ANTAI TECHNOLOGY CO., LTD

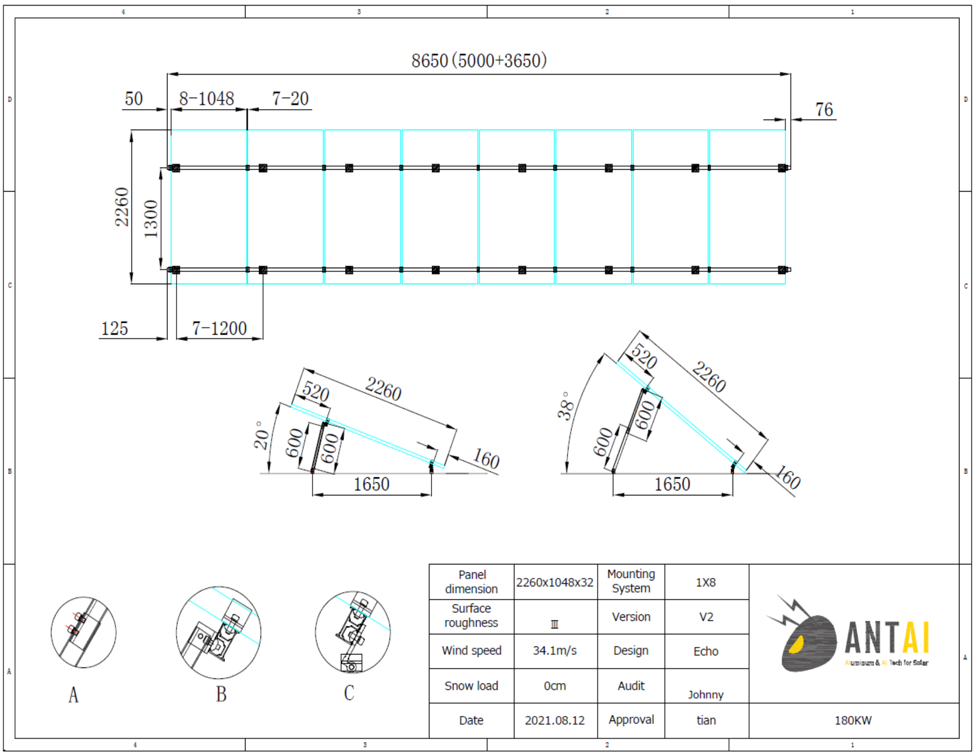
Load Calculation

Contents

1 Design Conditions

a) Panel specification 2260 x 1048 x 32 mm
b) Panel weight 30 kg
c) Orientation Portrait
d) Panel quantity 1 x 8 = 8
e) Tilt angleθ 38 °
f) Wind speed 34.1 m/s
g) Ground vertical snowfall 0 cm
h) Ground surface roughness Ⅲ
i) Maximum height 12 m
j) Installation site Roof
k) Calculation Standard Japan JIS C 8955:2011

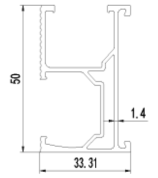
2 Drawing of Mounting System



3 Structure Material

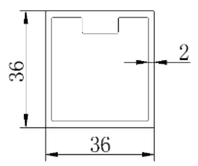
a) Rail CG-019

Material : AL6005-T6 ; σs= 215 N/mm^2; E= 69000 N/mm2;
L= 8650 mm;

<table>
<tr><td rowspan="7">
</td><td colspan="4">Sectional geometry paramater(mm)</td></tr>
<tr><td>A</td><td>281.197</td><td>IP</td><td>114044.6002</td></tr>
<tr><td>Ix</td><td>79249.6739</td><td>Iy</td><td>34794.9263</td></tr>
<tr><td>Wx（上）</td><td>2887.1075</td><td>Wy（左）</td><td>1988.4606</td></tr>
<tr><td>Wx（下）</td><td>3514.3209</td><td>Wy（右）</td><td>2194.6446</td></tr>
<tr><td>ix</td><td>16.7878</td><td>iy</td><td>11.1238</td></tr>
</table>

b) Rear Leg1 TYN-57

Material : AL6005-T6 ; σs= 215 N/mm^2; E= 69000 N/mm2;
L= 600 mm;

