

## **ANEXOS**



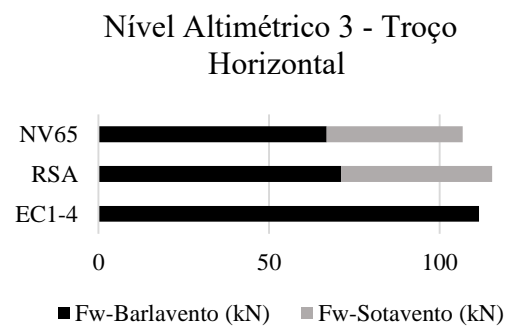
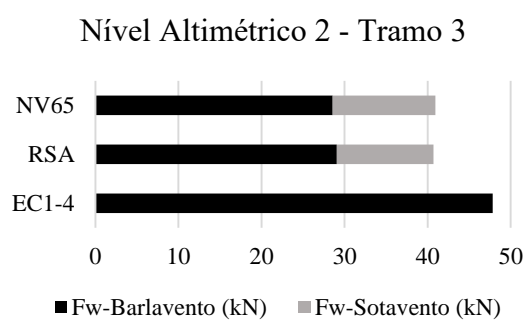
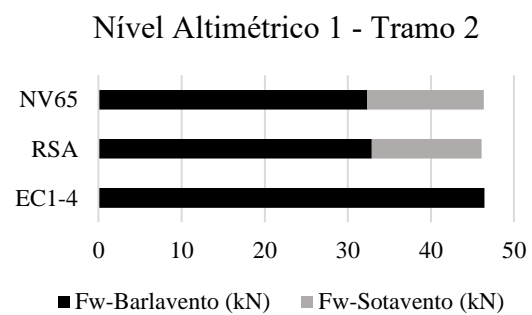
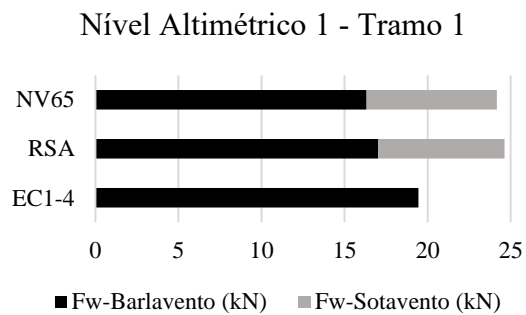
## **ANEXO I**

### **Estudo Comparativo da Ação do Vento**



## Ação do Vento segundo o EC1-4, RSA e NV65

|   |                                      | EC1-4  | RSA   | NV65  |
|---|--------------------------------------|--------|-------|-------|
| <b>Nível Altimétrico 1<br/>Tramo 1</b>          | <b>F<sub>w</sub>-barlavento (kN)</b> | 19.44  | 17.01 | 16.32 |
|   | <b>F<sub>w</sub>-sotavento (kN)</b>  | -      | 7.62  | 7.85  |
| <b>Nível Altimétrico 1<br/>Tramo 2</b>          | <b>F<sub>w</sub>-barlavento (kN)</b> | 46.45  | 32.90 | 32.34 |
|   | <b>F<sub>w</sub>-sotavento (kN)</b>  | -      | 13.19 | 14.01 |
| <b>Nível Altimétrico 2<br/>Tramo 3</b>          | <b>F<sub>w</sub>-barlavento (kN)</b> | 47.81  | 29.05 | 28.56 |
|   | <b>F<sub>w</sub>-sotavento (kN)</b>  | -      | 11.65 | 12.37 |
| <b>Nível Altimétrico 3<br/>Troço Horizontal</b> | <b>F<sub>w</sub>-barlavento (kN)</b> | 111.59 | 71.08 | 66.90 |
|   | <b>F<sub>w</sub>-sotavento (kN)</b>  | -      | 44.35 | 39.91 |





## **ANEXO II**

### Tabelas das Combinações de Ações



## Combinações de Ações

### Simbologia

|         |   |
|---------|---|
| ELU     | estado limite último;                   |
| ELS     | estado limite de serviço ou utilização; |
| PP      | peso próprio;                           |
| RCP     | restante carga permanente;              |
| SC_MAT  | sobrecarga do material na tela;         |
| SC_PASS | sobrecarga nas passerelles;             |
| W       | ação do vento;                          |
| VUT     | variação uniforme de temperatura;       |
| S       | ação do sismo.                          |

### Combinações de Ações para os Estados Limites Últimos

| Combinações (Estados Limites Últimos) (1/3)                  | Ações          |                |                |   |                |     |                                 |     |                                  |     |                                |     |                                 |     |                 |     |                |     |                  |     |                  |     |     |     |     |     |   |
|--|----------------|----------------|----------------|---|----------------|-----|---------------------------------|-----|----------------------------------|-----|--------------------------------|-----|---------------------------------|-----|-----------------|-----|----------------|-----|------------------|-----|------------------|-----|-----|-----|-----|-----|---|
|  | Permanentes    |                | Variáveis      |   |                |     |                                 |     |                                  |     |                                |     |                                 |     |                 |     |                |     |                  |     |                  |     |     |     |     |     |   |
|  | PP             | RCP            | SC_MAT         |   | SC_PASS        |     | W <sub>yy</sub> +W <sub>z</sub> |     | W <sub>yy</sub> +W <sub>zz</sub> |     | W <sub>y</sub> +W <sub>z</sub> |     | W <sub>y</sub> +W <sub>zz</sub> |     | W <sub>xx</sub> |     | W <sub>x</sub> |     | VUT <sup>+</sup> |     | VUT <sup>-</sup> |     | S1X | S1Y | S2X | S2Y |   |
|  | γ <sub>G</sub> | γ <sub>G</sub> | γ <sub>Q</sub> | Ψ | γ <sub>Q</sub> | Ψ   | γ <sub>Q</sub>                  | Ψ   | γ <sub>Q</sub>                   | Ψ   | γ <sub>Q</sub>                 | Ψ   | γ <sub>Q</sub>                  | Ψ   | γ <sub>Q</sub>  | Ψ   | γ <sub>Q</sub> | Ψ   | γ <sub>Q</sub>   | Ψ   | γ <sub>Q</sub>   | Ψ   | γ   | γ   | γ   | γ   |   |
| ELU_MAT_(W <sub>yy</sub> _W <sub>z</sub> _T <sup>+</sup> )   | 1.35           | 1.35           | 1.5            | - | 1.5            | 0.4 | 1.5                             | 0.6 | -                                | -   | -                              | -   | -                               | -   | -               | -   | -              | -   | -                | 1.5 | 0.6              | -   | -   | -   | -   | -   | - |
| ELU_MAT_(W <sub>yy</sub> _W <sub>zz</sub> _T <sup>+</sup> )  | 1.35           | 1.35           | 1.5            | - | 1.5            | 0.4 | -                               | -   | 1.5                              | 0.6 | -                              | -   | -                               | -   | -               | -   | -              | -   | -                | 1.5 | 0.6              | -   | -   | -   | -   | -   | - |
| ELU_MAT_(W <sub>yy</sub> _W <sub>z</sub> _T <sup>-</sup> )   | 1.35           | 1.35           | 1.5            | - | 1.5            | 0.4 | 1.5                             | 0.6 | -                                | -   | -                              | -   | -                               | -   | -               | -   | -              | -   | -                | -   | -                | 1.5 | 0.6 | -   | -   | -   | - |
| ELU_MAT_(W <sub>yy</sub> _W <sub>zz</sub> _T <sup>-</sup> )  | 1.35           | 1.35           | 1.5            | - | 1.5            | 0.4 | -                               | -   | 1.5                              | 0.6 | -                              | -   | -                               | -   | -               | -   | -              | -   | -                | -   | -                | 1.5 | 0.6 | -   | -   | -   | - |
| ELU_MAT_(W <sub>y</sub> _W <sub>z</sub> _T <sup>+</sup> )    | 1.35           | 1.35           | 1.5            | - | 1.5            | 0.4 | -                               | -   | -                                | -   | 1.5                            | 0.6 | -                               | -   | -               | -   | -              | -   | -                | 1.5 | 0.6              | -   | -   | -   | -   | -   | - |
| ELU_MAT_(W <sub>y</sub> _W <sub>zz</sub> _T <sup>+</sup> )   | 1.35           | 1.35           | 1.5            | - | 1.5            | 0.4 | -                               | -   | -                                | -   | -                              | -   | 1.5                             | 0.6 | -               | -   | -              | -   | -                | 1.5 | 0.6              | -   | -   | -   | -   | -   | - |
| ELU_MAT_(W <sub>y</sub> _W <sub>z</sub> _T <sup>-</sup> )    | 1.35           | 1.35           | 1.5            | - | 1.5            | 0.4 | -                               | -   | -                                | -   | 1.5                            | 0.6 | -                               | -   | -               | -   | -              | -   | -                | -   | -                | 1.5 | 0.6 | -   | -   | -   | - |
| ELU_MAT_(W <sub>y</sub> _W <sub>zz</sub> _T <sup>-</sup> )   | 1.35           | 1.35           | 1.5            | - | 1.5            | 0.4 | -                               | -   | -                                | -   | -                              | -   | 1.5                             | 0.6 | -               | -   | -              | -   | -                | -   | -                | 1.5 | 0.6 | -   | -   | -   | - |
| ELU_MAT_(W <sub>xx</sub> _T <sup>+</sup> )                   | 1.35           | 1.35           | 1.5            | - | 1.5            | 0.4 | -                               | -   | -                                | -   | -                              | -   | -                               | -   | 1.5             | 0.6 | -              | -   | 1.5              | 0.6 | -                | -   | -   | -   | -   | -   | - |
| ELU_MAT_(W <sub>x</sub> _T <sup>+</sup> )                    | 1.35           | 1.35           | 1.5            | - | 1.5            | 0.4 | -                               | -   | -                                | -   | -                              | -   | -                               | -   | -               | -   | 1.5            | 0.6 | 1.5              | 0.6 | -                | -   | -   | -   | -   | -   | - |
| ELU_MAT_(W <sub>xx</sub> _T <sup>-</sup> )                   | 1.35           | 1.35           | 1.5            | - | 1.5            | 0.4 | -                               | -   | -                                | -   | -                              | -   | -                               | -   | 1.5             | 0.6 | -              | -   | -                | -   | 1.5              | 0.6 | -   | -   | -   | -   | - |
| ELU_MAT_(W <sub>x</sub> _T <sup>-</sup> )                    | 1.35           | 1.35           | 1.5            | - | 1.5            | 0.4 | -                               | -   | -                                | -   | -                              | -   | -                               | -   | -               | -   | 1.5            | 0.6 | -                | -   | 1.5              | 0.6 | -   | -   | -   | -   | - |
| ELU_PASS_(W <sub>yy</sub> _W <sub>z</sub> _T <sup>+</sup> )  | 1.35           | 1.35           | 1.5            | 1 | 1.5            | -   | 1.5                             | 0.6 | -                                | -   | -                              | -   | -                               | -   | -               | -   | -              | -   | 1.5              | 0.6 | -                | -   | -   | -   | -   | -   | - |
| ELU_PASS_(W <sub>yy</sub> _W <sub>zz</sub> _T <sup>+</sup> ) | 1.35           | 1.35           | 1.5            | 1 | 1.5            | -   | -                               | -   | 1.5                              | 0.6 | -                              | -   | -                               | -   | -               | -   | -              | -   | 1.5              | 0.6 | -                | -   | -   | -   | -   | -   | - |
| ELU_PASS_(W <sub>yy</sub> _W <sub>z</sub> _T <sup>-</sup> )  | 1.35           | 1.35           | 1.5            | 1 | 1.5            | -   | 1.5                             | 0.6 | -                                | -   | -                              | -   | -                               | -   | -               | -   | -              | -   | -                | -   | 1.5              | 0.6 | -   | -   | -   | -   | - |
| ELU_PASS_(W <sub>yy</sub> _W <sub>zz</sub> _T <sup>-</sup> ) | 1.35           | 1.35           | 1.5            | 1 | 1.5            | -   | -                               | -   | 1.5                              | 0.6 | -                              | -   | -                               | -   | -               | -   | -              | -   | -                | -   | 1.5              | 0.6 | -   | -   | -   | -   | - |
| ELU_PASS_(W <sub>y</sub> _W <sub>z</sub> _T <sup>+</sup> )   | 1.35           | 1.35           | 1.5            | 1 | 1.5            | -   | -                               | -   | -                                | -   | 1.5                            | 0.6 | -                               | -   | -               | -   | -              | -   | 1.5              | 0.6 | -                | -   | -   | -   | -   | -   | - |
| ELU_PASS_(W <sub>y</sub> _W <sub>zz</sub> _T <sup>+</sup> )  | 1.35           | 1.35           | 1.5            | 1 | 1.5            | -   | -                               | -   | -                                | -   | -                              | -   | 1.5                             | 0.6 | -               | -   | -              | -   | 1.5              | 0.6 | -                | -   | -   | -   | -   | -   | - |
| ELU_PASS_(W <sub>y</sub> _W <sub>z</sub> _T <sup>-</sup> )   | 1.35           | 1.35           | 1.5            | 1 | 1.5            | -   | -                               | -   | -                                | -   | 1.5                            | 0.6 | -                               | -   | -               | -   | -              | -   | -                | -   | 1.5              | 0.6 | -   | -   | -   | -   | - |

| Combinções (Estados Limites Últimos) (2/3)                  | Ações          |                |                |   |                |     |                                 |     |                                  |     |                                |   |                                 |     |                 |     |                |     |                  |     |                  |     |                |     |     |     |   |   |
|---|----------------|----------------|----------------|---|----------------|-----|---------------------------------|-----|----------------------------------|-----|--------------------------------|---|---------------------------------|-----|-----------------|-----|----------------|-----|------------------|-----|------------------|-----|----------------|-----|-----|-----|---|---|
|   | Permanentes    |                | Variáveis      |   |                |     |                                 |     |                                  |     |                                |   |                                 |     |                 |     |                |     |                  |     |                  |     |                |     |     |     |   |   |
|   | PP             | RCP            | SC_MAT         |   | SC_PASS        |     | W <sub>yy</sub> +W <sub>z</sub> |     | W <sub>yy</sub> +W <sub>zz</sub> |     | W <sub>y</sub> +W <sub>z</sub> |   | W <sub>y</sub> +W <sub>zz</sub> |     | W <sub>xx</sub> |     | W <sub>x</sub> |     | VUT <sup>+</sup> |     | VUT <sup>-</sup> |     | S1X            | S1Y | S2X | S2Y |   |   |
|   | γ <sub>G</sub> | γ <sub>G</sub> | γ <sub>Q</sub> | Ψ | γ <sub>Q</sub> | Ψ   | γ <sub>Q</sub>                  | Ψ   | γ <sub>Q</sub>                   | Ψ   | γ <sub>Q</sub>                 | Ψ | γ <sub>Q</sub>                  | Ψ   | γ <sub>Q</sub>  | Ψ   | γ <sub>Q</sub> | Ψ   | γ <sub>Q</sub>   | Ψ   | γ <sub>Q</sub>   | Ψ   | γ <sub>Q</sub> | Ψ   | γ   | γ   | γ | γ |
| ELU_PASS_(W <sub>y</sub> _W <sub>zz</sub> _T <sup>-</sup> ) | 1.35           | 1.35           | 1.5            | 1 | 1.5            | -   | -                               | -   | -                                | -   | -                              | - | -                               | 1.5 | 0.6             | -   | -              | -   | -                | -   | -                | 1.5 | 0.6            | -   | -   | -   | - | - |
| ELU_PASS_(W <sub>xx</sub> _T <sup>+</sup> )                 | 1.35           | 1.35           | 1.5            | 1 | 1.5            | -   | -                               | -   | -                                | -   | -                              | - | -                               | 1.5 | 0.6             | -   | -              | 1.5 | 0.6              | -   | -                | -   | -              | -   | -   | -   | - | - |
| ELU_PASS_(W <sub>x</sub> _T <sup>+</sup> )                  | 1.35           | 1.35           | 1.5            | 1 | 1.5            | -   | -                               | -   | -                                | -   | -                              | - | -                               | -   | -               | 1.5 | 0.6            | 1.5 | 0.6              | -   | -                | -   | -              | -   | -   | -   | - | - |
| ELU_PASS_(W <sub>xx</sub> _T <sup>-</sup> )                 | 1.35           | 1.35           | 1.5            | 1 | 1.5            | -   | -                               | -   | -                                | -   | -                              | - | -                               | 1.5 | 0.6             | -   | -              | -   | -                | -   | -                | 1.5 | 0.6            | -   | -   | -   | - | - |
| ELU_PASS_(W <sub>x</sub> _T <sup>-</sup> )                  | 1.35           | 1.35           | 1.5            | 1 | 1.5            | -   | -                               | -   | -                                | -   | -                              | - | -                               | -   | -               | 1.5 | 0.6            | -   | -                | -   | -                | 1.5 | 0.6            | -   | -   | -   | - | - |
| ELU_W <sub>yy</sub> _W <sub>z</sub> _(T <sup>+</sup> )      | 1.35           | 1.35           | 1.5            | 1 | 1.5            | 0.4 | 1.5                             | -   | -                                | -   | -                              | - | -                               | -   | -               | -   | -              | 1.5 | 0.6              | -   | -                | -   | -              | -   | -   | -   | - | - |
| ELU_W <sub>yy</sub> _W <sub>zz</sub> _(T <sup>+</sup> )     | 1.35           | 1.35           | 1.5            | 1 | 1.5            | 0.4 | -                               | -   | 1.5                              | -   | -                              | - | -                               | -   | -               | -   | -              | 1.5 | 0.6              | -   | -                | -   | -              | -   | -   | -   | - | - |
| ELU_W <sub>yy</sub> _W <sub>z</sub> _(T <sup>-</sup> )      | 1.35           | 1.35           | 1.5            | 1 | 1.5            | 0.4 | 1.5                             | -   | -                                | -   | -                              | - | -                               | -   | -               | -   | -              | -   | -                | -   | 1.5              | 0.6 | -              | -   | -   | -   | - | - |
| ELU_W <sub>yy</sub> _W <sub>zz</sub> _(T <sup>-</sup> )     | 1.35           | 1.35           | 1.5            | 1 | 1.5            | 0.4 | -                               | -   | 1.5                              | -   | -                              | - | -                               | -   | -               | -   | -              | -   | -                | -   | 1.5              | 0.6 | -              | -   | -   | -   | - | - |
| ELU_W <sub>y</sub> _W <sub>z</sub> _(T <sup>+</sup> )       | 1.35           | 1.35           | 1.5            | 1 | 1.5            | 0.4 | -                               | -   | -                                | -   | 1.5                            | - | -                               | -   | -               | -   | -              | 1.5 | 0.6              | -   | -                | -   | -              | -   | -   | -   | - | - |
| ELU_W <sub>y</sub> _W <sub>zz</sub> _(T <sup>+</sup> )      | 1.35           | 1.35           | 1.5            | 1 | 1.5            | 0.4 | -                               | -   | -                                | -   | -                              | - | 1.5                             | -   | -               | -   | -              | -   | 1.5              | 0.6 | -                | -   | -              | -   | -   | -   | - | - |
| ELU_W <sub>y</sub> _W <sub>z</sub> _(T <sup>-</sup> )       | 1.35           | 1.35           | 1.5            | 1 | 1.5            | 0.4 | -                               | -   | -                                | -   | 1.5                            | - | -                               | -   | -               | -   | -              | -   | -                | -   | 1.5              | 0.6 | -              | -   | -   | -   | - | - |
| ELU_W <sub>y</sub> _W <sub>zz</sub> _(T <sup>-</sup> )      | 1.35           | 1.35           | 1.5            | 1 | 1.5            | 0.4 | -                               | -   | -                                | -   | -                              | - | 1.5                             | -   | -               | -   | -              | -   | -                | -   | 1.5              | 0.6 | -              | -   | -   | -   | - | - |
| ELU_W <sub>xx</sub> _(T <sup>+</sup> )                      | 1.35           | 1.35           | 1.5            | 1 | 1.5            | 0.4 | -                               | -   | -                                | -   | -                              | - | -                               | 1.5 | -               | -   | -              | 1.5 | 0.6              | -   | -                | -   | -              | -   | -   | -   | - | - |
| ELU_W <sub>x</sub> _(T <sup>+</sup> )                       | 1.35           | 1.35           | 1.5            | 1 | 1.5            | 0.4 | -                               | -   | -                                | -   | -                              | - | -                               | -   | -               | 1.5 | -              | 1.5 | 0.6              | -   | -                | -   | -              | -   | -   | -   | - | - |
| ELU_W <sub>xx</sub> _(T <sup>-</sup> )                      | 1.35           | 1.35           | 1.5            | 1 | 1.5            | 0.4 | -                               | -   | -                                | -   | -                              | - | -                               | 1.5 | -               | -   | -              | -   | -                | -   | 1.5              | 0.6 | -              | -   | -   | -   | - | - |
| ELU_W <sub>x</sub> _(T <sup>-</sup> )                       | 1.35           | 1.35           | 1.5            | 1 | 1.5            | 0.4 | -                               | -   | -                                | -   | -                              | - | -                               | -   | -               | 1.5 | -              | -   | -                | -   | 1.5              | 0.6 | -              | -   | -   | -   | - | - |
| ELU_T <sup>+</sup> _(W <sub>yy</sub> _W <sub>z</sub> )      | 1.35           | 1.35           | 1.5            | 1 | 1.5            | 0.4 | 1.5                             | 0.6 | -                                | -   | -                              | - | -                               | -   | -               | -   | -              | 1.5 | -                | -   | -                | -   | -              | -   | -   | -   | - | - |
| ELU_T <sup>+</sup> _(W <sub>yy</sub> _W <sub>zz</sub> )     | 1.35           | 1.35           | 1.5            | 1 | 1.5            | 0.4 | -                               | -   | 1.5                              | 0.6 | -                              | - | -                               | -   | -               | -   | -              | 1.5 | -                | -   | -                | -   | -              | -   | -   | -   | - | - |

| Combinções (Estados Limites Últimos) (3/3) | Ações          |                |                |     |                |     |                                 |     |                                  |     |                                |     |                                 |     |                 |     |                |     |                  |     |                  |     |                |     |     |     |     |     |
|--|----------------|----------------|----------------|-----|----------------|-----|---------------------------------|-----|----------------------------------|-----|--------------------------------|-----|---------------------------------|-----|-----------------|-----|----------------|-----|------------------|-----|------------------|-----|----------------|-----|-----|-----|-----|-----|
|  | Permanentes    |                | Variáveis      |     |                |     |                                 |     |                                  |     |                                |     |                                 |     |                 |     |                |     |                  |     |                  |     |                |     |     |     |     |     |
|  | PP             | RCP            | SC_MAT         |     | SC_PASS        |     | W <sub>yy</sub> +W <sub>z</sub> |     | W <sub>yy</sub> +W <sub>zz</sub> |     | W <sub>y</sub> +W <sub>z</sub> |     | W <sub>y</sub> +W <sub>zz</sub> |     | W <sub>xx</sub> |     | W <sub>x</sub> |     | VUT <sup>+</sup> |     | VUT <sup>-</sup> |     | S1X            | S1Y | S2X | S2Y |     |     |
|  | γ <sub>G</sub> | γ <sub>G</sub> | γ <sub>Q</sub> | Ψ   | γ <sub>Q</sub> | Ψ   | γ <sub>Q</sub>                  | Ψ   | γ <sub>Q</sub>                   | Ψ   | γ <sub>Q</sub>                 | Ψ   | γ <sub>Q</sub>                  | Ψ   | γ <sub>Q</sub>  | Ψ   | γ <sub>Q</sub> | Ψ   | γ <sub>Q</sub>   | Ψ   | γ <sub>Q</sub>   | Ψ   | γ <sub>Q</sub> | Ψ   | γ   | γ   | γ   | γ   |
| ELU_T-(W <sub>yy</sub> _W <sub>z</sub> )   | 1.35           | 1.35           | 1.5            | 1   | 1.5            | 0.4 | 1.5                             | 0.6 | -                                | -   | -                              | -   | -                               | -   | -               | -   | -              | -   | -                | -   | -                | -   | 1.5            | -   | -   | -   | -   | -   |
| ELU_T-(W <sub>yy</sub> _W <sub>zz</sub> )  | 1.35           | 1.35           | 1.5            | 1   | 1.5            | 0.4 | -                               | -   | 1.5                              | 0.6 | -                              | -   | -                               | -   | -               | -   | -              | -   | -                | -   | -                | -   | 1.5            | -   | -   | -   | -   | -   |
| ELU_T+(W <sub>y</sub> _W <sub>z</sub> )    | 1.35           | 1.35           | 1.5            | 1   | 1.5            | 0.4 | -                               | -   | -                                | -   | 1.5                            | 0.6 | -                               | -   | -               | -   | -              | -   | -                | 1.5 | -                | -   | -              | -   | -   | -   | -   | -   |
| ELU_T+(W <sub>y</sub> _W <sub>zz</sub> )   | 1.35           | 1.35           | 1.5            | 1   | 1.5            | 0.4 | -                               | -   | -                                | -   | -                              | -   | 1.5                             | 0.6 | -               | -   | -              | -   | -                | 1.5 | -                | -   | -              | -   | -   | -   | -   | -   |
| ELU_T-(W <sub>y</sub> _W <sub>z</sub> )    | 1.35           | 1.35           | 1.5            | 1   | 1.5            | 0.4 | -                               | -   | -                                | -   | 1.5                            | 0.6 | -                               | -   | -               | -   | -              | -   | -                | -   | -                | -   | 1.5            | -   | -   | -   | -   | -   |
| ELU_T-(W <sub>y</sub> _W <sub>zz</sub> )   | 1.35           | 1.35           | 1.5            | 1   | 1.5            | 0.4 | -                               | -   | -                                | -   | -                              | -   | 1.5                             | 0.6 | -               | -   | -              | -   | -                | -   | -                | -   | 1.5            | -   | -   | -   | -   | -   |
| ELU_T+(W <sub>xx</sub> )                   | 1.35           | 1.35           | 1.5            | 1   | 1.5            | 0.4 | -                               | -   | -                                | -   | -                              | -   | -                               | -   | 1.5             | 0.6 | -              | -   | 1.5              | -   | -                | -   | -              | -   | -   | -   | -   | -   |
| ELU_T+(W <sub>x</sub> )                    | 1.35           | 1.35           | 1.5            | 1   | 1.5            | 0.4 | -                               | -   | -                                | -   | -                              | -   | -                               | -   | -               | -   | 1.5            | 0.6 | 1.5              | -   | -                | -   | -              | -   | -   | -   | -   | -   |
| ELU_T-(W <sub>xx</sub> )                   | 1.35           | 1.35           | 1.5            | 1   | 1.5            | 0.4 | -                               | -   | -                                | -   | -                              | -   | -                               | -   | 1.5             | 0.6 | -              | -   | -                | -   | -                | 1.5 | -              | -   | -   | -   | -   | -   |
| ELU_T-(W <sub>x</sub> )                    | 1.35           | 1.35           | 1.5            | 1   | 1.5            | 0.4 | -                               | -   | -                                | -   | -                              | -   | -                               | -   | -               | -   | 1.5            | 0.6 | -                | -   | -                | 1.5 | -              | -   | -   | -   | -   | -   |
| ELU_S1X                                    | 1              | 1              | 1              | 0.8 | 1              | 0   | 1                               | 0   | 1                                | 0   | 1                              | 0   | 1                               | 0   | 1               | 0   | 1              | 0   | 1                | 0   | 1                | 0   | 1              | 0   | 1   | 0.3 | -   | -   |
| ELU_S1Y                                    | 1              | 1              | 1              | 0.8 | 1              | 0   | 1                               | 0   | 1                                | 0   | 1                              | 0   | 1                               | 0   | 1               | 0   | 1              | 0   | 1                | 0   | 1                | 0   | 1              | 0   | 0.3 | 1   | -   | -   |
| ELU_S2X                                    | 1              | 1              | 1              | 0.8 | 1              | 0   | 1                               | 0   | 1                                | 0   | 1                              | 0   | 1                               | 0   | 1               | 0   | 1              | 0   | 1                | 0   | 1                | 0   | 1              | 0   | -   | -   | 1   | 0.3 |
| ELU_S2Y                                    | 1              | 1              | 1              | 0.8 | 1              | 0   | 1                               | 0   | 1                                | 0   | 1                              | 0   | 1                               | 0   | 1               | 0   | 1              | 0   | 1                | 0   | 1                | 0   | 1              | 0   | -   | -   | 0.3 | 1   |

### Combinações de Ações para os Estados Limites de Serviço

| Combinações (Estados Limites de Serviço)<br>(1/3) | Ações          |                |                |   |                |     |                                 |     |                                  |     |                                |     |                                 |     |                 |     |                |     |                  |     |                  |     |
|---|----------------|----------------|----------------|---|----------------|-----|---------------------------------|-----|----------------------------------|-----|--------------------------------|-----|---------------------------------|-----|-----------------|-----|----------------|-----|------------------|-----|------------------|-----|
|   | Permanentes    |                | Variáveis      |   |                |     |                                 |     |                                  |     |                                |     |                                 |     |                 |     |                |     |                  |     |                  |     |
|   | PP             | RCP            | SC_MAT         |   | SC_PASS        |     | W <sub>yy</sub> +W <sub>z</sub> |     | W <sub>yy</sub> +W <sub>zz</sub> |     | W <sub>y</sub> +W <sub>z</sub> |     | W <sub>y</sub> +W <sub>zz</sub> |     | W <sub>xx</sub> |     | W <sub>x</sub> |     | VUT <sup>+</sup> |     | VUT <sup>-</sup> |     |
|   | γ <sub>G</sub> | γ <sub>G</sub> | γ <sub>Q</sub> | Ψ | γ <sub>Q</sub> | Ψ   | γ <sub>Q</sub>                  | Ψ   | γ <sub>Q</sub>                   | Ψ   | γ <sub>Q</sub>                 | Ψ   | γ <sub>Q</sub>                  | Ψ   | γ <sub>Q</sub>  | Ψ   | γ <sub>Q</sub> | Ψ   | γ <sub>Q</sub>   | Ψ   | γ <sub>Q</sub>   | Ψ   |
| ELS_MAT_(W <sub>yy</sub> _W <sub>z</sub> _T+)     | 1              | 1              | 1              | - | 1              | 0.4 | 1                               | 0.6 | -                                | -   | -                              | -   | -                               | -   | -               | -   | -              | -   | 1                | 0.6 | -                | -   |
| ELS_MAT_(W <sub>yy</sub> _W <sub>zz</sub> _T+)    | 1              | 1              | 1              | - | 1              | 0.4 | -                               | -   | 1                                | 0.6 | -                              | -   | -                               | -   | -               | -   | -              | -   | 1                | 0.6 | -                | -   |
| ELS_MAT_(W <sub>yy</sub> _W <sub>z</sub> _T-)     | 1              | 1              | 1              | - | 1              | 0.4 | 1                               | 0.6 | -                                | -   | -                              | -   | -                               | -   | -               | -   | -              | -   | -                | -   | 1                | 0.6 |
| ELS_MAT_(W <sub>yy</sub> _W <sub>zz</sub> _T-)    | 1              | 1              | 1              | - | 1              | 0.4 | -                               | -   | 1                                | 0.6 | -                              | -   | -                               | -   | -               | -   | -              | -   | -                | -   | 1                | 0.6 |
| ELS_MAT_(W <sub>y</sub> _W <sub>z</sub> _T+)      | 1              | 1              | 1              | - | 1              | 0.4 | -                               | -   | -                                | -   | 1                              | 0.6 | -                               | -   | -               | -   | -              | -   | 1                | 0.6 | -                | -   |
| ELS_MAT_(W <sub>y</sub> _W <sub>zz</sub> _T+)     | 1              | 1              | 1              | - | 1              | 0.4 | -                               | -   | -                                | -   | -                              | -   | 1                               | 0.6 | -               | -   | -              | -   | 1                | 0.6 | -                | -   |
| ELS_MAT_(W <sub>y</sub> _W <sub>z</sub> _T-)      | 1              | 1              | 1              | - | 1              | 0.4 | -                               | -   | -                                | -   | 1                              | 0.6 | -                               | -   | -               | -   | -              | -   | -                | -   | 1                | 0.6 |
| ELS_MAT_(W <sub>y</sub> _W <sub>zz</sub> _T-)     | 1              | 1              | 1              | - | 1              | 0.4 | -                               | -   | -                                | -   | -                              | -   | 1                               | 0.6 | -               | -   | -              | -   | -                | -   | 1                | 0.6 |
| ELS_MAT_(W <sub>xx</sub> _T+)                     | 1              | 1              | 1              | - | 1              | 0.4 | -                               | -   | -                                | -   | -                              | -   | -                               | -   | 1               | 0.6 | -              | -   | 1                | 0.6 | -                | -   |
| ELS_MAT_(W <sub>x</sub> _T+)                      | 1              | 1              | 1              | - | 1              | 0.4 | -                               | -   | -                                | -   | -                              | -   | -                               | -   | -               | -   | 1              | 0.6 | 1                | 0.6 | -                | -   |
| ELS_MAT_(W <sub>xx</sub> _T-)                     | 1              | 1              | 1              | - | 1              | 0.4 | -                               | -   | -                                | -   | -                              | -   | -                               | -   | 1               | 0.6 | -              | -   | -                | -   | 1                | 0.6 |
| ELS_MAT_(W <sub>x</sub> _T-)                      | 1              | 1              | 1              | - | 1              | 0.4 | -                               | -   | -                                | -   | -                              | -   | -                               | -   | -               | -   | 1              | 0.6 | -                | -   | 1                | 0.6 |
| ELS_PASS_(W <sub>yy</sub> _W <sub>z</sub> _T+)    | 1              | 1              | 1              | 1 | 1              | -   | 1                               | 0.6 | -                                | -   | -                              | -   | -                               | -   | -               | -   | -              | -   | 1                | 0.6 | -                | -   |
| ELS_PASS_(W <sub>yy</sub> _W <sub>zz</sub> _T+)   | 1              | 1              | 1              | 1 | 1              | -   | -                               | -   | 1                                | 0.6 | -                              | -   | -                               | -   | -               | -   | -              | -   | 1                | 0.6 | -                | -   |
| ELS_PASS_(W <sub>yy</sub> _W <sub>z</sub> _T-)    | 1              | 1              | 1              | 1 | 1              | -   | 1                               | 0.6 | -                                | -   | -                              | -   | -                               | -   | -               | -   | -              | -   | -                | -   | 1                | 0.6 |
| ELS_PASS_(W <sub>yy</sub> _W <sub>zz</sub> _T-)   | 1              | 1              | 1              | 1 | 1              | -   | -                               | -   | 1                                | 0.6 | -                              | -   | -                               | -   | -               | -   | -              | -   | -                | -   | 1                | 0.6 |
| ELS_PASS_(W <sub>y</sub> _W <sub>z</sub> _T+)     | 1              | 1              | 1              | 1 | 1              | -   | -                               | -   | -                                | -   | 1                              | 0.6 | -                               | -   | -               | -   | -              | -   | 1                | 0.6 | -                | -   |
| ELS_PASS_(W <sub>y</sub> _W <sub>zz</sub> _T+)    | 1              | 1              | 1              | 1 | 1              | -   | -                               | -   | -                                | -   | -                              | -   | 1                               | 0.6 | -               | -   | -              | -   | 1                | 0.6 | -                | -   |
| ELS_PASS_(W <sub>y</sub> _W <sub>z</sub> _T-)     | 1              | 1              | 1              | 1 | 1              | -   | -                               | -   | -                                | -   | 1                              | 0.6 | -                               | -   | -               | -   | -              | -   | -                | -   | 1                | 0.6 |

| Combinções (Estados Limites de Serviço)<br>(2/3)        | Ações          |                |                |   |                |     |                                 |     |                                  |     |                                |   |                                 |   |                 |   |                |     |                  |     |                  |     |     |
|---|----------------|----------------|----------------|---|----------------|-----|---------------------------------|-----|----------------------------------|-----|--------------------------------|---|---------------------------------|---|-----------------|---|----------------|-----|------------------|-----|------------------|-----|-----|
|   | Permanentes    |                | Variáveis      |   |                |     |                                 |     |                                  |     |                                |   |                                 |   |                 |   |                |     |                  |     |                  |     |     |
|   | PP             | RCP            | SC_MAT         |   | SC_PASS        |     | W <sub>yy</sub> +W <sub>z</sub> |     | W <sub>yy</sub> +W <sub>zz</sub> |     | W <sub>y</sub> +W <sub>z</sub> |   | W <sub>y</sub> +W <sub>zz</sub> |   | W <sub>xx</sub> |   | W <sub>x</sub> |     | VUT <sup>+</sup> |     | VUT <sup>-</sup> |     |     |
|   | γ <sub>G</sub> | γ <sub>G</sub> | γ <sub>Q</sub> | Ψ | γ <sub>Q</sub> | Ψ   | γ <sub>Q</sub>                  | Ψ   | γ <sub>Q</sub>                   | Ψ   | γ <sub>Q</sub>                 | Ψ | γ <sub>Q</sub>                  | Ψ | γ <sub>Q</sub>  | Ψ | γ <sub>Q</sub> | Ψ   | γ <sub>Q</sub>   | Ψ   | γ <sub>Q</sub>   | Ψ   |     |
| ELS_PASS_(W <sub>y</sub> _W <sub>zz</sub> _T-)          | 1              | 1              | 1              | 1 | 1              | -   | -                               | -   | -                                | -   | -                              | - | -                               | 1 | 0.6             | - | -              | -   | -                | -   | -                | 1   | 0.6 |
| ELS_PASS_(W <sub>xx</sub> _T+)                          | 1              | 1              | 1              | 1 | 1              | -   | -                               | -   | -                                | -   | -                              | - | -                               | - | -               | 1 | 0.6            | -   | -                | 1   | 0.6              | -   | -   |
| ELS_PASS_(W <sub>x</sub> _T+)                           | 1              | 1              | 1              | 1 | 1              | -   | -                               | -   | -                                | -   | -                              | - | -                               | - | -               | - | 1              | 0.6 | 1                | 0.6 | -                | -   | -   |
| ELS_PASS_(W <sub>xx</sub> _T-)                          | 1              | 1              | 1              | 1 | 1              | -   | -                               | -   | -                                | -   | -                              | - | -                               | - | -               | 1 | 0.6            | -   | -                | -   | -                | 1   | 0.6 |
| ELS_PASS_(W <sub>x</sub> _T-)                           | 1              | 1              | 1              | 1 | 1              | -   | -                               | -   | -                                | -   | -                              | - | -                               | - | -               | - | 1              | 0.6 | -                | -   | 1                | 0.6 | -   |
| ELS_W <sub>yy</sub> _W <sub>z</sub> _(T+)               | 1              | 1              | 1              | 1 | 1              | 0.4 | 1                               | -   | -                                | -   | -                              | - | -                               | - | -               | - | -              | -   | -                | 1   | 0.6              | -   | -   |
| ELS_W <sub>yy</sub> _W <sub>zz</sub> _(T+)              | 1              | 1              | 1              | 1 | 1              | 0.4 | -                               | -   | 1                                | -   | -                              | - | -                               | - | -               | - | -              | -   | -                | 1   | 0.6              | -   | -   |
| ELS_W <sub>yy</sub> _W <sub>z</sub> _(T-)               | 1              | 1              | 1              | 1 | 1              | 0.4 | 1                               | -   | -                                | -   | -                              | - | -                               | - | -               | - | -              | -   | -                | -   | -                | 1   | 0.6 |
| ELS_W <sub>yy</sub> _W <sub>zz</sub> _(T-)              | 1              | 1              | 1              | 1 | 1              | 0.4 | -                               | -   | 1                                | -   | -                              | - | -                               | - | -               | - | -              | -   | -                | -   | -                | 1   | 0.6 |
| ELS_W <sub>y</sub> _W <sub>z</sub> _(T+)                | 1              | 1              | 1              | 1 | 1              | 0.4 | -                               | -   | -                                | -   | 1                              | - | -                               | - | -               | - | -              | -   | -                | 1   | 0.6              | -   | -   |
| ELS_W <sub>y</sub> _W <sub>zz</sub> _(T+)               | 1              | 1              | 1              | 1 | 1              | 0.4 | -                               | -   | -                                | -   | -                              | - | 1                               | - | -               | - | -              | -   | -                | 1   | 0.6              | -   | -   |
| ELS_W <sub>y</sub> _W <sub>z</sub> _(T-)                | 1              | 1              | 1              | 1 | 1              | 0.4 | -                               | -   | -                                | -   | 1                              | - | -                               | - | -               | - | -              | -   | -                | -   | -                | 1   | 0.6 |
| ELS_W <sub>y</sub> _W <sub>zz</sub> _(T-)               | 1              | 1              | 1              | 1 | 1              | 0.4 | -                               | -   | -                                | -   | -                              | - | 1                               | - | -               | - | -              | -   | -                | -   | -                | 1   | 0.6 |
| ELS_W <sub>xx</sub> _(T+)                               | 1              | 1              | 1              | 1 | 1              | 0.4 | -                               | -   | -                                | -   | -                              | - | -                               | - | -               | 1 | -              | -   | -                | 1   | 0.6              | -   | -   |
| ELS_W <sub>x</sub> _(T+)                                | 1              | 1              | 1              | 1 | 1              | 0.4 | -                               | -   | -                                | -   | -                              | - | -                               | - | -               | - | -              | 1   | -                | 1   | 0.6              | -   | -   |
| ELS_W <sub>xx</sub> _(T-)                               | 1              | 1              | 1              | 1 | 1              | 0.4 | -                               | -   | -                                | -   | -                              | - | -                               | - | -               | 1 | -              | -   | -                | -   | -                | 1   | 0.6 |
| ELS_W <sub>x</sub> _(T-)                                | 1              | 1              | 1              | 1 | 1              | 0.4 | -                               | -   | -                                | -   | -                              | - | -                               | - | -               | - | -              | 1   | -                | -   | -                | 1   | 0.6 |
| ELS_T <sub>+</sub> _(W <sub>yy</sub> _W <sub>z</sub> )  | 1              | 1              | 1              | 1 | 1              | 0.4 | 1                               | 0.6 | -                                | -   | -                              | - | -                               | - | -               | - | -              | -   | -                | 1   | -                | -   | -   |
| ELS_T <sub>+</sub> _(W <sub>yy</sub> _W <sub>zz</sub> ) | 1              | 1              | 1              | 1 | 1              | 0.4 | -                               | -   | 1                                | 0.6 | -                              | - | -                               | - | -               | - | -              | -   | -                | 1   | -                | -   | -   |

| Combinções (Estados Limites de Serviço)<br>(3/3) | Ações          |                |                |   |                |     |                                 |     |                                  |     |                                |     |                                 |     |                 |     |                |     |                  |   |                  |   |   |
|--|----------------|----------------|----------------|---|----------------|-----|---------------------------------|-----|----------------------------------|-----|--------------------------------|-----|---------------------------------|-----|-----------------|-----|----------------|-----|------------------|---|------------------|---|---|
|  | Permanentes    |                | Variáveis      |   |                |     |                                 |     |                                  |     |                                |     |                                 |     |                 |     |                |     |                  |   |                  |   |   |
|  | PP             | RCP            | SC_MAT         |   | SC_PASS        |     | W <sub>yy</sub> +W <sub>z</sub> |     | W <sub>yy</sub> +W <sub>zz</sub> |     | W <sub>y</sub> +W <sub>z</sub> |     | W <sub>y</sub> +W <sub>zz</sub> |     | W <sub>xx</sub> |     | W <sub>x</sub> |     | VUT <sup>+</sup> |   | VUT <sup>-</sup> |   |   |
|  | γ <sub>G</sub> | γ <sub>G</sub> | γ <sub>Q</sub> | Ψ | γ <sub>Q</sub> | Ψ   | γ <sub>Q</sub>                  | Ψ   | γ <sub>Q</sub>                   | Ψ   | γ <sub>Q</sub>                 | Ψ   | γ <sub>Q</sub>                  | Ψ   | γ <sub>Q</sub>  | Ψ   | γ <sub>Q</sub> | Ψ   | γ <sub>Q</sub>   | Ψ | γ <sub>Q</sub>   | Ψ |   |
| ELS_T-(W <sub>yy</sub> _Wz)                      | 1              | 1              | 1              | 1 | 1              | 0.4 | 1                               | 0.6 | -                                | -   | -                              | -   | -                               | -   | -               | -   | -              | -   | -                | - | -                | 1 | - |
| ELS_T-(W <sub>yy</sub> _Wzz_)                    | 1              | 1              | 1              | 1 | 1              | 0.4 | -                               | -   | 1                                | 0.6 | -                              | -   | -                               | -   | -               | -   | -              | -   | -                | - | -                | 1 | - |
| ELS_T+(W <sub>y</sub> _Wz)                       | 1              | 1              | 1              | 1 | 1              | 0.4 | -                               | -   | -                                | -   | 1                              | 0.6 | -                               | -   | -               | -   | -              | -   | -                | - | 1                | - | - |
| ELS_T+(W <sub>y</sub> _Wzz)                      | 1              | 1              | 1              | 1 | 1              | 0.4 | -                               | -   | -                                | -   | -                              | -   | 1                               | 0.6 | -               | -   | -              | -   | -                | - | 1                | - | - |
| ELS_T-(W <sub>y</sub> _Wz)                       | 1              | 1              | 1              | 1 | 1              | 0.4 | -                               | -   | -                                | -   | 1                              | 0.6 | -                               | -   | -               | -   | -              | -   | -                | - | -                | 1 | - |
| ELS_T-(W <sub>y</sub> _Wzz)                      | 1              | 1              | 1              | 1 | 1              | 0.4 | -                               | -   | -                                | -   | -                              | -   | 1                               | 0.6 | -               | -   | -              | -   | -                | - | -                | 1 | - |
| ELS_T+(W <sub>xx</sub> )                         | 1              | 1              | 1              | 1 | 1              | 0.4 | -                               | -   | -                                | -   | -                              | -   | -                               | -   | 1               | 0.6 | -              | -   | -                | - | 1                | - | - |
| ELS_T+(W <sub>x</sub> )                          | 1              | 1              | 1              | 1 | 1              | 0.4 | -                               | -   | -                                | -   | -                              | -   | -                               | -   | -               | -   | 1              | 0.6 | 1                | - | -                | - | - |
| ELS_T-(W <sub>xx</sub> )                         | 1              | 1              | 1              | 1 | 1              | 0.4 | -                               | -   | -                                | -   | -                              | -   | -                               | -   | 1               | 0.6 | -              | -   | -                | - | -                | 1 | - |
| ELS_T-(W <sub>x</sub> )                          | 1              | 1              | 1              | 1 | 1              | 0.4 | -                               | -   | -                                | -   | -                              | -   | -                               | -   | -               | -   | 1              | 0.6 | -                | - | -                | 1 | - |



