Rules to Calculate Wind Loading on Equipment
Based on ABNT standard NBR-6123

Colaboração Grupo Engenharia Básica da Petrobras

1. Scope

This standard sets the rules to calculate wind loading on pressure vessels, and the effects of static and dynamic behavior, in according with the Brazilian regulations. Only the greatest value (between the total static loading calculation and the total dynamic loading calculation) must be considered for design of pressure vessels submitted to wind forces.

2. Definitions

2.1 BASIC WIND VELOCITY (Vo)

It is the velocity from a three seconds gust, exceeded once in 50 years. It is measured at 10 meters over a plane and opened ground and it depends on the plant location. As general rule, the basic wind may throw whichever horizontal direction. This velocity is taken from Figure 1, and item 8 which shows the iso-velocities over Brazil.

2.2 TOPOGRAPHICAL FACTOR (S1)

It takes into account the variations on profile of the ground.
Value to be used (S1) = 1.0

2.3 RUGOSITY FACTOR (S_2)

This factor considers the combined effect from the rugosity of the ground, the variation of the wind velocity against the level above ground, and the dimensions of the equipment. See below and **Table I**.

- Category III: Apply to on-site equipment;
- Category IV: Apply to off-site equipment.

2.4 EQUIPMENT DIMENSION CLASSES

It takes into account the greatest horizontal or vertical dimension of the equipment.

- Class “A”: When the greatest dimension is equal or lower than 20 m;
- Class “B”: When the greatest dimension is between 20 and 50 m;
- Class “C”: When the greatest dimension is equal or bigger than 50 m.

2.5 STATISTICAL FACTOR (S_3)

It takes into account the security required to the installation and the expected life of the equipment.
For industrial plants, use (S3) = 1.0

2.6 CHARACTERISTIC VELOCITY (V_k)

It is the wind velocity that acts at each level in the total height of the equipment, and takes into account the basic wind velocity and the factors (S1), (S2) and (S3).

2.7 SHAPE COEFFICIENT (C_a)

It considers the geometry of the equipment. See **Figure 4a** and **Table II** - for cylindrical shapes and **Figure 4b** for prismatic shapes.

2.8 WIND PRESSURE (q)

It is the pressure on the equipment due the wind. It has to be calculated considering the characteristic velocity in each corresponding level of the equipment height.

$$q = \frac{V_k^2}{16.3}$$

2.9 DESIGN WIND VELOCITY (V_p)

It is the average wind velocity over 10 minutes in 10 meters of height above the ground, and takes into account the basic wind velocity and the factors (S1) and (S3).

3. Dimensional units

A = Effective frontal area [m²]
Ca= Shape coefficient [dimensionless]
d = Total external diameter of the equipment [m]

Fa = Static wind load [daN]
Fg = Dynamic force due vibration at gust wind velocity [daN]
H = Total height of the equipment [m]
q = Wind pressure [daN/m2]
T = Period of vibration [s]
Vo = Basic wind velocity [m/s]
Vk = Characteristic wind velocity [m/s]
Vp = Design wind velocity [m/s]

4. Static wind loading

The static loading shall be determined by the following procedure:

4.1. Take the basic wind velocity (Vo) from Figure 1, according to plant location or **item 8** for PETROBRAS refineries.

4.2. Multiply the basic wind velocity by the factors – (S1), (S2) and (S3) – to get the characteristic wind velocity:
Vk = Vo × S1 × S2 × S3

4.3. Obtain the wind pressure by the expression:

$$q = \frac{V_k^2}{16.3}$$

4.4. Determine the shape coefficient (Ca), from **Figures 4a** or 4**b** and **Table II**.

4.5. Determine the effective frontal area (A), projecting the equipment, including piping, ladders, platforms, accessories, thermal insulation and helical strakes, over a orthogonal plane to wind direction.

4.6. Static wind load will be calculated for each considered level of the equipment by the expression:
Fa = Ca × q × A

4.7. This static load should be determined in each level of **Table I** and/or each change of the equipment section. The total static load it will be the sum of all static loads calculated before.

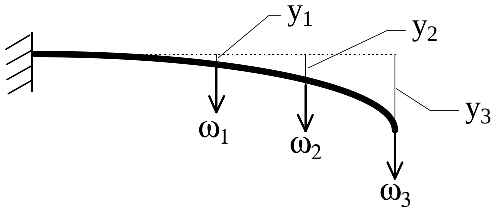
5. Dynamic wind loading

The dynamic loading calculations, due to wind gusts, must be performed when the fundamental period of vibration of the equipment is bigger than one second. Independently of the fundamental period of the equipment, we consider this calculation indispensable.

