Planner

Calculation Report

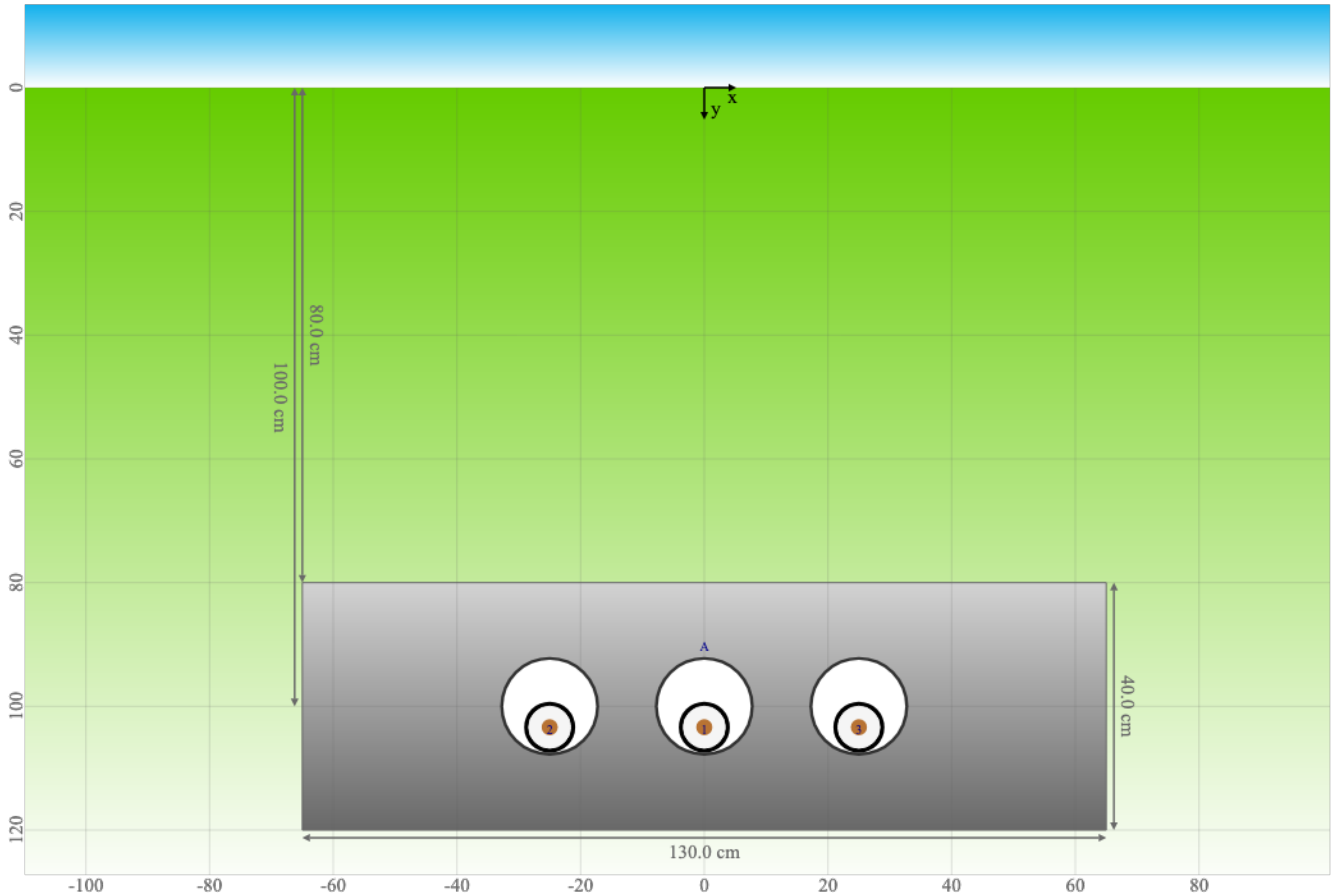
Title	Verification Phase 2 case 01
Project	Verification
Description	
Created	2020-05-17 11:56
Solver	2020-03-31 (bc60f)

Arrangement

Arrangement type	**buried**
Activated options	None
Active systems	A

Statistics

Number of iterations of the solver	N_{calc}	5
Sum of currents from all systems	I_{sum}	766.5 A
Sum of average conductor temperatures from all systems	θ_{sum}	87.9 °C
Number of overheated electrical systems		0
Sum of losses from all systems	W_{sum}	86.0 W/m