<table>
<tr><td rowspan="7">
</td><td colspan="4">Sectional geometry paramater(mm)</td></tr>
<tr><td>A</td><td>332</td><td>IP</td><td>114959.7588</td></tr>
<tr><td>Ix</td><td>61667.3018</td><td>Iy</td><td>53292.457</td></tr>
<tr><td>Wx（上）</td><td>3963.5261</td><td>Wy（左）</td><td>2960.6921</td></tr>
<tr><td>Wx（下）</td><td>3016.799</td><td>Wy（右）</td><td>2960.6921</td></tr>
<tr><td>ix</td><td>13.6288</td><td>iy</td><td>12.6696</td></tr>
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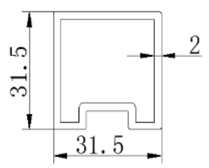
c) Rear Leg2 TYN-58

Material : AL6005-T6 ; σs= 215 N/mm^2; E= 69000 N/mm2;
L= 600 mm;

<table>
<tr><td rowspan="7">
</td><td colspan="4">Sectional geometry paramater(mm)</td></tr>
<tr><td>A</td><td>255.3562</td><td>IP</td><td>69135.3994</td></tr>
<tr><td>Ix</td><td>33784.8711</td><td>Iy</td><td>35350.5283</td></tr>
<tr><td>Wx（上）</td><td>2094.7394</td><td>Wy（左）</td><td>2244.478</td></tr>
<tr><td>Wx（下）</td><td>2197.8812</td><td>Wy（右）</td><td>2244.478</td></tr>
<tr><td>ix</td><td>11.5024</td><td>iy</td><td>11.7659</td></tr>
</table>

4 Assumed Load

Load conditions and load combinations, see Table 1.

Table 1 − Load conditions & load combinations

Load Conditions		Classification	
		General region	Snowy region
Long term	Usual	G	*G*
	During snow		G+0.7S
Short term	During snow	G+S	G+S
	During storm	G+W	G+W
			G+0.35S+W
	During earthquak	G+K	G+0.35S+K

In addition, any of following conditions is also defined as Snowy Region.

− The area that vertical snow amount is more than 1 meter

− The area that the average snowy day of one year is more than 30 days (Count the days that the percentage of snow cover in the area is continuously more than half)

5 Fixed Load

Module weight	G1=	30	x	8	x 9.8	=	2352	N
Rail weight	G2=	2	x	0.762	x	8.65	x 9.8	
	=	129		N				
Rear Leg1 weight	G3=	8	x	0.900	x	0.6	x9.8	
	=	42		N				
Rear Leg2 weight	G4=	8	x	0.692	x	0.6	x9.8	
	=	33		N				
Fix load on Rail	G5=G1+G2=			2352	+	129		
	=	2481		N				
Fix load on Beam	G6=G3+G4+G5			2481	+	42	+	33
	=	2556		N				

6 Wind Load

6.1 Wind load for design

The wind load actting on the array could be calculated by equation (1).

$$Wp = Cw \times qp \times Aw \quad \cdots\cdots\cdots \quad (1)$$

Here, Wp : Wind load for design（N）
Cw : Wind power coefficient
qp : Velocity pressure for design（$N \bullet m^{-2}$）
Aw : Wind swept area（m^2）
(The total area of all the modules that make up the array）

6.2 Velocity pressure for design

$$q_p = 0.6 \times V_0^2 \times E \times I \quad \cdots\cdots\cdots \quad (2)$$

Here, q_p : Velocity pressure for design（$N \cdot m^{-2}$）
V_0 : Wind speed for design（$m \bullet s^{-1}$）
E : Environmental coefficient
I : Applications coefficient

a) Wind speed for design Wind speed for design is determined in the range of 30 $m \cdot s^{-1}$～46 $m \cdot s^{-1}$ based on damage situation of the past typhoon record and consideration of other wind in the local construction site.

b) Environmental coefficient It is calculated by equation (3).

$$E = E_r^2 \times G_f \quad \cdots\cdots\cdots \quad (3)$$

Here, E : Environmental coefficient
E_r : Coefficient representing the distribution of the height direction of the average wind speed calculated by Formula (4) or (5)
G_f : Gust influence coefficient

