Constructive Memory for Solar Photovoltaic Canopies:

Foundations Sizing Annex

V.01.Eng. – November 2018

SUMMARY

1 STUDY OBJECT

At the request of CIRCUTOR S.A., this technical report is drafted whose objective is to dimension the foundation for its canopy structures designed to support photovoltaic panels. The foundations for different site conditions are calculated to give an orientation of their size in the most probable cases of combination of climatic loads with a type of terrain of medium compactness.

The validity of this study is subject to the update regarding the technical report of the canopies with visa number 2018903139 CETIB, given that in this technical report are described the canopy geometries and other parameters that may affect the calculation of the shoes .

During the writing of this report, the following hypotheses are carried out:
• Carrying capacity of the terrain surrounding the foundation. (1)
• Carrying capacity of the pavement surrounding the foundation if it exists. (1)
• The support of the foundation on land filling is not supported, it is assumed that its base will always be supported on resistant ground through possible fillings of grading or plant substrates.
• There are no aggressive elements to the concrete in the ground, if aggressive elements are detected in the concrete, the appropriate measures must be taken according to EHE or Eurocode 2.
• For all canopies, pvs and pv are assumed to have an obstruction coefficient equal to 0 (no obstruction at the rear of the canopy)
• All pvs and pv canopies are assumed with a centred foundation.
• All pvb canopies are assumed to have an obstruction coefficient equal to 1 (total obstruction at the rear of the canopy)
• All pvb canopies are assumed with an eccentric foundation.

(1) The characterization of the carrying capacity of the terrain is carried out exposing in each case the minimum necessary capacity of the terrain surrounding the foundations and the ground where it supports it so that the calculations are valid.

2 APPLICABLE REGULATIONS

European regulations:
• Eurocode 0, (project bases)
• Eurocode 1, (actions on structures) especially part 1-4 (wind actions)
• Eurocode 2, Concrete structures.

Equivalent Spanish regulation:
•Technical building Code (CTE)
• DB-SE-SE
• DB-SE-AE
• DB-SE-A
• EHE-08

3 SECURITY AND HEALTH

In the present report, no safety and health study is carried out, given that it is a justifying calculation report. The person in charge of the construction of the structure must carry out a safety and health study to assess the risks arising from its construction, to estimate the safety measures and the individual and collective protection equipment to be used by the different guilds of the construction that can intervene in the work, according to the nature of the site where it is intended to build such a structure.

4 GEOTECHNICAL STUDY

In this report are defined the minimum characteristics that the land must have for the calculations made to be valid, it is the responsibility of the person in charge of the work of the foundation to verify in a reliable way that the existing land has at least the capacity indicated in this memory for each foundation case. It is recommended for each work the realization of a geotechnical study by a specialized technician.

5 TECHNICAL PROJECT

The person responsible for the execution of the work must carry out a technical project in which the foundation is dimensioned for the specific case of climatic loads and the existing ground in the work, since this report, as explained in section 1, has The objective is only to give a valid estimate for the analysis of the economic viability of any marquee in terms of foundation.
Although, the usual thing will be that the obtained results in the present memory can be refined by means of a study more detailed in the corresponding technical project.

6 CALCULATION REPORT

6.1 Considered actions

Dead loads

Materials:	**kN/m^3**
Structural steel	78.5
Mass Concrete	23.0

Coatings	**kN/m^2**
Solar modules with their aluminium profiles	0.15
Straps	0.10

Variable loads (Q)

- Use loading: There are no use loadings other than maintenance

- Loading reduction: No reduction of loadings in the structural elements, neither vertical nor horizontal.

- Wind action:
Static pressure considered: $q_e = q_b \times c_e \times c_p$
q_b It is taken according to the location.
Local pressure and suction coefficients, c_p, according to Table D.8 of the CTE-DB-SE-AE or equivalently Eurocode 1
Total pressure and suction coefficients, c_p, according to Table 10.3.1 of Eurocode 1

- Snow loading:
The snow load is determined according to height and climatic zone.
Coefficient of shape of the roof inclined up to 15º: μ = 1
Snow load considered on the deck:

$$q_n = \mu \cdot s_k$$

- Thermal actions:
The thermal effects on the structure is not taken into account every 8 meters at the most given that the belts are interrupted on each foot of the marquee, without reaching in any case the 40m indicated by the norm.

Accidental actions(A)

- Earthquake:
Seismic loads have not been taken into account. No checks will be required since the structure is considered to be classified as moderate importance.

- Impacts:
Resistance to impacts does not fall within the scope of this study.

6.2 Checking resistance and stability

In order to guarantee the strength and stability of the structure, structural verification has been made by calculating using the Limit States method:

- Ultimate Limit States
- Service Limit State
- Limit State of Durability

Checking that, considering the values of the actions, the characteristics of the materials and the geometric data (all of them affected by the corresponding partial safety factors) the structural response is not inferior to the effects of the actions applied with the reliability index sufficient for each of the project situations considered, which are:

- Persistent situations, which correspond to the conditions of normal use of the structure

• Transient situations, such as those that occur during the construction or repair of the structure
• Accidental situations, which correspond to exceptional conditions

To obtain the calculation values of the effect of the actions, the actions specified in section 6.1 of this report have been taken into account with the combinations of actions and the coefficients specified below.
The calculation values of the resistance are obtained by reducing the structural materials with the coefficients indicated in point 6.3. Materials.

- for **persistent or transitory situations,**

$$\sum_{j\geq 1} \gamma_{G,j} * G_{k,j} + \gamma_{Q,1} * Q_{k,1} + \sum_{i>1} \gamma_{Q,i} * \psi_{0,i} * Q_{k,i}$$

- for **extraordinary situations,**

$$\sum_{j\geq 1} \gamma_{G,j} * G_{k,j} + A_d + \gamma_{Q,1} * \psi_{1,1} * Q_{k,1} + \sum_{i>1} \gamma_{Q,i} * \psi_{2,i} * Q_{k,i}$$

The security coefficients for the actions used in the verifications of the Ultimate Limit States are adjusted to those specified in the DB SE and in addition to those of the EHE or equivalently in the Eurocode are the following:

Partial security coefficients (γ) for de actions in ultimate limit state					
Verification Type	**Action type**	**persistent or transitory situations**		**Extraordinary situation**	
		unfavourable	**favourable**	**unfavourable**	**favourable**
Strength	**Permanent:**				
	Dead load, ground weight	1.35	0.80	1.0	1.0
	ground thrusts	1.35	0.70	1.0	1.0
	Variable	1.50	0	1.0	0
Stability	**Permanent:**				
	Dead load, ground weight	1.10	0.90	1.0	1.0
	ground thrusts	1.35	0.80	1.0	1.0
	Variable	1.50	0	1.0	0

The values of the simultaneity coefficients also correspond to those defined in the DB SE or equivalently in the Eurocógido and are the following:

simultaneity coefficients	**Category**	ψ_0	ψ_1	ψ_2
Surface use loading				
Residential zones	A	0.7	0.5	0.3
Commercial zones	D	0.7	0.7	0.6
Traffic areas and parking light vehicles (total weight <30 kN)	E	0.7	0.7	0.6
Transitable roofs	F	0.7	0.5	0.6
Roofs accessible only for conservation	G	0	0	0
Snow				
For heights ≤ 1000 m		0.5	0.2	0
Wind		0.6	0.5	0
Variable terrain actions		0.7	0.7	0.7

6.3 Materials

- Reinforcement steel

Steel B-500-S. Material safety coefficient: γM1 =1.15

- Concrete:

HA-25/B/20/IIa. Material safety coefficient: γM1 =1.5

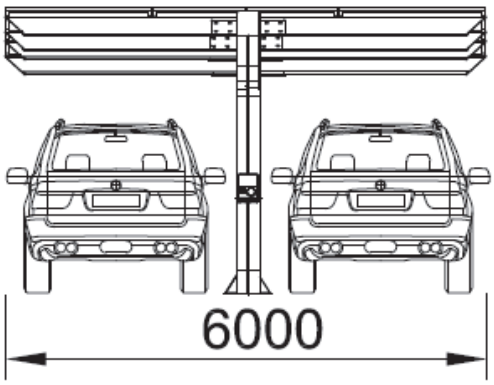
Or,

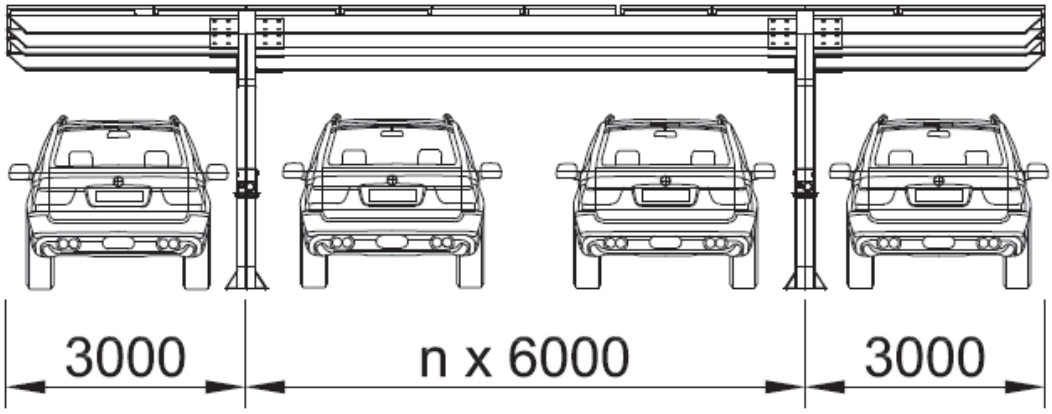
HRF-25/B/20/IIa. Material safety coefficient: γM1 =1.5

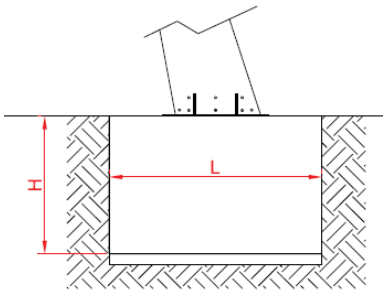
7 PVS1 CANOPY only one support LENGHT 3,3 m AND 12º

