भारतीय मानक

तटबन्ध बाँधों में मुक्त बोर्ड अपेक्षाओं के मार्गदर्शी सिद्धान्त

(पहला पुनरीक्षण)

Indian Standard

FREEBOARD REQUIREMENT IN EMBANKMENT DAMS — GUIDELINES

(First Revision)

UDC 627·8·066 : 627·18

BUREAU OF INDIAN STANDARDS
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NEW DELHI 110002

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Price Group 3

Dams (Overflow and Non-overflow) Sectional Committee, RVD 9

FOREWORD

This Indian Standard (First Revision) was adopted by the Bureau of Indian Standards, after the draft finalized by the Dams (Overflow and Non-overflow) Sectional Committee had been approved by the River Valley Division Council.

This standard was first published in 1983. The revision of this standard has been taken to incorporate the latest practices being followed in the field. The major changes in this revision include modifications in the method for computation of freeboard, requirement of minimum freeboard, etc, and inclusion of a typical computation for freeboard.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Indian Standard

FREEBOARD REQUIREMENT IN EMBANKMENT DAMS — GUIDELINES

(First Revision)

1 SCOPE

This standard gives guidelines regarding procedures for working out freeboard for embankment dams.

2 TERMINOLOGY

2.0 For the purpose of this standard, the following terminology should apply.

2.1 Design Wave Height

It is that wave height which the structure is designed to withstand so that it does not undergo more than the accepted probability of damage, should the same wave height be exceeded. It is a suitable multiple of the significant wave height depending on the degree of risk to be accepted.

2.2 Fetch Length

It is the straight line distance along the wind direction (along central radial of fetch) over open water on which the wind blows.

2.2.1 *Effective Fetch*

It is the weighted average fetch length of water spread, covered by 45° angle on either side of trial fetch (assuming the wind to be completely non-effective beyond this area) and measured in a direction parallel to the central radial line of the trial fetch.

2.3 Free Board

It is the vertical distance between the crest of embankment (excluding camber) and the still reservoir water surface.

2.3.1 *Normal Free Board*

It is the freeboard above the full reservoir level (FRL).

2.3.2 *Minimum Freeboard*

It is the freeboard above the maximum water level (MWL) worked out for designed inflow flood (DIF).

2.4 Maximum Wave Height

It is the average wave height of the highest one percent of waves in a representative spectrum.

2.5 Significant Wave Height

It is the average wave height of the highest one third of the wave present in each sampling interval.

2.6 Wave Length

It is the length in m from crest to crest for significant wave.

2.7 Wave Period

It is the average interval in seconds between successive crests or troughs of significant waves.

2.8 Wave Run-Up

It is the difference (vertical height) between maximum elevation attained by wave run-up on a slope and the water elevation on the slope excluding wave action.

2.9 Wind Set-Up

When wind blows over a water surface it exerts a horizontal force on the water surface driving it in the direction of the wind. This effect results in piling up of the water on one shore of the lake or reservoir. The magnitude of rise above the still reservoir water surface is called 'wind set-up' or 'wind-tide'.

3 FACTORS CONSIDERED FOR FREEBOARD ESTIMATE

3.1 The following factors are considered for the estimation of freeboard:

a) Wave characteristics, particularly wave height and wave length;

b) Height of wind set-up above the still water level adopted as freeboard reference elevation; and

c) Slope of the dam and roughness of the pitching.

3.2 Freeboard requirement does not account for effects of earthquake, settlement of dam and dam foundation, and earthquake seiches.

4 NOTATIONS

For the purpose of this standard the following notations shall apply:

D = Reasonable approximate average depth of water in m along the fetch length,

F = Fetch length in km,

F_e = Effective fetch in km,

f_e = Effective fetch in m,

g = Acceleration due to gravity in m/sec^2,

H = Height of any specified wave in m measured from trough to crest,

H_{max} = Maximum wave height in m,

H_0 = Designed wave height in m,

H_s = Significant wave height in m,

L_s = Wave length of significant wave in m,

Q = Coefficient described as the ratio of wind velocity over the water surface V to the wind velocity on land U,

R = Wave run-up in m,

R_a = Designed wave run up corresponding to upstream pitching,

S = Wind set-up in m,

T_s = Wave period of significant wave in sec,

U = Maximum wind velocity in km/h, measured over land surface during the minimum period of time required for generation of waves,

V = Wind velocity in km/h over water surface, and

v = Wind velocity in m/sec over water surface.