Systems

Following systems are active in the arrangement:

System	Object	Current I_c [A]	max Temp. θ_c | θ_e [°C]	Losses W_{sys} [W/m]
System A	Verification Phase 2 case 01	766.5	90.0 | 72.2	86.0

Objects

Following objects are used:

Verification Phase 2 case 01

Ambient

Ambient temperature	θ_a	20.0 °C
Thermal resistivity of soil	ρ_4	1.5 K.m/W
Ratio thermal resistivity dry/moist soil	υ_4	1.000

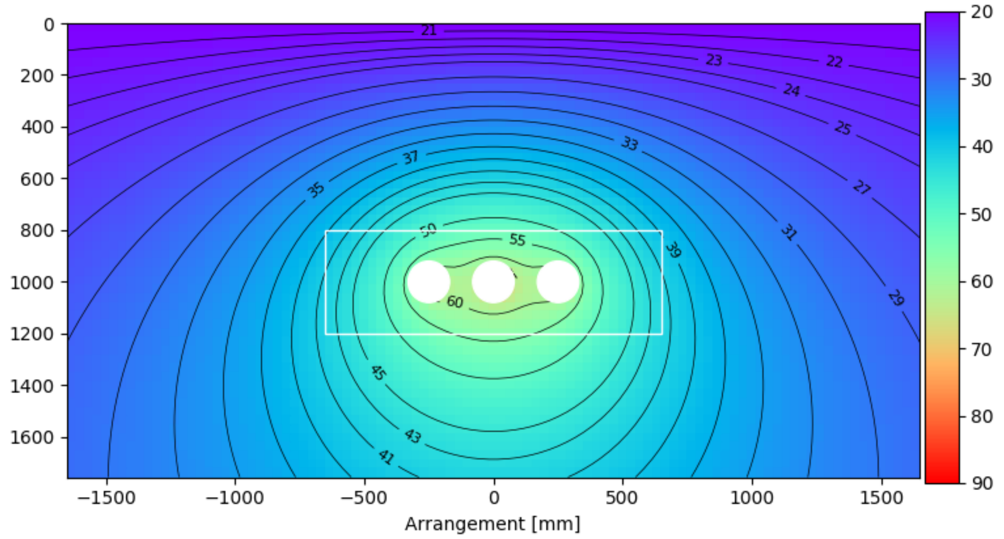
Backfill

Calculation method	acc. El-Kady et al (1985)

Backfill Area 1

Thermal resistivity backfill	ρ_b	0.8 K.m/W
Horizontal center of backfill	x_b	0.0 mm
Vertical center of backfill	L_b	1000.0 mm
Height of the backfill	h_b	400.0 mm
Width of the backfill	w_b	1300.0 mm
Geometric factor for backfill	G_b	1.4835

Approximate steady-state temperature field [°C] with 1.267 K.m/W



System A (High voltage cable)

Ampacity

Name of cable		Verification Phase 2 case 01
Conductor current	I_c	766.5 A

$$\sqrt{\frac{-\Delta\theta_d - \Delta\theta_p v_4 + \Delta\theta_x (v_4 - 1) - \theta_a + \theta_c}{R_c \left(T_1 + T_2 n_c (\lambda_1 + 1) + \lambda_3 n_{cc} \left(\frac{T_{4ii}}{2} + T_{4\mu} v_4\right) + \left(T_3 n_c + n_{cc} (T_{4i} + T_{4ii} + T_{4\mu} v_4)\right)(\lambda_1 + \lambda_2 + 1)\right)}}$$

Operating voltage	U_o	110.0 kV
System frequency	f	50.0 Hz
Number of sources in system	N_c	3
Number of conductors combined	n_{cc}	1

Load

Continuous load	LF	1.0 p.u.

