SKEMA S.p.a

Switchgear steel structures. Stress analisys under seismic load

Calculation report

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Switchgear steel structures. Stress analisys under seismic load

Report title:

Calculation report

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EXECUTIVE SUMMARY

In the executive summary we report the status of strength of the structures (profiles, ground anchors, links between modulus, riveting…) obtained by calculation worked out hereinafter.

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In particular, we show variation ranges (between 0 and 1) of exploitation coefficients,assuming that 1 is the maximum allowed relative value:

- resistance and stability for individual modulus and for the various configurations;
- the anchors (in this case only the maximum value is reported);
- bolts linking modulus;
- internal links to modulus.

RESISTANCE AND STABILITY FOR INDIVIDUAL MODULUS AND FOR THE DIFFERENT CONFIGURATIONS

In the following table the comparison between the exercise situation (SLS) and that one in presence of seismic action (ULS) is introduced. We can observe that the exploitation coefficients increase in condition ULS, however they aren't higher than 1, so the verifications are satisfied.

MODULUS - CONFIGURATION	RESISTANCE/ BUCKLING COEFFICIENT RANGE	
	SLS (RES. / BUC.)	ULS (RES. / BUC.)
M20-251 (type 1)	0.00 - 0.02 / 0.00 - 0.08	0.02 - 0.32 / 0.03 - 0.81
P60-253 (type A)	0.00 - 0.01 / 0.00 - 0.10	0.00 - 0.20 / 0.00 - 0.78
M20-252 (type 1')	0.00 - 0.32 / 0.00 - 0.38	0.01 - 0.69 / 0.01 - 0.99
P60-254 (type A')	0.00 - 0.01 / 0.00 - 0.12	0.01 - 0.39 / 0.01 - 0.71
P60-255 (type A'')	0.00 - 0.02 / 0.00 - 0.19	0.01 - 0.62 / 0.01 – 1.00
G00-255 (type TR)	0.00 - 0.24 / 0.00 - 0.02	0.01 - 0.24 / 0.01 – 0.13
G00-256 (type M)	0.00 - 0.10 / 0.00 - 0.01	0.01 - 0.10 / 0.01 – 0.13
MSW-040	0.00 - 0.03 / 0.00 - 0.13	0.00 - 0.28 / 0.01 – 0.84
MSW-055	0.00 - 0.24 / 0.00 - 0.07	0.01 - 0.47 / 0.01 – 0.83
MSW-021	0.00 - 0.26 / 0.00 - 0.38	0.00 - 0.47 / 0.00 – 0.89
Elevated substations	0.00 - 0.03 / 0.00 - 0.09	0.01 - 0.29 / 0.01 – 0.75

ANCHORS BOLTS

In the next table the verifications on anchorages and elements that have to transfer load to the modules are introduced; because there are axial action and shear action, the resistance coefficient of the anchorage must be lower than 1.2, while for other elements the limitation is 1. <u>We can see that the verifications are satisfied</u>.

TYPE	RESISTANCE COEFFICIENT ULS
Anchors in Concrete	1.14<1.20
M12 (see fig. A cap. 6)	0.939
Angular (see fig. A cap. 6)	0.952

MODULUS LINKS CHECK

In the next table the verifications of the connection elements between single modules are introduced. <u>We can observe that the verifications are satisfied</u>.

CONFIGURATION	RESISTANCE COEFFICIENT ULS
MSW-040	0.30
MSW-055	0.16
MSW-040	0.72
Elevated substations	0.32

JOINT LINKS CHECKS

In the next table the verifications of two types of connection elements between single modules are introduced(type 1/1 ', TR/M); in both situations the status of solicitation for rivets and plate of connection are controlled. We can see that the verifications are satisfied.

TYPE	RESISTANCE COEFFICIENT ULS
Modulus type 1/1' – horizontal girders	0.397 (rivets), 0.796 (plate)
Modulus type TR/M – bracing links	0.061 (bolts), 0.016 (plate)

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1. TARGET

This calculation report summarize structural seismic checks that were done on every single modulus produced by SKEMA S.p.a and on their various configurations indicated at 1.1.2.

Modulus are composed of 2 mm cold-formend steel plate rivetted. The steel used is type DX51D with the mechanical caracteristic summerized at 2.1.

In the configuration of several modulus, one modulus is bolted to another in different points (see cap 7) .

Every riveting constrain is considered as a fixed support, instead bolts are considered as hinges (they can only transmit assial and shear forces).

In this calculation report it is used the Ultimeted State Method, and the seismic analysis are verified in agreement to [17].

To obtain an adequate design of modulus in agreement with [13], [14], [15], [16], [17] every single modulus produced by SKEMA S.p.a has been cheked by itself and in the configurations indicated at 1.1.2.

During design every section that did not observe limits imposed by [13], [14], [15], [16], [17] has been adeguately reinforced in agreement with SKEMA S.p.a.

References

1.1.1 *Design documents*

[1] M20CA00251- Perspective drawing of sections of Modulus type 1

[2] M20CA00252- Perspective drawing of sections of Modulus type 1'

[3] P60CA00253 - Perspective drawing of sections of Modulus type A

[4] P60CA00254 - Perspective drawing of sections of Modulus type A'

[5] G00CA00255 - Perspective drawing of sections of Modulus typeTR

[6] G00CA00256 - Perspective drawing of sections of Modulus type M

[7] P60CA00258 - Perspective drawing of sections of Modulus type A''

[8] M20CA00261- Mass position in Modulus type 1

[9] M20CA00262- Mass position in Modulus type 1'

[10] P60CA00271 - Mass position in Modulus type A

[11] P60CA00272 - Mass position in Modulus type A'

[12] P60CA00273 - Mass position in Modulus type A''

1.1.2 *Regulations*

[13] EN 1990 – Eurocode: Basic of structural design.

[14] EN 1991-1-1– Eurocode 1: Actions on structures – Part 1-1 : General actions – Densities, self-weight, imposed loads for building.

[15] EN 1993-1-1– Eurocode 3: Design of steel structures – Part 1-1: General rules and rules for buildings.

[16] ENV 1993-1-3 – Eurocode 3: Design of steel structures – Part 1-3: General rules – Supplementary rules for cold formed thin gauge members.

[16_2] ENV 1993-1-3 – Eurocode 3 - Design of steel structures - Part 1-8: Design of joints

[17] EN 1998-1 – Eurocode 8: Design of structures for earthquake resistance – Part 1: General rules, seismic actions and rules for building.