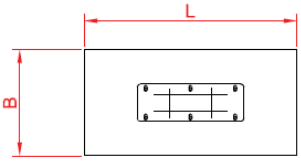
7.1 Foundation sizing tables

7.1.1 Up to 6 m of cover for each support









Wind zone C (29m/s)				
	Option 4	Option 3	Option 2	Option 1
Maximum snow load	110 Kg/m2	90 Kg/m2	50 Kg/m2	
Roughness of the environment (CTE)	IV	III	II	I
Roughness of the environment (Eurocode)	III	II	I	0
Exposure coefficient	1,3	1,6	2,1	2,4
Pressure wind load	41 Kg/m2	50 Kg/m2	64 Kg/m2	Not install
Wind load suction	-69 Kg/m2	-84 Kg/m2	-108 Kg/m2	
Own weight of the solar panels + aluminium substructure + straps	25 kg/m2	25 kg/m2	25 kg/m2	
Canopy weight	250 kg	250 kg	250 kg	
Maximum obstruction coefficient	***0***	***0***	***0***	
Foundation (L x B x H) (1)	***1,5x1,2x1,2***	***1,6x1,2x1,2***	***1,7x1,3x1,3***	
Required minimum ground resistance (2)	***0.65 Kg/cm2***	***0.65 Kg/cm2***	***0.60 Kg/cm2***	

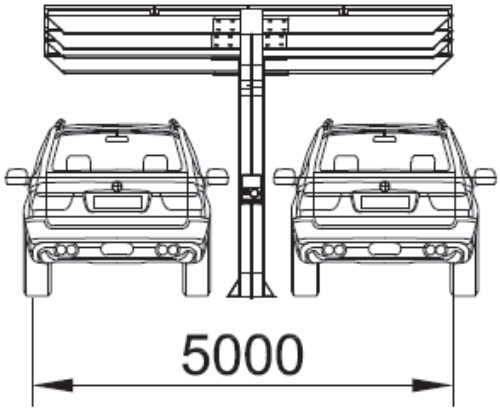
Wind zone B (27m/s)				
	Option 4	Option 3	Option 2	Option 1
Maximum snow load	110 Kg/m2	100 Kg/m2	80 Kg/m2	40Kg/m2
Roughness of the environment (CTE)	IV	III	II	I
Roughness of the environment (Eurocode)	III	II	I	0
Exposure coefficient	1,3	1,6	2,1	2,4
Pressure wind load	35 Kg/m2	43 Kg/m2	55 Kg/m2	62 Kg/m2
Wind load suction	-60 Kg/m2	-73 Kg/m2	-94 Kg/m2	-104 Kg/m2
Own weight of the solar panels + aluminium substructure + straps	25 kg/m2	25 kg/m2	25 kg/m2	25 kg/m2
Canopy weight	250 kg	250 kg	250 kg	250 kg
Maximum obstruction coefficient	***0***	***0***	***0***	***0***
Foundation (L x B x H) (1)	***1,4x1,1x1,1***	***1,5x1,2x1,2***	***1,7x1,2x1,2***	***1,8x1,3x1,3***
Required minimum ground resistance (2)	***0.65 Kg/cm2***	***0.65 Kg/cm2***	***0.60 Kg/cm2***	***0.55 Kg/cm2***

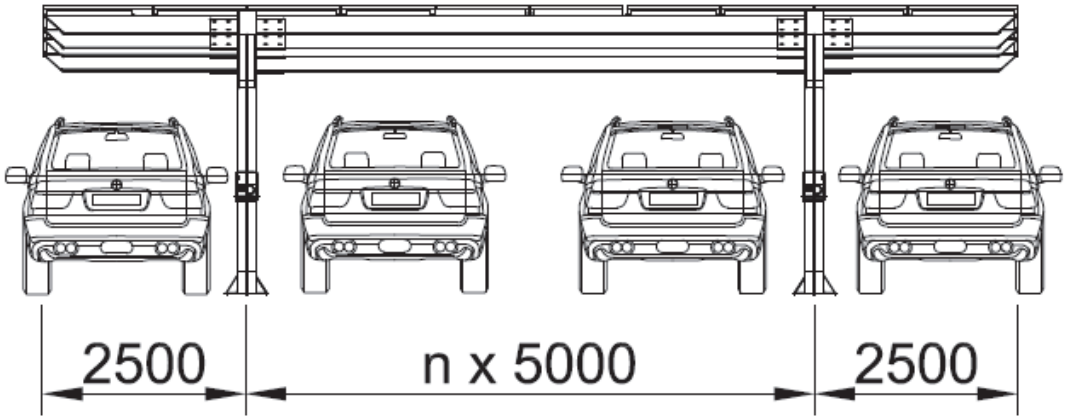
Wind zone A (26m/s)				
	Option 4	Option 3	Option 2	Option 1
Maximum snow load	120 Kg/m2	110 Kg/m2	90 Kg/m2	50Kg/m2
Roughness of the environment (CTE)	IV	III	II	I
Roughness of the environment (Eurocode)	III	II	I	0
Exposure coefficient	1,3	1,6	2,1	2,4
Pressure wind load	33 Kg/m2	40 Kg/m2	51 Kg/m2	57 Kg/m2
Wind load suction	-55 Kg/m2	-68 Kg/m2	-87 Kg/m2	-97 Kg/m2
Own weight of the solar panels + aluminium substructure + straps	25 kg/m2	25 kg/m2	25 kg/m2	25 kg/m2
Canopy weight	250 kg	250 kg	250 kg	250 kg
Maximum obstruction coefficient	***0***	***0***	***0***	***0***
Foundation (L x B x H) (1)	***1,3x1,1x1,1***	***1,4x1,2x1,2***	***1,6x1,2x1,2***	***1,7x1,3x1,3***
Required minimum ground resistance (2)	***0.70 Kg/cm2***	***0.65 Kg/cm2***	***0.60 Kg/cm2***	***0.55 Kg/cm2***

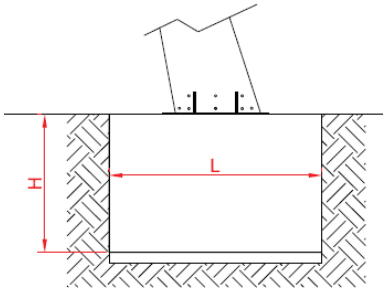
(1) The foundation is considered completely surrounded by lands up to its upper face. The land under consideration is medium compactness with a 20º friction angle and 1,8t / m3 density. For better terrains you can get smaller dimension of foundation. The foundation must be surrounded by a strip of land at least 3 times the edge of the shoe on all sides. If the foundation is located in the vicinity of a ground level change, a special study must be carried out.

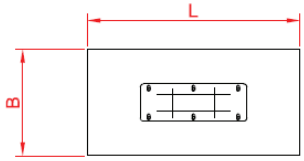
(2) It must be verified that the ground where the shoe rests has at least the indicated admissible tension.

7.1.1 *Up to 5 m of cover for each support*









Wind zone C (29m/s)				
	Option 4	**Option 3**	**Option 2**	**Option 1**
Maximum snow load	110 Kg/m2	100 Kg/m2	80 Kg/m2	40 Kg/m2
Roughness of the environment (CTE)	IV	III	II	I
Roughness of the environment (Eurocode)	III	II	I	0
Exposure coefficient	1,3	1,6	2,1	2,4
Pressure wind load	41 Kg/m2	50 Kg/m2	64 Kg/m2	71 Kg/m2
Wind load suction	-69 Kg/m2	-84 Kg/m2	-108 Kg/m2	-120 Kg/m2
Own weight of the solar panels + aluminium substructure + straps	25 kg/m2	25 kg/m2	25 kg/m2	25 kg/m2
Canopy weight	250 kg	250 kg	250 kg	250 kg
Maximum obstruction coefficient	***0***	***0***	***0***	***0***
Foundation (L x B x H) (1)	***1,3x1,1x1,1***	***1,4x1,2x1,2***	***1,5x1,3x1,3***	***1,7x1,3x1,3***
Required minimum ground resistance (2)	***0.65 Kg/cm2***	***0.65 Kg/cm2***	***0.65 Kg/cm2***	***0.60 Kg/cm2***

Wind zone B (27m/s)				
	Option 4	**Option 3**	**Option 2**	**Option 1**
Maximum snow load	120 Kg/m2	110 Kg/m2	90 Kg/m2	50 Kg/m2
Roughness of the environment (CTE)	IV	III	II	I
Roughness of the environment (Eurocode)	III	II	I	0
Exposure coefficient	1,3	1,6	2,1	2,4
Pressure wind load	35 Kg/m2	43 Kg/m2	55 Kg/m2	62 Kg/m2
Wind load suction	-60 Kg/m2	-73 Kg/m2	-94 Kg/m2	-104 Kg/m2
Own weight of the solar panels + aluminium substructure + straps	25 kg/m2	25 kg/m2	25 kg/m2	25 kg/m2
Canopy weight	250 kg	250 kg	250 kg	250 kg
Maximum obstruction coefficient	***0***	***0***	***0***	***0***
Foundation (L x B x H) (1)	***1,2x1,1x1,1***	***1,4x1,1x1,1***	***1,5x1,2x1,2***	***1,6x1,2x1,2***
Required minimum ground resistance (2)	***0.70Kg/cm2***	***0.65Kg/cm2***	***0.65Kg/cm2***	***0.60 Kg/cm2***

Wind zone A (26m/s)				
	Option 4	**Option 3**	**Option 2**	**Option 1**
Maximum snow load	130 Kg/m2	120 Kg/m2	100 Kg/m2	60 Kg/m2
Roughness of the environment (CTE)	IV	III	II	I
Roughness of the environment (Eurocode)	III	II	I	0
Exposure coefficient	1,3	1,6	2,1	2,4
Pressure wind load	33 Kg/m2	40 Kg/m2	51 Kg/m2	57 Kg/m2
Wind load suction	-55 Kg/m2	-68 Kg/m2	-87 Kg/m2	-97 Kg/m2
Own weight of the solar panels + aluminium substructure + straps	25 kg/m2	25 kg/m2	25 kg/m2	25 kg/m2
Canopy weight	250 kg	250 kg	250 kg	250 kg
Maximum obstruction coefficient	***0***	***0***	***0***	***0***
Foundation (L x B x H) (1)	***1,1x1,1x1,1***	***1,3x1,1x1,1***	***1,4x1,2x1,2***	***1,5x1,2x1,2***
Required minimum ground resistance (2)	***0.75 Kg/cm2***	***0.70 Kg/cm2***	***0.65 Kg/cm2***	***0.65 Kg/cm2***

(1) The foundation is considered completely surrounded by lands up to its upper face. The land under consideration is medium compactness with a 20º friction angle and 1,8t / m3 density. For better terrains you can get smaller dimension of foundation. The foundation must be surrounded by a strip of land at least 3 times the edge of the shoe on all sides. If the foundation is located in the vicinity of a ground level change, a special study must be carried out.

