Contents

1. Scope of Work

The scope of work of the following calculation includes the design and verification of all relevant load combinations applicable to the foundations of the Inverter Stations (MVPs) at Dunfermline Project. The Inverter Stations will be placed directly on top of the proposed foundation.

It is important to note that a worst-case scenario philosophy was adopted for the design of this particular Foundation Design, due to the complex soil and environmental conditions present on site. This approach results in safer design and is characterized by always assuming the worst-case scenario when it comes to both the material and site properties as well as the applicable loading combinations.

1. MVPs Specification

The full specification of the Inverter Station is shown in Appendix A and can be summarized (only essential information) as follows:

- Weight: <18tonnes, divided into 3 strips with 2 column loads each resulting in a 30kN, however due to SMA recommendations we will use a value of 55kN (5400kg).
- Dimensions: 2438x6058x2896mm.
- Grounding: shown on the drawings.

2. Relevant Standards

- BS EN 1991-1-3:2005 (Eurocode 1 – Part 3): Snow Loads + UK National Annex;
- BS EN 1991-1-4:2008 (Eurocode 1 – Part 4): Wind Actions;
- BS EN 1992:2004 (Eurocode 2): Design of concrete structures;

- BS EN 1997-1:2004, Geotechnical design ‑ Part 1: General rules.
- NA to BS EN 1991-1-4:2005+A1:2010, National Annex to BS EN 1991-1-1-4:2005,
- Eurocode 1 ‑ Actions on structures. Part 1-4: General actions ‑ Wind actions.
- Eurocode 7 – Geotechnical Design.

2. Introduction

3. Design Proposal

The current design solution proposal includes the usage of three (3) identical pre cast pad foundations of size 2900x500x500mm, including a r50 chamfer on the top surface to help mitigate concrete wear and damage. The pre cast concrete blocks will be placed on top of a 1100mm deep Type 1 Unbound Aggregate (803 (DMRB)) layer on top of a readily available geotextile (>200g/m^2), covered with a very thin layer of sand (<50mm), to protect the geotextile from perforation coming from the crushed coarse aggregate on top. This design methodology is suitable for particular site conditions and allows fast, easy and economically feasible solution for the Inverter Station installation on site.

4. Geotechnical Information

The site conditions on Dunfermline Project can be summarized as non-standard or with elevated complexity. For the full Dunfermline North Solar Farm Geotechnical Site Investigation 355577-R01(02) RSK Report please refer to the previously submitted documents. In general the following ground conditions are present on site:

> The made ground generally comprised predominantly cohesive soils interspersed with granular pockets and ranged in thickness from 0.20 m to >5.00 m. It has been assumed that the back filling of the quarry will have been engineered to a degree. The made ground encountered on site can be generally grouped into the following sub-strata:
>
> - firm to stiff dark grey sandy gravelly CLAY with low to moderate cobble content. Gravel is angular to subangular fine to coarse of mixed sandstone and mudstone lithics and coal-like fragments;

- loose light yellowish grey gravelly medium to coarse SAND with low cobble content. Gravel is subangular fine to coarse of extremely weak light yellowish grey sandstone. Sporadic pockets of black gravelly clay; and
- dense grey black gravelly fine to coarse SAND with low cobble content. Gravel is subangular fine to coarse of mixed mudstone, sandstone and coal fragments.

Common anthropogenic materials observed within made ground strata were brick and ceramic fragments.

A summary of the in-situ and laboratory test results recorded in the stratum are presented in Table 11.

Table 11 Summary of in-situ and laboratory test results for made ground

<table>
<tr><th colspan="2">Soil parameters</th><th>Min. Value</th><th>Max. Value</th><th>Average</th></tr>
<tr><td colspan="5">Cohesive soils</td></tr>
<tr><td colspan="2">Moisture content (%)</td><td>13.2</td><td>32.1</td><td>17.7</td></tr>
<tr><td colspan="2">Liquid limit (%)</td><td>29.0</td><td>38.0</td><td>32.7</td></tr>
<tr><td colspan="2">Plasticity limit (%)</td><td>15.0</td><td>19.0</td><td>16.2</td></tr>
<tr><td colspan="2">Plasticity index (%)</td><td>14.0</td><td>19.0</td><td>16.5</td></tr>
<tr><td colspan="2">Modified plasticity index (%)</td><td>8.8</td><td>16.2</td><td>12.0</td></tr>
<tr><td colspan="2">Plasticity term</td><td>Low</td><td>Intermediate</td><td>-</td></tr>
<tr><td colspan="2">Volume change potential</td><td colspan="3">Low</td></tr>
<tr><td rowspan="5">Grading (%)</td><td>Cobble</td><td colspan="3">0</td></tr>
<tr><td>Gravel</td><td>6.0</td><td>28.0</td><td>18.0</td></tr>
<tr><td>Sand</td><td>28.0</td><td>48.0</td><td>37.0</td></tr>
<tr><td>Silt</td><td>14.0</td><td>31.0</td><td>25.0</td></tr>
<tr><td>Clay</td><td>16.0</td><td>22.0</td><td>20.0</td></tr>
<tr><td rowspan="2">Small Shearbox</td><td>Effective Cohesion - c' (kN/m^2)</td><td colspan="3">22</td></tr>
<tr><td>Effective angle of shear resistance - ϕ' (degrees)</td><td colspan="3">38</td></tr>
<tr><td>Triaxial</td><td>Bulk Density (Mg/m^3)</td><td>2.06</td><td>2.13</td><td>2.09</td></tr>
</table>

(remoulded – 2.5kg rammer)	Dry Density (Mg/m^3)	1.79	1.87	1.82

Soil parameters		Min. Value	Max. Value	Average
	Undrained Shear Stress (kN/m^2)*	29	97	58.8
Consolidation	Bulk Density (Mg/m^3)	1.72	2.06	1.90
	Dry Density (Mg/m^3)	1.43	1.85	1.61
	Voids Ratio**	0.41	0.73	0.58
	Coefficient of compressibility (m^2/MN)**	0.11	0.92	0.57
	Coefficient of consolidation ($m^2/year$)**	4.50	25.21	50.56
Remoulded CBR (%)		0.40	10.00	3.83
Compaction (2.5 kg rammer)	Optimum moisture content (%)	11.20	15.30	13.43
	Maximum dry density (Mg/m^3)	1.76	1.90	1.84
SPT 'N' values		2	>50	17.8
Undrained shear strength inferred from SPT 'N' values (kN/m^2)***		9	>225	80.1
Undrained shear strength measured by shear vane testing (kN/m^2)		56	>120	87.7
Consistency term from field description		Very soft	Very stiff	-
Consistency term inferred from remoulded triaxials		Soft	Stiff	
Granular soils				
Moisture content (%)		7.9	13.1	10.5
Liquid limit (%)		27.0	28.0	27.5
Plasticity limit (%)		Non-plastic	15.0	-
Plasticity index (%)		Non-plastic	13.0	-

Grading (%)	Cobble	0		
	Gravel	13.0	35.0	24.0
	Sand	44.0	58.0	51.0
	Silt	10.0	13.0	12.0
	Clay	11.0	16.0	14.0
Remoulded CBR (%)		1.80		
Triaxial (remoulded – 2.5kg rammer)	Bulk Density (Mg/m^3)	2.03	2.09	2.06
	Dry Density (Mg/m^3)	1.81	1.83	1.82
	Undrained Shear Stress (kN/m^2)*	62.0	103.0	82.5
Consolidation	Bulk Density (Mg/m^3)	1.77	1.94	1.86
	Dry Density (Mg/m^3)	1.57	1.60	1.59
Soil parameters		**Min. Value**	**Max. Value**	**Average**
	Voids Ratio**	0.55	0.58	0.56
	Coefficient of compressibility (m^2/MN)**	0.47	0.84	0.65
	Coefficient of consolidation (m^2/year)**	4.35	4.63	4.49
Small Shearbox	Effective Cohesion - c' (kN/m^2)	4.0	11.0	7.5
	Effective angle of shear resistance - ϕ' (degrees)	33.0	39.0	36.0
Compaction testing (2.5 kg rammer)	Optimum moisture content (%)	10.2		
	Maximum dry density (Mg/m^3)	1.92		
SPT 'N' values		2	43	20.3
Density term inferred from SPT		Very loose	Dense	Medium dense

Notes:

*cell pressure of 20 kN/m^2

**at pressure of 80 kN/m^2

***derived using a Stroud Factor of 4.5

Superficial Deposits (Till)

Soil parameters	Min. Value	Max. Value	Average
Moisture content (%)	11.60	24.90	16.44
Liquid limit (%)	30	35	31.57
Plasticity limit (%)	14	16	15.29
Plasticity index (%)	15	19	16.29
Modified plasticity index (%)	11.25	15.96	12.98
Plasticity term	Low		
Volume change potential	Low		

Grading (%)	Cobble	0	0	0
	Gravel	4	20	14.43
	Sand	31	40	34.71

This stratum was encountered underlying made ground or topsoil and typically comprised firm to stiff slightly sandy gravelly clay with low cobble content. The stratum was proven to be between 1.20 and 11.20 m thick.

A summary of the in-situ and laboratory test results recorded in the stratum are presented in Table 12.

Table 12 Summary of in-situ and laboratory test results for superficial deposits

Soil parameters		Min. Value	Max. Value	Average
	Silt	22	33	27.29
	Clay	19	31	23.57
Small Shearbox	Effective Cohesion - C' (kN/m^2)	16		
	Effective angle of shear resistance - ϕ' (degrees)	34		
Compaction (2.5 kg rammer)	Optimum moisture content (%)	16.90		
	Maximum dry density (Mg/m^3)	1.69		
Triaxial	Bulk Density (Mg/m^3)	2.16	2.21	2.17
	Dry Density (Mg/m^3)	1.83	1.97	1.92
	Undrained Shear Stress (kN/m^2)*	49	149	101.2
Triaxial (remoulded – 2.5kg Rammer)	Bulk Density (Mg/m^3)	2.06		
	Dry Density (Mg/m^3)	1.73	1.76	1.75
	Undrained Shear Stress (kN/m^2)**	14	84	49
Consolidation	Bulk Density (Mg/m^3)	1.96	1.98	1.97

	Dry Density (Mg/m^3)	1.59	1.76	1.68
	Voids Ratio (Mg/m^3)	0.53	0.59	0.56
	Coefficient of compressibility (m^2/MN)	0.3	0.5	0.4
	Coefficient of consolidation (m^2/year)	4.77	10.19	7.44
Remoulded CBR (%)		0.40	0.50	0.47
SPT 'N' values		6	30	17.31
Undrained shear strength inferred from SPT 'N' values (kN/m^2)****		27	135	77.90
Undrained shear strength measured by shear vane testing (kN/m^2)		60	>120	105.87
Consistency term from field description		Soft	Stiff	-
Consistency term inferred from triaxials		Firm	Very stiff	Stiff
Notes: *note varying cell pressures between 65 and 150 kN/m^2 **note cell pressures between 20 and 24 kN/m^2 ***at pressure of 80 kN/m^2 ****derived using a Stroud Factor of 4.5				

According to the RSK report the bearing capacity of the soil for the foundation of shallow Inverter Stations can be taken as 100kN/m2, which has a significant factor of safety of 3 and those foundation should be at least 1 meter deep, fully penetrating the made ground to allow for the foundations to reach a stronger soil layer and help with mitigating any problems related to differential settlement and long-term deformations in the ground base. The approach of fully replacing any made ground with the compacted aggregate of choice will not only reduce any problems with the made ground, by fully replacing it, but will also in practice increase the design bearing capacity (something excluded from the design to allow for further conservativism) and it will allow the design to fully mitigate any differential settlement, by realizing the foundations directly on top of the stronger Glacial Till.

3. Design

The design calculation shall be in accordance with the fundamental requirements of BS EN 1990:2002, and it shall be verified that no relevant limit states are exceeded.

It shall be verified that the following limit states are not exceeded:

- Internal failure or excessive deformation of the structure in which the strength

of structural material is significant in providing resistance (STR);

- Failure or excessive deformation of the ground in which the strength of soil is

significant in providing resistance (GEO);

When considering a limit state or excessive deformation of a structural element (STR and GEO), it shall be verified that:

$$Ed \leq Rd$$

The partial factors on actions (Ed) may be applied to the action themselves or to their effects. The partial factors may be also applied either to the ground properties or resistance (Rd).

The manner in which actions with their partial factors are applied shall be determined by a Design Approach. The Design Approach 1 is used for the spread footing design, and it shall be verified that a limit state or excessive deformation will not occur with either of the following combinations of sets of partial factors.

- Combination 1: A1 + M1 + R1
- Combination 2: A2 + M2 + R1

The overall stability of the ground-structure system shall be verified also under the

Design Approach 2.

Combination A1 + M1 + R2

4. Loads on the Foundations

Applicable Loads on the Foundation can be summarized as follows:

- Dead Loads (Excluding substructure) – 55kN per support (directly taken from the SMA Specification)
- Wind Loads: q_p = 0.70kN/m^2

Table 4.1 – Design Cases Summary Tabel

```
------------------------------
Site Specific Factors
------------------------------
Distance from Building to Shoreline (L_distance_shore):                         30 m
Altitude above Sea Level (A_altitude):                                         115 m
Basic Wind Velocity (V_b_map_wind_velocity):                                  24.5 m/s
Directional Factor (c_dir_factor):                                             1.0
Season Factor (c_season_factor):                                               1.0
Shape Parameter (K_shape_parameter):                                           0.2
Exponent (n_exponent):                                                         0.5
Air Density (p_air_density):                                                  1.25 kg/m^3
Probability of Annual Exceedance (p_probability_of_annual_exceedance):        0.02
Altitude Factor (c_alt_factor):                                               1.115

------------------------------
Velocity and Pressure Profile
------------------------------
Fundamental Wind Velocity (V_b_0):                                           27.32 m/s
Probability Factor (c_prob_factor):                                           1.00
Basic Wind Velocity (V_b):                                                   27.32 m/s
Reference Mean Velocity Pressure (q_b):                                     466.40 N/m^2
Peak Velocity Pressure (q_p):                                               699.61 N/m^2
Total Wind Force per unit area (F_total):                                   699.61 N/m^2

------------------------------
```

- Snow Loads: s = 1kN/m^2

5. Calculations

Table 5.1 – Design Cases Summary Tabel

Summary table

Description	**Unit**	**Allowable**	**Actual**	**Utilisation**	**Result**
Sliding	kN	58.3	13.4	0.229	Pass
Base pressure	kN/m^2	551.4	115.8	0.210	Pass
Description	**Unit**	**Provided**	**Required**	**Utilisation**	**Result**
Reinforcement x-direction	mm^2	4624	1275	0.276	Pass
Reinforcement y-dir, top	mm^2	1005	340	0.339	Pass
		Allowable	Actual	Utilisation	
Description	**Unit**	**Allowable**	**Actual**	**Utilisation**	**Result**
Punching shear	N/mm^2	0.832	0.271	0.326	Pass

The full Calculation Information Produced by Tekla can be seen in Appendix B. Both a foundation design check and a pad foundation check have been conducted to further emphasize the importance of verifying all possible design cases.

6. Results

Verification of all applicable loads and possible loading combinations was achieved during the calculation process. In summary the design proposal for the Inverter Stations is deemed appropriate and suitable for the site conditions.

7. Appendix A

Transportation and Installation Requirements

MEDIUM VOLTAGE POWER STATION
SUNNY CENTRAL
SUNNY CENTRAL UP
SUNNY CENTRAL STORAGE
SUNNY CENTRAL STORAGE UP

Table of Contents

1 Information on this Document

1.1 Validity

Medium Voltage Power Station from production version 1.0

- MVPS-2660-S2-10 (Medium Voltage Power Station with 1 Sunny Central 2660 UP)
- MVPS-2800-S2-10 (Medium Voltage Power Station with 1 Sunny Central 2800 UP)
- MVPS-2930-S2-10 (Medium Voltage Power Station with 1 Sunny Central 2930 UP)
- MVPS-3060-S2-10 (Medium Voltage Power Station with 1 Sunny Central 3060 UP)
- MVPS-4000-S2-10 (Medium Voltage Power Station with 1 Sunny Central 4000 UP)
- MVPS-4200-S2-10 (Medium Voltage Power Station with 1 Sunny Central 4200 UP)
- MVPS-4400-S2-10 (Medium Voltage Power Station with 1 Sunny Central 4400 UP)
- MVPS-4600-S2-10 (Medium Voltage Power Station with 1 Sunny Central 4600 UP)
- MVPS-2660-S2-10 (Medium Voltage Power Station with 1 Sunny Central Storage 2300 UP-XT)
- MVPS-2800-S2-10 (Medium Voltage Power Station with 1 Sunny Central Storage 2400 UP-XT)
- MVPS-2930-S2-10 (Medium Voltage Power Station with 1 Sunny Central Storage 2530 UP-XT)
- MVPS-3060-S2-10 (Medium Voltage Power Station with 1 Sunny Central Storage 2630 UP-XT)
- MVPS-4000-S2-10 (Medium Voltage Power Station with 1 Sunny Central Storage 3450 UP(-XT))
- MVPS-4200-S2-10 (Medium Voltage Power Station with 1 Sunny Central Storage 3600 UP(-XT))
- MVPS-4400-S2-10 (Medium Voltage Power Station with 1 Sunny Central Storage 3800 UP(-XT))
- MVPS-4600-S2-10 (Medium Voltage Power Station with 1 Sunny Central Storage 3950 UP(-XT))
- MVPS-2200-S2-11 (Medium Voltage Power Station with 1 Sunny Central 2200)
- MVPS-2475-S2-11 (Medium Voltage Power Station with 1 Sunny Central 2475)
- MVPS-2200-S2-11 (Medium Voltage Power Station with 1 Sunny Central Storage 1900)
- MVPS-2200-S2-11 (Medium Voltage Power Station with 1 Sunny Central Storage 2200)
- MVPS-2475-S2-11 (Medium Voltage Power Station with 1 Sunny Central Storage 2475)
- MVPS-2900-S2-11 (Medium Voltage Power Station with 1 Sunny Central Storage 2900)

Inverters as of firmware version 8.00.##.R

- SC-2200-10 (Sunny Central 2200)
- SC-2475-10 (Sunny Central 2475)
- SCS-1900-10 (Sunny Central Storage 1900)
- SCS-2200-10 (Sunny Central Storage 2200)
- SCS-2475-10 (Sunny Central Storage 2475)
- SCS-2900-10 (Sunny Central Storage 2900)

Inverters as of firmware version 8.00.##.R

- SC 2660 UP (Sunny Central 2660 UP)
- SC 2800 UP (Sunny Central 2800 UP)
- SC 2930 UP (Sunny Central 2930 UP)
- SC 3060 UP (Sunny Central 3060 UP)
- SC 4000 UP (Sunny Central 4000 UP)
- SC 4200 UP (Sunny Central 4200 UP)
- SC 4400 UP (Sunny Central 4400 UP)
- SC 4600 UP (Sunny Central 4600 UP)
- SCS 3450 UP (Sunny Central Storage 3450 UP)
- SCS 3600 UP (Sunny Central Storage 3600 UP)
- SCS 3800 UP (Sunny Central Storage 3800 UP)
- SCS 3950 UP (Sunny Central Storage 3950 UP)
- SCS 2300 UP-XT (Sunny Central Storage 2300 UP-XT)
- SCS 2400 UP-XT (Sunny Central Storage 2400 UP-XT)
- SCS 2530 UP-XT (Sunny Central Storage 2530 UP-XT)
- SCS 2630 UP-XT (Sunny Central Storage 2630 UP-XT)
- SCS 3450 UP-XT (Sunny Central Storage 3450 UP-XT)
- SCS 3600 UP-XT (Sunny Central Storage 3600 UP-XT)
- SCS 3800 UP-XT (Sunny Central Storage 3800 UP-XT)
- SCS 3950 UP-XT (Sunny Central Storage 3950 UP-XT)

Illustrations in this document are reduced to the essential information and may deviate from the real product.

SMA Solar Technology reserves the right to make changes to the product.

2 Scope of Delivery

After the MV Power Station has arrived, check the scope of delivery for completeness and any apparent external damage. For this purpose, complete a digital transport checklist and send it back to the customer project manager of SMA Solar Technology AG no later than 3 days after the arrival at the construction site or warehouse.

