Connecting Strength

Base Report: annotations

Structural Analysis Report

Loads

LOADS	
Design method [1]	DIN EN
Failure consequence class (CC)	CC2
Design working life	25 years
Terrain category	II - Agricultural/farmland area

1. Applied standard for the project.

Wind load

WIND LOAD	
Wind load zone	1
Velocity pressure [1]	$q_{p,50}$ = 0.672 kN/m²
Adjustment factor for service life	f_w = 0.901
Velocity pressure [2]	$q_{p,25}$ = 0.606 kN/m²

1. Gust pressure on the roof for a return period of 50 years.
   (According to DIN EN 1991-1-4)
2. Gust pressure on the roof for a return period of 25 years.
   (According to DIN EN 1991-1-4 ($q_{p,25} = q_{p,50} \times fw$))

Snow load

SNOW LOAD	
Snow guard	No
Snow load on ground level [1]	s_k = 1.752 kN/m²
Shape Coefficient for Snow [2]	μ_i = 0.800
Factor for roof pitch [3]	d_i = 1.000
Snow load on roof [4]	$s_{i,50}$ = 1.402 kN/m²
Adjustment factor for service life	f_s = 0.929
Snow load on roof [5]	$s_{i,25}$ = 1.302 kN/m²

1. Determination with the help of the snow load zone and terrain height above sea level. The procedure varies from country to country. (See DIN EN 1991-1-3 National Annexes of corresponding countries)
2. Value of determining the load distribution on the roof. Depending on roof shape, angle of inclination and snow type (blowing snow or non-blowing snow). (From DIN EN 1991-1-3 + National Annex)

3. Conversion value for roof parallel and roof perpendicular force. Cosine value of roof pitch.
4. Snow load on the roof for a return period of 50 years.
   (According to DIN EN 1991-1-3)
5. Snow load on the roof for a return period of 25 years.
   (According to DIN EN 1991-1-3 ($s_{i,25} = s_{i,50} \times f_s$))

Dead load

DEAD LOAD

Weight module	G_M	= 20.0 kg
Weight mounting system per module area		= 1.7 kg
Module area [1]	A_M	= 1.63 m²
Dead weight module [2]		= 12.27 kg/m²
Dead weight mounting system [3]		= 1.04 kg/m²
Total Dead Weight (excl. ballast) [4]		= 0.13 kN/m²

1. Length × Width of the module
2. Dead Weight of the module per m²: Weight of modules divided by module area: GM / AM.
3. Dead Weight of the mounting system per m²: Weight of mounting systems divided by module area.
4. Total dead load per m² (Dead weight module + dead weight mounting system) × 9.81 / AM.

Connecting Strength

Load Combinations

Ultimate Limit State

ULTIMATE LIMIT STATE (1)

Partial safety factor unfavourable permanent load	$\gamma_{G,sup}$	= 1.35
Partial safety factor favourable permanent load	$\gamma_{G,inf}$	= 1.00
Partial safety factor destabilising permanent load (2)	$\gamma_{G,dst}$	= 1.10
Partial safety factor stabilising permanent load	$\gamma_{G,stb}$	= 0.90
Partial safety factor first variable load	γ_Q	= 1.50 (5)
Partial safety factor variable loads	γ_Q	= 1.50
Combination coefficient with regards to wind (3)	$\psi_{0,W}$	= 0.60
Combination coefficient with regards to wind (additional varying influences)	$\psi_{1,W}$	= 0.20
Combination coefficient with regards to Snow	$\psi_{0,S}$	= 0.50
Importance factor permanent (4)	$K_{FI,G}$	= 1.00
Importance factor variable	$K_{FI,Q}$	= 1.00

Load case combination 01 (6) $E_d = \gamma_{G,sup} * K_{FI,G} * G_k + \gamma_Q * K_{FI,Q} * S_{i,n}$ (6a, 6b, 6c)

Load case combination 02 (7) $E_d = \gamma_{G,sup} * K_{FI,G} * G_k + \gamma_Q * K_{FI,Q} * W_{k,Pressure}$ (7a)

Load case combination 03 (8) $E_d = \gamma_{G,sup} * K_{FI,G} * G_k + \gamma_Q * K_{FI,Q} * (W_{k,Pressure} + \psi_{0,S} * S_{i,n})$

Load case combination 04 (9) $E_d = \gamma_{G,sup} * K_{FI,G} * G_k + \gamma_Q * K_{FI,Q} * (S_{i,n} + \psi_{0,W} * W_{k,Pressure})$