(2) It must be verified that the ground where the shoe rests has at least the indicated admissible tension.

7.2 Calculation

The representative hypothesis for the foundation calculation for the total width of the roof of 6 meters is shown below.

In the case of width 6m, the values of option 2 in wind zone C are taken as reference, as these are the most unfavourable.

The rest of the options are calculated in the same way, and it is verified that there are no higher pressure and suction loads than in the options taken as representative.

In options 1 to 4 of each wind zone, different suctions and pressures will be produced, a fact that is used to define a greater or lesser admissible snow load as the admitted degree of roughness is varied.

In order to determine the different loading options for wind zones A, B and C, an analogous action is taken, keeping as a limit the values of pressure + snow and suction calculated in the representative option.

PV-PVS-PVB CANOPY FOUNDATION CALCULATION

CLIMATE DATA

Wind zone		C	
Roughness (according to CTE)		II	
Height in the center of the canopy	Hc	3	m
	Vb	29	m/s
	δ	1,25	kg/m3
$q_b = 0,5 \cdot \delta \cdot v_b^2$	qb	0,53	kN/m²
	K	0,17	
	L (m)	0,01	
	Z (m)	1	
$c_e = F \cdot (F + 7\,k)$ $F = k \ln (\max(z,Z) / L)$	F	0,97	
	Ce	2,09	

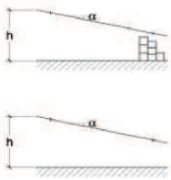
Grado de aspereza del entorno

I	Borde del mar o de un lago, con una superficie de agua en la dirección del viento de al menos 5 km de longitud
II	Terreno rural llano sin obstáculos ni arbolado de importancia
III	Zona rural accidentada o llana con algunos obstáculos aislados, como árboles o construcciones pequeñas
IV	Zona urbana en general, industrial o forestal
V	Centro de negocios de grandes ciudades, con profusión de edificios en altura

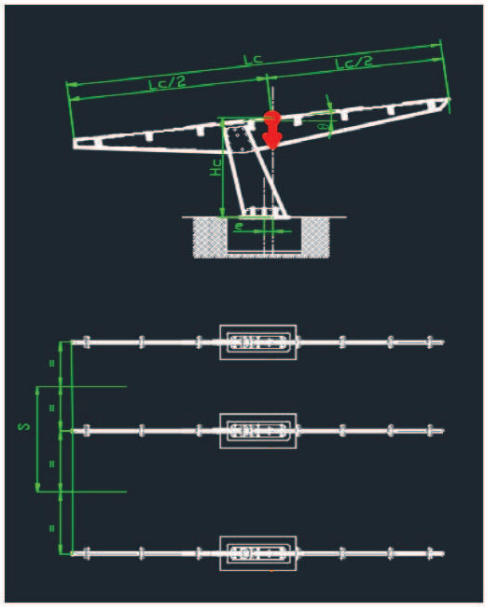
Height of the site above sea level		200	m
Winter climate zone		1	
Snow load Sk		0,50	kN/m²

Figura E.2 Zonas climáticas de invierno

ASSEMBLY DATA



Canopy type		PVS1/PV1	
Cover width that rests on the support	S	6	m
Obstruction coefficient	φ	0	
Support length	Lc	3,3	m
Eccentricity of the roof with respect to the pillar	e	0	m
Canopy angle	θ	12	º
Support weight	Pv	250	kg
Own weight panels + aluminium profiles + straps		25	kg/m²
Own weight panels + aluminium profiles + straps		0,25	kN/m²
Foundation lenght	Lz	1,7	m
Foundation width	Bz	1,3	m
Foundation height	Hz	1,3	m



GROUND DATA

Ground type		Tender	
Apparent density	γ	18	kN/m³
Horizontal friction angle	ϕ	20,0	º
Vertical friction angle	δ	13,3	º
Passive push coefficient	Kp	2,0	
Vertical active push coefficient	Kav	0,5	
orizontal active coefficient	Kah	0,1	
Thickness minimum pavement	t	n/p	m
Strength concrete pavement	σk	n/p	N/mm²

SNOW LOAD

$q_n = \mu \cdot s_k$

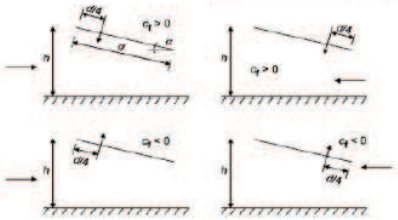
SNOW		
μ=	1	
qn=	0,5	kN/m²

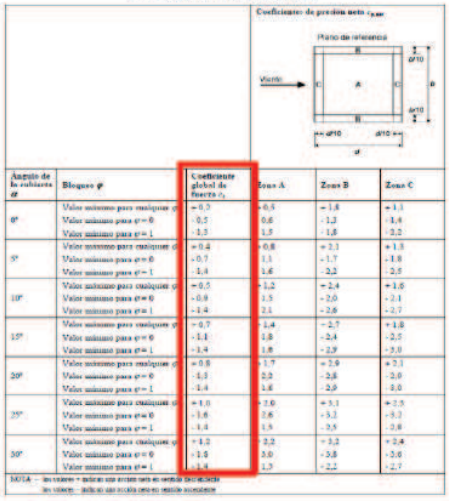
CALCULATION OF BASE PLATE REACTIONS

Wind load global coefficients

Global coefficient of pressure cp +	0,58	
Global suction coefficient cp-	0,98	
Pressure pressure wind qe +	0,64	kN/m²
Load wind suction qe-	1,08	kN/m²

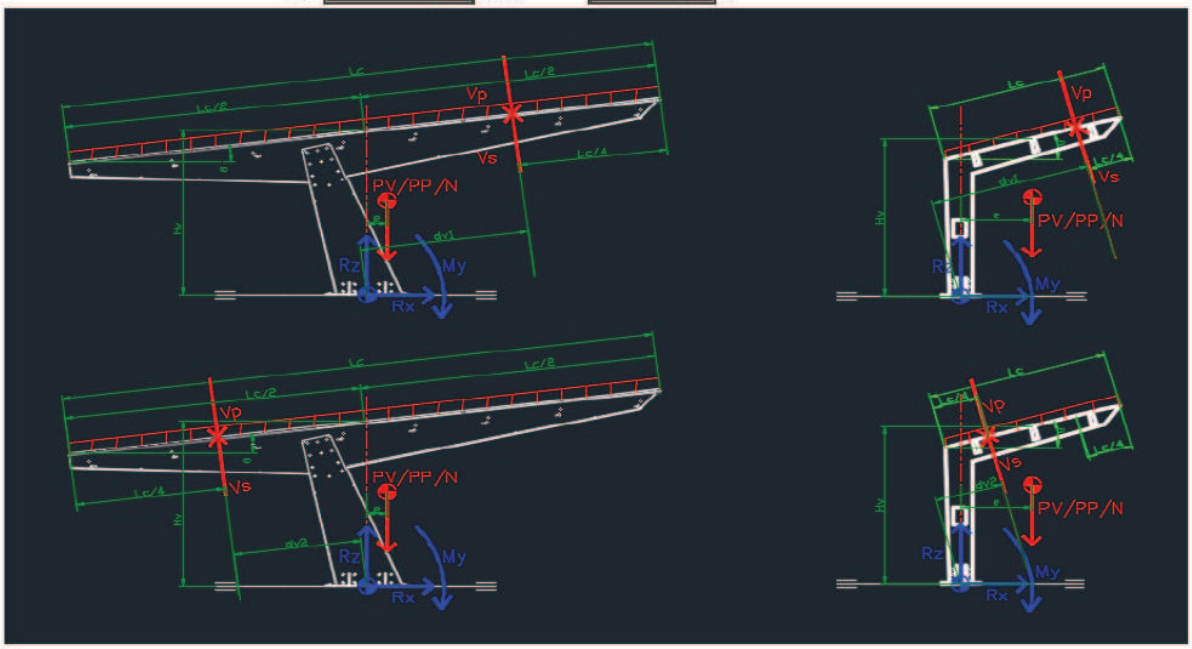
$$q_e = q_b \cdot c_e \cdot c_p$$





Scheme of loads on the cover of the canopy

PPk=	1,50	kN/m	4,95	kN
Nk=	2,93	kN/m	9,68	kN
Vkp=	3,83	kN/m	12,64	kN
Vks=	-6,47	kN/m	-21,36	kN



DetermDetermination of the most unfavorable calculation hypothesis

Comb.	PP	v+	v-	N	Total axial load kN	Total moment kNm
1	1,00				4,95	0,00
2	1,35				6,68	0,00
3	1,00	1,50			23,91	24,65
4	1,35	1,50			25,64	24,65
5	0,80		1,50		-28,08	-41,65
6	1,35		1,50		-25,35	-41,65
7	1,00			1,50	19,48	0,00
8	1,35			1,50	21,21	0,00
9	1,00	0,90		1,50	30,85	14,79
10	1,35	0,90		1,50	32,58	14,79
11	0,80		0,90	1,50	-0,74	-24,99
12	1,35		0,90	1,50	1,99	-24,99
13	1,00	1,50		0,75	31,17	24,65
14	1,35	1,50		0,75	32,91	24,65
15	0,80		1,50	0,75	-20,81	-41,65
16	1,35		1,50	0,75	-18,09	-41,65

	combination number
combination worse suction	5
combination worse moment pressure	3