Scope of delivery of the MV Power Station

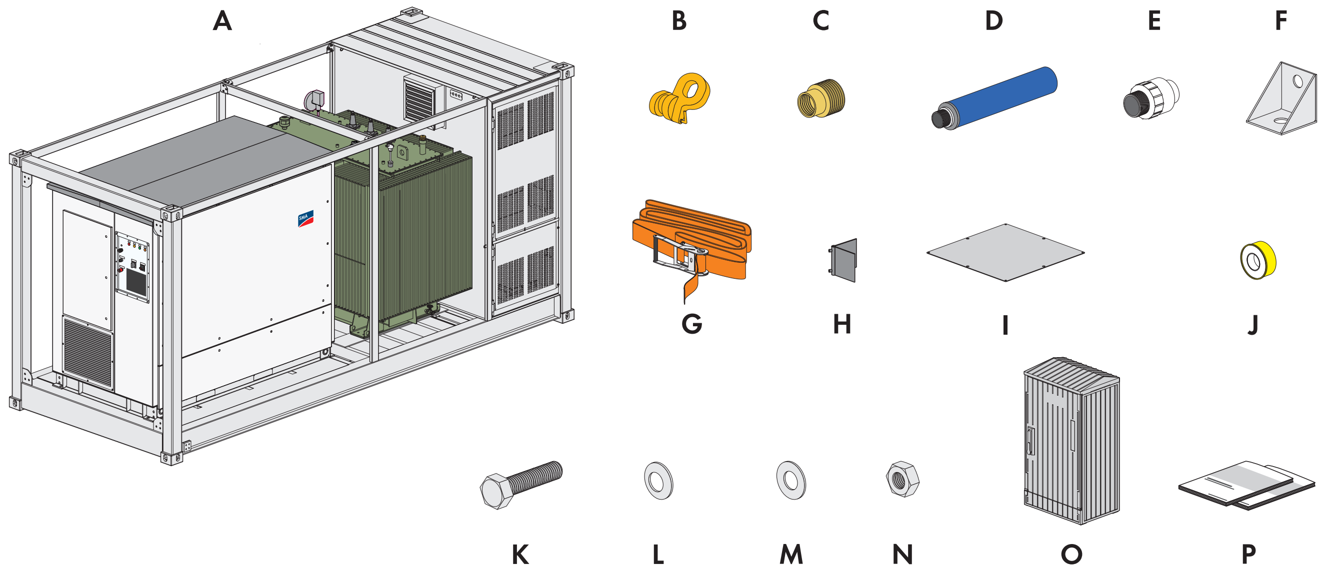


Figure 1: Scope of delivery of the MV Power Station

Position	Quantity	Designation
A	1	MV Power Station
B	4	Lifting lugs[1)]
C	1	Reducer[2)]
D	1	Oil filter[2)]
E	1	Pre-filter[2)]
F	4	Side twistlock[3)]
G	2	Tie-down strap[4)]
H	8	Edge protection angle[4)]
I	1	Covering plate[4)]
J	1	Teflon tape[2)]
K	8	Screw M12 for the grounding connection
L	8	Spring washer M12 for the grounding connection
M	16	Fender washer M12 for the grounding connection

[1)] Optional

[2)] In case of order option "Oil Containment"

[3)] For the order option "Earthquake and Storm Package"

[4)] For the order option "Earthquake and Storm Special"

Position	Quantity	Designation
N	8	Nut M12 for the grounding connection
O	1	Switch cabinet for the order option "Cascade Control"[1)]
P	1	Documentation, circuit diagram

Scope of Delivery of the Medium-Voltage Switchgear

The scope of delivery of the medium-voltage switchgear is located in the medium-voltage cabinet.

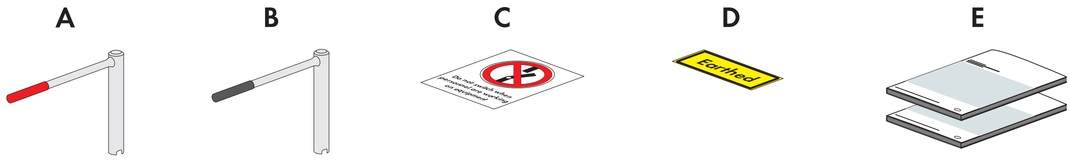


Figure 2: Scope of Delivery of the Medium-Voltage Switchgear

Position	Quantity	Designation
A	1	Actuation lever for grounding switch
B	1 / 2[5)]	Actuation lever for disconnection unit, load-break switch and circuit breaker
C	1	Magnetic sign "Do not switch"
D	1	Magnetic sign "Earthed"
E	1	Documentation for the medium-voltage switchgear

Scope of Delivery of the Inverter for Order Option "DC Input Configuration"

The scope of delivery is located in the DC connection area of the inverter.

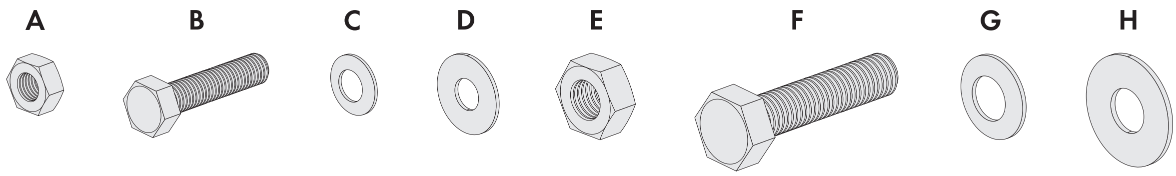


Figure 3: Scope of Delivery

Position	Designation	Application
A	Nut M8	-
B	Bolt M8	
C	Spring washer M8	
D	Fender washer M8	

[5)] Quantity depending on the manufacturer of the medium-voltage switchgear

Position	Designation	Application
E	Nut M12	Connection of the DC inputs
F	Bolt M12	
G	Spring washer M12	
H	Fender washer M12	

Scope of delivery of the order option "DC fuse"

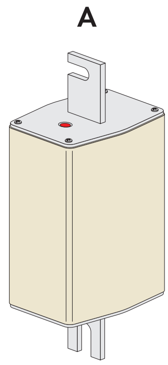


Figure 4: Scope of delivery

Position	Quantity	Designation
A	option-dependent	DC fuse

3 Product Overview

3.1 Design of the MV Power Station

The MV Power Station is a turnkey skid solution for PV and storage applications. It essentially includes the inverter, the medium voltage transformer and the optional medium-voltage switchgear.

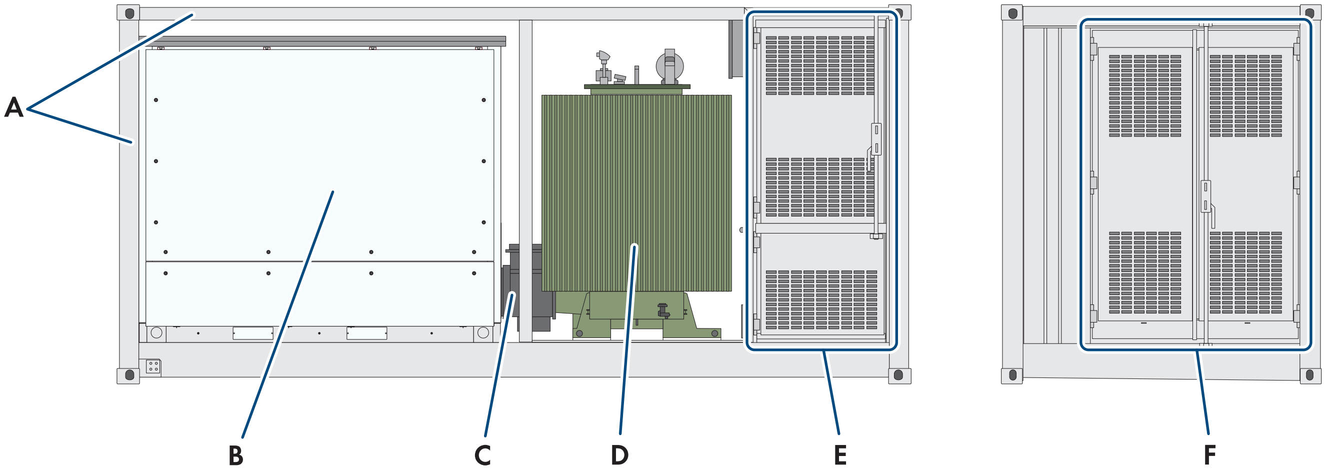


Figure 5: Design of the MV Power Station

Position	Designation	Explanation
A	Rack	The MV Power Station is equipped with a rack with the order option "Sea freight".
B	Sunny Central / Sunny Central Storage	The Sunny Central is a PV inverter that converts the direct current generated in the PV arrays into grid-compliant alternating current. Additionally, the Sunny Central for DC-coupled storage solutions can be operated with batteries. The Sunny Central Storage is a battery inverter that converts the direct current supplied by a battery into grid-compliant alternating current. It also charges the battery with energy drawn from the medium-voltage grid.
C	Low-voltage connection	Low-voltage connection between medium-voltage transformer and inverter with protective cover.
D	Medium-voltage transformer	The MV transformer converts the inverter output voltage to the voltage level of the medium-voltage grid.
E	LV cabinet	The low-voltage cabinet contains the station subdistribution and the optional low-voltage transformer.
F	Medium-voltage cabinet	The medium-voltage switchgear connects and disconnects the medium-voltage transformer to and from the medium-voltage grid.

3.2 Components of the Medium-Voltage Cabinet

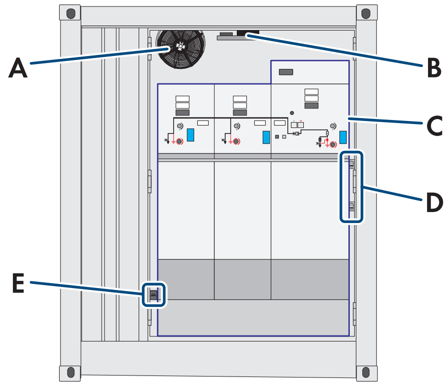


Figure 6: Components of the medium-voltage cabinet (example)

Position	Designation
A	Fan[6]
B	Lighting[6]/ heat detector[6]
C	Medium-voltage switchgear[6]
D	Thermostats for heating and safety shutdown of the medium-voltage switchgear[7]
E	Heating[7]

Further details are to be found in the circuit diagram.

3.3 Components of the Low-Voltage Cabinet

The low-voltage cabinet is divided into separate areas, one for the station subdistribution and one for the low-voltage transformer.

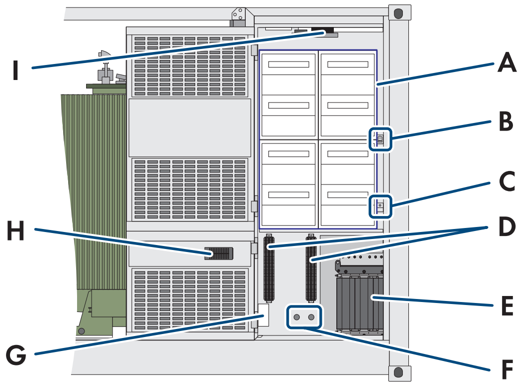


Figure 7: Components of the low-voltage cabinet (example)

Position	Designation
A	Station subdistribution[8]
B	Thermostat for fan control[9]

[6] Optional

[7] With order option "Ambient Temperature: -40 °C to +45 °C"

[8] Optional, quantity and size depending on the order option

[9] Optional

Position	Designation
C	Hygrostat[10]
D	Terminal blocks for the connection of external loads such as tracker motors, DC-DC converters or the supply of battery containers[8]
E	Low-voltage transformer[8]
F	Terminals for grounding resistance measuring device[11]
G	Fuse holder with thermal fuse for the low-voltage transformer[8]
H	Heating[10]
I	Lighting[9]

All miniature circuit breakers for the MV Power Station are located in the station subdistribution. The positions of the components vary depending on the order option. Reference designations are attached to the individual devices of the station subdistribution.

With the "LV Transformer" order option the MV Power Station is equipped with a low-voltage transformer.

The MV Power Station low-voltage transformer provides the supply voltage for various components (see MV Power Station circuit diagram). The low-voltage transformer is equipped with an EMC filtering device and lightning protection and protected by a thermal fuse on the primary side.

The fuse protection of the tracker motors is located in a separate area of the station subdistribution. The tracker motors must be designed to cope with voltage fluctuations that can occur at the point of interconnection.

3.4 Customer Installation Location

3.4.1 Design of the Customer Installation Location

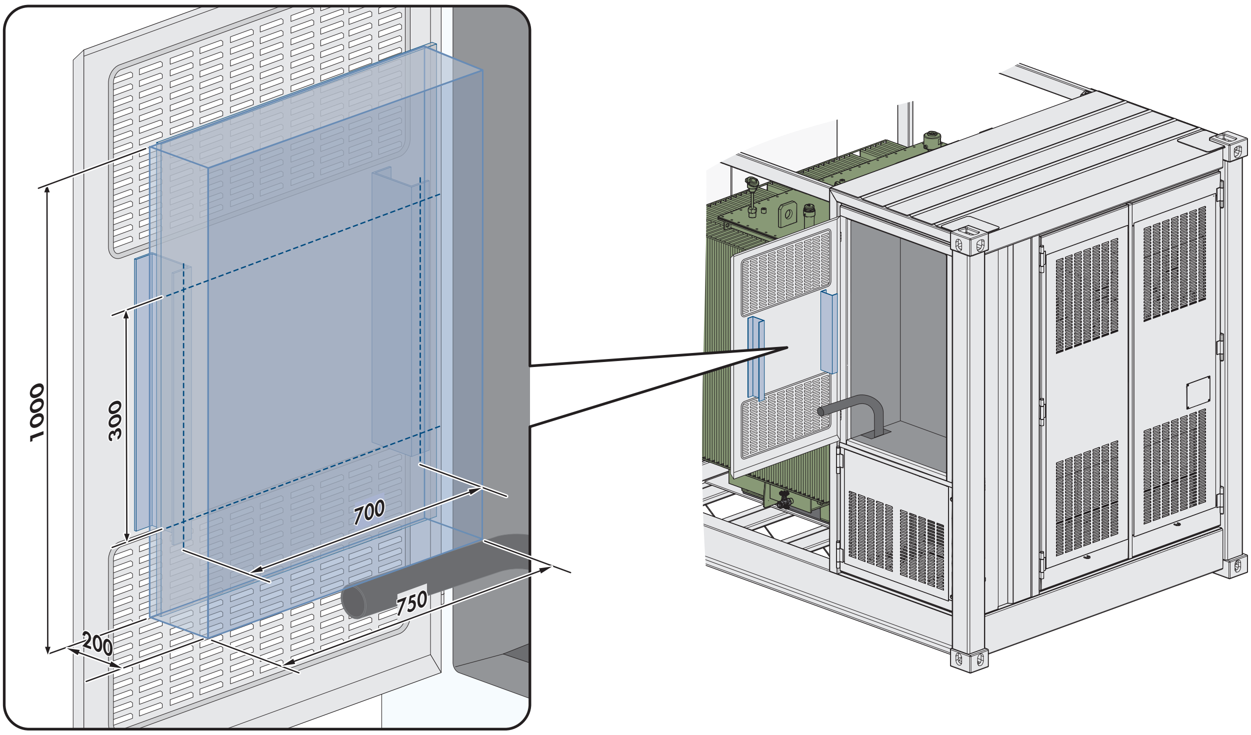


Figure 8: Position of customer installation location (Dimensions in mm)

[10] With order option "Ambient Temperature: -40 °C to +45 °C"

[11] With the order option "Country Package: Japan"

The location on the inside of the door of the low-voltage cabinet is reserved for customer-supplied devices. For mounting the customer's own devices, 2 brackets are provided on which a mounting plate can be attached by the customer.

The customer installations must satisfy the following requirements:

- ☐ The maximum dimensions of the customer installations may not exceed 1000 mm x 750 mm x 200 mm (height x width x depth).
- ☐ Narrow units must not exceed 800 mm x 600 mm x 210 mm (height x width x depth) and must be mounted on the holders using 2 profile rails or 1 mounting plate (not included in the scope of delivery).
- ☐ The maximum weight incl. mounting plate is 80 kg
- ☐ The 4 anchoring points for the brackets have the following distances: width 700 mm, height 300 mm, hole diameter 10 mm for bolts with 8 mm diameter
- ☐ Depending on application, the customer installations must be designed for temperatures from -40°C to 65°C.
- ☐ The customer installations must be at least degree of protection IP54.
- ☐ The customer devices must be designed to cope with voltage fluctuations that can occur at the point of interconnection.

The MV Power Station is equipped with cable channels (inside diameter: 45 mm) at the factory from the opening in the low-voltage cabinet to the customer installation location and from the station subdistribution to the customer installation location. The feed-throughs for the cables into the MV Power Station must be prepared. A network cable with RJ45 plug is located on the door to the customer installation location for the network connection. The length of the network cable from the customer installation location to the customer installations is 2000 mm.

Further details are to be found in the circuit diagram.

3.4.2 Power for Customer Devices

- ☐ Connection voltage for customer installations: 230 V ±10% tolerance, 50 Hz
- ☐ In addition, two miniature circuit breakers of type C16A (230 V) are available to protect the customer equipment.
- ☐ Maximum power loss of customer installations: 300 W
- ☐ There is a socket in the customer connection area of the inverter.
- ☐ For the order option "Country Package: Australia" there is 1 socket, 230 V, type I, maximal 300 W, in the station subdistribution.
- ☐ For the order option "Country Package: France" there are 2 sockets, 230 V, type E, maximal 300 W, in the station subdistribution. Here, one socket is reserved for an inspection lamp.
- ☐ For the order option "Country Package: Japan" with the order option "LV transformer 10 kVA, 173/100 V" the following terminals are available:
  - 3 miniature circuit breakers C16 A (100 V) + RCD 30 mA
  - 3 sockets, 100 V, type B, up to max. 1000 W each, in the station subdistribution
- ☐ The maximum power available for connection of customer equipment depending on the order option:
  - As standard: 2500 VA
  - For the order option "Country Package: Japan" with the order option "LV transformer 10 kVA, 173/100 V": 10 kVA at 100 VAC and 2500 A at 230 VAC

The following powers must be taken into consideration for the supply of the MV Power Station:

Component	Order option	Power
Fan in the medium-voltage cabinet	"Ambient Temperature -25° to +55°C", "Ambient Temperature -35°C to +55°C", "Environment: Harsh" or "Low-voltage transformer 40 / 50 / 60 kVA"	230 W

Component	Order option	Power
Lighting in the medium-voltage and low-voltage cabinet	"Lighting"	50 W
Cascade control	"Cascade control"	150 W
Monitoring and communication	"Monitoring"	100 W
Heaters in the medium-voltage and low-voltage cabinet	"Ambient temperature: -40°C to +45°C"	2300 W
Heaters in the station subdistribution	"Ambient temperature: -35°C to +55°C"	200 W

3.5 Configuration of Station Subdistribution

All fuse switches for the MV Power Station are located in the station subdistribution. The station subdistribution is still the central connection point for communication. The positions of the components can vary depending on the order option. Reference designations are attached to the individual devices of the station subdistribution.