5.1 DETERMINATION OF THE FUNDAMENTAL PERIOD OF VIBRATION (T_1)

For a tall and cylindrical equipment, with uniform diameter and thickness, the first natural period of vibration may be considered equivalent to a fixed-end cantilever beam, with the *Rayleigh's* method. Then, (T_1) is given by:

$$T_1 = \frac{2\pi}{\sqrt{g}} \sqrt{\frac{\sum \omega_n \times y_n^2}{\sum \omega_n \times y_n}}$$



Where: ω_n = Operating weight of each section [daN]
y_n = Deflection of the center of gravity of each section [m]
g = Gravitational acceleration [9.8 m/s^2]

5.2 DYNAMIC FORCE DUE VIBRATION AT GUST WIND VELOCITY

This force shall be determined by the following procedure:

5.2.1. Multiply the basic wind velocity by the factors – (0.69), (S_1) and (S_3) – to get the project wind velocity:

$V_p = 0.69 \times V_o \times S_1 \times S_3$

5.2.2. With all data of the vessel, calculate the following ratios:

$$\frac{d}{H} \qquad \frac{Vp \times T_1}{1800}$$

5.2.3. Determine the dynamic amplification coefficient (ξ), from the applicable figure (**Figures 2** and **3**), as a function of ground category. If necessary, use graphical interpolation.

5.2.4. Determine the dynamic response in the wind direction, with the following expression:

$$q(z) = 0.613 \times b^2 \times V_p^2 \left\{ \left(\frac{z}{10}\right)^{2p} + \left[\left(\frac{H}{10}\right)^{p} \times \left(\frac{z}{H}\right)^{1.7} \times \left(\frac{4.4}{2.7 + p}\right) \times \xi \right] \right\}$$

The equation above is valid only with the units showed in the item 3 of this specification.

Where: z = Level above the ground [m];

(b) and (p) parameters as table below:

	Ground category	
	III	IV
p	0.185	0.230
b	0.86	0.71

5.2.5. The expression above, indicates (q) as a continuous function of the level (z) over the ground. The static equivalent force (which take into account the static and dynamic actions of the wind) by unit of level, may be determined with the next formula:

$F_g(z) = q(z) \times d \times C_a$

6. Vibration due to the shedding frequency of vortices

Beside the dynamics effects of the wind, there is a force on the equipment, transverse to the direction of the wind flow, caused by the shedding vortices of the *Von Karman*. This force acts alternately on either side of the equipment and may be induced in tall equipments, even with a wind speed somewhat less than that basic wind velocity.

The equipment shall not be designed to support the shedding vortices. When there is the risk to develop the shedding vortices, it must be used the helical strakes, in according to **Item 6.2** below, to avoid the problem.

6.1 DETERMINATION OF THE OCCURRENCE OF THE SHEDDING VORTICES

This occurrence shall be determined by the following procedure:

6.1.1. Determine the $V_t(z) = S_{2,t} \times V_o$

Where: $V_t(z)$ = Average velocity over (t) seconds, in the level (z) above the ground [m/s];

$S_{2,t}$ = Rugosity factor for a specified time (t), in seconds, and for a specified ground category. See **Tables III** and **IV**.

For a quickly, practical and approximated engineering computations, this calculating would be done for 30 seconds and 60 seconds.

6.1.2. Then, calculate the value of (V_t) for each level (z), and each time (t).
6.1.3. At the same level and between the several times, calculate the average of (V_t).
6.1.4. Use the greatest (Max. V_t).
6.1.5. With the greatest velocity (Max. V_t), determine the *Strouhal Number* (S_t):

Reynold's Number = $\Re = 70000 \times (\text{Max. } V_t) \times d$

$\Re$	S_t
$10^3 < \Re < 2 \times 10^5$	0.20
$2 \times 10^5 < \Re < 10^6$	linear interpolating
$\Re > 10^6$	0.28

6.1.6. With the *Strouhal Number*, determine the first critical wind velocity (V_{cr1}):

$$V_{cr1} = \frac{d_{nom}}{T_1 \times S_t}$$

Where: V_{cr1} = First critical wind velocity [m/s]
d_{nom} = Nominal diameter of the equipment [m]
T_1 = First natural mode (period) of vibration of the equipment [s]

6.1.7. If this velocity (V_{cr1}) is greater than 25 m/s, the wind flow is turbulent enough to not induce the shedding vortices vibration.
6.1.8. If the first critical wind velocity (V_{cr1}) is lower than 25 m/s and lower or equal the (Max. V_t), then consider the possibility of occurrence of the shedding vortices effects, and in this case, a device for generate wind turbulence is needed, like the helical strakes, in according to **Item 6.2**, below.

