REGIONE BASILICATA | COMUNE DI BERNALDA | PROVINCIA DI MATERA

PROGETTO DEFINITIVO

Lavori di realizzazione di un parco agro-fotovoltaico denominato "Bernalda 1" con potenza in immissione pari a 14.1 MW integrato con un sistema di accumulo e relative opere di connessione

Titolo elaborato

B.1.a. Piano di manutenzione e gestione dell'impianto - Parte generale

Codice elaborato

F0538DR01A

Scala

-

Progettazione

F4 ingegneria srl
Via Di Giura - Centro direzionale, 85100 Potenza
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Firmato digitalmente da:
MARELLA MAURO
Firmato il 09/05/2023 10:30
Seriale Certificato: 565728
Valido dal 30/06/2021 al 30/06/2024
InfoCamere Qualified Electronic Signature CA

Il Direttore Tecnico
(ing. Mauro MARELLA)

Società certificata secondo le norme UNI-EN ISO 9001:2015 e UNI-EN ISO 14001:2015 per l'erogazione di servizi di ingegneria nei settori: civile, idraulica, acustica, energia, ambiente (settore IAF: 34).

Gruppo di lavoro

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Vito PIERRI

Consulenze specialistiche

Committente

APOLLO Solar 1 srl
Viale della Stazione 7, 39100 Bolzano (BZ)

Data	Descrizione	Redatto	Verificato	Approvato
Aprile 2023	Prima emissione	MNA	GZU	MMA

File sorgente: **F0538DR01A_B.1.a. Piano di manutenzione e gestione dell'impianto - Parte generale.docx**

Piano di manutenzione e gestione dell'impianto – Parte generale

Sommario

1 Premessa

Il presente progetto definitivo si riferisce alla realizzazione di un impianto di energia rinnovabile da fonte solare, a carattere agrivoltaico, nel comune di Bernalda (MT). La Soluzione Minima Tecnica Generale (STMG) prevede il collegamento in antenna a 36 kV su una futura Stazione Elettrica (SE) della RTN a 150/36 kV nel comune di Montescaglioso (MT), come definito nel preventivo di connessione con codice pratica 202202508.

Le opere in progetto sono proposte dalla società Apollo Solar S.r.l. con sede in Via della Stazione 7, 39100 Bolzano (BZ).

Nello specifico, l'impianto sarà costituito da 21450 moduli fotovoltaici suddivisi in 4 sottocampi, in cui i moduli sono organizzati in stringhe ciascuna da 30 moduli o coppie di stringhe da 15 moduli. La potenza nominale dell'impianto è pari a 14.1 MW (lato AC).

Si precisa, inoltre, che l'impianto in oggetto si caratterizza come un impianto "agrivoltaico", ovvero un impianto che permette di preservare l'attività di coltivazione agricola o pastorale, garantendo una buona produzione energetica. La progettazione è stata perseguita tenendo conto delle recenti Linee Guida in materia di impianti agrivoltaici del Ministero della Transizione Ecologica (Mite) del giugno 2022.

Pertanto, il progetto è perseguito in coerenza con le indicazioni del Piano Nazionale Integrato per l'Energia e il Clima (**PNIEC**) e tenendo conto del Piano Nazionale di Ripresa e Resilienza (**PNRR,** legge 29 luglio 2021, n.108).

2 Lista anagrafica dei componenti dell'impianto

I principali componenti dell'impianto fotovoltaico di progetto sono:

- I pannelli fotovoltaici (vedi allegato 4);
- Le strutture metalliche di supporto ed orientazione dei pannelli (vedi allegato 3);
- Le fondazioni delle strutture;
- L'inverter delle caratteristiche tecniche riportate nella scheda tecnica di questo componente (vedi allegato 2);
- Le cabine elettriche di campo e di interconnessione (vedi allegato 1);
- I cavidotti ed i conduttori elettrici;
- Il sistema di monitoraggio e controllo SCADA.

3 Schede tecniche dei componenti dell'impianto

In dettaglio, l'impianto fotovoltaico è dotato di:

- Numero di strutture: 766 stringhe;
- Numero di cabine di campo: 4;
- Numero di inverter: 49;
- Potenza di picco complessiva: 14.4 MW;
- Potenza totale immessa in rete: 14.1 MW;
- Numero di pannelli fotovoltaici: 21420.

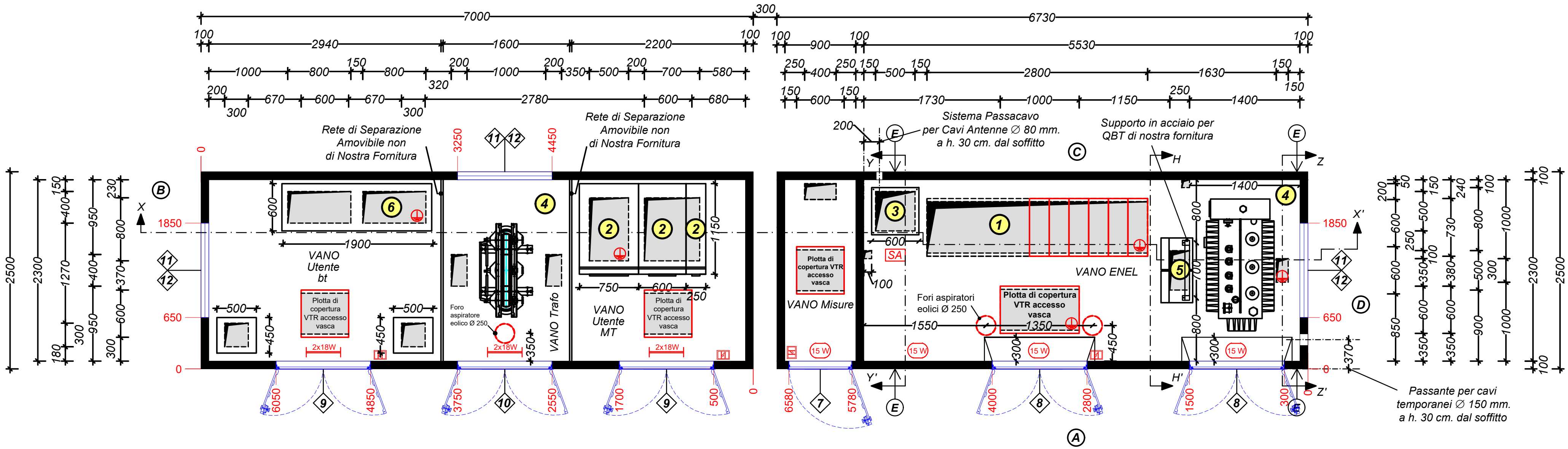
L'impianto, inoltre, è suddiviso in 4 sottocampi gestiti da inverter di stringa dalla potenza unitaria pari a 300 kW.

Si allegano, ad integrazione del presente documento, le schede tecniche dei componenti dell'impianto relative a:

- Cabine di campo;
- Inverter;
- Strutture di supporto;
- Pannelli fotovoltaici.

Allegato 1: Cabine di campo

Codice LP.CED.203



LEGENDA:

1. Foro x Moduli MT ENEL
2. Foro x Moduli MT Utente
3. Armadio Rack (DY3005)
4. Trasformatore
5. Quadri bt ENEL
6. Foro x Quadri bt Utente

7. Porta Un'Anta in Metallo (CM. 84 x h 210 Ut.) con custodia per chiave
8. Porta Due Ante in VTR (CM. 111 x h 206 Ut.) con Serr. ENEL Naz. - Chiave Esclusa
9. Porta Due Ante in VTR (CM. 111 x h 206 Ut.)
10. Porta Due Ante in VTR (CM. 111 x h 206 Ut.) con Serr. AREL
11. Griglia Alta in VTR (CM. 120 x 50 h)
12. Griglia Bassa in VTR (CM. 120 x 50 h)

E GOLFARI DI SOLLEVAMENTO

Nodo Equipotenziale

ACCESSORI:

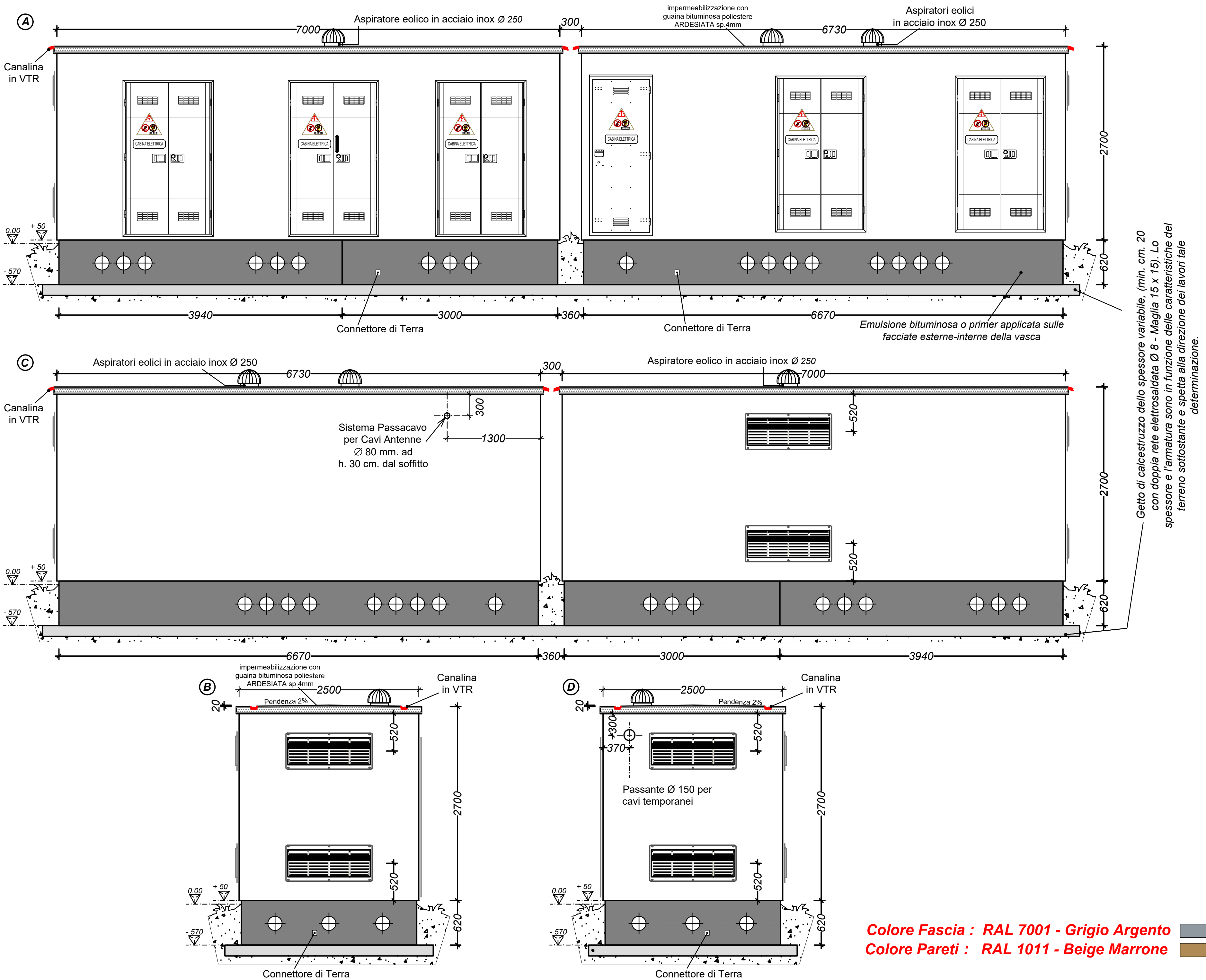
* N. 6 Elementi di copertura in VTR, per scomparti MT - sp. mm 40 (dim. mm. 730 x 250)
* N. 1 Copertura passaggio uomo in VTR per accesso alla vasca sp. mm. 40 (dim. mm. 595 x 995)
* N. 3 Coperture passaggio uomo in VTR per accesso alla vasca sp. mm. 40 (dim. mm. 595 x 595)
* N. 2 Kit Canaletta Uscita Acqua Piovana - 4 pz.
* N. 3 Torrini Eolici in Acciaio Inox Ø 250 mm.
* N. 1 Telaio in Acciaio Zincato supporto per quadri BT
* N. 1 Supporto per quadri BT (DS 3005)
* N. 1 Sistema Passacavo per Cavi Antenna
* N. 1 Sistema Passacavo per Cavi Temporanei Ø 150 mm.
* N. 4 Connettori interno-esterno al Basamento per collegamento rete di terra
* N. 1 Quadro Servizi Ausiliari om. ENEL DY 3016/3 per Rack (DY 3005)
* N. 1 Armadio Rack (DY 3005)

Legenda Imp. Elettr. di ns. fornitura:

- Interruttore Unipolare
- Interruttore Bipolare
- 2x18W — Apparecchio di Illuminazione a Tubi Fluorescenti 2x18W
- 15 W — Plafoniera Stagna con Lampada a LED TAB. ENEL DY 3021
- SA — Quadretto Servizi Ausiliari ENEL DY 3016/3 a servizio locale ENEL tensione nominale 400 V

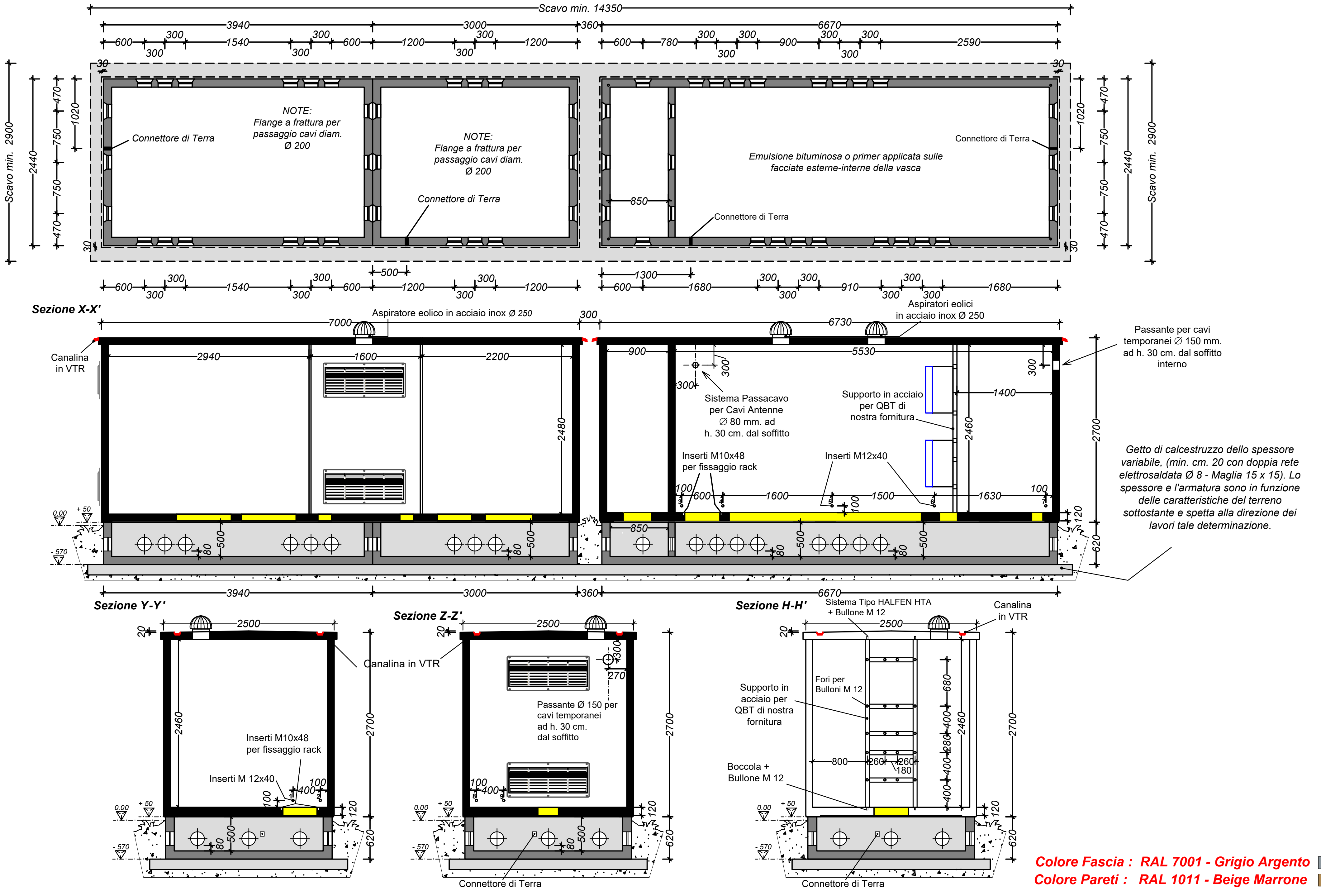
Colore Fascia : RAL 7001 - Grigio Argento

Colore Pareti : RAL 1011 - Beige Marrone



Colore Fascia : RAL 7001 - Grigio Argento

Colore Pareti : RAL 1011 - Beige Marrone



Colore Fascia : RAL 7001 - Grigio Argento

Colore Pareti : RAL 1011 - Beige Marrone

Allegato 2: Inverter

SUN2000-330KTL-H1

Technical Specifications (Preliminary)