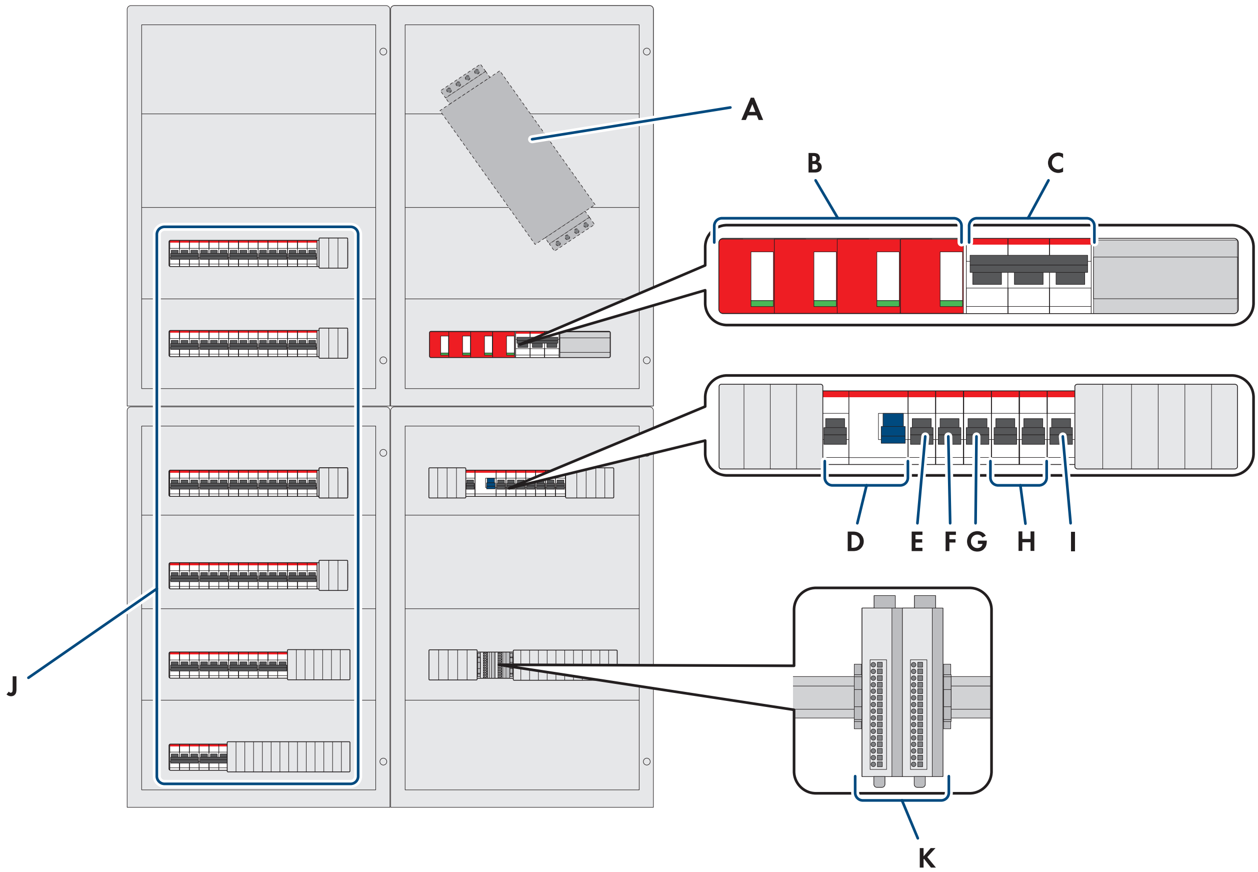


Figure 9: Devices in the station subdistribution (example)

Position	Designation
A	Low-voltage transformer EMC filtering device[12)]
B	Surge arrester **-F1** for tracker motors and DC-DC Converter[12)]
C	Main miniature circuit breaker **-F101** for tracker motors and DC-DC Converter[12)]
D	Miniature circuit breaker **-F32** and residual-current device **-F32D** for lighting systems[12)]

[12)] Optional

Position	Designation
E	Miniature circuit breaker **-F34** for the fan[12]
F	Miniature circuit breaker **-F36** for monitoring and communication in terms of order option "Monitoring Package"[12]
G	Miniature circuit breaker **-F37** for cascade control[12]
H	Miniature circuit breaker **-F41** and **-F42** for protection of the customer equipment
I	Miniature circuit breaker **-F50**[13] or **-F51**[14] for the heating
J	Miniature circuit breakers for external loads such as tracker motors, DC-DC converters or the supply of battery containers **-F2** to **-F25**[12]
K	I/O System Monitoring Package[12]

For the order option "Ambient Temperature: -35 °C to +55 °C" there are additional heaters and thermostats behind the cover of the station subdistribution.

Further details are to be found in the circuit diagram.

3.6 Design of the Inverter

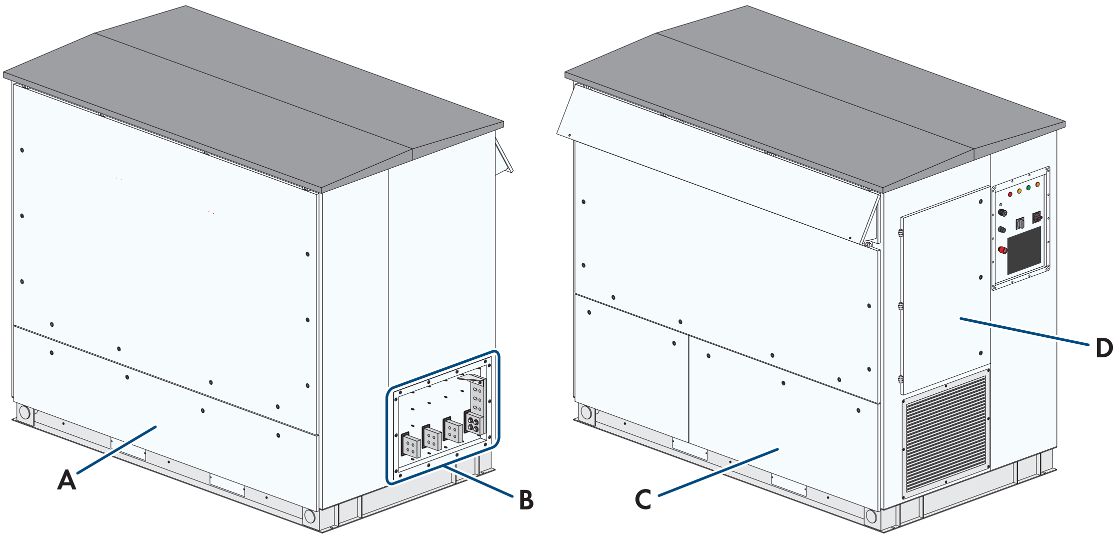


Figure 10: Design of the inverter

Position	Designation
A	DC connection area and grounding
B	AC connection area and grounding
C	Connection area for electronics
D	Customer installation location

[13] With order option "Ambient Temperature: -40 °C to +45 °C"

[14] With order option "Ambient Temperature: -35 °C to +55 °C"

3.7 Components of the Medium-Voltage Transformer

The medium-voltage transformer is the link between the inverter and the medium-voltage grid. The positions of the operating- and display elements of the medium-voltage transformer can vary depending on the manufacturer and the selected order option. Pressure and oil level can be monitored via an hermetic protection relay depending on the order option.

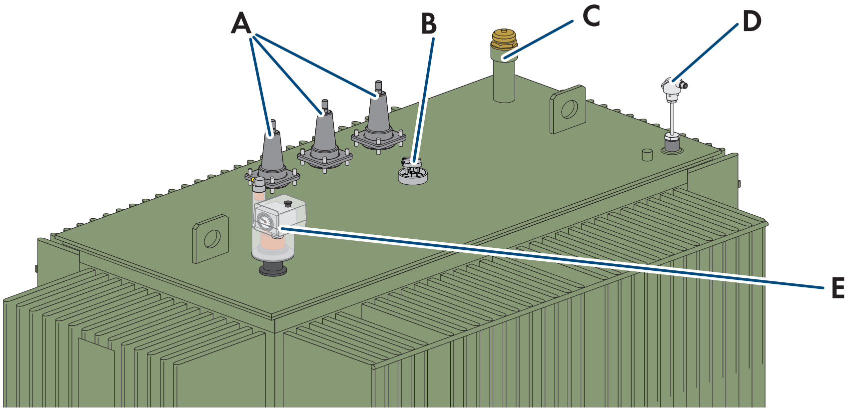


Figure 11: Components of the medium-voltage transformer (example)

Position	Designation
A	Medium-voltage bushings for connecting the AC cables
B	Tap changer for adjusting the turn ratio[15)]
C	Oil filler neck with pressure relief valve[15)]
D	Thermometer for oil temperature (PT100)
E	Hermetic protection device or single devices for pressure and oil level[15)]

[15)] Optional

3.8 Devices of the Medium-Voltage Switchgear

The MV Power Station is equipped with a medium-voltage switchgear depending on the order option. The medium-voltage switchgear is used to disconnect the MV Power Station from the medium-voltage grid.

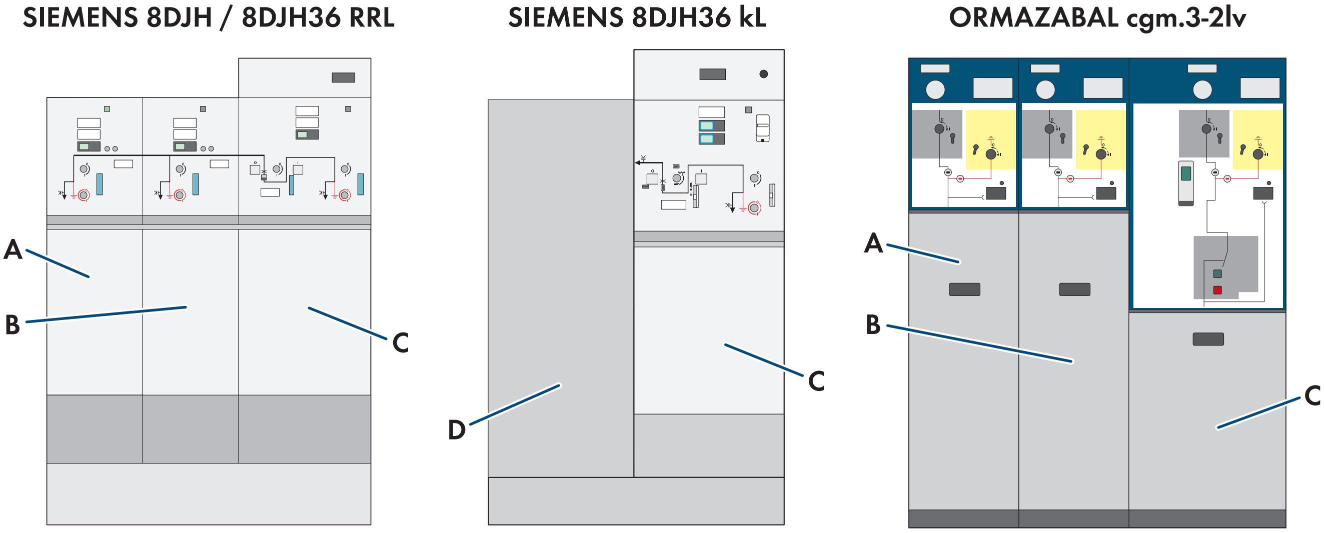


Figure 12: Components of the medium-voltage switchgear (example)

Position	Designation
A	Outer cable panel with load-break switch[16]
B	Central cable panel with load-break switch[16]
C	Transformer compartment with disconnector
D	Side cable connection panel[16]

[16] Optional

3.9 Connection Area of the Medium-Voltage Switchgear

Overview of the connection area on the medium-voltage switchgear

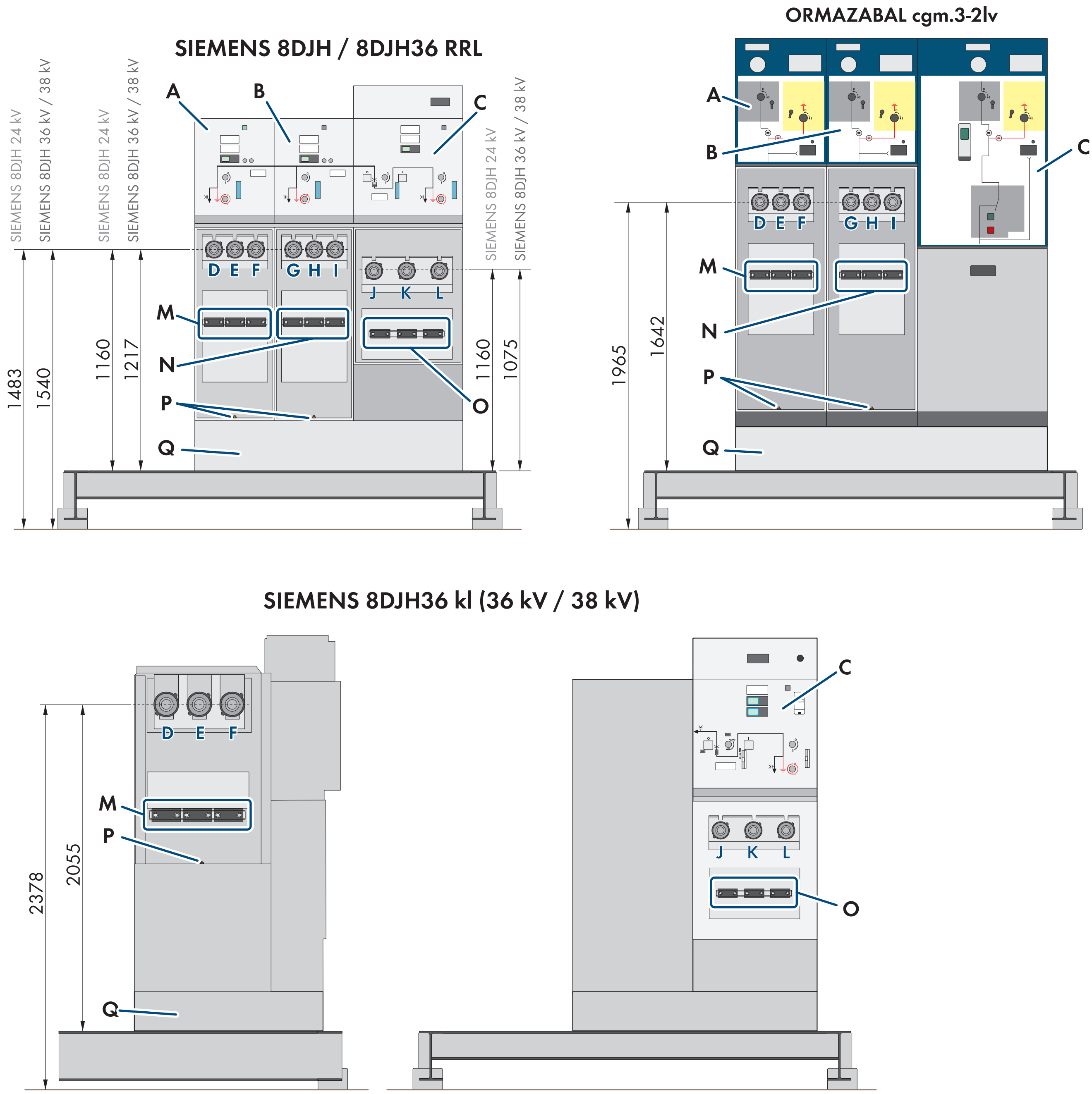


Figure 13: Connection area of medium-voltage switchgear (example) (Dimensions in mm)

Position	Designation
A	Cable compartment 1
B	Cable compartment 2
C	Transformer compartment
D	Line conductor L1 from cable panel 1
E	Line conductor L2 from cable panel 1

Position	Designation
F	Line conductor L3 from cable panel 1
G	Line conductor L1 from cable panel 2
H	Line conductor L2 from cable panel 2
I	Line conductor L3 from cable panel 2
J	Line conductor L1 from transformer field
K	Line conductor L2 from transformer compartment
L	Line conductor L3 from transformer compartment
M	Cable support rail cable panel 1[17]
N	Cable support rail cable panel 2[17]
O	Cable support rail from transformer compartment[18]
P	Grounding busbar for connecting AC cable shielding
Q	Kick plate

3.10 Oil spill containment

The MV Power Station is equipped with an integrated oil spill containment depending on the order option. The oil spill containment collects oil which may leak from the medium-voltage transformer under fault conditions.

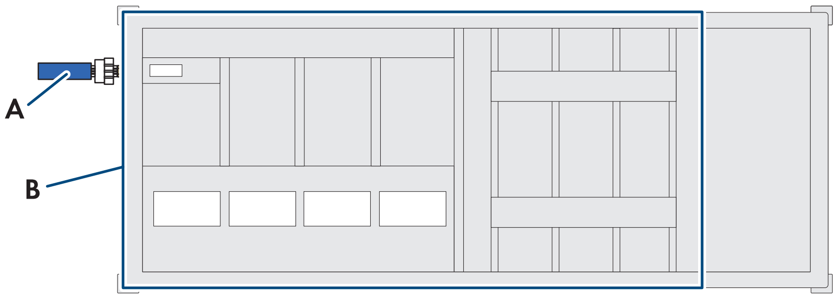


Figure 14: Position of the oil spill containment

Position	Designation
A	Oil filter[19]
B	Integrated oil spill containment[19]

The MV Power Station oil spill containment is integrated into the floor and the station container substructure.

In normal operation, penetrating rain water drains off via the mounted oil filter. If the medium-voltage transformer leaks and oil flows into the integrated oil spill containment and hence into the oil filter, the oil filter granulate reacts and prevents the oil being released into the environment. The oil filter is not mounted at the factory and must be installed after the MV Power Station has been set up.

In order to remove leaked oil from the substructure oil spill containment, an oil suction pump is required.

[17] 3 (6 with kL) strain-relief clamps per cable panel are mounted on the cable support rail for attaching the cables. The equipment for connection of 2 cables per line conductor can be provided by SMA Solar Technology AG upon request.

[18] With the order option "1 MVSG for 2 MVT"

[19] In case of order option "Oil Containment"

3.11 Circuitry Principle of the MV Power Station

Setup of 1 MV Power Station

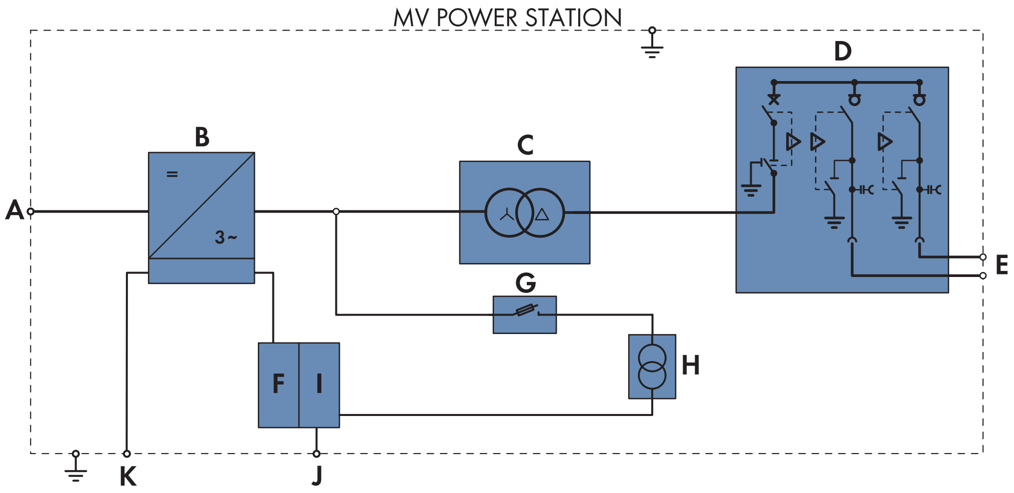


Figure 15: Circuitry principle of the MV Power Station (example)

Setup of 2 MV Power Stations with 1 medium-voltage switchgear

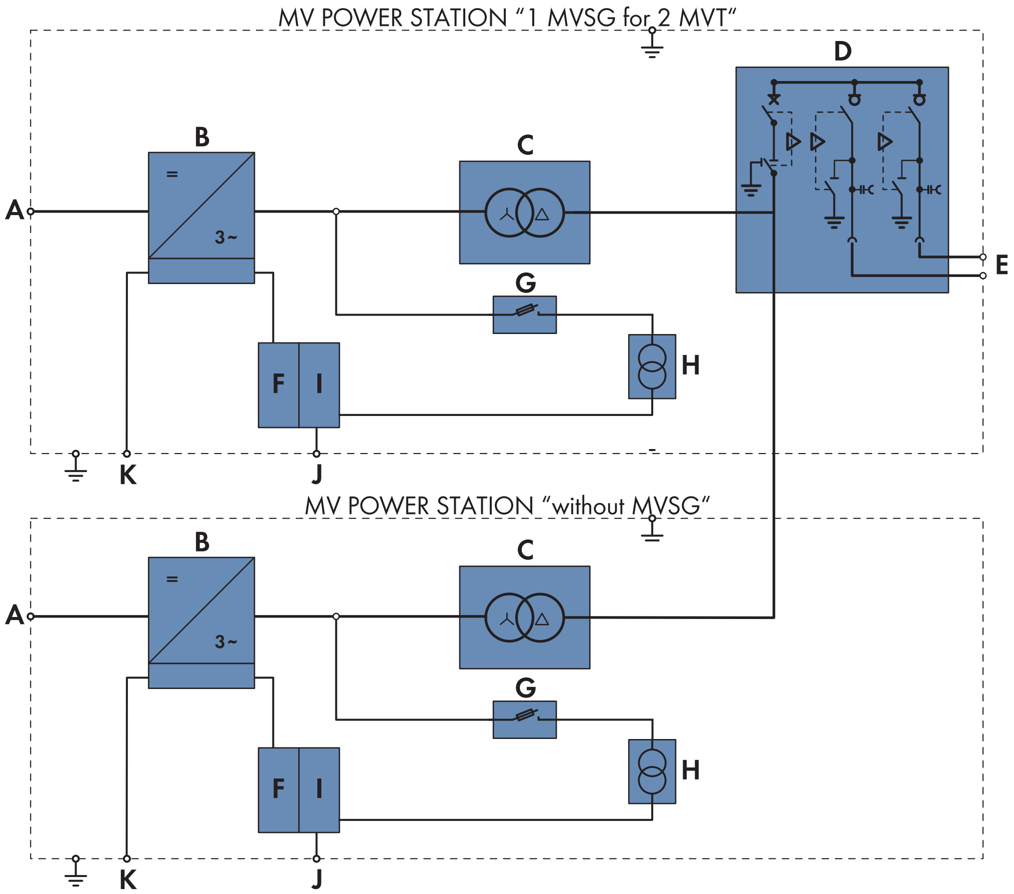


Figure 16: Circuitry principle of 2 MV Power Stations with 1 medium-voltage switchgear (example)

Position	Designation
A	DC Input

Position	Designation
B	Inverter
C	Medium-voltage transformer
D	Medium-voltage switchgear[20]
E	AC output
F	Station subdistribution
G	Fuse holder with thermal fuse of the low-voltage transformer[20]
H	Low-voltage transformer[20]
I	Surge protection device, load-break switch and EMC filtering device of the low-voltage transformer and miniature circuit breakers for tracker motors[20]
J	Connection of additional components (e.g. tracker motors)[20]
K	Customer connection point[21]

[20] Optional

[21] Depending on the order option, the terminal for the external communication is located on the station subdistribution or inverter.