## **ANEXO III**

### **Tabelas dos Modos de Vibração**



### Participações Modais dos Modos de Vibração nas Direções Principais

| Modo Nº | T (s) | U <sub>x</sub> | ΣU <sub>x</sub> | U <sub>y</sub> | ΣU <sub>y</sub> |
|---------|-------|----------------|-----------------|----------------|-----------------|
| 1       | 0.77  | 0.00%          | 0.00%           | 12.50%         | 12.50%          |
| 2       | 0.70  | 0.00%          | 0.00%           | 0.08%          | 12.58%          |
| 3       | 0.62  | 0.00%          | 0.00%           | 3.21%          | 15.79%          |
| 4       | 0.50  | 0.00%          | 0.00%           | 0.01%          | 15.81%          |
| 5       | 0.46  | 21.04%         | 21.05%          | 0.00%          | 15.81%          |
| 6       | 0.39  | 0.00%          | 21.05%          | 0.56%          | 16.37%          |
| 7       | 0.36  | 0.00%          | 21.05%          | 1.31%          | 17.68%          |
| 8       | 0.33  | 0.00%          | 21.05%          | 0.98%          | 18.66%          |
| 9       | 0.31  | 0.03%          | 21.07%          | 0.00%          | 18.66%          |
| 10      | 0.30  | 0.00%          | 21.07%          | 0.33%          | 18.99%          |
| 11      | 0.28  | 0.02%          | 21.09%          | 0.00%          | 18.99%          |
| 12      | 0.28  | 0.00%          | 21.10%          | 0.02%          | 19.01%          |
| 13      | 0.28  | 0.00%          | 21.10%          | 0.17%          | 19.19%          |
| 14      | 0.28  | 0.00%          | 21.10%          | 1.54%          | 20.73%          |
| 15      | 0.25  | 0.00%          | 21.10%          | 0.00%          | 20.73%          |
| 16      | 0.25  | 0.60%          | 21.70%          | 0.00%          | 20.73%          |
| 17      | 0.24  | 0.00%          | 21.70%          | 0.00%          | 20.73%          |
| 18      | 0.24  | 0.00%          | 21.71%          | 0.00%          | 20.73%          |
| 19      | 0.24  | 0.00%          | 21.71%          | 0.47%          | 21.20%          |
| 20      | 0.23  | 0.01%          | 21.71%          | 0.00%          | 21.20%          |
| 21      | 0.22  | 0.00%          | 21.71%          | 0.07%          | 21.28%          |
| 22      | 0.22  | 2.89%          | 24.61%          | 0.00%          | 21.28%          |
| 23      | 0.21  | 0.00%          | 24.61%          | 0.22%          | 21.49%          |
| 24      | 0.21  | 0.00%          | 24.61%          | 0.01%          | 21.50%          |
| 25      | 0.20  | 4.03%          | 28.64%          | 0.00%          | 21.50%          |
| 26      | 0.20  | 4.05%          | 32.69%          | 0.00%          | 21.50%          |
| 27      | 0.20  | 0.00%          | 32.69%          | 0.70%          | 22.20%          |
| 28      | 0.20  | 6.22%          | 38.91%          | 0.00%          | 22.20%          |
| 29      | 0.20  | 0.64%          | 39.55%          | 0.00%          | 22.20%          |
| 30      | 0.20  | 0.00%          | 39.55%          | 0.00%          | 22.20%          |
| 31      | 0.19  | 1.19%          | 40.73%          | 0.00%          | 22.21%          |
| 32      | 0.19  | 0.00%          | 40.74%          | 0.33%          | 22.54%          |
| 33      | 0.18  | 1.20%          | 41.94%          | 0.11%          | 22.65%          |
| 34      | 0.18  | 0.16%          | 42.10%          | 0.57%          | 23.22%          |
| 35      | 0.18  | 0.05%          | 42.15%          | 0.01%          | 23.23%          |
| 36      | 0.17  | 0.00%          | 42.15%          | 5.71%          | 28.94%          |
| 37      | 0.17  | 0.00%          | 42.15%          | 0.00%          | 28.94%          |
| 38      | 0.17  | 0.00%          | 42.15%          | 0.04%          | 28.99%          |
| 39      | 0.17  | 0.00%          | 42.15%          | 0.15%          | 29.13%          |
| 40      | 0.17  | 0.00%          | 42.15%          | 0.00%          | 29.13%          |
| 41      | 0.17  | 0.00%          | 42.15%          | 0.00%          | 29.13%          |
| 42      | 0.17  | 0.04%          | 42.19%          | 0.06%          | 29.20%          |
| 43      | 0.17  | 0.84%          | 43.03%          | 0.00%          | 29.20%          |
| 44      | 0.16  | 0.00%          | 43.03%          | 0.21%          | 29.41%          |
| 45      | 0.16  | 0.00%          | 43.03%          | 13.95%         | 43.35%          |
| 46      | 0.16  | 0.00%          | 43.03%          | 0.58%          | 43.93%          |
| 47      | 0.16  | 0.00%          | 43.03%          | 0.52%          | 44.45%          |
| 48      | 0.16  | 0.24%          | 43.27%          | 0.00%          | 44.45%          |
| 49      | 0.16  | 0.00%          | 43.27%          | 1.45%          | 45.90%          |
| 50      | 0.15  | 0.00%          | 43.27%          | 0.19%          | 46.09%          |
| 51      | 0.15  | 1.63%          | 44.90%          | 0.00%          | 46.09%          |
| 52      | 0.15  | 0.00%          | 44.90%          | 0.75%          | 46.84%          |
| 53      | 0.15  | 0.00%          | 44.90%          | 0.00%          | 46.84%          |
| 54      | 0.14  | 0.04%          | 44.94%          | 0.01%          | 46.85%          |
| 55      | 0.14  | 0.00%          | 44.94%          | 3.93%          | 50.78%          |

|     |      |       |        |       |        |
|-----|------|-------|--------|-------|--------|
| 56  | 0.14 | 0.00% | 44.94% | 0.10% | 50.88% |
| 57  | 0.14 | 0.00% | 44.94% | 0.41% | 51.29% |
| 58  | 0.13 | 0.00% | 44.95% | 0.00% | 51.29% |
| 59  | 0.13 | 0.00% | 44.95% | 0.66% | 51.95% |
| 60  | 0.13 | 0.00% | 44.95% | 0.30% | 52.25% |
| 61  | 0.12 | 0.00% | 44.95% | 0.36% | 52.61% |
| 62  | 0.12 | 0.00% | 44.95% | 0.00% | 52.61% |
| 63  | 0.12 | 0.00% | 44.95% | 0.03% | 52.65% |
| 64  | 0.12 | 0.00% | 44.95% | 0.00% | 52.65% |
| 65  | 0.12 | 0.01% | 44.96% | 0.00% | 52.65% |
| 66  | 0.11 | 0.00% | 44.96% | 0.00% | 52.65% |
| 67  | 0.11 | 0.00% | 44.96% | 0.05% | 52.70% |
| 68  | 0.11 | 0.00% | 44.96% | 0.05% | 52.75% |
| 69  | 0.11 | 0.00% | 44.96% | 0.00% | 52.75% |
| 70  | 0.11 | 0.00% | 44.96% | 0.01% | 52.76% |
| 71  | 0.11 | 0.00% | 44.96% | 0.00% | 52.76% |
| 72  | 0.11 | 0.00% | 44.97% | 0.28% | 53.04% |
| 73  | 0.11 | 0.17% | 45.13% | 0.00% | 53.04% |
| 74  | 0.11 | 0.17% | 45.30% | 0.00% | 53.04% |
| 75  | 0.11 | 0.00% | 45.30% | 0.00% | 53.04% |
| 76  | 0.11 | 0.03% | 45.33% | 0.00% | 53.04% |
| 77  | 0.10 | 0.00% | 45.33% | 0.00% | 53.04% |
| 78  | 0.10 | 0.00% | 45.33% | 0.00% | 53.04% |
| 79  | 0.10 | 0.00% | 45.33% | 0.00% | 53.04% |
| 80  | 0.10 | 0.00% | 45.33% | 0.00% | 53.04% |
| 81  | 0.10 | 0.00% | 45.33% | 0.00% | 53.04% |
| 82  | 0.10 | 0.01% | 45.34% | 0.00% | 53.04% |
| 83  | 0.10 | 0.00% | 45.34% | 0.02% | 53.06% |
| 84  | 0.10 | 0.00% | 45.34% | 0.00% | 53.06% |
| 85  | 0.10 | 0.00% | 45.34% | 0.00% | 53.06% |
| 86  | 0.10 | 0.00% | 45.34% | 0.07% | 53.13% |
| 87  | 0.10 | 0.00% | 45.34% | 0.01% | 53.14% |
| 88  | 0.10 | 0.00% | 45.34% | 0.00% | 53.14% |
| 89  | 0.10 | 0.01% | 45.35% | 0.00% | 53.14% |
| 90  | 0.10 | 0.01% | 45.36% | 0.00% | 53.14% |
| 91  | 0.10 | 0.56% | 45.92% | 0.00% | 53.14% |
| 92  | 0.10 | 0.00% | 45.92% | 0.00% | 53.14% |
| 93  | 0.10 | 0.37% | 46.30% | 0.02% | 53.16% |
| 94  | 0.10 | 0.01% | 46.30% | 0.00% | 53.16% |
| 95  | 0.10 | 0.04% | 46.34% | 0.04% | 53.20% |
| 96  | 0.10 | 0.08% | 46.42% | 0.21% | 53.41% |
| 97  | 0.10 | 3.69% | 50.10% | 0.00% | 53.41% |
| 98  | 0.10 | 4.07% | 54.17% | 0.00% | 53.41% |
| 99  | 0.10 | 4.71% | 58.88% | 0.00% | 53.41% |
| 100 | 0.10 | 4.15% | 63.02% | 0.00% | 53.41% |
| 101 | 0.10 | 0.00% | 63.03% | 0.00% | 53.41% |
| 102 | 0.10 | 4.50% | 67.53% | 0.00% | 53.41% |
| 103 | 0.10 | 0.01% | 67.54% | 0.88% | 54.29% |
| 104 | 0.10 | 0.00% | 67.54% | 0.00% | 54.29% |
| 105 | 0.10 | 0.00% | 67.54% | 0.00% | 54.29% |
| 106 | 0.10 | 0.01% | 67.55% | 0.01% | 54.30% |
| 107 | 0.10 | 0.00% | 67.56% | 1.18% | 55.48% |
| 108 | 0.10 | 0.00% | 67.56% | 0.00% | 55.48% |
| 109 | 0.09 | 0.00% | 67.56% | 1.53% | 57.02% |
| 110 | 0.09 | 0.00% | 67.56% | 0.00% | 57.02% |
| 111 | 0.09 | 0.00% | 67.56% | 0.05% | 57.06% |
| 112 | 0.09 | 3.85% | 71.40% | 0.00% | 57.06% |
| 113 | 0.09 | 0.00% | 71.40% | 0.00% | 57.06% |

|     |      |       |        |       |        |
|-----|------|-------|--------|-------|--------|
| 114 | 0.09 | 0.00% | 71.40% | 0.01% | 57.08% |
| 115 | 0.09 | 0.00% | 71.40% | 0.00% | 57.08% |
| 116 | 0.09 | 0.21% | 71.61% | 0.00% | 57.08% |
| 117 | 0.09 | 0.00% | 71.61% | 0.02% | 57.10% |
| 118 | 0.09 | 0.00% | 71.61% | 0.00% | 57.10% |
| 119 | 0.09 | 0.00% | 71.61% | 0.02% | 57.12% |
| 120 | 0.09 | 0.00% | 71.61% | 0.08% | 57.19% |
| 121 | 0.09 | 0.00% | 71.61% | 0.00% | 57.19% |
| 122 | 0.09 | 0.00% | 71.61% | 0.00% | 57.20% |
| 123 | 0.09 | 0.00% | 71.62% | 0.01% | 57.21% |
| 124 | 0.09 | 0.00% | 71.62% | 0.01% | 57.22% |
| 125 | 0.09 | 0.00% | 71.62% | 0.00% | 57.22% |
| 126 | 0.09 | 0.00% | 71.62% | 0.03% | 57.24% |
| 127 | 0.09 | 0.00% | 71.62% | 0.01% | 57.26% |
| 128 | 0.09 | 0.00% | 71.62% | 0.00% | 57.26% |
| 129 | 0.09 | 0.00% | 71.62% | 0.00% | 57.26% |
| 130 | 0.09 | 0.00% | 71.62% | 0.00% | 57.26% |
| 131 | 0.09 | 0.00% | 71.62% | 0.00% | 57.26% |
| 132 | 0.09 | 0.00% | 71.62% | 0.05% | 57.31% |
| 133 | 0.09 | 0.00% | 71.62% | 1.41% | 58.72% |
| 134 | 0.09 | 0.00% | 71.62% | 0.22% | 58.94% |
| 135 | 0.09 | 0.00% | 71.62% | 0.00% | 58.94% |
| 136 | 0.09 | 0.00% | 71.62% | 0.00% | 58.94% |
| 137 | 0.09 | 0.00% | 71.62% | 0.00% | 58.94% |
| 138 | 0.09 | 0.00% | 71.62% | 0.00% | 58.94% |
| 139 | 0.09 | 0.00% | 71.62% | 0.00% | 58.94% |
| 140 | 0.09 | 0.00% | 71.62% | 0.00% | 58.94% |
| 141 | 0.09 | 0.00% | 71.62% | 0.00% | 58.94% |
| 142 | 0.09 | 0.00% | 71.62% | 3.73% | 62.67% |
| 143 | 0.09 | 1.79% | 73.41% | 0.00% | 62.68% |
| 144 | 0.09 | 0.00% | 73.41% | 1.51% | 64.18% |
| 145 | 0.09 | 0.00% | 73.41% | 0.28% | 64.46% |
| 146 | 0.09 | 0.00% | 73.41% | 1.59% | 66.05% |
| 147 | 0.09 | 0.00% | 73.41% | 9.23% | 75.28% |
| 148 | 0.09 | 0.00% | 73.41% | 0.02% | 75.29% |
| 149 | 0.09 | 0.00% | 73.41% | 0.01% | 75.30% |
| 150 | 0.09 | 0.00% | 73.41% | 0.01% | 75.31% |
| 151 | 0.09 | 0.00% | 73.41% | 0.00% | 75.31% |
| 152 | 0.09 | 0.00% | 73.41% | 0.00% | 75.31% |
| 153 | 0.09 | 0.00% | 73.41% | 0.00% | 75.31% |
| 154 | 0.09 | 0.00% | 73.41% | 0.00% | 75.31% |
| 155 | 0.09 | 0.00% | 73.41% | 0.00% | 75.31% |
| 156 | 0.09 | 0.00% | 73.41% | 0.00% | 75.31% |
| 157 | 0.09 | 0.00% | 73.41% | 0.01% | 75.32% |
| 158 | 0.09 | 0.00% | 73.41% | 0.00% | 75.32% |
| 159 | 0.09 | 0.00% | 73.41% | 0.01% | 75.33% |
| 160 | 0.09 | 0.00% | 73.41% | 0.13% | 75.46% |
| 161 | 0.08 | 0.00% | 73.41% | 0.00% | 75.46% |
| 162 | 0.08 | 0.00% | 73.41% | 0.00% | 75.46% |
| 163 | 0.08 | 0.00% | 73.41% | 0.14% | 75.60% |
| 164 | 0.08 | 0.00% | 73.41% | 0.14% | 75.73% |
| 165 | 0.08 | 0.00% | 73.41% | 0.22% | 75.95% |
| 166 | 0.08 | 0.00% | 73.41% | 0.00% | 75.95% |
| 167 | 0.08 | 0.00% | 73.41% | 0.06% | 76.01% |
| 168 | 0.08 | 0.00% | 73.41% | 0.15% | 76.16% |
| 169 | 0.08 | 0.00% | 73.41% | 0.08% | 76.24% |
| 170 | 0.08 | 0.00% | 73.42% | 0.00% | 76.24% |
| 171 | 0.08 | 0.00% | 73.42% | 0.02% | 76.26% |

|     |      |       |        |       |        |
|-----|------|-------|--------|-------|--------|
| 172 | 0.08 | 0.00% | 73.42% | 0.00% | 76.26% |
| 173 | 0.08 | 0.00% | 73.42% | 0.60% | 76.86% |
| 174 | 0.08 | 0.01% | 73.43% | 0.00% | 76.86% |
| 175 | 0.08 | 0.03% | 73.46% | 0.00% | 76.86% |
| 176 | 0.08 | 0.00% | 73.46% | 0.00% | 76.86% |
| 177 | 0.08 | 0.25% | 73.71% | 0.00% | 76.86% |
| 178 | 0.08 | 0.02% | 73.72% | 0.02% | 76.87% |
| 179 | 0.08 | 0.00% | 73.72% | 0.00% | 76.87% |
| 180 | 0.08 | 0.00% | 73.72% | 0.00% | 76.87% |
| 181 | 0.08 | 0.00% | 73.72% | 0.00% | 76.88% |
| 182 | 0.08 | 0.00% | 73.72% | 0.00% | 76.88% |
| 183 | 0.08 | 0.11% | 73.83% | 0.00% | 76.88% |
| 184 | 0.08 | 0.01% | 73.83% | 0.00% | 76.88% |
| 185 | 0.08 | 0.00% | 73.84% | 0.13% | 77.00% |
| 186 | 0.08 | 0.01% | 73.85% | 0.01% | 77.02% |
| 187 | 0.08 | 0.07% | 73.92% | 0.01% | 77.03% |
| 188 | 0.08 | 0.23% | 74.15% | 0.01% | 77.04% |
| 189 | 0.07 | 0.02% | 74.17% | 0.15% | 77.19% |
| 190 | 0.07 | 0.00% | 74.17% | 0.06% | 77.25% |
| 191 | 0.07 | 0.02% | 74.19% | 0.00% | 77.25% |
| 192 | 0.07 | 0.01% | 74.20% | 0.01% | 77.26% |
| 193 | 0.07 | 0.01% | 74.21% | 0.20% | 77.46% |
| 194 | 0.07 | 1.41% | 75.63% | 0.00% | 77.46% |
| 195 | 0.07 | 6.19% | 81.82% | 0.00% | 77.46% |
| 196 | 0.07 | 3.97% | 85.79% | 0.00% | 77.46% |
| 197 | 0.07 | 3.85% | 89.65% | 0.00% | 77.46% |
| 198 | 0.07 | 3.75% | 93.40% | 0.00% | 77.46% |
| 199 | 0.07 | 0.01% | 93.40% | 0.50% | 77.97% |
| 200 | 0.07 | 0.00% | 93.41% | 0.00% | 77.97% |
| 201 | 0.07 | 4.29% | 97.70% | 0.00% | 77.97% |
| 202 | 0.07 | 0.08% | 97.78% | 1.90% | 79.87% |
| 203 | 0.07 | 0.00% | 97.78% | 0.00% | 79.87% |
| 204 | 0.07 | 0.00% | 97.78% | 0.00% | 79.87% |
| 205 | 0.07 | 0.00% | 97.78% | 0.00% | 79.87% |
| 206 | 0.07 | 0.00% | 97.78% | 0.00% | 79.87% |
| 207 | 0.07 | 0.00% | 97.78% | 0.00% | 79.88% |
| 208 | 0.07 | 0.01% | 97.78% | 1.53% | 81.41% |
| 209 | 0.07 | 0.00% | 97.78% | 0.02% | 81.43% |
| 210 | 0.07 | 0.00% | 97.78% | 0.00% | 81.43% |
| 211 | 0.07 | 0.00% | 97.78% | 0.13% | 81.56% |
| 212 | 0.07 | 0.00% | 97.78% | 0.09% | 81.65% |
| 213 | 0.07 | 0.00% | 97.78% | 7.27% | 88.92% |
| 214 | 0.07 | 0.00% | 97.78% | 9.60% | 98.52% |
| 215 | 0.07 | 0.00% | 97.78% | 0.81% | 99.33% |

## **ANEXO IV**

Pré-dimensionamento dos Elementos Metálicos



# Pré-dimensionamento dos Caixões Trelçados

## Painéis Verticais do Troço Horizontal

Modelo de cálculo

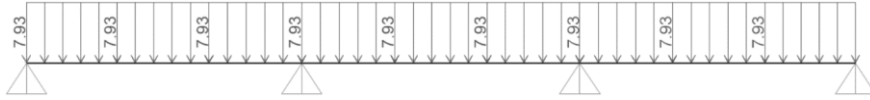


Diagrama de Momentos Fletores

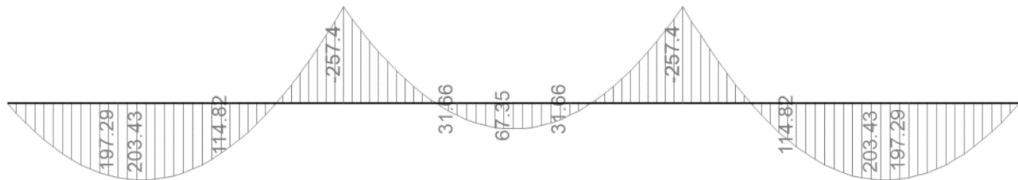
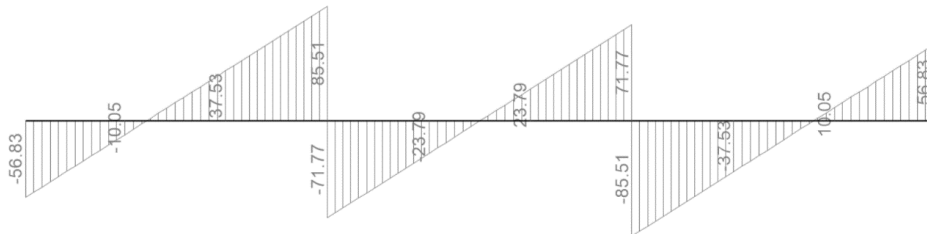
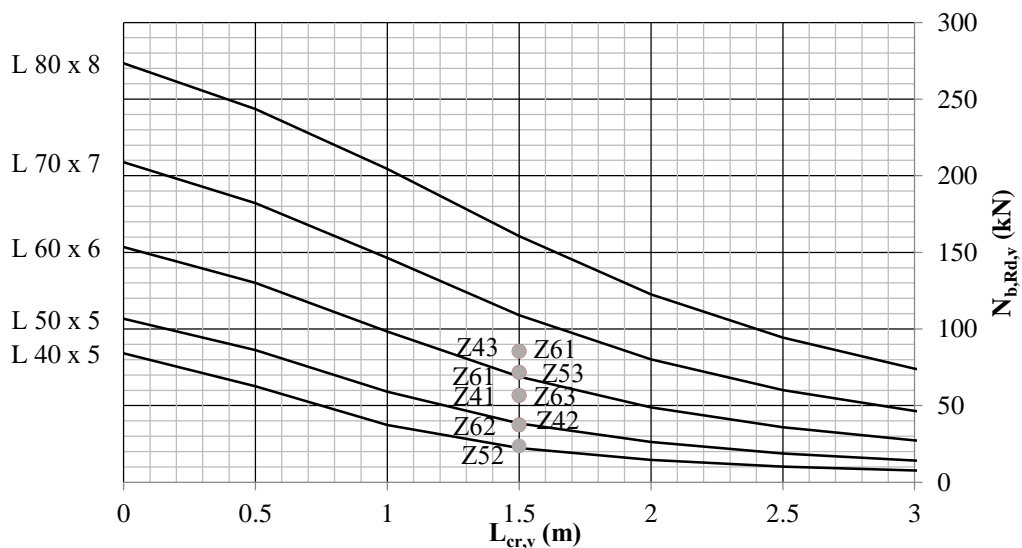


Diagrama de Esforços Transversos



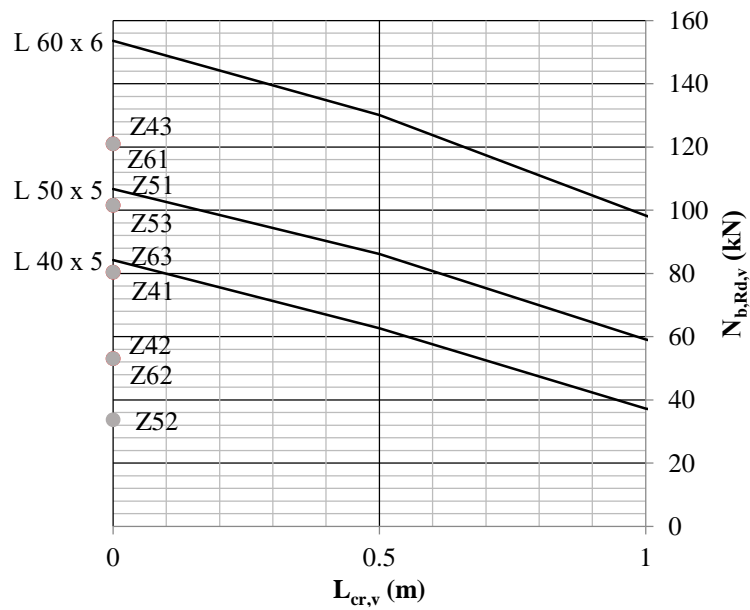
### Montantes

| Tramos | Zonas           | $N_{c,Ed,máx} = V_{Ed,máx}$ (kN) | $L_{cr,v}$ (m) | Perfil Adotado | $i_v$ (cm) | $\lambda$ ( $L_{cr,v}/i_v$ ) |
|--------|-----------------|----------------------------------|----------------|----------------|------------|------------------------------|
| 4      | Z <sub>41</sub> | 56.83                            | 1.50           | L 60x6         | 1.17       | 128                          |
|        | Z <sub>42</sub> | 37.53                            | 1.50           | L 60x6         | 1.17       | 128                          |
|        | Z <sub>43</sub> | 85.51                            | 1.50           | L 70x7         | 1.36       | 110                          |
| 5      | Z <sub>51</sub> | 71.77                            | 1.50           | L 70x7         | 1.36       | 110                          |
|        | Z <sub>52</sub> | 23.79                            | 1.50           | L 50x5         | 0.97       | 155                          |
|        | Z <sub>53</sub> | 71.77                            | 1.50           | L 70x7         | 1.36       | 110                          |
| 6      | Z <sub>61</sub> | 85.51                            | 1.50           | L 70x7         | 1.36       | 110                          |
|        | Z <sub>62</sub> | 37.53                            | 1.50           | L 60x6         | 1.17       | 128                          |
|        | Z <sub>63</sub> | 56.83                            | 1.50           | L 60x6         | 1.17       | 128                          |



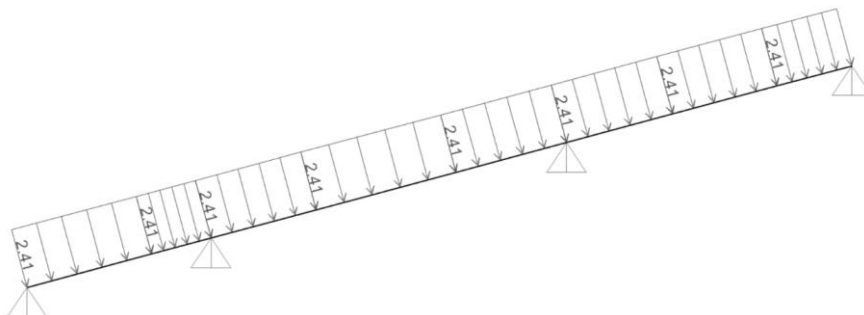
## Diagonais

| Tramos | Zonas           | $V_{Ed,m\acute{a}x}$ (kN) | $\alpha$ (°) | $N_{t,Ed,m\acute{a}x} = V_{Ed,m\acute{a}x} / \text{sen}(\alpha)$ | Perfil Adotado |
|--------|-----------------|---------------------------|--------------|--|----------------|
| 4      | Z <sub>41</sub> | 56.83                     | 45           | 80.37  | L 50x5         |
|        | Z <sub>42</sub> | 37.53                     | 45           | 53.08  | L 50x5         |
|        | Z <sub>43</sub> | 85.51                     | 45           | 120.93   | L 60x6         |
| 5      | Z <sub>51</sub> | 71.77                     | 45           | 101.50   | L 60x6         |
|        | Z <sub>52</sub> | 23.79                     | 45           | 33.64  | L 50x5         |
|        | Z <sub>53</sub> | 71.77                     | 45           | 101.50   | L 60x6         |
| 6      | Z <sub>61</sub> | 85.51                     | 45           | 120.93   | L 60x6         |
|        | Z <sub>62</sub> | 37.53                     | 45           | 53.08  | L 50x5         |
|        | Z <sub>63</sub> | 56.83                     | 45           | 80.37  | L 50x5         |

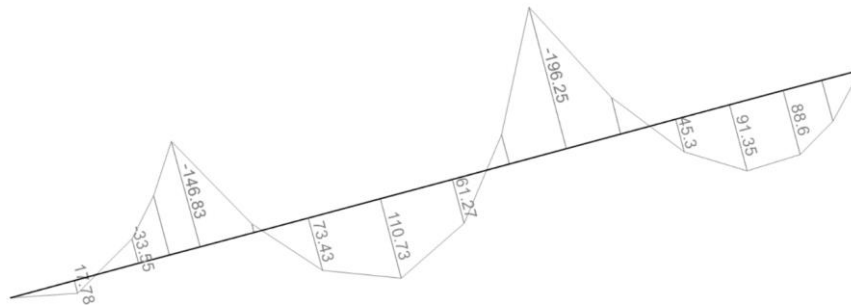


## Painel Horizontal Superior do Troço Inclinado

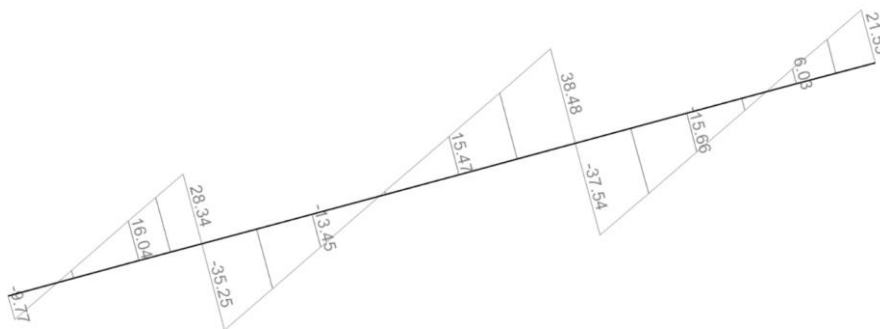
Modelo de Cálculo



## Diagrama de Momentos Fletores

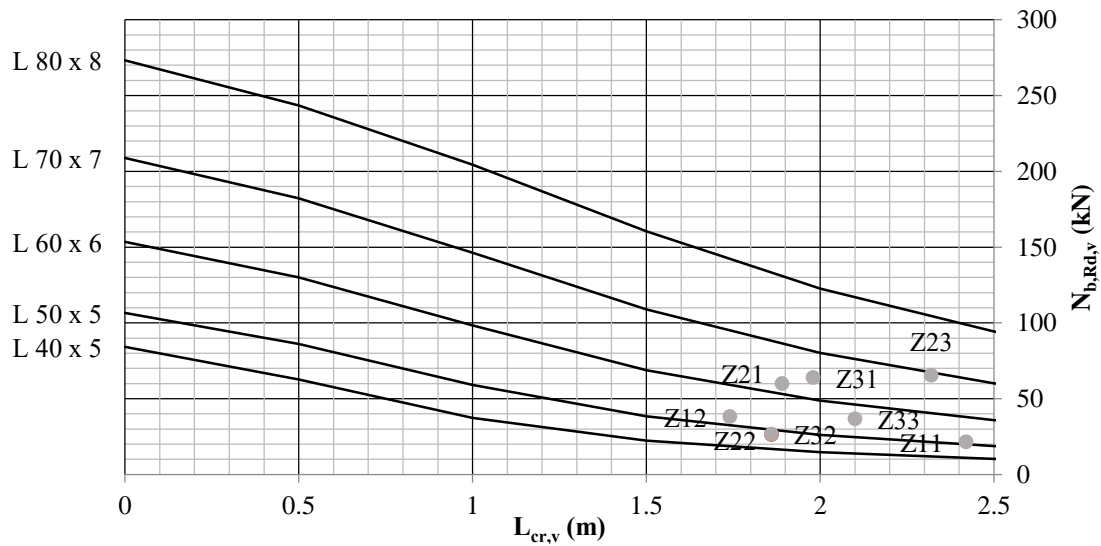


## Diagrama de Esforços Transversos



## Diagonais

| Tramos | Zonas           | $V_{Ed,máx}$<br>(kN) | $\alpha$ (°) | $N_{c,Ed,máx} = V_{Ed,máx} / \text{sen}(\alpha)$ | $L_{cr,v}$<br>(m) | Perfil<br>Adotado | $i_v$<br>(cm) | $\lambda$<br>( $L_{cr,v}/i_v$ ) |
|--------|-----------------|----------------------|--------------|--|-------------------|-------------------|---------------|---------------------------------|
| 1      | Z <sub>11</sub> | 16,04                | 48           | 21,58  | 2,42              | L 70x7            | 1,36          | 178                             |
|        | Z <sub>12</sub> | 28,34                | 48           | 38,14  | 1,74              | L 60x6            | 1,17          | 149                             |
| 2      | Z <sub>21</sub> | 35,25                | 36           | 59,97  | 1,89              | L 70x7            | 1,36          | 139                             |
|        | Z <sub>22</sub> | 15,47                | 36           | 26,32  | 1,86              | L 60x6            | 1,17          | 159                             |
|        | Z <sub>23</sub> | 38,48                | 36           | 65,47  | 2,32              | L 80x8            | 1,56          | 149                             |
| 3      | Z <sub>31</sub> | 37,54                | 36           | 63,87  | 1,98              | L 70x7            | 1,36          | 146                             |
|        | Z <sub>32</sub> | 15,66                | 36           | 26,64  | 1,86              | L 60x6            | 1,17          | 159                             |
|        | Z <sub>33</sub> | 21,53                | 36           | 36,63  | 2,10              | L 70x7            | 1,36          | 154                             |



## Painel Horizontal Superior do Troço Horizontal

Modelo de Cálculo

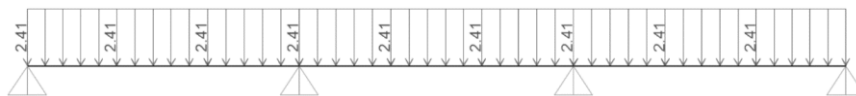


Diagrama de Momentos Fletores

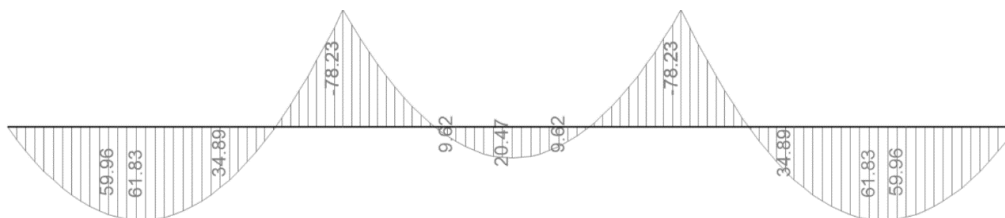
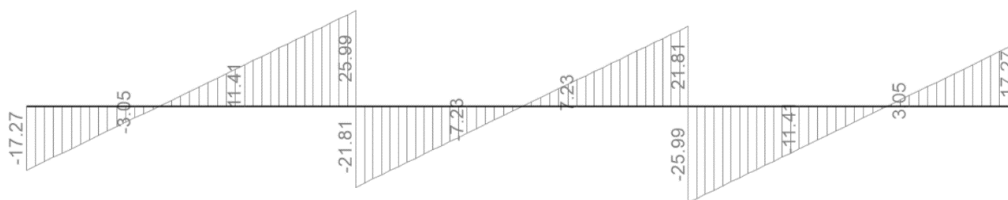
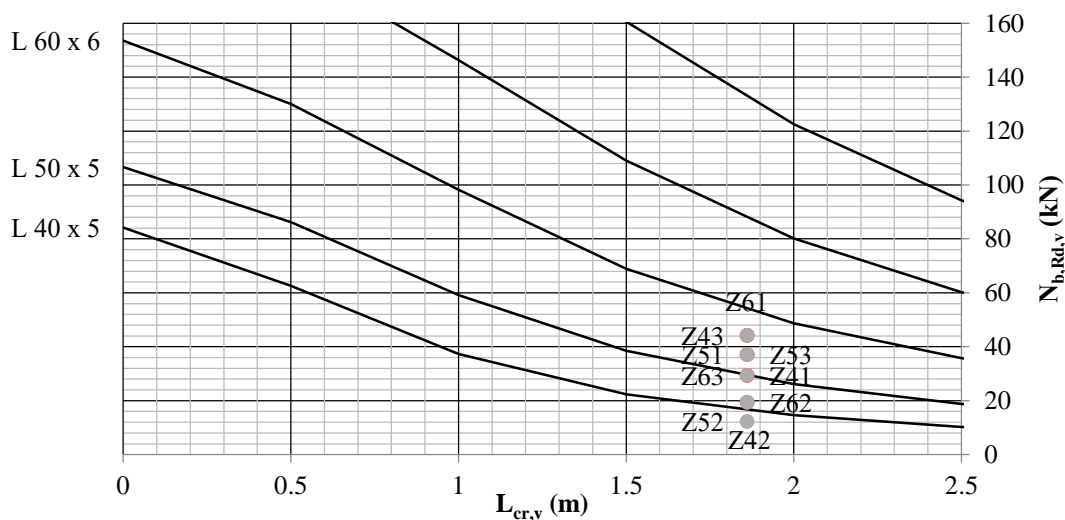


Diagrama de Esforços Transversos



### Diagonais

| Tramos | Zonas           | $V_{Ed,máx}$ (kN) | $\alpha$ (°) | $N_{c,Ed,máx} = V_{Ed,máx} / \sin(\alpha)$ | $L_{cr,v}$ (m) | Perfil Adotado | $i_v$ (cm) | $\lambda$ ( $L_{cr,v}/i_v$ ) |
|--------|-----------------|-------------------|--------------|--|----------------|----------------|------------|------------------------------|
| 4      | Z <sub>41</sub> | 17.27             | 36           | 29.38                                      | 1.86           | L 60x6         | 1.17       | 159                          |
|        | Z <sub>42</sub> | 11.41             | 36           | 19.41                                      | 1.86           | L 60x6         | 1.17       | 159                          |
|        | Z <sub>43</sub> | 25.99             | 36           | 44.22                                      | 1.86           | L 60x6         | 1.17       | 159                          |
| 5      | Z <sub>51</sub> | 21.81             | 36           | 37.11                                      | 1.86           | L 60x6         | 1.17       | 159                          |
|        | Z <sub>52</sub> | 7.23              | 36           | 12.30                                      | 1.86           | L 60x6         | 1.17       | 159                          |
|        | Z <sub>53</sub> | 21.81             | 36           | 37.11                                      | 1.86           | L 60x6         | 1.17       | 159                          |
| 6      | Z <sub>61</sub> | 25.99             | 36           | 44.22                                      | 1.86           | L 60x6         | 1.17       | 159                          |
|        | Z <sub>62</sub> | 11.41             | 36           | 19.41                                      | 1.86           | L 60x6         | 1.17       | 159                          |
|        | Z <sub>63</sub> | 17.27             | 36           | 29.38                                      | 1.86           | L 60x6         | 1.17       | 159                          |



## **ANEXO V**

### **Dimensionamento dos Elementos Metálicos**



## Diagonais dos Painéis Verticais da Estrutura Secundária

### 1º Procedimento – A partir do “SAP2000” (Barra mais solicitada)

|               |               |  |
|---------------|---------------|--|
| Frame : 360   | X Mid: 19.367 | Combo: ELU_PASS_(Wy_Wzz_Design Type: Brace |
| Length: 1.616 | Y Mid: 0.550  | Shape: TUBO50x4                            |
| Loc : 0.000   | Z Mid: 5.500  | Class: Class 1                             |
|               |               | Frame Type: DCL-MRF                        |
|               |               | Rolled : No                                |

#### STRESS CHECK FORCES & MOMENTS

| Location     | Ned     | Med,yy | Med,zz    | Ved,z  | Ved,y | Ted     |
|--------------|---------|--------|-----------|--------|-------|---------|
| 0.000        | -76.920 | 0.000  | 0.000     | -0.049 | 0.000 | 0.043   |
| Curve        | Alpha   | Ncr    | LambdaBar | Phi    | Chi   | Nb,Rd   |
| Major (y-y)  | c       | 0.490  | 207.679   | 0.913  | 1.091 | 102.412 |
| MajorB(y-y)  | c       | 0.490  | 207.679   | 0.913  | 1.091 | 102.412 |
| Minor (z-z)  | c       | 0.490  | 207.679   | 0.913  | 1.091 | 102.412 |
| MinorB(z-z)  | c       | 0.490  | 207.679   | 0.913  | 1.091 | 102.412 |
| Torsional TF | c       | 0.490  | 207.679   | 0.913  | 1.091 | 102.412 |

#### PMM DEMAND/CAPACITY RATIO (Governing Equation EC3 6.3.3(4)-6.61)

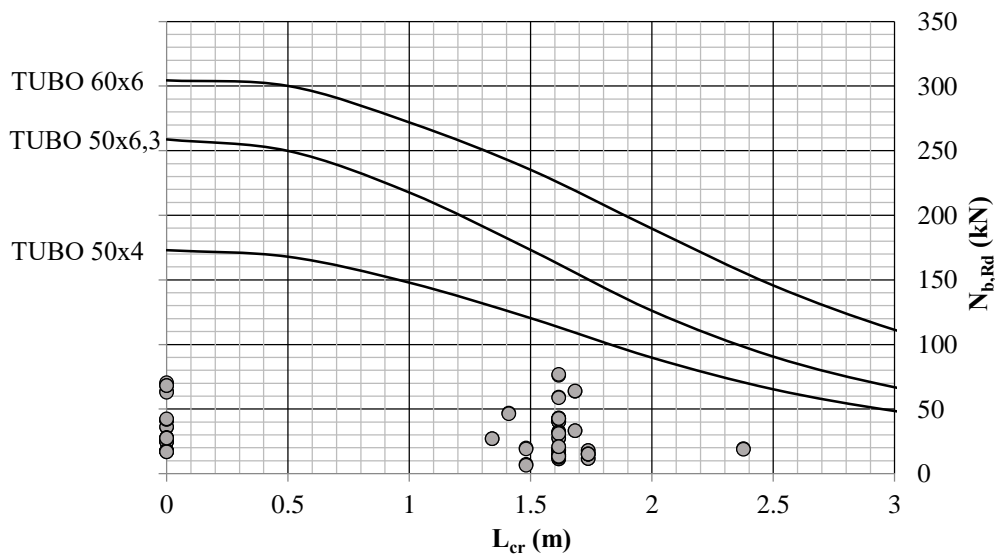
$$D/C \text{ Ratio: } 0.761 = 0.751 + 0.010 + 0.000 < 1.000 \quad \text{OK}$$

$$= NEd / (\chi_y N_{Rk} / \gamma_{M1}) + k_{yy} (M_y, Ed + NEd e_{Ny}) / (\chi_{LT} M_y, Rk / \gamma_{M1}) + k_{yz} (M_z, Ed + NEd e_{Nz}) / (M_z, Rk / \gamma_{M1}) \quad (\text{EC3 6.3.3(4)-6.61})$$

### 2º Procedimento – A partir da Folha de Cálculo em “Excel” (Barras mais solicitadas)

| Barra n° | Combinação Condicionante | N <sub>c,Ed</sub> (kN) | Perfil    | Resistência à Encurvadura |    |      |                        |       |
|----------|--------------------------|------------------------|-----------|---------------------------|----|------|------------------------|-------|
|          |                          |                        |           | L <sub>cr</sub> (m)       | λ  | χ    | N <sub>b,Rd</sub> (kN) | Rácio |
| 359      | ELU_PASS_(Wyy_Wzz_T+)    | 75.98                  | Tubo 50x4 | 1.62                      | 85 | 0.60 | 103.16                 | 0.74  |
| 360      | ELU_PASS_(Wy_Wzz_T+)     | 76.92                  | Tubo 50x4 | 1.62                      | 85 | 0.60 | 103.16                 | 0.75  |
| 739      | ELU_PASS_(Wy_Wzz_T-)     | 59.24                  | Tubo 50x4 | 1.62                      | 85 | 0.60 | 103.16                 | 0.57  |
| 740      | ELU_PASS_(Wyy_Wzz_T-)    | 58.85                  | Tubo 50x4 | 1.62                      | 85 | 0.60 | 103.16                 | 0.57  |
| 812      | ELU_PASS_(Wyy_Wzz_T-)    | 63.74                  | Tubo 50x4 | 1.68                      | 88 | 0.57 | 99.22                  | 0.64  |
| 813      | ELU_PASS_(Wy_Wzz_T-)     | 63.99                  | Tubo 50x4 | 1.68                      | 88 | 0.57 | 99.22                  | 0.64  |