[18] EN 10327: Continuously hot-dip coated strip and sheet of low carbon steels for cold forming - Technical delivery conditions

1.1.3 Programs

[19] CeAS s.r.l.: XFINEST

XFINEST is a linear elastic finite elements program, and it is composed of a series of programs with different task:

- XMESH program of INPUT generation for the solver
- XFINEST program that solve the analysis
- DYNFINEST program of post-processing for dynamic analysis
- XPOST program base on database for OUTPUT control
- XGRAPH display program

[20] CeAS s.r.l.: STEEL-WORLD

STEEL-WORLD is a post-processing program that checks every steel element in agreement with many regulations.

1.1.4 Correlation between European code (EN) and ASCE 7-05

Despite it’s very difficult we make a comparison between European standard and the American standard, in this paragraph we shall identify a correlation.

ARGUMENT	EN CODE	ASCE 7-05
Basic of structural design	EN 1990 - Eurocode	Chapter 1 : General
Actions on structures	EN 1991-1-1 - Eurocode 1	Chapter 2 : Combinations of loads; Chapter 3 : Dead loads, soil loads, and hydrostatic pressure; Chapter 4 : Live loads;
Design of steel structures: General rules and rules for buildings.	EN 1993-1-1– Eurocode 3	Chapter 14 : Material specific seismic design and detailing requirement;
Design of steel structures: Supplementary rules for cold formed thin gauge members.	ENV 1993-1-3 – Eurocode 3	
Design of steel structures: Design of joints	ENV 1993-1-3 – Eurocode 3	
Design of structures for earthquake resistance: General rules, seismic actions and rules for building.	EN 1998-1 – Eurocode 8	Chapter 11 : Seismic design criteria; Chapter 12 : Seismic design requirements for building structures; Chapter 13 : Seismic design requirements for nonstructural components; Chapter 15 : Seismic design requirements for nonbuilding structures; Chapter 16 : Seismic response history procedures; Chapter 20 : Site classification procedure for seismic design;

2. MATERIAL FINITE ELEMENTS MODEL

2.1 Material properties

Material properties that SKEMA S.p.a gave us are:

Steel DX51D:

Yielding stress $f_y = 250 N / mm^2$

Breaking stress $f_u = 500 N / mm^2$

Young Modulus: $E = 210000 N / mm^2$

Poisson Coefficient $\nu_c = 0.3$

Density: $\rho_s = 7{,}85 t / m^3$

2.2 Loads and Finite Elements Model

The load conditions and cheks included in this report are in agreement with [13], [14] e [17].

Single modulus and various configurations are checked with the ULTIMATE LIMIT STATE indicated in [13], [14] e [17].

Dynamic calculations based on the seismic load condictions described in [13], [14], [17] with a peak-ground acceleration of 0,83g in the horizontal direction and 0,59g in the vertical direction that SKEMA S.p.a gave us.

For the configuration "Elevated substations", the fundamental time period of the jetty is 1.05 s (=T_1); the foundamental vibration period of the non-structural element is 0.043784. According to par. 4.3.5 [17] we have that spectrum of response is amplified by a coefficient equal to 1.06385:

$$S_a = \alpha \cdot S \cdot \left[3 \cdot \frac{\left(1+\frac{z}{H}\right)}{\left(1+\left(1-\frac{T_a}{T_1}\right)^2\right)} - 0.50 \right] = \alpha \cdot S \cdot \left[3 \cdot \frac{1}{\left(1+\left(1-\frac{0.043784}{1.05}\right)^2\right)} - 0.50 \right] = \alpha \cdot S \cdot 1.06385;$$

It has been considered a behaviour factor q=2 for the horizontal direction (see 4.3.5 [17]) and q=1,5 for the vertical direction (see 3.2.2.5 [17]) (**See also ANNEX 1 at the end of the Report**).

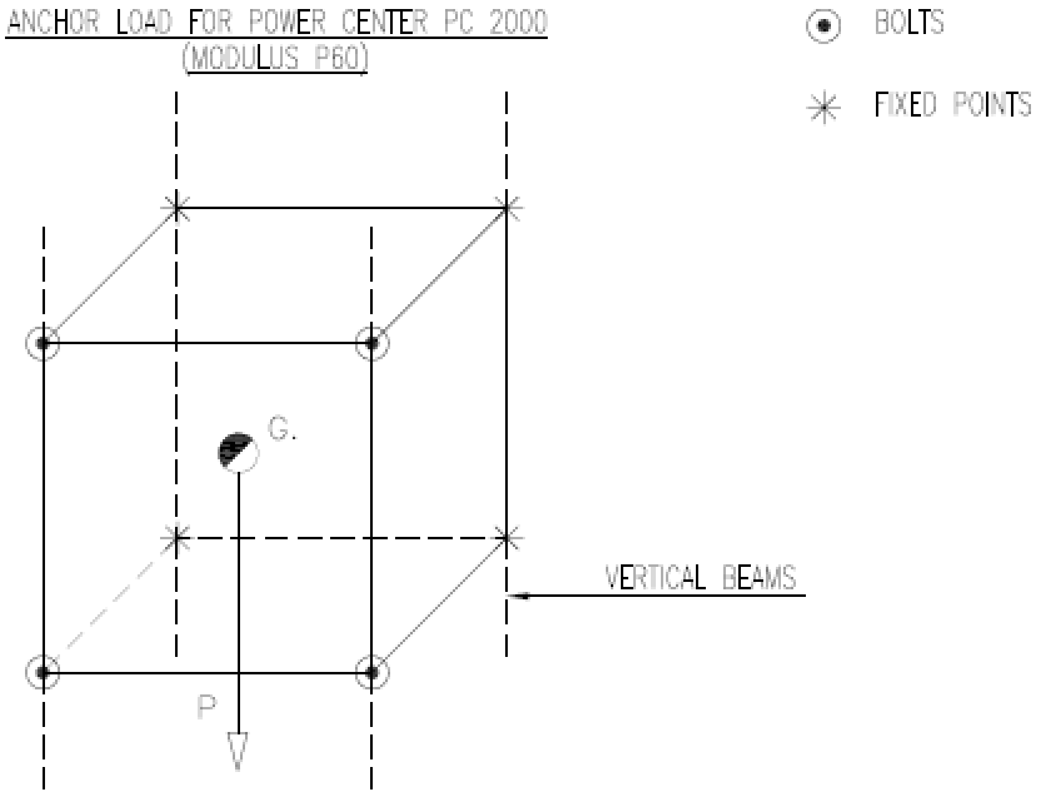
Checks are evaluated for the 25 load combinations starting from 7 load combinations of gravital laod (condiction 1) ad seismic analisys (condictions from 2 to 7).