Calculation of pressure hypothesis reactions factored 3

$\sum_0 M = 0 \rightarrow$ (Pvd + $ppd + Nd) \cdot e + dv \cdot Vpd = My$

$\sum_0 Fz = 0 \rightarrow$ Pvd + $ppd + Nd + Vpd \cdot cos(\theta)$=Rz

$\sum_0 Fx = 0 \rightarrow Vpd \cdot sin(\theta)$=Rx

dv1= 1,30 m

dv2= 0,36 m

Rzd= 26,00 kN (Vertical reaction: positive sign means compression on foundation)

Rxd= 3,94 kN (Horizontal reaction: can occur in both directions)

Myd= 24,65 kN·m (Moment: can occur in both directions)

Calculation factored suction reactions 5

$\sum_0 M = 0 \rightarrow$ (Pvd + $ppd) \cdot e + dv \cdot Vsd = My$

$\sum_0 Fz = 0 \rightarrow$ Pvd + $ppd + Vsd \cdot cos(\theta)$=Rz

$\sum_0 Fx = 0 \rightarrow Vsd \cdot sin(\theta)$=Rx

Rzd= -25,38 kN (Vertical reaction: positive sign means compression on foundation)

Rxd= 6,66 kN (Horizontal reaction: can occur in both directions)

Myd= 41,65 kN·m (Moment: can occur in both directions)

Calculation of characteristic reactions to calculate tensions in the ground with wind pressure

$\sum_0 M = 0 \rightarrow$ (Pvk + $ppk + Nk) \cdot e + dv \cdot Vpk = My$

$\sum_0 Fz = 0 \rightarrow$ Pvk + $ppd + Nk + Vpk \cdot cos(\theta)$=Rz

$\sum_0 Fx = 0 \rightarrow Vpk \cdot sin(\theta)$=Rx

Rzk= 29,50 kN (Vertical reaction: positive sign means compression on foundation)

Rxk= 2,63 kN (Horizontal reaction: can occur in both directions)

Myk= 16,43 kN·m (Moment: can occur in both directions)

Calculation of characteristic reactions to calculate tensions in the ground with wind suction

$\sum_0 M = 0 \rightarrow$ (Pvk + $ppk) \cdot e + dv \cdot Vsk = My$

$\sum_0 Fz = 0 \rightarrow$ Pvk + $ppk + Vsk \cdot cos(\theta)$=Rz

$\sum_0 Fx = 0 \rightarrow Vsk \cdot sin(\theta)$=Rx

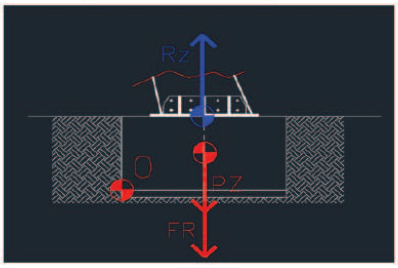
Rzk= -13,44 kN (Vertical reaction: positive sign means compression on foundation)

Rxk= 4,44 kN (Horizontal reaction: can occur in both directions)

Myk= 27,77 kN·m (Moment: can occur in both directions)

CALCULATION FOUNDATION UPRISING

$$\frac{(Pzk+Frk)\cdot 0{,}9}{RZd} \geq$$



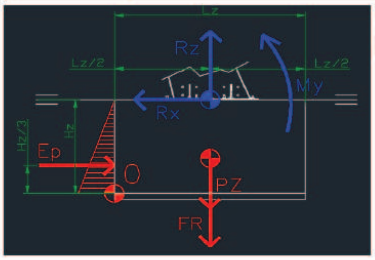
$PZ = Lz \cdot Bz \cdot Hz \cdot \rho$

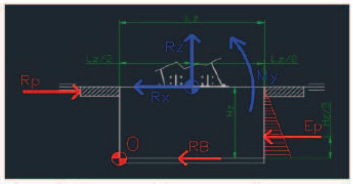
$Fr = \frac{1}{2} \cdot Kah \cdot \gamma \cdot Hz^2(2 \cdot Bz + 2 \cdot Lz)$

ρ=	23,00	kN/m³
PZ=	66,08	kN
Fr=	10,60	kN
(PZ+Fr)·0,9=	69,02	kN
Rzd=	25,38	kN
compliance factor η	2,72	
Uprising Result	Meet uprising	

OVERTURNING AND GROUND TENSION WITH CENTERED FOUNDATION PV / PVS

$$\frac{\left(Pzk+Frk\right)\frac{Lz}{2}+Ep\cdot Hz/3\cdot 0{,}9+\left(Ep\frac{2Hz}{3}+RB\cdot Hz\right)\cdot 0{,}9}{RZd\frac{Lz}{2}+Rxd\cdot Hz+Myd} \geq 1$$





$Ep = \frac{1}{2} \cdot Kp \cdot \gamma \cdot Hz^2 \cdot Bz$

$RB = (Pz\text{-}Rkz) \cdot 2/3 \cdot tg\phi$

$\left((Pzk + Frk) \cdot \frac{Lz}{2} + Ep \cdot Hz/3\right) \cdot 0{,}9 =$

$RZd \cdot \frac{Lz}{2} + Rxd \cdot Hz + Myd =$

$\left(Ep \cdot \frac{2Hz}{3} + RB \cdot Hz\right) \cdot 0{,}9 =$

Ep=	40,33	kN
RB=	n/p	kN
	79,23	kN·m
	71,88	kN·m
	n/p	kN·m
compliance factor without pavement η	1,10	
Overturning result without pavement	meet overturning	
compliance factor with pavement η	n/p	
Overturning result with pavement	n/p	

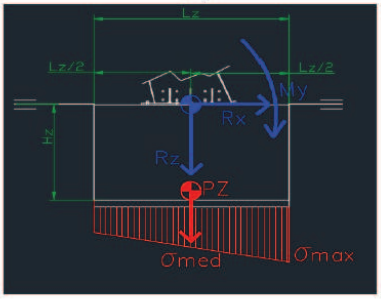
$Rp = (Ep + RB) =$ n/p kN

$\sigma adm = \sigma k / 1{,}5 =$ n/p N/mm²

$\sigma d = \frac{Rp \cdot 1{,}5}{Bz \cdot t} =$ n/p N/mm²

compliance factor pavement stress η	n/p
Result stress pavement	n/p

$$\sigma_{med} = \frac{Rzk + Pzk}{Lz \cdot Bz} \qquad \sigma_{max} = \sigma_{med} + \frac{Myk + Rxk \cdot Hz}{Wxx}$$



$Rzk = Pvk + PPk + Nk + Vpk \cdot cos(\theta) =$

$Pzk =$

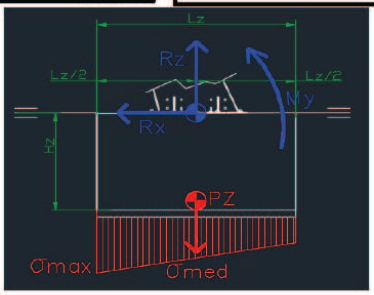
$Myk = (Pvk + ppk + Nk) \cdot e + dv \cdot Vpk =$

$Rxk = Vpk \cdot sin(\theta) =$

$Wxx = \frac{Bz \cdot Lz^2}{6} =$

	29,50	kN
Pzk=	66,08	kN
	16,43	KN·m
	2,63	kN
	0,626	m³
σmed=	0,43	kg/cm²
σmax=	0,75	kg/cm²
the minimum permissible stress of the terrain must be at least σmax / 1.25	0,60	kg/cm²

$$\sigma_{med} = \frac{Pzk - Rzk}{Lz \cdot Bz} \qquad \sigma_{max} = \sigma_{med} + \frac{Myk + Rxk \cdot Hz}{Wxx}$$



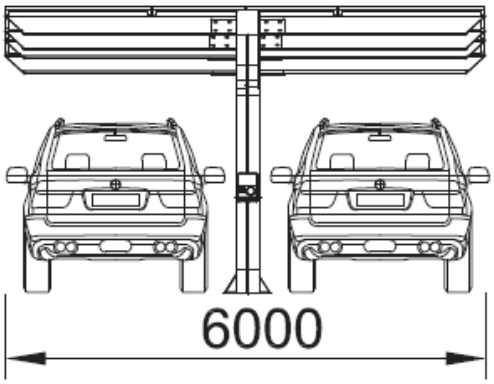
$Wxx = \frac{Bz \cdot Lz^2}{6} =$

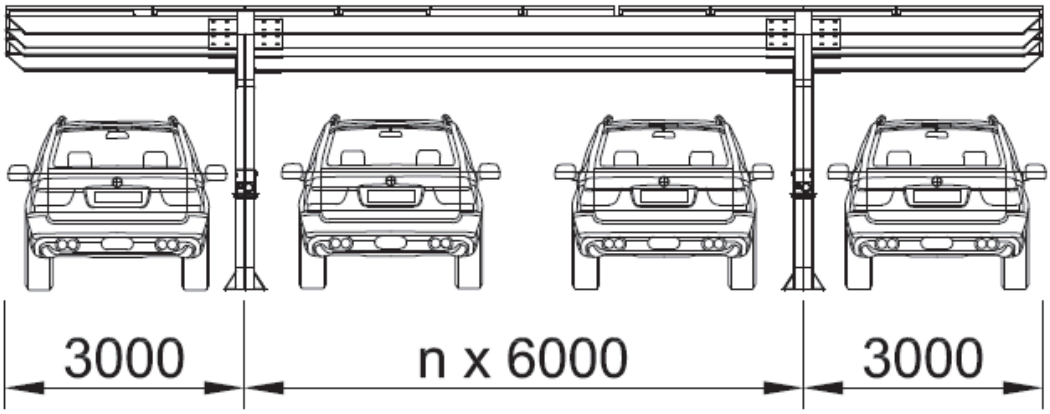
Rzk=	13,44	kN
Pzk=	66,08	kN
Myk=	27,77	KN·m
Rxk=	4,44	kN
	0,626	m³
σmed=	0,24	kg/cm²
σmax=	0,77	kg/cm²
the minimum permissible stress of the terrain must be at least σmax / 1.25	0,62	kg/cm²