### Restantes Barras



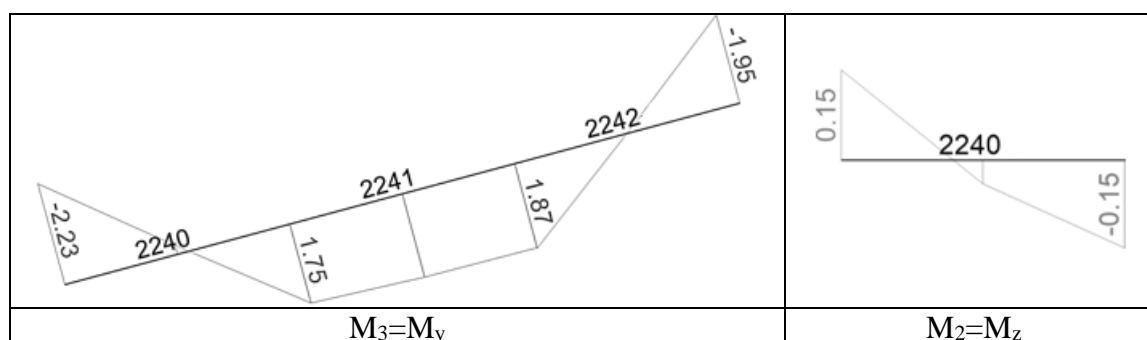
## Cordões da Estrutura Secundária

### Verificações

#### Estados Limites Últimos

| Perfil           | A<br>(cm <sup>2</sup> ) | I <sub>y</sub><br>(cm <sup>4</sup> ) | W <sub>el,y</sub><br>(cm <sup>3</sup> ) | W <sub>pl,y</sub><br>(cm <sup>3</sup> ) | i <sub>y</sub><br>(cm <sup>2</sup> ) | A <sub>vy</sub><br>(cm <sup>2</sup> ) | I <sub>z</sub><br>(cm <sup>4</sup> ) | W <sub>el,z</sub><br>(cm <sup>3</sup> ) | W <sub>pl,z</sub><br>(cm <sup>3</sup> ) | i <sub>z</sub><br>(cm) | A <sub>vz</sub><br>(cm <sup>2</sup> ) |
|------------------|-------------------------|--------------------------------------|---|---|--------------------------------------|---------------------------------------|--------------------------------------|---|---|------------------------|---------------------------------------|
| Tubo<br>100x50x4 | 11.36                   | 144.1                                | 27.92                                   | 36.13                                   | 3.56                                 | 3.79                                  | 47.37                                | 18.48                                   | 21.93                                   | 2.04                   | 7.57                                  |

| Barra<br>nº | Combinação<br>Condicionante | Secção<br>(m) | N <sub>c,Ed</sub><br>(kN) | V <sub>y,Ed</sub><br>(kN) | V <sub>z,Ed</sub><br>(kN) | M <sub>y,Ed</sub><br>(kN.m) | M <sub>z,Ed</sub><br>(kN.m) |       |
|-------------|-----------------------------|---------------|---------------------------|---------------------------|---------------------------|-----------------------------|-----------------------------|-------|
| 2240        | ELU_PASS_(Wyy_Wzz_T-)       | si -          | 0.00                      | 99.84                     | 0.47                      | 4.15                        | -2.23                       | 0.15  |
|             |                             | sm -          | 0.50                      | 99.83                     | 0.30                      | 3.98                        | -0.20                       | -0.04 |
|             |                             | sf -          | 1.00                      | 99.81                     | 0.14                      | 3.82                        | 1.75                        | -0.15 |



#### 1º Procedimento – A partir da Folha de Cálculo em “Excel”

| Barra<br>nº | Secção<br>(m) | Compressão                |   | Esforço Transverso           |  |                              |  |              |
|-------------|---------------|---------------------------|---|------------------------------|--|------------------------------|--|--------------|
|             |               | N <sub>c,Rd</sub><br>(kN) | Rácio<br>N <sub>c,Ed</sub> /N <sub>c,Rd</sub> | Eixo z-z                     |  | Eixo y-y                     |  |              |
|             |               |                           |   | V <sub>pl,z,Rd</sub><br>(kN) | Rácio<br>V <sub>z,Ed</sub> /V <sub>pl,z,Rd</sub> | V <sub>pl,y,Rd</sub><br>(kN) | Rácio<br>V <sub>y,Ed</sub> /V <sub>pl,y,Rd</sub> |              |
| 2240        | si -          | 0.00                      | 266.96  | <b>0.374</b>                 | 102.75   | <b>0.040</b>                 | 51.38  | <b>0.009</b> |
|             | sm -          | 0.50                      | 266.96  | <b>0.374</b>                 | 102.75   | <b>0.039</b>                 | 51.38  | <b>0.006</b> |
|             | sf -          | 1.00                      | 266.96  | <b>0.374</b>                 | 102.75   | <b>0.037</b>                 | 51.38  | <b>0.003</b> |

| Barra<br>nº | Secção<br>(m) | Flexão com Esforço Transverso                    |                               |   |  |                               |   |              |
|-------------|---------------|--|-------------------------------|---|--|-------------------------------|---|--------------|
|             |               | Eixo y-y   |                               |   | Eixo z-z   |                               |   |              |
|             |               | V <sub>z,Ed</sub> /V <sub>pl,z,Rd</sub><br>< 0,5 | M <sub>y,V,Rd</sub><br>(kN.m) | Rácio<br>M <sub>y,Ed</sub> /M <sub>y,V,Rd</sub> | V <sub>y,Ed</sub> /V <sub>pl,y,Rd</sub><br>< 0,5 | M <sub>z,V,Rd</sub><br>(kN.m) | Rácio<br>M <sub>z,Ed</sub> /M <sub>z,V,Rd</sub> |              |
| 2240        | si -          | 0.00   | V <sub>Ed</sub> s/ sign.      | 8.49  | <b>0.263</b>                                     | V <sub>Ed</sub> s/ sign.      | 5.15  | <b>0.030</b> |
|             | sm -          | 0.50   | V <sub>Ed</sub> s/ sign.      | 8.49  | <b>0.024</b>                                     | V <sub>Ed</sub> s/ sign.      | 5.15  | <b>0.008</b> |
|             | sf -          | 1.00   | V <sub>Ed</sub> s/ sign.      | 8.49  | <b>0.206</b>                                     | V <sub>Ed</sub> s/ sign.      | 5.15  | <b>0.029</b> |

| Barra n° |      | Secção |       | Flexão Composta com Esforço Transverso |                |                               |   |                |                               | Flexão Desviada |       |              |
|----------|------|--------|-------|--|----------------|-------------------------------|---|----------------|-------------------------------|-----------------|-------|--------------|
|          |      |        |       | n                                      | a <sub>w</sub> | Eixo y-y                      |   | Eixo z-z       |                               | α               | β     | Rácio        |
|          |      |        |       |  |                | M <sub>N,y,Rd</sub><br>(kN.m) | Rácio<br>M <sub>y,Ed</sub> /M <sub>N,y,Rd</sub> | a <sub>r</sub> | M <sub>N,z,Rd</sub><br>(kN.m) |                 |       |              |
| 2240     | si - | 0.00   | 0.374 | 0.500                                  | 7.09           | <b>0.315</b>                  | 0.300   | 3.79           | <b>0.004</b>                  | 1.971           | 1.971 | <b>0.078</b> |
|          | sm - | 1.08   | 0.374 | 0.500                                  | 7.09           | <b>0.028</b>                  | 0.300   | 3.79           | <b>0.011</b>                  | 1.971           | 1.971 | <b>0.015</b> |
|          | sf - | 2.16   | 0.374 | 0.500                                  | 7.09           | <b>0.247</b>                  | 0.300   | 3.79           | <b>0.004</b>                  | 1.971           | 1.971 | <b>0.010</b> |

| Encurvadura por Compressão (Coluna) |                          |                |                 |                |                             |                          |                |                 |                |                             |       |                      |   |
|-------------------------------------|--------------------------|----------------|-----------------|----------------|-----------------------------|--------------------------|----------------|-----------------|----------------|-----------------------------|-------|----------------------|---|
| Barra n°                            | Eixo y-y                 |                |                 |                |                             |                          | Eixo z-z       |                 |                |                             |       | Plano de Encurvadura | Rácio<br>N <sub>c,Ed</sub> /N <sub>b,Rd</sub> |
|                                     | L <sub>cr,y</sub><br>(m) | λ <sub>y</sub> | λ̄ <sub>y</sub> | χ <sub>y</sub> | N <sub>b,y,Rd</sub><br>(kN) | L <sub>cr,z</sub><br>(m) | λ <sub>z</sub> | λ̄ <sub>z</sub> | χ <sub>z</sub> | N <sub>b,z,Rd</sub><br>(kN) |       |                      |   |
| 2240                                | 3.00                     | 84             | 0.897           | 0.736          | 196.45                      | 1.00                     | 50             | 0.522           | 0.917          | 244.92                      | y - y | <b>0.508</b>         |   |

| Encurvadura por Flexão Composta com Compressão (Coluna-Viga) |                |                |                 |                         |                             |                             |                 |                 |                 |                 |                 |                 |                     |                     |
|--|----------------|----------------|-----------------|-------------------------|-----------------------------|-----------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|---------------------|---------------------|
| Barra n°   | χ <sub>z</sub> | χ <sub>y</sub> | χ <sub>LT</sub> | N <sub>Rk</sub><br>(kN) | M <sub>y,Rk</sub><br>(kN.m) | M <sub>z,Rk</sub><br>(kN.m) | C <sub>my</sub> | C <sub>mz</sub> | k <sub>yy</sub> | k <sub>yz</sub> | k <sub>zy</sub> | k <sub>zz</sub> | Eq.6.61 do EC3 -1-1 | Eq.6.62 do EC3 -1-1 |
| 2240   | 0.917          | 0.736          | 1.000           | 266.96                  | 8.49                        | 5.15                        | 0.663           | 0.400           | 0.897           | 0.271           | 0.538           | 0.452           | <b>0.752</b>        | <b>0.563</b>        |

**2º Procedimento – A partir do software “Semicomp+”**

**Barra nº2240 (Secção)**

### SEMICOMP Cross-Section Check

Choose method EN 1993-1-1 (elastic Resistance)

|              |   |              |   |
|--------------|---|--------------|---|
| $N_{Ed} =$   | <input style="width: 80%;" type="text" value="-99.841"/> kN | $V_{z,Ed} =$ | <input style="width: 80%;" type="text" value="4.149"/> kN |
| $M_{y,Ed} =$ | <input style="width: 80%;" type="text" value="-2.234"/> kNm | $V_{y,Ed} =$ | <input style="width: 80%;" type="text" value="0.469"/> kN |
| $M_{z,Ed} =$ | <input style="width: 80%;" type="text" value="0.153"/> kNm  |              |   |

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Reference values for classification

|           |   |                     |  |                   |  |                             |  |
|-----------|---|---------------------|--|-------------------|--|-----------------------------|--|
| $c/t_w =$ | <input style="width: 80%;" type="text" value="22.000"/> | $\alpha_{web} =$    | <input style="width: 80%;" type="text" value="1.000"/> | $\psi_{web} =$    | <input style="width: 80%;" type="text" value="0.161"/> | $\varepsilon =$             | <input style="width: 80%;" type="text" value="1.000"/> |
| $c/t_f =$ | <input style="width: 80%;" type="text" value="9.500"/>  | $\alpha_{flange} =$ | <input style="width: 80%;" type="text" value="1.000"/> | $\psi_{flange} =$ | <input style="width: 80%;" type="text" value="0.928"/> | $\varepsilon_{mod,c/3/4} =$ | <input style="width: 80%;" type="text" value="NaN"/>   |

Boundaries

|                            | Class 1   | Class 2   | Class 3   |
|----------------------------|---|---|---|
| $c/t_w \leq c/t_{w,max} =$ | <input style="width: 80%;" type="text" value="33.000"/> | <input style="width: 80%;" type="text" value="38.000"/> | <input style="width: 80%;" type="text" value="58.070"/> |
| $c/t_f \leq c/t_{f,max} =$ | <input style="width: 80%;" type="text" value="33.000"/> | <input style="width: 80%;" type="text" value="38.000"/> | <input style="width: 80%;" type="text" value="43.018"/> |

Cross section class =

Note: This tool is only applicable to Class 1 to 3. For Class 4 elastic cross-section values are used for all calculations.

---

|                 |  |                 |   |                 |  |
|-----------------|--|-----------------|---|-----------------|--|
| $M_{pl,y,Rd} =$ | <input style="width: 80%;" type="text" value="8.28"/> kNm  | $M_{pl,z,Rd} =$ | <input style="width: 80%;" type="text" value="5.05"/> kNm | $V_{pl,z,Rd} =$ | <input style="width: 80%;" type="text" value="101.20"/> kN |
| $M_{el,y,Rd} =$ | <input style="width: 80%;" type="text" value="6.56"/> kNm  | $M_{el,z,Rd} =$ | <input style="width: 80%;" type="text" value="4.34"/> kNm | $V_{pl,y,Rd} =$ | <input style="width: 80%;" type="text" value="50.60"/> kN  |
| $N_{Rd} =$      | <input style="width: 80%;" type="text" value="262.93"/> kN |                 |   |                 |  |

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**EN 1993-1-1, 6.2.3 / 6.2.4**  
Tension or compression

$U_{(6.5)/(6.9)} =$    $\leq 1,0$  ok

**EN 1993-1-1, 6.2.5**  
Bending moment

$U_{strong A.} =$    $\leq 1,0$  ok

$U_{weak A.} =$    $\leq 1,0$  ok

**EN 1993-1-1, 6.2.6**  
Shear

$U_{z-plastic} =$    $\leq 1,0$  ok      $U_{y-plastic} =$    $\leq 1,0$  ok

$U_{z-elastic} =$    $\leq 1,0$  ok      $U_{y-elastic} =$    $\leq 1,0$  ok

$h_w/t_w =$    $\leq 72\varepsilon/\eta =$   ok

**EN 1993-1-1, 6.2.9**  
Bending and axial force

$U_{(6.41)/(6.42)} =$    $\leq 1,0$  ok      $UF =$

Comment: Shear Interaction is not considered within this software tool. If the utilization for shear is higher that 0.5, an additional check for shear interaction is necessary.

### 3º Procedimento – A partir do software “SAP2000”

#### Barra nº2240 (Coluna-Viga)

##### STRESS CHECK FORCES & MOMENTS

| Location | Ned     | Med, yy | Med, zz | Ved, z | Ved, y | Ted   |
|----------|---------|---------|---------|--------|--------|-------|
| 0.000    | -99.841 | -2.234  | 0.153   | -4.149 | 0.469  | 0.004 |

|   |  |
|---|--|
| PMM DEMAND/CAPACITY RATIO (Governing Equation EC3 6.3.3(4)-6.61)  |  |
| D/C Ratio:  | 0.752 = 0.508 + 0.236 + 0.008 < 1.000 OK |
| = $NEd / (\chi_y N_{Rk} / \gamma_{M1}) + k_{yy} (M_y, Ed + NEd e_{Ny}) / (\chi_{LT} M_y, Rk / \gamma_{M1})$ |  |
| + $k_{yz} (M_z, Ed + NEd e_{Nz}) / (M_z, Rk / \gamma_{M1})$ (EC3 6.3.3(4)-6.61)                             |  |

##### AXIAL FORCE DESIGN

|              | Ned     | Nc, Rd   | Nt, Rd    |           |       |       |         |
|--------------|---------|----------|-----------|-----------|-------|-------|---------|
|              | Force   | Capacity | Capacity  |           |       |       |         |
| Axial        | -99.841 | 266.960  | 266.960   |           |       |       |         |
|              | Npl, Rd | Nu, Rd   | Ncr, T    | Ncr, TF   | An/Ag |       |         |
|              | 266.960 | 294.451  | 52642.199 | 331.909   | 1.000 |       |         |
|              | Curve   | Alpha    | Ncr       | LambdaBar | Phi   | Chi   | Nb, Rd  |
| Major (y-y)  | a       | 0.210    | 331.909   | 0.897     | 0.975 | 0.736 | 196.488 |
| MajorB(y-y)  | a       | 0.210    | 331.909   | 0.897     | 0.975 | 0.736 | 196.488 |
| Minor (z-z)  | a       | 0.210    | 981.713   | 0.521     | 0.670 | 0.917 | 244.928 |
| MinorB(z-z)  | a       | 0.210    | 981.713   | 0.521     | 0.670 | 0.917 | 244.928 |
| Torsional TF | a       | 0.210    | 331.909   | 0.897     | 0.975 | 0.736 | 196.488 |

##### MOMENT DESIGN

|             | Med    | Med, span | Mc, Rd      | Mv, Rd   | Mn, Rd   | Mb, Rd   |         |
|-------------|--------|-----------|-------------|----------|----------|----------|---------|
|             | Moment | Moment    | Capacity    | Capacity | Capacity | Capacity |         |
| Major (y-y) | -2.234 | -2.234    | 8.490       | 8.490    | 7.086    | 8.490    |         |
| Minor (z-z) | 0.153  | 0.153     | 5.153       | 5.153    | 3.786    |          |         |
|             | Curve  | AlphaLT   | LambdaBarLT | PhiLT    | ChiLT    | C1       | Mcr     |
| LTB         | d      | 0.760     | 0.103       | 0.469    | 1.000    | 2.700    | 796.909 |
|             | kyy    | kyz       | kzy         | kzz      |          |          |         |
| Factors     | 0.897  | 0.277     | 0.538       | 0.462    |          |          |         |

## Comparação de Resultados

| Estado Limite Último |       | Folha de Cálculo | "Semicomp+" | Desvio $\Delta$ (%) |
|----------------------|-------|------------------|-------------|---------------------|
| Compressão           |       | 0.374            | 0.380       | 1.6%                |
| Flexão               | y - y | 0.263            | 0.270       | 2.6%                |
|                      | z - z | 0.030            | 0.030       | 0.0%                |
| Esforço Transverso   | y - y | 0.009            | 0.009       | 0.0%                |
|                      | z - z | 0.040            | 0.041       | 2.4%                |
| Flexão Desviada      |       | 0.104            | 0.110       | 5.5%                |

|           |                       | Folha de Cálculo | "SAP2000" | Desvio $\Delta$ (%) |
|-----------|-----------------------|------------------|-----------|---------------------|
| Parâmetro | $\bar{\lambda}_y$     | 0.897            | 0.897     | 0.0%                |
|           | $\bar{\lambda}_z$     | 0.522            | 0.521     | 0.2%                |
|           | $\chi_y$              | 0.736            | 0.736     | 0.0%                |
|           | $\chi_z$              | 0.917            | 0.917     | 0.0%                |
| Rácio     | $N_{c,Ed}/N_{b,z,Rd}$ | 0.508            | 0.508     | 0.0%                |

|                           |          | Folha de Cálculo | "SAP2000" | Desvio $\Delta$ (%) |
|---------------------------|----------|------------------|-----------|---------------------|
| Coeficientes de Interação | $k_{yy}$ | 0.897            | 0.914     | 0.0%                |
|                           | $k_{yz}$ | 0.271            | 0.546     | 2.2%                |
|                           | $k_{zy}$ | 0.538            | 0.549     | 0.0%                |
|                           | $k_{zz}$ | 0.452            | 0.91      | 2.2%                |
| Rácio                     | Eq. 6.61 | 0.752            | 0.752     | 0.0%                |

### Estados Limites de Utilização

| Barra nº | Combinação Condicionante | $\delta_V$ (cm) | $\delta_{admissível}$ (cm) | Rácio       |
|----------|--------------------------|-----------------|----------------------------|-------------|
| 2240     | ELS_PASS_(Wy_Wzz_(T-)    | 0.38            | 1.2                        | <b>0.32</b> |

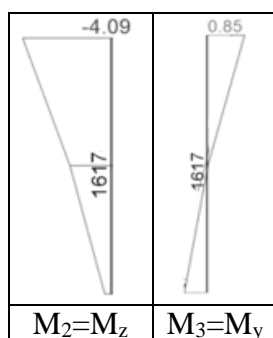
## Prumos da Estrutura Secundária

### Verificações

#### Estados Limites Últimos

| Perfil         | A<br>(cm <sup>2</sup> ) | I <sub>y</sub> =I <sub>z</sub><br>(cm <sup>4</sup> ) | W <sub>el,y</sub> =W <sub>el,z</sub><br>(cm <sup>3</sup> ) | W <sub>pl,y</sub> =W <sub>pl,z</sub><br>(cm <sup>3</sup> ) | i <sub>y</sub> =i <sub>z</sub><br>(cm <sup>2</sup> ) | A <sub>vy</sub> =A <sub>vz</sub><br>(cm <sup>2</sup> ) |
|----------------|-------------------------|--|--|--|--|--|
| Tubo 50x50x6,3 | 11.01                   | 35.78  | 13.10  | 18.17  | 1.84   | 5.30   |

| Barra nº | Combinação Condicionante | Secção (m) | N <sub>c,Ed</sub><br>(kN) | V <sub>y,Ed</sub><br>(kN) | V <sub>z,Ed</sub><br>(kN) | M <sub>y,Ed</sub><br>(kN.m) | M <sub>z,Ed</sub><br>(kN.m) |
|----------|--------------------------|------------|---------------------------|---------------------------|---------------------------|-----------------------------|-----------------------------|
| 1617     | ELU_S1Y                  | si - 0.00  | 13.04                     | 7.27                      | 2.89                      | -0.52                       | -0.29                       |
|          |                          | sm - 0.30  | 13.01                     | 7.27                      | 2.89                      | 0.03                        | -1.91                       |
|          |                          | sf - 0.60  | 12.99                     | 7.27                      | 2.89                      | 0.85                        | -4.09                       |



#### 1º Procedimento – A partir da Folha de Cálculo em “Excel”

| Barra nº | Secção (m) | Compressão                |   | Esforço Transverso           |  |                              |  |
|----------|------------|---------------------------|---|------------------------------|--|------------------------------|--|
|          |            | N <sub>c,Rd</sub><br>(kN) | Rácio<br>N <sub>c,Ed</sub> /N <sub>c,Rd</sub> | Eixo z-z                     |  | Eixo y-y                     |  |
|          |            |                           |   | V <sub>pl,z,Rd</sub><br>(kN) | Rácio<br>V <sub>z,Ed</sub> /V <sub>pl,z,Rd</sub> | V <sub>pl,y,Rd</sub><br>(kN) | Rácio<br>V <sub>y,Ed</sub> /V <sub>pl,y,Rd</sub> |
| 1617     | si - 0.00  | 258.74                    | <b>0.050</b>                                  | 74.69                        | <b>0.039</b>                                     | 74.69                        | <b>0.097</b>                                     |
|          | sm - 0.30  | 258.74                    | <b>0.050</b>                                  | 74.69                        | <b>0.039</b>                                     | 74.69                        | <b>0.097</b>                                     |
|          | sf - 0.60  | 258.74                    | <b>0.050</b>                                  | 74.69                        | <b>0.039</b>                                     | 74.69                        | <b>0.097</b>                                     |

| Barra nº | Secção (m) | Flexão com Esforço Transverso                    |                               |   |  |                               |   |
|----------|------------|--|-------------------------------|---|--|-------------------------------|---|
|          |            | Eixo y-y   |                               |   | Eixo z-z   |                               |   |
|          |            | V <sub>z,Ed</sub> /V <sub>pl,z,Rd</sub><br>< 0,5 | M <sub>y,V,Rd</sub><br>(kN.m) | Rácio<br>M <sub>y,Ed</sub> /M <sub>y,V,Rd</sub> | V <sub>y,Ed</sub> /V <sub>pl,y,Rd</sub><br>< 0,5 | M <sub>z,V,Rd</sub><br>(kN.m) | Rácio<br>M <sub>z,Ed</sub> /M <sub>z,V,Rd</sub> |
| 1617     | si - 0.00  | V <sub>Ed</sub> s/ sign.                         | 4.27                          | <b>0.121</b>                                    | V <sub>Ed</sub> s/ sign.                         | 4.27                          | <b>0.068</b>                                    |
|          | sm - 0.30  | V <sub>Ed</sub> s/ sign.                         | 4.27                          | <b>0.007</b>                                    | V <sub>Ed</sub> s/ sign.                         | 4.27                          | <b>0.447</b>                                    |
|          | sf - 0.60  | V <sub>Ed</sub> s/ sign.                         | 4.27                          | <b>0.199</b>                                    | V <sub>Ed</sub> s/ sign.                         | 4.27                          | <b>0.957</b>                                    |

|          |        | Flexão Composta com Esforço Transverso |   |                 |                     |                             |   |                 |                     |                             |              | Flexão Desviada |       |              |
|----------|--------|--|---|-----------------|---------------------|-----------------------------|---|-----------------|---------------------|-----------------------------|--------------|-----------------|-------|--------------|
|          |        | Eixo y-y                               |   |                 |                     |                             | Eixo z-z                                |                 |                     |                             |              |                 |       |              |
| Barra nº | Secção | $N_{Ed}/N_{pl,Rd} \leq 0,25$           | $N_{Ed}/h_w \cdot t_w \cdot f_y \leq 0,5$ | Red. $M_{y,Rd}$ | $M_{N,y,Rd}$ (kN.m) | Rácio $M_{y,Ed}/M_{N,y,Rd}$ | $N_{Ed}/h_w \cdot t_w \cdot f_y \leq 1$ | Red. $M_{z,Rd}$ | $M_{N,z,Rd}$ (kN.m) | Rácio $M_{z,Ed}/M_{N,z,Rd}$ | $\alpha$     | $\beta$         | Rácio |              |
| 1617     | si -   | 0.00                                   | 0.05                                      | 0.24            | N.A.                | 4.27                        | <b>0.121</b>                            | 0.24            | N.A.                | 4.27                        | <b>0.068</b> | 1.66            | 1.66  | <b>0.041</b> |
|          | sm -   | 0.30                                   | 0.05                                      | 0.23            | N.A.                | 4.27                        | <b>0.007</b>                            | 0.23            | N.A.                | 4.27                        | <b>0.447</b> | 1.66            | 1.66  | <b>0.262</b> |
|          | sf -   | 0.60                                   | 0.05                                      | 0.23            | N.A.                | 4.27                        | <b>0.199</b>                            | 0.23            | N.A.                | 4.27                        | <b>0.957</b> | 1.66            | 1.66  | <b>0.999</b> |

“N.A.”- redução de momento fletor pelo esforço normal não aplicável.

| Encurvadura por Compressão (Coluna) |                |             |                   |          |                   |                |             |                   |          |                   |                      |                           |
|-------------------------------------|----------------|-------------|-------------------|----------|-------------------|----------------|-------------|-------------------|----------|-------------------|----------------------|---------------------------|
|                                     |                | Eixo y-y    |                   |          |                   | Eixo z-z       |             |                   |          |                   | Plano de Encurvadura | Rácio $N_{c,Ed}/N_{b,Rd}$ |
| Barra nº                            | $L_{cr,y}$ (m) | $\lambda_y$ | $\bar{\lambda}_y$ | $\chi_y$ | $N_{b,y,Rd}$ (kN) | $L_{cr,z}$ (m) | $\lambda_z$ | $\bar{\lambda}_z$ | $\chi_z$ | $N_{b,z,Rd}$ (kN) |                      |                           |
| 1617                                | 0.60           | 33.28       | 0.354             | 0.964    | 249.53            | 0.60           | 33.28       | 0.354             | 0.964    | 249.53            | y - y / z - z        | <b>0.052</b>              |

| Encurvadura por Flexão Composta com Compressão (Coluna-Viga) |          |          |             |               |                   |                   |          |          |          |          |          |          |                     |                     |
|--|----------|----------|-------------|---------------|-------------------|-------------------|----------|----------|----------|----------|----------|----------|---------------------|---------------------|
| Barra nº   | $\chi_z$ | $\chi_y$ | $\chi_{LT}$ | $N_{Rk}$ (kN) | $M_{y,Rk}$ (kN.m) | $M_{z,Rk}$ (kN.m) | $C_{my}$ | $C_{mz}$ | $k_{yy}$ | $k_{yz}$ | $k_{zy}$ | $k_{zz}$ | Eq.6.61 do EC3 -1-1 | Eq.6.62 do EC3 -1-1 |
| 1617   | 0.964    | 0.964    | 1.000       | 258.74        | 4.27              | 4.27              | 0.400    | 0.628    | 0.403    | 0.380    | 0.242    | 0.634    | <b>0.496</b>        | <b>0.707</b>        |

## 2º Procedimento – A partir do software “Semicomp+”

### Barra nº 1617 (Secção)

| <b>SEMICOMP Cross-Section Check</b>  |         |                             |   |                   |        |
|--|---------|-----------------------------|---|-------------------|--------|
| Choose method <span style="border: 1px solid gray; padding: 2px;">EN 1993-1-1 (elastic Resistance)</span>  |         |                             |   |                   |        |
| $N_{Ed} =$   | -13.037 | kN                          | $V_{z,Ed} =$  | 2.888             | kN     |
| $M_{y,Ed} =$   | 0.851   | kNm                         | $V_{y,Ed} =$  | 7.274             | kN     |
| $M_{z,Ed} =$   | -4.088  | kNm                         | <span style="border: 1px solid gray; padding: 5px;">Perform cross-section checks</span> |                   |        |
| <i>Reference values for classification</i>   |         |                             |   |                   |        |
| $c/t_w =$  | 4.937   | $\alpha_{web} =$            | 1.000   | $\psi_{web} =$    | 0.778  |
| $c/t_f =$  | 4.937   | $\alpha_{flange} =$         | 0.783   | $\psi_{flange} =$ | -0.430 |
|  |         |                             | $\varepsilon =$   | 1.000             |        |
|  |         |                             | $\varepsilon_{mod,cl/3/4} =$  | NaN               |        |
| <i>Boundaries</i>  |         |                             |   |                   |        |
|  |         | <b>Class 1</b>              | <b>Class 2</b>  | <b>Class 3</b>    |        |
| $c/t_w \leq c/t_{w, max} =$  | 33.000  | 38.000                      | 45.313  |                   |        |
| $c/t_f \leq c/t_{f, max} =$  | 43.116  | 49.649                      | 79.553  |                   |        |
| Cross section class = <span style="border: 1px solid gray; padding: 2px;">1</span>   |         |                             |   |                   |        |
| <div style="border: 1px solid gray; padding: 5px; width: fit-content; margin: auto;">                     Note: This tool is only applicable to Class 1 to 3. For Class 4 elastic cross-section values are used for all calculations.                 </div> |         |                             |   |                   |        |
| $M_{pl,y,Rd} =$  | 4.00    | kNm                         | $M_{pl,z,Rd} =$   | 4.00              | kNm    |
| $M_{el,y,Rd} =$  | 3.08    | kNm                         | $M_{el,z,Rd} =$   | 3.08              | kNm    |
| $N_{Rd} =$   | 248.78  | kN                          | $V_{pl,z,Rd} =$   | 71.82             | kN     |
| $V_{pl,y,Rd} =$  | 71.82   | kN                          |   |                   |        |
| <b>EN 1993-1-1, 6.2.3 / 6.2.4</b>  |         |                             |   |                   |        |
| <i>Tension or compression</i>  |         |                             |   |                   |        |
| $U_{(6.5)/(6.9)} =$  | 0.052   | $\leq 1,0$                  | ok  |                   |        |
| <b>EN 1993-1-1, 6.2.5</b>  |         |                             |   |                   |        |
| <i>Bending moment</i>  |         |                             |   |                   |        |
| $U_{strong A.} =$  | 0.213   | $\leq 1,0$                  | ok  |                   |        |
| $U_{weak A.} =$  | 1.023   | $\leq 1,0$                  | not ok  |                   |        |
| <b>EN 1993-1-1, 6.2.6</b>  |         |                             |   |                   |        |
| <i>Shear</i>   |         |                             |   |                   |        |
| $U_{z-plastic} =$  | 0.040   | $\leq 1,0$                  | ok  | $U_{y-plastic} =$ | 0.101  |
| $U_{z-elastic} =$  | 0.044   | $\leq 1,0$                  | ok  | $U_{y-elastic} =$ | 0.110  |
| $h_w/t_w =$  | 5.937   | $\leq 72\varepsilon/\eta =$ | 60.000  | ok                |        |
| <b>EN 1993-1-1, 6.2.9</b>  |         |                             |   |                   |        |
| <i>Bending and axial force</i>   |         |                             |   |                   |        |
| $U_{(6.41)/(6.42)} =$  | 1.115   | $\leq 1,0$                  | not ok  | $UF =$            | 1.067  |
| Comment: Shear Interaction is not considered within this software tool. If the utilization for shear is higher than 0.5, an additional check for shear interaction is necessary.   |         |                             |   |                   |        |

# Barra nº 1617 (Coluna-Viga)

### SEMICOMP Member Check

Choose method for member check

Method 2 (EN 1993-1-1 Annex B)

Choose method for cross-section resistance

EN 1993-1-1:2010-12

Perform member design check

---

**Section classification for member design check** (based on 1. order cross-section forces)

Reference values for classification in the worst section along the member

|           |       |                     |       |                   |        |                 |       |
|-----------|-------|---------------------|-------|-------------------|--------|-----------------|-------|
| $c/t_w =$ | 4.937 | $\alpha_{web} =$    | 1.000 | $\psi_{web} =$    | 0.778  | $\varepsilon =$ | 1.000 |
| $c/t_f =$ | 4.937 | $\alpha_{flange} =$ | 0.783 | $\psi_{flange} =$ | -0.430 |                 |       |

**Boundaries**

|                             | Class 1 | Class 2 | Class 3 |
|-----------------------------|---------|---------|---------|
| $c/t_w \leq c/t_{w, max} =$ | 33.000  | 38.000  | 45.313  |
| $c/t_f \leq c/t_{f, max} =$ | 43.116  | 49.649  | 79.553  |

Member class = **1**

Note: This tool is only applicable to Class 1 to 3. For Class 4 elastic cross-section values are used for all calculations. The user should check if parts of member are Class 4 in the "Additional info"-sheet.

---

#### Member Check

|              |            |                 |           |                  |            |
|--------------|------------|-----------------|-----------|------------------|------------|
| $N_{Rd} =$   | 248.783 kN | $M_{pl,y,Rd} =$ | 3.996 kNm | $N_{Ed} =$       | -13.037 kN |
| $M_{y,Rd} =$ | 3.996 kNm  | $M_{pl,z,Rd} =$ | 3.996 kNm | $M_{y,Ed,max} =$ | 0.851 kNm  |
| $M_{z,Rd} =$ | 3.996 kNm  | $M_{el,y,Rd} =$ | 3.080 kNm | $M_{z,Ed,max} =$ | 4.088 kNm  |
|              |            | $M_{el,z,Rd} =$ | 3.080 kNm |                  |            |

|                             |                           |                                   |             |                   |           |
|-----------------------------|---------------------------|-----------------------------------|-------------|-------------------|-----------|
| <b>Strong axis buckling</b> | <b>Weak axis buckling</b> | <b>Lateral torsional buckling</b> |             |                   |           |
| $L_{cr,y} =$                | 0.600 m                   | $L_{cr,z} =$                      | 0.600 m     | $M_{cr} =$        | inf kNm   |
| $N_{cr,y} =$                | 1886.209 kN               | $N_{cr,z} =$                      | 1886.209 kN | $\alpha_{LT} =$   | 0.00 [-]  |
| $\alpha_y =$                | 0.21 [-]                  | $\alpha_z =$                      | 0.21 [-]    | $\lambda_{LT} =$  | 0.000 [-] |
| $\lambda_y =$               | 0.363 [-]                 | $\lambda_z =$                     | 0.363 [-]   | $\chi_{LT,mod} =$ | 1.000 [-] |
| $\chi_y =$                  | 0.962 [-]                 | $\chi_z =$                        | 0.962 [-]   | $f_{mod} =$       | 0.000 [-] |

---

#### EN 1993-1-1, 6.3.3

Uniform member in bending and axial compression

|             |       |       |            |           |
|-------------|-------|-------|------------|-----------|
| Eq. (6.61): | $U =$ | 0.530 | $\leq 1,0$ | <b>ok</b> |
| Eq. (6.62): | $U =$ | 0.755 | $\leq 1,0$ | <b>ok</b> |

Global interaction factors

|            |       |
|------------|-------|
| $k_{yy} =$ | 0.404 |
| $k_{yz} =$ | 0.380 |
| $k_{zy} =$ | 0.242 |
| $k_{zz} =$ | 0.634 |

Cross-section check at each end of the member

|            |       |       |            |               |        |       |
|------------|-------|-------|------------|---------------|--------|-------|
| Left end:  | $U =$ | 0.129 | $\leq 1,0$ | <b>ok</b>     | $UF =$ | 0.173 |
| Right end: | $U =$ | 1.115 | $\leq 1,0$ | <b>not ok</b> | $UF =$ | 1.067 |

---

#### Additional member checks

##### EN 1993-1-1, 6.3.1

Strong axis flexural buckling check

Eq. (6.46):  $N_{Ed}/N_{b,Rd} =$  0.054  $\leq 1,0$  **ok**

Weak axis flexural buckling check

Eq. (6.46):  $N_{Ed}/N_{b,Rd} =$  0.054  $\leq 1,0$  **ok**

##### EN 1993-1-1, 6.3.2

Lateral torsional buckling

Eq. (6.54):  $M_{Ed}/M_{b,Rd} =$  0.000  $\leq 1,0$  **ok**

### 3º Procedimento – A partir do software “SAP2000”

#### Barra nº 1617 (Secção)

| STRESS CHECK FORCES & MOMENTS |        |        |        |        |       |       |
|-------------------------------|--------|--------|--------|--------|-------|-------|
| Location                      | Ned    | Med,yy | Med,zz | Ved,z  | Ved,y | Ted   |
| 0.600                         | -0.513 | 0.851  | -4.088 | -2.888 | 7.274 | 0.063 |

|   |       |   |                          |   |                          |                  |
|---|-------|---|--------------------------|---|--------------------------|------------------|
| PMM DEMAND/CAPACITY RATIO (Governing Equation EC3 6.2.9.1(6)) |       |   |                          |   |                          |                  |
| D/C Ratio:  | 0.999 | = | (0.199) <sup>1.660</sup> | + | (0.957) <sup>1.660</sup> | <                |
|   |       |   |                          |   |                          | 1.000            |
|   |       |   |                          |   |                          | OK               |
|   |       |   |                          |   |                          | (EC3 6.2.9.1(6)) |

#### Comparação de Resultados

| Estado Limite Último | Folha de Cálculo | "Semicomp+" | "SAP2000" | Desvio Δ (%) |      |
|----------------------|------------------|-------------|-----------|--------------|------|
| Compressão           | 0.050            | 0.052       | -         | 3.8%         |      |
| Flexão               | y-y              | 0.199       | 0.213     | -            | 6.6% |
|                      | z-z              | 0.957       | 1.023     | -            | 6.5% |
| Esforço              | y-y              | 0.097       | 0.101     | -            | 4.0% |
| Transverso           | z-z              | 0.039       | 0.040     | -            | 2.5% |
| Flexão Desviada      | 0.999            | 1.115       | 0.999     | 5.25%        |      |

| Parâmetro | Folha de Cálculo "Semicomp+" Desvio Δ (%) |                  |             |              |
|-----------|---|------------------|-------------|--------------|
|           |   | Folha de Cálculo | "Semicomp+" | Desvio Δ (%) |
| λ         | λ <sub>y</sub>                            | 0.354            | 0.363       | 2.5%         |
|           | λ <sub>z</sub>                            | 0.354            | 0.363       | 2.5%         |
|           | χ <sub>y</sub>                            | 0.964            | 0.962       | 0.2%         |
|           | χ <sub>z</sub>                            | 0.964            | 0.962       | 0.2%         |
| Rácio     | N <sub>c,Ed</sub> /N <sub>b,z,Rd</sub>    | 0.052            | 0.054       | 3.7%         |

| Coeficientes de Interação | Folha de Cálculo "Semicomp+" Desvio Δ (%) |                  |             |              |
|---------------------------|---|------------------|-------------|--------------|
|                           |   | Folha de Cálculo | "Semicomp+" | Desvio Δ (%) |
| k                         | k <sub>yy</sub>                           | 0.403            | 0.404       | 0.2%         |
|                           | k <sub>yz</sub>                           | 0.380            | 0.380       | 0.0%         |
|                           | k <sub>zy</sub>                           | 0.242            | 0.242       | 0.0%         |
|                           | k <sub>zz</sub>                           | 0.640            | 0.634       | 0.9%         |
| Rácio                     | Eq. 6.61                                  | 0.496            | 0.529       | 6.7%         |
|                           | Eq. 6.62                                  | 0.707            | 0.755       | 6.8%         |

#### Estados Limites de Utilização

| Barra nº | Combinação Condicionante | δ <sub>v</sub> (cm) | δ <sub>admissível</sub> (cm) | Rácio |
|----------|--------------------------|---------------------|------------------------------|-------|
| 1617     | ELS_Wyy_Wzz_(T-)         | 0.25                | 0.24                         | 1.04  |

## Diagonais do Painel Horizontal Inferior dos Caixões Treliçados

### 1º Procedimento – A partir do “SAP2000” (barra mais solicitada)

|               |               |                         |                     |
|---------------|---------------|-------------------------|---------------------|
| Frame : 685   | X Mid: 47.665 | Combo: ELU_Wyy_Wzz_(T-) | Design Type: Brace  |
| Length: 2.144 | Y Mid: 0.000  | Shape: L60X6            | Frame Type: DCL-MRF |
| Loc : 0.000   | Z Mid: 11.219 | Class: Class 3          | Rolled : Yes        |

**STRESS CHECK FORCES & MOMENTS**

| Location | Ned     | Med,yy | Med,zz | Ved,z  | Ved,y | Ted       |
|----------|---------|--------|--------|--------|-------|-----------|
| 0.000    | -30.721 | 0.000  | 0.000  | -0.075 | 0.000 | 3.285E-04 |

| Curve        | Alpha | Ncr   | LambdaBar | Phi   | Chi   | Nb,Rd  |
|--------------|-------|-------|-----------|-------|-------|--------|
| Major (y-y)  | b     | 0.340 | 165.102   | 0.992 | 1.126 | 97.794 |
| MajorB(y-y)  | b     | 0.340 | 165.102   | 0.992 | 1.126 | 97.794 |
| Minor (z-z)  | b     | 0.340 | 40.505    | 2.002 | 2.811 | 33.945 |
| MinorB(z-z)  | b     | 0.340 | 40.505    | 2.002 | 2.811 | 33.945 |
| Torsional TF | b     | 0.340 | 148.057   | 1.047 | 1.192 | 92.123 |

**PMM DEMAND/CAPACITY RATIO (Governing Equation EC3 6.3.3(4)-6.62)**

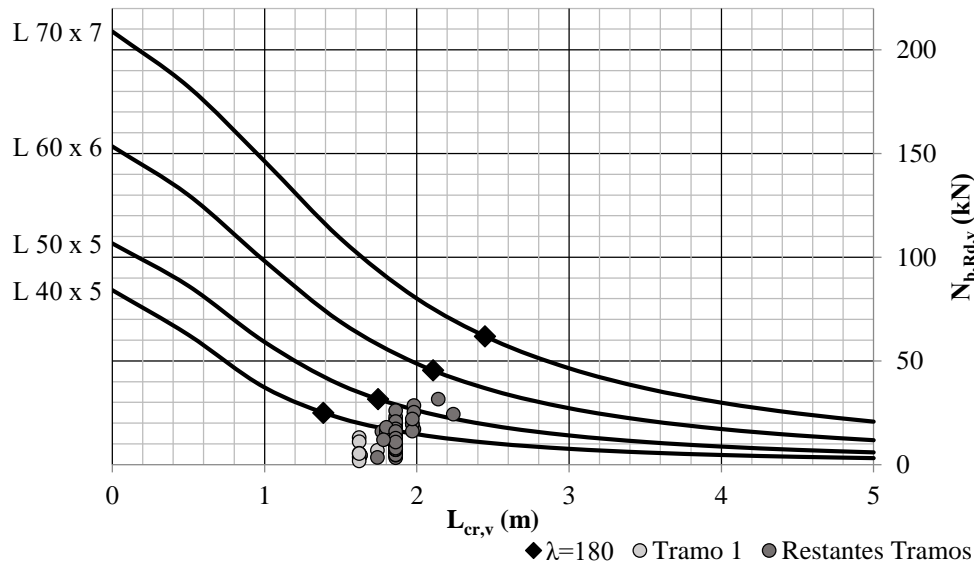
D/C Ratio: 0.940 = 0.905 + 0.035 + 0.000 < 1.000 **OK**

=  $N_{Ed} / (\chi_z N_{Rk} / \gamma_{M1}) + k_{zy} (M_y, Ed + N_{Ed} eNy) / (\chi_{LT} M_y, Rk / \gamma_{M1})$   
+  $k_{zz} (M_z, Ed + N_{Ed} eNz) / (M_z, Rk / \gamma_{M1})$  (EC3 6.3.3(4)-6.62)