4 Transport and Mounting

4.1 On-Site Services

The following provisions and services are not included in the product scope of delivery and must be provided:

- ☐ Crane for unloading the product at the construction site (can be supplied on request)
- ☐ Foundation for the product
- ☐ Shim plates to compensate for the height difference from the corners of the foundation to the middle foundation
- ☐ For the order option "Earthquake and Storm Package" suitable anchors in the foundation.
- ☐ Platforms or landings to overcome the step height. To prevent rust, the landings must not cover any parts of the MV Power Station.
- ☐ For the order option "Without MV Switchgear" without the order option "1 MVSG for 2 MVT": suitable protective relay for the medium-voltage transformer
- ☐ For the "1 MVSG for 2 MVT" order option: Connection plug (CELLPACK, CTKS 630 A, 24 kV or 36 kV) for connection to the transformer panel of the medium-voltage switchgear of another MV Power Station
- ☐ Cable for the external fast-stop function
- ☐ Ladder
- ☐ Drainage channel for rainwater that has penetrated the oil filter
- ☐ Conduit for cable entry
- ☐ Overvoltage protection of the entire system
- ☐ Site external grounding system
- ☐ Disassembly and Disposal of the Packaging Materials
- ☐ All mounting and connection work at the construction site
- ☐ Door locks
- ☐ Setting and measurement of the set tripping times of the circuit breaker panels' protective device of the medium-voltage switchgear
- ☐ Zinc paint and spare paint to touch up transport damage
- ☐ Touch up paint damage according to the specification of SMA
- ☐ To protect the electronic components against moisture, the desiccant bag in the inverter must be replaced every 2 months after their arrival at the construction site or in storage until commissioning. If necessary, desiccant bags can be ordered from SMA Solar Technology AG using the following material number: 85-0081.
- ☐ Replace the desiccant bags in the inverter with new desiccant bags from the scope of delivery 24 hours prior to commissioning. This will protect the electronic components against moisture. Moisture can delay commissioning and additional travel costs for SMA service personnel must be paid by the customer.
- ☐ For safe commissioning, the requirements for mounting must be fulfilled.
- ☐ After maritime transport, wash the station with clear water within 3 days after it arrives at the construction site or is placed in storage.
- ☐ Cleaning of all components after completing the assembly and installation work before commissioning
- ☐ Removal of the supporting struts in front of the inverter and medium-voltage cabinet
- ☐ Removal of the supporting struts of the lower right bracket corner in front of the medium-voltage cabinet

If you have any questions, please contact us (see Section 5, page 33).

4.2 Design of Entire System

Closed electrical operating area

The overall system includes all components of the system. For safety reasons, the entire system must be installed in a closed electrical operating area in accordance with IEC 61936-1.

- Ensure that unauthorized persons have no access to the entire system.
- The components of the entire system may only be switched and operated by trained and qualified persons.

4.3 External dimensions and weights

With oil spill containment

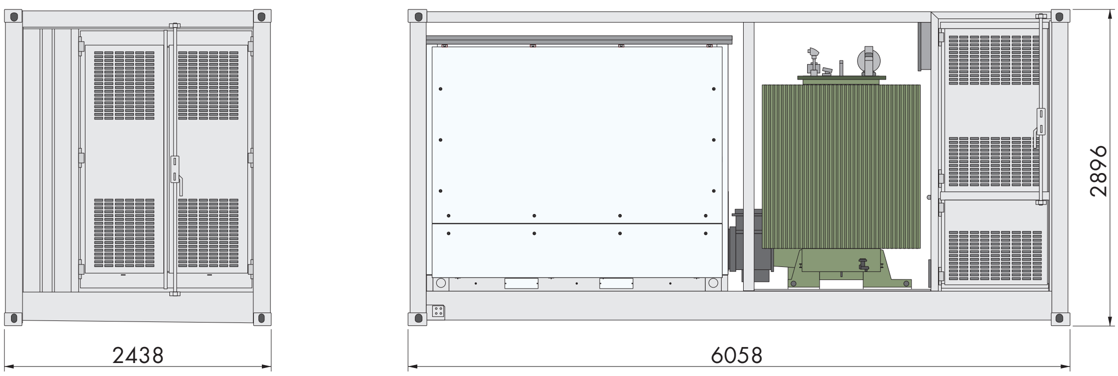


Figure 17: Dimensions of the MV Power Station(Dimensions in mm)

Width	Height	Depth	Weight
6058 mm	2896 mm	2438 mm	< 18 t

4.4 Minimum Clearances

Observe the following minimum clearances to ensure trouble-free operation of the MV Power Station. The minimum clearances are necessary to ensure trouble-free installation of the MV Power Station and easy replacement of the devices (e.g. with a crane) during service and maintenance. In addition, locally applicable regulations must be observed. Non-observance of the minimum clearances may result in the use of additional devices or greater amount of time and labor. The additional costs incurred will be invoiced also in case of a warranty claim.

The minimum clearances must be ensured for servicing. To avoid corrosion, the MV Power Station must be installed above the ground. If a higher setup is required, SMA Technology AG must first approve it. If the MV Power Station is placed higher, a mobile platform must be provided for servicing.

Shorter minimum clearances for servicing

The minimum clearances for servicing around the station can be reduced to 2500 mm if the following conditions are met:

- ☐ A spot for a crane from which all stations can be reached must be available.
- ☐ Access roads and areas must be accessible and passable for service vehicles (e.g. forklift or crane truck).
- ☐ The unloading site for the crane and trucks must be firm, dry and horizontal.
- ☐ The crane must have sufficient load-carrying capacity according to the operating conditions (medium-voltage transformer, medium-voltage switchgear including crane pallet fork, converter choke, inverter with crane traverse, station with crane traverse).
- ☐ For smaller loads, suitable lifting gear (e.g. pallet truck and forklift) must be available on site.
- ☐ To transport smaller loads to the MV Power Station, the areas between the stations must be accessible by pallet truck and forklift.

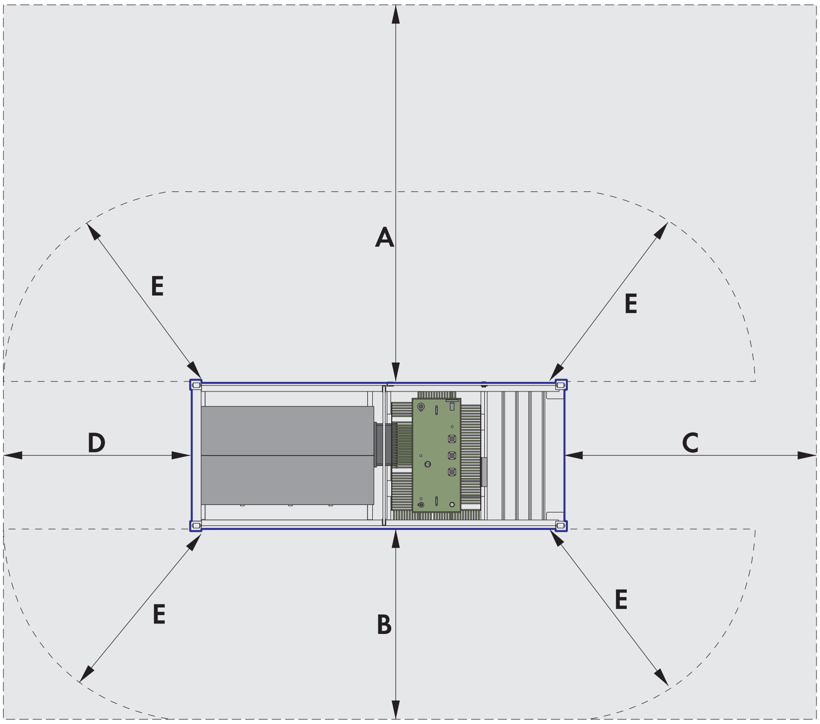


Figure 18: Minimum clearances

Position	Minimum clearance for servicing	Minimum clearance for trouble-free operation Shorter minimum clearances for servicing
A	6000 mm	2500 mm
B	3000 mm	2500 mm
C	4000 mm	2500 mm
D	3000 mm	2500 mm
Internal arc pressure safety areas to be observed during MV switchgear switching operations		
E	Minimum clearance for inflammable materials: 1000 mm Minimum clearance for personnel: 3000 mm[22)]	

[22)] The work area intended for switching in front of the medium-voltage switchgear is excluded

Arc pressure relief

In the event of arc faults in the medium-voltage switchgear, pressure and hot plasma escape to the medium-voltage transformer. At the same time, the safety area for arc pressure relief system must not be blocked. The MV Power Station has the arc fault qualification IAC A according to IEC 62271-202. The arc pressure relief system must be checked against the local regulations during installation.

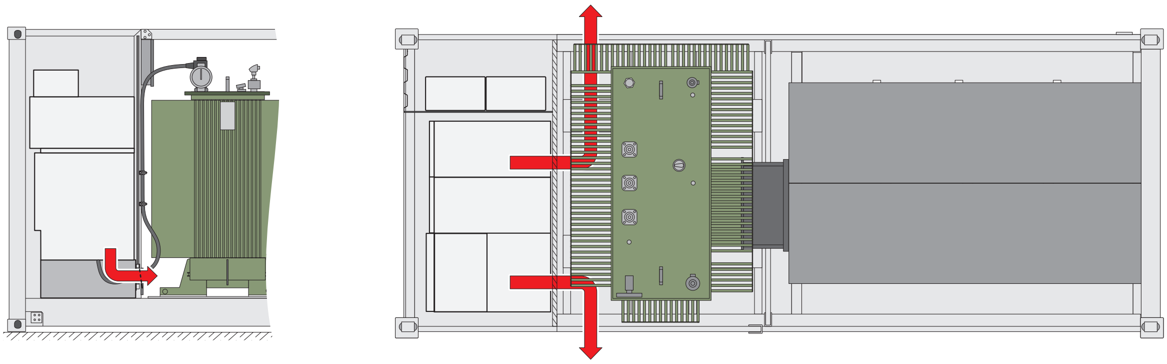


Figure 19: Internal arc pressure at the MV Power Station

4.5 Ambient Conditions

Requirements for the mounting location:

- ☐ The mounting location must be freely accessible at all times.
- ☐ The permissible maximum value for non-condensing relative humidity must not be exceeded. The permissible range is: 0% to 95%.
- ☐ The permissible maximum values for relative humidity must not be exceeded. The maximum values are as follows: 0% to 95% (annual average) and > 95% to 100% (up to two months per year).
- ☐ The fresh air consumption of the MV Power Station must be assured. The fresh air consumption is: 10000 m³/h.
- ☐ The mounting location must be below the maximum installation altitude.
- ☐ The system must have a minimum clearance of 30 m to radio equipment.
- ☐ The ambient temperature must be within the operating temperature range.
- ☐ The air quality for mechanically active substances in accordance with IEC 60721-3-4: 2019 must be observed.
- ☐ The air quality for chemically active substances in accordance with ISO 12944-2: 2019 must be observed.

Equipment and ambient conditions of the MV Power Station:

Component / order option	Class
Inverter standard	C5M / C4M / C3H (depending on the order option)
MV Power Station standard	C3 / 4S12 as per IEC 60721-3-4 (2019) or ISO 12944-2 / ISO 9223
MV Power Station Option Harsh	C5 / 4S13 as per IEC 60721-3-4 (2019) or ISO 12944-2 / ISO 9223

4.6 Dependence of the nominal current on the ambient temperature

The nominal current of the medium-voltage switchgear depends on the ambient temperature of the MV Power Station. During design, the maximum ampacity must be considered at high temperatures.

Ambient temperature of the MV Power Station	Nominal current at 1000 m
30°C	630 A

Ambient temperature of the MV Power Station	Nominal current at 1000 m
35°C	575 A
40°C	515 A
45°C	460 A
50°C	425 A
55°C	0 A

For nominal currents at an installation height greater than 1000 m, please contact us.

4.7 Grounding

4.7.1 Grounding Concept

In accordance with the latest technology, the inverters are discharged to ground. As a result, leakage currents to ground occur which must be taken into account when planning the system. The magnitude and distribution of such leakage currents is influenced by the grounding concept of all devices in the system. It is recommend that optical fiber technology is used for the transmission of signals, for example, when using cameras and monitoring equipment. This will counteract possible interference sources.

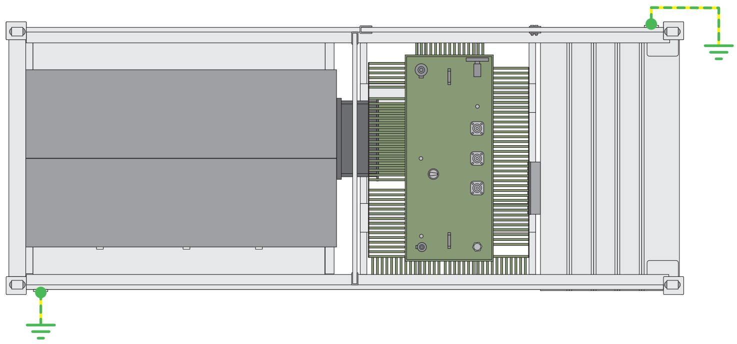


Figure 20: Grounding concept (example)

Double grounding of the MV Power Station

We recommend that the grounding concept provides for double grounding of the MV Power Station.

4.7.2 Requirements for the Grounding Arrangement

Cable Requirements for the Grounding Connection:

- ☐ All cables must be suitable for temperatures of up 90°C and must be in accordance with the national standards and directives.
- ☐ All cables must be suitable for outdoor applications. They must be resistant to solar irradiation and, if necessary, oil.
- ☐ Use copper or aluminum cables only.
- ☐ The cable cross-sections of the grounding conductor connections depend on the installed overcurrent protective device. Calculating the required cross-sections depends on the national standards and directives.
- ☐ The grounding of the system must be designed in accordance with the national standards and directives and is the responsibility of the installer.

Requirements for the cable connection with terminal lugs:

- ☐ All terminal lugs used must be suitable for temperatures of up 90°C and must be in accordance with the national standards and directives.

☐ The maximum material thickness of the terminal lugs must be observed:
  - When connecting with 1 terminal lug: 22.5 mm
  - When connecting with 2 terminal lugs: 11.25 mm

☐ The width of the terminal lugs must exceed the washer diameter. This will ensure that the specified torques are effective over the whole surface.

☐ Use only tin-plated terminal lugs made from copper or aluminum.

☐ The specified torques must always be complied with.

Requirements for the grounding arrangement design:

☐ Use copper or aluminum cables only.

☐ The cable cross-sections of the grounding depend on the installed overcurrent protective device. Calculating the required cross-sections depends on the national standards and directives. The following cable cross-sections are recommended:
  - For copper cable, at least: 185 mm^2
  - For aluminum cable, at least: 300 mm^2

☐ Depending on the design of the equipment, an additional grounding must be planned for a YNd11 / YNy0 transformer.

4.8 Foundation

4.8.1 Support surface

- The support surface must be a dry and solid foundation, e.g. gravel.
- In areas subject to strong precipitation or high groundwater levels, a drainage system is recommended.
- Do not mount the MV Power Station into ground depressions to prevent water ingress.
- The support surface underneath the MV Power Station must be clean and firm to avoid any dust circulation.

4.8.2 Pea gravel ground

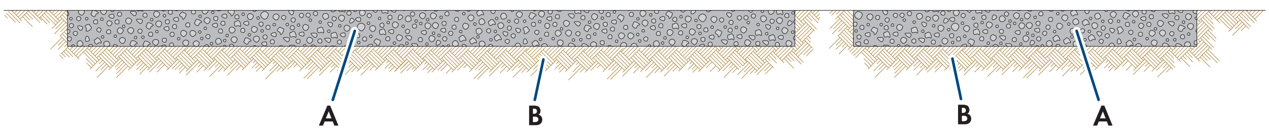


Figure 21: Structure of the support surface

Position	Designation
A	Pea gravel ground
B	Solid ground, e.g., gravel

The subgrade must meet the following minimum requirements:

☐ The load capacity of the subgrade must be given.

☐ Minimum clearances for servicing operations must be observed(see Section 4.4, page 21).

☐ Access roads and areas must be accessible and passable, without any obstructions, for service vehicles (e.g. forklift or crane truck).

4.8.3 Weight load on the support points

To ensure the stability and safe standing of the MV Power Station, the station container must stand on at least 4 support points on the outer feet and on 2 support points under the MV transformer. The weight load for each support point depends, among other things, on the height tolerance of the foundation. The weight loads must be determined on a project-specific basis.

It is recommended that the support points each be designed for 5400 kg.

4.8.4 Mounting options

Foundation properties:

- ☐ The design of the foundation and selection of building materials (e.g. type of concrete and reinforcement) depends on the soil conditions. The foundation is to be defined by the customer based on the given requirements (weights and tolerances) and ambient conditions.
- ☐ The foundation must be mounted on solid ground.
- ☐ The foundation must be suitable for the weight of the product.
- ☐ The burial depth of the foundation must satisfy the structural requirements.
- ☐ The height tolerance between the individual foundations must not exceed 3 mm. Deviations must be compensated.
- ☐ The middle foundation must be designed 45 mm ±1.5 mm higher than the outer foundation. Shim plates can be used to compensate for the height difference.
- ☐ In order that the opening for the cable is not covered, the foundation may not protrude more than 240 mm from the outer edge below the station.
- ☐ The professional welding of the station on steel foundations is permitted. The customer is responsible for taking the appropriate corrosion protection measures. Claims regarding rust at the welding points cannot be made.
- ☐ When designing the foundations, safety factors must be taken into account according to local conditions or country-specific regulations.
- ☐ With the order option "Earthquake and Storm Package", additional space is required for anchoring the side twistlocks. The surface area of the side twistlocks is: 130 mm x 135 mm.
- ☐ For the "Oil Containment" order option, the foundation must not obstruct the oil filter.
- ☐ A visual inspection of the underside of the oil spill containment must be possible in order to detect leaks at an early stage.

The design of the foundation is the responsibility of the customer. The MV Power Station can also be placed on posts driven into the ground. The weight distribution depends on the number and position of the piles and must be designed accordingly.