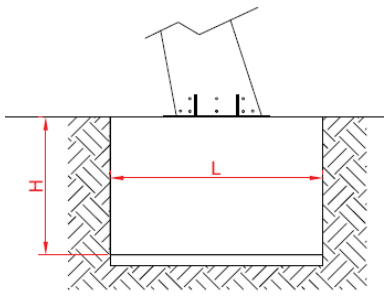
8 PVS2 CANOPY only one support LENGHT 5 m AND 12º

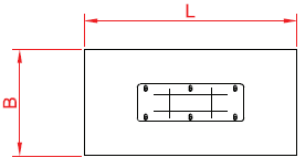
8.1 Foundation sizing tables

8.1.1 Up to 6 m of cover for each support









Wind zone C (29m/s)				
	Option 4	**Option 3**	**Option 2**	**Option 1**
Maximum snow load	100 Kg/m2	80 Kg/m2	30 Kg/m2	
Roughness of the environment (CTE)	IV	III	II	I
Roughness of the environment (Eurocode)	III	II	I	0
Exposure coefficient	1,3	1,6	2,1	2,4
Pressure wind load	41 Kg/m2	50 Kg/m2	64 Kg/m2	Not install
Wind load suction	-69 Kg/m2	-84 Kg/m2	-108 Kg/m2	
Own weight of the solar panels + aluminium substructure + straps	25 kg/m2	25 kg/m2	25 kg/m2	
Canopy weight	300 kg	300 kg	300 kg	
Maximum obstruction coefficient	***0***	***0***	***0***	
Foundation (L x B x H) (1)	***1,9x1,3x1,3***	***2,1x1,4x1,4***	***2,2x1,5x1,5***	
Required minimum ground resistance (2)	***0.8 Kg/cm2***	***0.75 Kg/cm2***	***0.70 Kg/cm2***	

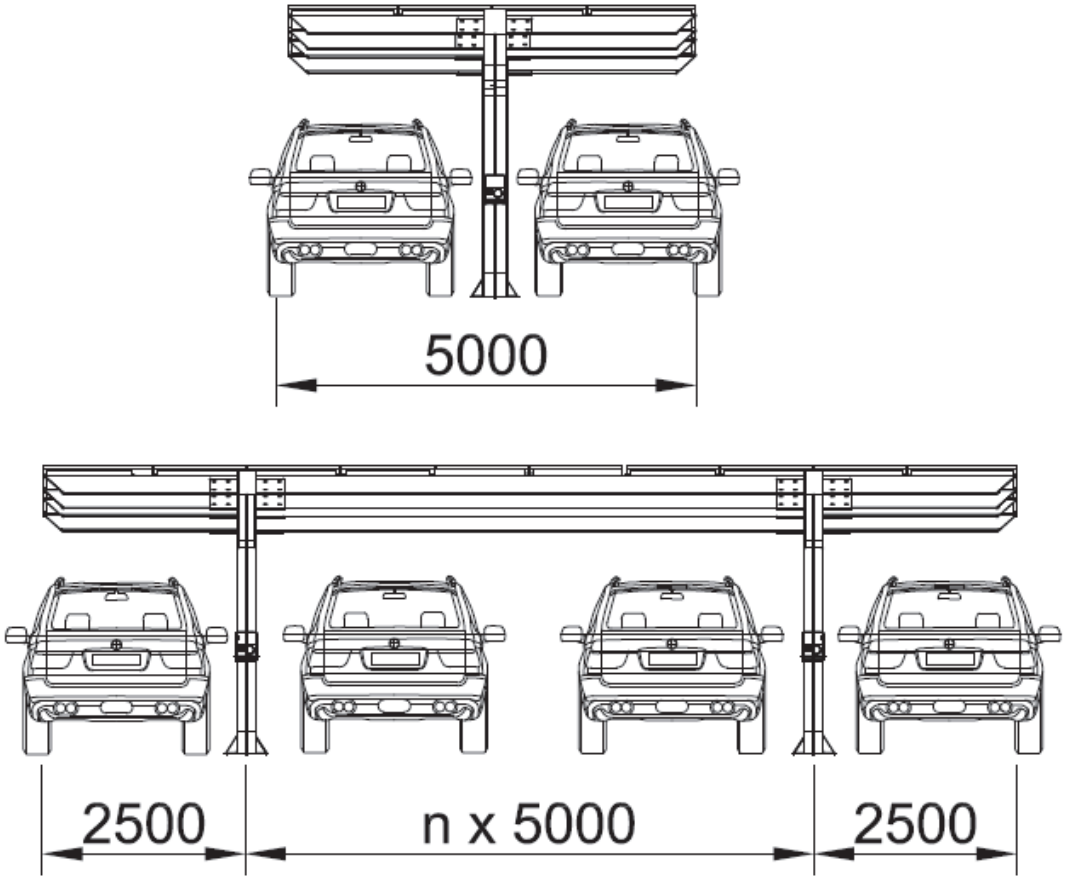
Wind zone (27m/s)				
	Option 4	**Option 3**	**Option 2**	**Option 1**
Maximum snow load	110 Kg/m2	100 Kg/m2	65 Kg/m2	35Kg/m2
Roughness of the environment (CTE)	IV	III	II	I
Roughness of the environment (Eurocode)	III	II	I	0
Exposure coefficient	1,3	1,6	2,1	2,4
Pressure wind load	35 Kg/m2	43 Kg/m2	55 Kg/m2	62 Kg/m2
Wind load suction	-60 Kg/m2	-73 Kg/m2	-94 Kg/m2	-104 Kg/m2
Own weight of the solar panels + aluminium substructure + straps	25 kg/m2	25 kg/m2	25 kg/m2	25 kg/m2
Canopy weight	300 kg	300 kg	300 kg	300 kg
Maximum obstruction coefficient	***0***	***0***	***0***	***0***
Foundation (L x B x H) (1)	***1,8x1,3x1,3***	***1,9x1,4x1,4***	***2,0x1,5x1,5***	***2,2x1,5x1,5***
Required minimum ground resistance (2)	***0.8 Kg/cm2***	***0.75 Kg/cm2***	***0.70 Kg/cm2***	***0.70 Kg/cm2***

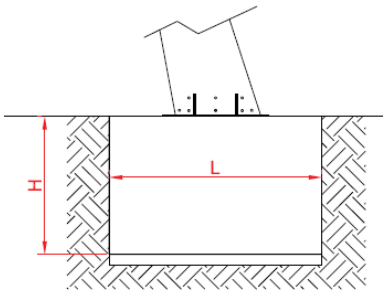
Wind zone A (26m/s)				
	Option 4	**Option 3**	**Option 2**	**Option 1**
Maximum snow load	120 Kg/m2	110 Kg/m2	75 Kg/m2	45Kg/m2
Roughness of the environment (CTE)	IV	III	II	I
Roughness of the environment (Eurocode)	III	II	I	0
Exposure coefficient	1,3	1,6	2,1	2,4
Pressure wind load	33 Kg/m2	40 Kg/m2	51 Kg/m2	57 Kg/m2
Wind load suction	-55 Kg/m2	-68 Kg/m2	-87 Kg/m2	-97 Kg/m2
Own weight of the solar panels + aluminium substructure + straps	25 kg/m2	25 kg/m2	25 kg/m2	25 kg/m2
Canopy weight	300 kg	300 kg	300 kg	300 kg
Maximum obstruction coefficient	***0***	***0***	***0***	***0***
Foundation (L x B x H) (1)	***1,7x1,3x1,3***	***1,8x1,4x1,4***	***1,9x1,5x1,5***	***2,1x1,5x1,5***
Required minimum ground resistance (2)	***0.85 Kg/cm2***	***0.80 Kg/cm2***	***0.80 Kg/cm2***	***0.75 Kg/cm2***

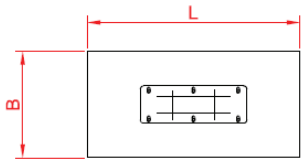
(1) The foundation is considered completely surrounded by lands up to its upper face. The land under consideration is medium compactness with a 20º friction angle and 1,8t / m3 density. For better terrains you can get smaller dimension of foundation. The foundation must be surrounded by a strip of land at least 3 times the edge of the shoe on all sides. If the foundation is located in the vicinity of a ground level change, a special study must be carried out.

(2) It must be verified that the ground where the shoe rests has at least the indicated admissible tension.