Temperatures

Temperature of conductor θ_c 1: 90.0 | 2: 86.8 | 3: 86.9 °C

$$\Delta\theta_c + \Delta\theta_p v_4 - \Delta\theta_x (v_4 - 1) + \theta_a$$

Temperature of screen/sheath θ_s 1: 74.2 | 2: 71.2 | 3: 71.2 °C

$$-T_1 \left(W_c + \frac{W_d}{2}\right) + \theta_c$$

External temperature of the object θ_e 1: 72.2 | 2: 69.3 | 3: 69.3 °C

$$-T_1 \left(W_c + \frac{W_d}{2}\right) - n_c \left(T_2 (W_c (\lambda_1 + 1) + W_d) + T_3 (W_I + W_d)\right) + \theta_c$$

Duct

Mean temperature of the medium in the duct θ_{dm} 1: 67.4 | 2: 64.4 | 3: 64.4 °C

$$\frac{\theta_{di}}{2} + \frac{\theta_e}{2}$$

Temperature of duct inner wall θ_{di} 1: 62.6 | 2: 59.6 | 3: 59.6 °C

$$-T_{4i} n_{cc} (W_I + W_d) + \theta_e$$

Temperature of duct outer wall θ_{de} 1: 61.5 | 2: 58.6 | 3: 58.6 °C

$$\frac{T_{4ii} W_p n_{cc}}{2} - T_{4ii} W_t n_{cc} + \theta_{di}$$

Temperature rises

Temperature rise of conductor $\Delta\theta_c$ 1: 70.0 | 2: 66.8 | 3: 66.9 K

$$W_I n_{cc} (T_{4i} + T_{4ii} + T_{4\mu} v_4) + W_d n_{cc} (T_{4i} + T_{4ii} + T_{4ss} v_4) + W_p n_{cc} \left(\frac{T_{4ii}}{2} + T_{4\mu} v_4\right) + n_c (T_d W_d + T_i W_c)$$

Temperature rise by dielectric losses $\Delta\theta_d$ 1: 0.4 | 2: 0.4 | 3: 0.4 K

$$W_d \left(T_d n_c + n_{cc} (T_{4i} + T_{4ii} + T_{4ss} v_4)\right)$$

Temperature rise by other buried objects $\Delta\theta_p$ 0.0 K

$$\sum_{k=1}^{q} \Delta\theta_{\mathrm{kp}}$$

Critical soil temperature rise $\Delta\theta_x$ 0.0 K

Losses

Ohmic

Conductor losses W_c 1: 28.463 | 2: 28.206 | 3: 28.207 W/m

$$I_c^2 R_c$$

Screen and sheath losses $W_c\lambda_1$	W_s	1: 0.364 | 2: 0.089 | 3: 0.094 W/m
Losses in pipe $W_c\lambda_3$	W_p	0.000 W/m
Ohmic losses per phase $W_c(\lambda_1+\lambda_2+1)$	W_I	1: 28.827 | 2: 28.295 | 3: 28.301 W/m

Dielectric

Dielectric losses $\frac{1000000 C_b U_o^2 \omega \tan\delta_i}{3}$	W_d	1: 0.207 | 2: 0.207 | 3: 0.207 W/m

Total

Total losses per phase $W_I+W_d+W_p$	W_t	1: 29.034 | 2: 28.502 | 3: 28.508 W/m
Total losses per object $W_t n_c$	W_{tot}	1: 29.034 | 2: 28.502 | 3: 28.508 W/m
Total losses of the system	W_{sys}	86.043 W/m

Arrangement

Material of duct pipe	M_d	Plastic duct made of PE (Polyethylene)
Inside / outside diameter of duct	Di_d/Do_d	150.0 | 160.0 mm
Thermal resistivity of duct material	ρ_d	3.500 K.m/W
Specific heat capacity of duct material	σ_d	2400000.0 J/K.m^3
Absorption coefficient of solar radiation	σ_{sun}	0.4
Center position of duct 1	x_1 / y_1	0.0 / 1000.0 mm
Center position of duct 2	x_2 / y_2	-250.0 / 1000.0 mm
Center position of duct 3	x_3 / y_3	250.0 / 1000.0 mm
Separation of conductors in a system	s_c	250.00 mm
Depth of laying of sources	L_c	1000.0 mm
Substitution coefficient u $\frac{2L_c}{Do_d}$	u	12.500