Mounting option with pile foundation

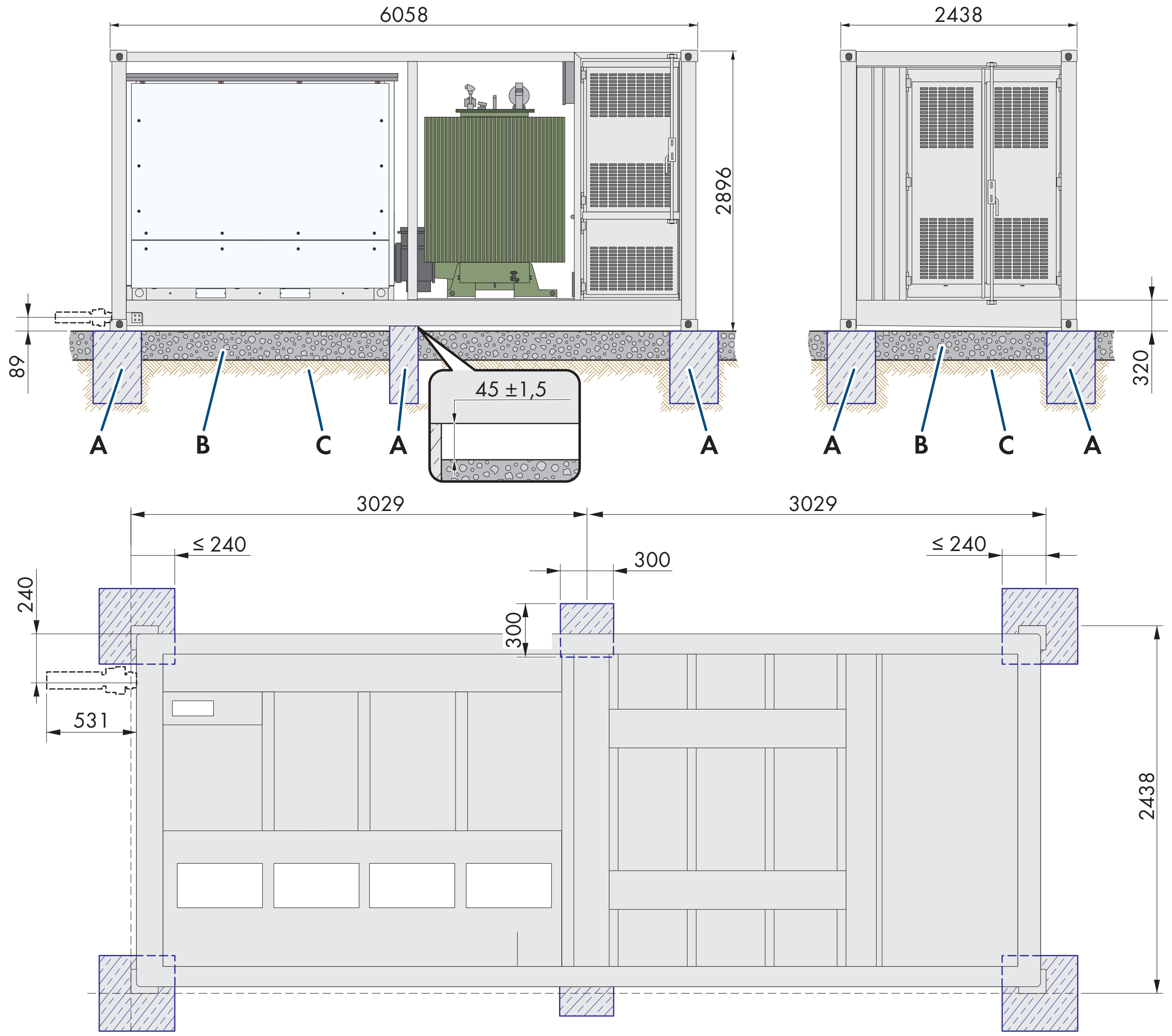


Figure 22: Mounting option with pile foundation (Dimensions in mm)

Position	Designation
A	Support point foundation
B	Pea gravel ground
C	Solid ground, e.g., gravel

Mounting option with strip foundations

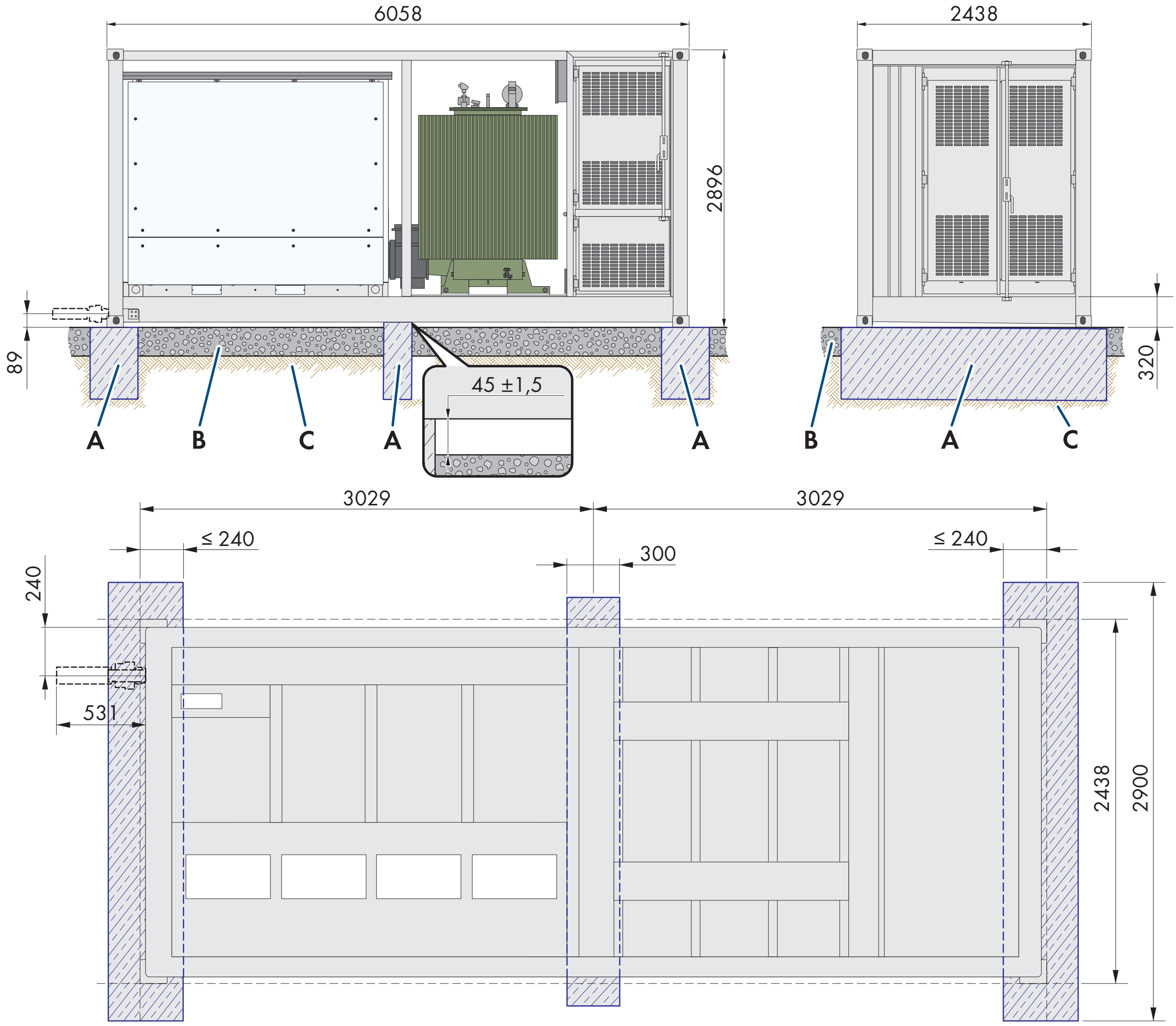


Figure 23: Mounting option with strip foundations (Dimensions in mm)

Position	Designation
A	Strip foundation
B	Pea gravel ground
C	Solid ground, e.g., gravel

4.9 Overview of Openings in the Base Plate of the MV Power Station

The MV Power Station is fitted with base plates through which the cables are inserted. The cables should be protected between the foundation and the MV Power Station. Cable protection measures are customer responsibility.

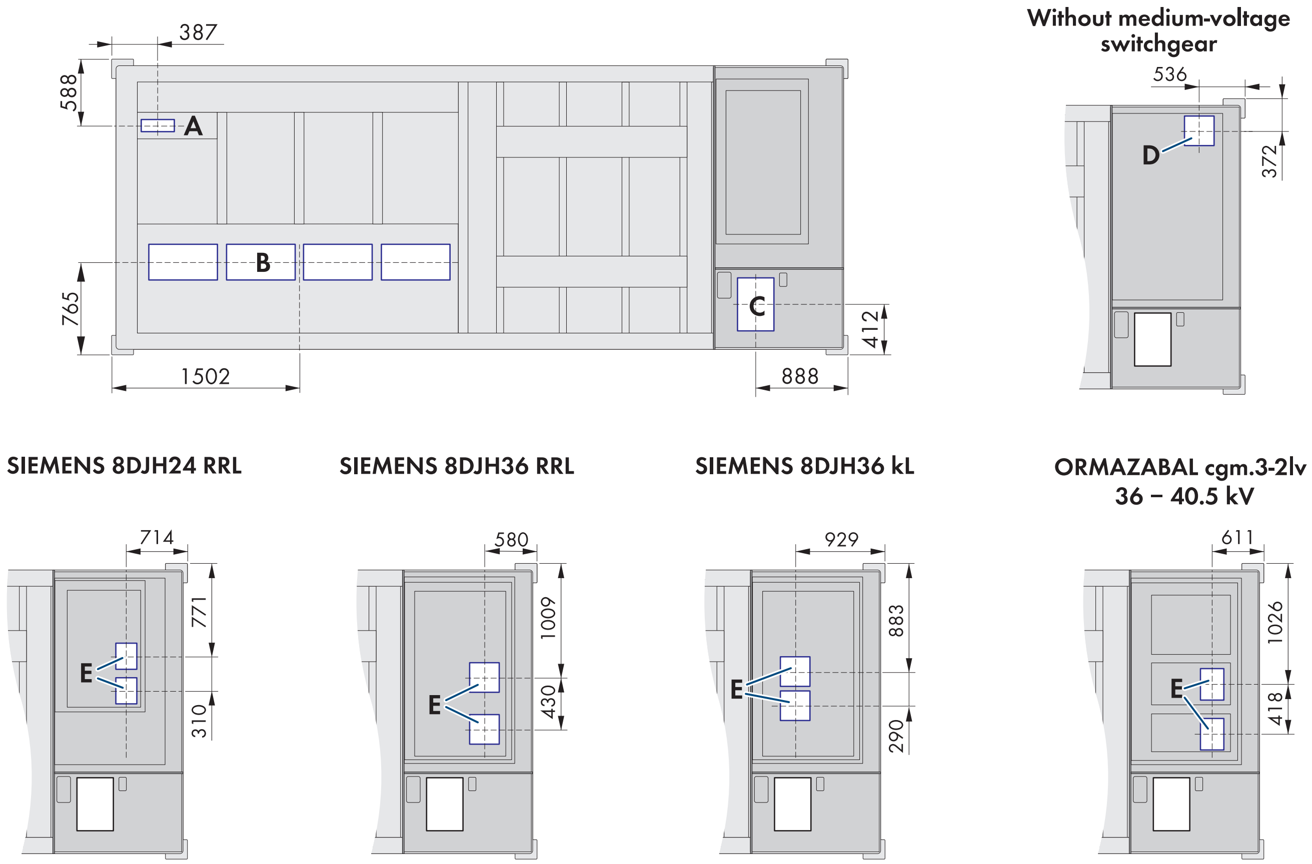


Figure 24: Positions of the openings for cable entry (Dimensions in mm)

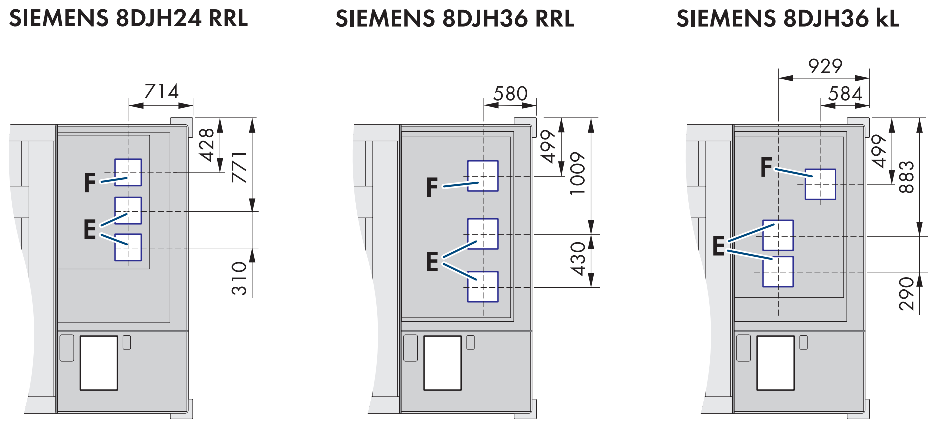


Figure 25: Positions of the openings for cable entry with order option "1 MVSG for 2 MVT" (Dimensions in mm)

Position	Designation	Recommended dimensions Width x depth
A	Opening underneath the inverter for insertion of the cables for communication, control, and monitoring With the order option "Cable Entry Kit", the opening is fitted with 2 sliding panels.	210 mm x 95 mm

Position	Designation	Recommended dimensions Width x depth
B	Opening underneath the inverter for insertion of the DC cables With the order option "Cable Entry Kit", the opening is fitted with 4 sliding panels.	Left: 560 mm x 386 mm Center: 578 mm x 386 mm Right: 544 mm x 386 mm
C	Opening for insertion of the communication and connection cables in the low-voltage room, of the tracker motors as well as the supply voltage of the DC/DC converters With the order option "Cable Entry Kit", the opening is fitted with 1 sliding panel.	300 mm x 430 mm
D	Opening for insertion of AC cables without medium-voltage switchgear With the order option "Cable Entry Kit", the openings are fitted with cable support sleeves.	255 mm x 255 mm
E	Openings underneath the MV switchgear for insertion of the AC cables With the order option "Cable Entry Kit", the openings are fitted with cable support sleeves.	255 mm x 255 mm
F	Openings underneath the MV switchgear for insertion of the AC cables with order option "1 MVSG for 2 MVT" With the order option "Cable Entry Kit", the openings are fitted with cable support sleeves.	255 mm x 255 mm

4.10 Requirements for Transport Routes and Means of Transport

Requirements for transport routes and means of transport

The product complies with the requirements of 2M4 in accordance with IEC 60721-3-2: 2018, with the exception of the free-fall requirements as well as rail transport. The transport routes and means of transport must be such that they comply with the requirements described in the standard.

☐ The access road must be accessible for servicing during the entire service life of the product.

☐ The maximum permissible gradient of the access road is 10%.

☐ During unloading, a distance of at least 2 m to neighboring obstacles must be observed.

☐ The access roads and the unloading site must be designed to accommodate the length, width, height, total weight and curve radius of the truck.

☐ Transport must be carried out by truck with air-sprung chassis.

☐ In order to avoid hard impacts during transport by truck, the driving speed must be adapted to the road conditions.

☐ The unloading site for the crane and truck must be firm, dry and horizontal.

☐ The external temperature during transport must be greater that -25°C.

☐ There must be no obstacles above the unloading site (e.g., live overhead power lines).

4.11 Transport Using a Crane

☐ The crane and hoist must be suitable for the weight.

☐ The hoist must be properly connected to the crane.

- ☐ The factory-fitted transport lock on the devices of the MV Power Station must be in place.
- ☐ All doors of the MV Power Station must be closed.
- ☐ The MV Power Station must be transported to its final position as close to the ground as possible.
- ☐ The MV Power Station must be set down with as little vibration as possible.
- ☐ The support surface must be suitable for the weight of the MV Power Station in accordance with the requirements (see Section 4.3, page 21).

4.12 Transport by truck or ship

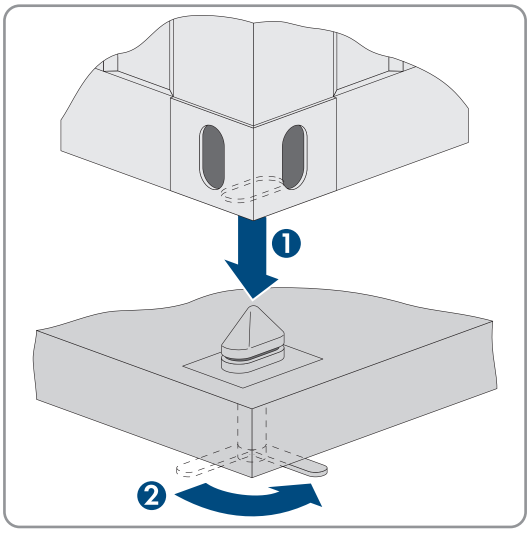
The dimensions of the MV Power Station correspond to those of an ISO container (High Cube Container). It can be transported by truck or ship. A truck with 16 m length, 2.7 m width, 5 m height, and with a total weight of 50 t is capable of transporting up to 2 MV Power Stations. Transport by railroad is not permitted.

Transport and unloading may cause damage to the surface (hot-dip galvanizing of the station frame or paint of the low or medium-voltage cabinet). Damage to the surface does not impair the function, but must be repaired after 3 weeks at the latest Servicing Schedule for General Work.

For transportation by truck or ship, the MV Power Station must be secured at least at all 4 lower corner castings. This can be done by various methods, depending on the fastening system of the means of transportation. The most common methods are described below.

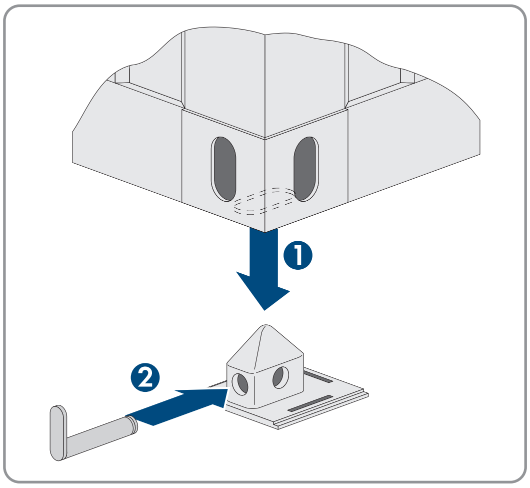
Twistlock

- The MV Power Station is set down on the locking mechanisms. By turning the twistlock, an interlocking is made.



Pinlock

- The MV Power Station is set down on the locking mechanisms. Any slippage of the load is prevented by inserting the pinlock.



- After the MV Power Station has arrived at the construction site, the transport checklist must be completed and sent to the SMA project manager. The transport checklist can be requested from the SMA project manager.

4.13 Storage

If you need to store the product prior to final installation, note the following points:

NOTICE

Damage to the system due to sand, dust and moisture ingress

Sand, dust and moisture penetration can damage the system and impair its functionality.

- Only open the product if the humidity is within the thresholds and the environment is free of sand and dust.
- Do not open the product during a dust storm or precipitation.
- In case of interruption of work or after finishing work, mount all enclosure parts and close and lock all doors.

i Desiccant bag in the inverter

The desiccant bag in the inverter protects the electronic components from moisture. The desiccant bag must be replaced by a new desiccant bag included in the scope of delivery one day before commissioning.

The commissioning is delayed by one day if the desiccant bag has not been replaced in the 24 hours prior to commissioning. Additional travel costs for SMA service personnel must be paid by the customer.

i Storage more than 2 months

In order to protect the electronic components against moisture, the desiccant bag in the inverter must be replaced every 2 months. If necessary, desiccant bags can be ordered from SMA Solar Technology AG using the following material number: 85-0081.

i Storage more than 18 months

If the product is stored for more than 18 months, measures other than those described here must be taken. You can get the required information from SMA Solar Technology AG.

For storage of the MV Power Station note the following points:

- Do not place the MV Power Station on an unstable, uneven surface.
- Once the MV Power Station has been set down on the surface, do not attempt to adjust its position by pulling or pushing.
- For the order option "Sea Freight", the foil must be removed.
- Prior to storage, ensure that the doors of the MV Power Station are tightly closed.

