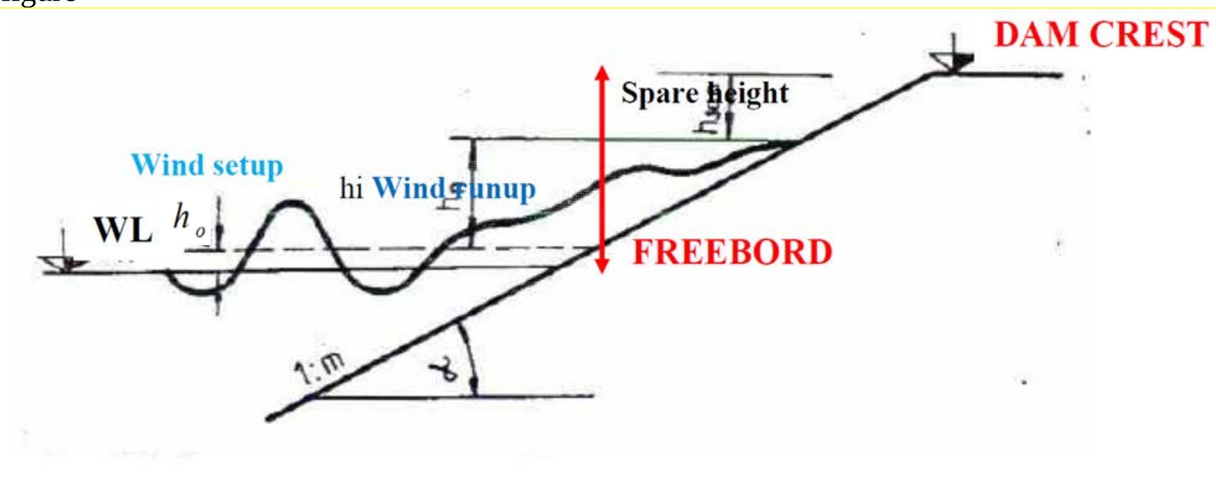
EMBANKMENT DAM FREEBORD AND DAM CREST EVALUATION

Freeboard is the vertical distance between the dam crest (top of the dam) and the full supply level in the reservoir. The freeboard has several components:

1. rise in reservoir level due to flood routing;
2. seiche effects;
3. wind set-up of the water surface;
4. wave action and run-up of waves on the dam.

(seiche effects: in very large reservoirs, it can be up to 0.5m high but in medium-sized reservoirs, it is usually ignored)

<u>For an Embankment Dam:</u> FREEBOARD AND DAM CREST EVALUATION is shown on the figure

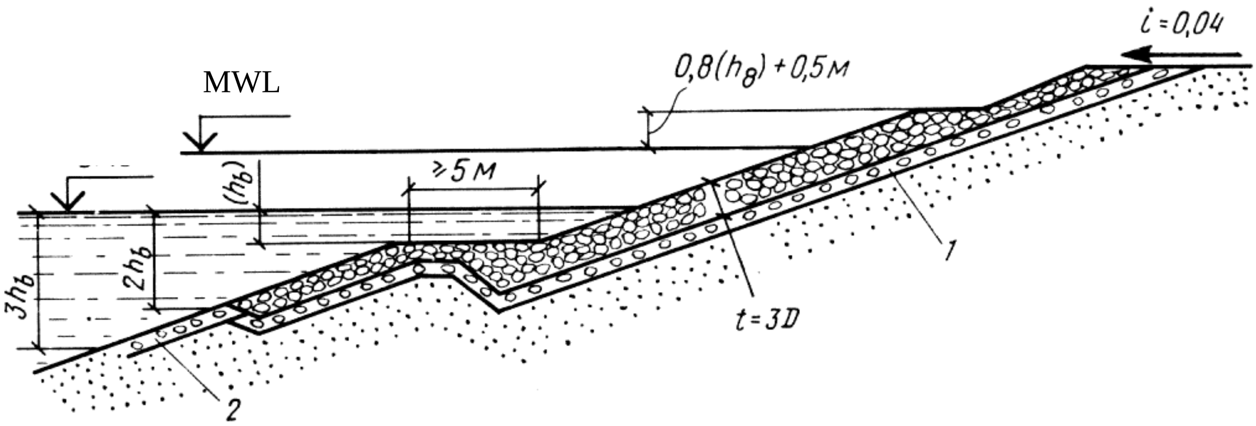


FREEBOARD=h_o+h_i+a

1. Wind set-up:

$$h_o = 2.10^{-6}\frac{W^2 D_o}{gH}\cos\beta,$$

Where beta is angle between reservoir axis and the wind direction, see the layout of the reservoir.