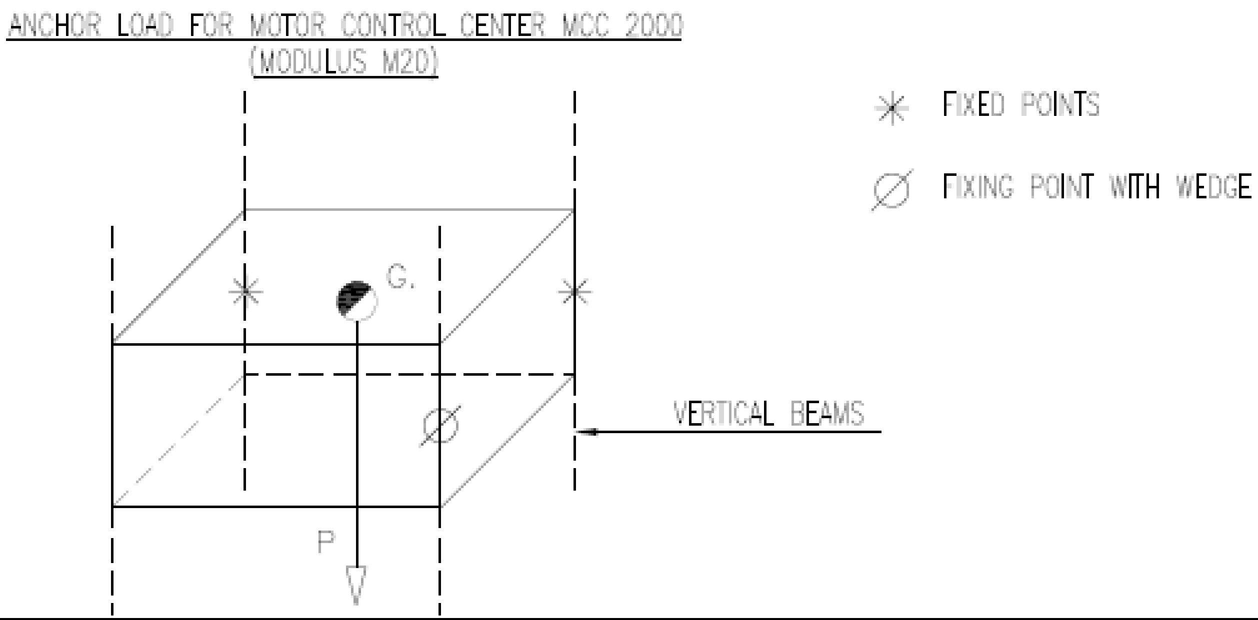
Combinations' numbers are:

- from 8 to 15 –ULS checks: gravital load + component 100% in direction x and 30% in directions z e y (in agreement with [17]);
- from 16 to 23 –ULS checks: gravital load + component 100% in direction y and 30% in directions x e y (in agreement with [17]);
- from 24 to 31 –ULS checks: gravital load + component 100% in direction z and 30% in directions x e y (in agreement with [17]);
- 32 –SLS check: gravital laod.

2.3 Mass- structure constraint

Mass ,that are positioned in the center of gravity described in [8], [9], [10], [11], [12], are rigidly linked to the structure as it is represented in the following figure:

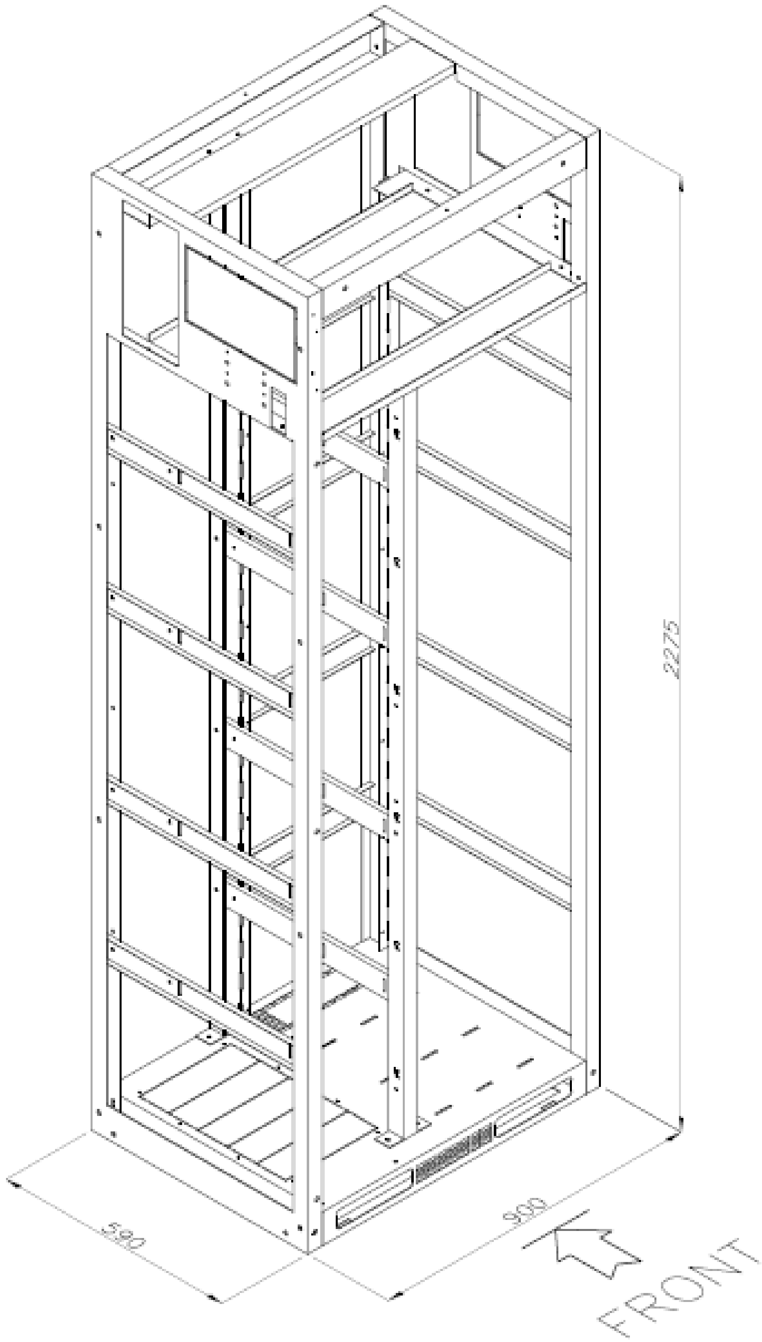




3. INPUT OF SINGLE MODULUS

3.1 Modulus M20-251 (type 1)

The perspective representation of Modulus type 1 is in the following figure.