(Ground surface roughness classification coefficient Ⅲ → 2.47)

Table 2 − Gust influence coefficient

Ground surface roughness classification	The average height above ground of the array H（m）		
	10 or less	More than 10 but less than 40	More than 40
	(1)	(2)	(3)
Ⅰ	2.0	Numerical value between (1) and (3)	1.8
Ⅱ	2.2		2.0
Ⅲ	2.5		2.1
Ⅳ	3.1		2.3

If H is less than or equal to Z_b, E_r is calculated by Equation (4) ;
if H is more than Z_b, it is calculated by Equation (5).

$$E_r = 1.7\left[\frac{Z_b}{Z_G}\right]^{\alpha} \quad \text{..} \quad (4)$$

$$E_r = 1.7\left[\frac{H}{Z_G}\right]^{\alpha} \quad \text{..} \quad (5)$$

Here, Z_b, Z_G and α : numerical value listed in Table 3 is in accordance with the ground surface roughness classification

H : The average height above ground of the array (m)

Table 3 – Z_b, Z_G and α				
Ground surface roughness classification		Z_b (m)	Z_G (m)	α
I	Areas outside city planning but prescribed in the Regulations by specific administrative agency where are very flat and there is no obstacle	5	250	0.10
II	Areas outside city palnning and whose ground surface roughness classification above I (Except the case that ground clearance of the array is less than 13m). Or areas in city planning zone and whose ground surface roughness classification below IV, and coastline or shoreline(Limited to those of distance to the opposite shore is more than 1500m. Following the same.) distance is under 500m(However, the occasions when ground clearance of array is under 13m or coastline/shoreline distance is more than 200m and ground clearance of array is under 31m are in exception.)	5	350	0.15
III	Areas that the ground surface roughness category is I, II or other than IV	5	450	0.20
IV	Areas in city planning zone and prescribed in the Regulations by specific administrative agency as an extremely significant urbanization area.	10	550	0.27
NOTE Source : Ministry of Construction Notification No. 1454 (May 31, 2000)				

Here, ground surface roughness coefficient depending (III :

Z_b= 5 , Z_G= 450 , α= 0.2

Therefore H= 12 > Z_b= 5 ;

$$Er = 1.7\left[\frac{H}{Z_G}\right]^{\alpha} = 0.823$$

$$E = E_r^2 \times G_f = 1.677$$

c) Applications coefficient I see Table 4.

Table 4 - Applications coefficient

Use of solar power generation system	Applications coefficient
Extremely important solar power system	1.32
Normal solar power system	1.0
NOTE The design wind speed for normal solar power system need to be reset every 50 years, which is equivalent to 1.0 of the application coefficient	

Here applications coefficient of normal solar power system is 1.0

6.3 Wind power coefficient Cw

6.3.1 Wind power coefficient of the module surface

Wind power coefficient of the module surface is determined by wind tunnel experiment. However, in the case of installation form shown in Table 5, numerical values shown in note or the table that calculated by approximate expression (6) to (13) may be used.

For ground installation(single-handed) of downwind(positive pressure), according to equation (6)

$$Cw=0.65+0.009\theta \quad \text{..........} \quad (6)$$

But, $15° \leqq \theta \leqq 45°$

For ground installation(single-handed) of headwind(negative pressure), according to equation (7)

$$Cw=0.71+0.016\theta \quad \text{..........} \quad (7)$$

But, $15° \leqq \theta \leqq 45°$

For roof installation of downwind(positive pressure), according to equation (8)

$$Cw=0.95-0.017\theta \quad \text{..........} \quad (8)$$

But, $12° \leqq \theta \leqq 27°$

For roof installation of headwind(negative pressure), according to equation (9)

$$Cw=-0.1+0.077\theta-0.0026\theta^2 \quad \text{..........} \quad (9)$$

But, $12° \leqq \theta \leqq 27°$

For concrete flat roof installation of downwind(positive pressure), according to equation (10) or (11)

$$Cw=0.785 \quad \text{..........} \quad (10)$$

But, $0° \leqq \theta < 15°$

$$Cw=0.65+0.009\theta \quad \text{..........} \quad (11)$$

But, $15° \leqq \theta \leqq 45°$

For concrete flat roof installation of headwind(gegative pressure), according to equation (12) or (13)