5 METHOD FOR FREEBOARD COMPUTATIONS

5.1 Out of the available methods for freeboard computations, assistance has been derived from T. Saville's method, which is widely used for freeboard computations of embankment dams. The details of the procedure to be followed for computation of freeboard are given in Annex A and typical computations for freeboard are given in Annex B.

5.2 The freeboard should be calculated for following conditions:

i) Normal freeboard that is at FRL.

ii) Minimum freeboard that is at MWL.

The freeboard which gives the highest requirement of TBL (Top Bund Level) should finally be adopted.

5.3 Normal Freeboard

While calculating normal freeboard at FRL, full wind velocity should be adopted. The design wave height (H_0) be taken as 1·67 times the significant wave height (H_s). Normal freeboard should not be less than 2·0 m.

5.4 Minimum Freeboard

While calculating minimum freeboard at MWL, half to two third wind velocity should be adopted. The lower values may be adopted in regions where maximum wind velocities occur during the period when water level in the reservoir is at or below FRL. This freeboard should be subject to a minimum of 1·5 m. The design wave height (H_0) be taken as 1·27 times the significant wave height (H_s).

6 PARAPET WALL

6.1 1·0 m high parapet wall may be provided in all embankment dams but the same is not to be considered as a part of freeboard.

ANNEX A

(*Clause* 5.1)

PROCEDURE FOR COMPUTATION OF FREEBOARD FOR EMBANKMENT DAMS

A-0 Step by step procedure for computation of freeboard for embankment dams is explained below.

A-1 NORMAL FREEBOARD

A-1.1 Select a line AB, with 'A' on dam axis and 'B' on FRL contour in Fig. 1 so as to cover the maximum reservoir water spread area within 45° on either side of line AB (fetch length) Draw 7 radials at 6° interval on each side of line AB and compute effective fetch (F_e) as shown in Fig. 1 for FRL by the following formula:

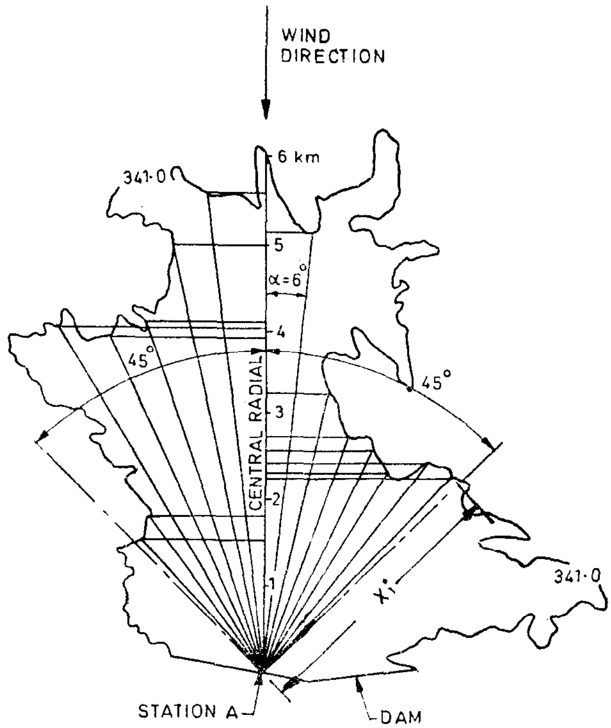
$$F_e = \frac{\Sigma X_1 \cos\alpha \cos\alpha}{\Sigma \cos\alpha}$$

where X_i denotes the length of any radial which is at an angle from the central radial.

If felt necessary more trials may be done so that maximum effective fetch may be computed. Enter effective fetch (F_e) as step (1).

A-1.2 From Fig. 1 of IS 875 (Part 3) : 1987 read basic wind speed on land for 50 years return period (U) for region in which proposed dam falls. Enter wind velocity on land (U) as step (2).

A-1.3 Compute wind velocity on water surface (V), by multiplying coefficient Q from Table 1 corresponding to effective fetch to the wind velocity on land (U). Enter Q and wind velocity on water surface as steps (3) and (4) respectively.