Thermal Resistances

Internal thermal resistance for current losses $\frac{T_1}{n_c}+T_2(\lambda_1+1)+T_3(\lambda_1+\lambda_2+1)$	T_i	1: 0.622 | 2: 0.621 | 3: 0.621 K.m/W
Internal thermal resistance for dielectric losses $\frac{T_1}{2n_c}+T_2+T_3$	T_d	0.344 K.m/W
Thermal resistance to ambient $\frac{\rho_4 \, ln\left(F_{eq}\left(u+\sqrt{u^2-1}\right)\right)}{2\pi}$	$T_{4\mu}$	1: 1.431 | 2: 1.355 | 3: 1.355 K.m/W
Thermal resistance of medium in the duct $\frac{U_d}{D_{eq}(0.1V_d+0.1Y_d\theta_{dm})+1}$	T_{4i}	1: 0.332 | 2: 0.337 | 3: 0.337 K.m/W
Thermal resistance of the duct wall $\frac{\rho_d \, ln\left(\frac{Do_d}{Di_d}\right)}{2\pi}$	T_{4ii}	0.036 K.m/W

Correction of thermal resistance for backfill T_{4db} 1: 0.490 | 2: 0.499 | 3: 0.499 K.m/W

$$\frac{G_b N_b (\rho_4 - \rho_b)}{2\pi}$$

Number of loaded objects in backfill N_b 1: 2.96 | 2: 3.02 | 3: 3.02

Mutual heating coefficient F_{eq} 1: 65.000 | 2: 33.242 | 3: 33.242

$$\prod_{k=1}^{q} \frac{d_{\mathrm{pk1}}}{d_{\mathrm{pk2}}}$$

Other characteristics

Earthing

Earthing of cable screen/sheath Single side

Substitution coefficient λ_0 for eddy-currents λ_0 1: 0.00313 | 2: 0.000797 | 3: 0.000797

$$\frac{3d_e^2 m_0^2}{2s_c^2 (m_0^2 + 1)}$$

$$\frac{0.375 d_e^2 m_0^2}{s_c^2 (m_0^2 + 1)}$$

$$\frac{0.375 d_e^2 m_0^2}{s_c^2 (m_0^2 + 1)}$$

Substitution coefficient Δ_1 for eddy-currents Δ_1 1: 0.000509 | 2: -0.0337 | 3: 0.0261

$$0.86 m_0^{3.08} \left(\frac{d_e}{2s_c}\right)^{1.4m_0+0.7}$$

$$-\frac{\sqrt{m_0}\left(\frac{d_e}{2s_c}\right)^{m_0+1}(0.74m_0 + 1.48)}{(m_0 - 0.3)^2 + 2}$$

$$4.7 m_0^{0.7} \left(\frac{d_e}{2s_c}\right)^{0.16m_0+2}$$

Substitution coefficient Δ_2 for eddy-currents Δ_2 1: 0 | 2: 1.6e-05 | 3: 1.77e-06

$$0$$

$$0.92 m_0^{3.7} \left(\frac{d_e}{2s_c}\right)^{m_0+2}$$

$$21 m_0^{3.3} \left(\frac{d_e}{2s_c}\right)^{1.47m_0+5.06}$$

Substitution coefficient m_0 for eddy-currents m_0 1: 0.1599 | 2: 0.1615 | 3: 0.1615 Hz.m/Ω

$$\frac{1.0 \cdot 10^{-7} \omega}{R_e}$$

Substitution coefficient β_1 for eddy-currents β_1 151.3208

$$0.000632455532033676 \sqrt{\frac{\omega \pi}{\rho_{sh}}}$$

Substitution coefficient g_s for eddy-currents g_s 1.0071

$$\left(\frac{t_{sc} + t_{scs} + t_{sh}}{D_s}\right)^{1.74} (0.001 D_s \beta_1 - 1.6) + 1$$

Loss Factors

Loss factor of screen and sheath λ_1 1: 0.013 | 2: 0.003 | 3: 0.003

$$\lambda_{1c} + \lambda_{1e}$$

Loss factor by circulating currents λ_{1c} 0.000

Loss factor by eddy currents λ_{1e} 1: 0.013 | 2: 0.003 | 3: 0.003

$$\lambda_{1es}$$

Loss factor for single point bonding | λ_{1es} | 1: 0.013 | 2: 0.003 | 3: 0.003

$$\frac{R_e\left(8.33333333333333 \cdot 10^{-14} \beta_1^4 t_{sh}^4 + g_s \lambda_0 \left(\Delta_1 + \Delta_2 + 1\right)\right)}{R_c}$$