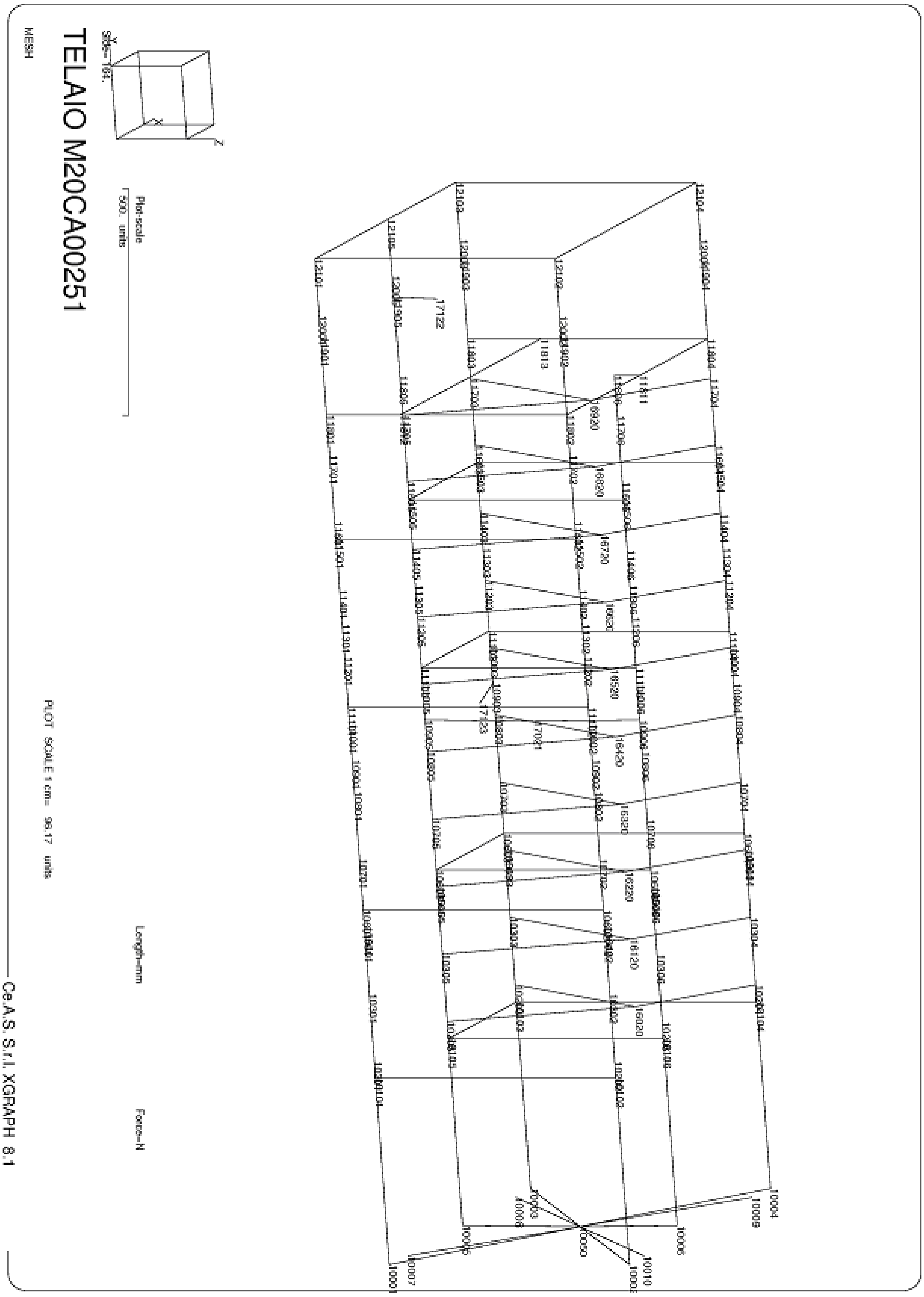


3.1.1 Mesh definition (input xfinest file):

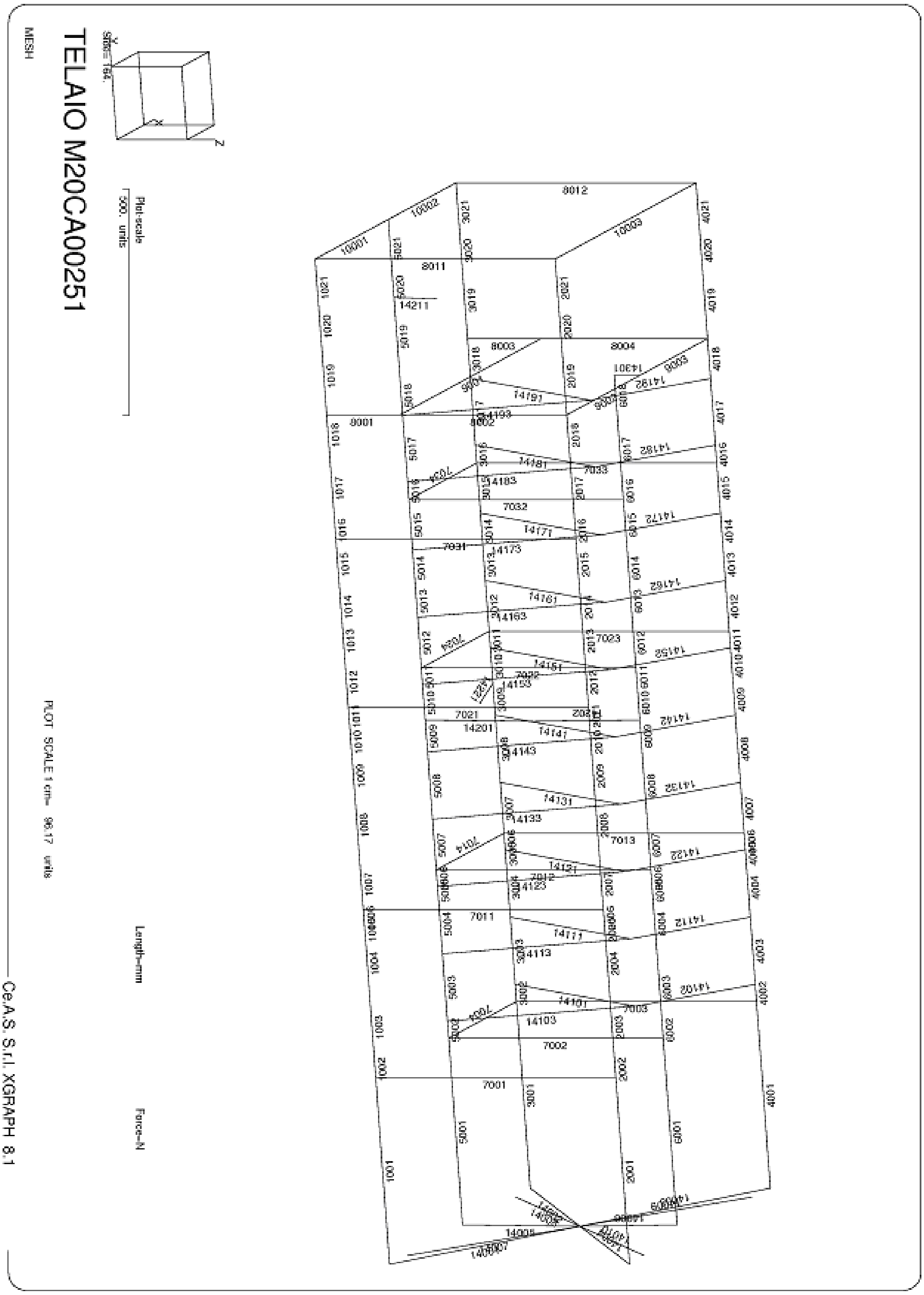
```
_title
TELAIO M20CA00251
_option
solve static analysis
solve eigenvalue extraction
param iestyp=lw
param nfreq=250
solve eigenresult recovery
param xper=90
param yper=90
param zper=90
keep dynamic files

_units  mm  N  Kg  sec
```