α	cos α	X_i	X_i cos α	X_i cos α. cos α
42°	·743	2·08	1·55	1·151
36°	·809	2 29	1·85	1·499
30°	·866	4·73	4·10	3·550
24°	·914	4·32	3·95	3·610
18°	·951	4·26	4·05	3·851
12°	·978	5·11	5·00	4·890
6°	·995	5·68	5·65	5·621
0°	1·000	6·00	6·00	6 000
6°	·995	5·18	5·15	5·124
12°	·978	3·37	3·30	3·227
18°	·951	2·95	2·80	2·662
24°	·914	2·90	2·65	2·422
30°	·866	2·77	2·40	2·078
36°	·809	3·09	2·50	2·023
42°	·733	3·16	2·35	1·746
	Σ = 13·512			Σ = 49·454

$$Fe = \frac{\Sigma X_i \cos\alpha . \cos\alpha}{\Sigma \cos\alpha} = \frac{49{\cdot}454}{13{\cdot}512} = 3{\cdot}66 \text{ km}$$

FIG. 1 COMPUTATION OF EFFECTIVE FETCH

Table 1 Wind Velocity Relationship Land to Water

(*Clause* A-1.3)

Effective Fetch in km (*Fe*)	**1**	**2**	**4**	**6**	**8**	**10 and Above**
Coefficient *Q*	1·1	1·16	1·24	1·27	1·30	1·31

A-1.4 Using relationship given below or graphical diagram shown in Fig. 2, compute significant wave height (H_s)

$$g.H_s/v^2 = 0{\cdot}002\,6\,(g.f_e/v^2)^{0{\cdot}47} \quad \dots \quad \dots (1)$$

Enter significant wave height (H_s) as step (5).

A-1.5 Using relationship given below or graphical diagram shown in Fig. 3, compute wave period (T_s)

$$g.T_s/v = 0{\cdot}45\,(g.f_e/v^2)^{0{\cdot}25} \quad \dots \quad \dots (2)$$

Enter T_s as step (6)