### 2º Procedimento – A partir da Folha de Cálculo em “Excel” (barras mais solicitadas)

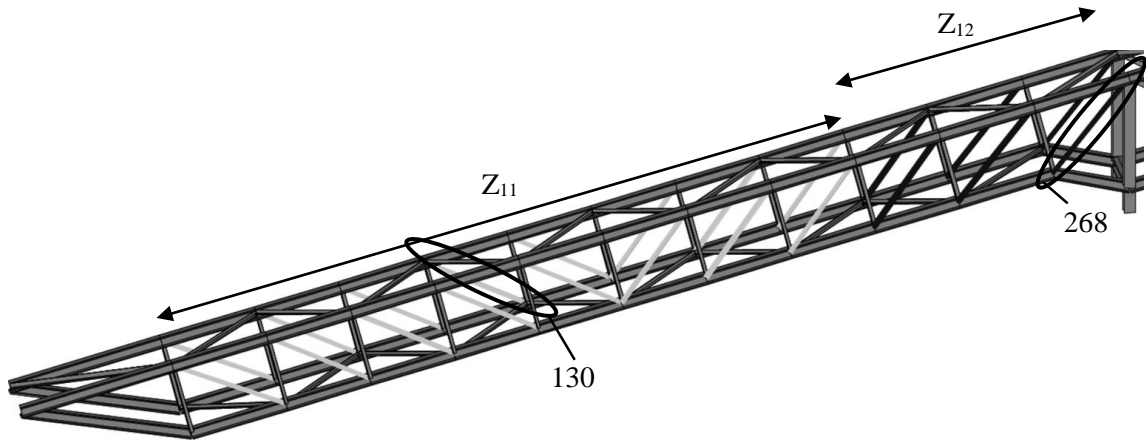
| Barra nº | Combinação Condicionante | N <sub>c,Ed</sub> (kN) | Resistência à Encurvadura |                       |                |                |                          | Rácio       |
|----------|--------------------------|------------------------|---------------------------|-----------------------|----------------|----------------|--------------------------|-------------|
|          |                          |                        | Perfil                    | L <sub>cr,v</sub> (m) | λ <sub>v</sub> | χ <sub>v</sub> | N <sub>b,Rd,v</sub> (kN) |             |
| 39       | ELU_S1Y                  | 13.02                  | L50x5                     | 1.62                  | 167            | 0.31           | 34.91                    | <b>0.37</b> |
| 229      | ELU_S1Y                  | 24.42                  | L60x6                     | 2.237                 | 191            | 0.26           | 41.91                    | <b>0.58</b> |
| 685      | ELU_Wyy_Wzz_(T-)         | 30.72                  | L60x6                     | 2.144                 | 183            | 0.27           | 44.45                    | <b>0.69</b> |
| 1096     | ELU_Wyy_Wzz_(T+)         | 19.89                  | L60x6                     | 1.966                 | 168            | 0.31           | 49.85                    | <b>0.40</b> |

### Restantes Barras

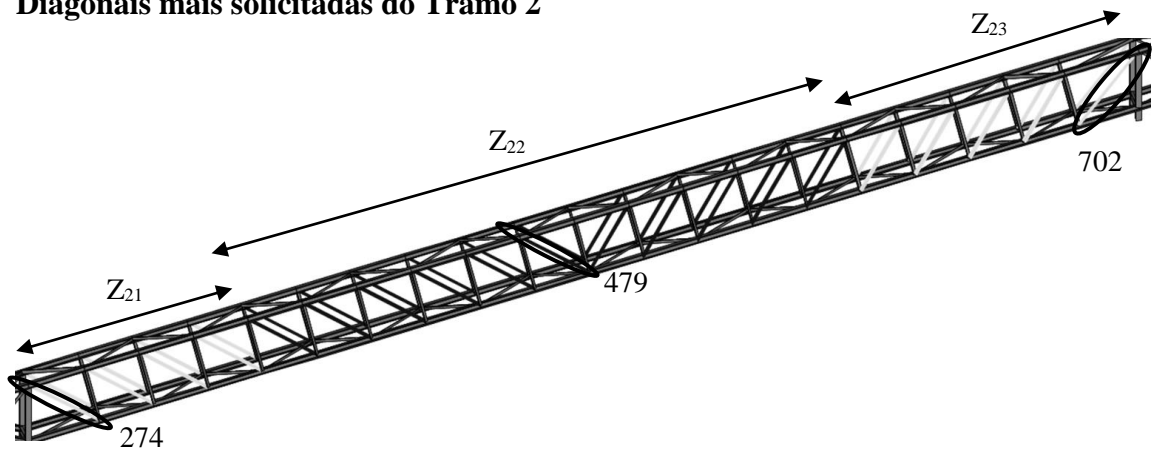


## Diagonais dos Painéis Verticais dos Caixões Treliçados

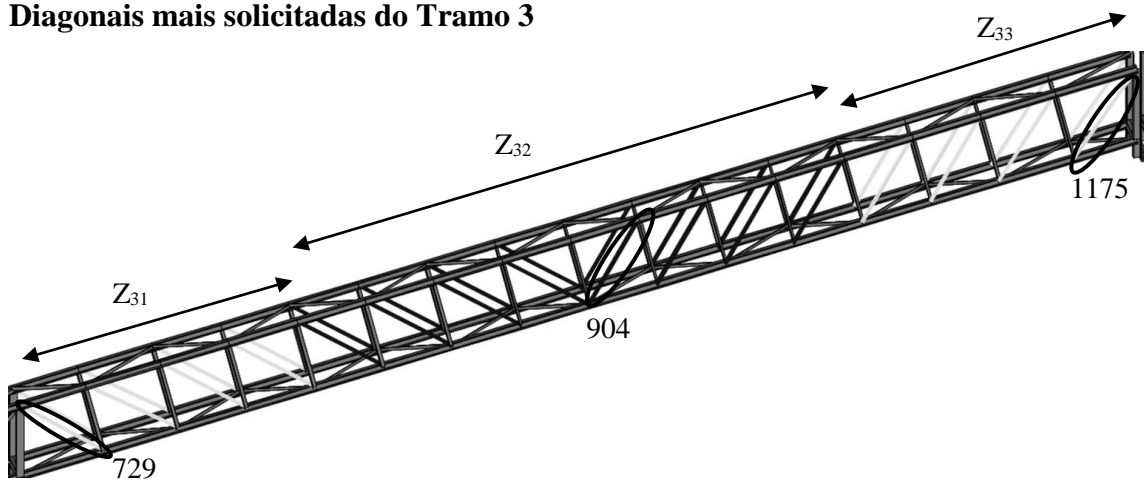
### Diagonais mais solicitadas do Tramo 1



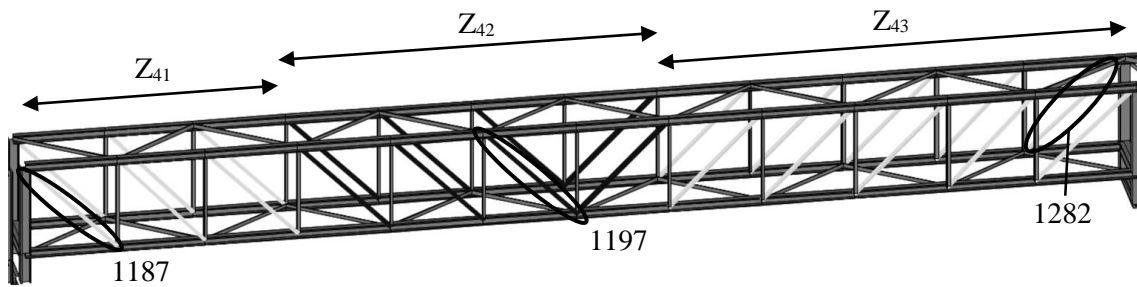
### Diagonais mais solicitadas do Tramo 2



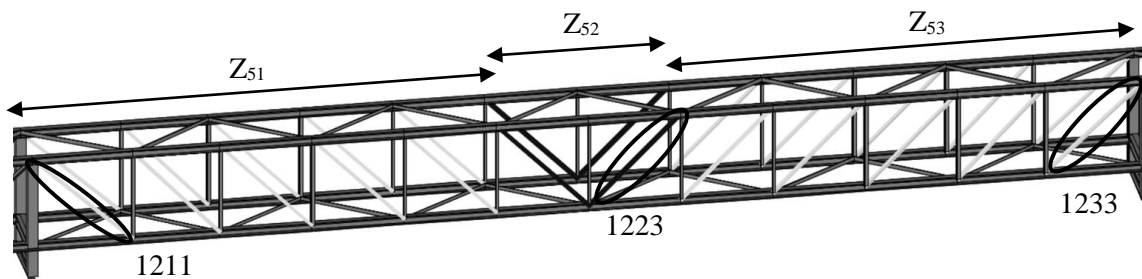
### Diagonais mais solicitadas do Tramo 3



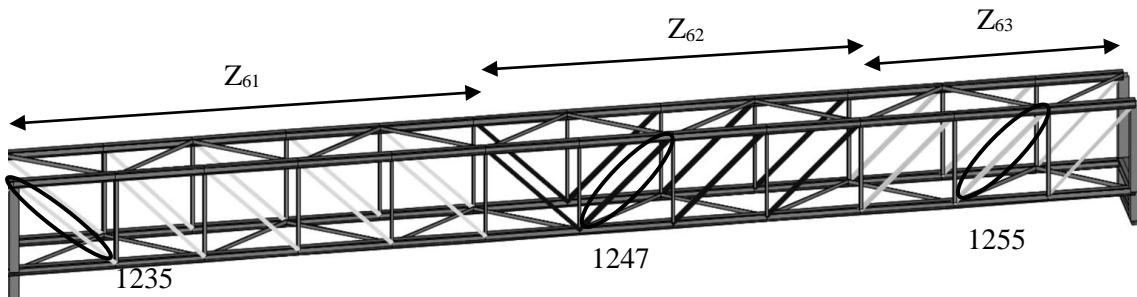
### Diagonais mais solicitadas do Tramo 4



### Diagonais mais solicitadas do Tramo 5



### Diagonais mais solicitadas do Tramo 6



### 1º Procedimento – A partir do “SAP2000” (Diagonal Comprimida mais solicitada)

|               |               |                |                     |
|---------------|---------------|----------------|---------------------|
| Frame : 268   | X Mid: 16.703 | Combo: ELU_S1X | Design Type: Brace  |
| Length: 1.682 | Y Mid: -0.550 | Shape: L60X6   | Frame Type: DCL-MRF |
| Loc : 0.000   | Z Mid: 3.958  | Class: Class 3 | Rolled : Yes        |

#### STRESS CHECK FORCES & MOMENTS

| Location     | Ned     | Med,yy | Med,zz  | Ved,z     | Ved,y | Ted    |         |
|--------------|---------|--------|---------|-----------|-------|--------|---------|
| 0.000        | -43.183 | 0.000  | 0.000   | -0.028    | 0.000 | -0.004 |         |
|              | Curve   | Alpha  | Ncr     | LambdaBar | Phi   | Chi    | Nb,Rd   |
| Major (y-y)  | b       | 0.340  | 268.104 | 0.778     | 0.901 | 0.738  | 119.791 |
| MajorB(y-y)  | b       | 0.340  | 268.104 | 0.778     | 0.901 | 0.738  | 119.791 |
| Minor (z-z)  | b       | 0.340  | 65.775  | 1.571     | 1.967 | 0.317  | 51.522  |
| MinorB(z-z)  | b       | 0.340  | 65.775  | 1.571     | 1.967 | 0.317  | 51.522  |
| Torsional TF | b       | 0.340  | 222.540 | 0.854     | 0.976 | 0.691  | 112.111 |

**PMM DEMAND/CAPACITY RATIO** (Governing Equation EC3 6.3.3(4)-6.62)  
 D/C Ratio: 0.848 = 0.838 + 0.010 + 0.000 < 1.000 OK  

$$= \frac{N_{Ed}}{\chi_z N_{Rk} / \gamma_{M1}} + k_{zy} \frac{(M_y, Ed + N_{Ed} e_{Ny})}{(\chi_{LT} M_y, Rk / \gamma_{M1})} + k_{zz} \frac{(M_z, Ed + N_{Ed} e_{Nz})}{(M_z, Rk / \gamma_{M1})}$$
 (EC3 6.3.3(4)-6.62)

**2º Procedimento – A partir da Folha de Cálculo em “Excel” (Diagonais Comprimidas mais solicitadas)**

| Tramo | Zona            | Barra n° | Combinação Condicionante | N <sub>c,Ed</sub> (kN) | Perfil | Resistência à Encurvadura |                |                |                          |       |
|-------|-----------------|----------|--------------------------|------------------------|--------|---------------------------|----------------|----------------|--------------------------|-------|
|       |                 |          |                          |                        |        | L <sub>cr,v</sub> (m)     | λ <sub>v</sub> | χ <sub>v</sub> | N <sub>b,Rd,v</sub> (kN) | Rácio |
| 1     | Z <sub>11</sub> | 130      | ELU_PASS_(Wy_Wzz_T+)     | 30.9                   | L50x5  | 1.56                      | 161            | 0.32           | 36.5                     | 0.85  |
|       | Z <sub>12</sub> | 268      | ELU_S1X                  | 43.1                   | L60x6  | 1.68                      | 143            | 0.37           | 60.5                     | 0.71  |
| 2     | Z <sub>22</sub> | 479      | ELU_S1Y                  | 9.8                    | L60x6  | 2.12                      | 181            | 0.28           | 45.0                     | 0.22  |
| 3     | Z <sub>32</sub> | 904      | ELU_PASS_(Wyy_Wzz_T-)    | 34.7                   | L60x6  | 2.12                      | 181            | 0.28           | 45.1                     | 0.76  |
| 4     | Z <sub>42</sub> | 1197     | ELU_S1X                  | 20.4                   | L60x6  | 2.12                      | 181            | 0.28           | 45.1                     | 0.45  |
| 5     | Z <sub>52</sub> | 1223     | ELU_S1Y                  | 8.13                   | L60x6  | 2.12                      | 181            | 0.28           | 45.1                     | 0.18  |
| 6     | Z <sub>62</sub> | 1247     | ELU_S1Y                  | 18.4                   | L60x6  | 2.12                      | 181            | 0.28           | 45.1                     | 0.41  |

**1º Procedimento – A partir do “SAP2000” (Diagonal Tracionada mais solicitada)**

|               |               |  |
|---------------|---------------|--|
| Frame : 702   | X Mid: 45.983 | Combo: ELU_PASS_(Wyy_WzzDesign Type: Brace |
| Length: 2.537 | Y Mid: -0.550 | Shape: L80X8                               |
| Loc : 1.268   | Z Mid: 11.545 | Class: Class 3                             |
|               |               | Frame Type: DCL-MRF                        |
|               |               | Rolled : Yes                               |

STRESS CHECK FORCES & MOMENTS

| Location | Ned     | Med, yy | Med, zz | Ved, z | Ved, y | Ted        |
|----------|---------|---------|---------|--------|--------|------------|
| 1.268    | 230.990 | 0.064   | 0.000   | 0.000  | 0.000  | -6.700E-04 |

AXIAL FORCE DESIGN

| Axial | Ned Force | Nc, Rd Capacity | Nt, Rd Capacity |
|-------|-----------|-----------------|-----------------|
|       | 230.990   | 288.345         | 288.345         |

PMM DEMAND/CAPACITY RATIO (Governing Equation EC3 6.2.1(7))

|  |                |
|--|----------------|
| D/C Ratio: 0.823 = 0.801 + 0.022 + 0.000 < 1.000 | OK             |
| = (Ned/NRd) + (My,Ed/My,Rd) + (Mz,Ed/Mz,Rd)      | (EC3 6.2.1(7)) |

**2º Procedimento – A partir da folha de cálculo em “Excel” – Diagonais Tracionadas mais solicitadas**

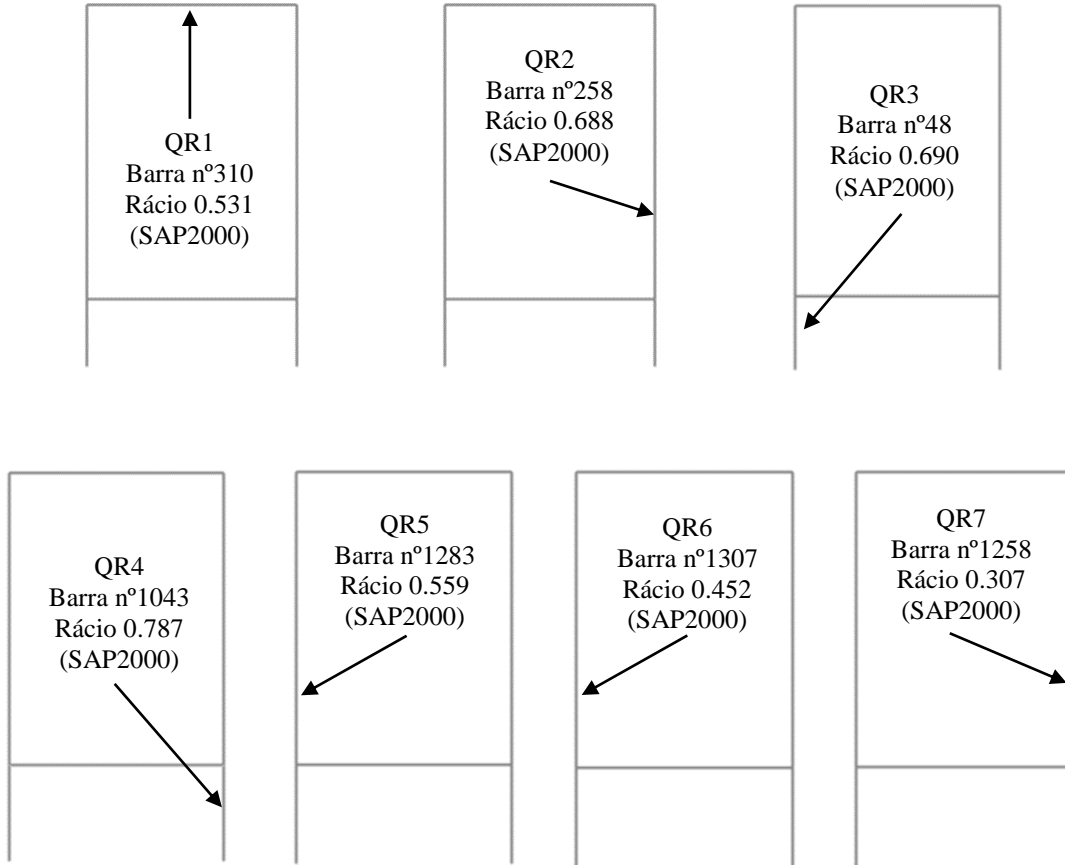
| Tramo | Zona            | Barra n° | Combinação Condicionante | N <sub>t,Ed</sub> (kN) | Perfil | Resistência da secção  |       |
|-------|-----------------|----------|--------------------------|------------------------|--------|------------------------|-------|
|       |                 |          |                          |                        |        | N <sub>t,Rd</sub> (kN) | Rácio |
| 2     | Z <sub>21</sub> | 274      | ELU_PASS_(Wy_Wzz_T+)     | 181.7                  | L70x7  | 220.9                  | 0.82  |
|       | Z <sub>23</sub> | 702      | ELU_PASS_(Wyy_Wzz_T-)    | 230.9                  | L80x8  | 289.1                  | 0.80  |
| 3     | Z <sub>31</sub> | 729      | ELU_PASS_(Wy_Wzz_T-)     | 190.2                  | L70x7  | 220.9                  | 0.86  |
|       | Z <sub>33</sub> | 1175     | ELU_PASS_(Wyy_Wzz_T+)    | 96.3                   | L50x5  | 112.8                  | 0.85  |
| 4     | Z <sub>41</sub> | 1187     | ELU_PASS_(Wy_Wzz_T-)     | 70.3                   | L50x5  | 112.8                  | 0.62  |
|       | Z <sub>43</sub> | 1282     | ELU_PASS_(Wy_Wzz_T+)     | 127.9                  | L60x6  | 162.4                  | 0.79  |
| 5     | Z <sub>51</sub> | 1211     | ELU_PASS_(Wyy_Wzz_T-)    | 114.3                  | L60x6  | 162.4                  | 0.70  |
|       | Z <sub>53</sub> | 1233     | ELU_PASS_(Wyy_Wzz_T+)    | 114.9                  | L60x6  | 162.4                  | 0.71  |
| 6     | Z <sub>61</sub> | 1235     | ELU_PASS_(Wyy_Wzz_T-)    | 126.9                  | L60x6  | 162.4                  | 0.78  |
|       | Z <sub>63</sub> | 1255     | ELU_PASS_(Wyy_Wzz_T+)    | 71.2                   | L50x5  | 112.8                  | 0.63  |

# Quadros Rígidos

## Verificações

### Estados Limites Últimos

#### Barras mais solicitadas



| Perfil     | A<br>(cm <sup>2</sup> ) | I <sub>y</sub><br>(cm <sup>4</sup> ) | W <sub>el,y</sub><br>(cm <sup>3</sup> ) | W <sub>pl,y</sub><br>(cm <sup>3</sup> ) | i <sub>y</sub><br>(cm <sup>2</sup> ) | A <sub>vy</sub><br>(cm <sup>2</sup> ) | I <sub>z</sub><br>(cm <sup>4</sup> ) | W <sub>el,z</sub><br>(cm <sup>3</sup> ) | W <sub>pl,z</sub><br>(cm <sup>3</sup> ) | i <sub>z</sub><br>(cm) | A <sub>vz</sub><br>(cm <sup>2</sup> ) | I <sub>t</sub><br>(cm <sup>4</sup> ) | I <sub>w</sub><br>(cm <sup>6</sup> ) |
|------------|-------------------------|--------------------------------------|---|---|--------------------------------------|---------------------------------------|--------------------------------------|---|---|------------------------|---------------------------------------|--------------------------------------|--------------------------------------|
| HEB<br>160 | 54.25                   | 2492                                 | 311.5                                   | 353.97                                  | 6.78                                 | 41.6                                  | 889.24                               | 111.15                                  | 169.96                                  | 4.05                   | 17.59                                 | 31.37                                | 47943.19                             |

| Quadro | Barra nº | Combinação Condicionante | Secção (m) |      | N <sub>c,Ed</sub> (kN) | V <sub>y,Ed</sub> (kN) | V <sub>z,Ed</sub> (kN) | M <sub>y,Ed</sub> (kN.m) | M <sub>z,Ed</sub> (kN.m) |
|--------|----------|--------------------------|------------|------|------------------------|------------------------|------------------------|--------------------------|--------------------------|
|        |          |                          |            |      |                        |                        |                        |                          |                          |
| QR1    | 310      | ELU_S1Y                  | si -       | 0.00 | 30.89                  | 11.58                  | 46.07                  | -25.87                   | 9.02                     |
|        |          |                          | sm -       | 0.55 | 30.89                  | 11.64                  | 46.29                  | -0.35                    | 2.90                     |
|        |          |                          | sf -       | 1.10 | 30.89                  | 11.69                  | 46.51                  | 25.66                    | 9.02                     |
| QR2    | 258      | ELU_S1Y                  | si -       | 0.00 | 230.86                 | 0.59                   | 48.70                  | -33.69                   | 0.11                     |
|        |          |                          | sm -       | 0.78 | 231.19                 | 0.59                   | 48.70                  | -0.64                    | 0.47                     |
|        |          |                          | sf -       | 1.55 | 231.51                 | 0.59                   | 48.70                  | -38.29                   | 0.91                     |
| QR3    | 48       | ELU_S1X                  | si -       | 0.00 | 91.19                  | 7.89                   | 149.91                 | -57.39                   | -2.11                    |
|        |          |                          | sm -       | 0.20 | 91.12                  | 7.89                   | 149.91                 | -28.72                   | -0.73                    |
|        |          |                          | sf -       | 0.39 | 91.03                  | 7.89                   | 149.91                 | -14.46                   | -1.55                    |
| QR4    | 1043     | ELU_S1X                  | si -       | 0.00 | 64.59                  | 7.35                   | 147.27                 | 65.49                    | -2.58                    |
|        |          |                          | sm -       | 0.24 | 64.49                  | 7.35                   | 147.27                 | 29.95                    | -0.69                    |
|        |          |                          | sf -       | 0.49 | 64.39                  | 7.35                   | 147.27                 | 17.08                    | -1.22                    |
| QR5    | 1283     | ELU_S1Y                  | si -       | 0.00 | 164.63                 | 0.36                   | 40.52                  | -33.05                   | 0.06                     |
|        |          |                          | sm -       | 0.75 | 164.94                 | 0.36                   | 40.52                  | -0.78                    | 0.27                     |
|        |          |                          | sf -       | 1.50 | 165.26                 | 0.36                   | 40.52                  | -30.89                   | 0.54                     |
| QR6    | 1307     | ELU_S1Y                  | si -       | 0.00 | 148.38                 | 0.28                   | 30.81                  | -25.70                   | 0.07                     |
|        |          |                          | sm -       | 0.75 | 148.69                 | 0.28                   | 30.81                  | -0.78                    | 0.20                     |
|        |          |                          | sf -       | 1.50 | 149.00                 | 0.28                   | 30.81                  | -23.67                   | 0.41                     |
| QR7    | 1258     | ELU_Wxx_(T+)             | si -       | 0.00 | 56.68                  | 8.31                   | 1.08                   | 0.37                     | 12.25                    |
|        |          |                          | sm -       | 0.75 | 56.25                  | 8.31                   | 1.08                   | -0.45                    | 6.02                     |
|        |          |                          | sf -       | 1.50 | 55.83                  | 8.31                   | 1.08                   | -1.26                    | -0.21                    |

### 1º Procedimento – A partir da Folha de Cálculo em “Excel”

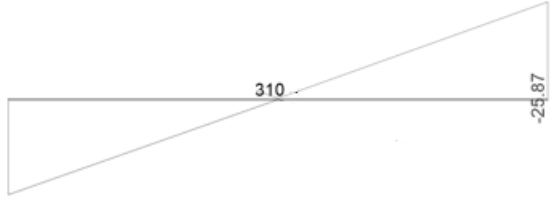

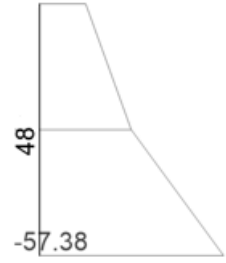
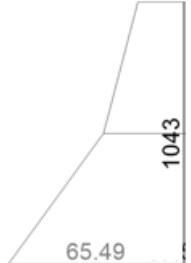


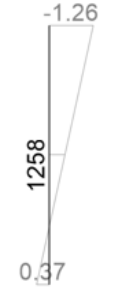
|     | Barra nº | Compressão             |   | Esforço Transverso        |  |                           |  |
|-----|----------|------------------------|---|---------------------------|--|---------------------------|--|
|     |          | N <sub>c,Rd</sub> (kN) | Rácio<br>N <sub>c,Ed</sub> /N <sub>c,Rd</sub> | Eixo z-z                  |  | Eixo y-y                  |  |
|     |          |                        |   | V <sub>pl,z,Rd</sub> (kN) | Rácio<br>V <sub>z,Ed</sub> /V <sub>pl,z,Rd</sub> | V <sub>pl,y,Rd</sub> (kN) | Rácio<br>V <sub>y,Ed</sub> /V <sub>pl,y,Rd</sub> |
| QR1 | 310      | 1274.88                | <b>0.024</b>                                  | 238.66                    | <b>0.195</b>                                     | 564.42                    | <b>0.021</b>                                     |
| QR2 | 258      | 1274.88                | <b>0.182</b>                                  | 238.66                    | <b>0.204</b>                                     | 564.42                    | <b>0.001</b>                                     |
| QR3 | 48       | 1274.88                | <b>0.072</b>                                  | 238.66                    | <b>0.628</b>                                     | 564.42                    | <b>0.014</b>                                     |
| QR4 | 1043     | 1274.88                | <b>0.051</b>                                  | 238.66                    | <b>0.617</b>                                     | 564.42                    | <b>0.013</b>                                     |
| QR5 | 1283     | 1274.88                | <b>0.130</b>                                  | 238.66                    | <b>0.170</b>                                     | 564.42                    | <b>0.001</b>                                     |
| QR6 | 1307     | 1274.88                | <b>0.117</b>                                  | 238.66                    | <b>0.129</b>                                     | 564.42                    | <b>0.000</b>                                     |
| QR7 | 1258     | 1274.88                | <b>0.044</b>                                  | 238.66                    | <b>0.005</b>                                     | 564.42                    | <b>0.015</b>                                     |

|     | Barra nº | Flexão com Esforço Transverso                 |      |                            |   |   |                            |   |
|-----|----------|---|------|----------------------------|---|---|----------------------------|---|
|     |          | Eixo y-y                                      |      |                            |   | Eixo z-z                                      |                            |   |
|     |          | V <sub>z,Ed</sub> /V <sub>pl,z,Rd</sub> < 0,5 | ρ    | M <sub>y,V,Rd</sub> (kN.m) | Rácio<br>M <sub>y,Ed</sub> /M <sub>y,V,Rd</sub> | V <sub>y,Ed</sub> /V <sub>pl,y,Rd</sub> < 0,5 | M <sub>z,V,Rd</sub> (kN.m) | Rácio<br>M <sub>z,Ed</sub> /M <sub>z,V,Rd</sub> |
| QR1 | 310      | V <sub>Ed</sub> s/ sign.                      | -    | 83.19                      | <b>0.311</b>                                    | V <sub>Ed</sub> s/ sign.                      | 39.95                      | <b>0.226</b>                                    |
| QR2 | 258      | V <sub>Ed</sub> s/ sign.                      | -    | 83.19                      | <b>0.460</b>                                    | V <sub>Ed</sub> s/ sign.                      | 39.95                      | <b>0.023</b>                                    |
| QR3 | 48       | V <sub>Ed</sub> c/ sign.                      | 0.07 | 77.73                      | <b>0.738</b>                                    | V <sub>Ed</sub> s/ sign.                      | 39.95                      | <b>0.053</b>                                    |
| QR4 | 1043     | V <sub>Ed</sub> c/ sign.                      | 0.05 | 78.63                      | <b>0.833</b>                                    | V <sub>Ed</sub> s/ sign.                      | 39.95                      | <b>0.065</b>                                    |
| QR5 | 1283     | V <sub>Ed</sub> s/ sign.                      | -    | 83.19                      | <b>0.397</b>                                    | V <sub>Ed</sub> s/ sign.                      | 39.95                      | <b>0.013</b>                                    |
| QR6 | 1307     | V <sub>Ed</sub> s/ sign.                      | -    | 83.19                      | <b>0.309</b>                                    | V <sub>Ed</sub> s/ sign.                      | 39.95                      | <b>0.010</b>                                    |
| QR7 | 1258     | V <sub>Ed</sub> s/ sign.                      | -    | 83.19                      | <b>0.015</b>                                    | V <sub>Ed</sub> s/ sign.                      | 39.95                      | <b>0.307</b>                                    |

|          |                    | Flexão Composta com Esforço Transverso |       |                     |                             |                    |                     |                             |              | Flexão Desviada |         |              |
|----------|--------------------|--|-------|---------------------|-----------------------------|--------------------|---------------------|-----------------------------|--------------|-----------------|---------|--------------|
|          |                    | n                                      | a     | Eixo y-y            |                             |                    | Eixo z-z            |                             |              | $\alpha$        | $\beta$ | Rácio        |
| Barra nº | Red. de $M_{y,Rd}$ |  |       | $M_{N,y,Rd}$ (kN.m) | Rácio $M_{y,Ed}/M_{N,y,Rd}$ | Red. de $M_{z,Rd}$ | $M_{N,z,Rd}$ (kN.m) | Rácio $M_{z,Ed}/M_{N,z,Rd}$ |              |                 |         |              |
| QR1      | 310                | -                                      | -     | N.A.                | 83.19                       | <b>0.311</b>       | N.A.                | 39.95                       | <b>0.226</b> | 2               | 1       | <b>0.322</b> |
| QR2      | 258                | 0.1816                                 | 0.233 | Aplicável           | 77.07                       | <b>0.497</b>       | N.A.                | 39.95                       | <b>0.023</b> | 2               | 1       | <b>0.270</b> |
| QR3      | 48                 | -                                      | -     | N.A.                | 77.73                       | <b>0.738</b>       | N.A.                | 39.95                       | <b>0.053</b> | 2               | 1       | <b>0.598</b> |
| QR4      | 1043               | -                                      | -     | N.A.                | 78.63                       | <b>0.833</b>       | N.A.                | 39.95                       | <b>0.065</b> | 2               | 1       | <b>0.758</b> |
| QR5      | 1283               | 0.1291                                 | 0.233 | Aplicável           | 82.01                       | <b>0.403</b>       | N.A.                | 39.95                       | <b>0.013</b> | 2               | 1       | <b>0.164</b> |
| QR6      | 1307               | 0.1164                                 | 0.233 | Aplicável           | 83.21                       | <b>0.309</b>       | N.A.                | 39.95                       | <b>0.010</b> | 2               | 1       | <b>0.097</b> |
| QR7      | 1258               | -                                      | -     | N.A.                | 83.19                       | <b>0.015</b>       | N.A.                | 39.95                       | <b>0.307</b> | 2               | 1       | <b>0.307</b> |

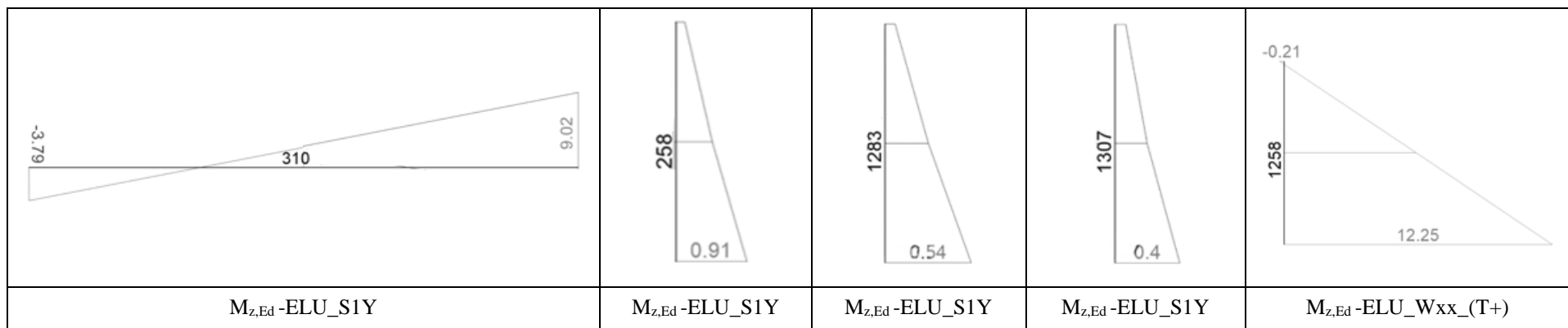
|          |                | Encurvadura por Compressão (Colunas) |                   |                            |                     |             |                   |                            |                       |  |
|----------|----------------|--------------------------------------|-------------------|----------------------------|---------------------|-------------|-------------------|----------------------------|-----------------------|--|
|          |                | Eixo y-y                             |                   |                            |                     | Eixo z-z    |                   |                            |                       |  |
| Barra nº | $L_{cr,y}$ (m) | $\lambda_y$                          | $\bar{\lambda}_y$ | $\bar{\lambda}_y \leq 0,2$ | $L_{cr,z}$ (m)      | $\lambda_z$ | $\bar{\lambda}_z$ | $\bar{\lambda}_z \leq 0,2$ |                       |  |
| QR1      | 310            | 1.10                                 | 16                | 0.173                      | Ignorar encurvadura | 1.10        | 27                | 0.289                      | Verificar encurvadura |  |
| QR3      | 48             | 0.39                                 | 6                 | 0.062                      | Ignorar encurvadura | 0.39        | 10                | 0.104                      | Ignorar encurvadura   |  |
| QR4      | 1043           | 0.49                                 | 7                 | 0.077                      | Ignorar encurvadura | 0.49        | 12                | 0.129                      | Ignorar encurvadura   |  |

|          |                | Encurvadura por Compressão (Colunas) |                   |          |                   |                |             |                   |          |                   |         |                      |                           |
|----------|----------------|--------------------------------------|-------------------|----------|-------------------|----------------|-------------|-------------------|----------|-------------------|---------|----------------------|---------------------------|
|          |                | Eixo y-y                             |                   |          |                   |                | Eixo z-z    |                   |          |                   |         | Plano de Encurvadura | Rácio $N_{c,Ed}/N_{b,Rd}$ |
| Barra nº | $L_{cr,y}$ (m) | $\lambda_y$                          | $\bar{\lambda}_y$ | $\chi_y$ | $N_{b,y,Rd}$ (kN) | $L_{cr,z}$ (m) | $\lambda_z$ | $\bar{\lambda}_z$ | $\chi_z$ | $N_{b,z,Rd}$ (kN) |         |                      |                           |
| QR1      | 310            | 1.10                                 | 16                | 0.173    | 1.000             | 1274.88        | 1.10        | 27                | 0.289    | 0.955             | 1217.03 | z - z                | <b>0.030</b>              |
| QR2      | 258            | 1.55                                 | 23                | 0.244    | 0.984             | 1254.97        | 1.55        | 38                | 0.408    | 0.893             | 1138.33 | z - z                | <b>0.204</b>              |
| QR5      | 1283           | 1.50                                 | 22                | 0.236    | 0.987             | 1258.75        | 1.50        | 37                | 0.394    | 0.900             | 1147.72 | z - z                | <b>0.140</b>              |
| QR6      | 1307           | 1.50                                 | 22                | 0.236    | 0.987             | 1258.75        | 1.50        | 37                | 0.394    | 0.900             | 1147.72 | z - z                | <b>0.130</b>              |
| QR7      | 1258           | 1.50                                 | 22                | 0.236    | 0.987             | 1258.75        | 1.50        | 37                | 0.394    | 0.900             | 1147.72 | z - z                | <b>0.050</b>              |

|   |   |  |   |   |   |   |
|---|---|--|---|---|---|---|
|  |  |  |  |  |  |  |
| $M_{y,Ed-ELU\_S1Y}$   | $M_{y,Ed-ELU\_S1Y}$   | $M_{y,Ed-ELU\_S1X}$  | $M_{y,Ed-ELU\_S1X}$   | $M_{y,Ed-ELU\_S1Y}$   | $M_{y,Ed-ELU\_S1Y}$   | $M_{y,Ed-ELU\_WXX_(T+)}$  |

| Encurvadura Lateral (Bambeamento) |                |                                      |                                   |       |       |       |       |                 |                      |                               |                     |                     |                         |              |
|-----------------------------------|----------------|--------------------------------------|-----------------------------------|-------|-------|-------|-------|-----------------|----------------------|-------------------------------|---------------------|---------------------|-------------------------|--------------|
| Barra nº                          | $L_{cr,z}$ (m) | Rotação das secções em z-z ( $K_L$ ) | Empenamento das secções ( $K_w$ ) | $K_L$ | $K_w$ | $C_1$ | $C_2$ | $M_{cr}$ (kN.m) | $\bar{\lambda}_{LT}$ | $\bar{\lambda}_{LT} \leq 0,2$ | $\chi_{LT}$         | $M_{b,y,Rd}$ (kN.m) | Rácio $M_{Ed}/M_{b,Rd}$ |              |
| QR1                               | 310            | 1.10                                 | Livre                             | Livre | 1.0   | 1.0   | 2.758 | 0.000           | 3526.05              | 0.154                         | Ign. enc. lateral   | -                   | -                       | -            |
| QR2                               | 258            | 1.55                                 | Livre                             | Livre | 1.0   | 1.0   | 1.068 | 0.000           | 760.79               | 0.331                         | Verif. enc. lateral | 0.970               | 80.71                   | <b>0.474</b> |
| QR3                               | 48             | 0.39                                 | Livre                             | Livre | 1.0   | 1.0   | 1.561 | 0.000           | 13888.01             | 0.077                         | Ign. enc. lateral   | -                   | -                       | -            |
| QR4                               | 1043           | 0.49                                 | Livre                             | Livre | 1.0   | 1.0   | 1.553 | 0.000           | 9042.99              | 0.096                         | Ign. enc. lateral   | -                   | -                       | -            |
| QR5                               | 1283           | 1.50                                 | Livre                             | Livre | 1.0   | 1.0   | 1.037 | 0.000           | 781.71               | 0.326                         | Verif. enc. lateral | 0.971               | 80.80                   | <b>0.409</b> |
| QR6                               | 1307           | 1.50                                 | Livre                             | Livre | 1.0   | 1.0   | 1.044 | 0.000           | 787.46               | 0.325                         | Verif. enc. lateral | 0.972               | 80.83                   | <b>0.318</b> |
| QR7                               | 1258           | 1.50                                 | Livre                             | Livre | 1.0   | 1.0   | 2.351 | 0.000           | 1772.68              | 0.217                         | Verif. enc. lateral | 0.996               | 82.89                   | <b>0.015</b> |

| "LTBeamN"  |            |                |              |                                |            |                |              |                                |        |         |     |   |  |  |  |      |            |                |              |   |       |         |      |  |  |  |  |      |            |                |              |   |       |         |   |
|--|------------|----------------|--------------|--------------------------------|------------|----------------|--------------|--------------------------------|--------|---------|-----|---|--|--|--|------|------------|----------------|--------------|---|-------|---------|------|--|--|--|--|------|------------|----------------|--------------|---|-------|---------|---|
| <table border="1"> <tr><th>Mode</th><th><math>\mu_{cr}</math></th><th>Mmax,cr [kN.m]</th><th>x (Mmax) [m]</th></tr> <tr><td>1</td><td>136.01</td><td>3518.7</td><td>1.1</td></tr> </table> |            |                |              | Mode                           | $\mu_{cr}$ | Mmax,cr [kN.m] | x (Mmax) [m] | 1                              | 136.01 | 3518.7  | 1.1 | <table border="1"> <tr><th>Mode</th><th><math>\mu_{cr}</math></th><th>Mmax,cr [kN.m]</th><th>x (Mmax) [m]</th></tr> <tr><td>1</td><td>19.89</td><td>-761.44</td><td>1.55</td></tr> </table> |  |  |  | Mode | $\mu_{cr}$ | Mmax,cr [kN.m] | x (Mmax) [m] | 1 | 19.89 | -761.44 | 1.55 | <table border="1"> <tr><th>Mode</th><th><math>\mu_{cr}</math></th><th>Mmax,cr [kN.m]</th><th>x (Mmax) [m]</th></tr> <tr><td>1</td><td>23.62</td><td>-780.64</td><td>0</td></tr> </table> |  |  |  | Mode | $\mu_{cr}$ | Mmax,cr [kN.m] | x (Mmax) [m] | 1 | 23.62 | -780.64 | 0 |
| Mode   | $\mu_{cr}$ | Mmax,cr [kN.m] | x (Mmax) [m] |                                |            |                |              |                                |        |         |     |   |  |  |  |      |            |                |              |   |       |         |      |  |  |  |  |      |            |                |              |   |       |         |   |
| 1  | 136.01     | 3518.7         | 1.1          |                                |            |                |              |                                |        |         |     |   |  |  |  |      |            |                |              |   |       |         |      |  |  |  |  |      |            |                |              |   |       |         |   |
| Mode   | $\mu_{cr}$ | Mmax,cr [kN.m] | x (Mmax) [m] |                                |            |                |              |                                |        |         |     |   |  |  |  |      |            |                |              |   |       |         |      |  |  |  |  |      |            |                |              |   |       |         |   |
| 1  | 19.89      | -761.44        | 1.55         |                                |            |                |              |                                |        |         |     |   |  |  |  |      |            |                |              |   |       |         |      |  |  |  |  |      |            |                |              |   |       |         |   |
| Mode   | $\mu_{cr}$ | Mmax,cr [kN.m] | x (Mmax) [m] |                                |            |                |              |                                |        |         |     |   |  |  |  |      |            |                |              |   |       |         |      |  |  |  |  |      |            |                |              |   |       |         |   |
| 1  | 23.62      | -780.64        | 0            |                                |            |                |              |                                |        |         |     |   |  |  |  |      |            |                |              |   |       |         |      |  |  |  |  |      |            |                |              |   |       |         |   |
| M <sub>cr</sub> – Barra nº310  |            |                |              | M <sub>cr</sub> – Barra nº258  |            |                |              | M <sub>cr</sub> – Barra nº1283 |        |         |     |   |  |  |  |      |            |                |              |   |       |         |      |  |  |  |  |      |            |                |              |   |       |         |   |
| <table border="1"> <tr><th>Mode</th><th><math>\mu_{cr}</math></th><th>Mmax,cr [kN.m]</th><th>x (Mmax) [m]</th></tr> <tr><td>1</td><td>30.59</td><td>-786.07</td><td>0</td></tr> </table>   |            |                |              | Mode                           | $\mu_{cr}$ | Mmax,cr [kN.m] | x (Mmax) [m] | 1                              | 30.59  | -786.07 | 0   | <table border="1"> <tr><th>Mode</th><th><math>\mu_{cr}</math></th><th>Mmax,cr [kN.m]</th><th>x (Mmax) [m]</th></tr> <tr><td>1</td><td>1366</td><td>-1719.7</td><td>1.5</td></tr> </table>   |  |  |  | Mode | $\mu_{cr}$ | Mmax,cr [kN.m] | x (Mmax) [m] | 1 | 1366  | -1719.7 | 1.5  |  |  |  |  |      |            |                |              |   |       |         |   |
| Mode   | $\mu_{cr}$ | Mmax,cr [kN.m] | x (Mmax) [m] |                                |            |                |              |                                |        |         |     |   |  |  |  |      |            |                |              |   |       |         |      |  |  |  |  |      |            |                |              |   |       |         |   |
| 1  | 30.59      | -786.07        | 0            |                                |            |                |              |                                |        |         |     |   |  |  |  |      |            |                |              |   |       |         |      |  |  |  |  |      |            |                |              |   |       |         |   |
| Mode   | $\mu_{cr}$ | Mmax,cr [kN.m] | x (Mmax) [m] |                                |            |                |              |                                |        |         |     |   |  |  |  |      |            |                |              |   |       |         |      |  |  |  |  |      |            |                |              |   |       |         |   |
| 1  | 1366       | -1719.7        | 1.5          |                                |            |                |              |                                |        |         |     |   |  |  |  |      |            |                |              |   |       |         |      |  |  |  |  |      |            |                |              |   |       |         |   |
| M <sub>cr</sub> – Barra nº1307   |            |                |              | M <sub>cr</sub> – Barra nº1258 |            |                |              |                                |        |         |     |   |  |  |  |      |            |                |              |   |       |         |      |  |  |  |  |      |            |                |              |   |       |         |   |



| Encurvadura por Flexão Composta com Compressão (Colunas-Viga) |          |          |          |             |                      |                          |                          |                 |                  |                 |                 |                 |                 |                 |                     |                     |
|---|----------|----------|----------|-------------|----------------------|--------------------------|--------------------------|-----------------|------------------|-----------------|-----------------|-----------------|-----------------|-----------------|---------------------|---------------------|
|   | Barra nº | $\chi_z$ | $\chi_y$ | $\chi_{LT}$ | N <sub>Rk</sub> (kN) | M <sub>y,Rk</sub> (kN.m) | M <sub>z,Rk</sub> (kN.m) | C <sub>my</sub> | C <sub>mLT</sub> | C <sub>mz</sub> | k <sub>yy</sub> | k <sub>yz</sub> | k <sub>zy</sub> | k <sub>zz</sub> | Eq.6.61 do EC3 -1-1 | Eq.6.62 do EC3 -1-1 |
| QR1   | 310      | 0.955    | 1.000    | 1.000       | 1274.88              | 83.18                    | 39.95                    | 0.400           | 0.400            | 1.000           | 0.400           | 0.599           | 0.889           | 0.999           | <b>0.284</b>        | <b>0.528</b>        |
| QR2   | 258      | 0.893    | 0.984    | 0.970       | 1274.88              | 83.18                    | 39.95                    | 0.952           | 0.952            | 0.648           | 0.960           | 0.406           | 0.988           | 0.677           | <b>0.648</b>        | <b>0.687</b>        |
| QR5   | 1283     | 0.900    | 0.987    | 0.971       | 1274.88              | 83.18                    | 39.95                    | 0.974           | 0.974            | 0.646           | 0.978           | 0.398           | 0.704           | 0.664           | <b>0.536</b>        | <b>0.558</b>        |
| QR6   | 1307     | 0.900    | 0.987    | 0.972       | 1274.88              | 83.18                    | 39.95                    | 0.968           | 0.968            | 0.665           | 0.973           | 0.409           | 0.729           | 0.681           | <b>0.431</b>        | <b>0.452</b>        |
| QR7   | 1258     | 0.900    | 0.987    | 0.996       | 1274.88              | 83.18                    | 39.95                    | 0.483           | 0.483            | 0.593           | 0.484           | 0.359           | 0.992           | 0.599           | <b>0.162</b>        | <b>0.247</b>        |