$$Cw=0.95 \quad \text{..........} \quad (12)$$

But, $0° \leqq \theta < 15°$

$$Cw=0.71+0.016\theta \quad \text{..........} \quad (13)$$

But, $15° \leqq \theta \leqq 45°$

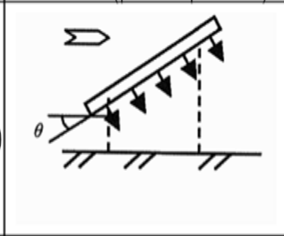
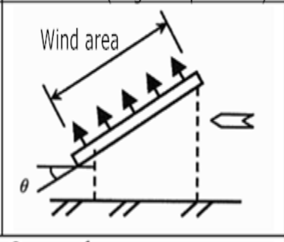
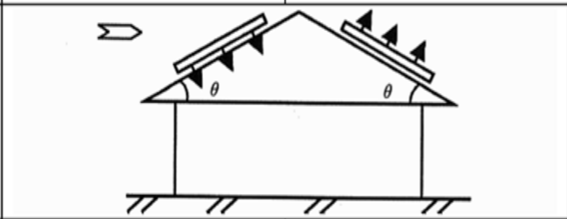
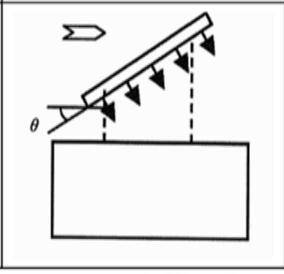
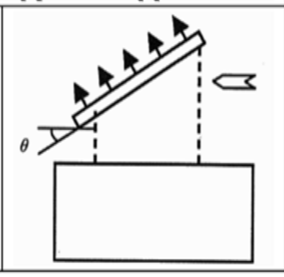
Here, θ : tilt angle of array surface (°)

$\theta = 38 > 15$

Downwind situation $Cw=0.65+0.009 \times 38 = 0.992$

Headwind situation $Cw=0.71+0.016 \times 38 = 1.318$

Table 5 – Wind power coefficient of solar module surface

Setting Form	Wind power coefficient(C_W)		Diagram
	Downwind(positive pressure)	Headwind(negative pressure)	
Ground mount (single-handed)			For duplex installation, peripheral edge part takes a value of approximate formula and 1/2 of approximate formula value for central part.
Pitch roof			When roof tiles etc. raised more than 10cm, it takes 1/2 load value of approximate formula. Besides, scope should begin from the inside edge of the wall, excluding the eaves and gables.
Flat roof			When installed at the edge of roof, it is outside of application scope. The roof edge refers to the edge length of 10% of the area. But if the side length of 10% is over 3m, then takes 3m.
Note wind direction → direction of the wind pressure			

6.4 Wind swept area Aw（m^2）

Aw= 2.26 x 1.048 x 1 x 8 = 18.95

Assumed wind load on modules(downwind)

$$W_P = C_W \times 0.6 \times V_0^2 \times E \times I \times A_W$$

= 0.99 x0.6 x 34 ^2 x 1.677 x 1.0 x 18.95

= 21994 N

Assumed wind load on support(headwind)

$$W_P' = C_W \times 0.6 \times V_0^2 \times E \times I \times A_W$$

= 1.32 x0.6 x 34 ^2 x 1.677 x 1.0 x 18.95

= 29222 N

Horizontal wind pressure

Downwind $W_{P1}=W_P \times \sin\theta=$ 21994 x sin 38 °

= 13541 N

Headwind $W_{P1}'=W_P' \times \sin\theta=$ 29222 x sin 38 °

= 17991 N

Vertical wind pressure

Downwind $W_{P2}=W_P \times \cos\theta=$ 21994 x cos 38 °

= 17331 N

Headwind $W_{P2}'=W_P' \times \cos\theta=$ 29222 x cos 38 °

= 23027 N

7 Snow Load

Snow load for design is calculated by the equation (23).

$$S_P = Cs \times P \times Zs \times As \quad \text{......} \quad (23)$$

Here, Sp : Snow load (N)