Efficiency	
Max. Efficiency	≥99.0%
European Efficiency	≥98.8%
Input	
Max. Input Voltage	1,500 V
Number of MPP Trackers	6
Max. Current per MPPT	65 A
Max. Short Circuit Current per MPPT	115 A
Max. PV Inputs per MPPT	4/5/5/4/5/5
Start Voltage	550 V
MPPT Operating Voltage Range	500 V ~ 1,500 V
Nominal Input Voltage	1,080 V
Output	
Nominal AC Active Power	300,000 W
Max. AC Apparent Power	330,000 VA
Max. AC Active Power (cosφ=1)	330,000 W
Nominal Output Voltage	800 V, 3W + PE
Rated AC Grid Frequency	50 Hz / 60 Hz
Nominal Output Current	216.6 A
Max. Output Current	238.2 A
Adjustable Power Factor Range	0.8 LG ... 0.8 LD
Total Harmonic Distortion	< 1%
Protection	
Smart String-Level Disconnector(SSLD)	Yes
Anti-islanding Protection	Yes
AC Overcurrent Protection	Yes
DC Reverse-polarity Protection	Yes
PV-array String Fault Monitoring	Yes
DC Surge Arrester	Type II
AC Surge Arrester	Type II
DC Insulation Resistance Detection	Yes
AC Grounding Fault Protection	Yes
Residual Current Monitoring Unit	Yes
Communication	
Display	LED Indicators, WLAN + APP
USB	Yes
MBUS	Yes
RS485	Yes
General	
Dimensions (W x H x D)	1,048 x 732 x 395 mm
Weight (with mounting plate)	≤108 kg
Operating Temperature Range	-25 ℃ ~ 60 ℃
Cooling Method	Smart Air Cooling
Max. Operating Altitude without Derating	4,000 m （13,123 ft.）
Relative Humidity	0 ~ 100%
AC Connector	Waterproof Connector + OT/DT Terminal
Protection Degree	IP66
Topology	Transformerless

Allegato 3: Strutture di supporto

CONVERT **TRJ**

HORIZONTAL SINGLE AXIS TRACKER

Preliminary Structural Calculation Report

TRJ HT 30 MODULES

(Italy)

REVISIONS			
N.	**DATE**	**PAG./SECT.**	**NOTES**
0A	27/11/2018	-	First document emission
0B	05/12/2018	-	Update photovoltaic module and load combination coefficients

PREPARED	CHECKED	APPROVED
Name: XXX Date: XXX	Name: XXX Date: XXX	Name: XXX Date: XXX

INDEX

1. GENERAL DESCRIPTION

BASIC INFORMATION

Project name	*XXX*
Country	*Italy*
Power (MWp)	*X*
GPS Coordinates	*XXX*
Altitude	*XXX*
Type of tracking system	*Horizontal single axis tracking system with backtracking*
Tracking angle	*±55°*
Tracker type	*1x30 pv-modules in portrait configuration*
Height over ground at maximum tilt angle	*300 mm*
Photovoltaic panel	*XXX – dim: 1994mmx1000mm*
Module mounting slots interaxis	*400 mm*

INTRODUCTION

The mechanical structure is composed of a large frame supported by *omega piles* fixed on the ground by driving and made of cold formed Ω section steel. At the top of the latest some *saddles* are fixed and hold up the *main beams*, horizontal elements with a square tubular section which are the central axis of the structure.

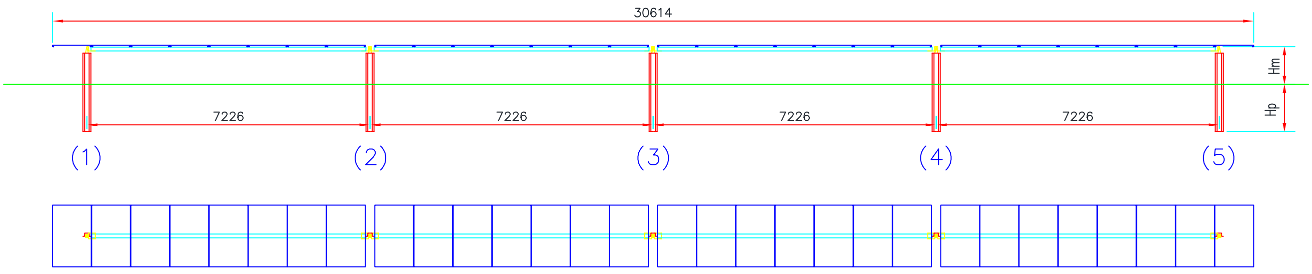
On the main beams photovoltaic panels are fixed through different kind of *module support*. These are secondary cross beams with Ω section steel profiles.

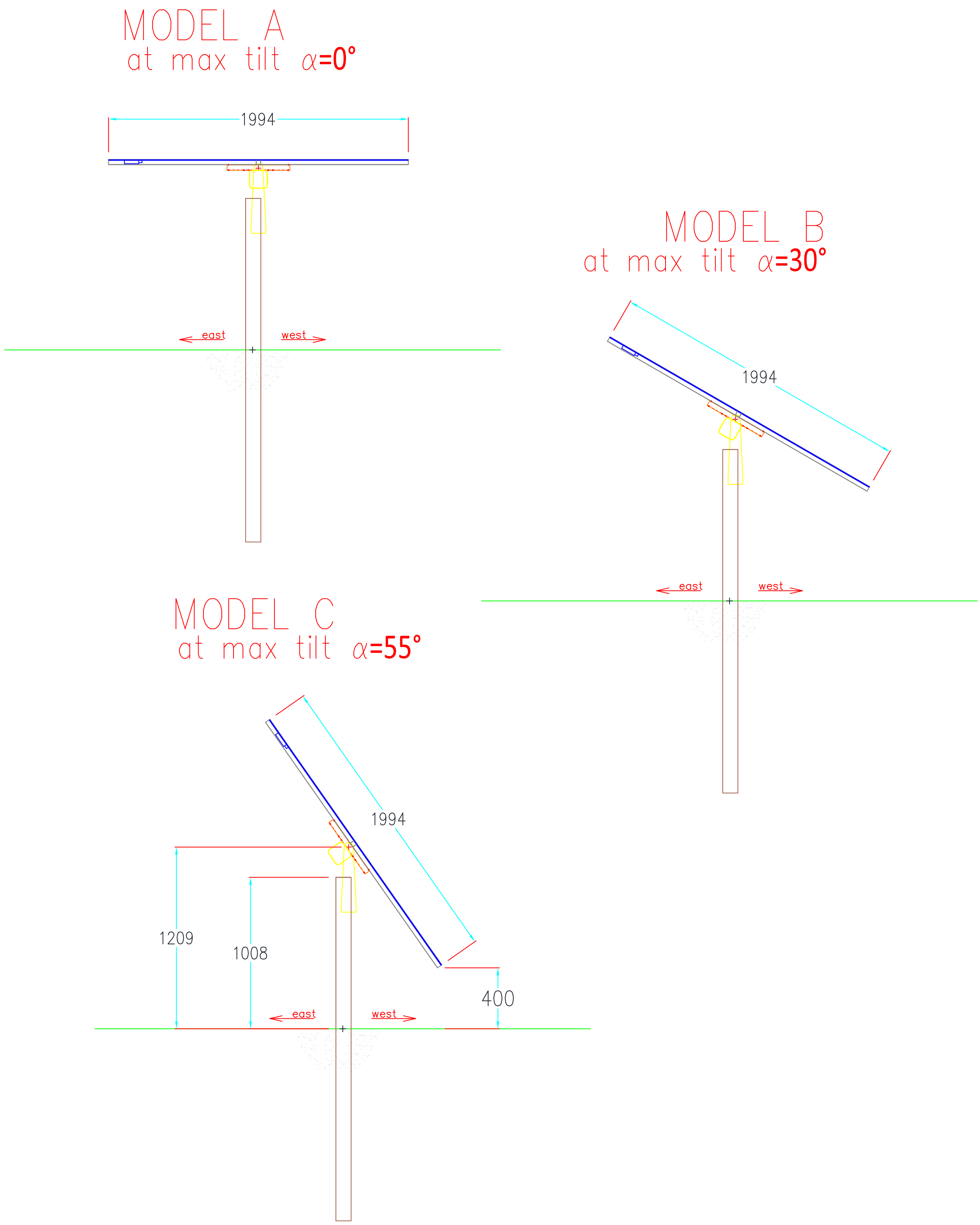
GEOMETRIC SCHEME

For the structural calculation report we have been only considered three main configurations:

- **MODEL A → α = 0°**
- **MODEL B → α = 30°**
- **MODEL C → α = 55°**

These configurations are those that generate the maximum stress in the structure. Below it is shown a diagram of the geometric dimensions for these configurations




MODEL A
at max tilt α=0°
1994
east
west
MODEL B
at max tilt α=30°
1994
east
west
MODEL C
at max tilt α=55°
1994
1209
1008
400
east
west

2. STANDARD RULES

EUROPEAN CODES

- EUROCODICE 1 – Azioni sulle strutture – Parte 1-4: Azioni in generale – azioni del vento (UNI EN 1991-1-4:2005);
- EUROCODICE 3 – Progettazione delle Strutture in acciaio – Parte 1-1: Regole generali e regole per gli edifici (UNI EN 1993-1-1:2005);
- EUROCODICE 3 – Progettazione delle Strutture in acciaio – Parte 1-8: Progettazione dei collegamenti (UNI EN 1993-1-8:2005);

ITALIAN CODES

- D.M. 17 gennaio 2018 – Norme Tecniche per le Costruzioni;
- Legge 2/2/74 n. 64 e DDMM 3/3/1975 – Norme tecniche per la costruzione in zone sismiche.
- Costruzioni in acciaio: Istruzioni per il calcolo, l’esecuzione, il collaudo e la manutenzione. (C.N.R. 10011/85);
- Istruzioni per la valutazione delle Azioni sulle Costruzioni. (C.N.R. 10012/85);

3. LOAD ANALYSIS

PERMANENT LOAD

Structural permanent loads

Tubolar beam - 120x120

L1=	7.226	*m - length beaam*
pp1=	81.1	*N/m - load cross section*
n°=	1	
p1.1=	**585.8**	*(N)*

Pannel support stand - type Ω

L2=	0.700	*m - length beaam*
pp2=	20.0	*N/m - load cross section*
n°=	8	
p2=	**112.1**	*(N)*

KIT's elements for fixing the beam to the pole

pp3=	143	*N/m - load cross section*
n°=	1	
p3=	**143.0**	*(N)*

Foundation pile - type Ω

L4.1=	1.500	*m - preliminary embedment length in to the ground*
L4.2=	1.0	*m - length above the ground*
pp4=	96	*N/m - load cross section*
n°=	1	
p4=	**95.9**	*(N)*

Ptot.=	**351**	N

Photovoltaic Modules

A=	1000	*(mm)*
B=	1994	*(mm)*
p5=	**226**	*(N)*

WIND LOAD

INTRODUCTION

The wind load calculation is determined in according to D.M. 17 gennaio 2018 – *Norme Tecniche per le Costruzioni*.

- In stow position (α = 0°) the main speed wind is $v_{b,0} = 28\ m/s$ according to NTC2018;
- In working position (α ≠ 0°) the wind speed is $v_{b,0} = 15\ m/s$. It is calculated as 10 minutes average wind speed value at tracker height.

Only for the configurations of non-standard angles the pressure coefficents c_p of the named fluido-dynamic study – *"Aerodynamic performance of a solar tracker panel"* by A. Corsini and G. Delibra was used.

BASIC WIND VELOCITY

The basic wind velocity is determined according to the Table 3.3.I of the *D.M. 17 gennaio 2018 – Norme Tecniche per le Costruzioni.*

The value is the characteristic 10 minutes mean wind velocity, irrespective of the wind direction and time of year, at 10m above ground level in open country terrain with low vegetation such as grass and isolated obstacles with separations of at least 20 obstacles heights, with a probability of exceeding the designed force not more than 2% in 50 years.

The photovoltaic site is in xxx, in the xxx Department, region 4. It is underline in following figure.

Tab. 3.3.I -*Valori dei parametri* $v_{b,0}$, a_0, k_s

Zona	Descrizione	$v_{b,0}$ [m/s]	a_0 [m]	k_s
1	Valle d'Aosta, Piemonte, Lombardia, Trentino Alto Adige, Veneto, Friuli Venezia Giulia (con l'eccezione della provincia di Trieste)	25	1000	0,40
2	Emilia Romagna	25	750	0,45
3	Toscana, Marche, Umbria, Lazio, Abruzzo, Molise, Puglia, Campania, Basilicata, Calabria (esclusa la provincia di Reggio Calabria)	27	500	0,37
4	Sicilia e provincia di Reggio Calabria	28	500	0,36
5	Sardegna (zona a oriente della retta congiungente Capo Teulada con l'Isola di Maddalena)	28	750	0,40
6	Sardegna (zona a occidente della retta congiungente Capo Teulada con l'Isola di Maddalena)	28	500	0,36
7	Liguria	28	1000	0,54
8	Provincia di Trieste	30	1500	0,50
9	Isole (con l'eccezione di Sicilia e Sardegna) e mare aperto	31	500	0,32

Therefore the basic wind velocity is $v_{b,0} = 28\ m/s$.

MEAN WIND

The main wind velocity is determined according to the Section 3.3.1 of the *D.M. 17 gennaio 2018 – Norme Tecniche per le Costruzioni*, with the following equation:

$$v_b = c_a \cdot v_{b,0}$$

Where:

- $\boldsymbol{v_{b,0}}$ is the basic wind speed. The values are the following:

  $\boldsymbol{v_{b,0} = 28\, m/s}$ for the tracker inclination angle α=+0°;

  $\boldsymbol{v_{b,0} = 15\, m/s}$ for the tracker inclination angle α≠0°;

- c_a is the altitude coefficient $c_a = 1$

Therefore, the values of main wind velocity based on tracker inclination angle are:

- $v_b = c_a \cdot v_{b,0} = 1 \cdot 28 = 28\, m/s$ (α=0°)
- $v_b = c_a \cdot v_{b,0°} = 1 \cdot 15 = 15\, m/s$ (α≠0°)

REFERENCE WIND SPEED

The reference wind speed is determined according to the Section 3.3.2 of the *D.M. 17 gennaio 2018 – Norme Tecniche per le Costruzioni*, with the following equation:

$$v_{b,r} = c_r \cdot v_b$$

Where:

- $\boldsymbol{v_b}$ is the main wind speed. The values are the following:

  $\boldsymbol{v_b = 28\,m/s}$ for the tracker inclination angle α=+0°;

  $\boldsymbol{v_b = 15\,m/s}$ for the tracker inclination angle α≠0°;

- c_r is the return coefficient. It depends on the return period T_R equals to 25 years, with the following equation:

$$c_r = 0{,}75\sqrt{1 - 0{,}20 \cdot \ln\left[-\ln\left(1 - \frac{1}{T_R}\right)\right]} = 0{,}75\sqrt{1 - 0{,}20 \cdot \ln\left[-\ln\left(1 - \frac{1}{25}\right)\right]} = 0{,}960$$

Therefore, the values of main wind velocity based on tracker inclination angle are:

- $v_{b,r} = c_r \cdot v_b = 0{,}960 \cdot 28 = 26{,}9\ m/s$ (α=0°)
- $v_{b,r} = c_r \cdot v_b = 0{,}960 \cdot 15 = 14{,}4\ m/s$ (α≠0°)

PEAK VELOCITY PRESSURE

The peak velocity pressure is determined by the following expression according to Section 3.3.6 of the *D.M. 17 gennaio 2018 – Norme Tecniche per le Costruzioni*:

$$q_r = \frac{1}{2} \cdot \rho \cdot v_{b,r}^2$$

Where:

– ρ the density air is determinate according to the *International Standard ISO 2533-1975* - "Standard atmosphere”. It is an atmospheric model of how the pressure, temperature, density, and viscosity of the Earth's atmosphere changes with altitude. Following the table of the density air values:

ISO 2533:1975/Add.2:1997(E/F/R) © ISO

Table 1 *(continued)*
Tableau 1 *(suite)*
Таблица 1 *(продолжение)*
Tabla 1 *(continuación)*

Values in terms of geometrical altitude. Valeurs en fonction de l'altitude géométrique.
Значения величин в функции геометрической высоты. Valores en función de la altitud geométrica.