6.2 DESIGN OF THE HELICAL STRAKES

To prevent vortex-excited vibration of tall cylindrical equipments use helical vortex breakers, according to the following:

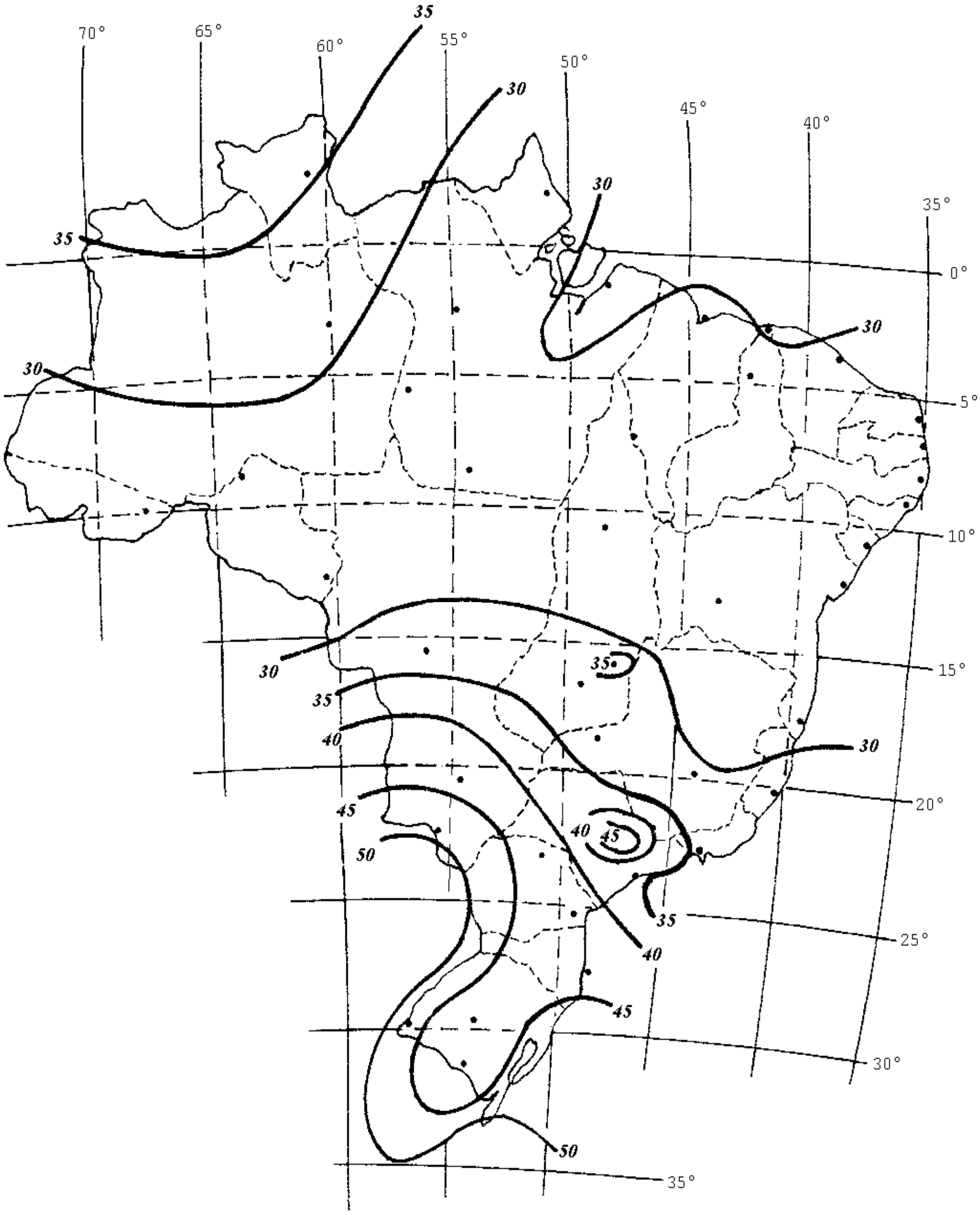
6.2.1. Three helical plates, equally spaced on the diameter, with helix-pitch equal to five times the diameter of the equipment (5d). It must be installed on the top 1/3 of the pressure vessel height (1/3H);
6.2.2. Width of each plate: 10% of the diameter of the equipment (0,1d), taking into account the thermal insulation;
6.2.3. Minimum thickness of each plate: 6.3 mm.

7. Allowable deflection

The maximum bending effect, in any design condition, must not exceed 1/200 of the total height of the pressure vessel (H).