3.1.2 Nodes Display



3.1.3 Elements Display



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6. ANCHOR BOLTS

Anchor bolts design is in agreement with "Anchor Bolts Details for Equipement Sellers" produced by Chilean LNG Project (**See also ANNEX 2 at the end of the Report**).

The maximum values of reactions on a single bolt (see cap 4 and 5) obtained for single modulus and for the four configuration, for the 25 load conditions, are:

$$N_{ua} = 13.51kN \;\; (compression: 20.40kN);$$
$$V_{ua} = 6.29kN;$$

The forces prescribed in 13.4.2 a. of rule ASCE 7-05 result:

$$N_{ua} = 1.3 \cdot 13.51 = 17.56kN$$
$$V_{ua} = 6.29 \cdot 1.3 = 8.18kN;$$

For these values of actions in bolts, conditions 1) , 2) and 3) are verified, assuming k=0.75, because this is a check in seismic condition, in particular:

$$N_{ua} > 0{,}20 \cdot (\phi N_n) \qquad 1)$$

$$V_{ua} > 0{,}20 \cdot (\phi V_n) \qquad 2)$$

$$\frac{N_{ua}}{(\phi N_n) \cdot k} + \frac{V_{ua}}{(\phi V_n) \cdot k} \le 1{,}20 \qquad 3)$$

Using a MILD STEEL ANCHOR BOLT with 16 mm diameter and substituting numbers in condiction 3):

$$\frac{N_{ua}}{(\phi N_n) \cdot k} + \frac{V_{ua}}{(\phi V_n) \cdot k} = \frac{17.56}{47 \cdot 0.75} + \frac{8.18}{17 \cdot 0.75} = 0.498 + 0.642 = 1.14 < 1.20 \rightarrow \text{ Ok! Verified}$$

Load is transmitted from vertical truss to foundation as described in figures: A, B, C.

Maximum reactions transferred in foundation are defined in figure D:

$N_{TENSION}$ = 13.51 kN;

$N_{TENSION}$ = 20.40 kN;

V_1 = ± 3.18 kN;

V_2 = ± 5.88 kN;

