ALUMINIUM INNOVATIONS FOR TIMBER BUILDINGS

CALCULATION MODE FOR ALUHD40/SH18®

Traction and shear aluminium sheet for Alufoot® system

INTRODUCTION

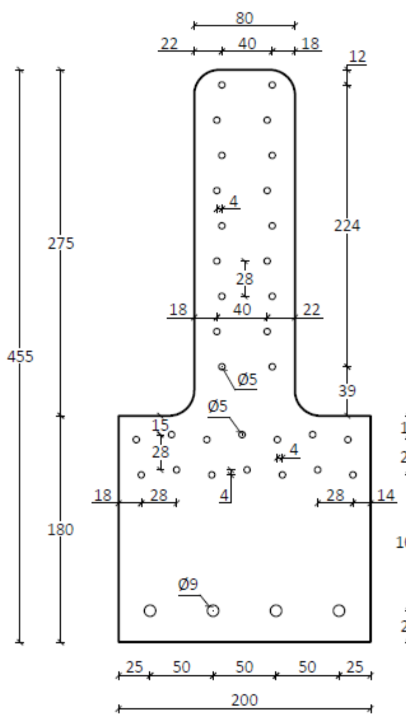
ALUHD40/SH18® sheet, being part of Alufoot® system, is used in order to connect the CLT wall to the Alufoot® aluminium beam. HD40/SH18 geometry has been optimized in order to withstand both the shear forces and the traction forces. We suggest to apply them at the beginning/end of the wall. Below you can find the report of the strength verification of the sheet, following Eurocode 9, using the limit state design, that leads to the definition of the design strength domain compared to the ultimate limit state

Strength verification is led with the only attention to the failure modes on the metal side (*metal side verification*). Strength verifications of the sheet fastening to the timber wall (*timber side verification*) are left to the designer, being subject of many design variables, such as class, wooden type, service class, period of the load, type of fasteners.

SET OF RULES

Eurocode 9 - EN 1999-1-1 (EC9 below)
Eurocode 3 - EN 1993-1-8 (EC3 below)

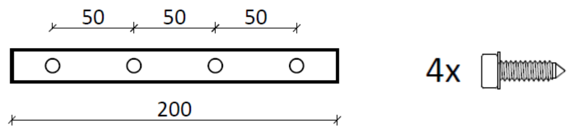
GEOMETRY AND MATERIALS



The system is composed of:

- ALUHD40/SH18 sheet, using EN AW-5754, aluminium, dimensions 455X200X5 mm;
- EN AW-6082 aluminium guide, L=200 mm, with 4 threaded holes, for M8 bolts;
- 4 self –threading M8 bolts, steel class 8.8, hot galvanizing

The holes (9 mm diameters) for the insertion of the M8 bolts are designed in order to respect the minimum distances as prescribed in EC9 (§8.5.1).



Pic. 1: Geometry of HD40/SH18 sheet

MATERIAL STRENGTH

According to EC9, for EN AW-5754 it is correct to use the characteristic strength values below:

- Yelding: f_o=80 MPa
- Failure: f_u=190 MPa

According to EC3, for steel class 8.8 bolts the characteristic strength values below are assumeable:

- Yelding: f_{yb}=640 MPa
- Failure: f_{ub}=800 MPa

The Eurocodes provides the safety factors below:

- Aluminium ductile failure (EN 1999-1-1 §6.1.3) γ_{M1}= 1.10
- Aluminium brittle failure (EN 1999-1-1 §6.1.3) γ_{M2}= 1.25
- Bolts (EN 1993-1-8 §2.2) γ_{M2}= 1.25

SECTION CLASSIFICATION

The section classification of the sheet is calculated according to §6.1.4 of EC9. For HD40/SH18, section A level (see pic. 2) we have:

- $\beta = 0{,}4\, b/t = 0{,}4 \cdot 200/5 = 16$
- $\varepsilon = \sqrt{(250/80)} = 1.77$
- $\beta/\varepsilon = 9.05$

And for section C (see pic. 2):

- $\beta = 0.4\, b/t = 0.4 \cdot 80/5 = 6.4$
- $\varepsilon = \sqrt{(250/80)} = 1.77$
- $\beta/\varepsilon = 3.62$