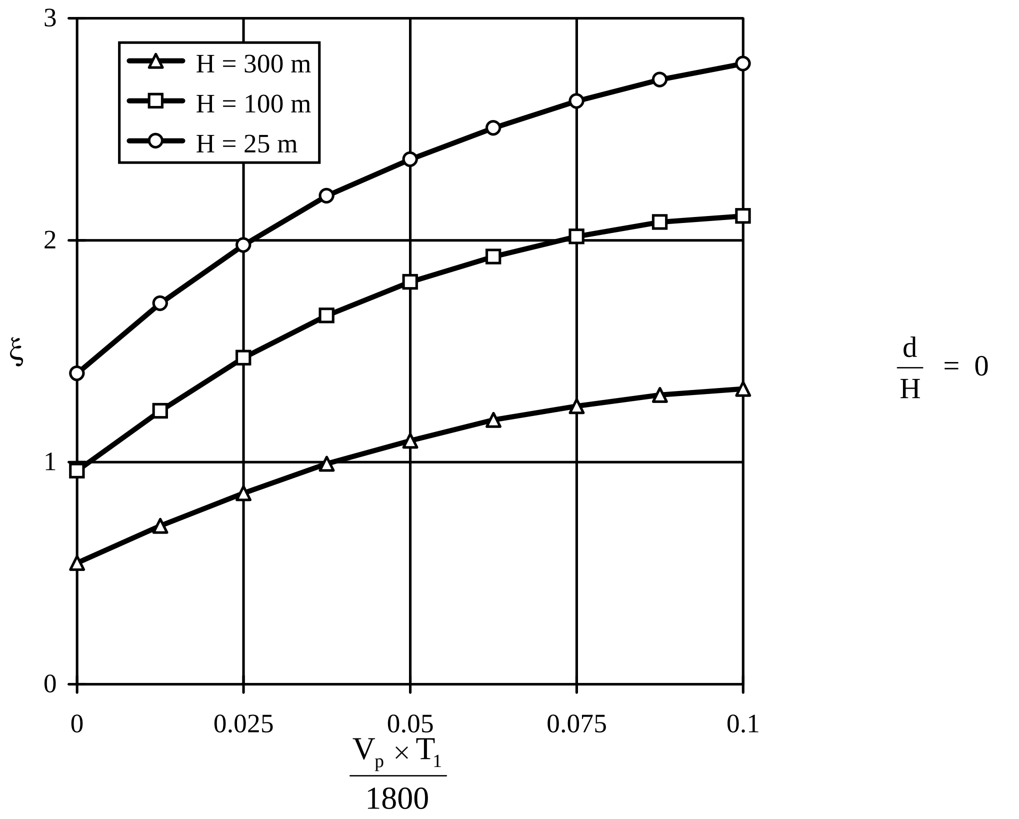
8. References

ABNT NBR-6123 – Forças Devidas ao Vento em Edificações (Brazilian Standard for Determination of Wind Forces on Buildings) – *Associação Brasileira de Normas Técnicas (Brazilian Organization for Technical Standards), Brazil.*



Vo: Maximum average velocity reached during three seconds, and exceeded once in 50 years at 10 meters, over a plane and opened ground [m/s].