Cs : Slope coefficient

P : The average unit load of snow (Snow 1cm per $N \cdot m^{-2}$)

Zs : Ground vertical snowfall (m)

As : Snow cover(Horizontal projected area of array surface n

a) Slope coefficient the slope coefficient Cs of equation(23)is calculated by equation(24). However, if β is more than 60 degrees, C_s can be set to 0.

$$Cs=\sqrt{}[\cos(1.5\beta)] \quad \text{......} \quad (24)$$

$$= \sqrt{}[\cos(1.5 \times 38)] = 0.738$$

Here, β : The slope of the snow surface (degrees) is 38 °

b) The average unit load of snow The average unit load of snow (P)(Snow 1cı per $N \cdot m^{-2}$) in the equation(23) is above 20N for general region, and above 30N for snowy region.

c) Snow accumulation The snowfall for design of the plane of the array is the amount of vertical snow (Zs) on the ground, and the amount of snow that is calculated by equation(25) takes into account the impact of local terrain factors in the area. However, if it is possible to determine the 50-year reproduction expected value based on the ground snow depth of observational data from the weather station of the zone or area in the vicinity thereof and by the way of statistical processing, it can be used.

$$Zs=\alpha \times ls+\beta \times rs+\gamma \quad \text{......} \quad (25)$$

Here, ls : Standard altitude (m) of the area

rs : Standard Umiritsu(sea rate) of the area

α, β and γ : Coefficients determined according to area

Snowfall in the present design , regardless of the above formula , based on the numerical value established by the Governor.

Zs= 0 cm

$$SP=Cs \times P \times Zs \times As=Cs \times P \times Zs \times Aw \times \cos\theta$$

$$= 1.000 \times 20 \times 0 \times 18.95 \times \cos 38°$$

$$= 0 \text{ N}$$

8 Seismic Load for Design

Regarding of the seismic load for design, it is calculated by equation(26) for general region, and by equation(27) for snowy region.

$$K_P = k_p \times G \quad \text{......} \quad (26)$$

$$K_P = k_p \times (G + 0.35S) \quad \text{......} \quad (27)$$

Here, Kp : Seismic load for design (N)

kp : Horizontal seismic intensity for design

G : Fix load (N)

S : Snow load (N)

a) Horizontal seismic intensity for design For the scheme to be tightened to building, both of the structure part and foundation part of horizntal seismic intensity are calculated by equatin(28). Besides, to prevent the harm caused by falling or movement of array, it is an effective way to put the weight basis on the building. For the structure part, calculate by equation(28), and for the foundation part, calculate by equation(29). However, it does not apply to the solar system using the application coefficient of 1.5.

$$k_P \geq 1.0 \times Z \times I \quad \text{..........} \quad (28)$$

$$k_P \geq 0.5 \times Z \times I \quad \text{..........} \quad (29)$$

Here, Z : Earthquake area coefficient（1.0-0.7）

I : Applications coefficient

kp= 1.0 x 1.0 x 1.0 = 1.0

b) Applications coefficient See Table 6.

Table 6 - Applications coefficient

Use of solar power generation system	Applications coefficient
Extremely important solar power	1.5
Normal solar power system	1.0

Summary $K_P = kp$ G

= 1.0 x 2556

= 2556 N

9 Allowable Stress

For the allowable stress, it shall be as follows.

a) Steel for construction The allowable stress of steel for construction in long term load is as follow. In the case of short term load, it is 1.5 times of long term load.

1) Allowable tensile stress

$$\sigma_y / 1.5 \quad \text{..........} \quad (21)$$

But, below $0.7\sigma_B / 1.5$

2) Allowable compressive stress

$$\sigma_y / 1.5 \quad \text{..........} \quad (22)$$

3) Allowable bending stress

$$\sigma_y / 1.5 \quad \text{..........} \quad (23)$$

4) Allowable shear stress

$$\sigma_y / (1.5 \times \sqrt{3}) \quad \text{..........} \quad (24)$$

But, below $0.7\sigma_B / (1.5 \times \sqrt{3})$

5) Allowable bearing stress

$$1.1\sigma_y \cdots\cdots (25)$$

Here, σ_y : Yield point stress of material $(\mathrm{N \cdot mm^{-2}})$

σ_B : Tensile stress of material $(\mathrm{N \cdot mm^{-2}})$

b) Aluminum for construction The allowable stress of aluminum for construction in long term load is as follow. In the case of short term load, it is 1.5 times of long term load.