h m м	H m м	T K	t °C	p hPa гПа	ρ $kg \cdot m^{-3}$ $кг \cdot м^{-3}$	g $m \cdot s^{-2}$ $м \cdot с^{-2}$
−2 000	−2 001	301.154	28.004	1.27783 +3	1.47816 +0	9.8128
−1 950	−1 951	300.829	27.679	1.27059	1.47138	9.8127
−1 900	−1 901	300.504	27.354	1.26339	1.46462	9.8125
−1 850	−1 851	300.179	27.029	1.25622	1.45789	9.8124
−1 800	−1 801	299.853	26.703	1.24909	1.45118	9.8122
−1 750	−1 750	299.528	26.378	1.24198	1.44449	9.8121
−1 700	−1 700	299.203	26.053	1.23491	1.43783	9.8119
−1 650	−1 650	298.878	25.728	1.22787	1.43119	9.8117
−1 600	−1 600	298.553	25.403	1.22087	1.42458	9.8116
−1 550	−1 550	298.227	25.077	1.21390	1.41799	9.8114
−1 500	−1 500	297.902	24.752	1.20696 +3	1.41142 +0	9.8113
−1 450	−1 450	297.577	24.427	1.20005	1.40487	9.8111
−1 400	−1 400	297.252	24.102	1.19317	1.39835	9.8110
−1 350	−1 350	296.927	23.777	1.18633	1.39186	9.8108
−1 300	−1 300	296.602	23.452	1.17952	1.38538	9.8107
−1 250	−1 250	296.277	23.127	1.17274	1.37893	9.8105
−1 200	−1 200	295.951	22.801	1.16599	1.37250	9.8104
−1 150	−1 150	295.626	22.476	1.15927	1.36610	9.8102
−1 100	−1 100	295.301	22.151	1.15259	1.35971	9.8100
−1 050	−1 050	294.976	21.826	1.14593	1.35335	9.8099
−1 000	−1 000	294.651	21.501	1.13931 +3	1.34702 +0	9.8097
−950	−950	294.326	21.176	1.13272	1.34070	9.8096
−900	−900	294.001	20.851	1.12616	1.33441	9.8094
−850	−850	293.676	20.526	1.11963	1.32814	9.8093
−800	−800	293.351	20.201	1.11313	1.32190	9.8091
−750	−750	293.026	19.876	1.10666	1.31567	9.8090
−700	−700	292.701	19.551	1.10023	1.30947	9.8088
−650	−650	292.375	19.225	1.09382	1.30330	9.8087
−600	−600	292.050	18.900	1.08744	1.29714	9.8085
−550	−550	291.725	18.575	1.08110	1.29101	9.8083
−500	−500	291.400	18.250	1.07478 +3	1.28490 +0	9.8082
−450	−450	291.075	17.925	1.06849	1.27881	9.8080
−400	−400	290.750	17.600	1.06224	1.27274	9.8079
−350	−350	290.425	17.275	1.05601	1.26670	9.8077
−300	−300	290.100	16.950	1.04981	1.26067	9.8076
−250	−250	289.775	16.625	1.04365	1.25467	9.8074
−200	−200	289.450	16.300	1.03751	1.24870	9.8073
−150	−150	289.125	15.975	1.03140	1.24274	9.8071
−100	−100	288.800	15.650	1.02532	1.23680	9.8070
−50	−50	288.475	15.325	1.01927	1.23089	9.8068
0	0	288.150	15.000	1.01325 +3	1.22500 +0	9.8067
50	50	287.825	14.675	1.00726	1.21913	9.8065
100	100	287.500	14.350	1.00129	1.21328	9.8063
150	150	287.175	14.025	9.95359 +2	1.20746	9.8062
200	200	286.850	13.700	9.89453	1.20165	9.8060
250	250	286.525	13.375	9.83576	1.19587	9.8059
300	300	286.200	13.050	9.77727	1.19011	9.8057
350	350	285.875	12.725	9.71906	1.18437	9.8056
400	400	285.550	12.400	9.66113	1.17865	9.8054
450	450	285.225	12.075	9.60349	1.17295	9.8053
500	500	284.900	11.750	9.54612 +2	1.16727 +0	9.8051
550	550	284.575	11.425	9.48904	1.16162	9.8050
600	600	284.250	11.100	9.43223	1.15598	9.8048
650	650	283.925	10.775	9.37569	1.15037	9.8046
700	700	283.601	10.451	9.31944	1.14478	9.8045
750	750	283.276	10.126	9.26345	1.13921	9.8043
800	800	282.951	9.801	9.20775	1.13365	9.8042
850	850	282.626	9.476	9.15231	1.12812	9.8040
900	900	282.301	9.151	9.09714	1.12262	9.8039
950	950	281.976	8.826	9.04225	1.11713	9.8037

For the altitude above the sea level h=300m result

$$\rho = 1{,}190 \, {}^{kg}/_{m^3}$$

- $v_{b,r}$ is the reference wind speed. The values are the following:

$v_{b,r} = 26{,}9 \; m/s$ (α=0°)

$v_{b,r} = 14{,}4 \; m/s$ (α≠0°)

Therefore, the values of the peak velocity pressure based on tracker inclination angle α are:

- $q_r = \left(\frac{1}{2} \cdot \rho \cdot v_{b,r}^2\right) = \left(\frac{1}{2} \cdot 1{,}19 \cdot 26{,}9^2\right) = 430 \; N/m^2$ for the tracker inclination angle α=0°
- $q_r = \left(\frac{1}{2} \cdot \rho \cdot v_{b,r}^2\right) = \left(\frac{1}{2} \cdot 1{,}19 \cdot 14{,}4^2\right) = 123 \; N/m^2$ for the tracker inclination angle α≠0°

EXPOSURE FACTOR

The exposure coefficient depends on the structure height z above the terrain and on the exposure category of the site where the structure is located.

$$c_e(z) = k_r^2 c_t \ln(z/z_0)\left[7 + c_t \ln(z/z_0)\right] \quad \text{per } z \geq z_{min}$$

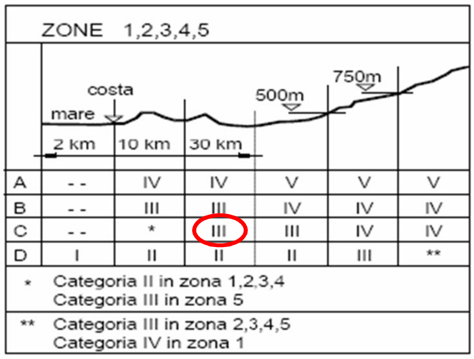
$$c_e(z) = c_e(z_{min}) \quad \text{per } z < z_{min}$$

The site is 17 km far from the coast, the overall roughness class of the intervention can be considered the D, an area free of obstacles.

Tab. 3.3.III - *Classi di rugosità del terreno*

Classe di rugosità del terreno	Descrizione
A	Aree urbane in cui almeno il 15% della superficie sia coperto da edifici la cui altezza media superi i 15 m
B	Aree urbane (non di classe A), suburbane, industriali e boschive
C	Aree con ostacoli diffusi (alberi, case, muri, recinzioni,....); aree con rugosità non riconducibile alle classi A, B, D
D	a) Mare e relativa fascia costiera (entro 2 km dalla costa); b) Lago (con larghezza massima pari ad almeno 1 km) e relativa fascia costiera (entro 1 km dalla costa) c) Aree prive di ostacoli o con al più rari ostacoli isolati (aperta campagna, aeroporti, aree agricole, pascoli, zone paludose o sabbiose, superfici innevate o ghiacciate, ...)

L'assegnazione della classe di rugosità non dipende dalla conformazione orografica e topografica del terreno. Si può assumere che il sito appartenga alla Classe A o B, purché la costruzione si trovi nell'area relativa per non meno di 1 km e comunque per non meno di 20 volte l'altezza della costruzione, per tutti i settori di provenienza del vento ampi almeno 30°. Si deve assumere che il sito appartenga alla Classe D, qualora la costruzione sorga nelle aree indicate con le lettere a) o b), oppure entro un raggio di 1 km da essa vi sia un settore ampio 30°, dove il 90% del terreno sia del tipo indicato con la lettera c). Laddove sussistano dubbi sulla scelta della classe di rugosità, si deve assegnare la classe più sfavorevole (l'azione del vento è in genere minima in Classe A e massima in Classe D).



The parameters for calculating c_e, for site with exposure category III and having a topographic factor equals to $c_t = 1$, are given in the following table:

Tab. 3.3.II - *Parametri per la definizione del coefficiente di esposizione*

Categoria di esposizione del sito	K_r	z_0 [m]	z_{min} [m]
I	0,17	0,01	2
II	0,19	0,05	4
III	0,20	0,10	5
IV	0,22	0,30	8
V	0,23	0,70	12

Therefore the value of the exposure coefficient is:

$$c_e = k_r^2 c_t \ln\left(\frac{z}{z_0}\right)\left[7 + c_t \ln\left(\frac{z}{z_0}\right)\right] = 0,20^2 \ln\left(\frac{5}{0.1}\right)\left[7 + \ln\left(\frac{5}{0.1}\right)\right] = 1,708$$

In $p_{w,\alpha}$ we will use $c_e(z) = 1$ because $v_{b,0} = 15m/s$ is a misured basic wind speed, and so it considers the different factors related to the terrain.

DYNAMIC FACTOR

The dynamic factor c_d was determined by referring to the Eurocode factor $c_s c_d$.

The structural factor $c_s c_d$ should take into account the effect on wind actions from the non-simultaneous occurrence of peak wind pressures on the surface (c_s) together with the effect of the vibrations of the structure due to turbulence (c_d). The structural factor $c_s c_d$ may be separated into a size factor (c_s) and a dynamic factor (c_d), based on chapter 6.3.1.

The calculation of the structural factor $c_s c_d$ was performed through the use of a sheet excels follows below.

Calculation of the structural factor c_s*c_d - for upwind (α=0°)

Geometrical and mechanical characteristics

	II	= *Terrain category*
zs=	1.200	*(m) reference height of the structure*
z_0=	0.05	*(m)*
z_{min}=	4	*(m)*
V_m=	**26.9**	**(m/s) mean wind velocity**
ρ=	1.1900	(Kg/m³) air density
C_f=	**0.20**	**force coefficient for the structure (Section 7)**
c_0=	1	*orography factor*
Massa del 1° modo	34.56	*(Kg) is the equivalent mass per unit length according to EN 1991-1-4 § F.4.*
	[illegible]	*turbulence intensity*

$$I_v(z) = \frac{\sigma_v}{v_m(z)} = \frac{k_I}{c_o(z)\cdot \ln(z/z_0)} \quad \text{for} \quad z_{min} \le z \le z_{max} \qquad (4.7)$$
$$I_v(z) = I_v(z_{min}) \quad \text{for} \quad z < z_{min}$$

where:

k_I is the turbulence factor. The value of k_I may be given in the National Annex. The recommended value for k_I is 1,0.

c_o is the orography factor as described in 4.3.3

z_0 is the roughness length, given in Table 4.1

Wind turbolence

$L(z) = L_t \cdot \left(\frac{z}{z_t}\right)^{\alpha}$ for $z \ge z_{min}$; $L(z) = L(z_{min})$ for $z < z_{min}$	39.201	Turblent length scale
Lt=	300	m
zt=	200	m
$S_L(z,n) = \frac{n\cdot S_v(z,n)}{\sigma_v^2} = \frac{6{,}8\cdot f_L(z,n)}{(1+10{,}2\cdot f_L(z,n))^{5/3}}$	0.0633	non dimensional power spectral density
T=	**0.47**	**Fundamental period of the structure**
n=	2.13	natural frequency of the structure in Hz
$f_L(z,n) = \frac{n\cdot L(z)}{v_m(z)}$	3.101	non dimensionale frequency

Calculation of the background factor B - procedure 1 - Annex B

$B^2 = \frac{1}{1+0{,}9\cdot\left(\frac{b+h}{L(z_s)}\right)^{0{,}63}}$	0.560	background factor
b=	**29.588**	**(m) length tracker - see fig.6.1**
h=	**1.994**	**(m) width tracker - see fig.6.1**

Calculation of the peak factor Kp

$k_p = \sqrt{2\cdot\ln(\nu\cdot T)} + \frac{0.6}{\sqrt{2\cdot\ln(\nu\cdot T)}}$	3.433	
T=	600	*(sec) is the averaging time for the mean wind velocity*
$\nu = n_{1,x}\sqrt{\frac{R^2}{B^2+R^2}}$	0.326	*is the up-crossing frequency*
$R^2 = \frac{\pi^2}{2\cdot\delta}\cdot S_L(z_s,n_{1,x})\cdot R_h(\eta_h)\cdot R_b(\eta_b)$	0.013	Resonance response factor
$\eta_h = \frac{4{,}6\cdot h}{L(z_s)}\cdot f_L(z_s,n_{1,x})$	0.725	
$\eta_b = \frac{4{,}6\cdot b}{L(z_s)}\cdot f_L(z_s,n_{1,x})$	10.765	
$R_h = \frac{1}{\eta_h} - \frac{1}{2\cdot\eta_h^2}(1-e^{-2\cdot\eta_h})$	0.651	
$R_b = \frac{1}{\eta_b} - \frac{1}{2\cdot\eta_b^2}(1-e^{-2\cdot\eta_b})$	0.089	

Calculation logarithmic decrement of damping

δ_s=	0.05	logarithmic decrement of structural damping - Table F.2
$\delta_a = \frac{c_f\cdot\rho\cdot b\cdot v_m(z_s)}{2\cdot n_1\cdot m_e}$	1.29	logarithmic decrement of of aerodynamic damping
δ_d=	0	when no special device is used.
$\delta = \delta_s + \delta_a + \delta_d$	1.338	logaritmic decrement of damping

Structural factor cd*cs

$c_s c_d = \frac{1+2\cdot k_p\cdot I_v(z_s)\cdot\sqrt{B^2+R^2}}{1+7\cdot I_v(z_s)}$	**0.842**

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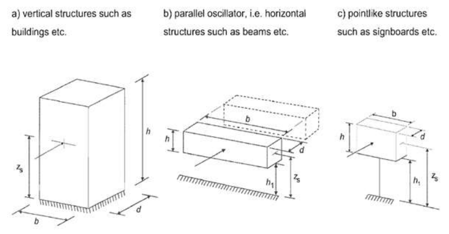
EN 1991-1-4:2005+A1:2010 (E)



NOTE Limitations are also given in 1.1 (2)

$z_s = 0{,}6\cdot h \ge z_{min}$ $\qquad z_s = h_1 + \frac{h}{2} \ge z_{min}$ $\qquad z_s = h_1 + \frac{h}{2} \ge z_{min}$

Figure 6.1 — General shapes of structures covered by the design procedure. The structural dimensions and the reference height used are also shown.

6.3.1 Structural factor $c_s c_d$

(1) The detailed procedure for calculating the structural factor $c_s c_d$ is given in Expression (6.1). This procedure can only be used if the conditions given in 6.3.1 (2) apply.

$$c_s c_d = \frac{1+2\cdot k_p\cdot I_v(z_s)\cdot\sqrt{B^2+R^2}}{1+7\cdot I_v(z_s)} \qquad (6.1)$$

where:

z_s is the reference height for determining the structural factor, see Figure 6.1. For structures where Figure 6.1 does not apply z_s may be set equal to h, the height of the structure.

k_p is the peak factor defined as the ratio of the maximum value of the fluctuating part of the response to its standard deviation

I_v is the turbulence intensity defined in 4.4

B^2 is the background factor, allowing for the lack of full correlation of the pressure on the structure surface

R^2 is the resonance response factor, allowing for turbulence in resonance with the vibration mode

NOTE 1 The size factor c_s takes into account the reduction effect on the wind action due to the non-simultaneity of occurrence of the peak wind pressures on the surface and may be obtained from Expression (6.2):

$$c_s = \frac{1+7\cdot I_v(z_s)\cdot\sqrt{B^2}}{1+7\cdot I_v(z_s)} \qquad (6.2)$$

NOTE 2 The dynamic factor c_d takes into account the increasing effect from vibrations due to turbulence in resonance with the structure and may be obtained from Expression (6.3):

$$c_d = \frac{1+2\cdot k_p\cdot I_v(z_s)\cdot\sqrt{B^2+R^2}}{1+7\cdot I_v(z_s)\cdot\sqrt{B^2}} \qquad (6.3)$$

NOTE 3 The procedure to be used to determine k_p, B and R may be given in the National Annex. A recommended procedure is given in Annex B. An alternative procedure is given in Annex C. As an indication to the users the differences in $c_s c_d$ using Annex C compared to Annex B does not exceed approximately 5%.

(2)P Expression (6.1) shall only be used if all of the following requirements are met:

— the structure corresponds to one of the general shapes shown in Figure 6.1.

— only the along-wind vibration in the fundamental mode is significant, and this mode shape has a constant sign.

NOTE The contribution to the response from the second or higher alongwind vibration modes is negligible.