Figure 1: Basic wind iso-velocities over Brazil



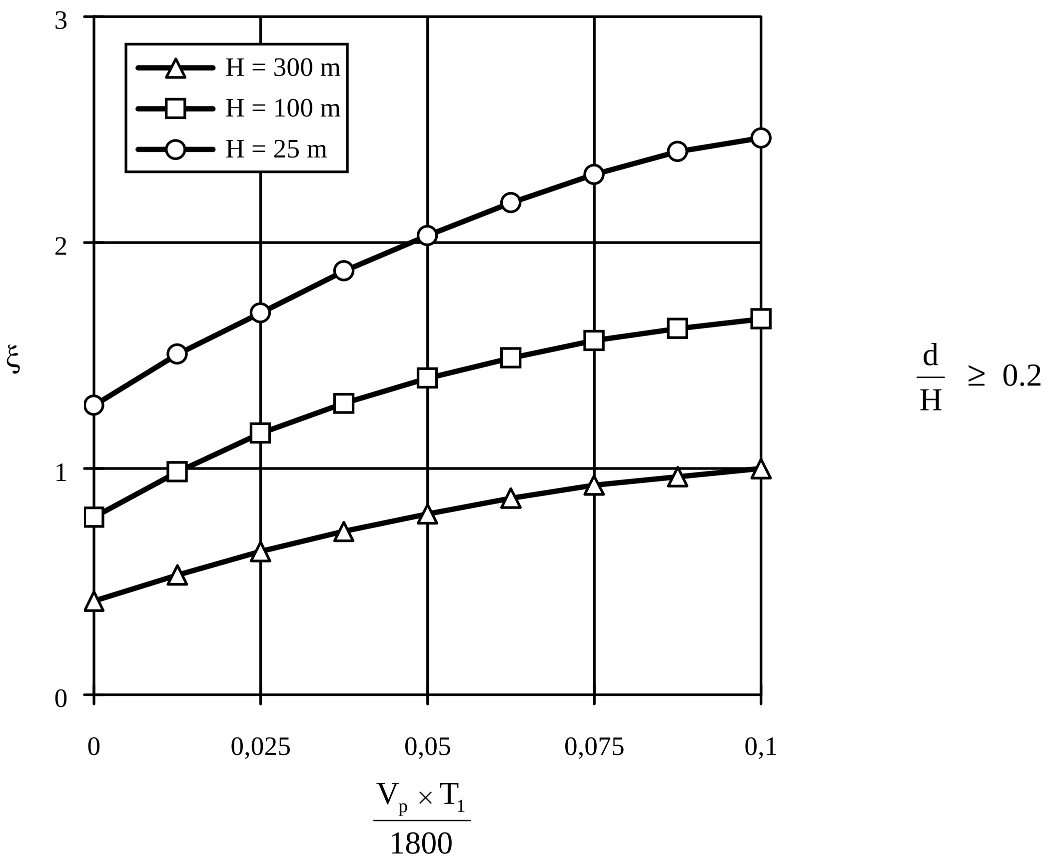


Figure 2: Dynamic amplification