8.1.1 *Up to 5 m of cover for each support*







Wind zone C (29m/s)				
	Option 4	**Option 3**	**Option 2**	**Option 1**
Maximum snow load	110 Kg/m2	100 Kg/m2	80 Kg/m2	40 Kg/m2
Roughness of the environment (CTE)	IV	III	II	I
Roughness of the environment (Eurocode)	III	II	I	0
Exposure coefficient	1,3	1,6	2,1	2,4
Pressure wind load	41 Kg/m2	50 Kg/m2	64 Kg/m2	71 Kg/m2
Wind load suction	-69 Kg/m2	-84 Kg/m2	-108 Kg/m2	-120 Kg/m2
Own weight of the solar panels + aluminium substructure + straps	25 kg/m2	25 kg/m2	25 kg/m2	25 kg/m2
Canopy weight	300 kg	300 kg	300 kg	300 kg
Maximum obstruction coefficient	***0***	***0***	***0***	***0***
Foundation (L x B x H) (1)	***1,7x1,3x1,3***	***1,9x1,3x1,3***	***2,1x1,4x1,4***	***2,3x1,4x1,4***
Required minimum ground resistance (2)	***0,80 Kg/cm2***	***0,75 Kg/cm2***	***0,70 Kg/cm2***	***0,65 Kg/cm2***

Wind zone B (27m/s)				
	Option 4	**Option 3**	**Option 2**	**Option 1**
Maximum snow load	120 Kg/m2	110 Kg/m2	90 Kg/m2	50 Kg/m2
Roughness of the environment (CTE)	IV	III	II	I
Roughness of the environment (Eurocode)	III	II	I	0
Exposure coefficient	1,3	1,6	2,1	2,4
Pressure wind load	35 Kg/m2	43 Kg/m2	55 Kg/m2	62 Kg/m2
Wind load suction	-60 Kg/m2	-73 Kg/m2	-94 Kg/m2	-104 Kg/m2
Own weight of the solar panels + aluminium substructure + straps	25 kg/m2	25 kg/m2	25 kg/m2	25 kg/m2
Canopy weight	300 kg	300 kg	300 kg	300 kg
Maximum obstruction coefficient	***0***	***0***	***0***	***0***
Foundation (L x B x H) (1)	***1,7x1,2x1,2***	***1,8x1,3x1,3***	***1,9x1,4x1,4***	***2,0x1,4x1,4***
Required minimum ground resistance (2)	***0,80 Kg/cm2***	***0,75 Kg/cm2***	***0,75 Kg/cm2***	***0,70 Kg/cm2***

Wind zone A (26m/s)				
	Option 4	**Option 3**	**Option 2**	**Option 1**
Maximum snow load	130 Kg/m2	120 Kg/m2	100 Kg/m2	60 Kg/m2
Roughness of the environment (CTE)	IV	III	II	I
Roughness of the environment (Eurocode)	III	II	I	0
Exposure coefficient	1,3	1,6	2,1	2,4
Pressure wind load	33 Kg/m2	40 Kg/m2	51 Kg/m2	57 Kg/m2
Wind load suction	-55 Kg/m2	-68 Kg/m2	-87 Kg/m2	-97 Kg/m2
Own weight of the solar panels + aluminium substructure + straps	25 kg/m2	25 kg/m2	25 kg/m2	25 kg/m2
Canopy weight	300 kg	300 kg	300 kg	300 kg
Maximum obstruction coefficient	***0***	***0***	***0***	***0***
Foundation (L x B x H) (1)	***1,6x1,2x1,2***	***1,7x1,3x1,3***	***1,8x1,4x1,4***	***1,9x1,4x1,4***
Required minimum ground resistance (2)	***0,85 Kg/cm2***	***0,80 Kg/cm2***	***0,80 Kg/cm2***	***0,75 Kg/cm2***

(1) The foundation is considered completely surrounded by lands up to its upper face. The land under consideration is medium compactness with a 20º friction angle and 1,8t / m3 density. For better terrains you can get smaller dimension of foundation. The foundation must be surrounded by a strip of land at least 3 times the edge of the shoe on all sides. If the foundation is located in the vicinity of a ground level change, a special study must be carried out.

(2) It must be verified that the ground where the shoe rests has at least the indicated admissible tension.

8.2 Calculation

The representative hypothesis for the foundation calculation for the total width of the roof of 6 meters is shown below.

In the case of width 6m, the values of option 2 in wind zone C are taken as reference, as these are the most unfavourable.

The rest of the options are calculated in the same way, and it is verified that there are no higher pressure and suction loads than in the options taken as representative.

In options 1 to 4 of each wind zone, different suctions and pressures will be produced, a fact that is used to define a greater or lesser admissible snow load as the admitted degree of roughness is varied.

In order to determine the different loading options for wind zones A, B and C, an analogous action is taken, keeping as a limit the values of pressure + snow and suction calculated in the representative option.

PV-PVS-PVB CANOPY FOUNDATION CALCULATION

CLIMATE DATA

Wind zone		C	
Roughness (according to CTE)		II	
Height in the center of the canopy	Hc	3	m
	Vb	29	m/s
	δ	1,25	kg/m3
$q_b = 0{,}5 \cdot \delta \cdot v_b^2$	qb	0,53	kN/m²
	K	0,17	
	L (m)	0,01	
	Z (m)	1	
$c_e = F \cdot (F + 7\,k)$	F	0,97	
$F = k \ln(\max(z,Z) / L)$	Ce	2,09	

Height of the site above sea level	0	m
Winter climate zone	1	
Snow load Sk	0,30	kN/m²

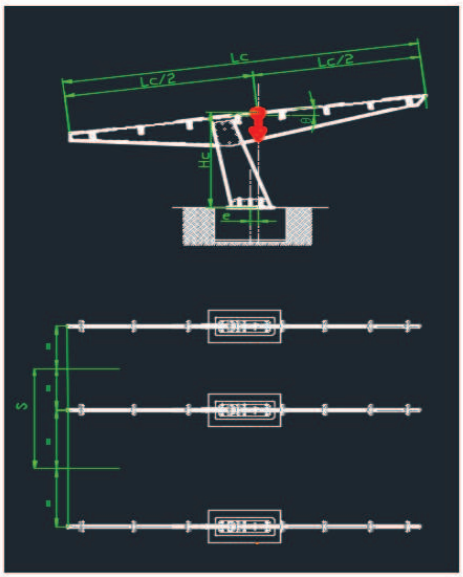
Grado de aspereza del entorno

I	Borde del mar o de un lago, con una superficie de agua en la dirección del viento de al menos 5 km de longitud
II	Terreno rural llano sin obstáculos ni arbolado de importancia
III	Zona rural accidentada o llana con algunos obstáculos aislados, como árboles o construcciones pequeñas
IV	Zona urbana en general, industrial o forestal
V	Centro de negocios de grandes ciudades, con profusión de edificios en altura

Figura E.2 Zonas climáticas de invierno

ASSEMBLY DATA

Canopy type		PVS2/PV2	
Cover width that rests on the support	S	6	m
Obstruction coefficient	φ	0	
Support length	Lc	5	m
Eccentricity of the roof with respect to the pillar	e	0,17	m
Canopy angle	θ	12	º
Support weight	Pv	300	kg
Own weight panels + aluminium profiles + straps		25	kg/m²
Own weight panels + aluminium profiles + straps		0,25	kN/m²
Foundation lenght	Lz	2,2	m
Foundation width	Bz	1,4	m
Foundation height	Hz	1,5	m



GROUND DATA

Ground type	Tender	
Apparent density γ	18	kN/m³
Horizontal friction angle ϕ	20,0	º
Vertical friction angle δ	13,3	º
Passive push coefficient Kp	2,0	
Vertical active push coefficient Kav	0,5	
orizontal active coefficient Kah	0,1	
Thickness minimum pavement t	n/p	m
Strength concrete pavement σk	n/p	N/mm²

SNOW LOAD

$q_n = \mu \cdot s_k$

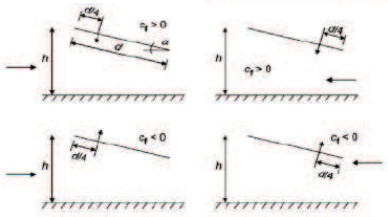
SNOW		
μ=	1	
qn=	0,3	kN/m²

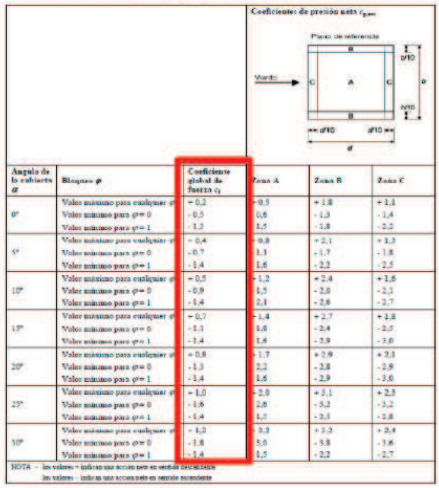
CALCULATION OF BASE PLATE REACTIONS

Wind load global coefficients

Global coefficient of pressure cp +	0,58	
Global suction coefficient cp-	0,98	
Pressure pressure wind qe +	0,64	kN/m²
Load wind suction qe-	1,08	kN/m²

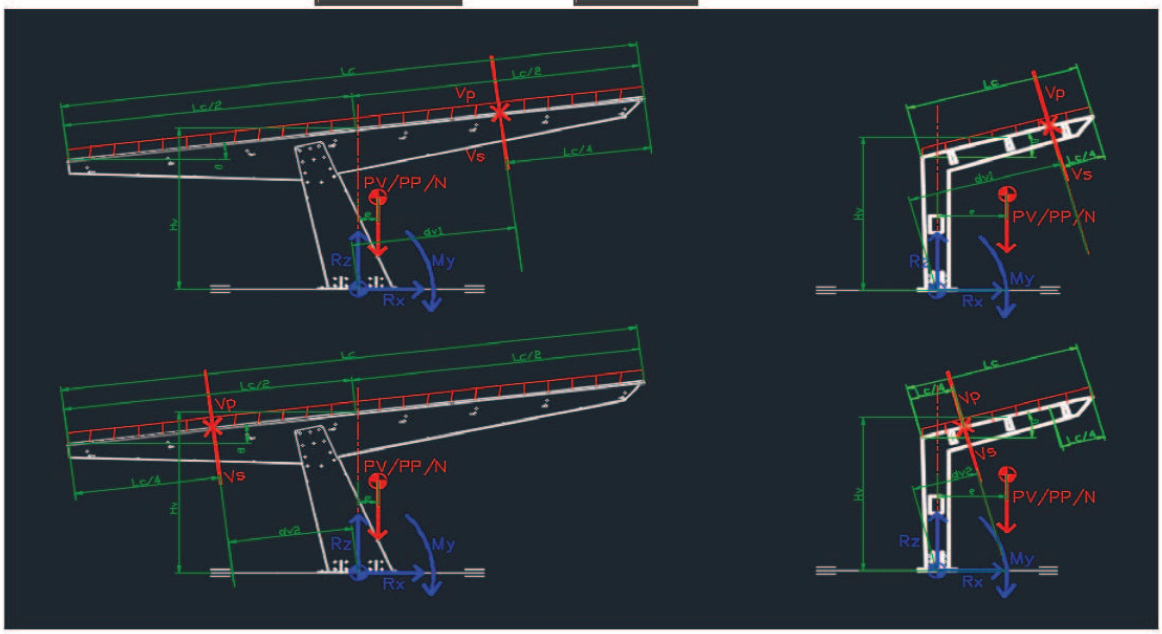
$$q_e = q_b \cdot c_e \cdot c_p$$





Scheme of loads on the cover of the canopy

PPk=	1,50	kN/m	7,50	kN
Nk=	1,76	kN/m	8,80	kN
Vkp=	3,83	kN/m	19,15	kN
Vks=	-6,47	kN/m	-32,36	kN