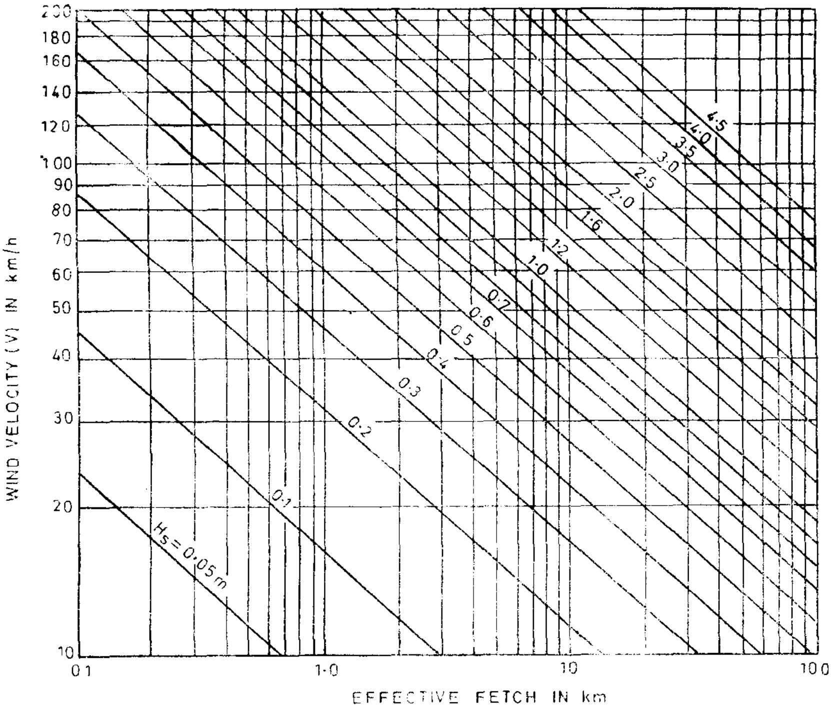


Fig. 2 Correlations of Significant Wave Heights (H_s) with Related Factors

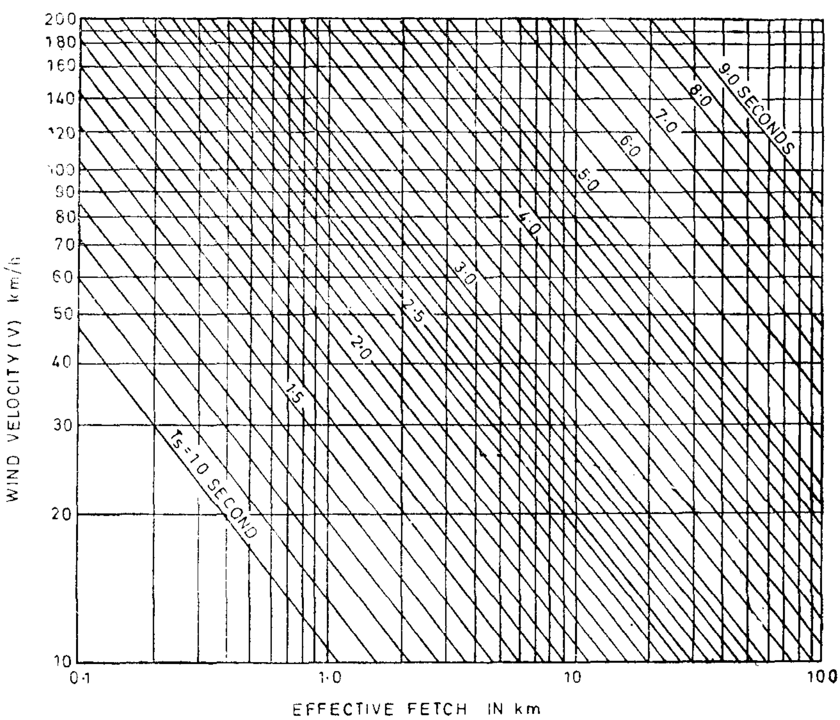


Fig. 3 Relation Between Wave Periods (T_s) and Related Factors

A-1.6 Compute wave length (L_s) with the following relationship:

$$L_s = 1{\cdot}56\ T_s^2 \qquad \ldots \ldots (3)$$

Enter L_s as step (7)

A-1.7 Compute design wave height H_0, with the relationship

$$H_0 = 1{\cdot}67\ H_s \qquad \ldots \ldots (4)$$

Enter H_0 as step (8).

A-1.8 Work out steepness ratio H_0/L_s. With the help of curves given in graph in Fig. 4, between different values of steepness ratio and the embankment slopes read R/H_0 ratio, and compute wave run up on smooth surface (R). The wave run up on rough surface (R_a) may be computed by multiplying surface roughness coefficient, given in Table 2 below, to the wave run up on smooth surface (R).

Table 2 Surface Roughness Coefficient

Sl No.	Type of Pitching	Recommended Coefficient
(1)	(2)	(3)
i)	Cement concrete surface	1·0
ii)	Flexible brick pitching	0·8
iii)	Hand placed rip rap:	
	a) Laid flat	0·75
	b) Laid with projection	0·60
iv)	Dumped rip rap	0·50

Enter H_0/L_s, R/H_0, R and designed R_a corresponding to upstream pitching as step (9), (10), (11) and (12) respectively.

NOTE — If the wave run on rough surface (R_a) calculated above is less than the designed wave height (H_0) as obtained in step 7, keep $R_a = H_0$.

A-1.9 Calculate average water depth (D) along fetch length (F). Enter average reservoir depth (D) as step (13).

A-1.10 Compute wind set-up (S) from the formula:

$$s = V^2 . F/62\ 000\ D \qquad \ldots \ldots (5)$$

If wind set-up as calculated above is higher than the average depth of water, the value of wind set-up should be limited to average depth of water. Enter wind set-up as step (14).

A-1.11 Compute freeboard as step (12) + step (14). Enter as step (15).

A-1.12 Check, if freeboard calculated in step (15) is less then 2·0 m, if so provide at least 2·0 m freeboard.

Enter required freeboard as step (16).