Load case combination 06 (10) $E_d = \gamma_{G,inf} * G_k + \gamma_Q * K_{FI,Q} * W_{k,Uplift}$ (10a)

1. Ultimate limit states are states beyond which a collapse of the structure or other forms of failure may occur. Characteristics of ultimate limit states are:
   - Loss of equilibrium of the entire structure or individual parts of the structure (note assembly conditions).
   - Loss of stability (especially with slender components)
   - Occurrence of failure mechanisms on the entire system or individual structural components

   Load-bearing capacity is calculated with safety values.
2. Partial safety factors: They distinguish between e.g. permanent and variable loads, as well as whether a load has a favorable/ stabilizing or unfavorable/destabilizing effect.
3. Combination coefficients: If several loads, e.g. wind and snow, act simultaneously, then they determine in which ratio they occur, e.g.
   1 × max. snow load + 0.6 × max. wind load
   The standard uses them to take into account the statistical improbability that a maximum snow event and a maximum wind event will occur at the same time.
4. Safety values: Depending on the interpretation of EN 1990 by national authorities, it is also possible to adjust loads according to their expected damage consequences (damage consequence classes CC1, CC2, CC3). For example, the damage consequences for an agricultural building without significant passenger traffic are assessed lower than for a hospital or stadium with high passenger traffic. Accordingly, they are adjusted by the importance factor in accordance with EN 1990.
5. Values Depending on country.

6. Maximum load from dead load and snow
   6a Design value: If design value < load-bearing capacity, the components do not fail
   6b G_k=characteristic dead load
   6c $S_{i,n}$ = characteristic snow load on the roof for a return period of n years
7. Maximum load from dead load and wind pressure
   7a $W_{k,pressure}$ = characteristic wind pressure
8. Maximum load from dead load and wind pressure and $\psi_{si0,S}$ × of snow load
9. Maximum load from dead load and snow and $\psi_{si0,W}$ × of wind pressure
10. Maximum load from dead load and wind suction
    10a $W_{k,sog}$ = characteristic wind suction

Position Safety

POSITION SAFETY	
Uplift Verification 1	$E_d = \gamma_{G,stb} * G_k + \gamma_Q * K_{Fl,Q} * W_{k,n,Uplift}$
Displacement verification	$E_d = \gamma_{G,stb} * G_k + \gamma_Q * K_{Fl,Q} * W_{k,n,Displacement}$

1. Proof of static equilibrium

Serviceability Limit State

SERVICEABILITY LIMIT STATE 1	
Combination coefficient with regards to wind	$\psi_{0,W} = 0.60$
Combination coefficient with regards to Snow 2	$\psi_{0,S} = 0.50$
Combination coefficient with regards to wind (additional varying influences)	$\psi_{1,W} = 0.20$
Load case combination 01 3	$E_d = G_k + S_{i,n}$ 3a
Load case combination 02 4	$E_d = G_k + W_{k,Pressure}$ 4a
Load case combination 03 5	$E_d = G_k + W_{k,Pressure} + \psi_{0,S} * S_{i,n}$
Load case combination 04 6	$E_d = G_k + S_{i,n} + \psi_{0,W} * W_{k,Pressure}$
Load case combination 06 7	$E_d = G_k + W_{k,Uplift}$ 7a

1. Serviceability Limit State (SLS) [1]. [1]
   The deformations or deflections of a structure due to stresses should be kept within defined limits in order to avoid possible damage (e.g. cracking) to structural components such as ceilings, floors, partition walls, installations, etc. It is also important to meet the requirements regarding usability (deflections, vibrations) and the appearance or well-being of the users.
   Serviceability is calculated without safety values.
2. Combination coefficients: If several loads, e.g. wind and snow, act simultaneously, then they determine in which ratio they occur, e.g.
   1 × max. snow load + 0.6 × max. wind load
   The standard uses them to take into account the statistical improbability that a maximum snow event and a maximum wind event will occur at the same time
3. Maximum load from dead load and snow

3a $S_{i,n}$ = Characteristic snow load on the roof for a return period of n years

4. Maximum load from dead load and wind pressure

   4a $W_{k,pressure}$ = Characteristic wind pressure

5. Maximum load from dead load and wind pressure and $\psi_{si0,S}$ × snow
6. Maximum load from dead load and snow and $\psi_{si0,W}$ × wind pressure
7. Maximum load from dead load and wind suction
8. $W_{k,Suction}$ = Characteristic wind suction