**2º Procedimento – A partir do software “Semicomp+”**

**Barra nº1043 (Secção)**

| <b>SEMICOMP Cross-Section Check</b>  |   |  |   |
|--|---|--|---|
| Choose method <span style="border: 1px solid black; padding: 2px;">EN 1993-1-1 (elastic Resistance) ▾</span>   |   |  |   |
| $N_{Ed} =$ <span style="border: 1px solid black; padding: 2px;">-64.593</span> kN  | $M_{y,Ed} =$ <span style="border: 1px solid black; padding: 2px;">65.489</span> kNm                                   | $V_{z,Ed} =$ <span style="border: 1px solid black; padding: 2px;">147.273</span> kN            | <span style="border: 1px solid black; padding: 5px; display: inline-block;">Perform cross-section checks</span> |
| $M_{z,Ed} =$ <span style="border: 1px solid black; padding: 2px;">-2.584</span> kNm  | $V_{y,Ed} =$ <span style="border: 1px solid black; padding: 2px;">7.350</span> kN                                     |  |   |
| <i>Reference values for classification</i>   |   |  |   |
| $c/t_w =$ <span style="border: 1px solid black; padding: 2px;">13.000</span>   | $\alpha_{web} =$ <span style="border: 1px solid black; padding: 2px;">0.591</span>                                    | $\psi_{web} =$ <span style="border: 1px solid black; padding: 2px;">-0.840</span>              | $\varepsilon =$ <span style="border: 1px solid black; padding: 2px;">1.000</span>                               |
| $c/t_f =$ <span style="border: 1px solid black; padding: 2px;">4.692</span>  | $\alpha_{flange} =$ <span style="border: 1px solid black; padding: 2px;">1.000</span>                                 | $\psi_{flange} =$ <span style="border: 1px solid black; padding: 2px;">0.928</span>            | $\varepsilon_{mod,cl3/4} =$ <span style="border: 1px solid black; padding: 2px;">NaN.</span>                    |
| <i>Boundaries</i>  | <b>Class 1</b>  | <b>Class 2</b>   | <b>Class 3</b>  |
| $c/t_w \leq c/t_{w,max} =$   | <span style="border: 1px solid black; padding: 2px;">59.215</span>  | <span style="border: 1px solid black; padding: 2px;">68.187</span>                             | <span style="border: 1px solid black; padding: 2px;">106.899</span>   |
| $c/t_f \leq c/t_{f,max} =$   | <span style="border: 1px solid black; padding: 2px;">9.000</span>   | <span style="border: 1px solid black; padding: 2px;">10.000</span>                             | <span style="border: 1px solid black; padding: 2px;">13.857</span>  |
| Cross section class =  | <span style="border: 1px solid black; padding: 2px; display: inline-block; width: 50px; text-align: center;">1</span> |  |   |
| <div style="border: 1px solid black; padding: 5px; margin-top: 10px;"> <p>Note: This tool is only applicable to Class 1 to 3. For Class 4 elastic cross-section values are used for all calculations.</p> </div> |   |  |   |
| $M_{pl,y,Rd} =$ <span style="border: 1px solid black; padding: 2px;">83.18</span> kNm  | $M_{pl,z,Rd} =$ <span style="border: 1px solid black; padding: 2px;">39.94</span> kNm                                 | $V_{pl,z,Rd} =$ <span style="border: 1px solid black; padding: 2px;">238.68</span> kN          |   |
| $M_{el,y,Rd} =$ <span style="border: 1px solid black; padding: 2px;">73.20</span> kNm  | $M_{el,z,Rd} =$ <span style="border: 1px solid black; padding: 2px;">26.12</span> kNm                                 | $V_{pl,y,Rd} =$ <span style="border: 1px solid black; padding: 2px;">564.42</span> kN          |   |
| $N_{Rd} =$ <span style="border: 1px solid black; padding: 2px;">1274.91</span> kN  |   |  |   |
| <b>EN 1993-1-1, 6.2.3 / 6.2.4</b>  |   |  |   |
| <i>Tension or compression</i>  |   |  |   |
| $U_{(6.5)/(6.9)} =$ <span style="border: 1px solid black; padding: 2px;">0.051</span> $\leq 1,0$   | ok  |  |   |
| <b>EN 1993-1-1, 6.2.5</b>  |   |  |   |
| <i>Bending moment</i>  |   |  |   |
| $U_{strong A.} =$ <span style="border: 1px solid black; padding: 2px;">0.787</span> $\leq 1,0$   | ok  |  |   |
| $U_{weak A.} =$ <span style="border: 1px solid black; padding: 2px;">0.065</span> $\leq 1,0$   | ok  |  |   |
| <b>EN 1993-1-1, 6.2.6</b>  |   |  |   |
| <i>Shear</i>   |   |  |   |
| $U_{z-plastic} =$ <span style="border: 1px solid black; padding: 2px;">0.617</span> $\leq 1,0$   | ok  | $U_{y-plastic} =$ <span style="border: 1px solid black; padding: 2px;">0.013</span> $\leq 1,0$ | ok  |
| $U_{z-elastic} =$ <span style="border: 1px solid black; padding: 2px;">0.964</span> $\leq 1,0$   | ok  | $U_{y-elastic} =$ <span style="border: 1px solid black; padding: 2px;">0.019</span> $\leq 1,0$ | ok  |
| $h_w/t_w =$ <span style="border: 1px solid black; padding: 2px;">18.000</span> $\leq 72\varepsilon/\eta =$ <span style="border: 1px solid black; padding: 2px;">60.000</span>                                    | ok  |  |   |
| <b>EN 1993-1-1, 6.2.9</b>  |   |  |   |
| <i>Bending and axial force</i>   |   |  |   |
| $U_{(6.41)/(6.42)} =$ <span style="border: 1px solid black; padding: 2px;">0.685</span> $\leq 1,0$   | ok  |  | $UF =$ <span style="border: 1px solid black; padding: 2px;">0.820</span>  |
| <p><i>Comment: Shear Interaction is not considered within this software tool. If the utilization for shear is higher that 0.5, an additional check for shear interaction is necessary.</i></p>                   |   |  |   |

## Barra nº258 (Coluna-Viga)

| <b>SEMICOMP Member Check</b>  |   |  |  |                      |                    |                            |                      |                             |                       |                           |                          |                             |                       |                       |                            |                         |                         |                             |                      |                      |                       |
|---|---|--|--|----------------------|--------------------|----------------------------|----------------------|-----------------------------|-----------------------|---------------------------|--------------------------|-----------------------------|-----------------------|-----------------------|----------------------------|-------------------------|-------------------------|-----------------------------|----------------------|----------------------|-----------------------|
| Choose method for member check<br>Method 2 (EN 1993-1-1 Annex B)  | Choose method for cross-section resistance<br>EN 1993-1-1:2010-12 | <input type="button" value="Perform member design check"/> |  |                      |                    |                            |                      |                             |                       |                           |                          |                             |                       |                       |                            |                         |                         |                             |                      |                      |                       |
| <b>Section classification for member design check</b> (based on 1. order cross-section forces)<br>Reference values for classification in the worst section along the member   |   |  |  |                      |                    |                            |                      |                             |                       |                           |                          |                             |                       |                       |                            |                         |                         |                             |                      |                      |                       |
| $c/t_w = 13.000$  | $\alpha_{web} = 0.009$  | $\psi_{web} = -3.314$                                      | $\varepsilon = 1.000$  |                      |                    |                            |                      |                             |                       |                           |                          |                             |                       |                       |                            |                         |                         |                             |                      |                      |                       |
| $c/t_f = 4.692$   | $\alpha_{flange} = 1.000$   | $\psi_{flange} = 0.991$                                    |  |                      |                    |                            |                      |                             |                       |                           |                          |                             |                       |                       |                            |                         |                         |                             |                      |                      |                       |
| <b>Boundaries</b> <table style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 30%;"></th> <th style="width: 15%;">Class 1</th> <th style="width: 15%;">Class 2</th> <th style="width: 15%;">Class 3</th> </tr> </thead> <tbody> <tr> <td><math>c/t_w \leq c/t_{w, max} =</math></td> <td style="text-align: center;">#####</td> <td style="text-align: center;">4573.777</td> <td style="text-align: center;">486.940</td> </tr> <tr> <td><math>c/t_f \leq c/t_{f, max} =</math></td> <td style="text-align: center;">9.000</td> <td style="text-align: center;">10.000</td> <td style="text-align: center;">13.781</td> </tr> </tbody> </table>   |   |  |  |                      | Class 1            | Class 2                    | Class 3              | $c/t_w \leq c/t_{w, max} =$ | #####                 | 4573.777                  | 486.940                  | $c/t_f \leq c/t_{f, max} =$ | 9.000                 | 10.000                | 13.781                     |                         |                         |                             |                      |                      |                       |
|   | Class 1   | Class 2  | Class 3  |                      |                    |                            |                      |                             |                       |                           |                          |                             |                       |                       |                            |                         |                         |                             |                      |                      |                       |
| $c/t_w \leq c/t_{w, max} =$   | #####   | 4573.777   | 486.940  |                      |                    |                            |                      |                             |                       |                           |                          |                             |                       |                       |                            |                         |                         |                             |                      |                      |                       |
| $c/t_f \leq c/t_{f, max} =$   | 9.000   | 10.000   | 13.781   |                      |                    |                            |                      |                             |                       |                           |                          |                             |                       |                       |                            |                         |                         |                             |                      |                      |                       |
| Member class = <span style="border: 1px solid black; padding: 2px 10px;">1</span>   |   |  | Note: This tool is only applicable to Class 1 to 3. For Class 4 elastic cross-section values are used for all calculations. The user should check if parts of member are Class 4 in the "Additional info"-sheet. |                      |                    |                            |                      |                             |                       |                           |                          |                             |                       |                       |                            |                         |                         |                             |                      |                      |                       |
| <b>Member Check</b>   |   |  |  |                      |                    |                            |                      |                             |                       |                           |                          |                             |                       |                       |                            |                         |                         |                             |                      |                      |                       |
| $N_{Rd} = 1274.908$ kN  | $M_{pl,y,Rd} = 83.182$ kNm  | $N_{Ed} = 232.514$ kN                                      |  |                      |                    |                            |                      |                             |                       |                           |                          |                             |                       |                       |                            |                         |                         |                             |                      |                      |                       |
| $M_{y,Rd} = 83.182$ kNm   | $M_{pl,z,Rd} = 39.941$ kNm  | $M_{y,Ed,max} = 38.290$ kNm                                |  |                      |                    |                            |                      |                             |                       |                           |                          |                             |                       |                       |                            |                         |                         |                             |                      |                      |                       |
| $M_{z,Rd} = 39.941$ kNm   | $M_{el,y,Rd} = 73.203$ kNm  | $M_{z,Ed,max} = 0.912$ kNm                                 |  |                      |                    |                            |                      |                             |                       |                           |                          |                             |                       |                       |                            |                         |                         |                             |                      |                      |                       |
| $M_{el,z,Rd} = 26.121$ kNm  |   |  |  |                      |                    |                            |                      |                             |                       |                           |                          |                             |                       |                       |                            |                         |                         |                             |                      |                      |                       |
| <table style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 33%;">Strong axis buckling</th> <th style="width: 33%;">Weak axis buckling</th> <th style="width: 33%;">Lateral torsional buckling</th> </tr> </thead> <tbody> <tr> <td style="padding: 5px;"><math>L_{cr,y} = 1.550</math> m</td> <td style="padding: 5px;"><math>L_{cr,z} = 1.550</math> m</td> <td style="padding: 5px;"><math>M_{cr} = 760.79</math> kNm</td> </tr> <tr> <td style="padding: 5px;"><math>N_{cr,y} = 21498.287</math> kN</td> <td style="padding: 5px;"><math>N_{cr,z} = 7671.355</math> kN</td> <td style="padding: 5px;"><math>\alpha_{LT} = 0.34</math> [-]</td> </tr> <tr> <td style="padding: 5px;"><math>\alpha_y = 0.34</math> [-]</td> <td style="padding: 5px;"><math>\alpha_z = 0.49</math> [-]</td> <td style="padding: 5px;"><math>\lambda_{LT} = 0.331</math> [-]</td> </tr> <tr> <td style="padding: 5px;"><math>\lambda_y = 0.244</math> [-]</td> <td style="padding: 5px;"><math>\lambda_z = 0.408</math> [-]</td> <td style="padding: 5px;"><math>\chi_{LT,mod} = 1.000</math> [-]</td> </tr> <tr> <td style="padding: 5px;"><math>\chi_y = 0.985</math> [-]</td> <td style="padding: 5px;"><math>\chi_z = 0.893</math> [-]</td> <td style="padding: 5px;"><math>f_{mod} = 0.989</math> [-]</td> </tr> </tbody> </table> |   |  |  | Strong axis buckling | Weak axis buckling | Lateral torsional buckling | $L_{cr,y} = 1.550$ m | $L_{cr,z} = 1.550$ m        | $M_{cr} = 760.79$ kNm | $N_{cr,y} = 21498.287$ kN | $N_{cr,z} = 7671.355$ kN | $\alpha_{LT} = 0.34$ [-]    | $\alpha_y = 0.34$ [-] | $\alpha_z = 0.49$ [-] | $\lambda_{LT} = 0.331$ [-] | $\lambda_y = 0.244$ [-] | $\lambda_z = 0.408$ [-] | $\chi_{LT,mod} = 1.000$ [-] | $\chi_y = 0.985$ [-] | $\chi_z = 0.893$ [-] | $f_{mod} = 0.989$ [-] |
| Strong axis buckling  | Weak axis buckling  | Lateral torsional buckling                                 |  |                      |                    |                            |                      |                             |                       |                           |                          |                             |                       |                       |                            |                         |                         |                             |                      |                      |                       |
| $L_{cr,y} = 1.550$ m  | $L_{cr,z} = 1.550$ m  | $M_{cr} = 760.79$ kNm                                      |  |                      |                    |                            |                      |                             |                       |                           |                          |                             |                       |                       |                            |                         |                         |                             |                      |                      |                       |
| $N_{cr,y} = 21498.287$ kN   | $N_{cr,z} = 7671.355$ kN  | $\alpha_{LT} = 0.34$ [-]                                   |  |                      |                    |                            |                      |                             |                       |                           |                          |                             |                       |                       |                            |                         |                         |                             |                      |                      |                       |
| $\alpha_y = 0.34$ [-]   | $\alpha_z = 0.49$ [-]   | $\lambda_{LT} = 0.331$ [-]                                 |  |                      |                    |                            |                      |                             |                       |                           |                          |                             |                       |                       |                            |                         |                         |                             |                      |                      |                       |
| $\lambda_y = 0.244$ [-]   | $\lambda_z = 0.408$ [-]   | $\chi_{LT,mod} = 1.000$ [-]                                |  |                      |                    |                            |                      |                             |                       |                           |                          |                             |                       |                       |                            |                         |                         |                             |                      |                      |                       |
| $\chi_y = 0.985$ [-]  | $\chi_z = 0.893$ [-]  | $f_{mod} = 0.989$ [-]                                      |  |                      |                    |                            |                      |                             |                       |                           |                          |                             |                       |                       |                            |                         |                         |                             |                      |                      |                       |
| <b>EN 1993-1-1, 6.3.3</b>   |   |  |  |                      |                    |                            |                      |                             |                       |                           |                          |                             |                       |                       |                            |                         |                         |                             |                      |                      |                       |
| Uniform member in bending and axial compression   |   | Global interaction factors                                 |  |                      |                    |                            |                      |                             |                       |                           |                          |                             |                       |                       |                            |                         |                         |                             |                      |                      |                       |
| Eq. (6.61): $U = 0.636 \leq 1,0$  | <b>ok</b>   | $k_{yy} = 0.960$   |  |                      |                    |                            |                      |                             |                       |                           |                          |                             |                       |                       |                            |                         |                         |                             |                      |                      |                       |
| Eq. (6.62): $U = 0.674 \leq 1,0$  | <b>ok</b>   | $k_{yz} = 0.406$   |  |                      |                    |                            |                      |                             |                       |                           |                          |                             |                       |                       |                            |                         |                         |                             |                      |                      |                       |
|   |   | $k_{zy} = 0.988$   |  |                      |                    |                            |                      |                             |                       |                           |                          |                             |                       |                       |                            |                         |                         |                             |                      |                      |                       |
|   |   | $k_{zz} = 0.676$   |  |                      |                    |                            |                      |                             |                       |                           |                          |                             |                       |                       |                            |                         |                         |                             |                      |                      |                       |
| Cross-section check at each end of the member   |   |  |  |                      |                    |                            |                      |                             |                       |                           |                          |                             |                       |                       |                            |                         |                         |                             |                      |                      |                       |
| Left end: $U = 0.460 \leq 1,0$  | <b>ok</b>   | $UF = 0.589$   |  |                      |                    |                            |                      |                             |                       |                           |                          |                             |                       |                       |                            |                         |                         |                             |                      |                      |                       |
| Right end: $U = 0.405 \leq 1,0$   | <b>ok</b>   | $UF = 0.541$   |  |                      |                    |                            |                      |                             |                       |                           |                          |                             |                       |                       |                            |                         |                         |                             |                      |                      |                       |
| <b>Additional member checks</b>   |   |  |  |                      |                    |                            |                      |                             |                       |                           |                          |                             |                       |                       |                            |                         |                         |                             |                      |                      |                       |
| <b>EN 1993-1-1, 6.3.1</b>   |   |  |  |                      |                    |                            |                      |                             |                       |                           |                          |                             |                       |                       |                            |                         |                         |                             |                      |                      |                       |
| Strong axis flexural buckling check   |   |  |  |                      |                    |                            |                      |                             |                       |                           |                          |                             |                       |                       |                            |                         |                         |                             |                      |                      |                       |
| Eq. (6.46): $N_{Ed}/N_{b,Rd} = 0.185 \leq 1,0$  | <b>ok</b>   |  |  |                      |                    |                            |                      |                             |                       |                           |                          |                             |                       |                       |                            |                         |                         |                             |                      |                      |                       |
| Weak axis flexural buckling check   |   |  |  |                      |                    |                            |                      |                             |                       |                           |                          |                             |                       |                       |                            |                         |                         |                             |                      |                      |                       |
| Eq. (6.46): $N_{Ed}/N_{b,Rd} = 0.204 \leq 1,0$  | <b>ok</b>   |  |  |                      |                    |                            |                      |                             |                       |                           |                          |                             |                       |                       |                            |                         |                         |                             |                      |                      |                       |
| <b>EN 1993-1-1, 6.3.2</b>   |   |  |  |                      |                    |                            |                      |                             |                       |                           |                          |                             |                       |                       |                            |                         |                         |                             |                      |                      |                       |
| Lateral torsional buckling  |   |  |  |                      |                    |                            |                      |                             |                       |                           |                          |                             |                       |                       |                            |                         |                         |                             |                      |                      |                       |
| Eq. (6.54): $M_{Ed}/M_{b,Rd} = 0.460 \leq 1,0$  | <b>ok</b>   |  |  |                      |                    |                            |                      |                             |                       |                           |                          |                             |                       |                       |                            |                         |                         |                             |                      |                      |                       |

### 3º Procedimento – A partir do software “SAP2000”

#### Barra nº1043 (Secção)

STRESS CHECK FORCES & MOMENTS

| Location | Ned     | Med,yy | Med,zz | Ved,z    | Ved,y | Ted    |
|----------|---------|--------|--------|----------|-------|--------|
| 0.000    | -64.593 | 65.489 | -2.584 | -147.273 | 7.350 | -0.028 |

|  |                                     |
|--|-------------------------------------|
| PMM DEMAND/CAPACITY RATIO (Governing Equation EC3 6.2.9.1(6y)) |                                     |
| D/C Ratio:   | 0.787 = 0.787 < 1.000 OK            |
|  | = (My,Ed/Mn,y,Rd) (EC3 6.2.9.1(6y)) |

#### Barra nº258 (Coluna-Viga)

STRESS CHECK FORCES & MOMENTS

| Location | Ned      | Med,yy  | Med,zz | Ved,z  | Ved,y  | Ted    |
|----------|----------|---------|--------|--------|--------|--------|
| 1.553    | -231.514 | -38.290 | 0.912  | 48.700 | -0.589 | -0.013 |

|  |  |
|--|--|
| PMM DEMAND/CAPACITY RATIO (Governing Equation EC3 6.3.3(4)-6.62) |  |
| D/C Ratio:   | 0.688 = 0.203 + 0.469 + 0.015 < 1.000 OK   |
|  | = NEd/(Chi_z NRk/GammaM1) + kzy (My,Ed+NEd eNy)/(Chi_LT My,Rk/GammaM1) + kzz (Mz,Ed+NEd eNz)/(Mz,Rk/GammaM1) (EC3 6.3.3(4)-6.62) |

AXIAL FORCE DESIGN

|              | Ned      | Nc,Rd    | Nt,Rd     |           |       |       |          |
|--------------|----------|----------|-----------|-----------|-------|-------|----------|
|              | Force    | Capacity | Capacity  |           |       |       |          |
| Axial        | -231.514 | 1276.050 | 1276.050  |           |       |       |          |
|              | Npl,Rd   | Nu,Rd    | Ncr,T     | Ncr,TF    | An/Ag |       |          |
|              | 1276.050 | 1407.456 | 10689.286 | 10689.286 | 1.000 |       |          |
|              | Curve    | Alpha    | Ncr       | LambdaBar | Phi   | Chi   | Nb,Rd    |
| Major (y-y)  | b        | 0.340    | 21417.665 | 0.244     | 0.537 | 0.984 | 1256.049 |
| MajorB(y-y)  | b        | 0.340    | 21417.665 | 0.244     | 0.537 | 0.984 | 1256.049 |
| Minor (z-z)  | c        | 0.490    | 7640.571  | 0.409     | 0.635 | 0.893 | 1139.165 |
| MinorB(z-z)  | c        | 0.490    | 7640.571  | 0.409     | 0.635 | 0.893 | 1139.165 |
| Torsional TF | c        | 0.490    | 10689.286 | 0.346     | 0.595 | 0.926 | 1181.355 |

MOMENT DESIGN

|             | Med     | Med,span | Mc,Rd       | Mv,Rd    | Mn,Rd    | Mb,Rd    |         |
|-------------|---------|----------|-------------|----------|----------|----------|---------|
|             | Moment  | Moment   | Capacity    | Capacity | Capacity | Capacity |         |
| Major (y-y) | -38.290 | -38.290  | 83.190      | 83.190   | 77.115   | 80.661   |         |
| Minor (z-z) | 0.912   | 0.912    | 39.950      | 39.950   | 39.950   |          |         |
|             | Curve   | AlphaLT  | LambdaBarLT | PhiLT    | ChiLT    | C1       | Mcr     |
| LTB         | a       | 0.210    | 0.333       | 0.569    | 0.970    | 1.051    | 749.288 |
|             | kyy     | kzy      | kzz         |          |          |          |         |
| Factors     | 0.960   | 0.406    | 0.988       | 0.677    |          |          |         |

## Comparação de Resultados

### Barra nº1043 (Secção)

| Estado Limite Último     |     | Folha de Cálculo | "Semicomp+" | "SAP2000" | Desvio $\Delta$ (%) |
|--------------------------|-----|------------------|-------------|-----------|---------------------|
| Compressão               |     | 0.051            | 0.051       | -         | 0.0%                |
| Flexão                   | y-y | 0.833            | 0.787       | 0.787     | 5.52%               |
|                          | z-z | 0.065            | 0.065       | -         | 0.0%                |
| Esforço Transverso       | y-y | 0.013            | 0.013       | -         | 0.0%                |
|                          | z-z | 0.617            | 0.617       | -         | 0.0%                |
| Flexão Composta Desviada |     | 0.758            | 0.685       | -         | 9.63%               |

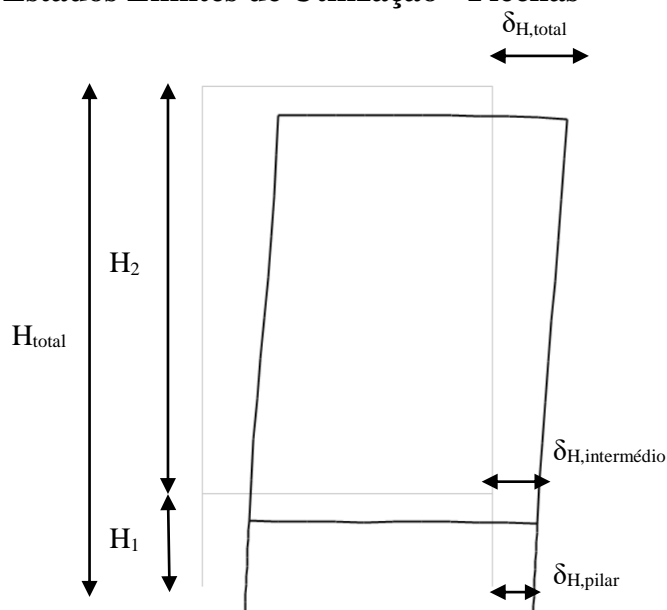
### Barra nº258 (Coluna-Viga)

|           |                       | Folha de Cálculo | "Semicomp+" | "SAP2000" | Desvio $\Delta$ (%) |
|-----------|-----------------------|------------------|-------------|-----------|---------------------|
| Parâmetro | $\bar{\lambda}_y$     | 0.244            | 0.244       | 0.244     | 0.00%               |
|           | $\bar{\lambda}_z$     | 0.408            | 0.408       | 0.409     | 0.12%               |
|           | $\chi_y$              | 0.984            | 0.985       | 0.984     | 0.05%               |
|           | $\chi_z$              | 0.893            | 0.893       | 0.893     | 0.00%               |
| Rácio     | $N_{c,Ed}/N_{b,z,Rd}$ | 0.204            | 0.204       | 0.203     | 0.25%               |

|           |                      | Folha de Cálculo | "Semicomp+" | "SAP2000" | "LTBeamN" | Desvio $\Delta$ (%) |
|-----------|----------------------|------------------|-------------|-----------|-----------|---------------------|
| Parâmetro | $M_{cr}$             | 760.79           | -           | 749.29    | 761.44    | 0.8%                |
|           | $\bar{\lambda}_{LT}$ | 0.331            | 0.331       | 0.333     | -         | 0.30%               |
|           | $\chi_{LT}$          | 0.970            | 1.000       | 0.970     | -         | 3.00%               |
| Rácio     | $M_{Ed}/M_{b,Rd}$    | 0.474            | 0.460       | 0.475     | -         | 2.84%               |

|                           |          | Folha de Cálculo | "Semicomp+" | "SAP2000" | Desvio $\Delta$ (%) |
|---------------------------|----------|------------------|-------------|-----------|---------------------|
| Coeficientes de Interação | $k_{yy}$ | 0.960            | 0.960       | 0.950     | 0.5%                |
|                           | $k_{yz}$ | 0.406            | 0.406       | 0.406     | 0.0%                |
|                           | $k_{zy}$ | 0.988            | 0.988       | 0.988     | 1.2%                |
|                           | $k_{zz}$ | 0.677            | 0.676       | 0.677     | 0.1%                |
| Rácio                     | Eq. 6.61 | 0.648            | 0.636       | -         | 1.9%                |
|                           | Eq. 6.62 | 0.687            | 0.674       | 0.688     | 0.9%                |

## Estados Limites de Utilização - Flechas



$$\delta_{H,quadro} = \delta_{H,total} - \delta_{H,pilar} \leq \frac{H_{total}}{300}$$

$$\delta_{H,1} = \delta_{H,intermedio} - \delta_{H,pilar} \leq \frac{H_1}{300}$$

$$\delta_{H,2} = \delta_{H,total} - \delta_{H,intermedio} \leq \frac{H_2}{300}$$

| Quadros | H <sub>1</sub> (m) | Combinação Condicionante | δ <sub>H,1</sub> (cm) | δ <sub>H,admissível</sub> (cm) | Rácio       |
|---------|--------------------|--------------------------|-----------------------|--------------------------------|-------------|
| QR1     | 0.35               | ELS_Wy_Wzz_(T-)          | 0.04                  | 0.12                           | <b>0.33</b> |
| QR2     | 0.35               | ELS_Wy_Wzz_(T-)          | 0.09                  | 0.12                           | <b>0.75</b> |
| QR3     | 0.39               | ELS_Wy_Wzz_(T-)          | 0.10                  | 0.13                           | <b>0.77</b> |
| QR4     | 0.49               | ELS_Wy_Wzz_(T-)          | 0.12                  | 0.16                           | <b>0.75</b> |
| QR5     | 0.50               | ELS_Wyy_Wz_(T+)          | 0.15                  | 0.17                           | <b>0.88</b> |
| QR6     | 0.50               | ELS_Wyy_Wz_(T+)          | 0.14                  | 0.17                           | <b>0.82</b> |
| QR7     | 0.50               | ELS_Wy_Wzz_(T-)          | 0.09                  | 0.17                           | <b>0.53</b> |

| Quadros | H <sub>2</sub> (m) | Combinação Condicionante | δ <sub>H,2</sub> (cm) | δ <sub>H,admissível</sub> (cm) | Rácio       |
|---------|--------------------|--------------------------|-----------------------|--------------------------------|-------------|
| QR1     | 1.55               | ELS_Wy_Wzz_(T-)          | 0.22                  | 0.52                           | <b>0.42</b> |
| QR2     | 1.55               | ELS_Wy_Wzz_(T-)          | 0.48                  | 0.52                           | <b>0.92</b> |
| QR3     | 1.55               | ELS_Wy_Wzz_(T-)          | 0.49                  | 0.52                           | <b>0.94</b> |
| QR4     | 1.50               | ELS_Wy_Wzz_(T-)          | 0.45                  | 0.50                           | <b>0.90</b> |
| QR5     | 1.50               | ELS_Wyy_Wz_(T+)          | 0.50                  | 0.50                           | <b>1.00</b> |
| QR6     | 1.50               | ELS_Wyy_Wz_(T+)          | 0.46                  | 0.50                           | <b>0.92</b> |
| QR7     | 1.50               | ELS_Wy_Wzz_(T-)          | 0.33                  | 0.50                           | <b>0.66</b> |

| <b>Quadros</b> | <b>H<sub>total</sub> (m)</b> | <b>Combinação Condicionante</b> | <b>δ<sub>H,quadro</sub> (cm)</b> | <b>δ<sub>H,admissivel</sub> (cm)</b> | <b>Rácio</b> |
|----------------|------------------------------|---------------------------------|----------------------------------|--------------------------------------|--------------|
| <b>QR1</b>     | 1.90                         | ELS_Wy_Wzz_(T-)                 | 0.26                             | 0.63                                 | <b>0.41</b>  |
| <b>QR2</b>     | 1.90                         | ELS_Wy_Wzz_(T-)                 | 0.57                             | 0.63                                 | <b>0.90</b>  |
| <b>QR3</b>     | 1.94                         | ELS_Wy_Wzz_(T-)                 | 0.59                             | 0.65                                 | <b>0.91</b>  |
| <b>QR4</b>     | 1.99                         | ELS_Wy_Wzz_(T-)                 | 0.57                             | 0.66                                 | <b>0.86</b>  |
| <b>QR5</b>     | 2.00                         | ELS_Wyy_Wz_(T+)                 | 0.64                             | 0.67                                 | <b>0.96</b>  |
| <b>QR6</b>     | 2.00                         | ELS_Wyy_Wz_(T+)                 | 0.60                             | 0.67                                 | <b>0.90</b>  |
| <b>QR7</b>     | 2.00                         | ELS_Wy_Wzz_(T-)                 | 0.42                             | 0.67                                 | <b>0.63</b>  |

## Pilar Composto

| Perfil     | A<br>(cm <sup>2</sup> ) | I <sub>y</sub><br>(cm <sup>4</sup> ) | W <sub>el,y</sub><br>(cm <sup>3</sup> ) | W <sub>pl,y</sub><br>(cm <sup>3</sup> ) | i <sub>y</sub><br>(cm <sup>2</sup> ) | A <sub>vy</sub><br>(cm <sup>2</sup> ) | I <sub>z</sub><br>(cm <sup>4</sup> ) | W <sub>el,z</sub><br>(cm <sup>3</sup> ) | W <sub>pl,z</sub><br>(cm <sup>3</sup> ) | i <sub>z</sub><br>(cm) | A <sub>vz</sub><br>(cm <sup>2</sup> ) | I <sub>t</sub><br>(cm <sup>4</sup> ) | I <sub>w</sub><br>(cm <sup>6</sup> ) |
|------------|-------------------------|--------------------------------------|---|---|--------------------------------------|---------------------------------------|--------------------------------------|---|---|------------------------|---------------------------------------|--------------------------------------|--------------------------------------|
| HEB<br>160 | 54.25                   | 2492                                 | 311.5                                   | 353.97                                  | 6.78                                 | 41.6                                  | 889.24                               | 111.15                                  | 169.96                                  | 4.05                   | 17.59                                 | 31.37                                | 47943.19                             |

| Barra<br>nº | Combinação<br>Condicionante | Secção<br>(m) |      | N <sub>c,Ed</sub><br>(kN) | V <sub>y,Ed</sub><br>(kN) | V <sub>z,Ed</sub><br>(kN) | M <sub>y,Ed</sub><br>(kN.m) | M <sub>z,Ed</sub><br>(kN.m) |
|-------------|-----------------------------|---------------|------|---------------------------|---------------------------|---------------------------|-----------------------------|-----------------------------|
|             |                             | si -          | 0.00 |                           |                           |                           |                             |                             |
| 1900        | ELU_S1X                     | sm -          | 0.30 | 257.65                    | 4.64                      | 27.09                     | -10.06                      | -2.28                       |
|             |                             | sf -          | 0.59 | 257.74                    | 4.64                      | 26.99                     | -2.09                       | -1.05                       |
|             |                             |               |      | 257.82                    | 4.64                      | 26.91                     | -6.95                       | -1.02                       |
| 29          | ELU_S1X                     | si -          | 0.00 | 135.61                    | 9.81                      | 51.17                     | -13.63                      | -2.35                       |
|             |                             | sm -          | 0.21 | 135.69                    | 9.81                      | 51.17                     | -2.97                       | -1.24                       |
|             |                             | sf -          | 0.42 | 135.78                    | 9.81                      | 51.17                     | -10.15                      | -1.95                       |
| 1901        | ELU_S1X                     | si -          | 0.00 | 262.83                    | 7.01                      | 23.05                     | -10.17                      | 3.11                        |
|             |                             | sm -          | 0.30 | 262.92                    | 7.01                      | 23.14                     | -2.09                       | 1.32                        |
|             |                             | sf -          | 0.59 | 263.01                    | 7.01                      | 23.23                     | -7.03                       | 1.31                        |
| 30          | ELU_S1X                     | si -          | 0.00 | 137.13                    | 7.79                      | 47.80                     | -13.79                      | 3.09                        |
|             |                             | sm -          | 0.21 | 137.22                    | 7.79                      | 47.80                     | -2.96                       | 1.38                        |
|             |                             | sf -          | 0.42 | 137.30                    | 7.79                      | 47.80                     | -10.26                      | 2.35                        |

### 1º Procedimento – A partir da Folha de Cálculo em “Excel”

| Barra<br>nº | Compressão                |   | Esforço Transverso           |  |                              |  |
|-------------|---------------------------|---|------------------------------|--|------------------------------|--|
|             |                           |   | Eixo z-z                     |  | Eixo y-y                     |  |
|             | N <sub>c,Rd</sub><br>(kN) | Rácio<br>N <sub>c,Ed</sub> /N <sub>c,Rd</sub> | V <sub>pl,z,Rd</sub><br>(kN) | Rácio<br>V <sub>z,Ed</sub> /V <sub>pl,z,Rd</sub> | V <sub>pl,y,Rd</sub><br>(kN) | Rácio<br>V <sub>y,Ed</sub> /V <sub>pl,y,Rd</sub> |
| 1900        | 1274.88                   | <b>0.202</b>                                  | 238.66                       | <b>0.113</b>                                     | 564.42                       | <b>0.008</b>                                     |
| 29          | 1274.88                   | <b>0.107</b>                                  | 238.66                       | <b>0.214</b>                                     | 564.42                       | <b>0.017</b>                                     |
| 1901        | 1274.88                   | <b>0.206</b>                                  | 238.66                       | <b>0.097</b>                                     | 564.42                       | <b>0.012</b>                                     |
| 30          | 1274.88                   | <b>0.108</b>                                  | 238.66                       | <b>0.200</b>                                     | 564.42                       | <b>0.014</b>                                     |

| Barra<br>nº | Flexão com Esforço Transverso                    |                               |   |  |                               |   |
|-------------|--|-------------------------------|---|--|-------------------------------|---|
|             | Eixo y-y   |                               |   | Eixo z-z   |                               |   |
|             | V <sub>z,Ed</sub> /V <sub>pl,z,Rd</sub><br>< 0,5 | M <sub>y,V,Rd</sub><br>(kN.m) | Rácio<br>M <sub>y,Ed</sub> /M <sub>y,V,Rd</sub> | V <sub>y,Ed</sub> /V <sub>pl,y,Rd</sub><br>< 0,5 | M <sub>z,V,Rd</sub><br>(kN.m) | Rácio<br>M <sub>z,Ed</sub> /M <sub>z,V,Rd</sub> |
| 1900        | V <sub>Ed</sub> s/ sign.                         | 83.19                         | <b>0.121</b>                                    | V <sub>Ed</sub> s/ sign.                         | 39.95                         | <b>0.057</b>                                    |
| 29          | V <sub>Ed</sub> s/ sign.                         | 83.19                         | <b>0.164</b>                                    | V <sub>Ed</sub> s/ sign.                         | 39.95                         | <b>0.059</b>                                    |
| 1901        | V <sub>Ed</sub> s/ sign.                         | 83.19                         | <b>0.122</b>                                    | V <sub>Ed</sub> s/ sign.                         | 39.95                         | <b>0.078</b>                                    |
| 30          | V <sub>Ed</sub> s/ sign.                         | 83.19                         | <b>0.166</b>                                    | V <sub>Ed</sub> s/ sign.                         | 39.95                         | <b>0.077</b>                                    |

| Barra nº | Flexão Composta com Esforço Transverso |      |                    |                     |                             |                    |                     |                             | Flexão Desviada |         |              |
|----------|--|------|--------------------|---------------------|-----------------------------|--------------------|---------------------|-----------------------------|-----------------|---------|--------------|
|          | n                                      | a    | Eixo y-y           |                     |                             | Eixo z-z           |                     |                             | $\alpha$        | $\beta$ | Rácio        |
|          |  |      | Red. de $M_{y,Rd}$ | $M_{N,y,Rd}$ (kN.m) | Rácio $M_{y,Ed}/M_{N,y,Rd}$ | Red. de $M_{z,Rd}$ | $M_{N,z,Rd}$ (kN.m) | Rácio $M_{z,Ed}/M_{N,z,Rd}$ |                 |         |              |
| 1900     | 0.20                                   | 0.23 | Aplicável.         | 75.14               | <b>0.134</b>                | Aplicável.         | 39.95               | <b>0.057</b>                | 2               | 1.01    | <b>0.073</b> |
| 29       | 0.11                                   | 0.23 | Aplicável.         | 84.15               | <b>0.162</b>                | N.A.               | 39.95               | <b>0.059</b>                | 2               | 1.00    | <b>0.085</b> |
| 1901     | 0.21                                   | 0.23 | Aplicável.         | 74.75               | <b>0.136</b>                | Aplicável.         | 39.95               | <b>0.078</b>                | 2               | 1.03    | <b>0.090</b> |
| 30       | 0.11                                   | 0.23 | Aplicável.         | 84.04               | <b>0.164</b>                | N.A.               | 39.95               | <b>0.077</b>                | 2               | 1.00    | <b>0.104</b> |

| Encurvadura por Compressão (Colunas) |                |             |                   |                            |                |             |                   |                            |
|--------------------------------------|----------------|-------------|-------------------|----------------------------|----------------|-------------|-------------------|----------------------------|
| Barra nº                             | Eixo y-y       |             |                   |                            | Eixo z-z       |             |                   |                            |
|                                      | $L_{cr,y}$ (m) | $\lambda_y$ | $\bar{\lambda}_y$ | $\bar{\lambda}_y \leq 0,2$ | $L_{cr,z}$ (m) | $\lambda_z$ | $\bar{\lambda}_z$ | $\bar{\lambda}_z \leq 0,2$ |
| 1900                                 | 0.59           | 9           | 0.093             | Ignorar encurvadura        | 0.59           | 15          | 0.155             | Ignorar encurvadura        |
| 29                                   | 0.42           | 6           | 0.066             | Ignorar encurvadura        | 0.42           | 10          | 0.110             | Ignorar encurvadura        |
| 1901                                 | 0.59           | 9           | 0.093             | Ignorar encurvadura        | 0.59           | 15          | 0.155             | Ignorar encurvadura        |
| 30                                   | 0.42           | 6           | 0.066             | Ignorar encurvadura        | 0.42           | 10          | 0.110             | Ignorar encurvadura        |

| Encurvadura Lateral (Bambeamento) |                |                          |                                    |       |       |       |       |                 |                      |                               |
|-----------------------------------|----------------|--------------------------|------------------------------------|-------|-------|-------|-------|-----------------|----------------------|-------------------------------|
| Nº                                | $L_{cr,z}$ (m) | Rotação em z-z ( $K_L$ ) | Restrição ao Empenamento ( $K_w$ ) | $K_L$ | $K_w$ | $C_1$ | $C_2$ | $M_{cr}$ (kN.m) | $\bar{\lambda}_{LT}$ | $\bar{\lambda}_{LT} \leq 0,2$ |
| 1900                              | 0.59           | Sim                      | Não                                | 1.0   | 1.0   | 1.184 | 0.000 | 4785.11         | 0.132                | Ignorar encurvadura lateral   |
| 29                                | 0.42           | Sim                      | Não                                | 1.0   | 1.0   | 1.145 | 0.000 | 9061.70         | 0.096                | Ignorar encurvadura lateral   |
| 1901                              | 0.59           | Sim                      | Não                                | 1.0   | 1.0   | 1.184 | 0.000 | 4783.11         | 0.132                | Ignorar encurvadura lateral   |
| 30                                | 0.42           | Sim                      | Não                                | 1.0   | 1.0   | 1.145 | 0.000 | 9067.99         | 0.096                | Ignorar encurvadura lateral   |