coefficient (ξ) for category III

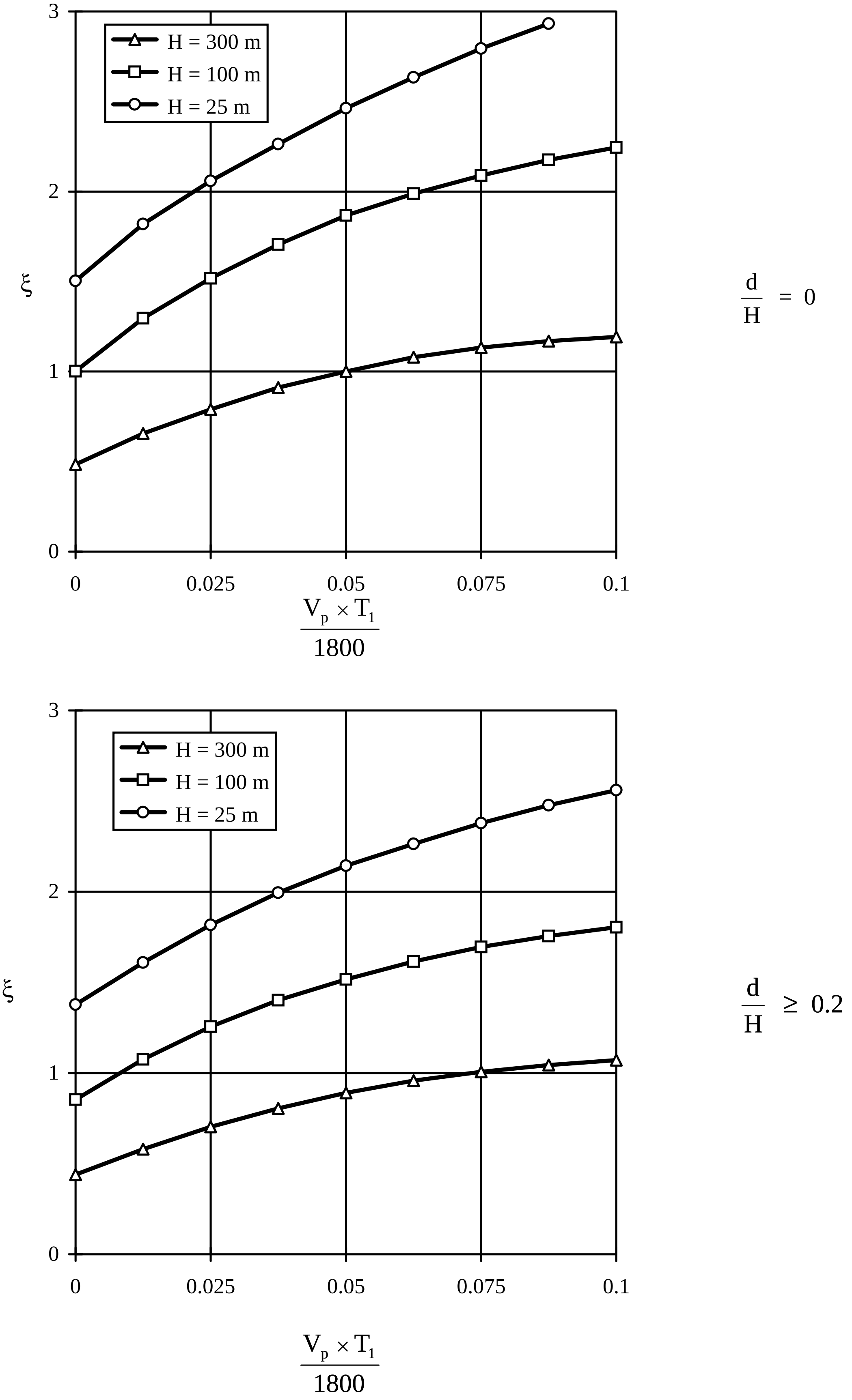
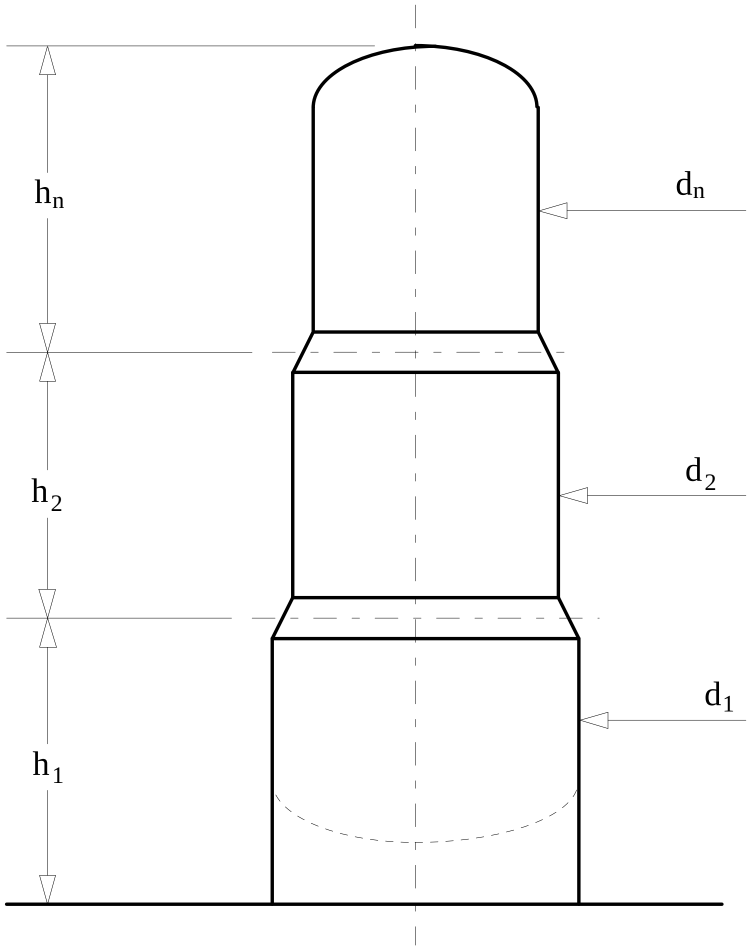