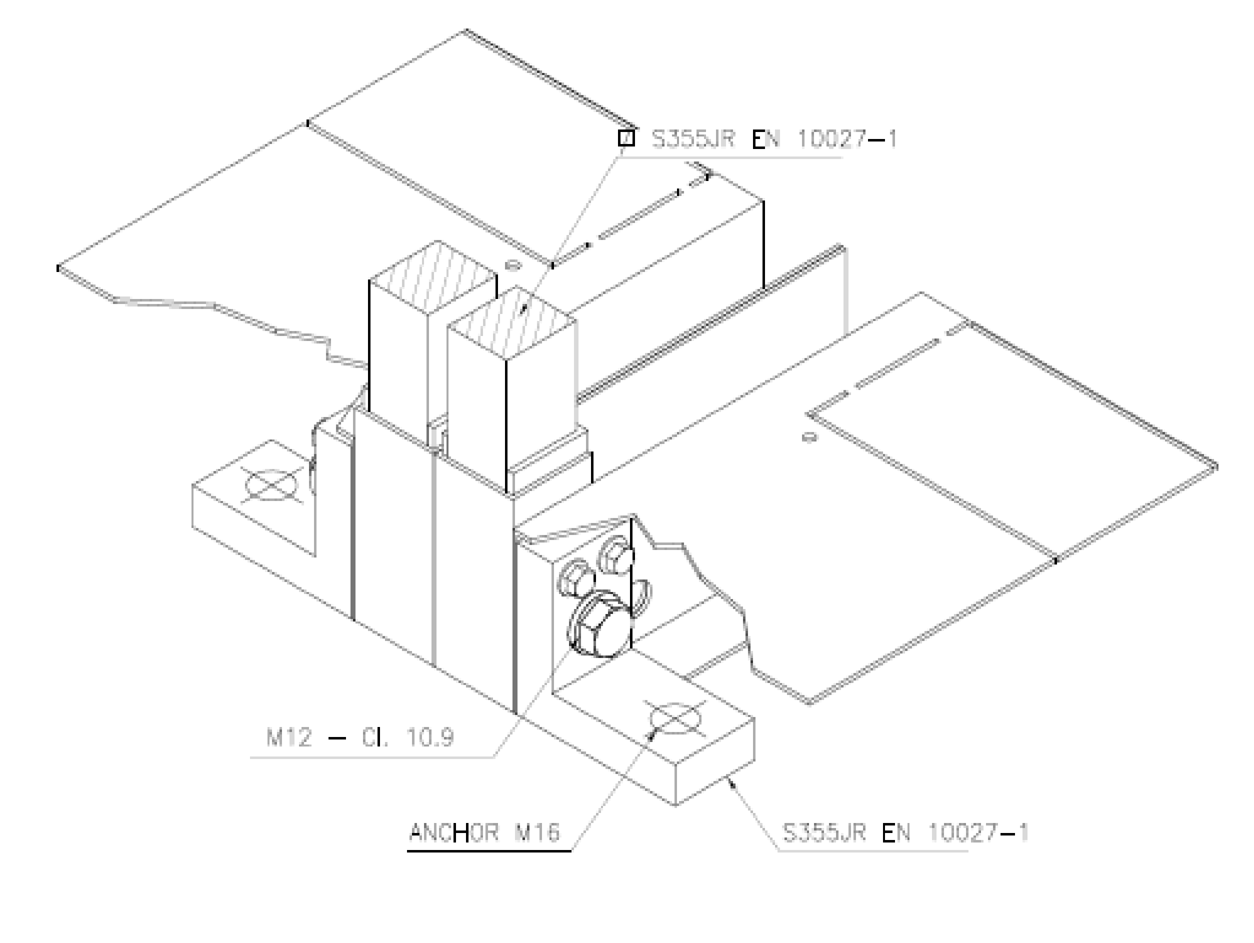

Fig. A: Assonometric view of vertical truss-foundation link

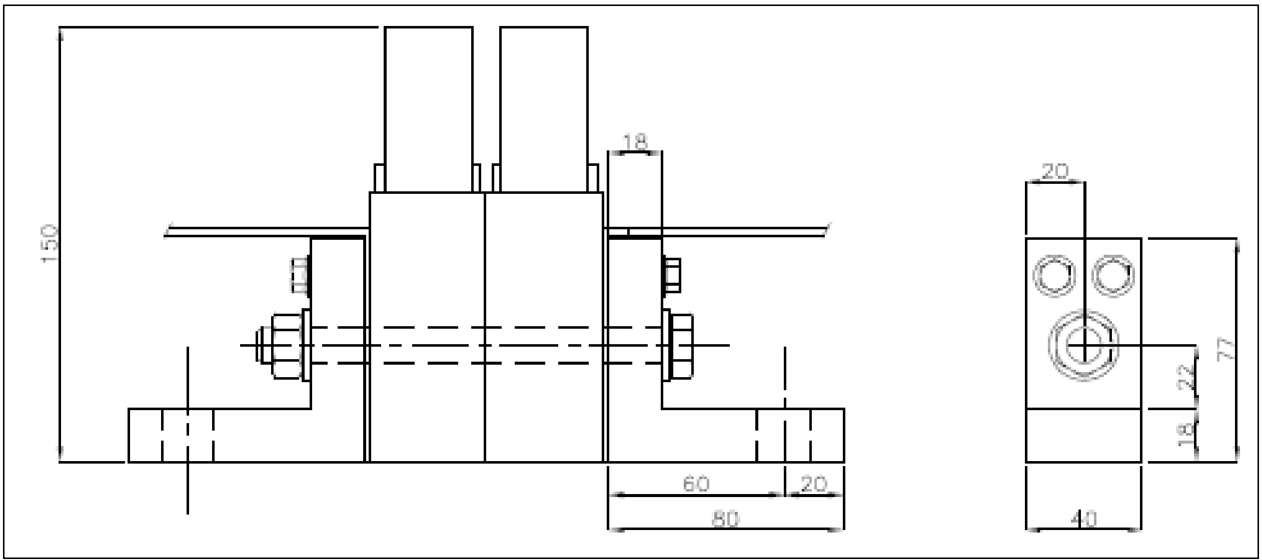

Fig. B: Section of vertical truss-foundation link

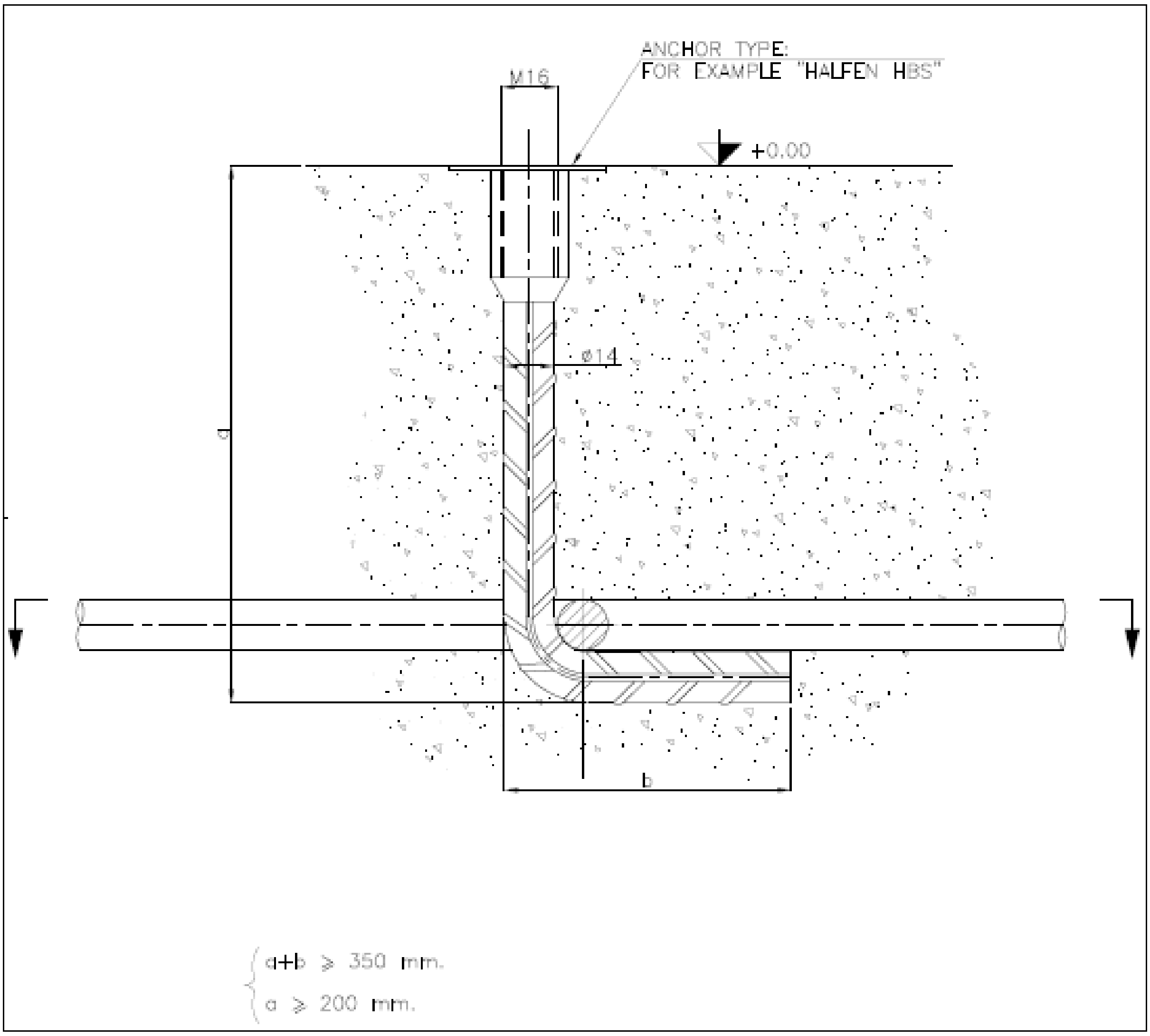

Fig. C: View of clamping bolt in foundation

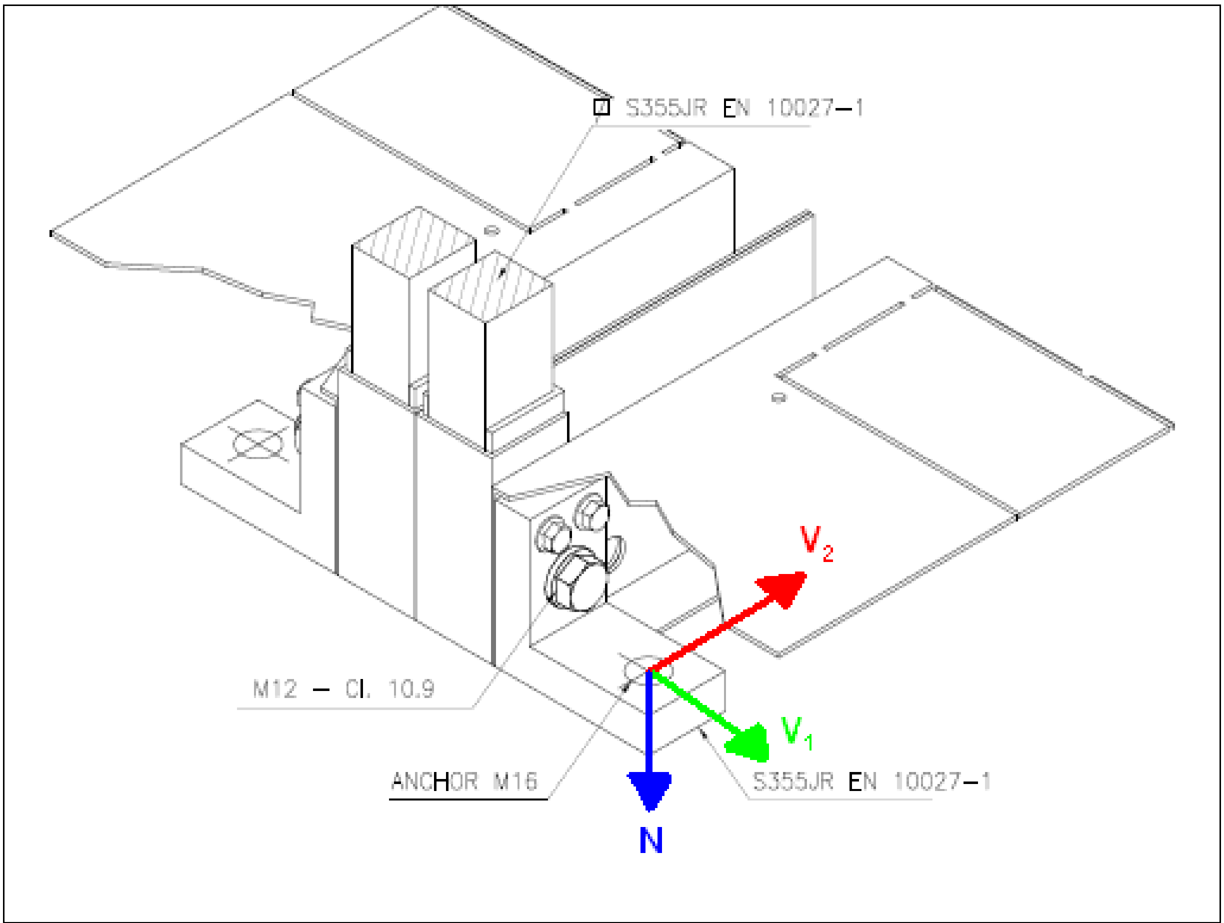

Fig. D: Actions envelope on anchor bolt

Resistence checks are in agreement with [14], [15], [16_2];

Eccentricity from anchor M16 and the vertical truss causes on bolt M12 (Cl. 10.9) the following actions:

$$F_{V,Ed} = 14.74\ kN;$$

$$F_{T,Ed} = 35.86\ kN;$$

Bolt resistence at ULS are:

- Bolt shear resistence

$$F_{v,Rd} = \frac{\alpha_v \cdot f_{ub} \cdot A_s}{\gamma_{M2}} = \frac{0.5 \cdot 1000 \frac{N}{mm^2} \cdot 84mm^2}{1.25} \cdot 0.85 = 28560N$$

- Bolt tension resistence

$$F_{t,Rd} = \frac{0.9 \cdot f_{ub} \cdot A_s}{\gamma_{M2}} = \frac{0.9 \cdot 1000 \frac{N}{mm^2} \cdot 84mm^2}{1.25} = 60480N$$

Checks are verified:

$$\frac{F_{V,Ed}}{F_{V,Rd}} = 0.516 < 1 \rightarrow Ok$$

$$\frac{F_{t,Ed}}{F_{t,Rd}} = 0.59 < 1 \rightarrow Ok$$