Max. Pressure on Insulation

General Information

GENERAL INFORMATION

dead load system	g_{System}	= 0.13 kN/m² [1]
aerodynamic coefficient	$c_{p,Pressure}$	= 0.20 [2]

1. (Dead weight module + dead weight mounting system) × 9.81 / A_M
2. Total dead weight per module area
3. C_p value for the entire system from standard 1991-1-1

Load Distribution Underneath the Building Protection Mat Under Peak (45°)

LOAD DISTRIBUTION UNDERNEATH THE BUILDING PROTECTION MAT UNDER PEAK (45°)

Dimensions [1]	380.0 * 75.3 * 27.6 mm	
	A_{eff} [1a]	= 28,614.00 mm²
	$A_{load\ range\ area}$ [1b]	= 1.63 m²
maximum ballast	$G_{Ballast\ required}$	= 8.3 kg

1. Dimension of the building protection (Mat-S)
   - 1a Effective contact area under the mats, which are located under the Peak.
     In an angle of 45° down from the rail is the effective area of the building protection mat
   - 1b The area that transfers the load to the building protection mat. E.g. 4 modules meet above the peak, 4 × ¼ module areas act, i.e. 1 whole module area per peak.
     The used area is depending on the chosen system

Load Distribution Underneath the Building Protection Mat Under SD (45°)

LOAD DISTRIBUTION UNDERNEATH THE BUILDING PROTECTION MAT UNDER SD (45°)

Dimensions	380.0 * 75.3 * 27.6 mm	
	A_{eff} [1]	= 28,614.00 mm²
	$A_{load\ range\ area}$ [2]	= 1.63 m²
maximum ballast	$G_{Ballast\ required}$	= 2.1 kg

Connecting Strength

1. Effective contact area under the mats, which are located under the SDs.
   In an angle of 45° down from the rail is the effective area of the building protection mat.
2. The area that transfers the load to the building protection mat. E.g. 2 modules meet above the SD, 2 × ¼ module areas, i.e. half a module area per SD.
   The used area is depending on the chosen system.

Load Combinations

Load Combinations

	$\sigma_{Ek,heat\ insulation,D6\_10Eco}$ [Pa] (1)	$\sigma_{Ek,heat\ insulation,SD}$ [Pa] (2)
LFK 01	10.265	8.165
LFK 02	83.332	81.233
LFK 03	17.166	15.067
LFK 04	53.700	51.601
LFK 05	87.473	85.374
LFK 06 (3)	0	0

1. Area load acting on the insulation under a peak on the roof. The load under the peak is higher because an entire module (see load bearing area) transfers the load to the peak.
   Furthermore, the size and amount of the building protection mat also plays a role.
2. Area load acting on the insulation under a SD on the roof. The load under the peak is higher because half of the module (see load bearing area) transfers the load to the SD.
   Furthermore, the size and amount of the building protection mat also plays a role.
3. Load combinations as above mentioned

Dead Loads (PV Systems + Ballast)

DEAD LOADS (PV SYSTEM + BALLAST) (1)

$\sigma_{Ek,heat\ insulation,D6\_10Eco}$	σ_{Ek} = 10,265 Pa
$\sigma_{Ek,heat\ insulation,SD}$	σ_{Ek} = 8,165 Pa

1. Load case combination 0

Maximum Actions

1. Worst case of the load case combinations is selected.

Connecting Strength

H-V-LOADS

Aerodynamic Coefficients

AERODYNAMIC COEFFICIENTS

	$C_{p,Pressure}$	= according to EN 1991-1-4
	$C_{F,x,averaged}$	= -0.05 (1)
	$C_{F,y,averaged}$	= 0.01
edge distance correction	$k_{S,xy}$	= 1.00
Parapet wall- correction coefficient	k_p	= 1.00
Factor building height		= 1.00

1. Load coefficient Horizontal and vertical
   x- and y-direction: From wind tunnel expertise
   Pressure: From the standard

Horizontal Pressure

HORIZONTAL PRESSURE

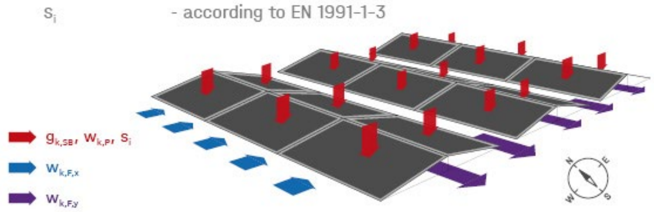
$W_{k,F,x}$ = 0.015 kN/m² (1)
$W_{k,F,y}$ = 0.006 kN/m²

1. Wind force in x and y direction

Vertical Pressure

VERTICAL PRESSURE

$g_{k,System\ incl.\ ballast}$ = 0.13 kN/m²
$W_{k,Pressure}$ (1) - according to EN 1991-1-4
s_i - according to EN 1991-1-3



Comment:
Flat roof vertical wind loads are essentially determined by its displacement effect and remain unchanged even with a flat pv structure. We advise using the aerodynamic coefficients according to DIN EN 1991-1-4 to calculate flat roofs.