5 Contact

If you have technical problems with our products, please contact the SMA Service Line. The following data is required in order to provide you with the necessary assistance:

- Device type
- Serial numbers
- Firmware version
- Event message
- Type of communication
- Type and number of PV modules
- Type and size of additional energy sources
- Optional equipment, e.g. communication products
- Detailed description of the problem

You can find your country's contact information at:

https://go.sma.de/service

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8. Appendix B

FOUNDATION ANALYSIS

In accordance with EN1997-1:2004 + A1:2013 incorporating corrigendum February 2009 and the UK National Annex incorporating corrigendum No.1

Tedds calculation version 3.3.05

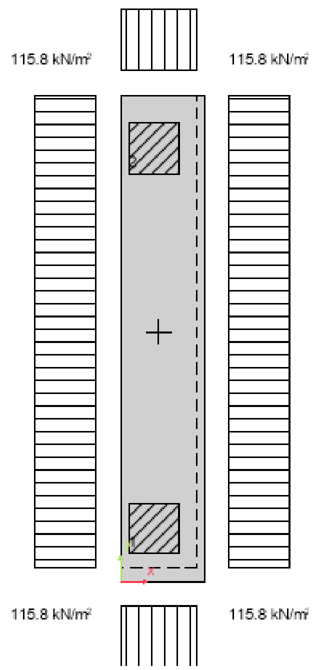
Summary table

Description	**Unit**	**Allowable**	**Actual**	**Utilisation**	**Result**
Sliding	kN	58.3	13.4	0.229	Pass
Base pressure	kN/m^2	551.4	115.8	0.210	Pass
Description	**Unit**	**Provided**	**Required**	**Utilisation**	**Result**
Reinforcement x-direction	mm^2	4624	1275	0.276	Pass
Reinforcement y-dir, top	mm^2	1005	340	0.339	Pass
		Allowable	Actual	Utilisation	
Description	**Unit**	**Allowable**	**Actual**	**Utilisation**	**Result**
Punching shear	N/mm^2	0.832	0.271	0.326	Pass

Pad foundation details

Length of foundation	L_x = **500** mm
Width of foundation	L_y = **2900** mm
Foundation area	$A = L_x \times L_y$ = **1.450** m^2
Depth of foundation	h = **500** mm
Depth of soil over foundation	h_{soil} = **0** mm
Level of water	h_{water} = **0** mm
Density of water	γ_{water} = **9.8** kN/m^3
Density of concrete	γ_{conc} = **25.0** kN/m^3

Tekla Tedds	Project				Job Ref.	
	Section				Sheet no./rev. 2	
	Calc. by P	Date 5/28/2024	Chk'd by	Date	App'd by	Date



Column no.1 details

Length of column l_{x1} = **300** mm

Width of column l_{y1} = **300** mm

position in x-direction x_1 = **200** mm

position in y-direction y_1 = **317** mm

Column no.2 details

Length of column l_{x2} = **300** mm

Width of column l_{y2} = **300** mm

position in x-direction x_2 = **200** mm

position in y-direction y_2 = **2583** mm

Soil properties

Density of soil γ_{soil} = **18.0** kN/m^3

Characteristic cohesion c'_k = **20** kN/m^2

Characteristic effective shear resistance angle ϕ'_k = **33** deg

Characteristic friction angle δ_k = **25** deg

Foundation loads

Self weight $F_{swt} = h \times \gamma_{conc}$ = **12.5** kN/m^2

Column no.1 loads

Permanent axial load F_{Gz1} = **55.0** kN

Variable axial load F_{Qz1} = **5.0** kN

Wind horizontal load in x-direction F_{Wx1} = **2.5** kN

Wind horizontal load in y-direction F_{Wy1} = **4.5** kN

Snow axial load F_{Sz1} = **9.0** kN

Column no.2 loads

Permanent axial load F_{Gz2} = **55.0** kN

Variable axial load F_{Qz2} = **5.0** kN

Wind horizontal load in x-direction F_{Wx2} = **2.5** kN

Wind horizontal load in y-direction F_{Wy2} = **4.5** kN

Snow axial load F_{Sz2} = **9.0** kN

Design approach 1

Partial factors on actions - Combination1

Partial factor set A1

Permanent unfavourable action - Table A.3 γ_G = **1.35**

Permanent favourable action - Table A.3 γ_{Gf} = **1.00**

Variable unfavourable action - Table A.3 γ_Q = **1.50**

Variable favourable action - Table A.3 γ_{Qf} = **0.00**

Partial factors for soil parameters - Combination1

Soil factor set M1

Angle of shearing resistance - Table A.4 $\gamma_{\phi'}$ = **1.00**

Effective cohesion - Table A.4 $\gamma_{c'}$ = **1.00**

Weight density - Table A.4 γ_γ = **1.00**

Partial factors for spread foundations - Combination1

Resistance factor set R1

Bearing - Table A.5 $\gamma_{R.v}$ = **1.00**

Sliding - Table A.5 $\gamma_{R.h}$ = **1.00**

Bearing resistance (Section 6.5.2)

Forces on foundation

Force in x-direction $F_{dx} = \gamma_Q \times (F_{Wx1} + F_{Wx2})$ = **7.5** kN

Force in y-direction $F_{dy} = \gamma_Q \times (F_{Wy1} + F_{Wy2})$ = **13.5** kN

Force in z-direction $F_{dz} = \gamma_G \times (A \times F_{swt} + F_{Gz1} + F_{Gz2}) + \gamma_Q \times \psi_{Q0} \times (F_{Qz1} + F_{Qz2}) + \gamma_Q \times \psi_{S0} \times (F_{Sz1} + F_{Sz2})$ = **197.0** kN

Moments on foundation

Moment in x-direction $M_{dx} = \gamma_G \times (A \times F_{swt} \times L_x / 2 + F_{Gz1} \times x_1 + F_{Gz2} \times x_2) + \gamma_Q \times \psi_{Q0} \times (F_{Qz1} \times x_1 + F_{Qz2} \times x_2) + \gamma_Q \times \psi_{S0} \times (F_{Sz1} \times x_1 + F_{Sz2} \times x_2) + (\gamma_Q \times (F_{Wx1} + F_{Wx2})) \times h$ = **44.4** kNm

Moment in y-direction $M_{dy} = \gamma_G \times (A \times F_{swt} \times L_y / 2 + F_{Gz1} \times y_1 + F_{Gz2} \times y_2) + \gamma_Q \times \psi_{Q0} \times (F_{Qz1} \times y_1 + F_{Qz2} \times y_2) + \gamma_Q \times \psi_{S0} \times (F_{Sz1} \times y_1 + F_{Sz2} \times y_2) + (\gamma_Q \times (F_{Wy1} + F_{Wy2})) \times h$ = **292.4** kNm

Eccentricity of base reaction

Eccentricity of base reaction in x-direction $e_x = M_{dx} / F_{dz} - L_x / 2$ = **-25** mm

Eccentricity of base reaction in y-direction $e_y = M_{dy} / F_{dz} - L_y / 2$ = **34** mm

Effective area of base

Effective length $L'_x = L_x + 2 \times e_x$ = **450** mm

Effective width $L'_y = L_y - 2 \times e_y$ = **2831** mm

Effective area — $A' = L'_x \times L'_y =$ **1.276** m^2

Pad base pressure

Design base pressure — $f_{dz} = F_{dz} / A' =$ **154.4** kN/m^2

Ultimate bearing capacity under drained conditions (Annex D.4)

Design angle of shearing resistance — $\phi'_d = atan(tan(\phi'_k) / \gamma_{\phi'}) =$ **33.000** deg

Design effective cohesion — $c'_d = c'_k / \gamma_{c'} =$ **20.000** kN/m^2

Effective overburden pressure — $q = (h + h_{soil}) \times \gamma_{soil} - h_{water} \times \gamma_{water} =$ **9.000** kN/m^2

Design effective overburden pressure — $q' = q / \gamma_\gamma =$ **9.000** kN/m^2

Bearing resistance factors — $N_q = Exp(\pi \times tan(\phi'_d)) \times (tan(45\ deg + \phi'_d / 2))^2 =$ **26.092**

$N_c = (N_q - 1) \times cot(\phi'_d) =$ **38.638**

$N_\gamma = 2 \times (N_q - 1) \times tan(\phi'_d) =$ **32.590**

Foundation shape factors — $s_q = 1 + (L'_x / L'_y) \times sin(\phi'_d) =$ **1.087**

$s_\gamma = 1 - 0.3 \times (L'_x / L'_y) =$ **0.952**

$s_c = (s_q \times N_q - 1) / (N_q - 1) =$ **1.090**

Load inclination factors — $H = [F_{dx}^2 + F_{dy}^2]^{0.5} =$ **15.4** kN

$m_y = [2 + (L'_y / L'_x)] / [1 + (L'_y / L'_x)] =$ **1.137**

$m_x = [2 + (L'_x / L'_y)] / [1 + (L'_x / L'_y)] =$ **1.863**

$m = m_x \times cos(atan(F_{dy} / F_{dx}))^2 + m_y \times sin(atan(F_{dy} / F_{dx}))^2 =$ **1.308**

$i_q = [1 - H / (F_{dz} + A' \times c'_d \times cot(\phi'_d))]^m =$ **0.915**

$i_\gamma = [1 - H / (F_{dz} + A' \times c'_d \times cot(\phi'_d))]^{m+1} =$ **0.856**

$i_c = i_q - (1 - i_q) / (N_c \times tan(\phi'_d)) =$ **0.912**

Ultimate bearing capacity — $n_f = c'_d \times N_c \times s_c \times i_c + q' \times N_q \times s_q \times i_q + 0.5 \times \gamma_{soil} \times L'_x \times N_\gamma \times s_\gamma \times i_\gamma =$ **1109.5** kN/m^2

PASS - Ultimate bearing capacity exceeds design base pressure

Sliding resistance (Section 6.5.3)

Forces on foundation

Force in x-direction — $F_{dx} = \gamma_Q \times (F_{Wx1} + F_{Wx2}) =$ **7.5** kN

Force in y-direction — $F_{dy} = \gamma_Q \times (F_{Wy1} + F_{Wy2}) =$ **13.5** kN

Force in z-direction — $F_{dz} = \gamma_{Gf} \times (A \times F_{swt} + F_{Gz1} + F_{Gz2}) + \gamma_{Qf} \times \psi_{Q0} \times (F_{Qz1} + F_{Qz2}) + \gamma_{Qf} \times \psi_{S0} \times (F_{Sz1} + F_{Sz2}) =$ **128.1** kN

Sliding resistance verification (Section 6.5.3)

Horizontal force on foundation — $H = [F_{dx}^2 + F_{dy}^2]^{0.5} =$ **15.4** kN

Angle to horizontal force — $\theta_H =$ **60.945** deg

Design friction angle — $\delta_d = atan(tan(\delta_k) / \gamma_{\phi'}) =$ **25** deg

Passive pressure coefficient — $K_p = (1 + sin(\phi'_d)) / (1 - sin(\phi'_d)) =$ **3.392**

Design soil density — $\gamma_{soil}' = \gamma_{soil} / \gamma_\gamma =$ **18** kN/m^3

Passive soil resistance — $F_p = \gamma_{Gf} \times K_p \times cos(\delta_d) \times \gamma_{soil}' \times (L_y \times cos(\theta_H) + L_x \times sin(\theta_H)) \times h \times (h + 2 \times h_{soil}) / 2 =$ **12.8** kN

Sliding resistance (exp.6.3a) — $R_{H.d} = F_{dz} \times tan(\delta_d) + F_p =$ **72.5** kN

$H / R_{H.d} =$ **0.213**

PASS - Foundation is not subject to failure by sliding

Design approach 1

Partial factors on actions - Combination2

Partial factor set A2

Permanent unfavourable action - Table A.3 γ_G = **1.00**

Permanent favourable action - Table A.3 γ_{Gf} = **1.00**

Variable unfavourable action - Table A.3 γ_Q = **1.30**

Variable favourable action - Table A.3 γ_{Qf} = **0.00**

Partial factors for soil parameters - Combination2

Soil factor set M2

Angle of shearing resistance - Table A.4 $\gamma_{\phi'}$ = **1.25**

Effective cohesion - Table A.4 $\gamma_{c'}$ = **1.25**

Weight density - Table A.4 γ_{γ} = **1.00**

Partial factors for spread foundations - Combination2

Resistance factor set R1

Bearing - Table A.5 $\gamma_{R.v}$ = **1.00**

Sliding - Table A.5 $\gamma_{R.h}$ = **1.00**

Bearing resistance (Section 6.5.2)

Forces on foundation

Force in x-direction $F_{dx} = \gamma_Q \times (F_{Wx1} + F_{Wx2})$ = **6.5** kN

Force in y-direction $F_{dy} = \gamma_Q \times (F_{Wy1} + F_{Wy2})$ = **11.7** kN

Force in z-direction $F_{dz} = \gamma_G \times (A \times F_{swt} + F_{Gz1} + F_{Gz2}) + \gamma_Q \times \psi_{Q0} \times (F_{Qz1} + F_{Qz2}) + \gamma_Q \times \psi_{S0} \times (F_{Sz1} + F_{Sz2})$ = **148.9** kN

Moments on foundation

Moment in x-direction $M_{dx} = \gamma_G \times (A \times F_{swt} \times L_x / 2 + F_{Gz1} \times x_1 + F_{Gz2} \times x_2) + \gamma_Q \times \psi_{Q0} \times (F_{Qz1} \times x_1 + F_{Qz2} \times x_2) + \gamma_Q \times \psi_{S0} \times (F_{Sz1} \times x_1 + F_{Sz2} \times x_2) + (\gamma_Q \times (F_{Wx1} + F_{Wx2})) \times h$ = **33.9** kNm

Moment in y-direction $M_{dy} = \gamma_G \times (A \times F_{swt} \times L_y / 2 + F_{Gz1} \times y_1 + F_{Gz2} \times y_2) + \gamma_Q \times \psi_{Q0} \times (F_{Qz1} \times y_1 + F_{Qz2} \times y_2) + \gamma_Q \times \psi_{S0} \times (F_{Sz1} \times y_1 + F_{Sz2} \times y_2) + (\gamma_Q \times (F_{Wy1} + F_{Wy2})) \times h$ = **221.8** kNm

Eccentricity of base reaction

Eccentricity of base reaction in x-direction $e_x = M_{dx} / F_{dz} - L_x / 2$ = **-22** mm

Eccentricity of base reaction in y-direction $e_y = M_{dy} / F_{dz} - L_y / 2$ = **39** mm

Effective area of base

Effective length $L'_x = L_x + 2 \times e_x$ = **456** mm

Effective width $L'_y = L_y - 2 \times e_y$ = **2821** mm

Effective area $A' = L'_x \times L'_y$ = **1.286** m^2

Pad base pressure

Design base pressure $f_{dz} = F_{dz} / A'$ = **115.8** kN/m^2

Ultimate bearing capacity under drained conditions (Annex D.4)

Design angle of shearing resistance $\phi'_d = \text{atan}(\tan(\phi'_k) / \gamma_{\phi'})$ = **27.453** deg

Design effective cohesion $c'_d = c'_k / \gamma_{c'}$ = **16.000** kN/m^2

Effective overburden pressure $q = (h + h_{soil}) \times \gamma_{soil} - h_{water} \times \gamma_{water} = \mathbf{9.000}$ kN/m^2

Design effective overburden pressure $q' = q / \gamma_\gamma = \mathbf{9.000}$ kN/m^2

Bearing resistance factors $N_q = Exp(\pi \times \tan(\phi'_d)) \times (\tan(45 \text{ deg} + \phi'_d / 2))^2 = \mathbf{13.865}$

$N_c = (N_q - 1) \times \cot(\phi'_d) = \mathbf{24.763}$

$N_\gamma = 2 \times (N_q - 1) \times \tan(\phi'_d) = \mathbf{13.367}$

Foundation shape factors $s_q = 1 + (L'_x / L'_y) \times \sin(\phi'_d) = \mathbf{1.074}$

$s_\gamma = 1 - 0.3 \times (L'_x / L'_y) = \mathbf{0.952}$

$s_c = (s_q \times N_q - 1) / (N_q - 1) = \mathbf{1.080}$

Load inclination factors $H = [F_{dx}^2 + F_{dy}^2]^{0.5} = \mathbf{13.4}$ kN

$m_y = [2 + (L'_y / L'_x)] / [1 + (L'_y / L'_x)] = \mathbf{1.139}$

$m_x = [2 + (L'_x / L'_y)] / [1 + (L'_x / L'_y)] = \mathbf{1.861}$

$m = m_x \times \cos(\text{atan}(F_{dy} / F_{dx}))^2 + m_y \times \sin(\text{atan}(F_{dy} / F_{dx}))^2 = \mathbf{1.309}$

$i_q = [1 - H / (F_{dz} + A' \times c'_d \times \cot(\phi'_d))]^m = \mathbf{0.908}$

$i_\gamma = [1 - H / (F_{dz} + A' \times c'_d \times \cot(\phi'_d))]^{m+1} = \mathbf{0.844}$

$i_c = i_q - (1 - i_q) / (N_c \times \tan(\phi'_d)) = \mathbf{0.901}$

Ultimate bearing capacity $n_f = c'_d \times N_c \times s_c \times i_c + q' \times N_q \times s_q \times i_q + 0.5 \times \gamma_{soil} \times L'_x \times N_\gamma \times s_\gamma \times i_\gamma =$ **551.4** kN/m^2

PASS - Ultimate bearing capacity exceeds design base pressure

Sliding resistance (Section 6.5.3)

Forces on foundation

Force in x-direction $F_{dx} = \gamma_Q \times (F_{Wx1} + F_{Wx2}) = \mathbf{6.5}$ kN

Force in y-direction $F_{dy} = \gamma_Q \times (F_{Wy1} + F_{Wy2}) = \mathbf{11.7}$ kN

Force in z-direction $F_{dz} = \gamma_{Gf} \times (A \times F_{swt} + F_{Gz1} + F_{Gz2}) + \gamma_{Qf} \times \psi_{Q0} \times (F_{Qz1} + F_{Qz2}) + \gamma_{Qf} \times \psi_{S0} \times (F_{Sz1} + F_{Sz2}) = \mathbf{128.1}$ kN

Sliding resistance verification (Section 6.5.3)

Horizontal force on foundation $H = [F_{dx}^2 + F_{dy}^2]^{0.5} = \mathbf{13.4}$ kN

Angle to horizontal force $\theta_H = \mathbf{60.945}$ deg

Design friction angle $\delta_d = \text{atan}(\tan(\delta_k) / \gamma_{\phi'}) = \mathbf{20.458}$ deg

Passive pressure coefficient $K_p = (1 + \sin(\phi'_d)) / (1 - \sin(\phi'_d)) = \mathbf{2.711}$

Design soil density $\gamma_{soil}' = \gamma_{soil} / \gamma_\gamma = \mathbf{18}$ kN/m^3

Passive soil resistance $F_p = \gamma_{Gf} \times K_p \times \cos(\delta_d) \times \gamma_{soil}' \times (L_y \times \cos(\theta_H) + L_x \times \sin(\theta_H)) \times h \times (h + 2 \times h_{soil}) / 2 = \mathbf{10.5}$ kN

Sliding resistance (exp.6.3a) $R_{H.d} = F_{dz} \times \tan(\delta_d) + F_p = \mathbf{58.3}$ kN

$H / R_{H.d} = \mathbf{0.229}$

PASS - Foundation is not subject to failure by sliding

FOUNDATION DESIGN

In accordance with EN1992-1-1:2004 + A1:2014 incorporating corrigenda January 2008, November 2010 and January 2014 and the UK National Annex incorporating National Amendment No.1 and No.2

Tedds calculation version 3.3.05

Concrete details (Table 3.1 - Strength and deformation characteristics for concrete)

Concrete strength class C30/37

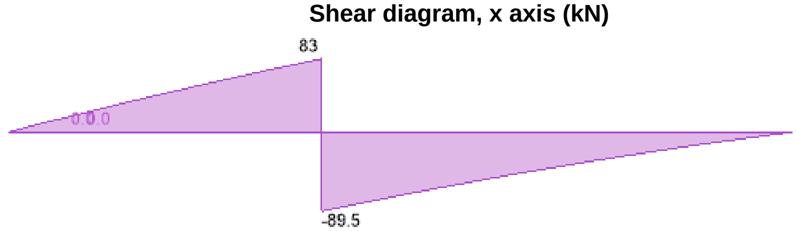
Characteristic compressive cylinder strength $f_{ck} = \mathbf{30}$ N/mm^2