**2º Procedimento – A partir do software “Semicomp+”**

**Barra nº 1901 (Secção)**

| <b>SEMICOMP Cross-Section Check</b>   |  |   |  |  |
|---|--|---|--|--|
| Choose method <span style="border: 1px solid gray; padding: 2px;">EN 1993-1-1 (elastic Resistance)</span> ▾   |  |   |  |  |
| $N_{Ed} =$ <span style="border: 1px solid gray; padding: 2px;">-263.008</span> kN   | $V_{z,Ed} =$ <span style="border: 1px solid gray; padding: 2px;">23.228</span> kN    | <span style="border: 1px solid gray; padding: 5px;">Perform cross-section checks</span> |  |  |
| $M_{y,Ed} =$ <span style="border: 1px solid gray; padding: 2px;">-10.174</span> kNm   | $V_{y,Ed} =$ <span style="border: 1px solid gray; padding: 2px;">7.005</span> kN     |   |  |  |
| $M_{z,Ed} =$ <span style="border: 1px solid gray; padding: 2px;">3.105</span> kNm   |  |   |  |  |
| <i>Reference values for classification</i>  |  |   |  |  |
| $c/t_w =$ <span style="border: 1px solid gray; padding: 2px;">13.000</span>   | $\alpha_{web} =$ <span style="border: 1px solid gray; padding: 2px;">1.000</span>    | $\psi_{web} =$ <span style="border: 1px solid gray; padding: 2px;">0.391</span>         | $\varepsilon =$ <span style="border: 1px solid gray; padding: 2px;">1.000</span>   |  |
| $c/t_f =$ <span style="border: 1px solid gray; padding: 2px;">4.692</span>  | $\alpha_{flange} =$ <span style="border: 1px solid gray; padding: 2px;">1.000</span> | $\psi_{flange} =$ <span style="border: 1px solid gray; padding: 2px;">0.805</span>      | $\varepsilon_{mod,c/3/4} =$ <span style="border: 1px solid gray; padding: 2px;">NaN</span>   |  |
| <i>Boundaries</i>   |  |   |  |  |
|   | <b>Class 1</b>   | <b>Class 2</b>  | <b>Class 3</b>   |  |
| $c/t_w \leq c/t_{w,max} =$  | 33.000   | 38.000  | 52.566   |  |
| $c/t_f \leq c/t_{f,max} =$  | 9.000  | 10.000  | 14.030   |  |
| Cross section class = <span style="border: 1px solid gray; padding: 2px; margin-left: 20px;">1</span>   |  |   |  |  |
| Note: This tool is only applicable to Class 1 to 3. For Class 4 elastic cross-section values are used for all calculations.   |  |   |  |  |
| $M_{pl,y,Rd} =$ <span style="border: 1px solid gray; padding: 2px;">83.18</span> kNm  | $M_{pl,z,Rd} =$ <span style="border: 1px solid gray; padding: 2px;">39.94</span> kNm | $V_{pl,z,Rd} =$ <span style="border: 1px solid gray; padding: 2px;">238.68</span> kN    |  |  |
| $M_{el,y,Rd} =$ <span style="border: 1px solid gray; padding: 2px;">73.20</span> kNm  | $M_{el,z,Rd} =$ <span style="border: 1px solid gray; padding: 2px;">26.12</span> kNm | $V_{pl,y,Rd} =$ <span style="border: 1px solid gray; padding: 2px;">564.42</span> kN    |  |  |
| $N_{Rd} =$ <span style="border: 1px solid gray; padding: 2px;">1274.91</span> kN  |  |   |  |  |
| <b>EN 1993-1-1, 6.2.3 / 6.2.4</b>   |  |   |  |  |
| <i>Tension or compression</i>   |  |   |  |  |
| $U_{(6.5)/(6.9)} =$ <span style="border: 1px solid gray; padding: 2px;">0.206</span> $\leq 1,0$   |  | <span style="background-color: #ccc; padding: 2px;">ok</span>                           |  |  |
| <b>EN 1993-1-1, 6.2.5</b>   |  |   |  |  |
| <i>Bending moment</i>   |  |   |  |  |
| $U_{strong A.} =$ <span style="border: 1px solid gray; padding: 2px;">0.122</span> $\leq 1,0$   |  | <span style="background-color: #ccc; padding: 2px;">ok</span>                           |  |  |
| $U_{weak A.} =$ <span style="border: 1px solid gray; padding: 2px;">0.078</span> $\leq 1,0$   |  | <span style="background-color: #ccc; padding: 2px;">ok</span>                           |  |  |
| <b>EN 1993-1-1, 6.2.6</b>   |  |   |  |  |
| <i>Shear</i>  |  |   |  |  |
| $U_{z-plastic} =$ <span style="border: 1px solid gray; padding: 2px;">0.097</span> $\leq 1,0$   |  | <span style="background-color: #ccc; padding: 2px;">ok</span>                           | $U_{y-plastic} =$ <span style="border: 1px solid gray; padding: 2px;">0.012</span> $\leq 1,0$ <span style="background-color: #ccc; padding: 2px; margin-left: 10px;">ok</span> |  |
| $U_{z-elastic} =$ <span style="border: 1px solid gray; padding: 2px;">0.152</span> $\leq 1,0$   |  | <span style="background-color: #ccc; padding: 2px;">ok</span>                           | $U_{y-elastic} =$ <span style="border: 1px solid gray; padding: 2px;">0.019</span> $\leq 1,0$ <span style="background-color: #ccc; padding: 2px; margin-left: 10px;">ok</span> |  |
| $h_w/t_w =$ <span style="border: 1px solid gray; padding: 2px;">18.000</span> $\leq 72\varepsilon/\eta =$ <span style="border: 1px solid gray; padding: 2px;">60.000</span>             |  | <span style="background-color: #ccc; padding: 2px;">ok</span>                           |  |  |
| <b>EN 1993-1-1, 6.2.9</b>   |  |   |  |  |
| <i>Bending and axial force</i>  |  |   |  |  |
| $U_{(6.41)/(6.42)} =$ <span style="border: 1px solid gray; padding: 2px;">0.090</span> $\leq 1,0$   |  | <span style="background-color: #ccc; padding: 2px;">ok</span>                           | $UF =$ <span style="border: 1px solid gray; padding: 2px;">0.316</span>  |  |
| <i>Comment: Shear Interaction is not considered within this software tool. If the utilization for shear is higher that 0.5, an additional check for shear interaction is necessary.</i> |  |   |  |  |

### **Comparação de Resultados**

| <b>Estado Limite Último</b>     |            | <b>Folha de Cálculo</b> | <b>"Semicomp+"</b> | <b>Desvio <math>\Delta</math> (%)</b> |
|---------------------------------|------------|-------------------------|--------------------|---------------------------------------|
| <b>Compressão</b>               |            | 0.206                   | 0.206              | 0.0%                                  |
| <b>Flexão</b>                   | <b>y-y</b> | 0.122                   | 0.122              | 0.0%                                  |
|                                 | <b>z-z</b> | 0.078                   | 0.078              | 0.0%                                  |
| <b>Esforço Transverso</b>       | <b>y-y</b> | 0.012                   | 0.012              | 0.0%                                  |
|                                 | <b>z-z</b> | 0.097                   | 0.097              | 0.0%                                  |
| <b>Flexão Composta Desviada</b> |            | 0.090                   | 0.090              | 0.0%                                  |

## **ANEXO VI**

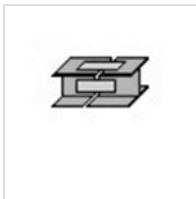
Relatórios do Dimensionamento das Ligações Metálicas

*“Robot Structural Analysis Professional”*

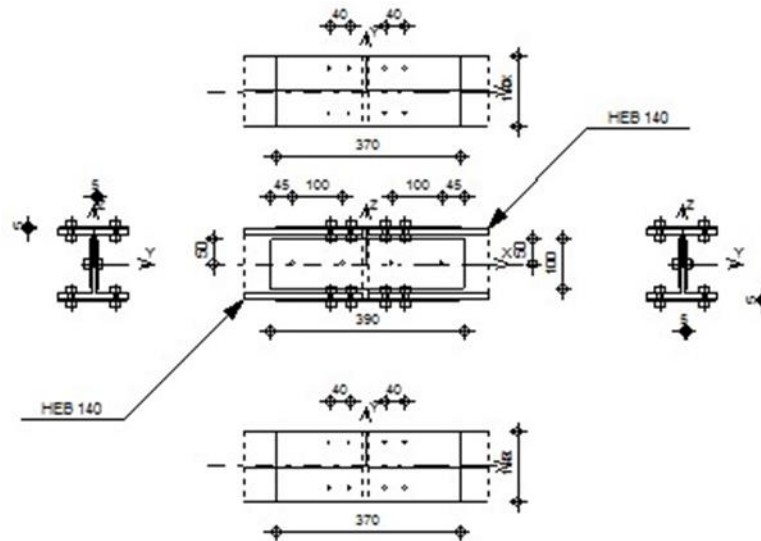


# Cobre-junta dos Cordões dos Caixões Treliçados do Troço Horizontal (HEB 140-HEB 140)

Página 1 de 8



Autodesk Robot Structural Analysis Professional 2016  
**Calculation of the beam-to-beam splice connection**  
 EN 1993-1-8:2005/AC:2009



## I. General

Connection no.: -

Connection name: Empalme\_Cordões\_do\_Caixaão

### 1. Right beam

Section: HEB 140

$h_{b1} = 140$  [mm] Height of beam section  
 $b_{fb1} = 140$  [mm] Width of beam section  
 $t_{wb1} = 7$  [mm] Thickness of the web of beam section  
 $t_{fb1} = 12$  [mm] Thickness of the flange of beam section  
 $r_{b1} = 12$  [mm] Radius of beam section fillet  
 $A_{b1} = 42.96$  [cm<sup>2</sup>] Cross-sectional area of a beam  
 $I_{yb1} = 1509.23$  [cm<sup>4</sup>] Moment of inertia of the beam section  
 Material: S235  
 $f_{yb1} = 235.00$  [MPa] Resistance  
 $f_{ub1} = 360.00$  [MPa]

### 2. Left beam

Section: HEB 140

$h_{b2} = 140$  [mm] Height of beam section  
 $b_{fb2} = 140$  [mm] Width of beam section  
 $t_{wb2} = 7$  [mm] Thickness of the web of beam section  
 $t_{fb2} = 12$  [mm] Thickness of the flange of beam section  
 $r_{b2} = 12$  [mm] Radius of beam section fillet  
 $A_{b2} = 42.96$  [cm<sup>2</sup>] Cross-sectional area of a beam  
 $I_{yb2} = 1509.23$  [cm<sup>4</sup>] Moment of inertia of the beam section  
 Material: S235

$f_{yb2} = 235.00$  [MPa] Resistance  
 $f_{ub2} = 360.00$  [MPa]

### 3. Splice plate

Type: bilateral  
 $l_{pw} = 390$  [mm] Plate length  
 $h_{pw} = 100$  [mm] Plate height  
 $t_{pw} = 5$  [mm] Plate thickness  
 Material: S235  
 $f_{ypw} = 235.00$  [MPa] Design resistance  
 $f_{upw} = 360.00$  [MPa] Tensile resistance

### 4. Upper external plate

$l_{pe} = 370$  [mm] Plate length  
 $h_{pe} = 140$  [mm] Plate height  
 $t_{pe} = 5$  [mm] Plate thickness  
 Material: S235  
 $f_{ype} = 235.00$  [MPa] Design resistance  
 $f_{upe} = 360.00$  [MPa] Tensile resistance

### 5. Lower external plate

$l_{pe} = 370$  [mm] Plate length  
 $h_{pe} = 140$  [mm] Plate height  
 $t_{pe} = 5$  [mm] Plate thickness  
 Material: S235  
 $f_{ype} = 235.00$  [MPa] Design resistance  
 $f_{upe} = 360.00$  [MPa] Tensile resistance

## 6. Right side

### 6.1. Bolts connecting a splice plate with the beam web

The shear plane passes through the UNTHREADED portion of the bolt.

Connection category A

Class = 5.6 Bolt class  
 $d = 10$  [mm] Bolt diameter  
 $d_0 = 11$  [mm] Bolt opening diameter  
 $A_s = 0.58$  [cm<sup>2</sup>] Effective section area of a bolt  
 $A_v = 0.79$  [cm<sup>2</sup>] Area of bolt section  
 $f_{yb} = 300.00$  [MPa] Yield strength of bolt  
 $f_{ub} = 500.00$  [MPa] Bolt tensile resistance  
 $n_h = 2$  Number of bolt columns  
 $n_v = 1$  Number of bolt rows  
 $e_1 = 50$  [mm] Level of first bolt  
 $p_2 = 100$  [mm] Horizontal spacing

### 6.2. Bolts connecting a flange plate with the beam top flange

The shear plane passes through the UNTHREADED portion of the bolt.

Connection category A

Class = 5.6 Bolt class  
 $d = 10$  [mm] Bolt diameter  
 $d_0 = 11$  [mm] Bolt opening diameter  
 $A_s = 0.58$  [cm<sup>2</sup>] Effective section area of a bolt  
 $A_v = 0.79$  [cm<sup>2</sup>] Area of bolt section  
 $f_{yb} = 300.00$  [MPa] Yield strength of bolt  
 $f_{ub} = 500.00$  [MPa] Bolt tensile resistance  
 $n_h = 1$  Number of bolt columns  
 $n_v = 2$  Number of bolt rows  
 $e_1 = 30$  [mm] Level of first bolt  
 $p_1 = 40$  [mm] Vertical spacing

### 6.3. Bolts connecting a flange plate with the beam bottom flange

The shear plane passes through the UNTHREADED portion of the bolt.

Connection category A

|                   |        |                    |                                  |
|-------------------|--------|--------------------|----------------------------------|
| Class =           | 5.6    |                    | Bolt class                       |
| d =               | 10     | [mm]               | Bolt diameter                    |
| d <sub>0</sub> =  | 11     | [mm]               | Bolt opening diameter            |
| A <sub>s</sub> =  | 0.58   | [cm <sup>2</sup> ] | Effective section area of a bolt |
| A <sub>v</sub> =  | 0.79   | [cm <sup>2</sup> ] | Area of bolt section             |
| f <sub>yb</sub> = | 300.00 | [MPa]              | Yield strength of bolt           |
| f <sub>ub</sub> = | 500.00 | [MPa]              | Bolt tensile resistance          |
| n <sub>h</sub> =  | 1      |                    | Number of bolt columns           |
| n <sub>v</sub> =  | 2      |                    | Number of bolt rows              |
| e <sub>1</sub> =  | 30     | [mm]               | Level of first bolt              |
| p <sub>1</sub> =  | 40     | [mm]               | Vertical spacing                 |

## 7. Left side

### 7.1. Bolts connecting a splice plate with the beam web

The shear plane passes through the UNTHREADED portion of the bolt.

Connection category A

|                   |        |                    |                                  |
|-------------------|--------|--------------------|----------------------------------|
| Class =           | 5.6    |                    | Bolt class                       |
| d =               | 10     | [mm]               | Bolt diameter                    |
| d <sub>0</sub> =  | 11     | [mm]               | Bolt opening diameter            |
| A <sub>s</sub> =  | 0.58   | [cm <sup>2</sup> ] | Effective section area of a bolt |
| A <sub>v</sub> =  | 0.79   | [cm <sup>2</sup> ] | Area of bolt section             |
| f <sub>yb</sub> = | 300.00 | [MPa]              | Yield strength of bolt           |
| f <sub>ub</sub> = | 500.00 | [MPa]              | Bolt tensile resistance          |
| n <sub>h</sub> =  | 2      |                    | Number of bolt columns           |
| n <sub>v</sub> =  | 1      |                    | Number of bolt rows              |
| e <sub>1</sub> =  | 50     | [mm]               | Level of first bolt              |
| p <sub>2</sub> =  | 100    | [mm]               | Horizontal spacing               |

### 7.2. Bolts connecting a flange plate with the beam top flange

The shear plane passes through the UNTHREADED portion of the bolt.

Connection category A

|                   |        |                    |                                  |
|-------------------|--------|--------------------|----------------------------------|
| Class =           | 5.6    |                    | Bolt class                       |
| d =               | 10     | [mm]               | Bolt diameter                    |
| d <sub>0</sub> =  | 11     | [mm]               | Bolt opening diameter            |
| A <sub>s</sub> =  | 0.58   | [cm <sup>2</sup> ] | Effective section area of a bolt |
| A <sub>v</sub> =  | 0.79   | [cm <sup>2</sup> ] | Area of bolt section             |
| f <sub>yb</sub> = | 300.00 | [MPa]              | Yield strength of bolt           |
| f <sub>ub</sub> = | 500.00 | [MPa]              | Bolt tensile resistance          |
| n <sub>h</sub> =  | 1      |                    | Number of bolt columns           |
| n <sub>v</sub> =  | 2      |                    | Number of bolt rows              |
| e <sub>1</sub> =  | 30     | [mm]               | Level of first bolt              |
| p <sub>1</sub> =  | 40     | [mm]               | Vertical spacing                 |

### 7.3. Bolts connecting a flange plate with the beam bottom flange

The shear plane passes through the UNTHREADED portion of the bolt.

Connection category A

|                   |        |                    |                                  |
|-------------------|--------|--------------------|----------------------------------|
| Class =           | 5.6    |                    | Bolt class                       |
| d =               | 10     | [mm]               | Bolt diameter                    |
| d <sub>0</sub> =  | 11     | [mm]               | Bolt opening diameter            |
| A <sub>s</sub> =  | 0.58   | [cm <sup>2</sup> ] | Effective section area of a bolt |
| A <sub>v</sub> =  | 0.79   | [cm <sup>2</sup> ] | Area of bolt section             |
| f <sub>yb</sub> = | 300.00 | [MPa]              | Yield strength of bolt           |
| f <sub>ub</sub> = | 500.00 | [MPa]              | Bolt tensile resistance          |
| n <sub>h</sub> =  | 1      |                    | Number of bolt columns           |

## 8. Material factors

|                  |      |                       |       |
|------------------|------|-----------------------|-------|
| $\square_{M0} =$ | 1.00 | Partial safety factor | [2.2] |
| $\square_{M2} =$ | 1.25 | Partial safety factor | [2.2] |

## II. Loads

Case: Manual calculations.




### 1. Ultimate limit state

|               |             |                |
|---------------|-------------|----------------|
| $N_{Ed1} =$   | 34.42 [kN]  | Axial force    |
| $V_{z,Ed1} =$ | -1.58 [kN]  | Shear force    |
| $M_{y,Ed1}$   | 1.89 [kN*m] | Bending moment |
| $=$           |             |                |
| $N_{Ed2} =$   | 34.42 [kN]  | Axial force    |
| $V_{z,Ed2} =$ | -1.58 [kN]  | Shear force    |
| $M_{y,Ed2}$   | 1.89 [kN*m] | Bending moment |
| $=$           |             |                |

## III. Results

Results for one side of connection (geometry and loads are symmetrical)


**Axial force**

| Plate   | $A_i$ [cm <sup>2</sup> ] | EQUIVALENT FORCES<br>$N_i$ [kN] | EQUIVALENT FORCES<br>$N_i(M_{y,Ed})$ [kN] | Resultant force<br>$N_{Ed,i}$ [kN] |
|---|--------------------------|---------------------------------|---|------------------------------------|
|    | $A_{pw} = 10.00$         | 14.34                           | -   | $N_{Ed,pw} = 14.34$                |
|  | $A_{pfue} = 7.00$        | 10.04                           | 11.71                                     | $N_{Ed,pfue} = 21.75$              |
|  | $A_{pfle} = 7.00$        | 10.04                           | -11.71                                    | $N_{Ed,pfle} = -1.67$              |




$$N_i = (N_{Ed} * A_i) / (2 * A_{pw} + A_{pfue} + A_{pfle})$$

$$N_{Ed,i} = N_i + N_i(M_{y,Ed})$$

**Shear force Z**

| Plate   | $A_i$ [cm <sup>2</sup> ] | $V_{z,Ed,i}$ [kN]     |
|---|--------------------------|-----------------------|
|  | $A_{z,pw} = 10.00$       | $V_{z,Ed,pw} = -1.58$ |

**Bending moment Y**

| Plate   | $I_{y,i}$ [cm <sup>4</sup> ] | EQUIVALENT FORCES<br>$M_{y,i}$ [kN*m] | Resultant force<br>$M_{y,Ed,i}$ [kN*m] |
|---|------------------------------|---------------------------------------|--|
|  | $I_{y,pw} = 83.33$           | 0.19                                  | $M_{y,Ed,pw} = 0.19$                   |
|  | $I_{y,pfue} = 368.08$        | 0.85                                  | -                                      |
|  | $I_{y,pfle} = 368.08$        | 0.85                                  | -                                      |

$$M_{y,i} = (M_{y,Ed} * I_{y,i}) / (2 * I_{pw} + I_{pfue} + I_{pfle})$$

## 1. Bolts connecting a splice plate with the beam web

### 1.1. Bolt capacities

$$F_{v,Rd} = 37.70 \text{ [kN]} \text{ Shear bolt resistance in the unthreaded portion of a bolt} \quad F_{v,Rd} = 0.6 * f_{ub} * A_v * m / \square_{M2}$$

**Bolt bearing on the beam**

Direction x

$$k_{1x} = 2.50 \quad \text{Coefficient for calculation of } F_{b,Rd} \quad k_{1x} = \min[2.8 * (e_1/d_0) - 1.7, 2.5]$$

$$k_{1x} > 0.0 \quad 2.50 > 0.00 \quad \text{verified}$$

$$\square_{bx} = 1.00 \quad \text{Coefficient for calculation of } F_{b,Rd} \quad \square_{bx} = \min[e_2/(3*d_0), p_2/(3*d_0) - 0.25, f_{ub}/f_u, 1]$$

$$\square_{bx} > 0.0 \quad 1.00 > 0.00 \quad \text{verified}$$

$F_{b,Rd1x} = 50.40$  [kN] Bearing resistance of a single bolt  $F_{b,Rd1x} = k_{1x} * \alpha_{bx} * f_u * d * \sum t_i / \alpha_{M2}$

Direction z

$k_{1z} = 2.50$  Coefficient for calculation of  $F_{b,Rd}$   $k_{1z} = \min[2.8 * (e_2/d_0) - 1.7, 1.4 * (p_2/d_0) - 1.7, 2.5]$

$k_{1z} > 0.0$   $2.50 > 0.00$  **verified**

$\alpha_{bz} = 1.00$  Coefficient for calculation of  $F_{b,Rd}$   $\alpha_{bz} = \min[e_1/(3 * d_0), f_{ub}/f_u, 1]$

$\alpha_{bz} > 0.0$   $1.00 > 0.00$  **verified**

$F_{b,Rd1z} = 50.40$  [kN] Bearing resistance of a single bolt  $F_{b,Rd1z} = k_{1z} * \alpha_{bz} * f_u * d * \sum t_i / \alpha_{M2}$

### Bolt bearing on the plate

Direction x

$k_{1x} = 2.50$  Coefficient for calculation of  $F_{b,Rd}$   $k_{1x} = \min[2.8 * (e_1/d_0) - 1.7, 2.5]$

$k_{1x} > 0.0$   $2.50 > 0.00$  **verified**

$\alpha_{bx} = 1.00$  Coefficient for calculation of  $F_{b,Rd}$   $\alpha_{bx} = \min[e_2/(3 * d_0), p_2/(3 * d_0) - 0.25, f_{ub}/f_u, 1]$

$\alpha_{bx} > 0.0$   $1.00 > 0.00$  **verified**

$F_{b,Rd2x} = 72.00$  [kN] Bearing resistance of a single bolt  $F_{b,Rd2x} = k_{1x} * \alpha_{bx} * f_u * d * \sum t_i / \alpha_{M2}$

Direction z

$k_{1z} = 2.50$  Coefficient for calculation of  $F_{b,Rd}$   $k_{1z} = \min[2.8 * (e_2/d_0) - 1.7, 1.4 * (p_2/d_0) - 1.7, 2.5]$

$k_{1z} > 0.0$   $2.50 > 0.00$  **verified**

$\alpha_{bz} = 1.00$  Coefficient for calculation of  $F_{b,Rd}$   $\alpha_{bz} = \min[e_1/(3 * d_0), f_{ub}/f_u, 1]$

$\alpha_{bz} > 0.0$   $1.00 > 0.00$  **verified**

$F_{b,Rd2z} = 72.00$   $\left[ \begin{matrix} \text{kN} \\ \end{matrix} \right]$  Bearing resistance of a single bolt  $F_{b,Rd2z} = k_{1z} * \alpha_{bz} * f_u * d * \sum t_i / \alpha_{M2}$

## 1.2. Ultimate limit state

### Bolt shear

|                            |       |        |   |   |
|----------------------------|-------|--------|---|---|
| $e_0 =$                    | 100   | [mm]   | Shear force eccentricity relative to the center of gravity of a bolt group              | $e_0 = e_{2b} + 0.5 * (s_1 + (c-1) * p_2)$      |
| $M_y =$                    | 0.03  | [kN*m] | Real bending moment   | $M_y = M_{y,Ed,pw} + V_{z,Ed,pw} * e_0$         |
| $F_{x,N} =$                | 7.17  | [kN]   | Component force in a bolt due to influence of the longitudinal force on the x direction | $F_{x,N} =  N_{Ed,pw}  / n_b$                   |
| $F_{z,Vz} =$               | 0.79  | [kN]   | Component force in a bolt due to influence of the shear force Vz on the z direction     | $F_{z,Vz} =  V_{z,Ed,pw}  / n_b$                |
| $F_{z,My} =$               | 0.34  | [kN]   | Component force in a bolt due to influence of the moment My on the z direction          | $F_{z,My} =  M_y  * X_i / \sum (X_i^2 + Z_i^2)$ |
| $F_{x,Ed} =$               | 7.17  | [kN]   | Design total force in a bolt on the direction x   | $F_{x,Ed} = F_{x,N}$                            |
| $F_{z,Ed} =$               | 1.13  | [kN]   | Design total force in a bolt on the direction z   | $F_{z,Ed} = F_{z,Vz} + F_{z,My}$                |
| $F_{Ed} =$                 | 7.26  | [kN]   | Resultant shear force in a bolt   | $F_{Ed} = \sqrt{(F_{x,Ed}^2 + F_{z,Ed}^2)}$     |
| $F_{Rd,x} =$               | 50.40 | [kN]   | Effective design capacity of a bolt on the direction x                                  | $F_{Rd,x} = \min(F_{bRd1,x}, F_{bRd2,x})$       |
| $F_{Rd,z} =$               | 50.40 | [kN]   | Effective design capacity of a bolt on the direction z                                  | $F_{Rd,z} = \min(F_{bRd1,z}, F_{bRd2,z})$       |
| $ F_{x,Ed}  \leq F_{Rd,x}$ |       |        | $ 7.17  < 50.40$  | <b>verified</b> (0.14)                          |
| $ F_{z,Ed}  \leq F_{Rd,z}$ |       |        | $ 1.13  < 50.40$  | <b>verified</b> (0.02)                          |
| $F_{Ed} \leq F_{v,Rd}$     |       |        | $7.26 < 37.70$  | <b>verified</b> (0.19)                          |

## 2. Bolts connecting a flange plate with the beam top flange

### 2.1. Bolt capacities

$F_{v,Rd} = 18.85$  [kN] Shear resistance of the shank of a single bolt  $F_{v,Rd} = 0.6 * f_{ub} * A_v * m / \alpha_{M2}$

### Bolt bearing on the beam flange

Direction x

$k_{1x} = 2.50$  Coefficient for calculation of  $F_{b,Rd}$   $k_{1x} = \min[2.8 * (e_2/d_0) - 1.7, 2.5]$

$k_{1x} > 0.0$   $2.50 > 0.00$  **verified**

$\alpha_{bx} = 0.91$  Coefficient for calculation of  $F_{b,Rd}$   $\alpha_{bx} = \min[e_1/(3 * d_0), p_1/(3 * d_0) - 0.25, f_{ub}/f_u, 1]$

$\alpha_{bx} > 0.0$   $0.91 > 0.00$  **verified**

$F_{b,Rd1x} = 78.55$  [kN] Bearing resistance of a single bolt  $F_{b,Rd1x} = k_{1x} * \alpha_{bx} * f_u * d * \sum t_i / \alpha_{M2}$

Direction y

$k_{1y} = 2.50$  Coefficient for calculation of  $F_{b,Rd}$   $k_{1y} = \min[2.8 * (e_1/d_0) - 1.7, 1.4 * (p_1/d_0) - 1.7, 2.5]$

|                                  |   |                 |  |
|----------------------------------|---|-----------------|--|
| $k_{1y} > 0.0$                   | $2.50 > 0.00$                             | <b>verified</b> |  |
| $\square_{by} = 0.76$            | Coefficient for calculation of $F_{b,Rd}$ |                 | $\square_{by} = \min[e_2/(3*d_0), f_{ub}/f_u, 1]$                        |
| $\square_{by} > 0.0$             | $0.76 > 0.00$                             | <b>verified</b> |  |
| $F_{b,Rd1y} = 65.45$ [kN]        | Bearing resistance of a single bolt       |                 | $F_{b,Rd1y} = k_{1y} * \square_{by} * f_u * d * \sum t_i / \square_{M2}$ |
| <b>Bolt bearing on the plate</b> |   |                 |  |
| Direction x                      |   |                 |  |
| $k_{1x} = 2.50$                  | Coefficient for calculation of $F_{b,Rd}$ |                 | $k_{1x} = \min[2.8*(e_2/d_0) - 1.7, 2.5]$                                |
| $k_{1x} > 0.0$                   | $2.50 > 0.00$                             | <b>verified</b> |  |
| $\square_{bx} = 0.96$            | Coefficient for calculation of $F_{b,Rd}$ |                 | $\square_{bx} = \min[e_1/(3*d_0), p_1/(3*d_0) - 0.25, f_{ub}/f_u, 1]$    |
| $\square_{bx} > 0.0$             | $0.96 > 0.00$                             | <b>verified</b> |  |
| $F_{b,Rd2x} = 34.64$ [kN]        | Bearing resistance of a single bolt       |                 | $F_{b,Rd2x} = k_{1x} * \square_{bx} * f_u * d * \sum t_i / \square_{M2}$ |
| Direction y                      |   |                 |  |
| $k_{1y} = 2.50$                  | Coefficient for calculation of $F_{b,Rd}$ |                 | $k_{1y} = \min[2.8*(e_1/d_0) - 1.7, 1.4*(p_1/d_0) - 1.7, 2.5]$           |
| $k_{1y} > 0.0$                   | $2.50 > 0.00$                             | <b>verified</b> |  |
| $\square_{by} = 0.76$            | Coefficient for calculation of $F_{b,Rd}$ |                 | $\square_{by} = \min[e_2/(3*d_0), f_{ub}/f_u, 1]$                        |
| $\square_{by} > 0.0$             | $0.76 > 0.00$                             | <b>verified</b> |  |
| $F_{b,Rd2y} = 27.27$ [kN]        | Bearing resistance of a single bolt       |                 | $F_{b,Rd2y} = k_{1y} * \square_{by} * f_u * d * \sum t_i / \square_{M2}$ |

## 2.2. Ultimate limit state

### Bolt shear

|                                       |                                       |                 |  |
|---------------------------------------|---------------------------------------|-----------------|--|
| $F_{Ed} = 5.54$ [kN]                  | Shear force in a bolt                 |                 | $F_{Ed} = N_{Ed, p f u e} / n_b$                             |
| $\square_{Lr} = 1.00$                 | Reduction factor for long connections |                 | $\square_{Lr} = \max(0.75, \min(1; 1 - (L - 15*d)/(200*d)))$ |
| $F_{Rd} = 18.85$ [kN]                 | Effective design capacity of a bolt   |                 | $F_{Rd} = \min(F_{v,Rd}; F_{b,Rd1}; F_{b,Rd2})$              |
| $ F_{Ed}  \leq \square_{Lr} * F_{Rd}$ | $ 5.54  < 18.85$                      | <b>verified</b> | (0.29)   |

## 3. Bolts connecting a flange plate with the beam bottom flange

### 3.1. Bolt capacities

|                         |  |  |  |
|-------------------------|--|--|--|
| $F_{v,Rd} = 18.85$ [kN] | Shear resistance of the shank of a single bolt |  | $F_{v,Rd} = 0.6 * f_{ub} * A_v * m / \square_{M2}$ |
|-------------------------|--|--|--|

#### Bolt bearing on the beam flange

Direction x

|                       |   |                 |   |
|-----------------------|---|-----------------|---|
| $k_{1x} = 2.50$       | Coefficient for calculation of $F_{b,Rd}$ |                 | $k_{1x} = \min[2.8*(e_2/d_0) - 1.7, 2.5]$                             |
| $k_{1x} > 0.0$        | $2.50 > 0.00$                             | <b>verified</b> |   |
| $\square_{bx} = 0.91$ | Coefficient for calculation of $F_{b,Rd}$ |                 | $\square_{bx} = \min[e_1/(3*d_0), p_1/(3*d_0) - 0.25, f_{ub}/f_u, 1]$ |
| $\square_{bx} > 0.0$  | $0.91 > 0.00$                             | <b>verified</b> |   |

|                           |                                     |  |  |
|---------------------------|-------------------------------------|--|--|
| $F_{b,Rd1x} = 78.55$ [kN] | Bearing resistance of a single bolt |  | $F_{b,Rd1x} = k_{1x} * \square_{bx} * f_u * d * \sum t_i / \square_{M2}$ |
|---------------------------|-------------------------------------|--|--|

Direction y

|                       |   |                 |  |
|-----------------------|---|-----------------|--|
| $k_{1y} = 2.50$       | Coefficient for calculation of $F_{b,Rd}$ |                 | $k_{1y} = \min[2.8*(e_1/d_0) - 1.7, 1.4*(p_1/d_0) - 1.7, 2.5]$ |
| $k_{1y} > 0.0$        | $2.50 > 0.00$                             | <b>verified</b> |  |
| $\square_{by} = 0.76$ | Coefficient for calculation of $F_{b,Rd}$ |                 | $\square_{by} = \min[e_2/(3*d_0), f_{ub}/f_u, 1]$              |
| $\square_{by} > 0.0$  | $0.76 > 0.00$                             | <b>verified</b> |  |

|                           |                                     |  |  |
|---------------------------|-------------------------------------|--|--|
| $F_{b,Rd1y} = 65.45$ [kN] | Bearing resistance of a single bolt |  | $F_{b,Rd1y} = k_{1y} * \square_{by} * f_u * d * \sum t_i / \square_{M2}$ |
|---------------------------|-------------------------------------|--|--|

#### Bolt bearing on the plate

Direction x

|                       |   |                 |   |
|-----------------------|---|-----------------|---|
| $k_{1x} = 2.50$       | Coefficient for calculation of $F_{b,Rd}$ |                 | $k_{1x} = \min[2.8*(e_2/d_0) - 1.7, 2.5]$                             |
| $k_{1x} > 0.0$        | $2.50 > 0.00$                             | <b>verified</b> |   |
| $\square_{bx} = 0.96$ | Coefficient for calculation of $F_{b,Rd}$ |                 | $\square_{bx} = \min[e_1/(3*d_0), p_1/(3*d_0) - 0.25, f_{ub}/f_u, 1]$ |
| $\square_{bx} > 0.0$  | $0.96 > 0.00$                             | <b>verified</b> |   |

|                           |                                     |  |  |
|---------------------------|-------------------------------------|--|--|
| $F_{b,Rd2x} = 34.64$ [kN] | Bearing resistance of a single bolt |  | $F_{b,Rd2x} = k_{1x} * \square_{bx} * f_u * d * \sum t_i / \square_{M2}$ |
|---------------------------|-------------------------------------|--|--|

Direction y

|                       |   |                 |  |
|-----------------------|---|-----------------|--|
| $k_{1y} = 2.50$       | Coefficient for calculation of $F_{b,Rd}$ |                 | $k_{1y} = \min[2.8*(e_1/d_0) - 1.7, 1.4*(p_1/d_0) - 1.7, 2.5]$ |
| $k_{1y} > 0.0$        | $2.50 > 0.00$                             | <b>verified</b> |  |
| $\square_{by} = 0.76$ | Coefficient for calculation of $F_{b,Rd}$ |                 | $\square_{by} = \min[e_2/(3*d_0), f_{ub}/f_u, 1]$              |
| $\square_{by} > 0.0$  | $0.76 > 0.00$                             | <b>verified</b> |  |

|                           |                                     |  |  |
|---------------------------|-------------------------------------|--|--|
| $F_{b,Rd2y} = 27.27$ [kN] | Bearing resistance of a single bolt |  | $F_{b,Rd2y} = k_{1y} * \square_{by} * f_u * d * \sum t_i / \square_{M2}$ |
|---------------------------|-------------------------------------|--|--|

### 3.2. Ultimate limit state

#### Bolt shear

$$F_{Ed} = \frac{0.5 \text{ [kN] Shear force in a bolt}}{2} \quad F_{Ed} = N_{Ed,plf}/n_b$$

$$\alpha_{Lf} = \begin{matrix} 1.0 & \text{Reduction factor for long} \\ 0 & \text{connections} \end{matrix} \quad \alpha_{Lf} = \max(0.75, \min(1; 1 - (L - 15 \cdot d) / (200 \cdot d)))$$

$$F_{Rd} = \frac{18}{85} \text{ [kN] Effective design capacity of a bolt} \quad F_{Rd} = \min(F_{v,Rd}; F_{b,Rd1}; F_{b,Rd2})$$

$$|F_{Ed}| \leq \alpha_{Lf} \cdot F_{Rd} \quad |-0.52| < 18.85 \quad \text{verified} \quad (0.03)$$

## 4. Verification of the section due to block tearing - [3.10]

### 4.1. Beam

| Nr | Model | A <sub>nv</sub> [cm <sup>2</sup> ] | A <sub>nt</sub> [cm <sup>2</sup> ] | V <sub>0</sub> [kN] | V <sub>eff,Rd</sub> [kN] | V <sub>0</sub> /V <sub>eff,Rd</sub> | Status   |
|----|-------|------------------------------------|------------------------------------|---------------------|--------------------------|-------------------------------------|----------|
| 1  |       | 4.51                               | 8.99                               | -1.58 (*1)          | 190.79 (*)               | 0.01                                | verified |
| 2  |       | 8.99                               | 23.35                              | 14.34 (*2)          | 458.29 (*)               | 0.03                                | verified |
| 3  |       | 8.99                               | 23.35                              | 14.34 (*2)          | 458.29 (*)               | 0.03                                | verified |
| 4  |       | 17.99                              | 0.00                               | 14.34 (*2)          | 244.08 (**)              | 0.06                                | verified |
| 5  |       | 6.42                               | 2.34                               | 22.17 (*3)          | 241.60 (***)             | 0.09                                | verified |

(\*1)  $V_0 = V_{zEd1}$

(\*2)  $V_0 = N_{wEd}$

(\*3)  $V_0 = N_{fuEd}$

(\*)  $V_{effRd} = 0.5 \cdot f_u \cdot A_{nt} / \alpha_{M2} + (1/\alpha_3) \cdot f_y \cdot A_{nv} / \alpha_{M0}$

(\*\*)  $V_{effRd} = f_u \cdot A_{nt} / \alpha_{M2} + (1/\alpha_3) \cdot f_y \cdot A_{nv} / \alpha_{M0}$

(\*\*\*)  $V_{effRd} = 2 \cdot [0.5 \cdot f_u \cdot A_{nt} / \alpha_{M2} + (1/\alpha_3) \cdot f_y \cdot A_{nv} / \alpha_{M0}]$

### 4.2. Splice plate

| Nr | Model | A <sub>nv</sub> [cm <sup>2</sup> ] | A <sub>nt</sub> [cm <sup>2</sup> ] | V <sub>0</sub> [kN] | V <sub>eff,Rd</sub> [kN] | V <sub>0</sub> /V <sub>eff,Rd</sub> | Status   |
|----|-------|------------------------------------|------------------------------------|---------------------|--------------------------|-------------------------------------|----------|
| 1  |       | 2.22                               | 6.42                               | -0.79 (*1)          | 122.71 (*)               | 0.01                                | verified |
| 2  |       | 6.42                               | 2.22                               | 7.17 (*2)           | 119.21 (*)               | 0.06                                | verified |
| 3  |       | 6.42                               | 2.22                               | 7.17 (*2)           | 119.21 (*)               | 0.06                                | verified |

(\*1)  $V_0 = V_{zEd1}$

(\*2)  $V_0 = N_{wEd}$

(\*)  $V_{effRd} = 0.5 \cdot f_u \cdot A_{nt} / \alpha_{M2} + (1/\alpha_3) \cdot f_y \cdot A_{nv} / \alpha_{M0}$

### 4.3. Upper external plate

| Nr | Model | A <sub>nv</sub> [cm <sup>2</sup> ] | A <sub>nt</sub> [cm <sup>2</sup> ] | V <sub>0</sub> [kN] | V <sub>eff,Rd</sub> [kN] | V <sub>0</sub> /V <sub>eff,Rd</sub> | Status   |
|----|-------|------------------------------------|------------------------------------|---------------------|--------------------------|-------------------------------------|----------|
| 1  |       | 6.67                               | 4.92                               | 21.75 (*1)          | 161.48 (*)               | 0.13                                | verified |
| 2  |       | 13.35                              | 3.95                               | 21.75 (*1)          | 294.89 (**)              | 0.07                                | verified |

(\*1)  $V_0 = N_{fuEd}$

(\*)  $V_{effRd} = 0.5 \cdot f_u \cdot A_{nt} / \alpha_{M2} + (1/\alpha_3) \cdot f_y \cdot A_{nv} / \alpha_{M0}$

(\*\*)  $V_{effRd} = f_u \cdot A_{nt} / \alpha_{M2} + (1/\alpha_3) \cdot f_y \cdot A_{nv} / \alpha_{M0}$

## 5. Verification of sections weakened by openings - [5.4]

### 5.1. Beam

|  |                           |  |   |
|--|---------------------------|--|---|
| $A_t =$  | 17.42 [cm <sup>2</sup> ]  | Area of tension zone of the gross section    |   |
| $A_{t,net} =$  | 14.01 [cm <sup>2</sup> ]  | Net area of the section in tension           |   |
| $0.9*(A_{t,net}/A_t) \leq (f_y*\square M2)/(f_u*\square M0)$ | 0.72 < 0.82               |  | <b>verified</b>                                   |
| $W =$  | 215.60 [cm <sup>3</sup> ] | Elastic section modulus                      |   |
| $W_{net} =$  | 215.60 [cm <sup>3</sup> ] | Elastic section modulus                      |   |
| $M_{c,Rdnet} =$  | 50.67 [kN*m]              | Design resistance of the section for bending | $M_{c,Rdnet} = W_{net}*f_{yp}/\square M0$         |
| $ M_0  \leq M_{c,Rdnet}$                                     | 1.89  < 50.67             |  | <b>verified</b> (0.04)                            |
| $A_v =$  | 9.80 [cm <sup>2</sup> ]   | Effective section area for shear             | $A_v = h_p*t_p$                                   |
| $A_{v,net} =$  | 9.03 [cm <sup>2</sup> ]   | Net area of a section effective for shear    | $A_{v,net} = A_v - n_v*d_0*t_p$                   |
| $A_{v,net} \geq (f_{yp}/f_{up})*A_v$                         | 9.03 > 6.40               |  | <b>verified</b>                                   |
| $V_{pl,Rd} =$  | 132.96 [kN]               | Design plastic resistance for shear          | $V_{pl,Rd} = (A_v*f_{yp})/(\square 3*\square M0)$ |
| $ V_0  \leq V_{pl,Rd}$                                       | -1.58  < 132.96           |  | <b>verified</b> (0.01)                            |

### 5.2. Splice plate

|  |                         |  |   |
|--|-------------------------|--|---|
| $A_t =$  | 5.00 [cm <sup>2</sup> ] | Area of tension zone of the gross section    |   |
| $A_{t,net} =$  | 4.45 [cm <sup>2</sup> ] | Net area of the section in tension           |   |
| $0.9*(A_{t,net}/A_t) \leq (f_y*\square M2)/(f_u*\square M0)$ | 0.80 < 0.82             |  | <b>verified</b>                                   |
| $W =$  | 8.33 [cm <sup>3</sup> ] | Elastic section modulus                      |   |
| $W_{net} =$  | 8.32 [cm <sup>3</sup> ] | Elastic section modulus                      |   |
| $M_{c,Rdnet} =$  | 1.96 [kN*m]             | Design resistance of the section for bending | $M_{c,Rdnet} = W_{net}*f_{yp}/\square M0$         |
| $ M_0  \leq M_{c,Rdnet}$                                     | 0.02  < 1.96            |  | <b>verified</b> (0.01)                            |
| $A_v =$  | 5.00 [cm <sup>2</sup> ] | Effective section area for shear             | $A_v = h_p*t_p$                                   |
| $A_{v,net} =$  | 4.45 [cm <sup>2</sup> ] | Net area of a section effective for shear    | $A_{v,net} = A_v - n_v*d_0*t_p$                   |
| $A_{v,net} \geq (f_{yp}/f_{up})*A_v$                         | 4.45 > 3.26             |  | <b>verified</b>                                   |
| $V_{pl,Rd} =$  | 67.84 [kN]              | Design plastic resistance for shear          | $V_{pl,Rd} = (A_v*f_{yp})/(\square 3*\square M0)$ |
| $ V_0  \leq V_{pl,Rd}$                                       | -0.79  < 67.84          |  | <b>verified</b> (0.01)                            |