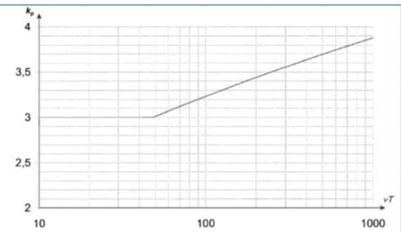


Figure B.2 —Peak factor

$$k_p = \sqrt{2\cdot\ln(\nu\cdot T)} + \frac{0.6}{\sqrt{2\cdot\ln(\nu\cdot T)}} \quad \text{or } k_p = 3 \text{ whichever is larger}$$

where:

Table F.2 —Approximate values of logarithmic decrement of structural damping in the fundamental mode, δ_s

Structural type		structural damping, δ_s
reinforced concrete buildings		0,10
steel buildings		0,05
mixed structures concrete + steel		0,08
reinforced concrete towers and chimneys		0,03
unlined welded steel stacks without external thermal insulation		0,012
unlined welded steel stack with external thermal insulation		0,020
steel stack with one liner with external thermal insulation[a]	h/b < 18	0,020
	20≤h/b<24	0,040
	h/b ≥ 26	0,014
steel stack with two or more liners with external thermal insulation [a]	h/b <18	0,020
	20≤h/b<24	0,040
	h/b ≥ 26	0,025
steel stack with internal brick liner		0,070
steel stack with internal gunite		0,030
coupled stacks without liner		0,015
guyed steel stack without liner		0,04
steel bridges + lattice steel towers	welded	0,02
	high resistance bolts	0,03
	ordinary bolts	0,05
composite bridges		0,04
concrete bridges	prestressed without cracks	0,04
	with cracks	0,10
Timber bridges		0,06 - 0,12
Bridges, aluminium alloys		0,02
Bridges, glass or fibre reinforced plastic		0,04 - 0,08
cables	parallel cables	0,006
	spiral cables	0,020

Calculation of the structural factor c_s*c_d - for downwind (α=0°)

Geometrical and mechanical characteristics

	II	= *Terrain category*
zs=	1.200	*(m) reference height of the structure*
z_0=	0.05	*(m)*
z_{min}=	4	*(m)*
V_m=	**26.9**	**(m/s) mean wind velocity**
ρ=	1.1900	(Kg/m^3) air density
C_f=	**0.50**	**force coefficient for the structure (Section 7)**
c_0=	1	*orography factor*
Massa del 1° modo	34.56	*(Kg) is the equivalent mass per unit length according to EN 1991-1-4 § F.4.*
Iv=	0.228	*turbulence intensity*

$$I_v(z) = \frac{\sigma_v}{v_m(z)} = \frac{k_I}{c_o(z)\cdot \ln(z/z_0)} \quad \text{for} \quad z_{min} \le z \le z_{max} \qquad (4.7)$$
$$I_v(z) = I_v(z_{min}) \quad \text{for} \quad z < z_{min}$$

where:

k_I is the turbulence factor. The value of k_I may be given in the National Annex. The recommended value for k_I is 1,0.

c_o is the orography factor as described in 4.3.3

z_0 is the roughness length, given in Table 4.1

Wind turbolence

$$L(z) = L_t \cdot \left(\frac{z}{z_t}\right)^{\alpha} \quad \text{for} \quad z \ge z_{min}$$
$$L(z) = L(z_{min}) \quad \text{for} \quad z < z_{min}$$

$L(z)$	39.201	Turblent length scale
Lt=	300	m
zt=	200	m
$S_L(z,n) = \frac{n\cdot S_v(z,n)}{\sigma_v^2} = \frac{6{,}8\cdot f_L(z,n)}{(1+10{,}2\cdot f_L(z,n))^{5/3}}$	0.0633	non dimensional power spectral density
T=	**0.47**	**Fundamental period of the structure**
n=	2.13	natural frequency of the structure in Hz
$f_L(z,n) = \frac{n\cdot L(z)}{v_m(z)}$	3.101	non dimensionale frequency

Calculation of the background factor B - procedure 1 - Annex B

$B^2 = \frac{1}{1+0{,}9\cdot\left(\frac{b+h}{L(z_s)}\right)^{0{,}63}}$	0.560	background factor
b=	**29.588**	**(m) length tracker - see fig.6.1**
h=	**1.994**	**(m) width tracker - see fig.6.1**

Calculation of the peak factor Kp

$k_p = \sqrt{2\cdot\ln(\nu\cdot T)} + \frac{0.6}{\sqrt{2\cdot\ln(\nu\cdot T)}}$	3.303	
T=	600	*(sec) is the averaging time for the mean wind velocity*
$\nu = n_{1,x}\sqrt{\frac{R^2}{B^2+R^2}}$	0.210	*is the up-crossing frequency*
$R^2 = \frac{\pi^2}{2\cdot\delta}\cdot S_L(z_s,n_{1,x})\cdot R_h(\eta_h)\cdot R_b(\eta_b)$	0.006	Resonance response factor
$\eta_h = \frac{4{,}6\cdot h}{L(z_s)}\cdot f_L(z_s,n_{1,x})$	0.725	
$\eta_b = \frac{4{,}6\cdot b}{L(z_s)}\cdot f_L(z_s,n_{1,x})$	10.765	
$R_h = \frac{1}{\eta_h} - \frac{1}{2\cdot\eta_h^2}(1-e^{-2\cdot\eta_h})$	0.651	
$R_b = \frac{1}{\eta_b} - \frac{1}{2\cdot\eta_b^2}(1-e^{-2\cdot\eta_b})$	0.089	

Calculation logarithmic decrement of damping

δ_s=	0.05	logarithmic decrement of structural damping - Table F.2
$\delta_a = \frac{c_f\cdot\rho\cdot b\cdot v_m(z_s)}{2\cdot n_1\cdot m_e}$	3.22	logarithmic decrement of of aerodynamic damping
δ_d=	0	when no special device is used.
$\delta = \delta_s + \delta_a + \delta_d$	3.270	logaritmic decrement of damping

Structural factor cd*cs

$c_s c_d = \frac{1+2\cdot k_p\cdot I_v(z_s)\cdot\sqrt{B^2+R^2}}{1+7\cdot I_v(z_s)}$	**0.821**

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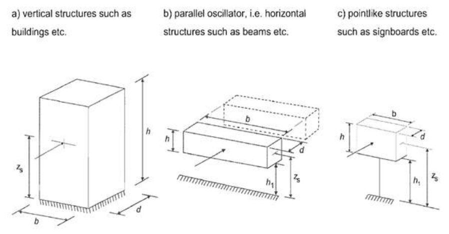
EN 1991-1-4:2005+A1:2010 (E)



NOTE Limitations are also given in 1.1 (2)

$$z_s = 0{,}6\cdot h \ge z_{min} \qquad z_s = h_1 + \frac{h}{2} \ge z_{min} \qquad z_s = h_1 + \frac{h}{2} \ge z_{min}$$

Figure 6.1 — General shapes of structures covered by the design procedure. The structural dimensions and the reference height used are also shown.

6.3.1 Structural factor $c_s c_d$

(1) The detailed procedure for calculating the structural factor $c_s c_d$ is given in Expression (6.1). This procedure can only be used if the conditions given in 6.3.1 (2) apply.

$$c_s c_d = \frac{1+2\cdot k_p\cdot I_v(z_s)\cdot\sqrt{B^2+R^2}}{1+7\cdot I_v(z_s)} \qquad (6.1)$$

where:

z_s is the reference height for determining the structural factor, see Figure 6.1. For structures where Figure 6.1 does not apply z_s may be set equal to h, the height of the structure.

k_p is the peak factor defined as the ratio of the maximum value of the fluctuating part of the response to its standard deviation

I_v is the turbulence intensity defined in 4.4

B^2 is the background factor, allowing for the lack of full correlation of the pressure on the structure surface

R^2 is the resonance response factor, allowing for turbulence in resonance with the vibration mode

NOTE 1 The size factor c_s takes into account the reduction effect on the wind action due to the non-simultaneity of occurrence of the peak wind pressures on the surface and may be obtained from Expression (6.2):

$$c_s = \frac{1+7\cdot I_v(z_s)\cdot\sqrt{B^2}}{1+7\cdot I_v(z_s)} \qquad (6.2)$$

NOTE 2 The dynamic factor c_d takes into account the increasing effect from vibrations due to turbulence in resonance with the structure and may be obtained from Expression (6.3):

$$c_d = \frac{1+2\cdot k_p\cdot I_v(z_s)\cdot\sqrt{B^2+R^2}}{1+7\cdot I_v(z_s)\cdot\sqrt{B^2}} \qquad (6.3)$$

NOTE 3 The procedure to be used to determine k_p, B and R may be given in the National Annex. A recommended procedure is given in Annex B. An alternative procedure is given in Annex C. As an indication to the users the differences in $c_s c_d$ using Annex C compared to Annex B does not exceed approximately 5%.

(2)P Expression (6.1) shall only be used if all of the following requirements are met:

— the structure corresponds to one of the general shapes shown in Figure 6.1.

— only the along-wind vibration in the fundamental mode is significant, and this mode shape has a constant sign.

NOTE The contribution to the response from the second or higher alongwind vibration modes is negligible.

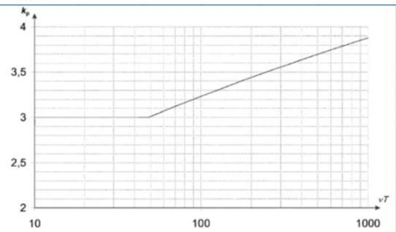


Figure B.2 —Peak factor

$$k_p = \sqrt{2\cdot\ln(\nu\cdot T)} + \frac{0.6}{\sqrt{2\cdot\ln(\nu\cdot T)}} \qquad \text{or } k_p = 3 \text{ whichever is larger}$$

where:

Table F.2 —Approximate values of logarithmic decrement of structural damping in the fundamental mode, δ_s

Structural type		structural damping, δ_s
reinforced concrete buildings		0,10
steel buildings		0,05
mixed structures concrete + steel		0,08
reinforced concrete towers and chimneys		0,03
unlined welded steel stacks without external thermal insulation		0,012
unlined welded steel stack with external thermal insulation		0,020
steel stack with one liner with external thermal insulation[a]	$h/b < 18$	0,020
	$20 \le h/b < 24$	0,040
	$h/b \ge 26$	0,014
steel stack with two or more liners with external thermal insulation [a]	$h/b < 18$	0,020
	$20 \le h/b < 24$	0,040
	$h/b \ge 26$	0,025
steel stack with internal brick liner		0,070
steel stack with internal gunite		0,030
coupled stacks without liner		0,015
guyed steel stack without liner		0,04
steel bridges + lattice steel towers	welded	0,02
	high resistance bolts	0,03
	ordinary bolts	0,05
composite bridges		0,04
concrete bridges	prestressed without cracks	0,04
	with cracks	0,10
Timber bridges		0,06 - 0,12
Bridges, aluminium alloys		0,02
Bridges, glass or fibre reinforced plastic		0,04 - 0,08
cables	parallel cables	0,006
	spiral cables	0,020

Calculation of the structural factor c_s*c_d - for upwind (α=30°)

Geometrical and mechanical characteristics

	II	= Terrain category
zs=	1.200	(m) reference height of the structure
z_0=	0.05	(m)
z_{min}=	4	(m)
V_m=	**14.4**	**(m/s) mean wind velocity**
ρ=	1.1900	(Kg/m³) air density
C_f=	**1.200**	**force coefficient for the structure (Section 7)**
c_0=	1	orography factor
Massa del 1° modo	34.56	(Kg) is the equivalent mass per unit length according to EN 1991-1-4 § F.4.
Iv=	0.228	turbulence intensity

$$I_v(z) = \frac{\sigma_v}{v_m(z)} = \frac{k_I}{c_o(z) \cdot \ln(z/z_0)} \quad \text{for} \quad z_{min} \le z \le z_{max} \qquad (4.7)$$
$$I_v(z) = I_v(z_{min}) \quad \text{for} \quad z < z_{min}$$

where:

k_I is the turbulence factor. The value of k_I may be given in the National Annex. The recommended value for k_I is 1,0.

c_o is the orography factor as described in 4.3.3

z_0 is the roughness length, given in Table 4.1

Wind turbolence

$L(z) = L_t \cdot \left(\frac{z}{z_t}\right)^{\alpha}$ for $z \ge z_{min}$; $L(z) = L(z_{min})$ for $z < z_{min}$	39.201	Turblent length scale
Lt=	300	m
zt=	200	m
$S_L(z,n) = \frac{n \cdot S_v(z,n)}{\sigma_v^2} = \frac{6{,}8 \cdot f_L(z,n)}{(1+10{,}2 \cdot f_L(z,n))^{5/3}}$	0.0427	non dimensional power spectral density
T=	**0.47**	**Fundamental period of the structure**
n=	2.13	natural frequency of the structure in Hz
$f_L(z,n) = \frac{n \cdot L(z)}{v_m(z)}$	5.792	non dimensionale frequency

Calculation of the background factor B - procedure 1 - Annex B

$B^2 = \frac{1}{1+0{,}9 \cdot \left(\frac{b+h}{L(z_s)}\right)^{0{,}63}}$	0.560	background factor
b=	**29.588**	**(m) length tracker - see fig.6.1**
h=	**1.994**	**(m) width tracker - see fig.6.1**

Calculation of the peak factor Kp

$k_p = \sqrt{2 \cdot \ln(\nu \cdot T)} + \frac{0.6}{\sqrt{2 \cdot \ln(\nu \cdot T)}}$	3.063	
T=	600	(sec) is the averaging time for the mean wind velocity
$\nu = n_{1,x}\sqrt{\frac{R^2}{B^2+R^2}}$	0.098	is the up-crossing frequency
$R^2 = \frac{\pi^2}{2 \cdot \delta} \cdot S_L(z_s, n_{1,x}) \cdot R_h(\eta_h) \cdot R_b(\eta_b)$	0.001	Resonance response factor
$\eta_h = \frac{4{,}6 \cdot h}{L(z_s)} \cdot f_L(z_s, n_{1,x})$	1.355	
$\eta_b = \frac{4{,}6 \cdot b}{L(z_s)} \cdot f_L(z_s, n_{1,x})$	20.110	
$R_h = \frac{1}{\eta_h} - \frac{1}{2 \cdot \eta_h^2}(1-e^{-2 \cdot \eta_h})$	0.484	
$R_b = \frac{1}{\eta_b} - \frac{1}{2 \cdot \eta_b^2}(1-e^{-2 \cdot \eta_b})$	0.048	

Calculation logarithmic decrement of damping

δ_s=	0.05	logarithmic decrement of structural damping - Table F.2
$\delta_a = \frac{c_f \cdot \rho \cdot b \cdot v_m(z_s)}{2 \cdot n_1 \cdot m_e}$	4.14	logarithmic decrement of of aerodynamic damping
δ_d=	0	when no special device is used.
$\delta = \delta_s + \delta_a + \delta_d$	4.187	logaritmic decrement of damping

Structural factor cd*cs

$c_s c_d = \frac{1+2 \cdot k_p \cdot I_v(z_s) \cdot \sqrt{B^2+R^2}}{1+7 \cdot I_v(z_s)}$	**0.788**

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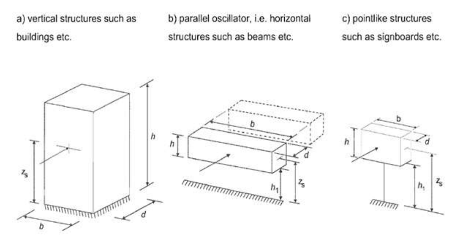
EN 1991-1-4:2005+A1:2010 (E)



$$z_s = 0{,}6 \cdot h \ge z_{min} \qquad z_s = h_1 + \frac{h}{2} \ge z_{min} \qquad z_s = h_1 + \frac{h}{2} \ge z_{min}$$

Figure 6.1 — General shapes of structures covered by the design procedure. The structural dimensions and the reference height used are also shown.

6.3.1 Structural factor c_sc_d

(1) The detailed procedure for calculating the structural factor c_sc_d is given in Expression (6.1). This procedure can only be used if the conditions given in 6.3.1 (2) apply.

$$c_s c_d = \frac{1+2 \cdot k_p \cdot I_v(z_s) \cdot \sqrt{B^2+R^2}}{1+7 \cdot I_v(z_s)} \qquad (6.1)$$

where:

z_s is the reference height for determining the structural factor, see Figure 6.1. For structures where Figure 6.1 does not apply z_s may be set equal to h, the height of the structure.

k_p is the peak factor defined as the ratio of the maximum value of the fluctuating part of the response to its standard deviation

I_v is the turbulence intensity defined in 4.4

B^2 is the background factor, allowing for the lack of full correlation of the pressure on the structure surface

R^2 is the resonance response factor, allowing for turbulence in resonance with the vibration mode

NOTE 1 The size factor c_s takes into account the reduction effect on the wind action due to the non-simultaneity of occurrence of the peak wind pressures on the surface and may be obtained from Expression (6.2):

$$c_s = \frac{1+7 \cdot I_v(z_s) \cdot \sqrt{B^2}}{1+7 \cdot I_v(z_s)} \qquad (6.2)$$

NOTE 2 The dynamic factor c_d takes into account the increasing effect from vibrations due to turbulence in resonance with the structure and may be obtained from Expression (6.3):

$$c_d = \frac{1+2 \cdot k_p \cdot I_v(z_s) \cdot \sqrt{B^2+R^2}}{1+7 \cdot I_v(z_s) \cdot \sqrt{B^2}} \qquad (6.3)$$

NOTE 3 The procedure to be used to determine k_p, B and R may be given in the National Annex. A recommended procedure is given in Annex B. An alternative procedure is given in Annex C. As an indication to the users the differences in c_sc_d using Annex C compared to Annex B does not exceed approximately 5%.

(2)P Expression (6.1) shall only be used if all of the following requirements are met:

- the structure corresponds to one of the general shapes shown in Figure 6.1.
- only the along-wind vibration in the fundamental mode is significant, and this mode shape has a constant sign.

NOTE The contribution to the response from the second or higher alongwind vibration modes is negligible.