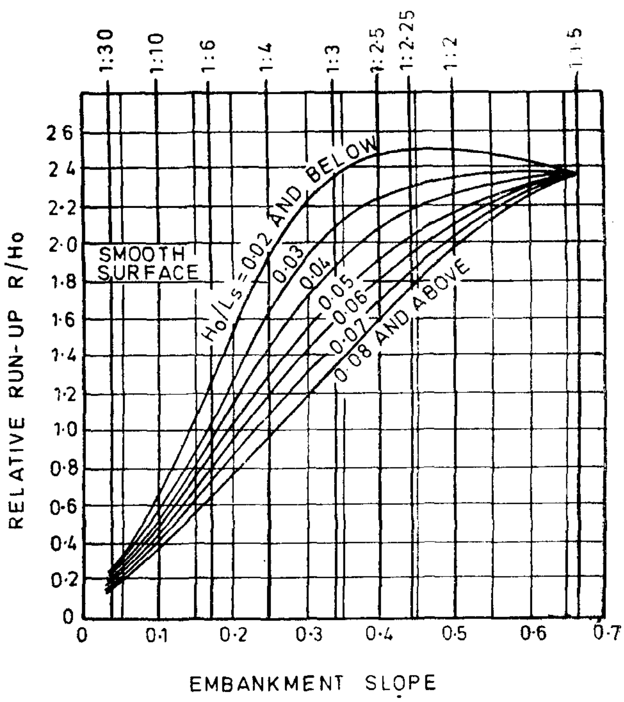


FIG. 4 WAVE RUN-UP RATIOS *Versus* WAVE-STEEPNESS AND EMBANKMENT SLOPE

A-2 MINIMUM FREEBOARD AT MWL

For obtaining minimum freeboard at MWL repeat above procedure by calculating fetch length (F) and effective fetch (F_e) at MWL. Half to two-third wind velocity on land and effective fetch at MWL may be adopted for different calculations using above steps. Check, if minimum freeboard is less than 1·5 m and if so, provide at least 1·5 m freeboard.

A-3 FIXING OF TBL

Calculate the TBL required for the following conditions and enter as step (17).

i) FRL + Normal freeboard (not less than 2·0 m).

ii) MWL + Minimum freeboard (not less than 1·5 m).

Adopt the highest of the above two values as TBL.

ANNEX B

(*Clause* 5.1)

TYPICAL COMPUTATIONS FOR FREEBOARD

BASIC DATA : Full Reservoir Level — 341·0 m

Max. Water Level — 343·2 m

Fetch Length — 6 km (*see* Fig. 1)

Slope of Embankment — 1 Vertical : 2·5 Horizontal

Sl No.	Computed Item	Calculations for Normal Free Board	Calculations for Minimum Free Board	Remarks
i)	Effective Fetch (F_e) in km	3·66	4	
ii)	Wind velocity over land (U) in km/h	150	75	
iii)	Wind coefficient (Q)	1·23	1·24	Table 1
iv)	Wind velocity over water surface (V) in km/h	184·5	93	Q × Sl No. (iii)
v)	Significant wave height (H_s) in m	2·39	1·2	Fig. 2 or Eq. 1
vi)	Wave period (T_s) in seconds	4·9	3·8	Fig. 1 or Eq. 2
vii)	Wave length (L_s) in m	37·45	22·53	Eq. 3
viii)	Design wave height (H_0) in m	3·99 (1·67 × 2·39)	1·52 (1·28 × 1·2)	
ix)	Wave steepness H_0/L_s	0·1065	0·067	
x)	Relative Run-up R/H_0	1·6	1·72	For embankment slope 1V : 2·5 m and Fig. 4
xi)	Run-up (R) in m	6·4	2·61	
xii)	Designed 'R_a' considering hand placed stone pitching for upstream slope protection (R X 0·75)	4·8	1·96	Table 2
xiii)	Average depth of reservoir (D) in m	29·0	31·2	
xiv)	Wind set-up in m	0·12	0·03	Eq. 5
xv)	Free board required	4·92	1·99	
xvi)	Permissible freeboard	4·92	1·99	Normal freeboard ⩾ 2·0 m
xvii)	Top of dam (as calculated)	341·0 + 4·92 = 345·92	343·2 + 1·99 = 345·19	Min. free board ⩾ 1·5 m
xviii)	Top of dam to be provided	345·92 m, say 346·0 m		

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