### 5.3. Upper external plate

|                           |                         |   |   |
|---------------------------|-------------------------|---|---|
| $A =$                     | 7.00 [cm <sup>2</sup> ] | Area of tension zone of the gross section                     | $A = h_{pi}*t_{pi}$                     |
| $A_{net} =$               | 5.90 [cm <sup>2</sup> ] | Net cross-sectional area                                      | $A_{net} = A - n_v*d_0*t_{pi}$          |
| $N_{pl,Rd} =$             | 164.50 [kN]             | Design plastic resistance of the gross section                | $N_{pl,Rd} = A*f_y/\square M0$          |
| $N_{u,Rd} =$              | 152.93 [kN]             | Design ultimate resistance to normal force of the net section | $N_{u,Rd} = 0.9*A_{net}*f_u/\square M2$ |
| $F_{Ed} =$                | 21.75 [kN]              |   | $F_{Ed} = N_{Ed,pfue}$                  |
| $ F_{Ed}  \leq N_{u,Rd}$  | 21.75  < 152.93         |   | <b>verified</b> (0.14)                  |
| $ F_{Ed}  \leq N_{pl,Rd}$ | 21.75  < 164.50         |   | <b>verified</b> (0.13)                  |



### 5.4. Lower external plate

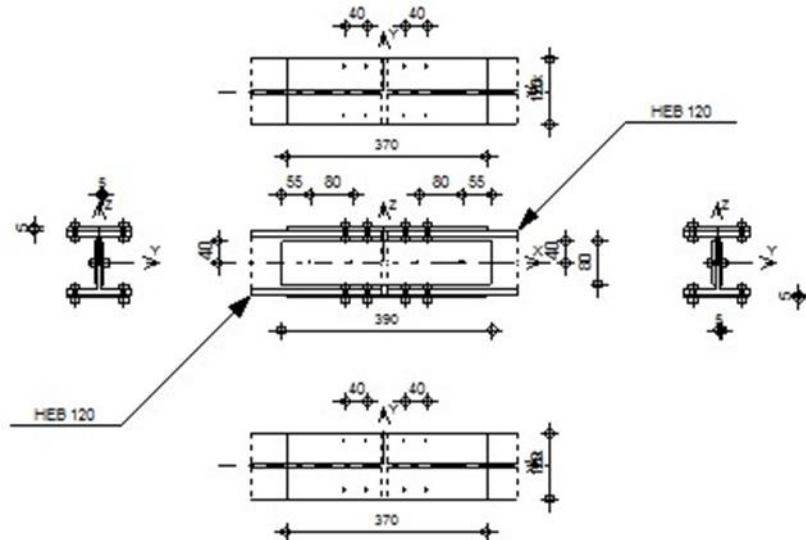
|                           |                         |   |   |
|---------------------------|-------------------------|---|---|
| $A =$                     | 7.00 [cm <sup>2</sup> ] | Area of tension zone of the gross section                     | $A = h_{pi}*t_{pi}$                     |
| $A_{net} =$               | 5.90 [cm <sup>2</sup> ] | Net cross-sectional area                                      | $A_{net} = A - n_v*d_0*t_{pi}$          |
| $N_{pl,Rd} =$             | 164.50 [kN]             | Design plastic resistance of the gross section                | $N_{pl,Rd} = A*f_y/\square M0$          |
| $N_{u,Rd} =$              | 152.93 [kN]             | Design ultimate resistance to normal force of the net section | $N_{u,Rd} = 0.9*A_{net}*f_u/\square M2$ |
| $F_{Ed} =$                | -1.67 [kN]              |   | $F_{Ed} = N_{Ed,pfli}$                  |
| $ F_{Ed}  \leq N_{u,Rd}$  | -1.67  < 152.93         |   | <b>verified</b> (0.01)                  |
| $ F_{Ed}  \leq N_{pl,Rd}$ | -1.67  < 164.50         |   | <b>verified</b> (0.01)                  |

**Connection conforms to the code**

**Ratio 0.29**

# Cobre-junta dos Cordões dos Caixões Treliçados do Troço Horizontal (HEB 120-HEB 120)

|   |  |   |
|---|--|---|
|  | Autodesk Robot Structural Analysis Professional 2016<br><b>Calculation of the beam-to-beam splice connection</b><br>EN 1993-1-8:2005/AC:2009 | <br>Ratio<br><b>0.70</b> |
|---|--|---|



## IV. General

Connection no.: 6

Connection name: Empalme\_Cordões\_Caixaõ\_THorizontal

### 1. Right beam

Section: HEB 120

|             |        |                    |   |
|-------------|--------|--------------------|---|
| $h_{b1} =$  | 120    | [mm]               | Height of beam section                  |
| $b_{fb1} =$ | 120    | [mm]               | Width of beam section                   |
| $t_{wb1} =$ | 7      | [mm]               | Thickness of the web of beam section    |
| $t_{fb1} =$ | 11     | [mm]               | Thickness of the flange of beam section |
| $r_{b1} =$  | 12     | [mm]               | Radius of beam section fillet           |
| $A_{b1} =$  | 34.01  | [cm <sup>2</sup> ] | Cross-sectional area of a beam          |
| $I_{yb1} =$ | 864.37 | [cm <sup>4</sup> ] | Moment of inertia of the beam section   |
| Material:   | S235   |                    |   |
| $f_{yb1} =$ | 235.00 | [MPa]              | Resistance                              |
| $f_{ub1} =$ | 360.00 | [MPa]              |   |

### 2. Left beam

Section: HEB 120

|             |        |                    |   |
|-------------|--------|--------------------|---|
| $h_{b2} =$  | 120    | [mm]               | Height of beam section                  |
| $b_{fb2} =$ | 120    | [mm]               | Width of beam section                   |
| $t_{wb2} =$ | 7      | [mm]               | Thickness of the web of beam section    |
| $t_{fb2} =$ | 11     | [mm]               | Thickness of the flange of beam section |
| $r_{b2} =$  | 12     | [mm]               | Radius of beam section fillet           |
| $A_{b2} =$  | 34.01  | [cm <sup>2</sup> ] | Cross-sectional area of a beam          |
| $I_{yb2} =$ | 864.37 | [cm <sup>4</sup> ] | Moment of inertia of the beam section   |
| Material:   | S235   |                    |   |
| $f_{yb2} =$ | 235.00 | [MPa]              | Resistance                              |
| $f_{ub2} =$ | 360.00 | [MPa]              |   |

### 3. Splice plate

|             |           |       |                    |
|-------------|-----------|-------|--------------------|
| Type:       | bilateral |       |                    |
| $l_{pw} =$  | 390       | [mm]  | Plate length       |
| $h_{pw} =$  | 80        | [mm]  | Plate height       |
| $t_{pw} =$  | 5         | [mm]  | Plate thickness    |
| Material:   | S235      |       |                    |
| $f_{ypw} =$ | 235.00    | [MPa] | Design resistance  |
| $f_{upw} =$ | 360.00    | [MPa] | Tensile resistance |

### 4. Upper external plate

|             |          |                 |                    |
|-------------|----------|-----------------|--------------------|
| $l_{pe} =$  | 370 [mm] | Plate length    |                    |
| $h_{pe} =$  | 120 [mm] | Plate height    |                    |
| $t_{pe} =$  | 5 [mm]   | Plate thickness |                    |
| Material:   | S235     |                 |                    |
| $f_{ype} =$ | 235.00   | [MPa]           | Design resistance  |
| $f_{upe} =$ | 360.00   | [MPa]           | Tensile resistance |

### 5. Lower external plate

|             |          |                 |                    |
|-------------|----------|-----------------|--------------------|
| $l_{pe} =$  | 370 [mm] | Plate length    |                    |
| $h_{pe} =$  | 120 [mm] | Plate height    |                    |
| $t_{pe} =$  | 5 [mm]   | Plate thickness |                    |
| Material:   | S235     |                 |                    |
| $f_{ype} =$ | 235.00   | [MPa]           | Design resistance  |
| $f_{upe} =$ | 360.00   | [MPa]           | Tensile resistance |

### 6. Right side

#### 6.1. Bolts connecting a splice plate with the beam web

The shear plane passes through the UNTHREADED portion of the bolt.

Connection category A

|            |                         |                                  |
|------------|-------------------------|----------------------------------|
| Class =    | 5.6                     | Bolt class                       |
| $d =$      | 8 [mm]                  | Bolt diameter                    |
| $d_0 =$    | 9 [mm]                  | Bolt opening diameter            |
| $A_s =$    | 0.37 [cm <sup>2</sup> ] | Effective section area of a bolt |
| $A_v =$    | 0.50 [cm <sup>2</sup> ] | Area of bolt section             |
| $f_{yb} =$ | 300.00 [MPa]            | Yield strength of bolt           |
| $f_{ub} =$ | 500.00 [MPa]            | Bolt tensile resistance          |
| $n_h =$    | 2                       | Number of bolt columns           |
| $n_v =$    | 1                       | Number of bolt rows              |
| $e_1 =$    | 40 [mm]                 | Level of first bolt              |
| $p_2 =$    | 80 [mm]                 | Horizontal spacing               |

#### 6.2. Bolts connecting a flange plate with the beam top flange

The shear plane passes through the UNTHREADED portion of the bolt.

Connection category A

|            |                         |                                  |
|------------|-------------------------|----------------------------------|
| Class =    | 5.6                     | Bolt class                       |
| $d =$      | 8 [mm]                  | Bolt diameter                    |
| $d_0 =$    | 9 [mm]                  | Bolt opening diameter            |
| $A_s =$    | 0.37 [cm <sup>2</sup> ] | Effective section area of a bolt |
| $A_v =$    | 0.50 [cm <sup>2</sup> ] | Area of bolt section             |
| $f_{yb} =$ | 300.00 [MPa]            | Yield strength of bolt           |
| $f_{ub} =$ | 500.00 [MPa]            | Bolt tensile resistance          |
| $n_h =$    | 1                       | Number of bolt columns           |
| $n_v =$    | 2                       | Number of bolt rows              |
| $e_1 =$    | 30 [mm]                 | Level of first bolt              |
| $p_1 =$    | 40 [mm]                 | Vertical spacing                 |

### 6.3. Bolts connecting a flange plate with the beam bottom flange

The shear plane passes through the UNTHREADED portion of the bolt.

Connection category A

|                   |                         |                                  |
|-------------------|-------------------------|----------------------------------|
| Class =           | 5.6                     | Bolt class                       |
| d =               | 8 [mm]                  | Bolt diameter                    |
| d <sub>0</sub> =  | 9 [mm]                  | Bolt opening diameter            |
| A <sub>s</sub> =  | 0.37 [cm <sup>2</sup> ] | Effective section area of a bolt |
| A <sub>v</sub> =  | 0.50 [cm <sup>2</sup> ] | Area of bolt section             |
| f <sub>yb</sub> = | 300.00 [MPa]            | Yield strength of bolt           |
| f <sub>ub</sub> = | 500.00 [MPa]            | Bolt tensile resistance          |
| n <sub>h</sub> =  | 1                       | Number of bolt columns           |
| n <sub>v</sub> =  | 2                       | Number of bolt rows              |
| e <sub>1</sub> =  | 30 [mm]                 | Level of first bolt              |
| p <sub>1</sub> =  | 40 [mm]                 | Vertical spacing                 |

## 7. Left side

### 7.1. Bolts connecting a splice plate with the beam web

The shear plane passes through the UNTHREADED portion of the bolt.

Connection category A

|                   |                         |                                  |
|-------------------|-------------------------|----------------------------------|
| Class =           | 5.6                     | Bolt class                       |
| d =               | 8 [mm]                  | Bolt diameter                    |
| d <sub>0</sub> =  | 9 [mm]                  | Bolt opening diameter            |
| A <sub>s</sub> =  | 0.37 [cm <sup>2</sup> ] | Effective section area of a bolt |
| A <sub>v</sub> =  | 0.50 [cm <sup>2</sup> ] | Area of bolt section             |
| f <sub>yb</sub> = | 300.00 [MPa]            | Yield strength of bolt           |
| f <sub>ub</sub> = | 500.00 [MPa]            | Bolt tensile resistance          |
| n <sub>h</sub> =  | 2                       | Number of bolt columns           |
| n <sub>v</sub> =  | 1                       | Number of bolt rows              |
| e <sub>1</sub> =  | 40 [mm]                 | Level of first bolt              |
| p <sub>2</sub> =  | 80 [mm]                 | Horizontal spacing               |

### 7.2. Bolts connecting a flange plate with the beam top flange

The shear plane passes through the UNTHREADED portion of the bolt.

Connection category A

|                   |                         |                                  |
|-------------------|-------------------------|----------------------------------|
| Class =           | 5.6                     | Bolt class                       |
| d =               | 8 [mm]                  | Bolt diameter                    |
| d <sub>0</sub> =  | 9 [mm]                  | Bolt opening diameter            |
| A <sub>s</sub> =  | 0.37 [cm <sup>2</sup> ] | Effective section area of a bolt |
| A <sub>v</sub> =  | 0.50 [cm <sup>2</sup> ] | Area of bolt section             |
| f <sub>yb</sub> = | 300.00 [MPa]            | Yield strength of bolt           |
| f <sub>ub</sub> = | 500.00 [MPa]            | Bolt tensile resistance          |
| n <sub>h</sub> =  | 1                       | Number of bolt columns           |
| n <sub>v</sub> =  | 2                       | Number of bolt rows              |
| e <sub>1</sub> =  | 30 [mm]                 | Level of first bolt              |
| p <sub>1</sub> =  | 40 [mm]                 | Vertical spacing                 |

### 7.3. Bolts connecting a flange plate with the beam bottom flange

The shear plane passes through the UNTHREADED portion of the bolt.

Connection category A

|                   |                         |                                  |
|-------------------|-------------------------|----------------------------------|
| Class =           | 5.6                     | Bolt class                       |
| d =               | 8 [mm]                  | Bolt diameter                    |
| d <sub>0</sub> =  | 9 [mm]                  | Bolt opening diameter            |
| A <sub>s</sub> =  | 0.37 [cm <sup>2</sup> ] | Effective section area of a bolt |
| A <sub>v</sub> =  | 0.50 [cm <sup>2</sup> ] | Area of bolt section             |
| f <sub>yb</sub> = | 300.00 [MPa]            | Yield strength of bolt           |
| f <sub>ub</sub> = | 500.00 [MPa]            | Bolt tensile resistance          |
| n <sub>h</sub> =  | 1                       | Number of bolt columns           |

## 8. Material factors

|                |        |                       |       |
|----------------|--------|-----------------------|-------|
| $\square_{M0}$ | = 1.00 | Partial safety factor | [2.2] |
| $\square_{M2}$ | = 1.25 | Partial safety factor | [2.2] |

## V. Loads

Case: Manual calculations.




### 1. Ultimate limit state

|             |               |                |
|-------------|---------------|----------------|
| $N_{Ed1}$   | = 84.45 [kN]  | Axial force    |
| $V_{z,Ed1}$ | = -0.45 [kN]  | Shear force    |
| $M_{y,Ed1}$ | = 0.76 [kN*m] | Bending moment |
| $N_{Ed2}$   | = 84.45 [kN]  | Axial force    |
| $V_{z,Ed2}$ | = -0.45 [kN]  | Shear force    |
| $M_{y,Ed2}$ | = 0.76 [kN*m] | Bending moment |

## VI. Results

Results for one side of connection (geometry and loads are symmetrical)


### Axial force

| Plate  | $A_i$ [cm <sup>2</sup> ] | EQUIVALENT FORCES<br>$N_i$ [kN] | EQUIVALENT FORCES<br>$N_i(M_{y,Ed})$ [kN] | Resultant force<br>$N_{Ed,i}$ [kN] |
|--|--------------------------|---------------------------------|---|------------------------------------|
|   | $A_{pw} = 8.00$          | 33.78                           | -   | $N_{Ed,pw} = 33.78$                |
|   | $A_{pfue} = 6.00$        | 25.34                           | 5.57                                      | $N_{Ed,pfue} = 30.91$              |
|  | $A_{pfle} = 6.00$        | 25.34                           | -5.57                                     | $N_{Ed,pfle} = 19.76$              |




$$N_i = (N_{Ed} * A_i) / (2 * A_{wp} + A_{pfue} + A_{pfle})$$

$$N_{Ed,i} = N_i + N_i(M_{y,Ed})$$

### Shear force Z

| Plate   | $A_i$ [cm <sup>2</sup> ] | $V_{z,Ed,i}$ [kN]     |
|---|--------------------------|-----------------------|
|  | $A_{z,pw} = 8.00$        | $V_{z,Ed,pw} = -0.45$ |

### Bending moment Y

| Plate   | $I_{y,i}$ [cm <sup>4</sup> ] | EQUIVALENT FORCES<br>$M_{y,i}$ [kN*m] | Resultant force<br>$M_{y,Ed,i}$ [kN*m] |
|---|------------------------------|---------------------------------------|--|
|  | $I_{y,pw} = 42.67$           | 0.06                                  | $M_{y,Ed,pw} = 0.06$                   |
|  | $I_{y,pfue} = 234.50$        | 0.35                                  | -                                      |
|  | $I_{y,pfle} = 234.50$        | 0.35                                  | -                                      |

$$M_{y,i} = (M_{y,Ed} * I_{y,i}) / (2 * I_{pw} + I_{pfue} + I_{pfle})$$

## 1. Bolts connecting a splice plate with the beam web

### 1.1. Bolt capacities

$F_{v,Rd} = 24.13$  [kN] Shear bolt resistance in the unthreaded portion of a bolt

$$F_{v,Rd} = 0.6 * f_{ub} * A_v * m / \square_{M2}$$

#### Bolt bearing on the beam

Direction x

$$k_{1x} = 2.50 \quad \text{Coefficient for calculation of } F_{b,Rd} \quad k_{1x} = \min[2.8 * (e_1/d_0) - 1.7, 2.5]$$

$$k_{1x} > 0.0 \quad 2.50 > 0.00 \quad \text{verified}$$

$$\square_{bx} = 1.00 \quad \text{Coefficient for calculation of } F_{b,Rd} \quad \square_{bx} = \min[e_2/(3 * d_0), p_2/(3 * d_0) - 0.25, f_{ub}/f_u, 1]$$

$$\square_{bx} > 0.0 \quad 1.00 > 0.00 \quad \text{verified}$$

$$F_{b,Rd1x} = 37.44 \quad [\text{kN}] \quad \text{Bearing resistance of a single bolt} \quad F_{b,Rd1x} = k_{1x} * \square_{bx} * f_u * d * \sum t_i / \square_{M2}$$

Direction z

$$k_{1z} = 2.50 \quad \text{Coefficient for calculation of } F_{b,Rd} \quad k_{1z} = \min[2.8*(e_2/d_0) - 1.7, 1.4*(p_2/d_0) - 1.7, 2.5]$$

$$k_{1z} > 0.0 \quad 2.50 > 0.00 \quad \text{verified}$$

$$\alpha_{bz} = 1.00 \quad \text{Coefficient for calculation of } F_{b,Rd} \quad \alpha_{bz} = \min[e_1/(3*d_0), f_{ub}/f_u, 1]$$

$$\alpha_{bz} > 0.0 \quad 1.00 > 0.00 \quad \text{verified}$$

$$F_{b,Rd1z} = \frac{37.}{44} \quad [\text{kN}] \quad \text{Bearing resistance of a single bolt} \quad F_{b,Rd1z} = k_{1z} * \alpha_{bz} * f_u * d * \sum t_i / \alpha_{M2}$$

### Bolt bearing on the plate

Direction x

$$k_{1x} = 2.50 \quad \text{Coefficient for calculation of } F_{b,Rd} \quad k_{1x} = \min[2.8*(e_1/d_0) - 1.7, 2.5]$$

$$k_{1x} > 0.0 \quad 2.50 > 0.00 \quad \text{verified}$$

$$\alpha_{bx} = 1.00 \quad \text{Coefficient for calculation of } F_{b,Rd} \quad \alpha_{bx} = \min[e_2/(3*d_0), p_2/(3*d_0) - 0.25, f_{ub}/f_u, 1]$$

$$\alpha_{bx} > 0.0 \quad 1.00 > 0.00 \quad \text{verified}$$

$$F_{b,Rd2x} = 57.60 \quad [\text{kN}] \quad \text{Bearing resistance of a single bolt} \quad F_{b,Rd2x} = k_{1x} * \alpha_{bx} * f_u * d * \sum t_i / \alpha_{M2}$$

Direction z

$$k_{1z} = 2.50 \quad \text{Coefficient for calculation of } F_{b,Rd} \quad k_{1z} = \min[2.8*(e_2/d_0) - 1.7, 1.4*(p_2/d_0) - 1.7, 2.5]$$

$$k_{1z} > 0.0 \quad 2.50 > 0.00 \quad \text{verified}$$

$$\alpha_{bz} = 1.00 \quad \text{Coefficient for calculation of } F_{b,Rd} \quad \alpha_{bz} = \min[e_1/(3*d_0), f_{ub}/f_u, 1]$$

$$\alpha_{bz} > 0.0 \quad 1.00 > 0.00 \quad \text{verified}$$

$$F_{b,Rd2z} = 57.60 \quad [\text{kN}] \quad \text{Bearing resistance of a single bolt} \quad F_{b,Rd2z} = k_{1z} * \alpha_{bz} * f_u * d * \sum t_i / \alpha_{M2}$$

## 1.2. Ultimate limit state

### Bolt shear

$$e_0 = 100 \quad [\text{mm}] \quad \text{Shear force eccentricity relative to the center of gravity of a bolt group} \quad e_0 = e_{2b} + 0.5*(s_1 + (c - 1)*p_2)$$

$$M_y = 0.02 \quad \frac{[\text{kN} * \text{m}]}{\text{m}} \quad \text{Real bending moment} \quad M_y = M_{y,Ed,pw} + V_{z,Ed,pw} * e_0$$

$$F_{x,N} = \frac{16.8}{9} \quad [\text{kN}] \quad \text{Component force in a bolt due to influence of the longitudinal force on the x direction} \quad F_{x,N} = |N_{Ed,pw}| / n_b$$

$$F_{z,Vz} = 0.23 \quad [\text{kN}] \quad \text{Component force in a bolt due to influence of the shear force } V_z \text{ on the z direction} \quad F_{z,Vz} = |V_{z,Ed,pw}| / n_b$$

$$F_{z,My} = 0.23 \quad [\text{kN}] \quad \text{Component force in a bolt due to influence of the moment } M_y \text{ on the z direction} \quad F_{z,My} = |M_y| * x_i / \sum (x_i^2 + z_i^2)$$

$$F_{x,Ed} = \frac{16.8}{9} \quad [\text{kN}] \quad \text{Design total force in a bolt on the direction x} \quad F_{x,Ed} = F_{x,N}$$

$$F_{z,Ed} = 0.45 \quad [\text{kN}] \quad \text{Design total force in a bolt on the direction z} \quad F_{z,Ed} = F_{z,Vz} + F_{z,My}$$

$$F_{Ed} = \frac{16.9}{0} \quad [\text{kN}] \quad \text{Resultant shear force in a bolt} \quad F_{Ed} = \sqrt{(F_{x,Ed}^2 + F_{z,Ed}^2)}$$

$$F_{Rd,x} = \frac{37.4}{4} \quad [\text{kN}] \quad \text{Effective design capacity of a bolt on the direction x} \quad F_{Rd,x} = \min(F_{bRd1,x}, F_{bRd2,x})$$

$$F_{Rd,z} = 37.44 \quad [\text{kN}] \quad \text{Effective design capacity of a bolt on the direction z} \quad F_{Rd,z} = \min(F_{bRd1,z}, F_{bRd2,z})$$

$$|F_{x,Ed}| \leq F_{Rd,x} \quad |16.89| < 37.44 \quad \text{verified} \quad (0.45)$$

$$|F_{z,Ed}| \leq F_{Rd,z} \quad |0.45| < 37.44 \quad \text{verified} \quad (0.01)$$

$$F_{Ed} \leq F_{v,Rd} \quad 16.90 < 24.13 \quad \text{verified} \quad (0.70)$$

## 2. Bolts connecting a flange plate with the beam top flange

### 2.1. Bolt capacities

$$F_{v,Rd} = 12.06 \quad [\text{kN}] \quad \text{Shear resistance of the shank of a single bolt} \quad F_{v,Rd} = 0.6 * f_{ub} * A_v * m / \alpha_{M2}$$

### Bolt bearing on the beam flange

Direction x

$$k_{1x} = 2.50 \quad \text{Coefficient for calculation of } F_{b,Rd} \quad k_{1x} = \min[2.8*(e_2/d_0) - 1.7, 2.5]$$

$$k_{1x} > 0.0 \quad 2.50 > 0.00 \quad \text{verified}$$

$$\alpha_{bx} = 1.00 \quad \text{Coefficient for calculation of } F_{b,Rd} \quad \alpha_{bx} = \min[e_1/(3*d_0), p_1/(3*d_0) - 0.25, f_{ub}/f_u, 1]$$

$$\alpha_{bx} > 0.0 \quad 1.00 > 0.00 \quad \text{verified}$$

$$F_{b,Rd1x} = 63.36 \quad [\text{kN}] \quad \text{Bearing resistance of a single bolt} \quad F_{b,Rd1x} = k_{1x} * \alpha_{bx} * f_u * d * \sum t_i / \alpha_{M2}$$

Direction y

|                      |   |  |
|----------------------|---|--|
| $k_{1y} = 2.50$      | Coefficient for calculation of $F_{b,Rd}$ | $k_{1y} = \min[2.8*(e_1/d_0)-1.7, 1.4*(p_1/d_0)-1.7, 2.5]$ |
| $k_{1y} > 0.0$       | $2.50 > 0.00$                             | <b>verified</b>  |
| $\alpha_{by} = 0.56$ | Coefficient for calculation of $F_{b,Rd}$ | $\alpha_{by} = \min[e_2/(3*d_0), f_{ub}/f_u, 1]$           |
| $\alpha_{by} > 0.0$  | $0.56 > 0.00$                             | <b>verified</b>  |

$F_{b,Rd1y} = 35.20$  [kN] Bearing resistance of a single bolt  $F_{b,Rd1y} = k_{1y} * \alpha_{by} * f_u * d * \sum t_i / \alpha_{M2}$

**Bolt bearing on the plate**

Direction x

|                      |   |  |
|----------------------|---|--|
| $k_{1x} = 2.50$      | Coefficient for calculation of $F_{b,Rd}$ | $k_{1x} = \min[2.8*(e_2/d_0)-1.7, 2.5]$                            |
| $k_{1x} > 0.0$       | $2.50 > 0.00$                             | <b>verified</b>  |
| $\alpha_{bx} = 1.00$ | Coefficient for calculation of $F_{b,Rd}$ | $\alpha_{bx} = \min[e_1/(3*d_0), p_1/(3*d_0)-0.25, f_{ub}/f_u, 1]$ |
| $\alpha_{bx} > 0.0$  | $1.00 > 0.00$                             | <b>verified</b>  |

$F_{b,Rd2x} = 28.80$  [kN] Bearing resistance of a single bolt  $F_{b,Rd2x} = k_{1x} * \alpha_{bx} * f_u * d * \sum t_i / \alpha_{M2}$

Direction y

|                      |   |  |
|----------------------|---|--|
| $k_{1y} = 2.50$      | Coefficient for calculation of $F_{b,Rd}$ | $k_{1y} = \min[2.8*(e_1/d_0)-1.7, 1.4*(p_1/d_0)-1.7, 2.5]$ |
| $k_{1y} > 0.0$       | $2.50 > 0.00$                             | <b>verified</b>  |
| $\alpha_{by} = 0.56$ | Coefficient for calculation of $F_{b,Rd}$ | $\alpha_{by} = \min[e_2/(3*d_0), f_{ub}/f_u, 1]$           |
| $\alpha_{by} > 0.0$  | $0.56 > 0.00$                             | <b>verified</b>  |

$F_{b,Rd2y} = 16.00$  [kN] Bearing resistance of a single bolt  $F_{b,Rd2y} = k_{1y} * \alpha_{by} * f_u * d * \sum t_i / \alpha_{M2}$

**2.2. Ultimate limit state**

**Bolt shear**

|                                      |                                       |   |
|--------------------------------------|---------------------------------------|---|
| $F_{Ed} = 7.79$ [kN]                 | Shear force in a bolt                 | $F_{Ed} = N_{Ed,plue} / n_b$                                |
| $\alpha_{Lf} = 1.00$                 | Reduction factor for long connections | $\alpha_{Lf} = \max(0.75, \min(1, 1 - (L - 15*d)/(200*d)))$ |
| $F_{Rd} = 12.06$ [kN]                | Effective design capacity of a bolt   | $F_{Rd} = \min(F_{v,Rd}, F_{b,Rd1}, F_{b,Rd2})$             |
| $ F_{Ed}  \leq \alpha_{Lf} * F_{Rd}$ | $ 7.79  < 12.06$                      | <b>verified</b> (0.65)                                      |

**3. Bolts connecting a flange plate with the beam bottom flange**

**3.1. Bolt capacities**

$F_{v,Rd} = 12.06$  [kN] Shear resistance of the shank of a single bolt  $F_{v,Rd} = 0.6 * f_{ub} * A_v * m / \alpha_{M2}$

**Bolt bearing on the beam flange**

Direction x

|                      |   |  |
|----------------------|---|--|
| $k_{1x} = 2.50$      | Coefficient for calculation of $F_{b,Rd}$ | $k_{1x} = \min[2.8*(e_2/d_0)-1.7, 2.5]$                            |
| $k_{1x} > 0.0$       | $2.50 > 0.00$                             | <b>verified</b>  |
| $\alpha_{bx} = 1.00$ | Coefficient for calculation of $F_{b,Rd}$ | $\alpha_{bx} = \min[e_1/(3*d_0), p_1/(3*d_0)-0.25, f_{ub}/f_u, 1]$ |
| $\alpha_{bx} > 0.0$  | $1.00 > 0.00$                             | <b>verified</b>  |

$F_{b,Rd1x} = 63.36$  [kN] Bearing resistance of a single bolt  $F_{b,Rd1x} = k_{1x} * \alpha_{bx} * f_u * d * \sum t_i / \alpha_{M2}$

Direction y

|                      |   |  |
|----------------------|---|--|
| $k_{1y} = 2.50$      | Coefficient for calculation of $F_{b,Rd}$ | $k_{1y} = \min[2.8*(e_1/d_0)-1.7, 1.4*(p_1/d_0)-1.7, 2.5]$ |
| $k_{1y} > 0.0$       | $2.50 > 0.00$                             | <b>verified</b>  |
| $\alpha_{by} = 0.56$ | Coefficient for calculation of $F_{b,Rd}$ | $\alpha_{by} = \min[e_2/(3*d_0), f_{ub}/f_u, 1]$           |
| $\alpha_{by} > 0.0$  | $0.56 > 0.00$                             | <b>verified</b>  |

$F_{b,Rd1y} = 35.20$  [kN] Bearing resistance of a single bolt  $F_{b,Rd1y} = k_{1y} * \alpha_{by} * f_u * d * \sum t_i / \alpha_{M2}$

**Bolt bearing on the plate**

Direction x

|                      |   |  |
|----------------------|---|--|
| $k_{1x} = 2.50$      | Coefficient for calculation of $F_{b,Rd}$ | $k_{1x} = \min[2.8*(e_2/d_0)-1.7, 2.5]$                            |
| $k_{1x} > 0.0$       | $2.50 > 0.00$                             | <b>verified</b>  |
| $\alpha_{bx} = 1.00$ | Coefficient for calculation of $F_{b,Rd}$ | $\alpha_{bx} = \min[e_1/(3*d_0), p_1/(3*d_0)-0.25, f_{ub}/f_u, 1]$ |
| $\alpha_{bx} > 0.0$  | $1.00 > 0.00$                             | <b>verified</b>  |

$F_{b,Rd2x} = 28.80$  [kN] Bearing resistance of a single bolt  $F_{b,Rd2x} = k_{1x} * \alpha_{bx} * f_u * d * \sum t_i / \alpha_{M2}$

Direction y

|                      |   |  |
|----------------------|---|--|
| $k_{1y} = 2.50$      | Coefficient for calculation of $F_{b,Rd}$ | $k_{1y} = \min[2.8*(e_1/d_0)-1.7, 1.4*(p_1/d_0)-1.7, 2.5]$ |
| $k_{1y} > 0.0$       | $2.50 > 0.00$                             | <b>verified</b>  |
| $\alpha_{by} = 0.56$ | Coefficient for calculation of $F_{b,Rd}$ | $\alpha_{by} = \min[e_2/(3*d_0), f_{ub}/f_u, 1]$           |
| $\alpha_{by} > 0.0$  | $0.56 > 0.00$                             | <b>verified</b>  |

$F_{b,Rd2y} = 16.00$  [kN] Bearing resistance of a single bolt  $F_{b,Rd2y} = k_{1y} * \alpha_{by} * f_u * d * \sum t_i / \alpha_{M2}$

### 3.2. Ultimate limit state

#### Bolt shear

|  |   |
|--|---|
| $F_{Ed} = 4.88$ [kN] Shear force in a bolt                 | $F_{Ed} = N_{Ed, pile} / n_b$   |
| $\alpha_{Lf} = 1.00$ Reduction factor for long connections | $\alpha_{Lf} = \max(0.75, \min(1; 1 - (L - 15 \cdot d) / (200 \cdot d)))$ |
| $F_{Rd} = 12.06$ [kN] Effective design capacity of a bolt  | $F_{Rd} = \min(F_{v,Rd}; F_{b,Rd1}; F_{b,Rd2})$                           |
| $ F_{Ed}  \leq \alpha_{Lf} \cdot F_{Rd}$ $ 4.88  < 12.06$  | <b>verified</b> (0.40)  |

## 4. Verification of the section due to block tearing - [3.10]

### 4.1. Beam

| Nr | Model | $A_{nv}$ [cm <sup>2</sup> ] | $A_{nt}$ [cm <sup>2</sup> ] | $V_0$ [kN] | $V_{eff,Rd}$ [kN] | $ V_0 /V_{eff,Rd}$ | Status   |
|----|-------|-----------------------------|-----------------------------|------------|-------------------|--------------------|----------|
| 1  |       | 3.61                        | 7.90                        | -0.45 (*1) | 162.67 (*)        | 0.00               | verified |
| 2  |       | 7.90                        | 18.97                       | 33.78 (*2) | 380.29 (*)        | 0.09               | verified |
| 3  |       | 7.90                        | 18.97                       | 33.78 (*2) | 380.29 (*)        | 0.09               | verified |
| 4  |       | 15.79                       | 0.00                        | 33.78 (*2) | 214.30 (**)       | 0.16               | verified |
| 5  |       | 6.21                        | 1.15                        | 31.14 (*3) | 201.91 (***)      | 0.15               | verified |
| 6  |       | 6.21                        | 1.15                        | 19.53 (*4) | 201.91 (***)      | 0.10               | verified |

(\*1)  $V_0 = V_{zEd1}$

(\*2)  $V_0 = N_{wEd}$

(\*3)  $V_0 = N_{fuEd}$

(\*4)  $V_0 = N_{flEd}$

(\*)  $V_{effRd} = 0.5 \cdot f_u \cdot A_{nt} / \alpha_{M2} + (1/\alpha_3) \cdot f_y \cdot A_{nv} / \alpha_{M0}$

(\*\*)  $V_{effRd} = f_u \cdot A_{nt} / \alpha_{M2} + (1/\alpha_3) \cdot f_y \cdot A_{nv} / \alpha_{M0}$

(\*\*\*)  $V_{effRd} = 2 \cdot [0.5 \cdot f_u \cdot A_{nt} / \alpha_{M2} + (1/\alpha_3) \cdot f_y \cdot A_{nv} / \alpha_{M0}]$

### 4.2. Splice plate

| Model | $A_{nv}$ [cm <sup>2</sup> ] | $A_{nt}$ [cm <sup>2</sup> ] | $V_0$ [kN] | $V_{eff,Rd}$ [kN] | $ V_0 /V_{eff,Rd}$ | Status   |
|-------|-----------------------------|-----------------------------|------------|-------------------|--------------------|----------|
|       | 1.77                        | 6.07                        | -0.23 (*1) | 111.56 (*)        | 0.00               | verified |
|       | 6.07                        | 1.77                        | 16.89 (*2) | 107.98 (*)        | 0.16               | verified |
|       | 6.07                        | 1.77                        | 16.89 (*2) | 107.98 (*)        | 0.16               | verified |

(\*1)  $V_0 = V_{zEd1}$

(\*2)  $V_0 = N_{wEd}$

(\*)  $V_{effRd} = 0.5 \cdot f_u \cdot A_{nt} / \alpha_{M2} + (1/\alpha_3) \cdot f_y \cdot A_{nv} / \alpha_{M0}$

### 4.3. Upper external plate

| Nr | Model | $A_{nv}$ [cm <sup>2</sup> ] | $A_{nt}$ [cm <sup>2</sup> ] | $V_0$ [kN] | $V_{eff,Rd}$ [kN] | $ V_0 /V_{eff,Rd}$ | Status   |
|----|-------|-----------------------------|-----------------------------|------------|-------------------|--------------------|----------|
| 1  |       | 6.82                        | 4.57                        | 30.91 (*1) | 158.48 (*)        | 0.20               | verified |
| 2  |       | 13.65                       | 4.05                        | 30.91 (*1) | 301.84 (**)       | 0.10               | verified |

(\*1)  $V_0 = N_{fueEd}$

(\*)  $V_{effRd} = 0.5 \cdot f_u \cdot A_{nt} / \alpha_{M2} + (1/\alpha_3) \cdot f_y \cdot A_{nv} / \alpha_{M0}$

(\*\*)  $V_{effRd} = f_u \cdot A_{nt} / \alpha_{M2} + (1/\alpha_3) \cdot f_y \cdot A_{nv} / \alpha_{M0}$

#### 4.4. Lower external plate

| Nr | Model | A <sub>nv</sub> [cm <sup>2</sup> ] | A <sub>nt</sub> [cm <sup>2</sup> ] | V <sub>0</sub> [kN] | V <sub>eff,Rd</sub> [kN] | V <sub>0</sub> /V <sub>eff,Rd</sub> | Status   |
|----|-------|------------------------------------|------------------------------------|---------------------|--------------------------|-------------------------------------|----------|
| 1  |       | 6.82                               | 4.57                               | 19.76 (*1)          | 158.48 (*)               | 0.12                                | verified |
| 2  |       | 13.65                              | 4.05                               | 19.76 (*1)          | 301.84 (**)              | 0.07                                | verified |

(\*1)  $V_0 = N_{fleEd}$

(\*)  $V_{effRd} = 0.5 \cdot f_u \cdot A_{nt} / \alpha_{M2} + (1/\alpha_3) \cdot f_y \cdot A_{nv} / \alpha_{M0}$

(\*\*)  $V_{effRd} = f_u \cdot A_{nt} / \alpha_{M2} + (1/\alpha_3) \cdot f_y \cdot A_{nv} / \alpha_{M0}$

### 5. Verification of sections weakened by openings - [5.4]

#### 5.1. Beam

|  |                           |  |  |
|--|---------------------------|--|--|
| A <sub>t</sub> =   | 13.82 [cm <sup>2</sup> ]  | Area of tension zone of the gross section    |  |
| A <sub>t,net</sub> =   | 11.25 [cm <sup>2</sup> ]  | Net area of the section in tension           |  |
| $0.9 \cdot (A_{t,net}/A_t) \leq (f_y \cdot \alpha_{M2}) / (f_u \cdot \alpha_{M0})$ | 0.73 < 0.82               |  | <b>verified</b>  |
| W =  | 144.06 [cm <sup>3</sup> ] | Elastic section modulus                      |  |
| W <sub>net</sub> =   | 144.06 [cm <sup>3</sup> ] | Elastic section modulus                      |  |
| M <sub>c,Rdnet</sub> =   | 33.85 [kN*m]              | Design resistance of the section for bending | M <sub>c,Rdnet</sub> = W <sub>net</sub> · f <sub>yp</sub> / α <sub>M0</sub>                    |
| M <sub>0</sub>   ≤ M <sub>c,Rdnet</sub>  | 0.76  < 33.85             |  | <b>verified</b> (0.02)   |
| A <sub>v</sub> =   | 7.80 [cm <sup>2</sup> ]   | Effective section area for shear             | A <sub>v</sub> = h <sub>p</sub> · t <sub>p</sub>   |
| A <sub>v,net</sub> =   | 7.21 [cm <sup>2</sup> ]   | Net area of a section effective for shear    | A <sub>vnet</sub> = A <sub>v</sub> - n <sub>v</sub> · d <sub>0</sub> · t <sub>p</sub>          |
| A <sub>v,net</sub> ≥ (f <sub>yp</sub> /f <sub>up</sub> ) · A <sub>v</sub>          | 7.21 > 5.09               |  | <b>verified</b>  |
| V <sub>pl,Rd</sub> =   | 105.83 [kN]               | Design plastic resistance for shear          | V <sub>pl,Rd</sub> = (A <sub>v</sub> · f <sub>yp</sub> ) / (α <sub>3</sub> · α <sub>M0</sub> ) |
| V <sub>0</sub>   ≤ V <sub>pl,Rd</sub>  | -0.45  < 105.83           |  | <b>verified</b> (0.00)   |

#### 5.2. Splice plate

|  |                         |  |  |
|--|-------------------------|--|--|
| A <sub>t</sub> =   | 4.00 [cm <sup>2</sup> ] | Area of tension zone of the gross section    |  |
| A <sub>t,net</sub> =   | 3.55 [cm <sup>2</sup> ] | Net area of the section in tension           |  |
| $0.9 \cdot (A_{t,net}/A_t) \leq (f_y \cdot \alpha_{M2}) / (f_u \cdot \alpha_{M0})$ | 0.80 < 0.82             |  | <b>verified</b>  |
| W =  | 5.33 [cm <sup>3</sup> ] | Elastic section modulus                      |  |
| W <sub>net</sub> =   | 5.33 [cm <sup>3</sup> ] | Elastic section modulus                      |  |
| M <sub>c,Rdnet</sub> =   | 1.25 [kN*m]             | Design resistance of the section for bending | M <sub>c,Rdnet</sub> = W <sub>net</sub> · f <sub>yp</sub> / α <sub>M0</sub>                    |
| M <sub>0</sub>   ≤ M <sub>c,Rdnet</sub>  | 0.01  < 1.25            |  | <b>verified</b> (0.01)   |
| A <sub>v</sub> =   | 4.00 [cm <sup>2</sup> ] | Effective section area for shear             | A <sub>v</sub> = h <sub>p</sub> · t <sub>p</sub>   |
| A <sub>v,net</sub> =   | 3.55 [cm <sup>2</sup> ] | Net area of a section effective for shear    | A <sub>vnet</sub> = A <sub>v</sub> - n <sub>v</sub> · d <sub>0</sub> · t <sub>p</sub>          |
| A <sub>v,net</sub> ≥ (f <sub>yp</sub> /f <sub>up</sub> ) · A <sub>v</sub>          | 3.55 > 2.61             |  | <b>verified</b>  |
| V <sub>pl,Rd</sub> =   | 54.27 [kN]              | Design plastic resistance for shear          | V <sub>pl,Rd</sub> = (A <sub>v</sub> · f <sub>yp</sub> ) / (α <sub>3</sub> · α <sub>M0</sub> ) |
| V <sub>0</sub>   ≤ V <sub>pl,Rd</sub>  | -0.23  < 54.27          |  | <b>verified</b> (0.00)   |

#### 5.3. Upper external plate

|  |                         |   |   |
|--|-------------------------|---|---|
| A =                                    | 6.00 [cm <sup>2</sup> ] | Area of tension zone of the gross section                     | A = h <sub>pi</sub> · t <sub>pi</sub>   |
| A <sub>net</sub> =                     | 5.10 [cm <sup>2</sup> ] | Net cross-sectional area                                      | A <sub>net</sub> = A - n <sub>v</sub> · d <sub>0</sub> · t <sub>pi</sub>      |
| N <sub>pl,Rd</sub> =                   | 141.00 [kN]             | Design plastic resistance of the gross section                | N <sub>pl,Rd</sub> = A · f <sub>y</sub> / α <sub>M0</sub>                     |
| N <sub>u,Rd</sub> =                    | 132.19 [kN]             | Design ultimate resistance to normal force of the net section | N <sub>u,Rd</sub> = 0.9 · A <sub>net</sub> · f <sub>u</sub> / α <sub>M2</sub> |
| F <sub>Ed</sub> =                      | 30.91 [kN]              |   | F <sub>Ed</sub> = N <sub>Ed,pfue</sub>  |
| F <sub>Ed</sub>   ≤ N <sub>u,Rd</sub>  | 30.91  < 132.19         |   | <b>verified</b> (0.23)  |
| F <sub>Ed</sub>   ≤ N <sub>pl,Rd</sub> | 30.91  < 141.00         |   | <b>verified</b> (0.22)  |

#### 5.4. Lower external plate

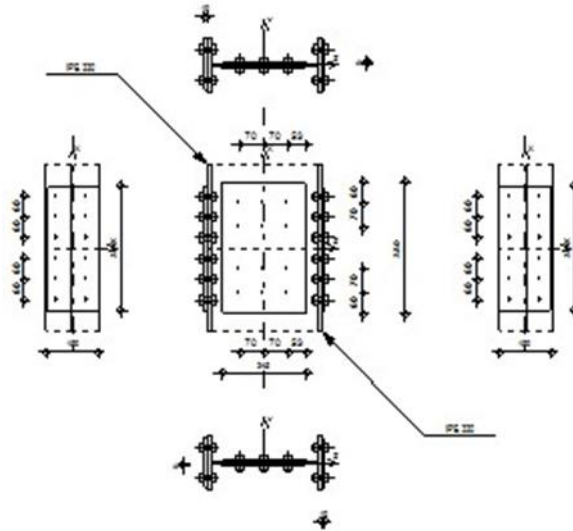
|  |                         |   |   |
|--|-------------------------|---|---|
| A =                                    | 6.00 [cm <sup>2</sup> ] | Area of tension zone of the gross section                     | A = h <sub>pi</sub> · t <sub>pi</sub>   |
| A <sub>net</sub> =                     | 5.10 [cm <sup>2</sup> ] | Net cross-sectional area                                      | A <sub>net</sub> = A - n <sub>v</sub> · d <sub>0</sub> · t <sub>pi</sub>      |
| N <sub>pl,Rd</sub> =                   | 141.00 [kN]             | Design plastic resistance of the gross section                | N <sub>pl,Rd</sub> = A · f <sub>y</sub> / α <sub>M0</sub>                     |
| N <sub>u,Rd</sub> =                    | 132.19 [kN]             | Design ultimate resistance to normal force of the net section | N <sub>u,Rd</sub> = 0.9 · A <sub>net</sub> · f <sub>u</sub> / α <sub>M2</sub> |
| F <sub>Ed</sub> =                      | 19.76 [kN]              |   | F <sub>Ed</sub> = N <sub>Ed,pfi</sub>   |
| F <sub>Ed</sub>   ≤ N <sub>u,Rd</sub>  | 19.76  < 132.19         |   | <b>verified</b> (0.15)  |
| F <sub>Ed</sub>   ≤ N <sub>pl,Rd</sub> | 19.76  < 141.00         |   | <b>verified</b> (0.14)  |

**Connection conforms to the code**

**Ratio 0.70**

# Cobre-junta dos Cordões dos Pilares (IPE 330 - IPE 330)

|   |  |   |
|---|--|---|
|  | Autodesk Robot Structural Analysis Professional 2016                                     |  |
|   | <b>Calculation of the column-to-column splice connection</b><br>EN 1993-1-8:2005/AC:2009 |   |
|   |  | Ratio<br><b>0.64</b>  |



## VII. General

Connection no.: 3

Connection name: Empalme\_Cordões\_dos\_Pilares

### 1. Lower column

Section: IPE 330

$h_{c1} = 330$  [mm] Height of beam section  
 $b_{fc1} = 160$  [mm] Width of beam section  
 $t_{wc1} = 8$  [mm] Thickness of the web of beam section  
 $t_{fc1} = 12$  [mm] Thickness of the flange of beam section  
 $r_{c1} = 18$  [mm] Radius of beam section fillet  
 $A_{c1} = 62.61$  [cm<sup>2</sup>] Cross-sectional area of a beam  
 $I_{yc1} = 11766.90$  [cm<sup>4</sup>] Moment of inertia of the beam section  
 Material: S235  
 $f_{yc1} = 235.00$  [MPa] Resistance  
 $f_{uc1} = 360.00$  [MPa]

### 2. Upper column

Section: IPE 330

$h_{c2} = 330$  [mm] Height of beam section  
 $b_{fc2} = 160$  [mm] Width of beam section  
 $t_{wc2} = 8$  [mm] Thickness of the web of beam section  
  
 $t_{fc2} = 12$  [mm] Thickness of the flange of beam section  
 $r_{c2} = 18$  [mm] Radius of beam section fillet  
 $A_{c2} = 62.61$  [cm<sup>2</sup>] Cross-sectional area of a beam  
 $I_{yc2} = 11766.90$  [cm<sup>4</sup>] Moment of inertia of the beam section  
 Material: S235  
 $f_{yc2} = 235.00$  [MPa] Resistance  
 $f_{uc2} = 360.00$  [MPa]

### 3. Splice plate

|             |           |       |                    |
|-------------|-----------|-------|--------------------|
| Type:       | bilateral |       |                    |
| $l_{pw} =$  | 380       | [mm]  | Plate length       |
| $h_{pw} =$  | 245       | [mm]  | Plate height       |
| $t_{pw} =$  | 5         | [mm]  | Plate thickness    |
| Material:   | S235      |       |                    |
| $f_{ypw} =$ | 235.00    | [MPa] | Design resistance  |
| $f_{upw} =$ | 360.00    | [MPa] | Tensile resistance |

### 4. Right external plate

|             |        |       |                    |
|-------------|--------|-------|--------------------|
| $l_{pe} =$  | 360    | [mm]  | Plate length       |
| $h_{pe} =$  | 150    | [mm]  | Plate height       |
| $t_{pe} =$  | 10     | [mm]  | Plate thickness    |
| Material:   | S235   |       |                    |
| $f_{ype} =$ | 235.00 | [MPa] | Design resistance  |
| $f_{upe} =$ | 360.00 | [MPa] | Tensile resistance |

### 5. Left external plate

|             |        |       |                    |
|-------------|--------|-------|--------------------|
| $l_{pe} =$  | 360    | [mm]  | Plate length       |
| $h_{pe} =$  | 150    | [mm]  | Plate height       |
| $t_{pe} =$  | 10     | [mm]  | Plate thickness    |
| Material:   | S235   |       |                    |
| $f_{ype} =$ | 235.00 | [MPa] | Design resistance  |
| $f_{upe} =$ | 360.00 | [MPa] | Tensile resistance |

### 6. Lower side

#### 6.1. Bolts connecting a splice plate with the column web

The shear plane passes through the UNTHREADED portion of the bolt.