$$\frac{F_{V,Ed}}{F_{V,Rd}} + \frac{F_{t,Ed}}{1.4 \cdot F_{t,Rd}} = 0.516 + 0.423 = 0.939 < 1 \rightarrow Ok$$

The lug angle, that links the anchor bolt to the verical truss, is projected with S355 steel and is subjected to the following maximum actions:

$$N_{Ed} = 3.18 \ \ kN;$$
$$M_{Ed,x} = 0.9 \ \ kN \cdot m;$$
$$M_{Ed,y} = 0.353 \ \ kN \cdot m;$$
$$V_{Ed,x} = 5.88 \ \ kN;$$
$$V_{Ed,y} = 13.51 \ \ kN;$$

ULS Resistence actions are:

$$N_{t,Rd} = 255.6 \ \ kN;$$
$$M_{C,Rd,x} = 1.15 \ \ kN \cdot m;$$
$$M_{C,Rd,y} = 2.2556 \ \ kN \cdot m;$$
$$V_{pl,Rd} = 147.57 \ \ kN;$$

$V_{Ed}<0.5 \cdot V_{pl,Rd}$ so ULS checks is :

$$\frac{N_{Ed}}{N_{t,Rd}} + \frac{M_{Ed,x}}{M_{C,Rd,x}} + \frac{M_{Ed,y}}{M_{C,Rd,y}} = 0.0125 + 0.7826 + 0.1565 = 0.9516 < 1 \rightarrow Ok$$

7. MODULUS LINKS CHECK

Bolt of 10mm diameter class 8.8 represent a single link point between two modulus and its check is in agreement with [16_2].

In particular, for the three configurations considered in the analysis, the resistence of every bolts and of the plate are checked.