DetermDetermination of the most unfavorable calculation hypothesis

Comb.	PP	v+	v-	N	Total axial load kN	Total moment kNm
1	1,00				7,50	1,79
2	1,35				10,13	2,41
3	1,00	1,50			36,23	60,68
4	1,35	1,50			38,85	61,30
5	0,80		1,50		-42,54	-98,08
6	1,35		1,50		-38,42	-97,10
7	1,00			1,50	20,70	4,03
8	1,35			1,50	23,33	4,65
9	1,00	0,90		1,50	37,94	39,37
10	1,35	0,90		1,50	40,57	39,99
11	0,80		0,90	1,50	-9,92	-56,03
12	1,35		0,90	1,50	-5,79	-55,05
13	1,00	1,50		0,75	42,83	61,80
14	1,35	1,50		0,75	45,46	62,43
15	0,80		1,50	0,75	-35,94	-96,96
16	1,35		1,50	0,75	-31,81	-95,98

	combination number
combination worse suction	5
combination worse moment pressure	14

Calculation of pressure hypothesis reactions factored 14

$\sum_0 M = 0 \rightarrow$ (Pvd + ppd + Nd) · e + dv · Vpd = My

$\sum_0 Fz = 0 \rightarrow$ Pvd + ppd + Nd + $Vpd \cdot cos(\theta)$=Rz

$\sum_0 Fx = 0 \rightarrow Vpd \cdot sin(\theta)$=Rx

dv1= 2,05 m

dv2= 0,61 m

Rzd= 48,88 kN (Vertical reaction: positive sign means compression on foundation)

Rxd= 5,97 kN (Horizontal reaction: can occur in both directions)

Myd= 62,43 kN·m (Moment: can occur in both directions)

Calculation factored suction reactions 5

$\sum_0 M = 0 \rightarrow$ (Pvd + ppd) · e + dv · Vsd = My

$\sum_0 Fz = 0 \rightarrow$ Pvd + ppd + $Vsd \cdot cos(\theta)$=Rz

$\sum_0 Fx = 0 \rightarrow Vsd \cdot sin(\theta)$=Rx

Rzd= -39,08 kN (Vertical reaction: positive sign means compression on foundation)

Rxd= 10,09 kN (Horizontal reaction: can occur in both directions)

Myd= 98,08 kN·m (Moment: can occur in both directions)

Calculation of characteristic reactions to calculate tensions in the ground with wind pressure

$\sum_0 M = 0 \rightarrow$ (Pvk + ppk + Nk) · e + dv · Vpk = My

$\sum_0 Fz = 0 \rightarrow$ Pvk + ppd + Nk + $Vpk \cdot cos(\theta)$=Rz

$\sum_0 Fx = 0 \rightarrow Vpk \cdot sin(\theta)$=Rx

Rzk= 38,04 kN (Vertical reaction: positive sign means compression on foundation)

Rxk= 3,98 kN (Horizontal reaction: can occur in both directions)

Myk= 42,54 kN·m (Moment: can occur in both directions)

Calculation of characteristic reactions to calculate tensions in the ground with wind suction

$\sum_0 M = 0 \rightarrow$ (Pvk + ppk) · e + dv · Vsk = My

$\sum_0 Fz = 0 \rightarrow$ Pvk + ppk + $Vsk \cdot cos(\theta)$=Rz

$\sum_0 Fx = 0 \rightarrow Vsk \cdot sin(\theta)$=Rx

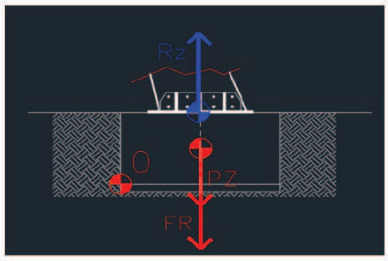
Rzk= -21,15 kN (Vertical reaction: positive sign means compression on foundation)

Rxk= 6,73 kN (Horizontal reaction: can occur in both directions)

Myk= 64,55 kN·m (Moment: can occur in both directions)

CALCULATION FOUNDATION UPRISING

$$\frac{(Pzk+Frk)\cdot 0{,}9}{RZd} \geq$$



$PZ = Lz \cdot Bz \cdot Hz \cdot \rho$

ρ= 23,00 kN/m³

PZ= 106,26 kN

$Fr = \frac{1}{2} \cdot Kah \cdot \gamma \cdot Hz^2 (2 \cdot Bz + 2 \cdot Lz)$

Fr= 16,94 kN

(PZ+Fr)·0,9= 110,88 kN

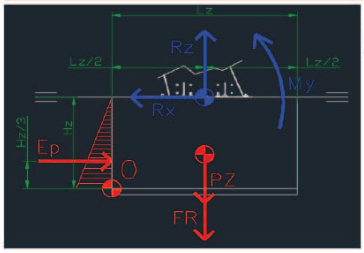
Rzd= 39,08 kN

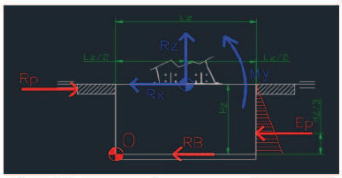
compliance factor η 2,84

Uprising Result: Meet uprising

OVERTURNING AND GROUND TENSION WITH CENTERED FOUNDATION PV / PVS

$$\frac{\left((Pzk+Frk)\frac{Lz}{2}+Ep\cdot Hz/3\right)\cdot 0{,}9+\left(Ep\frac{2Hz}{3}+RB\cdot Hz\right)\cdot 0{,}9}{RZd\cdot\frac{Lz}{2}+Rxd\cdot Hz+Myd} \geq 1$$





$Ep = \frac{1}{2} \cdot Kp \cdot \gamma \cdot Hz^2 \cdot Bz$ = 57,82 kN

RB= (Pz-Rkz)·2/3·tgϕ= n/p kN

$\left((Pzk+Frk)\cdot\frac{Lz}{2}+Ep\cdot Hz/3\right)\cdot 0{,}9$ = 160,13 kN·m

$RZd\cdot\frac{Lz}{2}+Rxd\cdot Hz+Myd$ = 156,21 kN·m

$\left(Ep\cdot\frac{2Hz}{3}+RB\cdot Hz\right)\cdot 0{,}9$ = n/p kN·m

compliance factor without pavement η: 1,03

Overturning result without pavement: meet overturning

compliance factor with pavement η: n/p

Overturning result with pavement: n/p

$Rp = (Ep + RB)$ = n/p kN

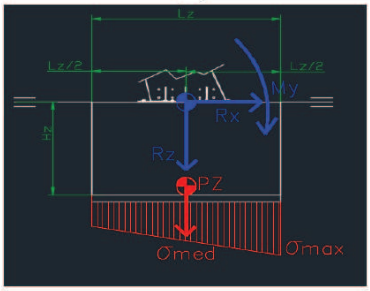
$\sigma adm = \sigma k/_{1,5}$ = n/p N/mm²

$\sigma d = \frac{Rp \cdot 1{,}5}{Bz \cdot t}$ = n/p N/mm²

compliance factor pavement stress η: n/p

Result stress pavement: n/p

$$\sigma_{med} = \frac{Rzk + Pzk}{Lz \cdot Bz} \qquad \sigma_{max} = \sigma_{med} + \frac{Myk + Rxk \cdot Hz}{Wxx}$$



$RZk = Pvk + PPk + Nk + Vpk \cdot cos(\theta)$ = 38,04 kN

Pzk= 106,26 kN

$Myk = (Pvk + ppk + Nk) \cdot e + dv \cdot Vpk$ = 42,54 KN·m

$Rxk = Vpk \cdot sin(\theta)$ = 3,98 kN

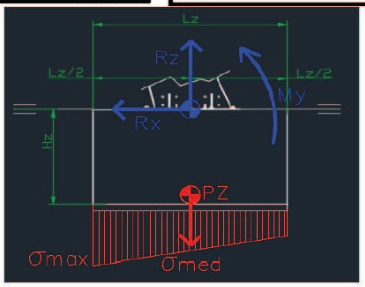
$Wxx = \frac{Bz \cdot Lz^2}{6}$ = 1,129 m³

σmed= 0,47 kg/cm²

σmax= 0,90 kg/cm²

the minimum permissible stress of the terrain must be at least σmax / 1.25: 0,72 kg/cm²

$$\sigma_{med} = \frac{Pzk - Rzk}{Lz \cdot Bz} \qquad \sigma_{max} = \sigma_{med} + \frac{Myk + Rxk \cdot Hz}{Wxx}$$