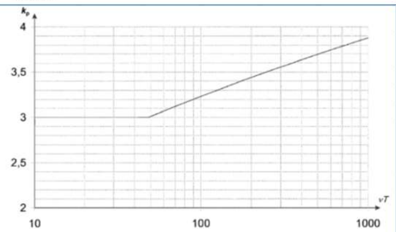


Figure B.2 —Peak factor

$$k_p = \sqrt{2 \cdot \ln(\nu \cdot T)} + \frac{0.6}{\sqrt{2 \cdot \ln(\nu \cdot T)}} \quad \text{or } k_p = 3 \text{ whichever is larger}$$

where:

Table F.2 —Approximate values of logarithmic decrement of structural damping in the fundamental mode, δ_s

Structural type		structural damping, δ_s
reinforced concrete buildings		0,10
steel buildings		0,05
mixed structures concrete + steel		0,08
reinforced concrete towers and chimneys		0,03
unlined welded steel stacks without external thermal insulation		0,012
unlined welded steel stack with external thermal insulation		0,020
steel stack with one liner with external thermal insulation[a]	h/b < 18	0,020
	20≤h/b<24	0,040
	h/b ≥ 26	0,014
steel stack with two or more liners with external thermal insulation [a]	h/b <18	0,020
	20≤h/b<24	0,040
	h/b ≥ 26	0,025
steel stack with internal brick liner		0,070
steel stack with internal gunite		0,030
coupled stacks without liner		0,015
guyed steel stack without liner		0,04
steel bridges + lattice steel towers	welded	0,02
	high resistance bolts	0,03
	ordinary bolts	0,05
composite bridges		0,04
concrete bridges	prestressed without cracks	0,04
	with cracks	0,10
Timber bridges		0,06 - 0,12
Bridges, aluminium alloys		0,02
Bridges, glass or fibre reinforced plastic		0,04 - 0,08
cables	parallel cables	0,006
	spiral cables	0,020

Calculation of the structural factor c_s*c_d - for downwind (α=30°)

Geometrical and mechanical characteristics

	II	= Terrain category
zs=	1.200	*(m) reference height of the structure*
z_0=	0.05	*(m)*
z_{min}=	4	*(m)*
V_m=	**14.4**	**(m/s) mean wind velocity**
ρ=	1.1900	(Kg/m[3]) air density
C_f=	**1.800**	**force coefficient for the structure (Section 7)**
c_0=	1	*orography factor*
Massa del 1° modo	34.56	*(Kg) is the equivalent mass per unit length according to EN 1991-1-4 § F.4.*
Iv=	0.228	*turbulence intensity*

$$I_v(z) = \frac{\sigma_v}{v_m(z)} = \frac{k_I}{c_o(z)\cdot \ln(z/z_0)} \quad \text{for} \quad z_{min} \le z \le z_{max} \qquad (4.7)$$
$$I_v(z) = I_v(z_{min}) \quad \text{for} \quad z < z_{min}$$

where:

k_I is the turbulence factor. The value of k_I may be given in the National Annex. The recommended value for k_I is 1,0.

c_o is the orography factor as described in 4.3.3

z_0 is the roughness length, given in Table 4.1

Wind turbolence

$L(z) = L_t \cdot \left(\frac{z}{z_t}\right)^{\alpha}$ for $z \ge z_{min}$; $L(z) = L(z_{min})$ for $z < z_{min}$	39.201	Turblent length scale
Lt=	300	m
zt=	200	m
$S_L(z,n) = \frac{n\cdot S_v(z,n)}{\sigma_v^2} = \frac{6{,}8\cdot f_L(z,n)}{(1+10{,}2\cdot f_L(z,n))^{5/3}}$	0.0427	non dimensional power spectral density
T=	**0.47**	**Fundamental period of the structure**
n=	2.13	natural frequency of the structure in Hz
$f_L(z,n) = \frac{n\cdot L(z)}{v_m(z)}$	5.792	non dimensionale frequency

Calculation of the background factor B - procedure 1 - Annex B

$B^2 = \frac{1}{1+0{,}9\cdot\left(\frac{b+h}{L(z_s)}\right)^{0{,}63}}$	0.560	background factor
b=	**29.588**	**(m) length tracker - see fig.6.1**
h=	**1.994**	**(m) width tracker - see fig.6.1**

Calculation of the peak factor Kp

$k_p = \sqrt{2\cdot\ln(\nu\cdot T)} + \frac{0.6}{\sqrt{2\cdot\ln(\nu\cdot T)}}$	2.998	
T=	600	*(sec) is the averaging time for the mean wind velocity*
$\nu = n_{1,x}\sqrt{\frac{R^2}{B^2+R^2}}$	0.080	*is the up-crossing frequency*
$R^2 = \frac{\pi^2}{2\cdot\delta}\cdot S_L(z_s,n_{1,x})\cdot R_h(\eta_h)\cdot R_b(\eta_b)$	0.001	Resonance response factor
$\eta_h = \frac{4{,}6\cdot h}{L(z_s)}\cdot f_L(z_s,n_{1,x})$	1.355	
$\eta_b = \frac{4{,}6\cdot b}{L(z_s)}\cdot f_L(z_s,n_{1,x})$	20.110	
$R_h = \frac{1}{\eta_h} - \frac{1}{2\cdot\eta_h^2}(1-e^{-2\cdot\eta_h})$	0.484	
$R_b = \frac{1}{\eta_b} - \frac{1}{2\cdot\eta_b^2}(1-e^{-2\cdot\eta_b})$	0.048	

Calculation logarithmic decrement of damping

δ_s=	0.05	logarithmic decrement of structural damping - Table F.2
$\delta_a = \frac{c_f\cdot\rho\cdot b\cdot v_m(z_s)}{2\cdot n_1\cdot m_e}$	6.21	logarithmic decrement of of aerodynamic damping
δ_d=	0	when no special device is used.
$\delta = \delta_s + \delta_a + \delta_d$	6.256	logaritmic decrement of damping

Structural factor cd*cs

$c_s c_d = \frac{1+2\cdot k_p\cdot I_v(z_s)\cdot\sqrt{B^2+R^2}}{1+7\cdot I_v(z_s)}$	**0.779**

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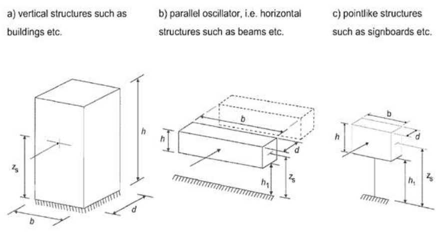

NOTE Limitations are also given in 1.1 (2)

$z_s = 0{,}6\cdot h \ge z_{min}$ $\qquad z_s = h_1 + \frac{h}{2} \ge z_{min}$ $\qquad z_s = h_1 + \frac{h}{2} \ge z_{min}$

Figure 6.1 — General shapes of structures covered by the design procedure. The structural dimensions and the reference height used are also shown.

6.3.1 Structural factor c_sc_d

(1) The detailed procedure for calculating the structural factor c_sc_d is given in Expression (6.1). This procedure can only be used if the conditions given in 6.3.1 (2) apply.

$$c_sc_d = \frac{1+2\cdot k_p\cdot I_v(z_s)\cdot\sqrt{B^2+R^2}}{1+7\cdot I_v(z_s)} \qquad (6.1)$$

where:

z_s is the reference height for determining the structural factor, see Figure 6.1. For structures where Figure 6.1 does not apply z_s may be set equal to h, the height of the structure.

k_p is the peak factor defined as the ratio of the maximum value of the fluctuating part of the response to its standard deviation

I_v is the turbulence intensity defined in 4.4

B^2 is the background factor, allowing for the lack of full correlation of the pressure on the structure surface

R^2 is the resonance response factor, allowing for turbulence in resonance with the vibration mode

NOTE 1 The size factor c_s takes into account the reduction effect on the wind action due to the non-simultaneity of occurrence of the peak wind pressures on the surface and may be obtained from Expression (6.2):

$$c_s = \frac{1+7\cdot I_v(z_s)\cdot\sqrt{B^2}}{1+7\cdot I_v(z_s)} \qquad (6.2)$$

NOTE 2 The dynamic factor c_d takes into account the increasing effect from vibrations due to turbulence in resonance with the structure and may be obtained from Expression (6.3):

$$c_d = \frac{1+2\cdot k_p\cdot I_v(z_s)\cdot\sqrt{B^2+R^2}}{1+7\cdot I_v(z_s)\cdot\sqrt{B^2}} \qquad (6.3)$$

NOTE 3 The procedure to be used to determine k_p, B and R may be given in the National Annex. A recommended procedure is given in Annex B. An alternative procedure is given in Annex C. As an indication to the users the differences in c_sc_d using Annex C compared to Annex B does not exceed approximately 5%.

(2)P Expression (6.1) shall only be used if all of the following requirements are met:

— the structure corresponds to one of the general shapes shown in Figure 6.1.

— only the along-wind vibration in the fundamental mode is significant, and this mode shape has a constant sign.

NOTE The contribution to the response from the second or higher alongwind vibration modes is negligible.

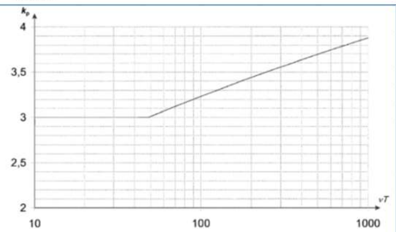

Figure B.2 —Peak factor

$$k_p = \sqrt{2\cdot\ln(\nu\cdot T)} + \frac{0.6}{\sqrt{2\cdot\ln(\nu\cdot T)}}$$ or k_p= 3 whichever is larger

where:

Table F.2 —Approximate values of logarithmic decrement of structural damping in the fundamental mode, δ_s

Structural type		structural damping, δ_s
reinforced concrete buildings		0,10
steel buildings		0,05
mixed structures concrete + steel		0,08
reinforced concrete towers and chimneys		0,03
unlined welded steel stacks without external thermal insulation		0,012
unlined welded steel stack with external thermal insulation		0,020
steel stack with one liner with external thermal insulation[a]	h/b < 18	0,020
	20≤h/b<24	0,040
	h/b ≥ 26	0,014
steel stack with two or more liners with external thermal insulation [a]	h/b <18	0,020
	20≤h/b<24	0,040
	h/b ≥ 26	0,025
steel stack with internal brick liner		0,070
steel stack with internal gunite		0,030
coupled stacks without liner		0,015
guyed steel stack without liner		0,04
steel bridges + lattice steel towers	welded	0,02
	high resistance bolts	0,03
	ordinary bolts	0,05
composite bridges		0,04
concrete bridges	prestressed without cracks	0,04
	with cracks	0,10
Timber bridges		0,06 - 0,12
Bridges, aluminium alloys		0,02
Bridges, glass or fibre reinforced plastic		0,04 - 0,08
cables	parallel cables	0,006
	spiral cables	0,020

Calculation of the structural factor c_s*c_d - for upwind (α=55°)

1.41

	II	= Terrain category
zs=	1.200	(m) reference height of the structure
z_0=	0.05	(m)
z_{min}=	4	(m)
V_m=	**14.4**	**(m/s) mean wind velocity**
ρ=	1.1900	(Kg/m^3) air density
C_f=	**1.410**	**force coefficient for the structure (Section 7)**
c_0=	1	orography factor
Massa del 1° modo	34.56	(Kg) is the equivalent mass per unit length according to EN 1991-1-4 § F.4.
Iv=	0.228	turbulence intensity

$$I_v(z) = \frac{\sigma_v}{v_m(z)} = \frac{k_I}{c_o(z)\cdot \ln(z/z_0)} \quad \text{for} \quad z_{min} \le z \le z_{max} \qquad (4.7)$$
$$I_v(z) = I_v(z_{min}) \quad \text{for} \quad z < z_{min}$$

where:

k_I is the turbulence factor. The value of k_I may be given in the National Annex. The recommended value for k_I is 1,0.

c_o is the orography factor as described in 4.3.3

z_0 is the roughness length, given in Table 4.1

Wind turbolence

$$L(z) = L_t \cdot \left(\frac{z}{z_t}\right)^{\alpha} \quad \text{for} \quad z \ge z_{min}$$
$$L(z) = L(z_{min}) \quad \text{for} \quad z < z_{min}$$

$L(z)$	39.201	Turblent length scale
Lt=	300	m
zt=	200	m
$S_L(z,n) = \frac{n\cdot S_v(z,n)}{\sigma_v^2} = \frac{6{,}8\cdot f_L(z,n)}{(1+10{,}2\cdot f_L(z,n))^{5/3}}$	0.0427	non dimensional power spectral density
T=	**0.47**	**Fundamental period of the structure**
n=	2.13	natural frequency of the structure in Hz
$f_L(z,n) = \frac{n\cdot L(z)}{v_m(z)}$	5.792	non dimensionale frequency

Calculation of the background factor B - procedure 1 - Annex B

$B^2 = \frac{1}{1+0{,}9\cdot\left(\frac{b+h}{L(z_s)}\right)^{0{,}63}}$	0.560	background factor
b=	**29.588**	**(m) length tracker - see fig.6.1**
h=	**1.994**	**(m) width tracker - see fig.6.1**

Calculation of the peak factor Kp

$k_p = \sqrt{2\cdot\ln(\nu\cdot T)} + \frac{0.6}{\sqrt{2\cdot\ln(\nu\cdot T)}}$	3.037	
T=	600	(sec) is the averaging time for the mean wind velocity
$\nu = n_{1,x}\sqrt{\frac{R^2}{B^2+R^2}}$	0.090	is the up-crossing frequency
$R^2 = \frac{\pi^2}{2\cdot\delta}\cdot S_L(z_s,n_{1,x})\cdot R_h(\eta_h)\cdot R_b(\eta_b)$	0.001	Resonance response factor
$\eta_h = \frac{4{,}6\cdot h}{L(z_s)}\cdot f_L(z_s,n_{1,x})$	1.355	
$\eta_b = \frac{4{,}6\cdot b}{L(z_s)}\cdot f_L(z_s,n_{1,x})$	20.110	
$R_h = \frac{1}{\eta_h} - \frac{1}{2\cdot\eta_h^2}(1-e^{-2\cdot\eta_h})$	0.484	
$R_b = \frac{1}{\eta_b} - \frac{1}{2\cdot\eta_b^2}(1-e^{-2\cdot\eta_b})$	0.048	

Calculation logarithmic decrement of damping

δ_s=	0.05	logarithmic decrement of structural damping - Table F.2
$\delta_a = \frac{c_f\cdot\rho\cdot b\cdot v_m(z_s)}{2\cdot n_1\cdot m_e}$	4.86	logarithmic decrement of of aerodynamic damping
δ_d=	0	when no special device is used.
$\delta = \delta_s + \delta_a + \delta_d$	4.911	logaritmic decrement of damping

Structural factor cd*cs

$c_sc_d = \frac{1+2\cdot k_p\cdot I_v(z_s)\cdot\sqrt{B^2+R^2}}{1+7\cdot I_v(z_s)}$	**0.785**	

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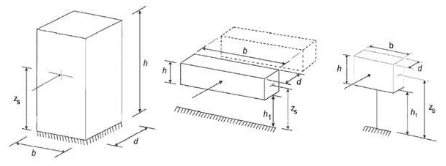
EN 1991-1-4:2005+A1:2010 (E)

a) vertical structures such as buildings etc. | b) parallel oscillator, i.e. horizontal structures such as beams etc. | c) pointlike structures such as signboards etc.



NOTE Limitations are also given in 1.1 (2)

$z_s = 0{,}6\cdot h \ge z_{min}$ | $z_s = h_1 + \frac{h}{2} \ge z_{min}$ | $z_s = h_1 + \frac{h}{2} \ge z_{min}$

Figure 6.1 — General shapes of structures covered by the design procedure. The structural dimensions and the reference height used are also shown.

6.3.1 Structural factor c_sc_d

(1) The detailed procedure for calculating the structural factor c_sc_d is given in Expression (6.1). This procedure can only be used if the conditions given in 6.3.1 (2) apply.

$$c_sc_d = \frac{1+2\cdot k_p\cdot I_v(z_s)\cdot\sqrt{B^2+R^2}}{1+7\cdot I_v(z_s)} \qquad (6.1)$$

where:

z_s is the reference height for determining the structural factor, see Figure 6.1. For structures where Figure 6.1 does not apply z_s may be set equal to h, the height of the structure.

k_p is the peak factor defined as the ratio of the maximum value of the fluctuating part of the response to its standard deviation

I_v is the turbulence intensity defined in 4.4

B^2 is the background factor, allowing for the lack of full correlation of the pressure on the structure surface

R^2 is the resonance response factor, allowing for turbulence in resonance with the vibration mode

NOTE 1 The size factor c_s takes into account the reduction effect on the wind action due to the non-simultaneity of occurrence of the peak wind pressures on the surface and may be obtained from Expression (6.2):

$$c_s = \frac{1+7\cdot I_v(z_s)\cdot\sqrt{B^2}}{1+7\cdot I_v(z_s)} \qquad (6.2)$$

NOTE 2 The dynamic factor c_d takes into account the increasing effect from vibrations due to turbulence in resonance with the structure and may be obtained from Expression (6.3):

$$c_d = \frac{1+2\cdot k_p\cdot I_v(z_s)\cdot\sqrt{B^2+R^2}}{1+7\cdot I_v(z_s)\cdot\sqrt{B^2}} \qquad (6.3)$$

NOTE 3 The procedure to be used to determine k_p, B and R may be given in the National Annex. A recommended procedure is given in Annex B. An alternative procedure is given in Annex C. As an indication to the users the differences in c_sc_d using Annex C compared to Annex B does not exceed approximately 5%.

(2)P Expression (6.1) shall only be used if all of the following requirements are met:

- the structure corresponds to one of the general shapes shown in Figure 6.1.
- only the along-wind vibration in the fundamental mode is significant, and this mode shape has a constant sign.

NOTE The contribution to the response from the second or higher alongwind vibration modes is negligible.