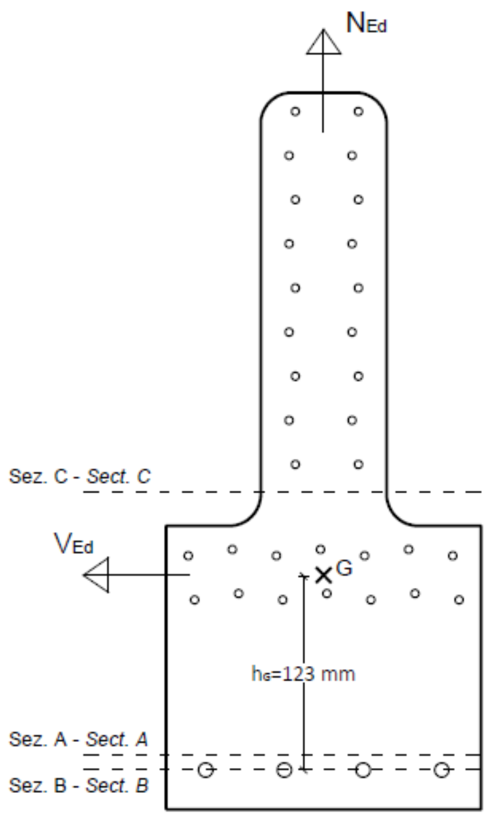
In both cases the section classi is 1, according to table 6.2 of EC9. For that class the ultimate strength of the section can be calculated with reference to the ultimate limit state of plastic failure.

DESIGN HYPOTHESIS

The design hypothesis is that the total design force pass through the mass center G of the nailing on the timber wall (see pic. 2). This assumption results the most cautionary compared to the strength verification of the sheet and of the bolts (metal side verifications).

STRENGTH VERIFICATIONS

The set of strength verifications to be led is illustrated in Picture 2. The strength field of the sheet, in terms of design forces N_{Ed} (traction) and V_{Ed} (shear) will be determined by the weakest strength mechanism.



Strength verification to be led:

- Sect. A: plastic strengh verification of the gross section;
- Sect. B: elastic strength verification of the net section;
- Sect. B: strength verification of the bolts;
- Sect. C: strength traction verification of the gross section.

Pic. 2: Strength verifications to be led

The bolts are fixed to the aluminium profile through an aluminium sliding bar, that is put into the specific pit realized on the profile.
Experimental tests have shown tha the fixing system is over-resistent compared to the bolts, as the failure always comes for the slicing of the bolt on the contact section between sheet and aluminium guide.

Section A: plastic strength of the gross section

Because of the geometry of the sheet and the material behaviour, the quantities below must be defined:

- Maximum traction strength:

  $N_{o,Rd} = A_g f_o/\gamma_{M1} = 1000 \cdot {}^{80}/_{1.10} = 72.73\ kN$

- Maximum shear strength:

  $V_{o,Rd} = A_g f_o/(\sqrt{3}\,\gamma_{M1}) = 1000 \cdot 80/(\sqrt{3} \cdot 1.10) = 41.99\ kN$

- Maximum moment strength:

  $M_{o,Rd} = W_{pl} f_o/\gamma_{M1} = {}^{1}/_{4} \cdot 5 \cdot 200^2 \cdot {}^{80}/_{1.10} = 3.64\ kNm$

Because of the calculation hypothesis, the design moment is the sum of the two moments obtained by the multiplication of the shear force and the traction force with their eccentricities:

$$M_{Ed} = |V_{Ed}| \cdot h_{G1} + |N_{Ed}| \cdot h_{G2}$$

where h_{G1} is the distance between the center of mass of the shear resistent nailing and the bolts center of mass, equal to 123 mm, while h_{G2} is the distance between the center of mass of the traction resistent nailing and the bolts center of mass, equal to 60.3 mm.

For the composition of shear and traction forces the designer must follow the disequation below:

$$\frac{N_{Ed}}{N_{o,Rd}} + \frac{|V_{Ed}| \cdot h_{G1} + |N_{Ed}| \cdot h_{G2}}{M_{o,Rd}} \leq 1 \qquad \text{(I)}$$

where V_{Ed} is the shear force and N_{Ed} the traction force on the sheet, calculated for USL combination.

EC9 provides the verification (I) with a design strength reduced, euqal to $f_{o,V} = f_o(1-\rho) = f_o(1-(2V_{Ed}/V_{Rd}-1)^2)$, whenever it is verified the condition $V_{Ed} > 0.5V_{o,Rd}$. For shear forces over than 21 kN, the strength domain for the gross section, is characterized by a soft bending.

Section B: verification of the net area of the sheet

Because of the geometry of the sheet and the material behaviour, the quantities below must be defined:

- Maximum traction strength:

$$N_{u,Rd} = 0.9A_{net}f_u/\gamma_{M2} = 0.9 \cdot 830 \cdot 190/1.25 = 113.54\ kN$$

- Maximum shear strength:

$$V_{u,Rd} = A_{net}f_o/\sqrt{3}\gamma_{M1} = 830 \cdot 80/\sqrt{3} \cdot 1.10 = 34.85\ kN$$

- Maximum moment strength:

$$M_{u,Rd} = W_{net}f_u/\gamma_{M2} = 2.8 \cdot 10^6 \cdot 190/1.25 = 4.26\ k\text{N}$$

Once determined the values of $N_{u,Rd}$, $V_{u,Rd}$ e $M_{u,Rd}$, the resistent field is obtained by the same considerations as the previous paragraph, by following the disequation:

$$\frac{N_{Ed}}{N_{u,Rd}} + \frac{|V_{Ed}| \cdot h_{G1} + |N_{Ed}| \cdot h_{G2}}{M_{o,Rd}} \leq 1 \qquad \text{(II)}$$

where h_{G1} is the distance between the center of mass of the shear resistent nailing and the bolts center of mass, equal to 123 mm, while h_{G2} is the distance between the center of mass of the traction resistent nailing and the bolts center of mass, equal to 60.3 mm.