Figure 3: Dynamic amplification coefficient (ξ) for category IV



$$\frac{H}{d} = \frac{H_t}{d_t}$$

Where : $H_t = \sum_{i=1}^{n} h_i$

$$d_t = \frac{\sum_{i=1}^{n} h_i \times d_i}{H_t}$$

Figure 4a: Determination of ratio H/d, for shape coefficient calculation for equipments with several diameters

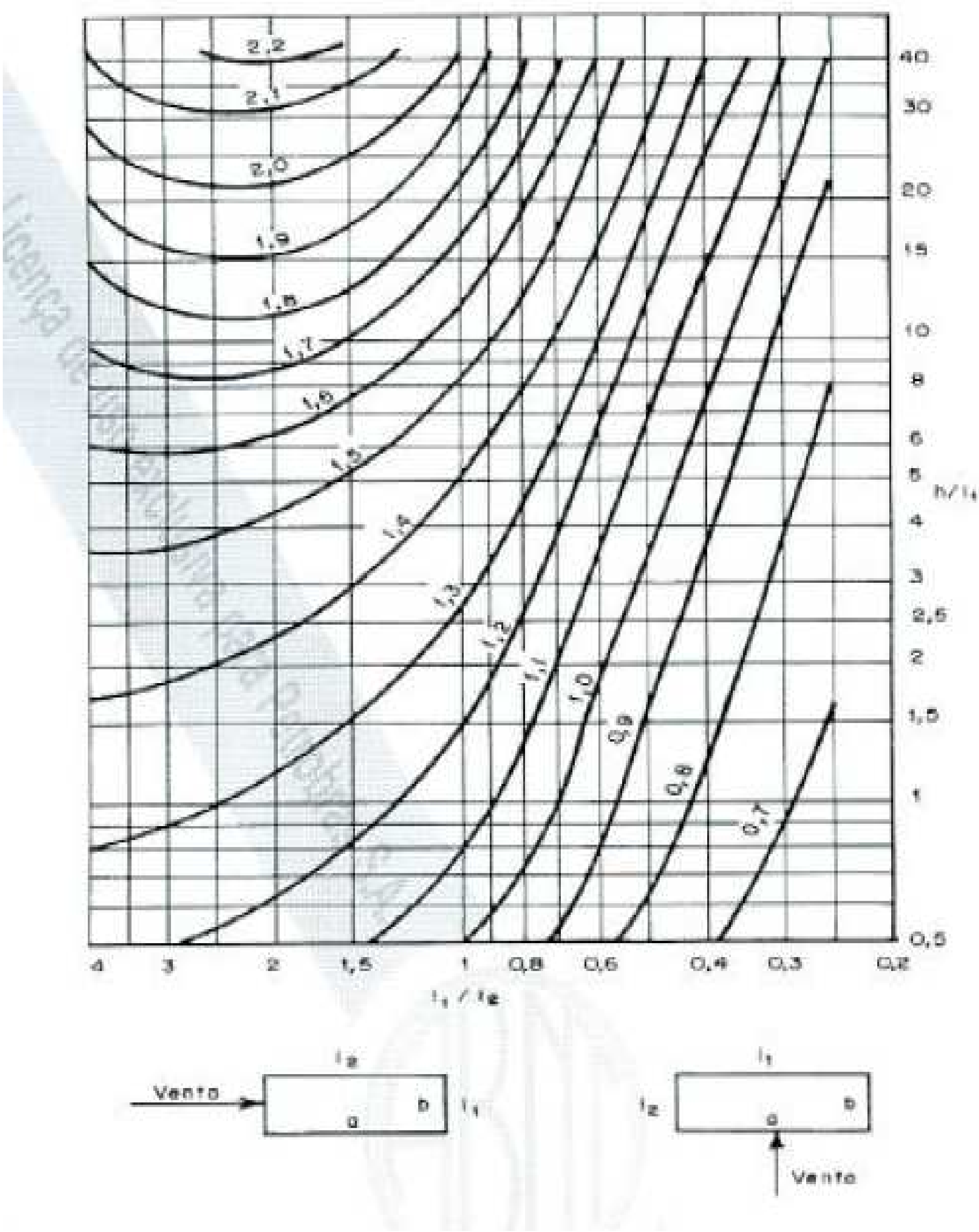


Figure 4b: Shape Coefficient (Ca) for prismatic members

LEVEL ABOVE THE GROUND [m]		CATEGORY					
		III			IV		
		CLASS			CLASS		
from	to	A	B	C	A	B	C
0	5	0.88	0.86	0.82	0.79	0.76	0.73
5	10	0.94	0.92	0.88	0.86	0.83	0.80
10	15	0.98	0.96	0.93	0.90	0.88	0.84
15	20	1.01	0.99	0.96	0.93	0.91	0.88
20	30	1.05	1.03	1.00	0.98	0.96	0.93
30	40	1.08	1.06	1.04	1.01	0.99	0.96
40	50	1.10	1.09	1.06	1.04	1.02	0.99
50	60	1.12	1.11	1.09	1.07	1.04	1.02
60	80	1.16	1.14	1.12	1.10	1.08	1.06
80	100	1.18	1.17	1.15	1.13	1.11	1.09
100	120	1.20	1.20	1.18	1.16	1.14	1.12
120	140	1.22	1.22	1.20	1.18	1.16	1.14
140	160	1.24	1.23	1.22	1.20	1.18	1.16
160	180	1.26	1.25	1.23	1.22	1.20	1.18
180	200	1.27	1.26	1.25	1.23	1.21	1.20

Table I: Rugosity factor (S_2)

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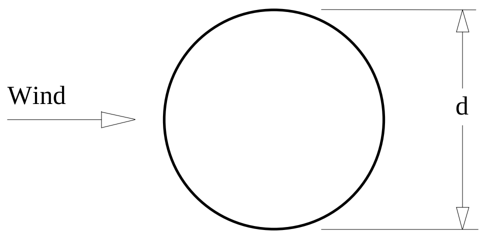
<tr><td></td><td rowspan="2">$V_k \times d$
[m²/s]
❶</td><td colspan="7">$\frac{H}{d}$
❶</td></tr>
<tr><td>Surface Finishing</td><td>0.5</td><td>1.0</td><td>2.0</td><td>5.0</td><td>10</td><td>20</td><td>∞</td></tr>
<tr><td>All types</td><td>≤ 5.0</td><td rowspan="2">0.7</td><td rowspan="2">0.7</td><td rowspan="2">0.7</td><td rowspan="2">0.8</td><td rowspan="2">0.9</td><td rowspan="2">1.0</td><td rowspan="2">1.2</td></tr>
<tr><td>Rugous</td><td>≥ 6.0</td></tr>
<tr><td>Smooth</td><td>≥ 6.0</td><td colspan="5">0.5</td><td>0.6</td><td>0.6</td></tr>
</table>