2. Run up (creeping of the broken wave) on the slope

$h_i = k_r . k_p . k_c . k_s . k_i . h_{1\%}$,

2.1. k_r. = f(Dmax/ $h_{1\%}$) coefficient of roughness

For permeable stone armoring of the upstream face of the dam:

Dmax- diameter of the single stone in the stone armoring

$Q=0.11.k.h_{1\%}$, [kN]

Where k=1.5 for steep slopes ; k=1.25 for gentle slopes

$Dmax=(Q/(0,524^* \gamma_{st}))$^(1/3) , [m] ← *$\gamma_{st}$ =25÷27 [kN/m^3]*

Dmax/ $h_{1\%}$ =? relative roughness

k_r = f(Dmax/ h1%)

Dmax/ $h_{1\%}$ relative roughness	k_r	k_p
—		
<0,005	1,0	0,9
0,005—0,01	1,0	0,9
0,01—0,02	0,95	0,85
0,02—0,05	0,9	0,8
0,05—0,10	0,8	0,7
>0,2	0,75	0,6
	0,7	0,5

2.2. k_p. = f(Dmax/ h1%) coefficient of permeability

2.3. k_c. coefficient of wind speed and slope ratio

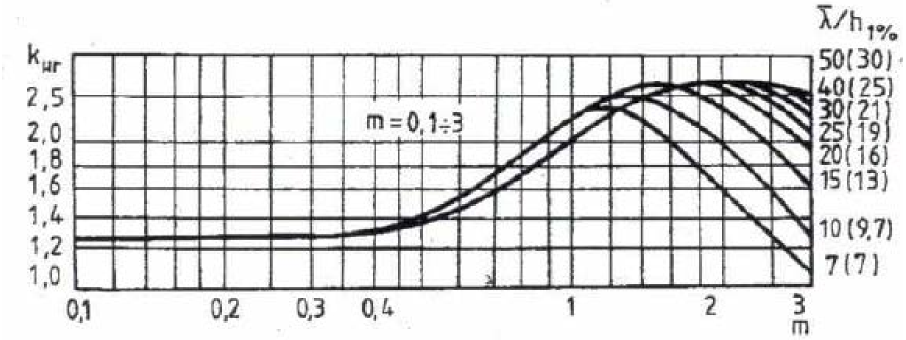
for 1:m m=0.4÷2.5 and W≥20 m/s k_c=1.4-1.5

for 1:m m=0.4÷2.5 and W<20 m/s kc=1.15-1.2

1:2.5

2.4. k_{ur} coefficient of slope ratio, λ/ h1% -

read from the next figure:



where if the depth in front of the dam is H≥2. h1%
then take the value of λ/ h1% outside of brackets;
if H<2. h1% - take the value of λ / h1% in brackets

2.5. k_i. coefficient of APE of the wind
k_i. =0.96 for 2% APE of the wind
k_i. =0.68 for 50% APE of the wind

	k_r	k_p	k_c	Кнг	k_i
W 2% >20					0.96
W 50% <20					0.68

3. Spare height

Spare height a=0.8m for NWL and 0.5m for MWL

FREEBOARD has to be calculated in

Scenario 1: WL=NWL, Wind with APE=2%

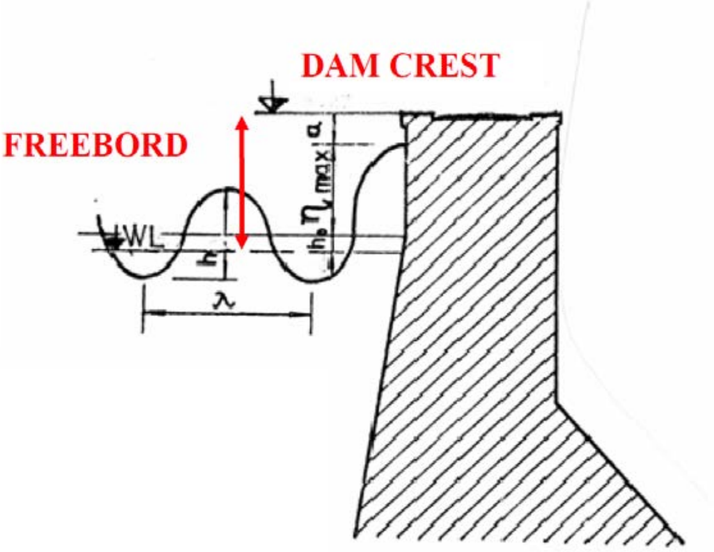
Scenario 2: WL=MWL, Wind with APE=50%

Then Dam Crest =WL+ FREEBOARD for both cases and you have to give the final conclusion.

PROBLEM 3

CONCRETE DAM FREEBORD AND DAM CREST EVALUATION

Concrete Dam: FREEBOARD AND DAM CREST



FREEBOARD=ho+ηmax+a

In case for standing waves on a vertical wall in the deep water zone,

the *wind wave run-up* on a vertical wall is: $\eta_{max} = h_i + \frac{kh_i^2}{2}$,

where $k = \frac{2\pi}{\lambda}$ is a wave number.

The spare height a=0.80m

FREEBOARD has to be calculated in

Scenario 1: WL=NWL, Wind with APE=2%

Scenario 2: WL=MWL, Wind with APE=50%

Then Dam Crest =WL+ FREEBOARD for both cases and you have to give the final conclusion.

Compare the results from **PROBLEM 2** and **PROBLEM 3**, give your explanation.