As before, there is an interaction between the shear force and the traction force: for shear values $V_{Ed} > 17.4\ kN$, the verification (II) has been led assuming the reduced design strength tension $f_{o,V}$, in the same way as done for the strength verification of the gross section.

Section B: strength verification of the bolts

The shear resistance of the single bolt M8 cl. 8.8 ($V_{b,Rd}$) is the minimum between the burr strength of the aluminium sheet and the shear resistance of the bolt, given by the expressions below:

- Slicing resistance of the bolt a tranciamento del bullone

$$F_{V,Rd} = \alpha_V \cdot \frac{f_{ub}A_s}{\gamma_{M2}} = 0.6 \cdot 800 \cdot \frac{36.6}{1.25} = 14.05\ kN$$

- Burr resistance

$$F_{b,Rd} = k_1\alpha_b \cdot \frac{f_u dt}{\gamma_{M2}} = 2.5 \cdot 0.926 \cdot 190 \cdot 8 \cdot \frac{5}{1.25} = 14.07\ kN$$

From the previous expressions it comes that the shear strength of the bolt is equal to:

$$V_{b,Rd} = \min\{F_{V,Rd}; F_{b,Rd}\} = 14.05\ kN.$$

The design strength domain of the bolts, in terms of shear forces V_{Ed} and traction forces N_{Ed}, has been determined according to the following expression:

$$V_{b,Ed} = \sqrt{\left(\frac{N_{Ed}}{4} + \frac{(V_{Ed} \cdot 123 + N_{Ed} \cdot 60.3) \cdot 75}{(75^2 + 25^2)}\right)^2 + \left(\frac{V_{Ed}}{4}\right)^2} \leq V_{b,Rd}$$

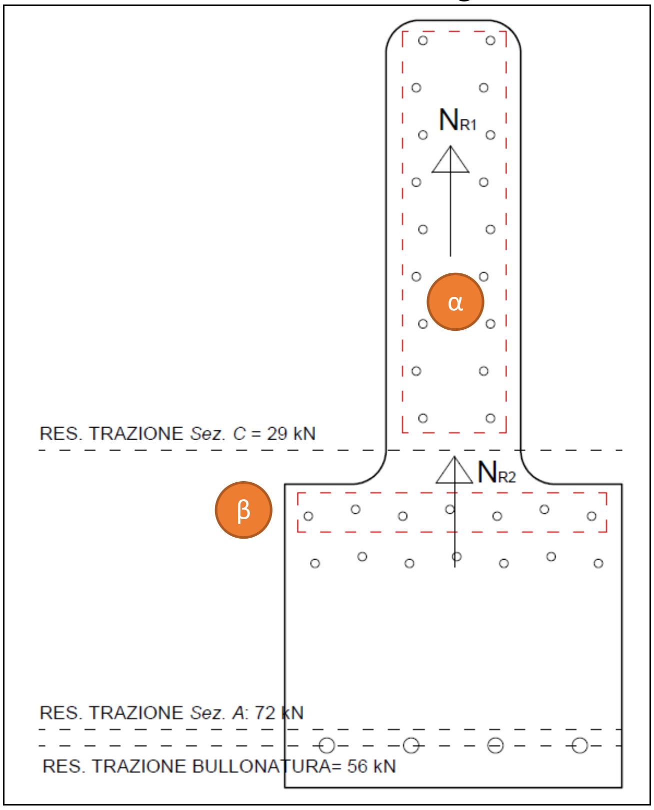
which verifies that the shear force on the most forced bolt results minor than the shear strength.

Section C: traction verification of the gross section

Because of the geometry and the characteristics of the aluminium (defined by EC9), the maximum design traction strength of the sheet, at section C level, is equal to:

$$N_{o2,Rd} = A_{g2} f_o / \gamma_{M1} = 400 \cdot {}^{80}/_{1.10} = 29.09\ kN$$

Considerations over traction strength of ALUHD40/SH18



Pic. 3: Traction strength evaluation for ALUHD40/SH18 whem inferior nails are used

The traction design strength for ALUHD40/SH18 is the minor between the ones calculated:

$$N_{Rd} = \min\{N_{o,Rd}; N_{u,Rd}; 4V_{b,Rd}; N_{o2,Rd}\} = 29.09\ kN$$

When using nails in the inferior part of the sheet, the strength can be rightly increased by the considerations below.