Loss factor of armour | λ_2 | 0.000

Conductor resistance

AC resistance of conductor at operating temperature | R_c | 1: 4.845e-02 | 2: 4.801e-02 | 3: 4.802e-02 Ω/km

$$R_{cDC}\left(y_p + y_s + 1\right)$$

DC resistance of conductor at operating temperature | R_{cDC} | 1: 4.667e-02 | 2: 4.622e-02 | 3: 4.622e-02 Ω/km

$$R_{co}\left(\alpha_c\left(\theta_c - 20\right) + 1\right)$$

Skin effect factor of conductor | y_s | 1: 0.0367 | 2: 0.0374 | 3: 0.0374

$$\frac{x_s^4}{0.8 x_s^4 + 192}$$

Factor for skin effect on conductor | x_s | 1: 1.6409 | 2: 1.6490 | 3: 1.6490

$$0.000894427190999916 \sqrt{\frac{f k_s \pi}{R_c}}$$

Proximity effect factor of conductors | y_p | 1: 0.0016 | 2: 0.0016 | 3: 0.0016

$$\frac{d_c^2 x_p^4 \left(\frac{0.312 d_c^2}{s_c^2} + \frac{1.18}{\frac{x_p^4}{0.8 x_p^4 + 192} + 0.27}\right)}{s_c^2\left(0.8 x_p^4 + 192\right)}$$

Factor for proximity effect of conductors | x_p | 1: 1.6409 | 2: 1.6490 | 3: 1.6490

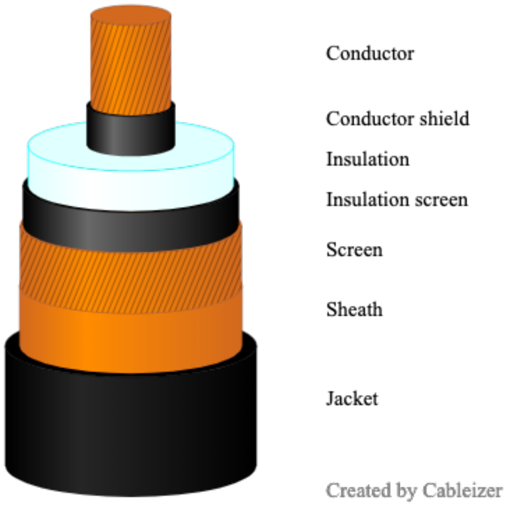
$$0.000894427190999916 \sqrt{\frac{f k_p \pi}{R_c}}$$

Cable: Verification Phase 2 case 01

Cable is used in following systems: A

General Data

Manufacturer		none
Description		Cableizer Testkabel
Rated line-to-line voltage	U_n	110.0 kV
Base voltage for tests	U_0	64.0 kV
Highest voltage for equipment	U_m	123.0 kV
System frequency	f	50.0 Hz



Conductor

Number of conductors in object	n_c	1
Cross-sectional area of conductor	A_c	500.0 mm^2
Material of conductor	M_c	Copper
Construction of conductor	c_{constr}	Round, stranded
Coating of wires	R_{co}	plain
Skin effect coefficient	k_s	1.0
Proximity effect coefficient	k_p	1.0
DC resistance of conductor at 20°C	R_{co}	3.66e-05 Ω/m
Electrical resistivity of conductor material	ρ_c	1.7241e-08 Ω.m
Temperature coefficient of conductor material	α_c	0.00393 1/K
Specific heat capacity of conductor material	σ_c	3450000.0 J/K.m^3
External diameter of conductor	d_c	26.2 mm
Thickness of s.c. tape wrapped around conductor	t_{ct}	0 mm

Insulation

Material of insulation	M_i	Crosslinked polyethylene (XLPE)
Thickness of conductor shield	t_{cs}	1.3 mm
Thickness of insulation	t_{ins}	19.4 mm
Thickness of insulation screen	t_{is}	1.6 mm
Thickness of insulation between conductors	t	44.6000 mm
$2t_{cs} + 2t_{ct} + 2t_{ins} + 2t_{is}$		
Max. conductor temperature	θ_{cmax}	90.0 °C
Max. emergency overload conductor temperature	θ_{cmaxeo}	130.0 °C
Max. short-circuit conductor temperature	θ_{cmaxsc}	250.0 °C
Relative permittivity of insulation	ϵ_i	2.5000
Loss factor of insulation	$\tan\delta_i$	0.0010
Thermal resistivity of insulation	ρ_i	3.5 K.m/W
Specific heat capacity of insulation material	σ_i	2400000.0 J/K.m^3
Capacitance of insulation	C_b	0.1630 μF/km
$\frac{2\epsilon_0\epsilon_i\pi}{ln\left(\frac{r_I}{r_F}\right)}$		
Vacuum permittivity	ϵ_0	8.85419e-12 F/m
Radius below the insulation	r_F	14.40 mm
$r_c + t_{cs} + t_{ct}$		
Radius of the insulation	r_I	33.80 mm
$r_F + t_{ins}$		