1) Allowable tensile stress

$$\sigma_{0.2}/1.5 \cdots\cdots (26)$$

But, below $(5\sigma_B/6)\times(1/1.5)$

2) Allowable shear stress

$$\sigma_{0.2}/(1.5\times\sqrt{3}) \cdots\cdots (27)$$

But, below $(5\sigma_B/6)\times[1/(1.5\times\sqrt{3})]$

3) Allowable compressive stress

$$\sigma_{0.2}/1.5 \cdots\cdots (28)$$

But, below $(5\sigma_B/6)\times(1/1.5)$

4) Allowable bending stress

$$\sigma_{0.2}/1.5 \cdots\cdots (29)$$

But, below $(5\sigma_B/6)\times(1/1.5)$

5) Allowable bearing stress

5.1) Pin and the contact area

$$\sigma_{0.2}/1.1 \cdots\cdots (30)$$

But, below $(5\sigma_B/6)\times(1/1.1)$

5.2) Sliding or rolling support part

$$1.9\sigma_{0.2} \cdots\cdots (31)$$

Here, $\sigma_{0.2}$: Minimum stamina $(\mathrm{N \cdot mm^{-2}})$

10 Load Calculation of Main Parts

10.1 Rail Verification of Calculation

10.1.1 Short term

The total load in the case of downwind :

G5+Wp	=	2481	+	21994	=	24475	N
G5+S	=	2481	+	0	=	2481	N

The total load in the case of headwind :

G5-Wp'	=	2481	-	29222	=	-26740	N

The Value K is from below sheet :

Rails with 2 spans

The bending coefficient of fulcrum	Kσ	0.125
The deflection coefficient in the spans	Kδ	0.521

Rails with 3 spans

The bending coefficient of fulcrum	Kσ	0.1
The deflection coefficient in the spans	Kδ	0.677

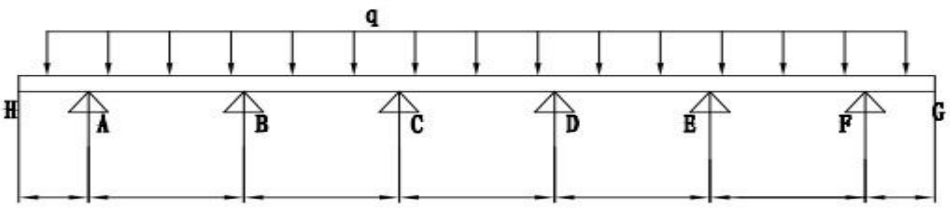
Rails with 4 spans

The bending coefficient of fulcrum	Kσ	0.107
The deflection coefficient in the spans	Kδ	0.632

ails with 5 (or more) span

The bending coefficient of fulcrum	Kσ	0.105
The deflection coefficient in the spans	Kδ	0.644

so it should calculate the structure load in the case of storm.



125 7 * 1200 125

F= 26740 / 2 = 13370 N
L= 8.65 M
q= 1546 N/M
Lq= 1.2 M Ls= 0.125 M

Calculation within the span
Stress
σmax=Kσ*q*Lq^2/Zx
= 0.105 x 1546 x 1.20 ^2 / 2.89
= 80.9 N/mm^2
Material to be used is AL6005-T6, allowable stress is 215 N/mm^2.
80.9 /215<1, is within the safe range

Deflection δ
δmax=Kδ*q*Lq^4/(100*E*Ix)
= 0.64 x 1546 x 1.2 ^4/(100 x 6.9x 7.925)
= 0.377 cm
= 3.77 mm
Strut and the pitch of strut 1200 mm,
The maximum amount of displacement 3.77 mm
（ 3.77 / 1200 ）<(1/100), is within the safe range