Being:

- n_1= number of nails on the upper side of the sheet (α zone);
- n_2= number of nails on the lower side of the sheet (β zone) reagent to traction;
- N_{R1}= traction force conveied to the sheet by the nails in α zone;
- N_{R2}= traction force conveied to the sheet by the nails in β zone.

As the sheet can spread the traction force equally to all the resistant nails (the 7 ones not highlighted in pic.3, zone β are not able to react to traction because they do not respect the minimum distances to the edge of the timber element), N_{R2} can be calculated by the proportion below:

$$N_{R1}: n_1 = N_{R2}: n_2$$

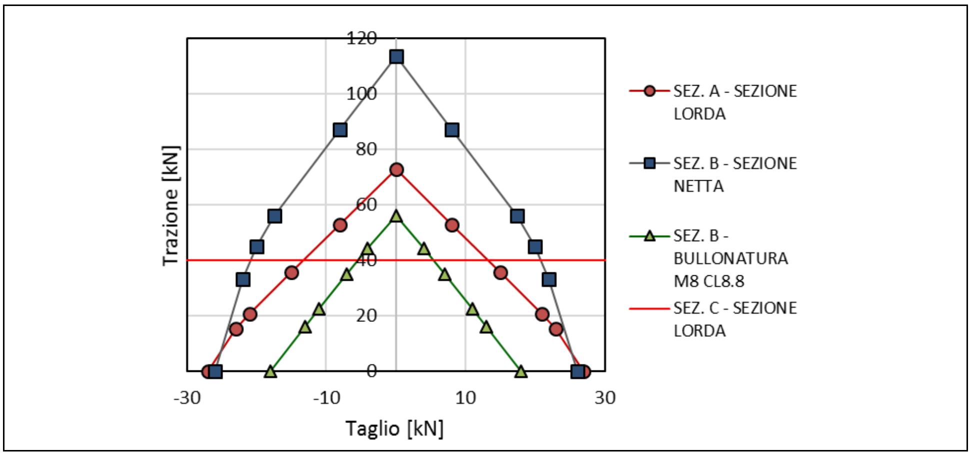
Where the maximum value of N_{R1} is known, equal to $29.09\ kN$.

When n_1=18 and n_2=7 (all nails used), the maximum traction design strength is:

$$N_{Rd,max} = N_{R1} + N_{R2} = 29 + 11 = 40\ kN$$

REPRESENTATION OF THE STRENGTH DOMAINS

The four verifications lead to the creation of three domains, represented in Pic.4



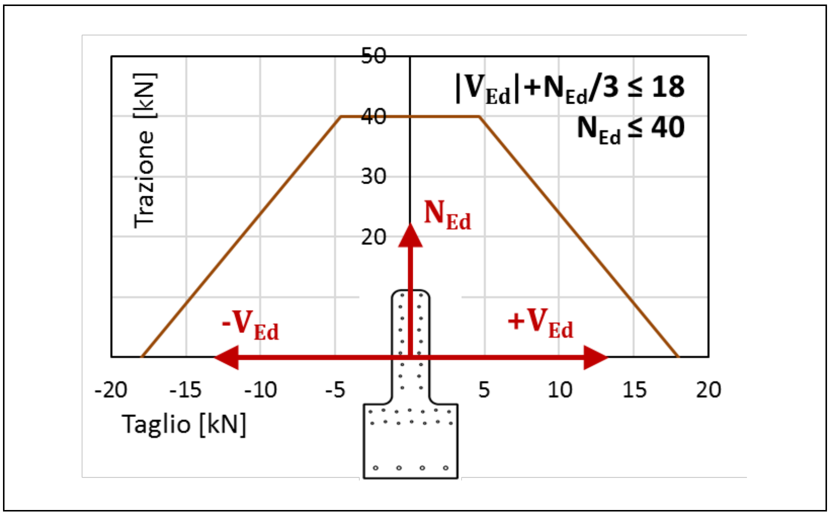
Pic.4: Results obrained by strength verifications

DESIGN RESISTANCE DOMAIN OF THE SHEET

The design domain for ALUHD40/SH18 is well described by the disequations:

$$|V_{Ed}| + \frac{N_{Ed}}{3} \leq 18\ kN$$

$$N_{Ed} \leq 40\ kN\ ^{(*)}$$



Pic. 5: Graphic representation of the design strength domain.

(*) *It is important to remember the the tracction strength equal to 40kN defined is correct only when all the nails are used; for different situations the designer must follow* "Considerations over traction strength of *ALUHD40/SH18".*