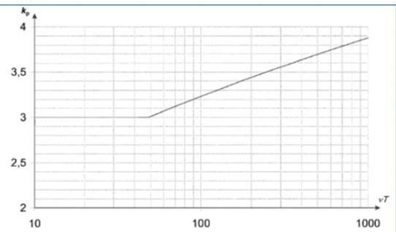


Figure B.2 —Peak factor

$$k_p = \sqrt{2\cdot\ln(\nu\cdot T)} + \frac{0.6}{\sqrt{2\cdot\ln(\nu\cdot T)}} \quad \text{or } k_p = 3 \text{ whichever is larger}$$

where:

Table F.2 —Approximate values of logarithmic decrement of structural damping in the fundamental mode, δ_s

Structural type		structural damping, δ_s
reinforced concrete buildings		0,10
steel buildings		0,05
mixed structures concrete + steel		0,08
reinforced concrete towers and chimneys		0,03
unlined welded steel stacks without external thermal insulation		0,012
unlined welded steel stack with external thermal insulation		0,020
steel stack with one liner with external thermal insulation[a]	$h/b < 18$	0,020
	$20 \le h/b < 24$	0,040
	$h/b \ge 26$	0,014
steel stack with two or more liners with external thermal insulation [a]	$h/b < 18$	0,020
	$20 \le h/b < 24$	0,040
	$h/b \ge 26$	0,025
steel stack with internal brick liner		0,070
steel stack with internal gunite		0,030
coupled stacks without liner		0,015
guyed steel stack without liner		0,04
steel bridges + lattice steel towers	welded	0,02
	high resistance bolts	0,03
	ordinary bolts	0,05
composite bridges		0,04
concrete bridges	prestressed without cracks	0,04
	with cracks	0,10
Timber bridges		0,06 - 0,12
Bridges, aluminium alloys		0,02
Bridges, glass or fibre reinforced plastic		0,04 - 0,08
cables	parallel cables	0,006
	spiral cables	0,020

Calculation of the structural factor c_s*c_d - for downwind (α=55°)

Geometrical and mechanical characteristics

	II	= *Terrain category*
zs=	1.200	*(m) reference height of the structure*
z_0=	0.05	*(m)*
z_{min}=	4	*(m)*
V_m=	**14.4**	**(m/s) mean wind velocity**
ρ=	1.1900	(Kg/m^3) air density
C_f=	**1.755**	**force coefficient for the structure (Section 7)**
c_0=	1	*orography factor*
Massa del 1° modo	34.56	*(Kg) is the equivalent mass per unit length according to EN 1991-1-4 § F.4.*
Iv=	0.228	*turbulence intensity*

$$I_v(z) = \frac{\sigma_v}{v_m(z)} = \frac{k_I}{c_o(z)\cdot \ln(z/z_0)} \quad \text{for} \quad z_{min} \le z \le z_{max} \qquad (4.7)$$
$$I_v(z) = I_v(z_{min}) \quad \text{for} \quad z < z_{min}$$

where:

k_I is the turbulence factor. The value of k_I may be given in the National Annex. The recommended value for k_I is 1,0.

c_o is the orography factor as described in 4.3.3

z_0 is the roughness length, given in Table 4.1

Wind turbolence

$L(z) = L_t \cdot \left(\frac{z}{z_t}\right)^{\alpha}$ for $z \ge z_{min}$; $L(z) = L(z_{min})$ for $z < z_{min}$	39.201	Turblent length scale
Lt=	300	m
zt=	200	m
$S_L(z,n) = \frac{n \cdot S_v(z,n)}{\sigma_v^2} = \frac{6{,}8 \cdot f_L(z,n)}{(1+10{,}2 \cdot f_L(z,n))^{5/3}}$	0.0427	non dimensional power spectral density
T=	**0.47**	**Fundamental period of the structure**
n=	2.13	natural frequency of the structure in Hz
$f_L(z,n) = \frac{n \cdot L(z)}{v_m(z)}$	5.792	non dimensionale frequency

Calculation of the background factor B - procedure 1 - Annex B

$B^2 = \frac{1}{1 + 0{,}9 \cdot \left(\frac{b+h}{L(z_s)}\right)^{0{,}63}}$	0.560	background factor
b=	**29.588**	**(m) length tracker - see fig.6.1**
h=	**1.994**	**(m) width tracker - see fig.6.1**

Calculation of the peak factor Kp

$k_p = \sqrt{2 \cdot \ln(\nu \cdot T)} + \frac{0.6}{\sqrt{2 \cdot \ln(\nu \cdot T)}}$	3.002	
T=	600	*(sec) is the averaging time for the mean wind velocity*
$\nu = n_{1,x}\sqrt{\frac{R^2}{B^2+R^2}}$	0.081	*is the up-crossing frequency*
$R^2 = \frac{\pi^2}{2 \cdot \delta} \cdot S_L(z_s, n_{1,x}) \cdot R_h(\eta_h) \cdot R_b(\eta_b)$	0.001	Resonance response factor
$\eta_h = \frac{4{,}6 \cdot h}{L(z_s)} \cdot f_L(z_s, n_{1,x})$	1.355	
$\eta_b = \frac{4{,}6 \cdot b}{L(z_s)} \cdot f_L(z_s, n_{1,x})$	20.110	
$R_h = \frac{1}{\eta_h} - \frac{1}{2 \cdot \eta_h^2}(1 - e^{-2 \cdot \eta_h})$	0.484	
$R_b = \frac{1}{\eta_b} - \frac{1}{2 \cdot \eta_b^2}(1 - e^{-2 \cdot \eta_b})$	0.048	

Calculation logarithmic decrement of damping

δ_s=	0.05	logarithmic decrement of structural damping - Table F.2
$\delta_a = \frac{c_f \cdot \rho \cdot b \cdot v_m(z_s)}{2 \cdot n_1 \cdot m_e}$	6.05	logarithmic decrement of of aerodynamic damping
δ_d=	0	when no special device is used.
$\delta = \delta_s + \delta_a + \delta_d$	6.101	logaritmic decrement of damping

Structural factor cd*cs

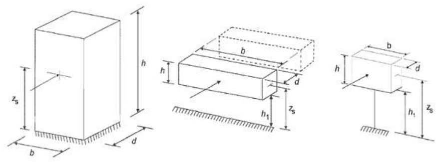
$c_s c_d = \frac{1 + 2 \cdot k_p \cdot I_v(z_s) \cdot \sqrt{B^2+R^2}}{1 + 7 \cdot I_v(z_s)}$	**0.780**

BS EN 1991-1-4:2005+A1:2010
EN 1991-1-4:2005+A1:2010 (E)

a) vertical structures such as buildings etc.

b) parallel oscillator, i.e. horizontal structures such as beams etc.

c) pointlike structures such as signboards etc.



NOTE Limitations are also given in 1.1 (2)

$z_s = 0{,}6 \cdot h \ge z_{min}$ $\qquad z_s = h_1 + \frac{h}{2} \ge z_{min}$ $\qquad z_s = h_1 + \frac{h}{2} \ge z_{min}$

Figure 6.1 — General shapes of structures covered by the design procedure. The structural dimensions and the reference height used are also shown.

6.3.1 Structural factor $c_s c_d$

(1) The detailed procedure for calculating the structural factor $c_s c_d$ is given in Expression (6.1). This procedure can only be used if the conditions given in 6.3.1 (2) apply.

$$c_s c_d = \frac{1 + 2 \cdot k_p \cdot I_v(z_s) \cdot \sqrt{B^2+R^2}}{1 + 7 \cdot I_v(z_s)} \qquad (6.1)$$

where:

z_s is the reference height for determining the structural factor, see Figure 6.1. For structures where Figure 6.1 does not apply z_s may be set equal to h, the height of the structure.

k_p is the peak factor defined as the ratio of the maximum value of the fluctuating part of the response to its standard deviation

I_v is the turbulence intensity defined in 4.4

B^2 is the background factor, allowing for the lack of full correlation of the pressure on the structure surface

R^2 is the resonance response factor, allowing for turbulence in resonance with the vibration mode

NOTE 1 The size factor c_s takes into account the reduction effect on the wind action due to the non-simultaneity of occurrence of the peak wind pressures on the surface and may be obtained from Expression (6.2):

$$c_s = \frac{1 + 7 \cdot I_v(z_s) \cdot \sqrt{B^2}}{1 + 7 \cdot I_v(z_s)} \qquad (6.2)$$

NOTE 2 The dynamic factor c_d takes into account the increasing effect from vibrations due to turbulence in resonance with the structure and may be obtained from Expression (6.3):

$$c_d = \frac{1 + 2 \cdot k_p \cdot I_v(z_s) \cdot \sqrt{B^2+R^2}}{1 + 7 \cdot I_v(z_s) \cdot \sqrt{B^2}} \qquad (6.3)$$

NOTE 3 The procedure to be used to determine k_p, B and R may be given in the National Annex. A recommended procedure is given in Annex B. An alternative procedure is given in Annex C. As an indication to the users the differences in $c_s c_d$ using Annex C compared to Annex B does not exceed approximately 5%.

(2)P Expression (6.1) shall only be used if all of the following requirements are met:

- the structure corresponds to one of the general shapes shown in Figure 6.1.
- only the along-wind vibration in the fundamental mode is significant, and this mode shape has a constant sign.

NOTE The contribution to the response from the second or higher alongwind vibration modes is negligible.

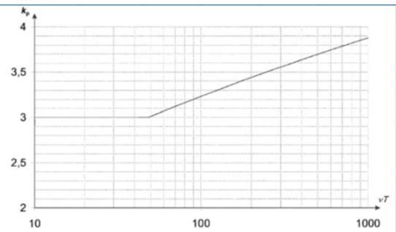


Figure B.2 —Peak factor

$k_p = \sqrt{2 \cdot \ln(\nu \cdot T)} + \frac{0.6}{\sqrt{2 \cdot \ln(\nu \cdot T)}}$ or k_p= 3 whichever is larger

where:

Table F.2 —Approximate values of logarithmic decrement of structural damping in the fundamental mode, δ_s

Structural type		structural damping, δ_s
reinforced concrete buildings		0,10
steel buildings		0,05
mixed structures concrete + steel		0,08
reinforced concrete towers and chimneys		0,03
unlined welded steel stacks without external thermal insulation		0,012
unlined welded steel stack with external thermal insulation		0,020
steel stack with one liner with external thermal insulation[a]	$h/b < 18$	0,020
	$20 \le h/b < 24$	0,040
	$h/b \ge 26$	0,014
steel stack with two or more liners with external thermal insulation [a]	$h/b < 18$	0,020
	$20 \le h/b < 24$	0,040
	$h/b \ge 26$	0,025
steel stack with internal brick liner		0,070
steel stack with internal gunite		0,030
coupled stacks without liner		0,015
guyed steel stack without liner		0,04
steel bridges + lattice steel towers	welded	0,02
	high resistance bolts	0,03
	ordinary bolts	0,05
composite bridges		0,04
concrete bridges	prestressed without cracks	0,04
	with cracks	0,10
Timber bridges		0,06 - 0,12
Bridges, aluminium alloys		0,02
Bridges, glass or fibre reinforced plastic		0,04 - 0,08
cables	parallel cables	0,006
	spiral cables	0,020

FORCE COEFFICIENT

The force coefficients are determined in according to the Eurocode 1, EN1991 – 1 – 1 – 4: 2010, for the configuration with angle inclination -30°<α<+30°.

For the angle -55°<α<–30°and 30°<α<55°, configurations for which there are no values reported in the European structural codes, the C_p is determined in according to a fluid dynamic study named "*Aerodynamic performance of a solar tracker panel with a ±55° inclination angle w.r.t. the ground*".

C_{pb} and C_{ps} for Configurations (A) and (B) with angle of inclination -30°<α<30°.

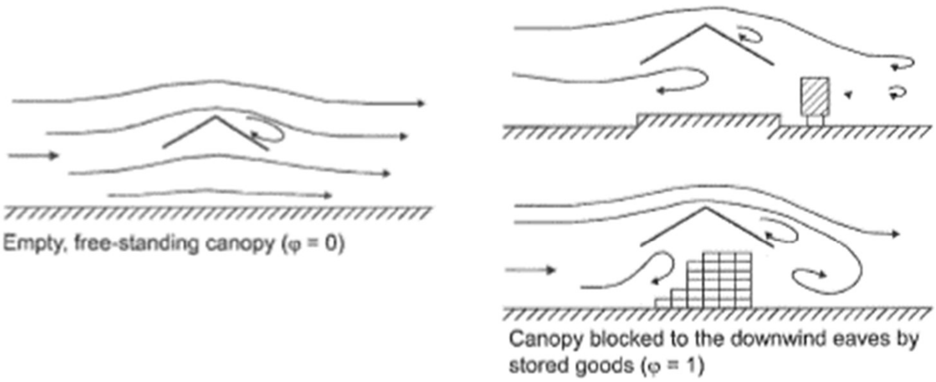
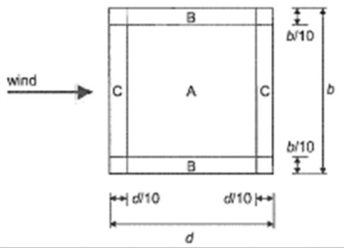


Figure 7.15 — Airflow over canopy roofs

Table 7.6 — $c_{p,net}$ and c_f values for monopitch canopies



			Net Pressure coefficients $c_{p,net}$		
Roof angle α	Blockage φ	Overall Force Coefficients c_f	Zone A	Zone B	Zone C
0°	Maximum all φ	+ 0,2	+ 0,5	+ 1,8	+ 1,1
	Minimum φ = 0	- 0,5	- 0,6	- 1,3	- 1,4
	Minimum φ = 1	- 1,3	- 1,5	- 1,8	- 2,2
5°	Maximum all φ	+ 0,4	+ 0,8	+ 2,1	+ 1,3
	Minimum φ = 0	- 0,7	- 1,1	- 1,7	- 1,8
	Minimum φ = 1	- 1,4	- 1,6	- 2,2	- 2,5
10°	Maximum all φ	+ 0,5	+ 1,2	+ 2,4	+ 1,6
	Minimum φ = 0	- 0,9	- 1,5	- 2,0	- 2,1
	Minimum φ = 1	- 1,4	AC2 - 1,6 AC2	- 2,6	- 2,7
15°	Maximum all φ	+ 0,7	+ 1,4	+ 2,7	+ 1,8
	Minimum φ = 0	- 1,1	- 1,8	- 2,4	- 2,5
	Minimum φ = 1	- 1,4	- 1,6	- 2,9	- 3,0
20°	Maximum all φ	+ 0,8	+ 1,7	+ 2,9	+ 2,1
	Minimum φ = 0	- 1,3	- 2,2	- 2,8	- 2,9
	Minimum φ = 1	- 1,4	- 1,6	- 2,9	- 3,0
25°	Maximum all φ	+ 1,0	+ 2,0	+ 3,1	+ 2,3
	Minimum φ = 0	- 1,6	- 2,6	- 3,2	- 3,2
	Minimum φ = 1	- 1,4	- 1,5	- 2,5	- 2,8
30°	Maximum all φ	+ 1,2	+ 2,2	+ 3,2	+ 2,4
	Minimum φ = 0	- 1,8	- 3,0	- 3,8	- 3,6
	Minimum φ = 1	- 1,4	- 1,5	- 2,2	- 2,7
NOTE	+ values indicate a net downward acting wind action - values represent a net upward acting wind action				

Model A, α=0°

- $c_{pn,+0°} = +0,20$ *upwind*
- $c_{pn,-0°} = -0,50$ *downwind*
-

Model B, α=30°

- $c_{pn,+30°} = +1,20$ *upwind*
- $c_{pn,-30°} = -1,80$ *downwind*

C_{pb} and C_{ps} for Configuration (C) with angle of inclination α=±55°.

The force coefficient for the structur cf for the canopy roofs is given in the report named – "*Aerodynamic performance of a solar tracker panel with a ±55° inclination angle w.r.t. the ground*" by A. Corsini and G. Delibra (Dept. of Mechanical and Aerospace Engineering, 'Sapienza', University of Rome, edition 05/01/2017). In the par. 3 are reported the force coefficients named c_p

+55° arrangement, Figure 3

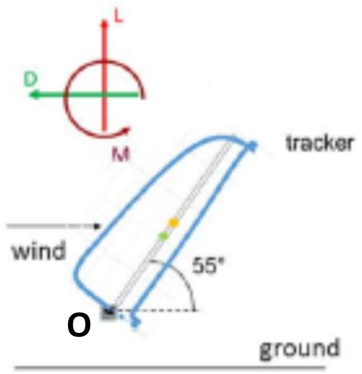


Figure 3 – Reference scheme. Black point: axis origin.
Green point: center of pressure. Yellow point: geometrical center of the tracker.

Cp=1,410 and coordinates of the center of pressure X=0,524m, Y=0,713m respect to point O.

-55° arrangement, Figure 5

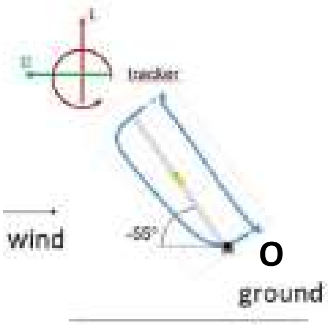
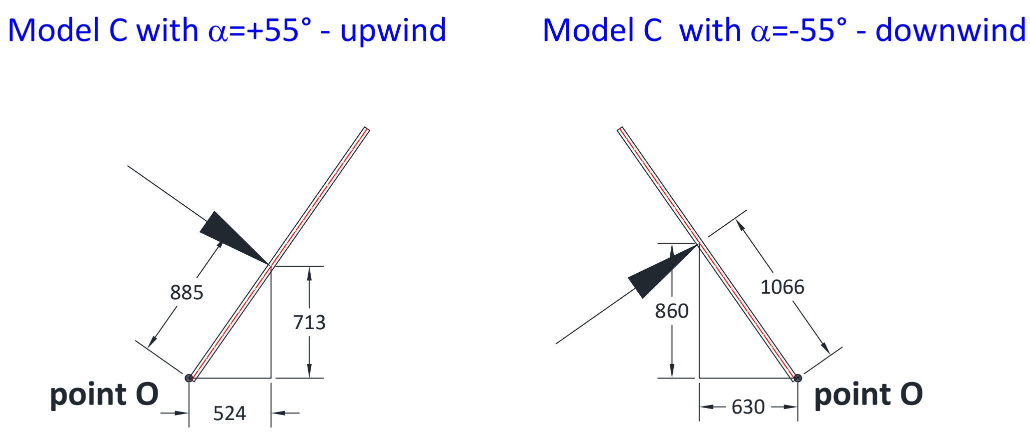


Figure 5 – Reference scheme. Black point: axis origin.
Green point: center of pressure. Yellow point: geometrical center of the tracker.