Screen

Type of screen		Round wires
Material of screen	M_{sc}	Copper
Diameter of screen wires	t_{sc}	0.92 mm
Number of screen wires	n_{sw}	74
Cross-sectional area of screen	A_{sc}	49.2 mm^2
$\frac{n_{sw}\pi t_{sc}^2}{4}$		
Electrical resistance of screen	R_{sc}	0.3505 Ω/km
$\frac{1000000\rho_{sc}}{A_{sc}}$		
Specific electrical resistivity of screen material	ρ_{sc}	1.7241e-08 Ω.m
Temperature coefficient of screen material	α_{sc}	0.00393 1/K
Specific heat capacity of screen material	σ_{sc}	3450000.0 J/K.m^3

Sheath

Material of sheath	M_{sh}	Copper
Thickness of the sheath	t_{sh}	0.25 mm
Corrugated sheath		No
Mean diameter of sheath	d_{sh}	72.89 mm
$D_{it} + \Delta d_{sh} + t_{sh}$		
Mean external diameter of the sheath	D_s	73.14 mm
$D_{oc} - \Delta d_{sh}$		
Cross-sectional area of sheath	A_{sh}	57.2 mm^2
$d_{sh}\pi t_{sh}$		
Electrical resistance of sheath	R_{sh}	0.3012 Ω/km
$\frac{1000000\rho_{sh}}{A_{sh}}$		

Specific electrical resistivity of sheath material	ρ_{sh}	1.7241e-08 Ω.m
Temperature coefficient of sheath material	α_{sh}	0.00393 1/K
Specific heat capacity of sheath material	σ_{sh}	3450000.0 J/K.m^3

Jacket

Material of jacket	M_j	Polyethylene (LD/MDPE, ST3)
Thickness of jacket	t_j	4.70 mm
External diameter of object	D_e	82.54 mm

$$D_{a_2} + 2t_j + 2t_{jj}$$

Thermal resistivity of jacket material	ρ_j	3.5 K.m/W
Specific heat capacity of jacket material	σ_j	2400000.0 J/K.m^3

Internal thermal resistances

Thermal resistance between one conductor and sheath | T_1 | 0.554 K.m/W

$$\frac{\rho_i ln\left(1 + \frac{2t_1}{d_c}\right)}{2\pi}$$

Thermal resistance between sheath and armour | T_2 | 0.000 K.m/W

$$T_{2_1} + T_{2_2}$$

Thermal resistance between sheath and 1st armour layer	T_{2_1}	0.000 K.m/W
Thermal resistance of material between armour layers	T_{2_2}	0.000 K.m/W
Thermal resistance of jacket	T_3	0.067 K.m/W

$$\frac{\rho_j ln\left(\frac{D_e}{D_e - 2t_3}\right)}{2\pi}$$

Thickness of insulation to sheath | t_1 | 22.300 mm

$$\frac{\Delta d_{sh}}{2} + \frac{t}{2} + t_{scb} + t_{scs}$$

Thickness of bedding under armour | t_2 | 0.000 mm

$$\frac{\Delta d_{sh}}{2} + t_{ab_1}$$

Thickness of serving over armour | t_3 | 4.700 mm

$$t_j + t_{jj}$$

Mechanical

Mass of object	m	9.93 kg/m
Heat energy content	H_c	187.54 MJ/m
Heat energy content	H_c	52.10 kWh/m
Embodied energy		745.43 MJ/kg
Embodied carbon		17.09 kgCO2/kg
Factor of permissible pull	f_{ppc}	60.0 N/mm^2
Permissible pull force on cable	F_{ppc}	3000.0 daN

$$\frac{A_c f_{ppc} n_c}{10}$$