- Bolt shear resistence

$$F_{v,Rd} = \frac{\alpha_v \cdot f_{ub} \cdot A_s}{\gamma_{M2}} = \frac{0.6 \cdot 800 \frac{N}{mm^2} \cdot 62mm^2}{1.25} \cdot 0.85 = 20237N$$

- Bolt tension resistence

$$F_{t,Rd} = \frac{0.9 \cdot f_{ub} \cdot A_s}{\gamma_{M2}} = \frac{0.9 \cdot 800 \frac{N}{mm^2} \cdot 62mm^2}{1.25} = 35712N$$

- Plate bearing resistence

$$F_{b,Rd} = \frac{k_1 \cdot \alpha_b \cdot f_u \cdot \phi \cdot t}{\gamma_{M2}} = \frac{2.5 \cdot 0.74 \cdot 500 \frac{N}{mm^2} \cdot 10mm \cdot 2mm}{1.25} = 14800N$$

It is checked taking account of the correct plate thickness in correspondence with the considered bolt.

This check is verified in all the plate for the configurations considered.

8. JOINT LINKS CHECKS

In this charter are presented some checks on bolted or riveted links that are realized in agreement with[16_2].

- **Modulus type 1/1' – Checks on horizontal girders**

Cheks on horizontal girder are in agreement with figure E; these transversal elements are defined in the FE model with labels from 7001 to 7034 and from 407001 to 407034.

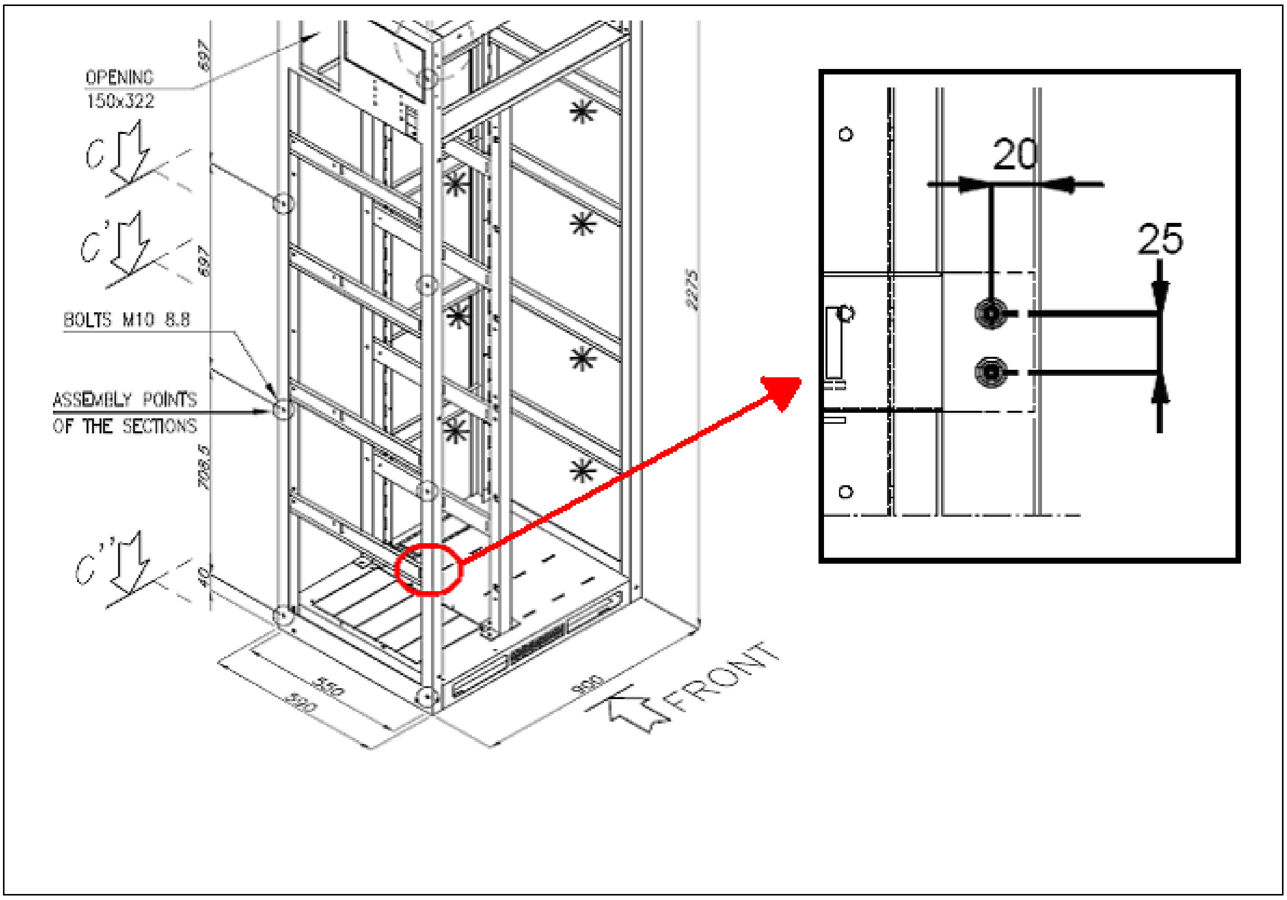

Fig. E: Transversal link and geometry identification

The actions transmitted from the node cause the following maximum shear and axial actions on every rivet:

$$F_{V,Ed} = 4132 \ \ N;$$
$$F_{T,Ed} = 650 \ \ N;$$

In agreement with data sheet (Avdel – Hemlok 2221) it is possibile to obtain the typical value of shear and tension resistence:

- Rivet shear resistence

$$F_{v,Rd} > 12000 N$$

- Rivet tension resistence

$$F_{t,Rd} = 8800 N$$

In agreement with[16_2] checks are verified:

$$\frac{F_{V,Ed}}{F_{V,Rd}} = 0.344 < 1 \rightarrow Ok$$
$$\frac{F_{t,Ed}}{F_{t,Rd}} = 0.074 < 1 \rightarrow Ok$$
$$\frac{F_{V,Ed}}{F_{V,Rd}} + \frac{F_{t,Ed}}{1.4 \cdot F_{t,Rd}} = 0.344 + 0.053 = 0.397 < 1 \rightarrow Ok$$

Checks on the plate are verified on bearing resistence and on the bending resistence to an application of a concentrated load.

$$m_{Ed} = 199 \ \ \frac{N \cdot mm}{mm};$$

In agreement with[16], [16_2] the bearing and bending resistence is:

$$F_{b,Rd} = 8040 N$$
$$m_{Rd} = 250 \frac{N \cdot mm}{mm}$$

In agreement with[16], [16_2] checks are verified:

$$\frac{F_{V,Ed}}{F_{b,Rd}} = 0.514 < 1 \rightarrow Ok$$
$$\frac{m_{Ed}}{m_{Rd}} = 0.796 < 1 \rightarrow Ok$$