Cp=-1,755 and coordinates of the center of pressure X=0,630m, Y=0,860m respect to point O.

The application of the wind force $F_w = p_w \cdot A_{ref}$ is given from the coordinates of the center of pressure contained in the par. 3 of the "*Aerodynamic performance of a solar tracker panel with a ±55° inclination angle w.r.t. the ground*" by A. Corsini and G. Delibra (Dept. of Mechanical and Aerospace Engineering, 'Sapienza', University of Rome):



The panel inserted in the fluid dynamic modeling has a length L=2000mm. Therefore, the eccentricity values are:

– ***α=+55°, direction upwind*** e = (2000/2 - 885) = 115mm;

– ***α=-55°, direction downwind*** e = (2000/2 - 1066) = -66mm;

The panel used has a length L=1960mm, for this reason, the coordinates of the center of pressure are:

Model C, α=+55°, direction upwind

- C_p = +1,410, e = 115 · (1994/2000) = 115mm;

Model C, α=-55°, direction downwind

- C_p = -1,755, e = -66 · (1994/2000) = -66mm;

WIND PRESSURE CALCULATION

The wind pressure calculation is determined in according to Section 3.3.4 of the *D.M. 17 gennaio 2018 – Norme Tecniche per le Costruzioni*, based on the following expression

$$P_{w,\alpha} = q_{r,\alpha} \cdot c_e \cdot c_d \cdot c_{pn,\alpha}$$

Therefore, the load conditions are:

Model A, α=0°

- $P_{w,+0°} = q_{r,+0°} \cdot c_e \cdot c_s c_d \cdot c_{pn,+0°} = 430 \cdot 1{,}708 \cdot 0{,}842 \cdot 0{,}20 = 124\ N/m^2$ .. (upwind);
- $P_{w,-0°} = q_{r,-0°} \cdot c_e \cdot c_s c_d \cdot c_{pn,-0°} = -430 \cdot 1{,}708 \cdot 0{,}821 \cdot 0{,}5 = -302\ N/m^2$ (downwind);

Model B, α=30°

- $P_{w,+30°} = q_{r,+30°} \cdot c_e \cdot c_s c_d \cdot c_{pn,+30°} = 123 \cdot 1 \cdot 0{,}788 \cdot 1{,}20 = 117\ N/m^2$ ..... (upwind);
- $P_{w,-30°} = q_{r,-30°} \cdot c_e \cdot c_s c_d \cdot c_{pn,-30°} = -123 \cdot 1 \cdot 0{,}779 \cdot 1{,}8 = -173\ N/m^2$. (downwind);

Model C, α=55°

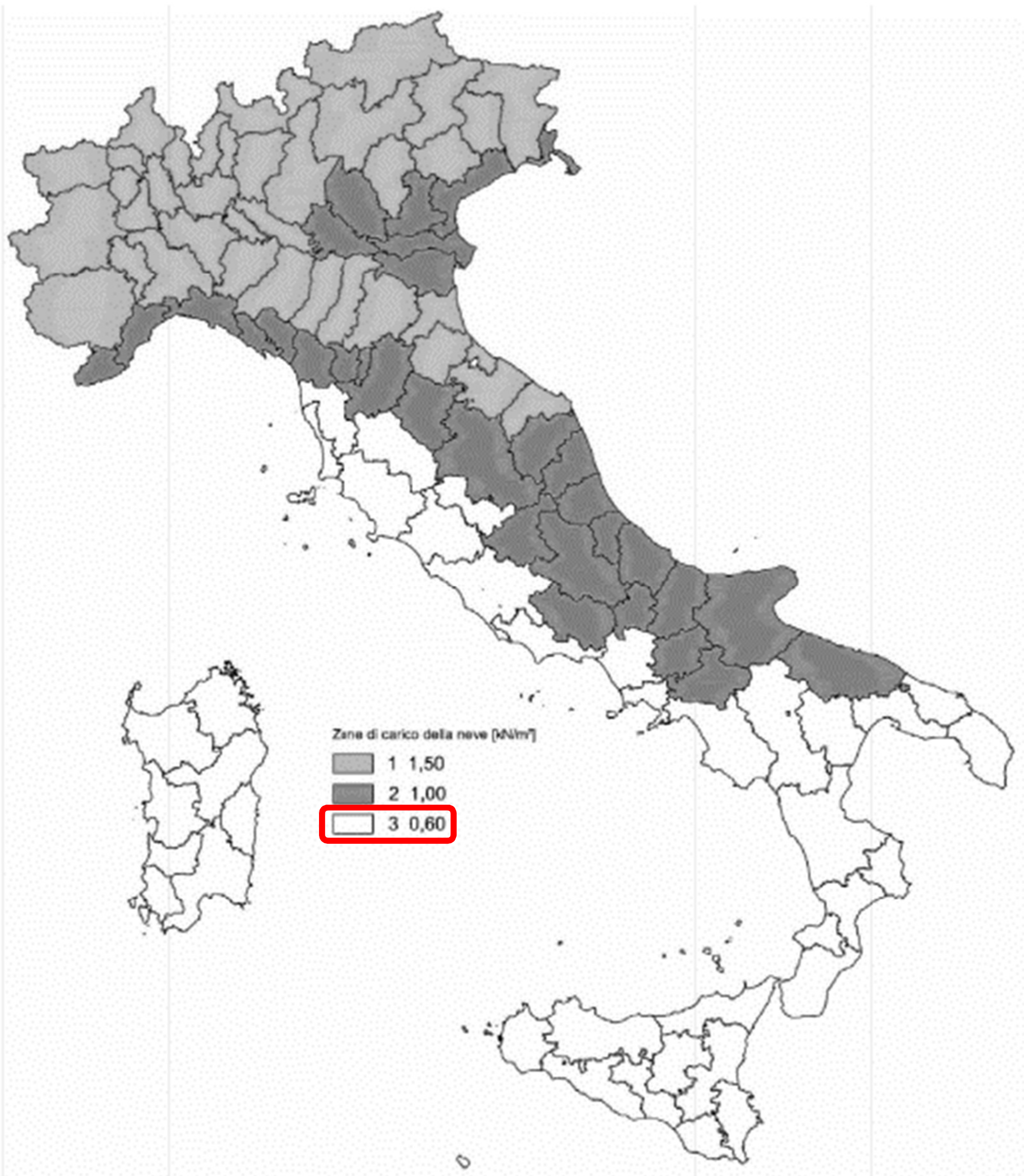
- $P_{w,+55°} = q_{r,+55°} \cdot c_e \cdot c_s c_d \cdot c_{pn,+55°} = 123 \cdot 1 \cdot 0{,}785 \cdot 1{,}410 = 137\ N/m^2$ ... (upwind);
- $P_{w,-55°} = q_{r,-55°} \cdot c_e \cdot c_s c_d \cdot c_{pn,-55°} = -123 \cdot 1 \cdot 0{,}780 \cdot 1{,}755 = -169\ N/m^2$ (downwind);

SNOW LOAD

The snow load calculation is determined in according to *D.M. 17 gennaio 2018 – Norme Tecniche per le Costruzioni*.

CHARACTERISTIC SNOW LOAD VALUE

The characteristic snow load value is determined according to *D.M. 17 gennaio 2018 – Norme Tecniche per le Costruzioni*, with the following Picture:



The site is located in the Zone 3, at an altitude equals to 300 m.

Zona III

Agrigento, Brindisi, Cagliari, Caltanissetta, Carbonia-Iglesias, Caserta, Catania, Catanzaro, Cosenza, Crotone, Enna, Grosseto, Latina, Lecce, Livorno, Matera, Medio Campidano, Messina, Napoli, Nuoro, Ogliastra, Olbia-Tempio, Oristano, Palermo, Pisa, Potenza, Ragusa, Reggio Calabria, Roma, Salerno, Sassari, Siena, Siracusa, Taranto, Terni, Trapani, Vibo Valentia, Viterbo:

$$q_{sk} = 0{,}60\ kN/m^2 \qquad a_s \leq 200\ m$$

[3.4.5]

$$q_{sk} = 0{,}51\ [1 + (a_s/481)^2]\ kN/m^2 \qquad a_s > 200\ m$$

Therefore, the value is

$$q_{sk} = 0{,}5[1 + (a_s/481)^2] = 0{,}5[1 + (300/481)^2] = 695 N/m^2$$

SNOW LOAD SHAPE COEFFICIENT "μ_i"

The size factor μ_i is calculated following the indication of Section 3.4.3 of the *D.M. 17 gennaio 2018 – Norme Tecniche per le Costruzioni*.

Tab. 3.4.II – *Valori del coefficiente di forma*

Coefficiente di forma	0° ≤ α ≤ 30°	30° < α < 60°	α ≥ 60°
μ_1	0,8	$0{,}8 \cdot \frac{(60-\alpha)}{30}$	0,0

- Model (A) – α=0° μ = 0,8;
- Model (B) – α=30° μ = 0,8;
- Model (C) – α=55° $\mu = \frac{0{,}8\cdot(60-\alpha)}{30} = \frac{0{,}8\cdot(60-55)}{30} = 0{,}13;$

The tracker structure cannot be classified as a standard *monopitch roof* because during a whole day the panels rotate from -55 ° to + 55 °. For all configurations it is assumed the simplification to use a shape coefficient equal to the average between the values reported for main configuration:

$$\mu = \frac{(0{,}47 \cdot 25°) + (0{,}8 \cdot 30°)}{55°} = 0{,}65$$

EXPOSURE COEFFICIENT

The exposure coefficient c_e should be used for determining the snow load on the roof.

According to the table 3.4.I of the *D.M. 17 gennaio 2018 – Norme Tecniche per le Costruzioni*, the value is:

$$c_e = 0,9$$

Tab. 3.4.I – *Valori di C_E per diverse classi di esposizione*

Topografia	Descrizione	C_E
Battuta dai venti	Aree pianeggianti non ostruite esposte su tutti i lati, senza costruzioni o alberi più alti	0,9
Normale	Aree in cui non è presente una significativa rimozione di neve sulla costruzione prodotta dal vento, a causa del terreno, altre costruzioni o alberi	1,0
Riparata	Aree in cui la costruzione considerata è sensibilmente più bassa del circostante terreno o circondata da costruzioni o alberi più alti	1,1

THERMAL COEFFICIENT

The thermal coefficient c_t should be used to account for the reduction of snow loads on the roofs with high thermal trasmittance.

According to the chapter 3.4.5 of the *D.M. 17 gennaio 2018 – Norme Tecniche per le Costruzioni*, the value is:

$$c_t = 1$$

SNOW PRESSURE CALCULATION

The snow pressure calculation is determined in according to the chapter 3.4.1 of the *D.M. 17 gennaio 2018 – Norme Tecniche per le Costruzioni.*

$$q_{s,\alpha} = \mu_{i,\alpha} \cdot c_e \cdot c_t \cdot q_{sk}$$

Therefore, for the three different configurations the loads are:

Model A, α=0°

- $q_{s,0°} = \mu_i \cdot c_e \cdot c_t \cdot s_k = 0{,}65 \cdot 0{,}9 \cdot 695 = 407\ N/m^2$

Model B, α=30°

- $q_{s,30°} = \mu_i \cdot c_e \cdot c_t \cdot s_k = 0{,}65 \cdot 0{,}9 \cdot 695 = 407\ N/m^2$

Model C, α=55°

- $q_{s,55°} = \mu_i \cdot c_e \cdot c_t \cdot s_k = 0{,}65 \cdot 0{,}9 \cdot 695 = 407\ N/m^2$

4. LOAD COMBINATION

The load combinations are determined in according to *D.M. 17 gennaio 2018 – Norme Tecniche per le Costruzioni*.

ULS – GEO

$$\gamma_{G1} \cdot G_1 + \gamma_{G2} \cdot G_2 + \gamma_P \cdot P + \gamma_{Q1} \cdot Q_{k1} + \gamma_{Q2} \cdot \psi_{02} \cdot Q_{k2} + \gamma_{Q3} \cdot \psi_{03} \cdot Q_{k3} + \ldots \qquad [2.5.1]$$

Tab. 2.6.I – *Coefficienti parziali per le azioni o per l'effetto delle azioni nelle verifiche SLU*

		Coefficiente γ_F	EQU	A1	A2
Carichi permanenti G_1	Favorevoli	γ_{G1}	0,9	1,0	1,0
	Sfavorevoli		1,1	1,3	1,0
Carichi permanenti non strutturali G_2[(1)]	Favorevoli	γ_{G2}	0,8	0,8	0,8
	Sfavorevoli		1,5	1,5	1,3
Azioni variabili Q	Favorevoli	γ_{Qi}	0,0	0,0	0,0
	Sfavorevoli		1,5	1,5	1,3

[(1)] Nel caso in cui l'intensità dei carichi permanenti non strutturali o di una parte di essi (ad es. carichi permanenti portati) sia ben definita in fase di progetto, per detti carichi o per la parte di essi nota si potranno adottare gli stessi coefficienti parziali validi per le azioni permanenti.

		G1	G2	W	S
n°	Combination	Dead load	Pannels	Wind	Snow
1	($W_{+0°}$)	1.00	1.00	1.30	
2	($W_{-0°}$)	1.00	1.00	1.30	
3	($W_{+0°}$ + S)	1.00	1.00	1.30	0.65
4	(S + $W_{+0°}$)	1.00	1.00	0.78	1.30
5	($W_{+30°}$)	1.00	1.00	1.30	
6	($W_{-30°}$)	1.00	1.00	1.30	
7	($W_{+30°}$ + S)	1.00	1.00	1.30	0.65
8	(S + $W_{+30°}$)	1.00	1.00	0.78	1.30
9	($W_{+55°}$)	1.00	1.00	1.30	
10	($W_{-55°}$)	1.00	1.00	1.30	
11	($W_{+55°}$ + S)	1.00	1.00	1.30	0.65
12	(S + $W_{+55°}$)	1.00	1.00	0.78	1.30

5. FORCES AT BASE OF THE PILES

The calculations were made using an excel spreadsheet follows.

EXTERNAL POLE - node 1 and 5

n°	Combination	tilt α	n° pannells	A (mm)	B (mm)	Lc (mm) calculation length	Dead permanent structural loads (N/m)	Dead permanent structural loads Tot. (N)	C_D	$P_{tot,1}*C_D$
1	$(W_{+0°})$	0	4.5	1000	1994	4613	81	725	1.00	725
2	$(W_{-0°})$	0	4.5	1000	1994	4613	81	725	1.00	725
3	$(W_{+0°} + S)$	0	4.5	1000	1994	4613	81	725	1.00	725
4	$(S + W_{+0°})$	0	4.5	1000	1994	4613	81	725	1.00	725
5	$(W_{+30°})$	30	4.5	1000	1994	4613	81	725	1.00	725
6	$(W_{-30°})$	30	4.5	1000	1994	4613	81	725	1.00	725
7	$(W_{+30°} + S)$	30	4.5	1000	1994	4613	81	725	1.00	725
8	$(S + W_{+30°})$	30	4.5	1000	1994	4613	81	725	1.00	725
9	$(W_{+55°})$	55	4.5	1000	1994	4613	81	725	1.00	725
10	$(W_{-55°})$	55	4.5	1000	1994	4613	81	725	1.00	725
11	$(W_{+55°} + S)$	55	4.5	1000	1994	4613	81	725	1.00	725
12	$(S + W_{+55°})$	55	4.5	1000	1994	4613	81	725	1.00	725

Dead load pannells - Ptot,2	$C_{D,p}$	$P_{tot,2}*C_{D,p}$	Wind - W	cp	C_{MAX}/C_{APT}	$C_{MAX}*cp*W$	Snow load - S	C_{MAX}/C_{APT}	$C_{MAX}*S$
226	1.00	226	619	0.200	1.30	161			
226	1.00	226	603	-0.500	1.30	-392			
226	1.00	226	619	0.200	1.30	161	407	0.65	264.2738
226	1.00	226	619	0.200	0.78	97	407	1.30	528.5475
226	1.00	226	97	1.200	1.30	151			
226	1.00	226	96	-1.800	1.30	-225			
226	1.00	226	97	1.200	1.30	151	407	0.65	264.2738
226	1.00	226	97	1.200	0.78	91	407	1.30	528.5475
226	1.00	226	97	1.410	1.30	178			
226	1.00	226	96	-1.755	1.30	-219			
226	1.00	226	97	1.410	1.30	178	407	0.65	264.2738
226	1.00	226	97	1.410	0.78	107	407	1.30	528.5475

N *(N)*	T *(N)*	Combination	tilt α
3184	0	(W+0°)	0
-1777	0	(W-0°)	0
5556	0	(W+0° + S)	0
7349	0	(S + W+0°)	0
2916	679	(W+30°)	30
-5	-1008	(W-30°)	30
5288	679	(W+30° + S)	30
7189	407	(S + W+30°)	30
2655	1307	(W+55°)	55
613	-1610	(W-55°)	55
5027	1307	(W+55° + S)	55
7032	784	(S + W+55°)	55