Characteristic compressive cube strength	$f_{ck,cube}$ = **37** N/mm^2
Mean value of compressive cylinder strength	f_{cm} = f_{ck} + 8 N/mm^2 = **38** N/mm^2
Mean value of axial tensile strength	f_{ctm} = 0.3 N/mm^2 × (f_{ck}/ 1 N/mm^2)$^{2/3}$ = **2.9** N/mm^2
5% fractile of axial tensile strength	$f_{ctk,0.05}$ = 0.7 × f_{ctm} = **2.0** N/mm^2
Secant modulus of elasticity of concrete	E_{cm} = 22 kN/mm^2 × [f_{cm}/10 N/mm^2]$^{0.3}$ = **32837** N/mm^2
Partial factor for concrete (Table 2.1N)	γ_C = **1.50**
Compressive strength coefficient (cl.3.1.6(1))	α_{cc} = **0.85**
Design compressive concrete strength (exp.3.15)	f_{cd} = α_{cc} × f_{ck} / γ_C = **17.0** N/mm^2
Tens.strength coeff.for plain concrete (cl.12.3.1(1))	$\alpha_{ct,pl}$ = **0.80**
Des.tens.strength for plain concrete (exp.12.1)	$f_{ctd,pl}$ = $\alpha_{ct,pl}$ × $f_{ctk,0.05}$ / γ_C = **1.1** N/mm^2
Maximum aggregate size	h_{agg} = **20** mm
Ultimate strain - Table 3.1	ε_{cu2} = **0.0035**
Shortening strain - Table 3.1	ε_{cu3} = **0.0035**
Effective compression zone height factor	λ = **0.80**
Effective strength factor	η = **1.00**
Bending coefficient k_1	K_1 = **0.40**
Bending coefficient k_2	K_2 = 1.00 × (0.6 + 0.0014/ε_{cu2}) =**1.00**
Bending coefficient k_3	K_3 =**0.40**
Bending coefficient k_4	K_4 =1.00 × (0.6 + 0.0014/ε_{cu2}) = **1.00**

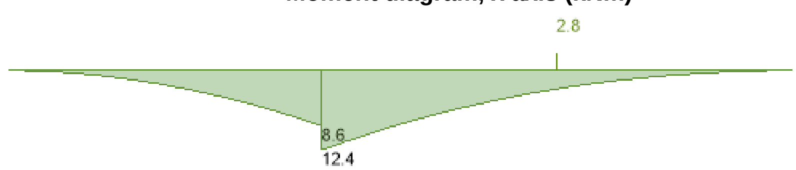
Reinforcement details

Characteristic yield strength of reinforcement	f_{yk} = **500** N/mm^2
Modulus of elasticity of reinforcement	E_s = **210000** N/mm^2
Partial factor for reinforcing steel (Table 2.1N)	γ_S = **1.15**
Design yield strength of reinforcement	f_{yd} = f_{yk} / γ_S = **435** N/mm^2
Nominal cover to top of foundation	c_{nom_t} = **40** mm
Nominal cover to bottom of foundation	c_{nom_b} = **40** mm
Nominal cover to side of foundation	c_{nom_s} = **40** mm
Nominal cover to top reinforcement	c_{nom_t} = **40** mm

Shear diagram, x axis (kN)



Moment diagram, x axis (kNm)



Rectangular section in flexure (Section 6.1)

Design bending moment $M_{Ed.x.max}$ = **2.8** kNm

Depth to tension reinforcement $d = h - c_{nom\_b} - \phi_{y.bot} - \phi_{x.bot} / 2$ = **292** mm

$K = M_{Ed.x.max} / (L_y \times d^2 \times f_{ck})$ = **0.000**

$K' = (2 \times \eta \times \alpha_{cc}/\gamma_C)\times(1 - \lambda \times (\delta - K_1)/(2 \times K_2))\times(\lambda \times (\delta - K_1)/(2 \times K_2))$

K' = **0.207**

K' > K - No compression reinforcement is required

Lever arm $z = \min(0.5 + 0.5 \times (1 - 2 \times K / (\eta \times \alpha_{cc} / \gamma_C))^{0.5}, 0.95) \times d$ = **277** mm

Depth of neutral axis $x = 2.5 \times (d - z)$ = **37** mm

Area of tension reinforcement required $A_{sx.bot.req} = M_{Ed.x.max} / (f_{yd} \times z)$ = **23** mm²

Tension reinforcement provided 16 ϕ bars @ 125 c/c bottom

Area of tension reinforcement provided $A_{sx.bot.prov}$ = **4624** mm²

Minimum area of reinforcement (exp.9.1N) $A_{s.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times L_y \times d$ = **1275** mm²

Maximum area of reinforcement (cl.9.2.1.1(3)) $A_{s.max} = 0.04 \times L_y \times d$ = **33872** mm²

PASS - Area of reinforcement provided is greater than area of reinforcement required

Crack control (Section 7.3)

Limiting crack width w_{max} = **0.3** mm

Variable load factor (EN1990 – Table A1.1) ψ_2 = **0.3**

Serviceability bending moment $M_{sls.x.max}$ = **1.5** kNm

Tensile stress in reinforcement $\sigma_s = M_{sls.x.max} / (A_{sx.bot.prov} \times z)$ = **1.2** N/mm²

Load duration factor k_t = **0.4**

Effective depth of concrete in tension $h_{c.ef} = \min(2.5 \times (h - d), (h - x) / 3, h / 2)$ = **155** mm

Effective area of concrete in tension $A_{c.eff} = h_{c.ef} \times L_y$ = **448050** mm²

Mean value of concrete tensile strength $f_{ct.eff} = f_{ctm}$ = **2.9** N/mm²

Reinforcement ratio $\rho_{p.eff} = A_{sx.bot.prov} / A_{c.eff}$ = **0.010**

Modular ratio $\alpha_e = E_s / E_{cm}$ = **6.395**

Bond property coefficient k_1 = **0.8**

Strain distribution coefficient k_2 = **0.5**

k_3 = 3.4 =**3.4**

k_4 = **0.425**

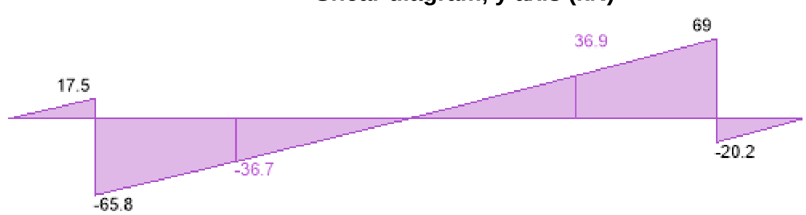
Maximum crack spacing (exp.7.11) $s_{r.max} = k_3 \times (c_{nom\_b} + \phi_{y.bot}) + k_1 \times k_2 \times k_4 \times \phi_{x.bot} / \rho_{p.eff}$ = **944** mm

Maximum crack width (exp.7.8) $w_k = s_{r.max} \times \max([\sigma_s – k_t \times (f_{ct.eff} / \rho_{p.eff}) \times (1 + \alpha_e \times \rho_{p.eff})] / E_s,$ $0.6 \times \sigma_s / E_s)$ = **0.003** mm

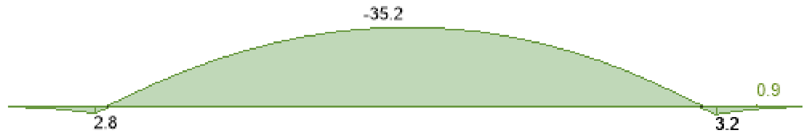
PASS - Maximum crack width is less than limiting crack width

Library item: Crack width output

Shear diagram, y axis (kN)



Moment diagram, y axis (kNm)



Rectangular section in flexure (Section 6.1)

Design bending moment	$\mathrm{abs}(M_{Ed.y.min})$ = **35.2** kNm
Depth to tension reinforcement	$d = h - c_{nom\_t} - \phi_{y.top} / 2$ = **452** mm
	$K = \mathrm{abs}(M_{Ed.y.min}) / (L_x \times d^2 \times f_{ck})$ = **0.011**
	$K' = (2 \times \eta \times \alpha_{cc}/\gamma_C)\times(1 - \lambda \times (\delta - K_1)/(2 \times K_2))\times(\lambda \times (\delta - K_1)/(2 \times K_2))$
	K' = **0.207**

K' > K - No compression reinforcement is required

Lever arm	$z = \min(0.5 + 0.5 \times (1 - 2 \times K / (\eta \times \alpha_{cc} / \gamma_C))^{0.5}, 0.95) \times d$ = **429** mm
Depth of neutral axis	$x = 2.5 \times (d - z)$ = **57** mm
Area of tension reinforcement required	$A_{sy.top.req} = \mathrm{abs}(M_{Ed.y.min}) / (f_{yd} \times z)$ = **189** mm^2
Tension reinforcement provided	16 ϕ bars @ 100 c/c top
Area of tension reinforcement provided	$A_{sy.top.prov}$ = **1005** mm^2
Minimum area of reinforcement (exp.9.1N)	$A_{s.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times L_x \times d$ = **340** mm^2
Maximum area of reinforcement (cl.9.2.1.1(3))	$A_{s.max} = 0.04 \times L_x \times d$ = **9040** mm^2

PASS - Area of reinforcement provided is greater than area of reinforcement required

Crack control (Section 7.3)

Limiting crack width	w_{max} = **0.3** mm
Variable load factor (EN1990 – Table A1.1)	ψ_2 = **0.3**
Serviceability bending moment	$\mathrm{abs}(M_{sls.y.min})$ = **23.4** kNm
Tensile stress in reinforcement	$\sigma_s = \mathrm{abs}(M_{sls.y.min}) / (A_{sy.top.prov} \times z)$ = **54.3** N/mm^2
Load duration factor	k_t = **0.4**
Effective depth of concrete in tension	$h_{c.ef} = \min(2.5 \times (h - d), (h - x) / 3, h / 2)$ = **120** mm
Effective area of concrete in tension	$A_{c.eff} = h_{c.ef} \times L_x$ = **60000** mm^2
Mean value of concrete tensile strength	$f_{ct.eff} = f_{ctm}$ = **2.9** N/mm^2
Reinforcement ratio	$\rho_{p.eff} = A_{sy.top.prov} / A_{c.eff}$ = **0.017**
Modular ratio	$\alpha_e = E_s / E_{cm}$ = **6.395**
Bond property coefficient	k_1 = **0.8**
Strain distribution coefficient	k_2 = **0.5**
	k_3 = 3.4 =**3.4**
	k_4 = **0.425**
Maximum crack spacing (exp.7.11)	$s_{r.max} = k_3 \times c_{nom\_t} + k_1 \times k_2 \times k_4 \times \phi_{y.top} / \rho_{p.eff}$ = **298** mm
Maximum crack width (exp.7.8)	$w_k = s_{r.max} \times \max([\sigma_s – k_t \times (f_{ct.eff} / \rho_{p.eff}) \times(1 + \alpha_e \times \rho_{p.eff})] / E_s,$
	$0.6 \times \sigma_s / E_s)$ = **0.046** mm

PASS - Maximum crack width is less than limiting crack width

Library item: Crack width output

Rectangular section in shear (Section 6.2)

Design shear force	$V_{Ed.y.max}$ = **36.9** kN

$C_{Rd,c} = 0.18 / \gamma_C = \mathbf{0.120}$

$k = \min(1 + \sqrt{(200\text{ mm} / d)}, 2) = \mathbf{1.741}$

Longitudinal reinforcement ratio $\rho_l = \min(A_{sy.bot.prov} / (L_x \times d), 0.02) = \mathbf{0.020}$

$v_{min} = 0.035\text{ N}^{1/2}\text{/mm} \times k^{3/2} \times f_{ck}^{0.5} = \mathbf{0.440}\text{ N/mm}^2$

Design shear resistance (exp.6.2a & 6.2b) $V_{Rd.c} = \max(C_{Rd.c} \times k \times (100\text{ N}^2\text{/mm}^4 \times \rho_l \times f_{ck})^{1/3}, v_{min}) \times L_x \times d$

$V_{Rd.c} = \mathbf{148.9}\text{ kN}$

PASS - Design shear resistance exceeds design shear force

Punching shear (Section 6.4)

Strength reduction factor (exp 6.6N) $v = 0.6 \times [1 - f_{ck} / 250\text{ N/mm}^2] = \mathbf{0.528}$

Average depth to reinforcement $d = \mathbf{372}\text{ mm}$

Maximum punching shear resistance (cl.6.4.5(3)) $v_{Rd.max} = 0.5 \times v \times f_{cd} = \mathbf{4.488}\text{ N/mm}^2$

$k = \min(1 + \sqrt{(200\text{ mm} / d)}, 2) = \mathbf{1.733}$

Longitudinal reinforcement ratio (cl.6.4.4(1)) $\rho_{lx} = A_{sx.bot.prov} / (L_y \times d) = \mathbf{0.004}$

$\rho_{ly} = A_{sy.bot.prov} / (L_x \times d) = \mathbf{0.432}$

$\rho_l = \min(\sqrt{(\rho_{lx} \times \rho_{ly})}, 0.02) = \mathbf{0.020}$

$C_{Rd,c} = 0.18 / \gamma_C = \mathbf{0.120}$

$v_{min} = 0.035\text{ N}^{1/2}\text{/mm} \times k^{3/2} \times f_{ck}^{0.5} = \mathbf{0.437}\text{ N/mm}^2$

Design punching shear resistance (exp.6.47) $v_{Rd.c} = \max(C_{Rd.c} \times k \times (100\text{ N}^2\text{/mm}^4 \times \rho_l \times f_{ck})^{1/3}, v_{min}) = \mathbf{0.814}\text{ N/mm}^2$

Design punching shear resistance at 1d (exp. 6.50) $v_{Rd.c1} = (2 \times d / d) \times v_{Rd.c} = \mathbf{1.628}\text{ N/mm}^2$

Column No.1 - Punching shear perimeter at column face

Punching shear perimeter $u_0 = \mathbf{1200}\text{ mm}$

Area within punching shear perimeter $A_0 = \mathbf{0.090}\text{ m}^2$

Maximum punching shear force $V_{Ed.max} = \mathbf{82.9}\text{ kN}$

Punching shear stress factor (fig 6.21N) $\beta = \mathbf{1.500}$

Maximum punching shear stress (exp 6.38) $v_{Ed.max} = \beta \times V_{Ed.max} / (u_0 \times d) = \mathbf{0.278}\text{ N/mm}^2$

PASS - Maximum punching shear resistance exceeds maximum punching shear stress

Column No.1 - Punching shear perimeter at 1d from column face

Punching shear perimeter $u_1 = \mathbf{505}\text{ mm}$

Area within punching shear perimeter $A_1 = \mathbf{0.418}\text{ m}^2$

Design punching shear force $V_{Ed.1} = \mathbf{48.8}\text{ kN}$

Punching shear stress factor (fig 6.21N) $\beta = \mathbf{1.500}$

Design punching shear stress (exp 6.38) $v_{Ed.1} = \beta \times V_{Ed.1} / (u_1 \times d) = \mathbf{0.390}\text{ N/mm}^2$

PASS - Design punching shear resistance exceeds increased design punching shear stress

Column No.1 - Punching shear perimeter at 2d from column face

Punching shear perimeter $u_2 = \mathbf{501}\text{ mm}$

Area within punching shear perimeter $A_2 = \mathbf{0.605}\text{ m}^2$

Design punching shear force $V_{Ed.2} = \mathbf{26}\text{ kN}$

Punching shear stress factor (fig 6.21N) $\beta = \mathbf{1.500}$

Design punching shear stress (exp 6.38) $v_{Ed.2} = \beta \times V_{Ed.2} / (u_2 \times d) = \mathbf{0.209}\text{ N/mm}^2$

PASS - Design punching shear resistance exceeds design punching shear stress

Column No.2 - Punching shear perimeter at column face

Punching shear perimeter $u_0 = \mathbf{1200}\text{ mm}$

Area within punching shear perimeter A_0 = **0.090** m^2

Maximum punching shear force $V_{Ed.max}$ = **82.9** kN

Punching shear stress factor (fig 6.21N) β = **1.500**

Maximum punching shear stress (exp 6.38) $v_{Ed.max} = \beta \times V_{Ed.max} / (u_0 \times d)$ = **0.278** N/mm^2

PASS - Maximum punching shear resistance exceeds maximum punching shear stress

Column No.2 - Punching shear perimeter at 1d from column face

Punching shear perimeter u_1 = **505** mm

Area within punching shear perimeter A_1 = **0.418** m^2

Design punching shear force $V_{Ed.1}$ = **44** kN

Punching shear stress factor (fig 6.21N) β = **1.500**

Design punching shear stress (exp 6.38) $v_{Ed.1} = \beta \times V_{Ed.1} / (u_1 \times d)$ = **0.352** N/mm^2

PASS - Design punching shear resistance exceeds increased design punching shear stress

Column No.2 - Punching shear perimeter at 2d from column face

Punching shear perimeter u_2 = **501** mm

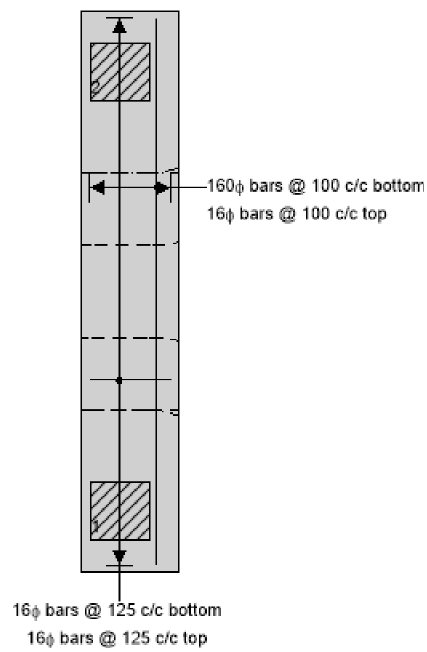
Area within punching shear perimeter A_2 = **0.605** m^2

Design punching shear force $V_{Ed.2}$ = **21.3** kN

Punching shear stress factor (fig 6.21N) β = **1.500**

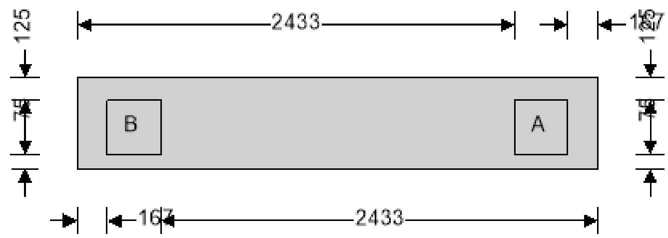
Design punching shear stress (exp 6.38) $v_{Ed.2} = \beta \times V_{Ed.2} / (u_2 \times d)$ = **0.171** N/mm^2

PASS - Design punching shear resistance exceeds design punching shear stress



PAD FOOTING ANALYSIS AND DESIGN (BS8110-1:1997)

Tedds calculation version 2.0.07



Pad footing details

Length of pad footing — $L = \mathbf{2900}$ mm

Width of pad footing — $B = \mathbf{500}$ mm

Area of pad footing — $A = L \times B = \mathbf{1.450}$ m^2

Depth of pad footing — $h = \mathbf{500}$ mm

Depth of soil over pad footing — $h_{soil} = \mathbf{0}$ mm

Density of concrete — $\rho_{conc} = \mathbf{25.0}$ kN/m^3

Column details	**Column A**	**Column B**
Column base length	$l_A = \mathbf{300}$ mm	$l_B = \mathbf{300}$ mm
Column base width	$b_A = \mathbf{300}$ mm	$b_B = \mathbf{300}$ mm
Column eccentricity in x	$e_{PxA} = \mathbf{1133}$ mm	$e_{PxB} = \mathbf{-1133}$ mm
Column eccentricity in y	$e_{PyA} = \mathbf{-25}$ mm	$e_{PyB} = \mathbf{-25}$ mm

Soil details

Density of soil — $\rho_{soil} = \mathbf{17.0}$ kN/m^3

Design shear strength — $\phi' = \mathbf{33.0}$ deg

Design base friction — $\delta = \mathbf{25.0}$ deg

Allowable bearing pressure — $P_{bearing} = \mathbf{100}$ kN/m^2

Axial loading on columns	**Column A**	**Column B**
Dead axial load on column	$P_{GA} = \mathbf{55.0}$ kN	$P_{GB} = \mathbf{55.0}$ kN
Imposed axial load on column	$P_{QA} = \mathbf{0.0}$ kN	$P_{QB} = \mathbf{0.0}$ kN
Wind axial load on column	$P_{WA} = \mathbf{0.0}$ kN	$P_{WB} = \mathbf{0.0}$ kN
Total axial load on column	$P_A = \mathbf{55.0}$ kN	$P_B = \mathbf{55.0}$ kN

Foundation loads

Dead surcharge load — $F_{Gsur} = \mathbf{0.000}$ kN/m^2

Imposed surcharge load — $F_{Qsur} = \mathbf{0.000}$ kN/m^2

Pad footing self weight — $F_{swt} = h \times \rho_{conc} = \mathbf{12.500}$ kN/m^2

Soil self weight — $F_{soil} = h_{soil} \times \rho_{soil} = \mathbf{0.000}$ kN/m^2

Total foundation load — $F = A \times (F_{Gsur} + F_{Qsur} + F_{swt} + F_{soil}) = \mathbf{18.1}$ kN