10.1.2 Long term

G = 2481 N
F= 2481 / 2 = 1241 N
L= 8.65 M
q= 143 N/M
Lq= 1.2 M Ls= 0.125 M

Calculation within the span
Stress
σmax=q*Lq^2*Kσ/Zx
= 143 x 1.20 ^2* 0.105 / 2.89
= 7.5 N/mm^2
Material to be used is AL6005-T6, allowable stress is（215/1.5=143）N/mm^2.
7.5 /143<1 , within the safe range

Deflection δ
δmax=Kδ*q*Lq^4/(100*E*Ix)
= 0.64 x 143 x 1.2 ^4/(100x6.9x 7.925)
= 0.035 cm
= 0.35 mm
Strut and the pitch of strut 1200 mm，
The maximum amount of displacement 0.35 mm
（ 0.35 / 1200 ）<(1/100), is within the safe range

10.2 Rear Pile Calculation

The load acting on each pile are equal if front pile and rear pile are in the same cross-sectional shape. Thus, only rear pile is calculated, for the long extention of Rear Pile becomes a disadvantage against buckling.

The total load in the case of downwind :

G6+Wp	=	2556	+	21994	=	24550	N
G6+S	=	2556	+	0	=	2556	N

The total load in the case of headwind :

G6-Wp'	=	2556	-	29222	=	-26665	N

so it should calculate the structure load in the case of storm.

The total load on piles :

The total load in the case of downwind :

G6+Wp = 24550 N

The total load in the case of headwind :

G6-Wp' = -26665 N

From the above, the buckling study is in the conditin of storm with max load, for the pull-out study, it is to examine structurally at the time of headwind.

10.2.1 Buckling study

For the long-term allowable compressive stress level, it can be calculated from the slenderness ratio λ and seek complience with the steel structure design criteria.

$\lambda \leqq \Lambda, fc=(1-0.4(\lambda/\Lambda)^2)F/\upsilon$

$\lambda > \Lambda, fc=0.277F/(\lambda/\Lambda)^2$

Here, fc: Allowable compressive stress level (N/mm^2)

λ: Slenderness ratio =L/k= 960 / 11.50 = 83.5

Λ : Limit slenderness ratio =$\sqrt{(\pi^2 E/0.6F)}$

= $\sqrt{(\pi^2}$ x 69000 / 0.6 / 215) = 72.7

E : Young modulus = 69000 N/mm^2

F : F-measure = 215 N/mm^2

υ:3/2+2/3x(λ/Λ)^2=3/2+2/3x(83.5 / 72.7)^2 = 2.38

L : Buckling length = 0.8*I = 0.8 x 1200 = 960 mm

※Conditions with respect to the displacement is restraint, conditions with respect to the rotation is one end free and the other end restraint, the recommended value is 0.8.

K : Cross-section secondary radius =$\sqrt{(i/A)}$

= $\sqrt{(}$ 33785 / 255.36)= 11.50 mm

I : Length of the strut = 1200 mm

i : Second moment of cross-section = 33785 mm^4

A : Cross-sectional area of the strut = 255.36 mm^2

λ > Λ

fc=0.277F/(λ/Λ)^2 = 45 N/mm^2

Short-term allowable stress is 1.5 times of the long-term allowable stress.

45 x 1.5 = 68 N/mm^2

Compressive stress to the rear pile

F/A= 24550 / 8 / 255.36 = 12.0 N/mm^2

< 68 N/mm^2 → OK

10.2.2 Tensile stress study

P= ｜G6-Wp'｜/ 8 = 26665 / 8 = 3333 N

Tensile stress

σ= P/A = 3333 / 255.36 = 13.1 N/mm^2 < 215 N/mm^2

→ OK

From the above, Pile is satisfied with the allowable value of buckling and tensile stress.

10.3 Bolt Calculation

Study on the bolt M8 of the strut

F= ｜G6-Wp'｜ / 16 = 26665 / 16 = 1667 N

A= 36.6 mm^2

τ= F/A = 1667 / 37 = 46 N/mm^2

A2-70 bolt shear stress values (700x0.7=490) N/mm^2

46 /490 <1 , is within the safe range

10.4 Calculation and measurement of clamp

The total load in the case of headwind :

| G6-Wp'| = 26665 N

The force on each clamp

F= | G6-Wp'| / n = 26665 / 16 = 1667 N