MIDDLE POLE - node 2 and 4

n°	Combination	tilt α	n° pannells	A (mm)	B (mm)	Lc (mm) calculation length	Dead permanent structural loads (N/m)	Dead permanent structural loads Tot. (N)	C_D	$P_{tot,1}$*C_D
1	($W_{+0°}$)	0	7	1000	1994	7226	81	937	1.00	937
2	($W_{-0°}$)	0	7	1000	1994	7226	81	937	1.00	937
3	($W_{+0°}$ + S)	0	7	1000	1994	7226	81	937	1.00	937
4	(S + $W_{+0°}$)	0	7	1000	1994	7226	81	937	1.00	937
5	($W_{+30°}$)	30	7	1000	1994	7226	81	937	1.00	937
6	($W_{-30°}$)	30	7	1000	1994	7226	81	937	1.00	937
7	($W_{+30°}$ + S)	30	7	1000	1994	7226	81	937	1.00	937
8	(S + $W_{+30°}$)	30	7	1000	1994	7226	81	937	1.00	937
9	($W_{+55°}$)	55	7	1000	1994	7226	81	937	1.00	937
10	($W_{-55°}$)	55	7	1000	1994	7226	81	937	1.00	937
11	($W_{+55°}$ + S)	55	7	1000	1994	7226	81	937	1.00	937
12	(S + $W_{+55°}$)	55	7	1000	1994	7226	81	937	1.00	937

Dead load pannells - Ptot,2	$C_{D,p}$	$P_{tot,2}$*$C_{D,p}$	Wind - W	cp	C_{MAX}/C_{APT}	C_{MAX}*cp*W	Snow load - S	C_{MAX}/C_{APT}	C_{MAX}*S
226	1.00	226	619	0.200	1.30	161			
226	1.00	226	603	-0.500	1.30	-392			
226	1.00	226	619	0.200	1.30	161	407	0.65	264.2738
226	1.00	226	619	0.200	0.78	97	407	1.30	528.5475
226	1.00	226	97	1.200	1.30	151			
226	1.00	226	96	-1.800	1.30	-225			
226	1.00	226	97	1.200	1.30	151	407	0.65	264.2738
226	1.00	226	97	1.200	0.78	91	407	1.30	528.5475
226	1.00	226	97	1.410	1.30	178			
226	1.00	226	96	-1.755	1.30	-219			
226	1.00	226	97	1.410	1.30	178	407	0.65	264.2738
226	1.00	226	97	1.410	0.78	107	407	1.30	528.5475

N *(N)*	**T** *(N)*	**Combination**	tilt α
4763	0	(W+0°)	0
-2955	0	(W-0°)	0
8451	0	(W+0° + S)	0
11242	0	(S + W+0°)	0
4345	1056	(W+30°)	30
-199	-1568	(W-30°)	30
8034	1056	(W+30° + S)	30
10991	634	(S + W+30°)	30
3940	2033	(W+55°)	55
763	-2504	(W-55°)	55
7628	2033	(W+55° + S)	55
10748	1220	(S + W+55°)	55

CENTRAL POLE - node 3

n°	Combination	tilt α	n° pannells	A (mm)	B (mm)	Lc (mm) calculation length	Dead permanent structural loads (N/m)	Dead permanent structural loads Tot. (N)	C_D	$P_{tot,1}*C_D$
1	$(W_{+0°})$	0	7	1000	1994	7226	81	937	1.00	937
2	$(W_{-0°})$	0	7	1000	1994	7226	81	937	1.00	937
3	$(W_{+0°} + S)$	0	7	1000	1994	7226	81	937	1.00	937
4	$(S + W_{+0°})$	0	7	1000	1994	7226	81	937	1.00	937
5	$(W_{+30°})$	30	7	1000	1994	7226	81	937	1.00	937
6	$(W_{-30°})$	30	7	1000	1994	7226	81	937	1.00	937
7	$(W_{+30°} + S)$	30	7	1000	1994	7226	81	937	1.00	937
8	$(S + W_{+30°})$	30	7	1000	1994	7226	81	937	1.00	937
9	$(W_{+55°})$	55	7	1000	1994	7226	81	937	1.00	937
10	$(W_{-55°})$	55	7	1000	1994	7226	81	937	1.00	937
11	$(W_{+55°} + S)$	55	7	1000	1994	7226	81	937	1.00	937
12	$(S + W_{+55°})$	55	7	1000	1994	7226	81	937	1.00	937

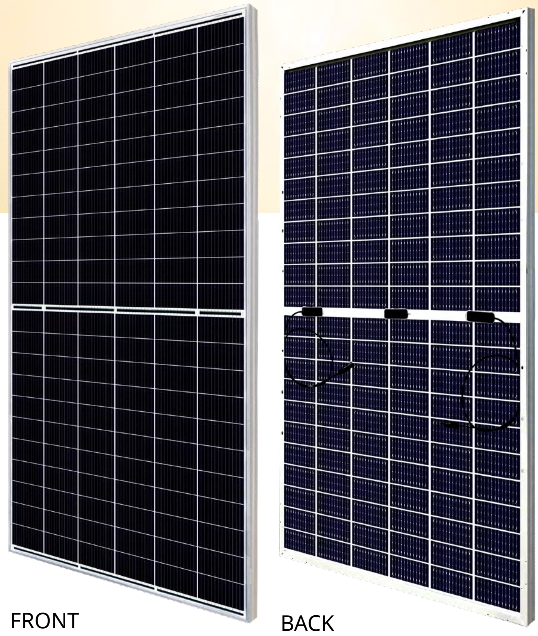
Dead load pannells - Ptot,2	$C_{D,p}$	$P_{tot,2}*C_{D,p}$	Wind - W	cp	C_{MAX}/C_{APT}	$C_{MAX}*cp*W$	Snow load - S	C_{MAX}/C_{APT}	$C_{MAX}*S$
226	1.00	226	619	0.200	1.30	161			
226	1.00	226	603	-0.500	1.30	-392			
226	1.00	226	619	0.200	1.30	161	407	0.65	264.2738
226	1.00	226	619	0.200	0.78	97	407	1.30	528.5475
226	1.00	226	97	1.200	1.30	151			
226	1.00	226	96	-1.800	1.30	-225			
226	1.00	226	97	1.200	1.30	151	407	0.65	264.2738
226	1.00	226	97	1.200	0.78	91	407	1.30	528.5475
226	1.00	226	97	1.410	1.30	178			
226	1.00	226	96	-1.755	1.30	-219			
226	1.00	226	97	1.410	1.30	178	407	0.65	264.2738
226	1.00	226	97	1.410	0.78	107	407	1.30	528.5475

N *(N)*	T *(N)*	Combination	tilt α
4763	0	(W+0°)	0
-2955	0	(W-0°)	0
8451	0	(W+0° + S)	0
11242	0	(S + W+0°)	0
4345	1056	(W+30°)	30
-199	-1568	(W-30°)	30
8034	1056	(W+30° + S)	30
10991	634	(S + W+30°)	30
3940	2033	(W+55°)	55
763	-2504	(W-55°)	55
7628	2033	(W+55° + S)	55
10748	1220	(S + W+55°)	55

Allegato 4: Pannelli fotovoltaici

NEW

CanadianSolar



FRONT BACK

BiHiKu7

BIFACIAL MONO PERC

640 W ~ 670 W

CS7N-640|645|650|655|660|665|670MB-AG

MORE POWER

670 W Module power up to 670 W
Module efficiency up to 21.6 %

Up to 8.9 % lower LCOE
Up to 4.6 % lower system cost

Comprehensive LID / LeTID mitigation technology, up to 50% lower degradation

Compatible with mainstream trackers, cost effective product for utility power plant

Better shading tolerance

MORE RELIABLE

40 °C lower hot spot temperature, greatly reduce module failure rate

Minimizes micro-crack impacts

Heavy snow load up to 5400 Pa, wind load up to 2400 Pa*

* For detailed information, please refer to the Installation Manual.

12 Years **Enhanced Product Warranty on Materials and Workmanship***

30 Years **Linear Power Performance Warranty***

1st year power degradation no more than 2%
Subsequent annual power degradation no more than 0.45%

*According to the applicable Canadian Solar Limited Warranty Statement.

MANAGEMENT SYSTEM CERTIFICATES*

ISO 9001:2015 / Quality management system
ISO 14001:2015 / Standards for environmental management system
ISO 45001: 2018 / International standards for occupational health & safety

PRODUCT CERTIFICATES*

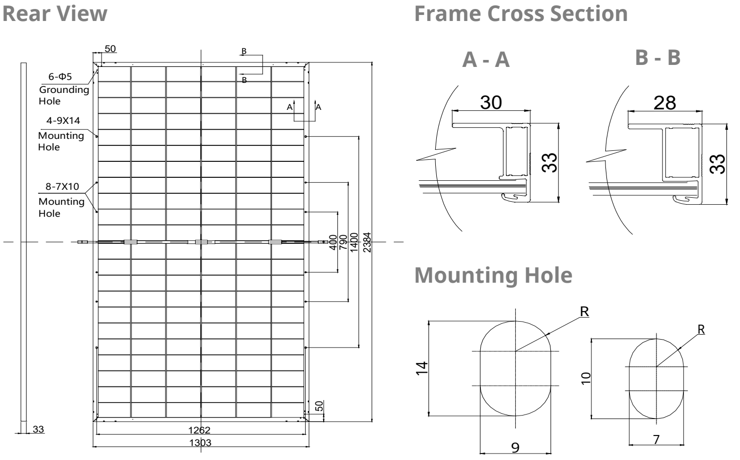
IEC 61215 / IEC 61730 / CE / INMETRO / MCS / UKCA
CEC listed (US California) / FSEC (US Florida)
UL 61730 / IEC 61701 / IEC 62716 / IEC 60068-2-68
Take-e-way

* The specific certificates applicable to different module types and markets will vary, and therefore not all of the certifications listed herein will simultaneously apply to the products you order or use. Please contact your local Canadian Solar sales representative to confirm the specific certificates available for your Product and applicable in the regions in which the products will be used.

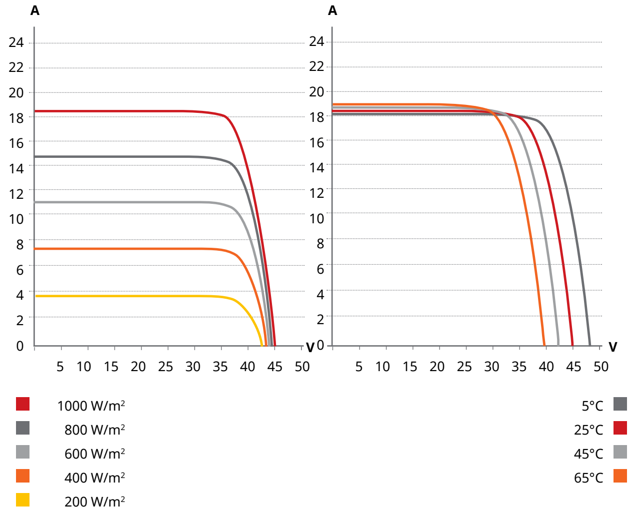
CSI Solar Co., Ltd. is committed to providing high quality solar photovoltaic modules, solar energy and battery storage solutions to customers. The company was recognized as the No. 1 module supplier for quality and performance/price ratio in the IHS Module Customer Insight Survey. Over the past 20 years, it has successfully delivered over 70 GW of premium-quality solar modules across the world.

CSI Solar Co., Ltd.
199 Lushan Road, SND, Suzhou, Jiangsu, China, 215129, www.csisolar.com, support@csisolar.com

ENGINEERING DRAWING (mm)



CS7N-650MB-AG / I-V CURVES



ELECTRICAL DATA | STC*

		Nominal Max. Power (Pmax)	Opt. Operating Voltage (Vmp)	Opt. Operating Current (Imp)	Open Circuit Voltage (Voc)	Short Circuit Current (Isc)	Module Efficiency
CS7N-640MB-AG		640 W	37.5 V	17.07 A	44.6 V	18.31 A	20.6%
Bifacial Gain**	5%	672 W	37.5 V	17.92 A	44.6 V	19.23 A	21.6%
	10%	704 W	37.5 V	18.78 A	44.6 V	20.14 A	22.7%
	20%	768 W	37.5 V	20.48 A	44.6 V	21.97 A	24.7%
CS7N-645MB-AG		645 W	37.7 V	17.11 A	44.8 V	18.35 A	20.8%
Bifacial Gain**	5%	677 W	37.7 V	17.97 A	44.8 V	19.27 A	21.8%
	10%	710 W	37.7 V	18.84 A	44.8 V	20.19 A	22.9%
	20%	774 W	37.7 V	20.53 A	44.8 V	22.02 A	24.9%
CS7N-650MB-AG		650 W	37.9 V	17.16 A	45.0 V	18.39 A	20.9%
Bifacial Gain**	5%	683 W	37.9 V	18.03 A	45.0 V	19.31 A	22.0%
	10%	715 W	37.9 V	18.88 A	45.0 V	20.23 A	23.0%
	20%	780 W	37.9 V	20.59 A	45.0 V	22.07 A	25.1%
CS7N-655MB-AG		655 W	38.1 V	17.20 A	45.2 V	18.43 A	21.1%
Bifacial Gain**	5%	688 W	38.1 V	18.06 A	45.2 V	19.35 A	22.1%
	10%	721 W	38.1 V	18.93 A	45.2 V	20.27 A	23.2%
	20%	786 W	38.1 V	20.64 A	45.2 V	22.12 A	25.3%
CS7N-660MB-AG		660 W	38.3 V	17.24 A	45.4 V	18.47 A	21.2%
Bifacial Gain**	5%	693 W	38.3 V	18.10 A	45.4 V	19.39 A	22.3%
	10%	726 W	38.3 V	18.96 A	45.4 V	20.32 A	23.4%
	20%	792 W	38.3 V	20.69 A	45.4 V	22.16 A	25.5%
CS7N-665MB-AG		665 W	38.5 V	17.28 A	45.6 V	18.51 A	21.4%
Bifacial Gain**	5%	698 W	38.5 V	18.14 A	45.6 V	19.44 A	22.5%
	10%	732 W	38.5 V	19.02 A	45.6 V	20.36 A	23.6%
	20%	798 W	38.5 V	20.74 A	45.6 V	22.21 A	25.7%
CS7N-670MB-AG		670 W	38.7 V	17.32 A	45.8 V	18.55 A	21.6%
Bifacial Gain**	5%	704 W	38.7 V	18.20 A	45.8 V	19.48 A	22.7%
	10%	737 W	38.7 V	19.05 A	45.8 V	20.41 A	23.7%
	20%	804 W	38.7 V	20.78 A	45.8 V	22.26 A	25.9%

* Under Standard Test Conditions (STC) of irradiance of 1000 W/m², spectrum AM 1.5 and cell temperature of 25°C.
** Bifacial Gain: The additional gain from the back side compared to the power of the front side at the standard test condition. It depends on mounting (structure, height, tilt angle etc.) and albedo of the ground.

ELECTRICAL DATA | NMOT*

	Nominal Max. Power (Pmax)	Opt. Operating Voltage (Vmp)	Opt. Operating Current (Imp)	Open Circuit Voltage (Voc)	Short Circuit Current (Isc)
CS7N-640MB-AG	480 W	35.2 V	13.64 A	42.2 V	14.77 A
CS7N-645MB-AG	484 W	35.3 V	13.72 A	42.3 V	14.80 A
CS7N-650MB-AG	487 W	35.5 V	13.74 A	42.5 V	14.83 A
CS7N-655MB-AG	491 W	35.7 V	13.76 A	42.7 V	14.86 A
CS7N-660MB-AG	495 W	35.9 V	13.79 A	42.9 V	14.89 A
CS7N-665MB-AG	499 W	36.1 V	13.83 A	43.1 V	14.93 A
CS7N-670MB-AG	502 W	36.3 V	13.85 A	43.3 V	14.96 A

* Under Nominal Module Operating Temperature (NMOT), irradiance of 800 W/m², spectrum AM 1.5, ambient temperature 20°C, wind speed 1 m/s.

MECHANICAL DATA

Specification	Data
Cell Type	Mono-crystalline
Cell Arrangement	132 [2 x (11 x 6)]
Dimensions	2384 × 1303 × 33 mm (93.9 × 51.3 × 1.30 in)
Weight	37.8 kg (83.3 lbs)
Front Glass	2.0 mm heat strengthened glass with anti-reflective coating
Back Glass	2.0 mm heat strengthened glass
Frame	Anodized aluminium alloy
J-Box	IP68, 3 bypass diodes
Cable	4.0 mm² (IEC), 10 AWG (UL)
Cable Length (Including Connector)	460 mm (18.1 in) (+) / 340 mm (13.4 in) (-) or customized length*
Connector	T6 or MC4-EVO2 or MC4-EVO2A
Per Pallet	33 pieces
Per Container (40' HQ)	594 pieces or 462 pieces (only for US)

* For detailed information, please contact your local Canadian Solar sales and technical representatives.

ELECTRICAL DATA

Operating Temperature	-40°C ~ +85°C
Max. System Voltage	1500 V (IEC/UL) or 1000 V (IEC/UL)
Module Fire Performance	TYPE 29 (UL 61730) or CLASS C (IEC61730)
Max. Series Fuse Rating	35 A
Application Classification	Class A
Power Tolerance	0 ~ + 10 W
Power Bifaciality*	70 %

* Power Bifaciality = $Pmax_{rear}$ / $Pmax_{front}$, both $Pmax_{rear}$ and $Pmax_{front}$ are tested under STC, Bifaciality Tolerance: ± 5 %

TEMPERATURE CHARACTERISTICS

Specification	Data
Temperature Coefficient (Pmax)	-0.34 % / °C
Temperature Coefficient (Voc)	-0.26 % / °C
Temperature Coefficient (Isc)	0.05 % / °C
Nominal Module Operating Temperature	41 ± 3°C

* The specifications and key features contained in this datasheet may deviate slightly from our actual products due to the on-going innovation and product enhancement. CSI Solar Co., Ltd. reserves the right to make necessary adjustment to the information described herein at any time without further notice.
Please be kindly advised that PV modules should be handled and installed by qualified people who have professional skills and please carefully read the safety and installation instructions before using our PV modules.

PARTNER SECTION

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