Horizontal loading on column bases	**Column A**	**Column B**
Dead horizontal load in x direction	$H_{GxA} = \mathbf{0.0}$ kN	$H_{GxB} = \mathbf{0.0}$ kN
Imposed horizontal load in x direction	$H_{QxA} = \mathbf{0.0}$ kN	$H_{QxB} = \mathbf{0.0}$ kN
Wind horizontal load in x direction	$H_{WxA} = \mathbf{-4.5}$ kN	$H_{WxB} = \mathbf{4.5}$ kN
Total horizontal load in x direction	$H_{xA} = \mathbf{-4.5}$ kN	$H_{xB} = \mathbf{4.5}$ kN

Dead horizontal load in y direction H_{GyA} = **0.0** kN H_{GyB} = **0.0** kN

Imposed horizontal load in y direction H_{QyA} = **0.0** kN H_{QyB} = **0.0** kN

Wind horizontal load in y direction H_{WyA} = **2.5** kN H_{WyB} = **2.5** kN

Total horizontal load in y direction H_{yA} = **2.5** kN H_{yB} = **2.5** kN

Check stability against sliding

Resistance to sliding due to base friction

$H_{friction} = \max([P_{GA} + P_{GB} + (F_{Gsur} + F_{swt} + F_{soil}) \times A], 0\text{ kN}) \times \tan(\delta)$ = **59.7** kN

Passive pressure coefficient $K_p = (1 + \sin(\phi')) / (1 - \sin(\phi'))$ = **3.392**

Stability against sliding in y direction

Passive resistance of soil in y direction $H_{ypas} = 0.5 \times K_p \times (h^2 + 2 \times h \times h_{soil}) \times L \times \rho_{soil}$ = **20.9** kN

Total resistance to sliding in y direction $H_{yres} = H_{friction} + H_{ypas}$ = **80.6** kN

PASS - Resistance to sliding is greater than horizontal load in y direction

Check stability against overturning in y direction

Total overturning moment $M_{yOT} = M_{yA} + M_{yB} + (H_{yA} + H_{yB}) \times h$ = **2.500** kNm

Restoring moment in y direction

Foundation loading $M_{ysur} = A \times (F_{Gsur} + F_{swt} + F_{soil}) \times B / 2$ = **4.531** kNm

Axial loading on column $M_{yaxial} = (P_{GA}) \times (B / 2 - e_{PyA}) + (P_{GB}) \times (B / 2 - e_{PyB})$ = **30.250** kNm

Total restoring moment $M_{yres} = M_{ysur} + M_{yaxial}$ = **34.781** kNm

PASS - Overturning safety factor exceeds the minimum of 1.5 in the y direction

Calculate pad base reaction

Total base reaction $T = F + P_A + P_B$ = **128.1** kN

Eccentricity of base reaction in x $e_{Tx} = (P_A \times e_{PxA} + P_B \times e_{PxB} + M_{xA} + M_{xB} + (H_{xA} + H_{xB}) \times h) / T$ = **0** mm

Eccentricity of base reaction in y $e_{Ty} = (P_A \times e_{PyA} + P_B \times e_{PyB} + M_{yA} + M_{yB} + (H_{yA} + H_{yB}) \times h) / T$ = **-2** mm

Check pad base reaction eccentricity

$\text{abs}(e_{Tx}) / L + \text{abs}(e_{Ty}) / B$ = **0.004**

Base reaction acts within middle third of base

Calculate pad base pressures

$q_1 = T / A - 6 \times T \times e_{Tx} / (L \times A) - 6 \times T \times e_{Ty} / (B \times A)$ = **90.431** kN/m²

$q_2 = T / A - 6 \times T \times e_{Tx} / (L \times A) + 6 \times T \times e_{Ty} / (B \times A)$ = **86.293** kN/m²

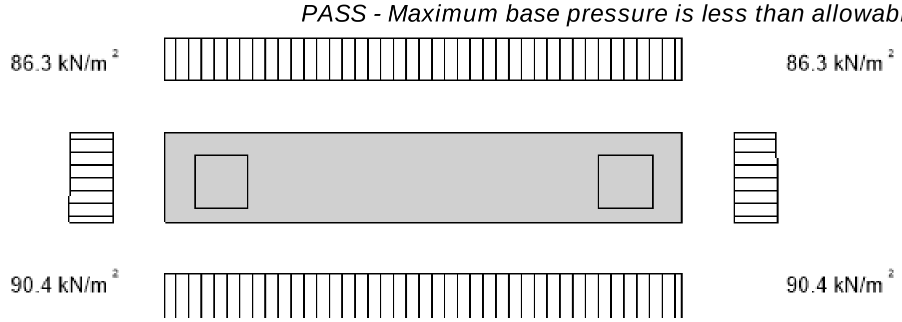
$q_3 = T / A + 6 \times T \times e_{Tx} / (L \times A) - 6 \times T \times e_{Ty} / (B \times A)$ = **90.431** kN/m²

$q_4 = T / A + 6 \times T \times e_{Tx} / (L \times A) + 6 \times T \times e_{Ty} / (B \times A)$ = **86.293** kN/m²

Minimum base pressure $q_{min} = \min(q_1, q_2, q_3, q_4)$ = **86.293** kN/m²

Maximum base pressure $q_{max} = \max(q_1, q_2, q_3, q_4)$ = **90.431** kN/m²

PASS - Maximum base pressure is less than allowable bearing pressure



Partial safety factors for loads

Partial safety factor for dead loads γ_{fG} = **1.40**

Partial safety factor for imposed loads γ_{fQ} = **1.60**

Partial safety factor for wind loads γ_{fW} = **0.00**

Ultimate axial loading on columns

Ultimate axial load on column A $P_{uA} = P_{GA} \times \gamma_{fG} + P_{QA} \times \gamma_{fQ} + P_{WA} \times \gamma_{fW}$ = **77.0** kN

Ultimate axial load on column B $P_{uB} = P_{GB} \times \gamma_{fG} + P_{QB} \times \gamma_{fQ} + P_{WB} \times \gamma_{fW}$ = **77.0** kN

Ultimate foundation loads

Ultimate foundation load $F_u = A \times [(F_{Gsur} + F_{swt} + F_{soil}) \times \gamma_{fG} + F_{Qsur} \times \gamma_{fQ}]$ = **25.4** kN

Ultimate horizontal loading on column A

Ultimate horizontal load in x direction $H_{xuA} = H_{GxA} \times \gamma_{fG} + H_{QxA} \times \gamma_{fQ} + H_{WxA} \times \gamma_{fW}$ = **0.0** kN

Ultimate horizontal load in y direction $H_{yuA} = H_{GyA} \times \gamma_{fG} + H_{QyA} \times \gamma_{fQ} + H_{WyA} \times \gamma_{fW}$ = **0.0** kN

Ultimate horizontal loading on column B

Ultimate horizontal load in x direction $H_{xuB} = H_{GxB} \times \gamma_{fG} + H_{QxB} \times \gamma_{fQ} + H_{WxB} \times \gamma_{fW}$ = **0.0** kN

Ultimate horizontal load in y direction $H_{yuB} = H_{GyB} \times \gamma_{fG} + H_{QyB} \times \gamma_{fQ} + H_{WyB} \times \gamma_{fW}$ = **0.0** kN

Ultimate moment on column A

Ultimate moment on column in x direction $M_{xuA} = M_{GxA} \times \gamma_{fG} + M_{QxA} \times \gamma_{fQ} + M_{WxA} \times \gamma_{fW}$ = **0.000** kNm

Ultimate moment on column in y direction $M_{yuA} = M_{GyA} \times \gamma_{fG} + M_{QyA} \times \gamma_{fQ} + M_{WyA} \times \gamma_{fW}$ = **0.000** kNm

Ultimate moment on column B

Ultimate moment on column in x direction $M_{xuB} = M_{GxB} \times \gamma_{fG} + M_{QxB} \times \gamma_{fQ} + M_{WxB} \times \gamma_{fW}$ = **0.000** kNm

Ultimate moment on column in y direction $M_{yuB} = M_{GyB} \times \gamma_{fG} + M_{QyB} \times \gamma_{fQ} + M_{WyB} \times \gamma_{fW}$ = **0.000** kNm

Calculate ultimate pad base reaction

Ultimate base reaction $T_u = F_u + P_{uA} + P_{uB}$ = **179.4** kN

Eccentricity of ultimate base reaction in x $e_{Txu} = (P_{uA} \times e_{PxA} + P_{uB} \times e_{PxB} + M_{xuA} + M_{xuB} + (H_{xuA} + H_{xuB}) \times h) / T_u$ = **0** mm

Eccentricity of ultimate base reaction in y $e_{Tyu} = (P_{uA} \times e_{PyA} + P_{uB} \times e_{PyB} + M_{yuA} + M_{yuB} + (H_{yuA} + H_{yuB}) \times h) / T_u$ = **-21** mm

Calculate ultimate pad base pressures

$q_{1u} = T_u/A - 6 \times T_u \times e_{Txu}/(L \times A) - 6 \times T_u \times e_{Tyu}/(B \times A)$ = **155.569** kN/m^2

$q_{2u} = T_u/A - 6 \times T_u \times e_{Txu}/(L \times A) + 6 \times T_u \times e_{Tyu}/(B \times A)$ = **91.845** kN/m^2

$q_{3u} = T_u/A + 6 \times T_u \times e_{Txu}/(L \times A) - 6 \times T_u \times e_{Tyu}/(B \times A)$ = **155.569** kN/m^2

$q_{4u} = T_u/A + 6 \times T_u \times e_{Txu}/(L \times A) + 6 \times T_u \times e_{Tyu}/(B \times A)$ = **91.845** kN/m^2

Minimum ultimate base pressure $q_{minu} = \min(q_{1u}, q_{2u}, q_{3u}, q_{4u})$ = **91.845** kN/m^2

Maximum ultimate base pressure $q_{maxu} = \max(q_{1u}, q_{2u}, q_{3u}, q_{4u})$ = **155.569** kN/m^2

Calculate rate of change of base pressure in x direction

Left hand base reaction $f_{uL} = (q_{1u} + q_{2u}) \times B / 2$ = **61.853** kN/m

Right hand base reaction $f_{uR} = (q_{3u} + q_{4u}) \times B / 2$ = **61.853** kN/m

Length of base reaction $L_x = L$ = **2900** mm

Rate of change of base pressure $C_x = (f_{uR} - f_{uL}) / L_x$ = **0.000** kN/m/m

Calculate pad lengths in x direction

Left hand length $L_L = L / 2 + \min(e_{PxA}, e_{PxB})$ = **317** mm

Middle length $L_M = \max(e_{PxA}, e_{PxB}) - \min(e_{PxA}, e_{PxB})$ = **2266** mm

Right hand length $L_R = L / 2 - \max(e_{PxA}, e_{PxB})$ = **317** mm

Calculate shear forces in x direction

Shear at left hand column $S_L = f_{uL} \times L_L + C_x \times L_L^2 / 2 - F_u \times L_L / L$ = **16.834** kN

Shear at right hand column $S_R = f_{uL} \times (L_L + L_M) + C_x \times (L_L + L_M)^2 / 2 - P_{uB} - F_u \times (L_L + L_M) / L$ = **60.166** kN

Calculate ultimate moments in x direction

Ultimate positive moment in x direction $M_x = f_{uL} \times L_L^2 / 2 + C_x \times L_L^3 / 6 - F_u \times L_L^2 / (2 \times L)$ = **2.668** kNm

Position of maximum negative moment L_z = **1450** mm

Ultimate negative moment in x direction $M_{xneg} = f_{uL} \times L_z^2 / 2 + C_x \times L_z^3 / 6 - P_{uB} \times (L_z - L_L) - F_u \times L_z^2 / (2 \times L) + H_{xuB} \times h + M_{xuB}$

M_{xneg} = **-31.416** kNm

Calculate rate of change of base pressure in y direction

Top edge base reaction $f_{uT} = (q_{2u} + q_{4u}) \times L / 2$ = **266.350** kN/m

Bottom edge base reaction $f_{uB} = (q_{1u} + q_{3u}) \times L / 2$ = **451.150** kN/m

Length of base reaction $L_y = B$ = **500** mm

Rate of change of base pressure $C_y = (f_{uB} - f_{uT}) / L_y$ = **369.600** kN/m/m

Calculate pad lengths in y direction

Top length $L_T = B / 2 - e_{PyA}$ = **275** mm

Bottom length $L_B = B / 2 + e_{PyA}$ = **225** mm

Calculate ultimate moments in y direction

Ultimate moment in y direction $M_y = f_{uT} \times L_T^2 / 2 + C_y \times L_T^3 / 6 - F_u \times L_T^2 / (2 \times B)$ = **9.433** kNm

Material details

Characteristic strength of concrete f_{cu} = **30** N/mm²

Characteristic strength of reinforcement f_y = **500** N/mm²

Characteristic strength of shear reinforcement f_{yv} = **500** N/mm²

Nominal cover to reinforcement c_{nom} = **30** mm

Moment design in x direction

Diameter of tension reinforcement ϕ_{xB} = **16** mm

Depth of tension reinforcement $d_x = h - c_{nom} - \phi_{xB} / 2$ = **462** mm

Design formula for rectangular beams (cl 3.4.4.4)

$K_x = M_x / (B \times d_x^2 \times f_{cu})$ = **0.001**

$K_x' = 0.156$

$K_x < K_x'$ compression reinforcement is not required

Lever arm $z_x = d_x \times \min([0.5 + \sqrt{(0.25 - K_x / 0.9)}], 0.95)$ = **439** mm

Area of tension reinforcement required $A_{s\_x\_req} = M_x / (0.87 \times f_y \times z_x)$ = **14** mm²

Minimum area of tension reinforcement $A_{s\_x\_min} = 0.0013 \times B \times h$ = **325** mm²

Tension reinforcement provided **5 No. 16 dia. bars bottom (100 centres)**

Area of tension reinforcement provided $A_{s\_xB\_prov} = N_{xB} \times \pi \times \phi_{xB}^2 / 4$ = **1005** mm²

PASS - Tension reinforcement provided exceeds tension reinforcement required

Negative moment design in x direction

Diameter of tension reinforcement ϕ_{xT} = **16** mm

Depth of tension reinforcement $d_x = h - c_{nom} - \phi_{xT} / 2 =$ **462** mm

Design formula for rectangular beams (cl 3.4.4.4)

$K_x = -M_{xneg} / (B \times d_x^2 \times f_{cu}) =$ **0.010**

$K_x' = 0.156$

$K_x < K_x'$ compression reinforcement is not required

Lever arm $z_x = d_x \times \min([0.5 + \sqrt{(0.25 - K_x / 0.9)}], 0.95) =$ **439** mm

Area of tension reinforcement required $A_{s\_x\_req} = -M_{xneg} / (0.87 \times f_y \times z_x) =$ **165** mm^2

Minimum area of tension reinforcement $A_{s\_x\_min} = 0.0013 \times B \times h =$ **325** mm^2

Tension reinforcement provided **5 No. 16 dia. bars top (100 centres)**

Area of tension reinforcement provided $A_{s\_xT\_prov} = N_{xT} \times \pi \times \phi_{xT}^2 / 4 =$ **1005** mm^2

PASS - Tension reinforcement provided exceeds tension reinforcement required

Moment design in y direction

Diameter of tension reinforcement $\phi_{yB} =$ **16** mm

Depth of tension reinforcement $d_y = h - c_{nom} - \phi_{xB} - \phi_{yB} / 2 =$ **446** mm

Design formula for rectangular beams (cl 3.4.4.4)

$K_y = M_y / (L \times d_y^2 \times f_{cu}) =$ **0.001**

$K_y' = 0.156$

$K_y < K_y'$ compression reinforcement is not required

Lever arm $z_y = d_y \times \min([0.5 + \sqrt{(0.25 - K_y / 0.9)}], 0.95) =$ **424** mm

Area of tension reinforcement required $A_{s\_y\_req} = M_y / (0.87 \times f_y \times z_y) =$ **51** mm^2

Minimum area of tension reinforcement $A_{s\_y\_min} = 0.0013 \times L \times h =$ **1885** mm^2

Tension reinforcement provided **23 No. 16 dia. bars bottom (125 centres)**

Area of tension reinforcement provided $A_{s\_yB\_prov} = N_{yB} \times \pi \times \phi_{yB}^2 / 4 =$ **4624** mm^2

PASS - Tension reinforcement provided exceeds tension reinforcement required

Calculate ultimate shear force at d from left face of column A

Ultimate pressure for shear $q_{su} = (q_{2u} + C_x \times (L / 2 + e_{PxA} - l_A / 2 - d_x) / B + q_{1u}) / 2$

$q_{su} =$ **123.707** kN/m^2

Area loaded for shear $A_s = B \times \min((L / 2 + e_{PxA} - l_A / 2 - d_x), 3 \times (L / 2 + e_{Tx})) =$ **0.986** m^2

Ultimate shear force $V_{su} = A_s \times (q_{su} - F_u / A) - P_{uB} =$ **27.667** kN

Shear stresses at d from left face of column A (cl 3.5.5.2)

Design shear stress $v_{su} = V_{su} / (B \times d_x) =$ **0.120** N/mm^2

From BS 8110:Part 1:1997 - Table 3.8

Design concrete shear stress $v_c = 0.79$ N/mm$^2 \times \min(3, [100 \times A_{s_xB_prov} / (B \times d_x)]^{1/3}) \times \max((400 \text{ mm} / d_x)^{1/4}, 0.67) \times (\min(f_{cu} / 1 \text{ N/mm}^2, 40) / 25)^{1/3} / 1.25 =$ **0.491** N/mm^2

Allowable design shear stress $v_{max} = \min(0.8 \text{ N/mm}^2 \times \sqrt{(f_{cu} / 1 \text{ N/mm}^2)}, 5 \text{ N/mm}^2) =$ **4.382** N/mm^2

PASS - $v_{su} < v_c$ - No shear reinforcement required

Calculate ultimate punching shear force at face of column A

Ultimate pressure for punching shear $q_{puA} = q_{1u}+[(L/2+e_{PxA}-l_A/2)+(l_A)/2]\times C_x/B-[(B/2+e_{PyA}-b_A/2)+(b_A)/2]\times C_y/L =$ **126.893** kN/m^2

Average effective depth of reinforcement $d = (d_x + d_y) / 2 =$ **454** mm

Area loaded for punching shear at column $A_{pA} = (l_A)\times(b_A) =$ **0.090** m^2

Length of punching shear perimeter $u_{pA} = 2\times(l_A)+2\times(b_A) =$ **1200** mm

Ultimate shear force at shear perimeter $V_{puA} = P_{uA} + (F_u / A - q_{puA}) \times A_{pA}$ = **67.155** kN

Effective shear force at shear perimeter $V_{puAeff} = V_{puA}$ = **67.155** kN

Punching shear stresses at face of column A (cl 3.7.7.2)

Design shear stress $v_{puA} = V_{puAeff} / (u_{pA} \times d)$ = **0.123** N/mm²

Allowable design shear stress $v_{max} = \min(0.8\text{N/mm}^2 \times \sqrt{(f_{cu} / 1\text{ N/mm}^2)}, 5\text{ N/mm}^2)$ = **4.382** N/mm²

PASS - Design shear stress is less than allowable design shear stress

Calculate ultimate punching shear force at face of column B

Ultimate pressure for punching shear $q_{puB} = q_{1u}+[(L/2+e_{PxB}-l_B/2)+(l_B)/2]\times C_x/B-[(B/2+e_{PyB}-b_B/2)+(b_B)/2]\times C_y/L$ = **126.893** kN/m²

Average effective depth of reinforcement $d = (d_x + d_y) / 2$ = **454** mm

Area loaded for punching shear at column $A_{pB} = (l_B)\times(b_B)$ = **0.090** m²

Length of punching shear perimeter $u_{pB} = 2\times(l_B)+2\times(b_B)$ = **1200** mm

Ultimate shear force at shear perimeter $V_{puB} = P_{uB} + (F_u / A - q_{puB}) \times A_{pB}$ = **67.155** kN

Effective shear force at shear perimeter $V_{puBeff} = V_{puB}$ = **67.155** kN

Punching shear stresses at face of column B (cl 3.7.7.2)

Design shear stress $v_{puB} = V_{puBeff} / (u_{pB} \times d)$ = **0.123** N/mm²

Allowable design shear stress $v_{max} = \min(0.8\text{N/mm}^2 \times \sqrt{(f_{cu} / 1\text{ N/mm}^2)}, 5\text{ N/mm}^2)$ = **4.382** N/mm²

PASS - Design shear stress is less than allowable design shear stress