Table II: Shape coefficient (C_a) for a vertical and cylindrical vessel

❶ ⇨ Linear interpolation is permitted for intermediate values

z [m]	$S_{2,t}$ values for t [s] =											
	3	5	10	15	20	30	45	60	120	300	600	3600
≤ 5	0.88	0.86	0.82	0.78	0.75	0.72	0.68	0.67	0.61	0.55	0.52	0.48
10	0.94	0.92	0.88	0.86	0.83	0.79	0.76	0.74	0.69	0.63	0.59	0.55
15	0.98	0.96	0.93	0.90	0.87	0.84	0.80	0.78	0.73	0.67	0.64	0.60
20	1.01	0.99	0.96	0.93	0.90	0.87	0.84	0.82	0.77	0.71	0.67	0.63
30	1.05	1.03	1.00	0.98	0.95	0.92	0.89	0.87	0.82	0.76	0.73	0.69
40	1.08	1.06	1.04	1.02	0.99	0.96	0.92	0.91	0.86	0.80	0.77	0.73
50	1.10	1.09	1.06	1.05	1.02	0.99	0.96	0.94	0.89	0.83	0.80	0.76
60	1.12	1.11	1.09	1.07	1.05	1.02	0.98	0.97	0.91	0.86	0.83	0.79
80	1.16	1.14	1.12	1.11	1.09	1.06	1.02	1.01	0.96	0.90	0.87	0.84
100	1.18	1.17	1.15	1.14	1.12	1.09	1.06	1.04	0.99	0.94	0.91	0.88
120	1.20	1.20	1.18	1.17	1.14	1.12	1.08	1.07	1.02	0.97	0.94	0.91
140	1.22	1.22	1.20	1.19	1.17	1.15	1.11	1.10	1.05	0.99	0.97	0.94
160	1.24	1.23	1.22	1.21	1.19	1.17	1.13	1.12	1.07	1.02	0.99	0.96
180	1.26	1.25	1.23	1.23	1.21	1.19	1.15	1.14	1.09	1.04	1.01	0.98
200	1.27	1.26	1.25	1.24	1.22	1.20	1.17	1.16	1.11	1.06	1.03	1.01

Table III: Rugosity factor as a function of time ($S_{2,t}$) for category III

z [m]	$S_{2,t}$ values for t [s] =											
	3	5	10	15	20	30	45	60	120	300	600	3600
≤ 5	0.79	0.76	0.73	0.70	0.67	0.64	0.60	0.57	0.51	0.45	0.42	0.37
10	0.86	0.83	0.80	0.77	0.74	0.71	0.67	0.65	0.59	0.53	0.49	0.44
15	0.90	0.88	0.84	0.82	0.79	0.76	0.72	0.70	0.63	0.57	0.54	0.49
20	0.93	0.91	0.88	0.85	0.83	0.80	0.76	0.73	0.67	0.61	0.57	0.53
30	0.98	0.96	0.93	0.90	0.88	0.85	0.81	0.79	0.73	0.67	0.63	0.58
40	1.01	0.99	0.96	0.94	0.92	0.89	0.85	0.83	0.77	0.71	0.67	0.62
50	1.04	1.02	0.99	0.97	0.95	0.92	0.88	0.86	0.80	0.74	0.71	0.66
60	1.07	1.04	1.02	1.00	0.98	0.95	0.91	0.89	0.83	0.77	0.74	0.69
80	1.10	1.08	1.06	1.04	1.02	0.99	0.96	0.93	0.88	0.82	0.79	0.74
100	1.13	1.11	1.09	1.08	1.06	1.03	0.99	0.97	0.92	0.86	0.83	0.78
120	1.16	1.14	1.12	1.11	1.08	1.06	1.03	1.00	0.95	0.90	0.87	0.82
140	1.18	1.16	1.14	1.13	1.11	1.09	1.05	1.03	0.98	0.93	0.90	0.85
160	1.20	1.18	1.16	1.15	1.13	1.11	1.08	1.05	1.00	0.95	0.93	0.88
180	1.22	1.20	1.18	1.17	1.15	1.13	1.10	1.07	1.03	0.98	0.95	0.91
200	1.23	1.21	1.20	1.19	1.17	1.15	1.12	1.09	1.05	1.00	0.97	0.93

Table IV: Rugosity factor as a function of time ($S_{2,t}$) for category IV