1. Wind load in the direction of gravity without safety values

Calculation of specific loads table

Specific loads

module block	No. of modules	Ballast [kg]	Dead weight [kg]	Module block area [m²] (incl. service corridor)	Dead Load [kN/m²]	Dead load (roof surface area) [kN/m²]
Block 1	[1] 8	562.0 [3]	751.60 [5]	15.84 [7]	0.47 [8]	
Block 2	4	392.0	486.80	7.91	0.60	
Block 3	48	1,335.0	2,472.60	91.59	0.26	
Block 4	24	781.0	1,349.80	45.71	0.29	
Block 5	18	778.0	1,204.60	34.59	0.34	
Total	[2] 102	3,848.0 [4]	6,265.40 [6]			[9] 0.15

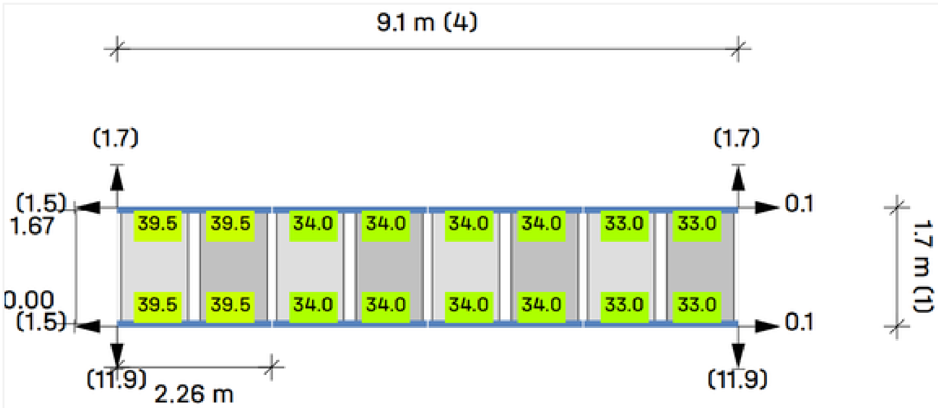
1. Number of modules per module block
2. Sum of modules of all module blocks = 8+4+48+24+18 = 102
3. Weight of ballast required per module block in kg
4. Sum of ballast of all module blocks= 562kg+392kg+1335kg+781kg+778kg = 3848kg
5. Dead weight per module block = weight of ballast required per module block (3) + total dead weight of the system per module block
   which is calculated as follows:
   Total dead weight of the system per module block = Weight of the mounting system per module * number of modules + weight of module * amount of modules

Dead Load

Weight of module	G_M	= 22.0 kg
Weight of mounting system per module		= 1.7 kg
Module area	A_M	= 1.64 m²
Dead weight of module per m²		= 13.40 kg/m²
Dead weight of mounting system per m²		= 1.04 kg/m²
Total Dead Load (excl. ballast) per m²		= 0.14 kN/m²

Total weight of system per module block without ballast = 1,7 kg × 8 + 22 kg × 8 = 189,6 kg
Total dead weight for module block 1 = 562 kg+ 189,6 kg = 751,6 kg

6. Sum of total dead weight of all module blocks = 751,6 kg + 486,8 kg + 2472,6 kg + 1349,8 kg + 1204,6 kg = 6265,4 kg
7. Module block area is calculated with the dimensions in the chapter "assembly plan"



6. Module block area = 9,1 m × 1,7 m = 15,47 m²
   The table displays a more accurate value.
7. Dead load for each module block= (dead weight per module block (5) × Gravitational acceleration / 1000) / module block area (7)
8. Dead load for module block 1 = (751,6 kg × 9,80655 m/s² / 1000) / (15,84 m²) = 0,465 kN/m²
9. Dead load for the whole roof area = (Total dead weight of the whole roof (6) × Gravitational acceleration / 1000) / roof area
   Dead load for the whole roof area = (6265,4 kg × 9,80655 / 1000) / 4