Rzk= 21,15 kN

Pzk= 106,26 kN

Myk= 64,55 KN·m

$Wxx = \frac{Bz \cdot Lz^2}{6}$

Rxk= 6,73 kN

1,129 m³

σmed= 0,28 kg/cm²

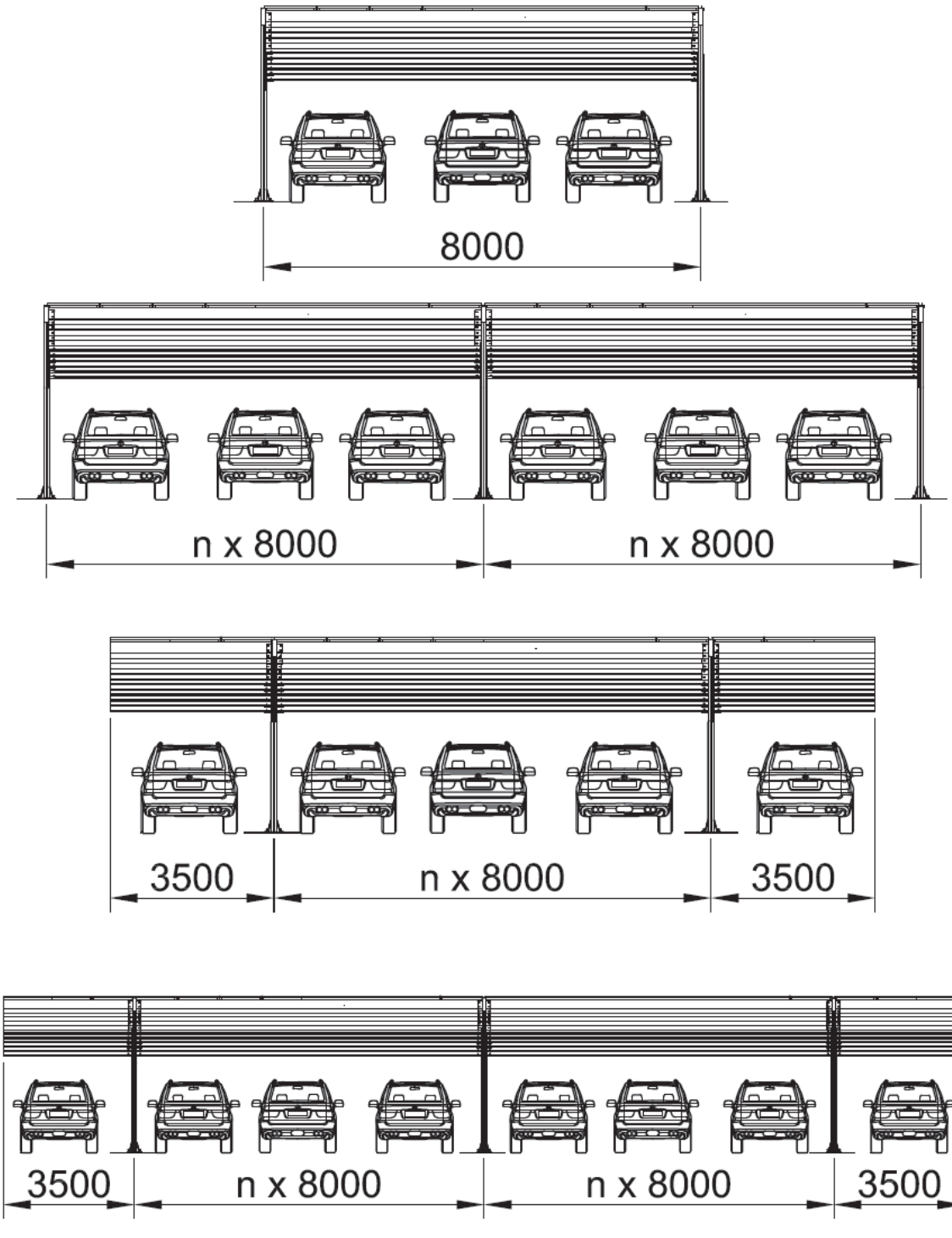
σmax= 0,94 kg/cm²

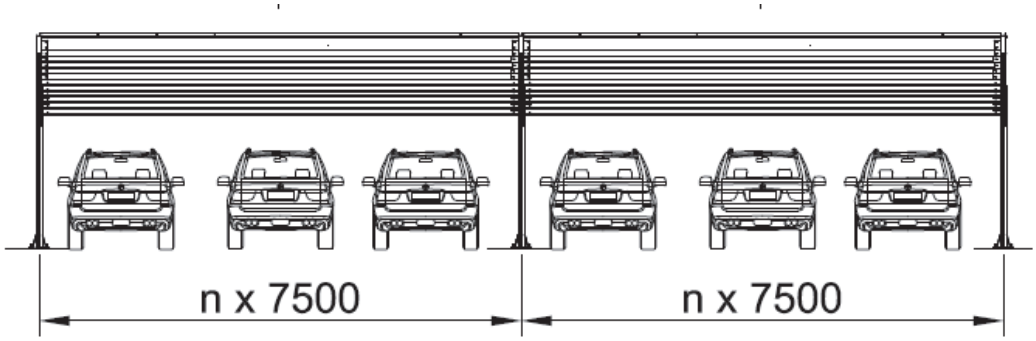
the minimum permissible stress of the terrain must be at least σmax / 1.25: 0,75 kg/cm²

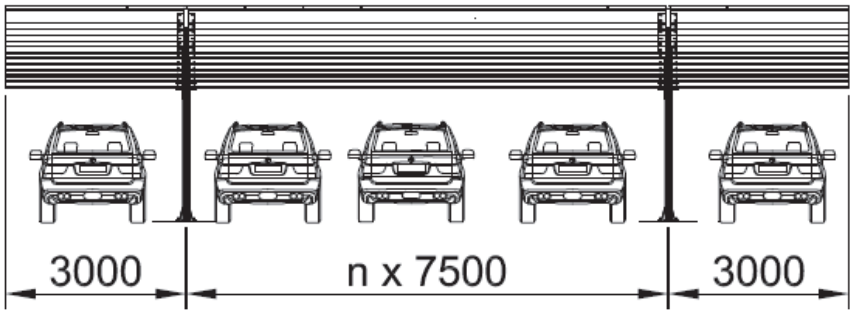
9 PV2 CANOPY LENGHT 5 m AND 12º

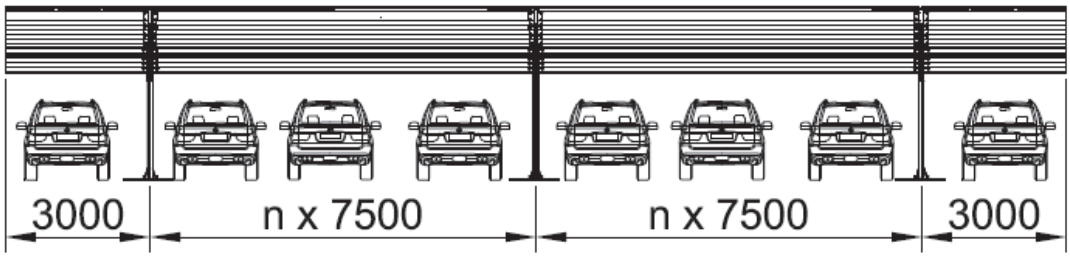
9.1 Foundation sizing tables

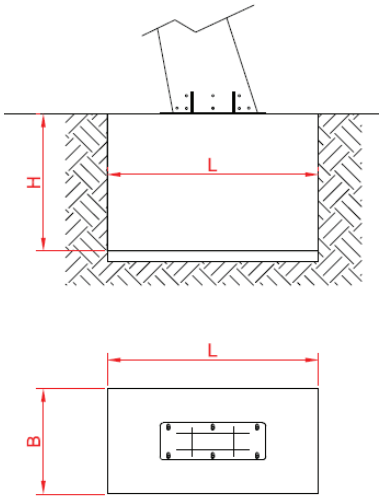
9.1.1 Up to 8 m of cover for each support











Wind zone C (29m/s)				
	Option 4	Option 3	Option 2	Option 1
Maximum snow load	50 Kg/m2			
Roughness of the environment (CTE)	IV	III	II	I
Roughness of the environment (Eurocode)	III	II	I	0
Exposure coefficient	1,3			
Pressure wind load	41 Kg/m2	Not install		
Wind load suction	-69 Kg/m2			
Own weight of the solar panels + aluminium substructure + straps	25 kg/m2			
Canopy weight	***300 kg***			
Maximum obstruction coefficient	***0***			
Foundation (L x B x H) (1)	***1,9x1,5x1,5***			
Required minimum ground resistance (2)	***0,80 Kg/cm2***			

Wind zone B (27m/s)				
	Option 4	Option 3	Option 2	Option 1
Maximum snow load	60 Kg/m2			
Roughness of the environment (CTE)	IV	III	II	I
Roughness of the environment (Eurocode)	III	II	I	0
Exposure coefficient	1,3			
Pressure wind load	35 Kg/m2	Not install		
Wind load suction	-60 Kg/m2			
Own weight of the solar panels + aluminium substructure + straps	25 kg/m2			
Canopy weight	***300 kg***			
Maximum obstruction coefficient	***0***			
Foundation (L x B x H) (1)	***1,9x1,4x1,4***			
Required minimum ground resistance (2)	***0,80 Kg/cm2***			

Wind zone A (26m/s)				
	Option 4	Option 3	Option 2	Option 1
Maximum snow load	65 Kg/m2	50 Kg/m2		
Roughness of the environment (CTE)	IV	III	II	I
Roughness of the environment (Eurocode)	III	II	I	0
Exposure coefficient	1,3	1,6		
Pressure wind load	33 Kg/m2	40 Kg/m2	Not install	
Wind load suction	-55 Kg/m2	-68 Kg/m2		
Own weight of the solar panels + aluminium substructure + straps	25 kg/m2	25 kg/m2		
Canopy weight	***300 kg***	***300 kg***		
Maximum obstruction coefficient	***0***	***0***		
Foundation (L x B x H) (1)	***1,8x1,4x1,4***	***1,8x1,5x1,5***		
Required minimum ground resistance (2)	***0,80 Kg/cm2***	***0,80 Kg/cm2***		

(1) The foundation is considered completely surrounded by lands up to its upper face. The land under consideration is medium compactness with a 20º friction angle and 1,8t / m3 density. For better terrains you can get smaller dimension of foundation. The foundation must be surrounded by a strip of land at least 3 times the edge of the shoe on all sides. If the foundation is located in the vicinity of a ground level change, a special study must be carried out.

(2) It must be verified that the ground where the shoe rests has at least the indicated admissible tension.