Connection category A

|            |        |   |
|------------|--------|---|
| Class =    | 5.6    | Bolt class  |
| $d =$      | 12     | [mm] Bolt diameter                                  |
| $d_0 =$    | 13     | [mm] Bolt opening diameter                          |
| $A_s =$    | 0.84   | [cm <sup>2</sup> ] Effective section area of a bolt |
| $A_v =$    | 1.13   | [cm <sup>2</sup> ] Area of bolt section             |
| $f_{yb} =$ | 300.00 | [MPa] Yield strength of bolt                        |
| $f_{ub} =$ | 500.00 | [MPa] Bolt tensile resistance                       |
| $n_h =$    | 2      | Number of bolt columns                              |
| $n_v =$    | 3      | Number of bolt rows                                 |
| $e_1 =$    | 52     | [mm] Level of first bolt                            |
| $p_2 =$    | 70     | [mm] Horizontal spacing                             |
| $p_1 =$    | 70     | [mm] Vertical spacing                               |

#### 6.2. Bolts connecting a flange plate with the column right flange

The shear plane passes through the UNTHREADED portion of the bolt.

Connection category A

|            |        |   |
|------------|--------|---|
| Class =    | 5.6    | Bolt class  |
| $d =$      | 12     | [mm] Bolt diameter                                  |
| $d_0 =$    | 13     | [mm] Bolt opening diameter                          |
| $A_s =$    | 0.84   | [cm <sup>2</sup> ] Effective section area of a bolt |
| $A_v =$    | 1.13   | [cm <sup>2</sup> ] Area of bolt section             |
| $f_{yb} =$ | 300.00 | [MPa] Yield strength of bolt                        |
| $f_{ub} =$ | 500.00 | [MPa] Bolt tensile resistance                       |
| $n_h =$    | 1      | Number of bolt columns                              |
| $n_v =$    | 3      | Number of bolt rows                                 |
| $e_1 =$    | 30     | [mm] Level of first bolt                            |
| $p_1 =$    | 60     | [mm] Vertical spacing                               |

### 6.3. Bolts connecting a flange plate with the column left flange

The shear plane passes through the UNTHREADED portion of the bolt.

Connection category A

|                   |        |                    |                                  |
|-------------------|--------|--------------------|----------------------------------|
| Class =           | 5.6    |                    | Bolt class                       |
| d =               | 12     | [mm]               | Bolt diameter                    |
| d <sub>0</sub> =  | 13     | [mm]               | Bolt opening diameter            |
| A <sub>s</sub> =  | 0.84   | [cm <sup>2</sup> ] | Effective section area of a bolt |
| A <sub>v</sub> =  | 1.13   | [cm <sup>2</sup> ] | Area of bolt section             |
| f <sub>yb</sub> = | 300.00 | [MPa]              | Yield strength of bolt           |
| f <sub>ub</sub> = | 500.00 | [MPa]              | Bolt tensile resistance          |
| n <sub>h</sub> =  | 1      |                    | Number of bolt columns           |
| n <sub>v</sub> =  | 3      |                    | Number of bolt rows              |
| e <sub>1</sub> =  | 30     | [mm]               | Level of first bolt              |
| p <sub>1</sub> =  | 60     | [mm]               | Vertical spacing                 |

## 7. Upper side

### 7.1. Bolts connecting a splice plate with the column web

The shear plane passes through the UNTHREADED portion of the bolt.

Connection category A

|                   |        |                    |                                  |
|-------------------|--------|--------------------|----------------------------------|
| Class =           | 5.6    |                    | Bolt class                       |
| d =               | 12     | [mm]               | Bolt diameter                    |
| d <sub>0</sub> =  | 13     | [mm]               | Bolt opening diameter            |
| A <sub>s</sub> =  | 0.84   | [cm <sup>2</sup> ] | Effective section area of a bolt |
| A <sub>v</sub> =  | 1.13   | [cm <sup>2</sup> ] | Area of bolt section             |
| f <sub>yb</sub> = | 300.00 | [MPa]              | Yield strength of bolt           |
| f <sub>ub</sub> = | 500.00 | [MPa]              | Bolt tensile resistance          |
| n <sub>h</sub> =  | 2      |                    | Number of bolt columns           |
| n <sub>v</sub> =  | 3      |                    | Number of bolt rows              |
| e <sub>1</sub> =  | 52     | [mm]               | Level of first bolt              |
| p <sub>2</sub> =  | 70     | [mm]               | Horizontal spacing               |
| p <sub>1</sub> =  | 70     | [mm]               | Vertical spacing                 |

### 7.2. Bolts connecting a flange plate with the column right flange

The shear plane passes through the UNTHREADED portion of the bolt.

Connection category A

|                   |        |                    |                                  |
|-------------------|--------|--------------------|----------------------------------|
| Class =           | 5.6    |                    | Bolt class                       |
| d =               | 12     | [mm]               | Bolt diameter                    |
| d <sub>0</sub> =  | 13     | [mm]               | Bolt opening diameter            |
| A <sub>s</sub> =  | 0.84   | [cm <sup>2</sup> ] | Effective section area of a bolt |
| A <sub>v</sub> =  | 1.13   | [cm <sup>2</sup> ] | Area of bolt section             |
| f <sub>yb</sub> = | 300.00 | [MPa]              | Yield strength of bolt           |
| f <sub>ub</sub> = | 500.00 | [MPa]              | Bolt tensile resistance          |
| n <sub>h</sub> =  | 1      |                    | Number of bolt columns           |
| n <sub>v</sub> =  | 3      |                    | Number of bolt rows              |
| e <sub>1</sub> =  | 30     | [mm]               | Level of first bolt              |
| p <sub>1</sub> =  | 60     | [mm]               | Vertical spacing                 |

### 7.3. Bolts connecting a flange plate with the column left flange

The shear plane passes through the UNTHREADED portion of the bolt.

Connection category A

|                   |        |                    |                                  |
|-------------------|--------|--------------------|----------------------------------|
| Class =           | 5.6    |                    | Bolt class                       |
| d =               | 12     | [mm]               | Bolt diameter                    |
| d <sub>0</sub> =  | 13     | [mm]               | Bolt opening diameter            |
| A <sub>s</sub> =  | 0.84   | [cm <sup>2</sup> ] | Effective section area of a bolt |
| A <sub>v</sub> =  | 1.13   | [cm <sup>2</sup> ] | Area of bolt section             |
| f <sub>yb</sub> = | 300.00 | [MPa]              | Yield strength of bolt           |
| f <sub>ub</sub> = | 500.00 | [MPa]              | Bolt tensile resistance          |

## 8. Material factors

|                 |      |                       |       |
|-----------------|------|-----------------------|-------|
| $\alpha_{M0} =$ | 1.00 | Partial safety factor | [2.2] |
| $\alpha_{M2} =$ | 1.25 | Partial safety factor | [2.2] |

## VIII. Loads

Case: Manual calculations.




### 1. Ultimate limit state

|                |        |        |                |
|----------------|--------|--------|----------------|
| $N_{Ed1} =$    | 339.64 | [kN]   | Axial force    |
| $V_{y,Ed1} =$  | -1.70  | [kN]   | Shear force    |
| $V_{z,Ed1} =$  | 6.47   | [kN]   | Shear force    |
| $M_{y,Ed1} =$  | -1.70  | [kN*m] | Bending moment |
| $M_{Vz,Ed1} =$ | 1.33   | [kN*m] | Bending moment |
| $N_{Ed2} =$    | 339.64 | [kN]   | Axial force    |
| $V_{y,Ed2} =$  | -1.70  | [kN]   | Shear force    |
| $V_{z,Ed2} =$  | 6.47   | [kN]   | Shear force    |
| $M_{y,Ed2} =$  | -1.70  | [kN*m] | Bending moment |
| $M_{Vz,Ed2} =$ | 1.33   | [kN*m] | Bending moment |

## IX. Results

Results for one side of connection (geometry and loads are symmetrical)


### Axial force

| Plate   | $A_i$ [cm <sup>2</sup> ] | EQUIVALENT FORCES<br>$N_i$ [kN] | EQUIVALENT FORCES<br>$N_i(M_{y,Ed})$ [kN] | Resultant force<br>$N_{Ed,i}$ [kN] |
|---|--------------------------|---------------------------------|---|------------------------------------|
|  | $A_{pw} = 24.50$         | 152.68                          | -   | $N_{Ed,pw} = 152.68$               |
|  | $A_{pfue} = 15.00$       | 93.48                           | -4.38                                     | $N_{Ed,pfue} = 89.10$              |
|  | $A_{pfle} = 15.00$       | 93.48                           | 4.38                                      | $N_{Ed,pfle} = 97.86$              |



$$N_i = (N_{Ed} * A_i) / (2 * A_{wp} + A_{pfue} + A_{pfle})$$

$$N_{Ed,i} = N_i + N_i(M_{y,Ed})$$

### Shear force Z




| Plate   | $A_i$ [cm <sup>2</sup> ] | $V_{z,Ed,i}$ [kN]    |
|---|--------------------------|----------------------|
|  | $A_{z,pw} = 24.50$       | $V_{z,Ed,pw} = 6.47$ |

### Shear force Y

| Plate   | $A_{y,i}$ [cm <sup>2</sup> ] | $V_{y,Ed,i}$ [kN]       |
|---|------------------------------|-------------------------|
|  | $A_{y,fupe} = 15.00$         | $V_{y,Ed,fupe} = -0.85$ |
|  | $A_{y,fple} = 15.00$         | $V_{y,Ed,fple} = -0.85$ |



$$V_{y,i} = (V_{y,Ed} * A_{y,i}) / (A_{pfue} + A_{pfle})$$

### Bending moment Y

| Plate   | $I_{y,i}$ [cm <sup>4</sup> ] | EQUIVALENT FORCES<br>$M_{y,i}$ [kN*m] | Resultant force<br>$M_{y,Ed,i}$ [kN*m] |
|---|------------------------------|---------------------------------------|--|
|  | $I_{y,pw} = 1225.51$         | -0.21                                 | $M_{y,Ed,pw} = -0.21$                  |
|  | $I_{y,pfue} = 4336.25$       | -0.74                                 | -                                      |
|  | $I_{y,pfle} = 4336.25$       | -0.74                                 | -                                      |

$$M_{y,i} = (M_{y,Ed} * I_{y,i}) / (2 * I_{pw} + I_{pfue} + I_{pfle})$$

**Bending moment Z**

| Plate   | I <sub>z,i</sub> [cm <sup>4</sup> ] | M <sub>z,i</sub> [kN*m]       |
|---|-------------------------------------|-------------------------------|
|  | I <sub>z,pfue</sub> = 281.25        | M <sub>z,Ed,pfue</sub> = 0.67 |
|  | I <sub>z,pfle</sub> = 281.25        | M <sub>z,Ed,pfle</sub> = 0.67 |

$$M_i = (M_{z,Ed} * I_{z,i}) / (I_{z,pfue} + I_{z,pfle})$$

**1. Bolts connecting a splice plate with the column web**

**1.1. Bolt capacities**

F<sub>v,Rd</sub> = 54.29 [kN] Shear bolt resistance in the unthreaded portion of a bolt F<sub>v,Rd</sub> = 0.6 \* f<sub>ub</sub> \* A<sub>v</sub> \* m / √M<sub>2</sub>

**Bolt bearing on the column web**

Direction x

k<sub>1x</sub> = 2.50 Coefficient for calculation of F<sub>b,Rd</sub> k<sub>1x</sub> = min[2.8\*(e<sub>1</sub>/d<sub>0</sub>)-1.7, 1.4\*(p<sub>1</sub>/d<sub>0</sub>)-1.7, 2.5]

k<sub>1x</sub> > 0.0 2.50 > 0.00 **verified**

∅<sub>bx</sub> = 1.00 Coefficient for calculation of F<sub>b,Rd</sub> ∅<sub>bx</sub> = min[e<sub>2</sub>/(3\*d<sub>0</sub>), p<sub>2</sub>/(3\*d<sub>0</sub>)-0.25, f<sub>ub</sub>/f<sub>u</sub>, 1]

∅<sub>bx</sub> > 0.0 1.00 > 0.00 **verified**

F<sub>b,Rd1x</sub> = 64.80 [kN] Bearing resistance of a single bolt F<sub>b,Rd1x</sub> = k<sub>1x</sub> \* ∅<sub>bx</sub> \* f<sub>u</sub> \* d \* ∑t<sub>i</sub> / √M<sub>2</sub>

Direction z

k<sub>1z</sub> = 2.50 Coefficient for calculation of F<sub>b,Rd</sub> k<sub>1z</sub> = min[2.8\*(e<sub>2</sub>/d<sub>0</sub>)-1.7, 1.4\*(p<sub>2</sub>/d<sub>0</sub>)-1.7, 2.5]

k<sub>1z</sub> > 0.0 2.50 > 0.00 **verified**

∅<sub>bz</sub> = 1.00 Coefficient for calculation of F<sub>b,Rd</sub> ∅<sub>bz</sub> = min[e<sub>1</sub>/(3\*d<sub>0</sub>), p<sub>1</sub>/(3\*d<sub>0</sub>)-0.25, f<sub>ub</sub>/f<sub>u</sub>, 1]

∅<sub>bz</sub> > 0.0 1.00 > 0.00 **verified**

F<sub>b,Rd1z</sub> = 64.80 [kN] Bearing resistance of a single bolt F<sub>b,Rd1z</sub> = k<sub>1z</sub> \* ∅<sub>bz</sub> \* f<sub>u</sub> \* d \* ∑t<sub>i</sub> / √M<sub>2</sub>

**Bolt bearing on the plate**

Direction x

k<sub>1x</sub> = 2.50 Coefficient for calculation of F<sub>b,Rd</sub> k<sub>1x</sub> = min[2.8\*(e<sub>1</sub>/d<sub>0</sub>)-1.7, 1.4\*(p<sub>1</sub>/d<sub>0</sub>)-1.7, 2.5]

k<sub>1x</sub> > 0.0 2.50 > 0.00 **verified**

∅<sub>bx</sub> = 1.00 Coefficient for calculation of F<sub>b,Rd</sub> ∅<sub>bx</sub> = min[e<sub>2</sub>/(3\*d<sub>0</sub>), p<sub>2</sub>/(3\*d<sub>0</sub>)-0.25, f<sub>ub</sub>/f<sub>u</sub>, 1]

∅<sub>bx</sub> > 0.0 1.00 > 0.00 **verified**

F<sub>b,Rd2x</sub> = 86.40 [kN] Bearing resistance of a single bolt F<sub>b,Rd2x</sub> = k<sub>1x</sub> \* ∅<sub>bx</sub> \* f<sub>u</sub> \* d \* ∑t<sub>i</sub> / √M<sub>2</sub>

Direction z

k<sub>1z</sub> = 2.50 Coefficient for calculation of F<sub>b,Rd</sub> k<sub>1z</sub> = min[2.8\*(e<sub>2</sub>/d<sub>0</sub>)-1.7, 1.4\*(p<sub>2</sub>/d<sub>0</sub>)-1.7, 2.5]

k<sub>1z</sub> > 0.0 2.50 > 0.00 **verified**

∅<sub>bz</sub> = 1.00 Coefficient for calculation of F<sub>b,Rd</sub> ∅<sub>bz</sub> = min[e<sub>1</sub>/(3\*d<sub>0</sub>), p<sub>1</sub>/(3\*d<sub>0</sub>)-0.25, f<sub>ub</sub>/f<sub>u</sub>, 1]

∅<sub>bz</sub> > 0.0 1.00 > 0.00 **verified**

F<sub>b,Rd2z</sub> = 86.40 [kN] Bearing resistance of a single bolt F<sub>b,Rd2z</sub> = k<sub>1z</sub> \* ∅<sub>bz</sub> \* f<sub>u</sub> \* d \* ∑t<sub>i</sub> / √M<sub>2</sub>

**1.2. Ultimate limit state**

**Bolt shear**

e<sub>0</sub> = 95 [mm] Shear force eccentricity relative to the center of gravity of a bolt group e<sub>0</sub> = e<sub>2b</sub> + 0.5 \* (s<sub>1</sub> + (c-1) \* p<sub>2</sub>)

M<sub>y</sub> = 0.40 [kN\*m] Real bending moment M<sub>y</sub> = M<sub>y,Ed,pw</sub> + V<sub>z,Ed,pw</sub> \* e<sub>0</sub>

F<sub>x,N</sub> = 25.45 [kN] Component force in a bolt due to influence of the longitudinal force on the x direction F<sub>x,N</sub> = |N<sub>Ed,pw</sub>| / n<sub>b</sub>

F<sub>z,Vz</sub> = 1.08 [kN] Component force in a bolt due to influence of the shear force V<sub>z</sub> on the z direction F<sub>z,Vz</sub> = |V<sub>z,Ed,pw</sub>| / n<sub>b</sub>

F<sub>x,My</sub> = 1.05 [kN] Component force in a bolt due to influence of the moment M<sub>y</sub> on the x direction F<sub>x,My</sub> = |M<sub>y</sub>| \* z<sub>i</sub> / ∑(x<sub>i</sub><sup>2</sup> + z<sub>i</sub><sup>2</sup>)

F<sub>z,My</sub> = 0.52 [kN] Component force in a bolt due to influence of the moment M<sub>y</sub> on the z direction F<sub>z,My</sub> = |M<sub>y</sub>| \* x<sub>i</sub> / ∑(x<sub>i</sub><sup>2</sup> + z<sub>i</sub><sup>2</sup>)

F<sub>x,Ed</sub> = 26.50 [kN] Design total force in a bolt on the direction x F<sub>x,Ed</sub> = F<sub>x,N</sub> + F<sub>x,My</sub>

F<sub>z,Ed</sub> = 1.60 [kN] Design total force in a bolt on the direction z F<sub>z,Ed</sub> = F<sub>z,Vz</sub> + F<sub>z,My</sub>

F<sub>Ed</sub> = 26.55 [kN] Resultant shear force in a bolt F<sub>Ed</sub> = √(F<sub>x,Ed</sub><sup>2</sup> + F<sub>z,Ed</sub><sup>2</sup>)

F<sub>Rd,x</sub> = 64.80 [kN] Effective design capacity of a bolt on the direction x F<sub>Rd,x</sub> = min(F<sub>bRd1,x</sub>, F<sub>bRd2,x</sub>)

F<sub>Rd,z</sub> = 64.80 [kN] Effective design capacity of a bolt on the direction z F<sub>Rd,z</sub> = min(F<sub>bRd1,z</sub>, F<sub>bRd2,z</sub>)

|                            |                   |                        |
|----------------------------|-------------------|------------------------|
| $ F_{x,Ed}  \leq F_{Rd,x}$ | $ 26.50  < 64.80$ | <b>verified</b> (0.41) |
| $ F_{z,Ed}  \leq F_{Rd,z}$ | $ 1.60  < 64.80$  | <b>verified</b> (0.02) |
| $F_{Ed} \leq F_{v,Rd}$     | $26.55 < 54.29$   | <b>verified</b> (0.49) |

## 2. Bolts connecting a flange plate with the column right flange

### 2.1. Bolt capacities

$F_{v,Rd} = 27.14$  [kN] Shear resistance of the shank of a single bolt  $F_{v,Rd} = 0.6 \cdot f_{ub} \cdot A_v \cdot m / \sqrt{M_2}$

#### Bolt bearing on the column flange

Direction x

$k_{1x} = 2.50$  Coefficient for calculation of  $F_{b,Rd}$   $k_{1x} = \min[2.8 \cdot (e_2/d_0) - 1.7, 2.5]$

$k_{1x} > 0.0$   $2.50 > 0.00$  **verified**

$\alpha_{bx} = 0.77$  Coefficient for calculation of  $F_{b,Rd}$   $\alpha_{bx} = \min[e_1/(3 \cdot d_0), p_1/(3 \cdot d_0) - 0.25, f_{ub}/f_u, 1]$

$\alpha_{bx} > 0.0$   $0.77 > 0.00$  **verified**

$F_{b,Rd1x} = 76.43$  [kN] Bearing resistance of a single bolt  $F_{b,Rd1x} = k_{1x} \cdot \alpha_{bx} \cdot f_u \cdot d \cdot \sum t_i / \sqrt{M_2}$

Direction y

$k_{1y} = 2.50$  Coefficient for calculation of  $F_{b,Rd}$   $k_{1y} = \min[2.8 \cdot (e_1/d_0) - 1.7, 1.4 \cdot (p_1/d_0) - 1.7, 2.5]$

$k_{1y} > 0.0$   $2.50 > 0.00$  **verified**

$\alpha_{by} = 0.90$  Coefficient for calculation of  $F_{b,Rd}$   $\alpha_{by} = \min[e_2/(3 \cdot d_0), f_{ub}/f_u, 1]$

$\alpha_{by} > 0.0$   $0.90 > 0.00$  **verified**

$F_{b,Rd1y} = 89.17$  [kN] Bearing resistance of a single bolt  $F_{b,Rd1y} = k_{1y} \cdot \alpha_{by} \cdot f_u \cdot d \cdot \sum t_i / \sqrt{M_2}$

#### Bolt bearing on the plate

Direction x

$k_{1x} = 2.50$  Coefficient for calculation of  $F_{b,Rd}$   $k_{1x} = \min[2.8 \cdot (e_2/d_0) - 1.7, 2.5]$

$k_{1x} > 0.0$   $2.50 > 0.00$  **verified**

$\alpha_{bx} = 0.77$  Coefficient for calculation of  $F_{b,Rd}$   $\alpha_{bx} = \min[e_1/(3 \cdot d_0), p_1/(3 \cdot d_0) - 0.25, f_{ub}/f_u, 1]$

$\alpha_{bx} > 0.0$   $0.77 > 0.00$  **verified**

$F_{b,Rd2x} = 66.46$  [kN] Bearing resistance of a single bolt  $F_{b,Rd2x} = k_{1x} \cdot \alpha_{bx} \cdot f_u \cdot d \cdot \sum t_i / \sqrt{M_2}$

Direction y

$k_{1y} = 2.50$  Coefficient for calculation of  $F_{b,Rd}$   $k_{1y} = \min[2.8 \cdot (e_1/d_0) - 1.7, 1.4 \cdot (p_1/d_0) - 1.7, 2.5]$

$k_{1y} > 0.0$   $2.50 > 0.00$  **verified**

$\alpha_{by} = 0.77$  Coefficient for calculation of  $F_{b,Rd}$   $\alpha_{by} = \min[e_2/(3 \cdot d_0), f_{ub}/f_u, 1]$

$\alpha_{by} > 0.0$   $0.77 > 0.00$  **verified**

$F_{b,Rd2y} = 66.46$  [kN] Bearing resistance of a single bolt  $F_{b,Rd2y} = k_{1y} \cdot \alpha_{by} \cdot f_u \cdot d \cdot \sum t_i / \sqrt{M_2}$

### 2.2. Ultimate limit state

$e_0 = 90$  [mm] Shear force eccentricity relative to the center of gravity of a bolt group  $e_0 = e_{1b} + 0.5 \cdot (r_1 - p_1)$

$M_z = 0.59$  [kN\*m] Real bending moment  $M_z = M_{z,Ed,pf} + V_{y,Ed,pf} \cdot e_0$

$F_{x,N} = 14.83$  [kN] Component force in a bolt due to influence of the longitudinal force on the x direction  $F_{x,N} = |N_{Ed,pf}| / n_b$

$F_{y,Vy} = 0.14$  [kN] Component force in a bolt due to influence of the shear force  $V_y$  on the y direction  $F_{y,Vy} = |V_{y,Ed,pf}| / n_b$

$F_{x,Mz} = 1.00$  [kN] Component force in a bolt due to influence of the moment  $M_z$  on the x direction  $F_{x,Mz} = |M_z| \cdot y_i / \sum (x_i^2 + y_i^2)$

$F_{y,Mz} = 1.33$  [kN] Component force in a bolt due to influence of the moment  $M_z$  on the y direction  $F_{y,Mz} = |M_z| \cdot x_i / \sum (x_i^2 + y_i^2)$

$F_{x,Ed} = 15.82$  [kN] Design total force in a bolt on the direction x  $F_{x,Ed} = F_{x,N} + F_{x,Mz}$

$F_{y,Ed} = 1.47$  [kN] Design total force in a bolt on the direction y  $F_{y,Ed} = F_{y,Vy} + F_{y,Mz}$

$F_{Ed} = 15.89$  [kN] Resultant shear force in a bolt  $F_{Ed} = \sqrt{F_{x,Ed}^2 + F_{y,Ed}^2}$

$F_{x,Rd} = 66.46$  [kN] Effective design capacity of a bolt on the direction x  $F_{x,Rd} = \min(F_{x,bRd1}, F_{x,bRd2})$

$F_{y,Rd} = 66.46$  [kN] Effective design capacity of a bolt on the direction y  $F_{y,Rd} = \min(F_{y,bRd1}, F_{y,bRd2})$

|                            |                   |                 |        |
|----------------------------|-------------------|-----------------|--------|
| $ F_{x,Ed}  \leq F_{x,Rd}$ | $ 15.82  < 66.46$ | <b>verified</b> | (0.24) |
| $ F_{y,Ed}  \leq F_{y,Rd}$ | $ 1.47  < 66.46$  | <b>verified</b> | (0.02) |
| $F_{Ed} \leq F_{v,Rd}$     | $15.89 < 27.14$   | <b>verified</b> | (0.59) |

### 3. Bolts connecting a flange plate with the column left flange

#### 3.1. Bolt capacities

$F_{v,Rd} = 27.14$  [kN] Shear resistance of the shank of a single bolt  $F_{v,Rd} = 0.6 \cdot f_{ub} \cdot A_v \cdot m / \gamma_{M2}$

##### Bolt bearing on the column flange

Direction x

$k_{1x} = 2.50$  Coefficient for calculation of  $F_{b,Rd}$   $k_{1x} = \min[2.8 \cdot (e_2/d_0) - 1.7, 2.5]$

$k_{1x} > 0.0$   $2.50 > 0.00$  **verified**

$\alpha_{bx} = 0.77$  Coefficient for calculation of  $F_{b,Rd}$   $\alpha_{bx} = \min[e_1/(3 \cdot d_0), p_1/(3 \cdot d_0) - 0.25, f_{ub}/f_u, 1]$

$\alpha_{bx} > 0.0$   $0.77 > 0.00$  **verified**

$F_{b,Rd1x} = 76.43$  [kN] Bearing resistance of a single bolt  $F_{b,Rd1x} = k_{1x} \cdot \alpha_{bx} \cdot f_u \cdot d \cdot \sum t_i / \gamma_{M2}$

Direction y

$k_{1y} = 2.50$  Coefficient for calculation of  $F_{b,Rd}$   $k_{1y} = \min[2.8 \cdot (e_1/d_0) - 1.7, 1.4 \cdot (p_1/d_0) - 1.7, 2.5]$

$k_{1y} > 0.0$   $2.50 > 0.00$  **verified**

$\alpha_{by} = 0.90$  Coefficient for calculation of  $F_{b,Rd}$   $\alpha_{by} = \min[e_2/(3 \cdot d_0), f_{ub}/f_u, 1]$

$\alpha_{by} > 0.0$   $0.90 > 0.00$  **verified**

$F_{b,Rd1y} = 89.17$  [kN] Bearing resistance of a single bolt  $F_{b,Rd1y} = k_{1y} \cdot \alpha_{by} \cdot f_u \cdot d \cdot \sum t_i / \gamma_{M2}$

##### Bolt bearing on the plate

Direction x

$k_{1x} = 2.50$  Coefficient for calculation of  $F_{b,Rd}$   $k_{1x} = \min[2.8 \cdot (e_2/d_0) - 1.7, 2.5]$

$k_{1x} > 0.0$   $2.50 > 0.00$  **verified**

$\alpha_{bx} = 0.77$  Coefficient for calculation of  $F_{b,Rd}$   $\alpha_{bx} = \min[e_1/(3 \cdot d_0), p_1/(3 \cdot d_0) - 0.25, f_{ub}/f_u, 1]$

$\alpha_{bx} > 0.0$   $0.77 > 0.00$  **verified**

$F_{b,Rd2x} = 66.46$  [kN] Bearing resistance of a single bolt  $F_{b,Rd2x} = k_{1x} \cdot \alpha_{bx} \cdot f_u \cdot d \cdot \sum t_i / \gamma_{M2}$

Direction y

$k_{1y} = 2.50$  Coefficient for calculation of  $F_{b,Rd}$   $k_{1y} = \min[2.8 \cdot (e_1/d_0) - 1.7, 1.4 \cdot (p_1/d_0) - 1.7, 2.5]$

$k_{1y} > 0.0$   $2.50 > 0.00$  **verified**

$\alpha_{by} = 0.77$  Coefficient for calculation of  $F_{b,Rd}$   $\alpha_{by} = \min[e_2/(3 \cdot d_0), f_{ub}/f_u, 1]$

$\alpha_{by} > 0.0$   $0.77 > 0.00$  **verified**

$F_{b,Rd2y} = 66.46$  [kN] Bearing resistance of a single bolt  $F_{b,Rd2y} = k_{1y} \cdot \alpha_{by} \cdot f_u \cdot d \cdot \sum t_i / \gamma_{M2}$

#### 3.2. Ultimate limit state

##### Bolt shear

$e_0 = 90$  [mm] Shear force eccentricity relative to the center of gravity of a bolt group  $e_0 = e_{1b} + 0.5 \cdot (r-1) \cdot p_1$

$M_z = 0.59$  [kN\*m] Real bending moment  $M_z = M_{z,Ed,pr} + V_{y,Ed,pr} \cdot e_0$

$F_{x,N} = 16.3$  [kN] Component force in a bolt due to influence of the longitudinal force on the x direction  $F_{x,N} = |N_{Ed,pr}| / n_b$

$F_{y,Vy} = 0.14$  [kN] Component force in a bolt due to influence of the shear force  $V_y$  on the y direction  $F_{y,Vy} = |V_{y,Ed,pr}| / n_b$

$F_{x,Mz} = 1.00$  [kN] Component force in a bolt due to influence of the moment  $M_z$  on the x direction  $F_{x,Mz} = |M_z| \cdot y_i / \sum (x_i^2 + y_i^2)$

$F_{y,Mz} = 1.33$  [kN] Component force in a bolt due to influence of the moment  $M_z$  on the y direction  $F_{y,Mz} = |M_z| \cdot x_i / \sum (x_i^2 + y_i^2)$

$F_{x,Ed} = 17.3$  [kN] Design total force in a bolt on the direction x  $F_{x,Ed} = F_{x,N} + F_{x,Mz}$

$F_{y,Ed} = 1.47$  [kN] Design total force in a bolt on the direction y  $F_{y,Ed} = F_{y,Vy} + F_{y,Mz}$

$F_{Ed} = 17.9$  [kN] Resultant shear force in a bolt  $F_{Ed} = \sqrt{F_{x,Ed}^2 + F_{y,Ed}^2}$

$F_{x,Rd} = 66.4$  [kN] Effective design capacity of a bolt on the direction x  $F_{x,Rd} = \min(F_{x,bRd1}, F_{x,bRd2})$

|  |   |
|--|---|
| $F_{y,Rd} = 66.46$ [kN] Effective design capacity of a bolt on the direction y | $F_{y,Rd} = \min(F_{y,bRd1}, F_{y,bRd2})$ |
| $ F_{x,Ed}  \leq F_{x,Rd}$   | $ 17.33  < 66.46$ <b>verified</b> (0.26)  |
| $ F_{y,Ed}  \leq F_{y,Rd}$   | $ 1.47  < 66.46$ <b>verified</b> (0.02)   |
| $F_{Ed} \leq F_{v,Rd}$   | $17.39 < 27.14$ <b>verified</b> (0.64)    |

## 4. Verification of the section due to block tearing - [3.10]

### 4.1. Column

| Nr | Model | $A_{nv}$ [cm <sup>2</sup> ] | $A_{nt}$ [cm <sup>2</sup> ] | $V_0$ [kN]  | $V_{eff,Rd}$ [kN] | $ V_0 /V_{eff,Rd}$ | Status   |
|----|-------|-----------------------------|-----------------------------|-------------|-------------------|--------------------|----------|
| 1  |       | 15.19                       | 8.29                        | 6.47 (*1)   | 325.40 (*)        | 0.02               | verified |
| 2  |       | 8.29                        | 39.20                       | 152.68 (*2) | 676.93 (*)        | 0.23               | verified |
| 3  |       | 8.29                        | 39.20                       | 152.68 (*2) | 676.93 (*)        | 0.23               | verified |
| 4  |       | 16.57                       | 8.55                        | 152.68 (*2) | 471.13 (**)       | 0.32               | verified |
| 5  |       | 13.51                       | 3.28                        | 88.97 (*3)  | 461.06 (***)      | 0.19               | verified |
| 6  |       | 13.51                       | 3.28                        | 97.99 (*4)  | 461.06 (***)      | 0.21               | verified |

(\*1)  $V_0 = V_{zEd1}$

(\*2)  $V_0 = N_{wEd}$

(\*3)  $V_0 = N_{fuEd}$

(\*4)  $V_0 = N_{flEd}$

(\*)  $V_{effRd} = 0.5 \cdot f_u \cdot A_{nt} / \gamma_{M2} + (1/\gamma_3) \cdot f_y \cdot A_{nv} / \gamma_{M0}$

(\*\*)  $V_{effRd} = f_u \cdot A_{nt} / \gamma_{M2} + (1/\gamma_3) \cdot f_y \cdot A_{nv} / \gamma_{M0}$

(\*\*\*)  $V_{effRd} = 2 \cdot [0.5 \cdot f_u \cdot A_{nt} / \gamma_{M2} + (1/\gamma_3) \cdot f_y \cdot A_{nv} / \gamma_{M0}]$

### 4.2. Splice plate

| Nr | Model | $A_{nv}$ [cm <sup>2</sup> ] | $A_{nt}$ [cm <sup>2</sup> ] | $V_0$ [kN] | $V_{eff,Rd}$ [kN] | $ V_0 /V_{eff,Rd}$ | Status   |
|----|-------|-----------------------------|-----------------------------|------------|-------------------|--------------------|----------|
| 1  |       | 8.00                        | 5.52                        | 3.23 (*1)  | 188.10 (*)        | 0.02               | verified |
| 2  |       | 5.52                        | 8.00                        | 76.34 (*2) | 190.16 (*)        | 0.40               | verified |
| 3  |       | 5.52                        | 8.00                        | 76.34 (*2) | 190.16 (*)        | 0.40               | verified |
| 4  |       | 11.05                       | 5.70                        | 76.34 (*2) | 314.08 (**)       | 0.24               | verified |

(\*1)  $V_0 = V_{zEd1}$

(\*2)  $V_0 = N_{wEd}$

(\*)  $V_{effRd} = 0.5 \cdot f_u \cdot A_{nt} / \gamma_{M2} + (1/\gamma_3) \cdot f_y \cdot A_{nv} / \gamma_{M0}$

(\*\*)  $V_{effRd} = f_u \cdot A_{nt} / \gamma_{M2} + (1/\gamma_3) \cdot f_y \cdot A_{nv} / \gamma_{M0}$

### 4.3. Right external plate

| Nr | Model | $A_{nv}$ [cm <sup>2</sup> ] | $A_{nt}$ [cm <sup>2</sup> ] | $V_0$ [kN] | $V_{eff,Rd}$ [kN] | $ V_0 /V_{eff,Rd}$ | Status   |
|----|-------|-----------------------------|-----------------------------|------------|-------------------|--------------------|----------|
| 1  |       | 7.05                        | 11.75                       | -0.85 (*1) | 264.85 (*)        | 0.00               | verified |
| 2  |       | 11.75                       | 10.05                       | 89.10 (*2) | 304.14 (*)        | 0.29               | verified |
| 3  |       | 23.50                       | 7.70                        | 89.10 (*2) | 540.60 (**)       | 0.16               | verified |

(\*1)  $V_0 = 0.5 \cdot V_{yEd1}$



(\*2)  $V_0 = N_{tueEd}$

(\*)  $V_{effRd} = 0.5 \cdot f_u \cdot A_{nt} / \gamma_{M2} + (1/\gamma_3) \cdot f_y \cdot A_{nv} / \gamma_{M0}$

(\*\*)  $V_{effRd} = f_u \cdot A_{nt} / \gamma_{M2} + (1/\gamma_3) \cdot f_y \cdot A_{nv} / \gamma_{M0}$

### 4.4. Left external plate

| Nr | Model | $A_{nv}$ [cm <sup>2</sup> ] | $A_{nt}$ [cm <sup>2</sup> ] | $V_0$ [kN] | $V_{eff,Rd}$ [kN] | $ V_0 /V_{eff,Rd}$ | Status   |
|----|-------|-----------------------------|-----------------------------|------------|-------------------|--------------------|----------|
| 1  |       | 7.05                        | 11.75                       | -0.85 (*1) | 264.85 (*)        | 0.00               | verified |

|   |   |       |       |            |             |      |                 |
|---|---|-------|-------|------------|-------------|------|-----------------|
| 2 |  | 11.75 | 10.05 | 97.86 (*2) | 304.14 (*)  | 0.32 | <b>verified</b> |
| 3 |  | 23.50 | 7.70  | 97.86 (*2) | 540.60 (**) | 0.18 | <b>verified</b> |

(\*1)  $V_0 = 0.5 \cdot V_{yEd1}$

(\*2)  $V_0 = N_{fleEd}$

(\*)  $V_{effRd} = 0.5 \cdot f_u \cdot A_{nt} / \sqrt{M_2} + (1/\sqrt{3}) \cdot f_y \cdot A_{nv} / \sqrt{M_0}$

(\*\*)  $V_{effRd} = f_u \cdot A_{nt} / \sqrt{M_2} + (1/\sqrt{3}) \cdot f_y \cdot A_{nv} / \sqrt{M_0}$

## 5. Verification of sections weakened by openings - [5.4]

### 5.1. Column

$A_t = 19.79$  [cm<sup>2</sup>] Area of tension zone of the gross section

$A_{t,net} = 16.80$  [cm<sup>2</sup>] Net area of the section in tension

$0.9 \cdot (A_{t,net}/A_t) \leq (f_y \cdot \sqrt{M_2}) / (f_u \cdot \sqrt{M_0})$   $0.76 < 0.82$  **verified**

$W = 713.15$  [cm<sup>3</sup>] Elastic section modulus

$W_{net} = 713.15$  [cm<sup>3</sup>] Elastic section modulus

$M_{c,Rdnet} = 167.59$  [kN\*m] Design resistance of the section for bending  $M_{c,Rdnet} = W_{net} \cdot f_{yp} / \sqrt{M_0}$

$|M_0| \leq M_{c,Rdnet}$   $|-1.70| < 167.59$  **verified** (0.01)

$A_v = 24.75$  [cm<sup>2</sup>] Effective section area for shear  $A_v = h_p \cdot t_p$

$A_{v,net} = 21.82$  [cm<sup>2</sup>] Net area of a section effective for shear  $A_{v,net} = A_v - n_v \cdot d_0 \cdot t_p$

$A_{v,net} \geq (f_{yp}/f_{up}) \cdot A_v$   $21.82 > 16.16$  **verified**

$V_{pl,Rd} = 335.80$  [kN] Design plastic resistance for shear  $V_{pl,Rd} = (A_v \cdot f_{yp}) / (\sqrt{3} \cdot \sqrt{M_0})$

$|V_0| \leq V_{pl,Rd}$   $|6.47| < 335.80$  **verified** (0.02)

### 5.2. Splice plate

$A_t = 12.25$  [cm<sup>2</sup>] Area of tension zone of the gross section

$A_{t,net} = 10.30$  [cm<sup>2</sup>] Net area of the section in tension

$0.9 \cdot (A_{t,net}/A_t) \leq (f_y \cdot \sqrt{M_2}) / (f_u \cdot \sqrt{M_0})$   $0.76 < 0.82$  **verified**

$W = 50.02$  [cm<sup>3</sup>] Elastic section modulus

$W_{net} = 44.80$  [cm<sup>3</sup>] Elastic section modulus

$M_{c,Rdnet} = 10.53$  [kN\*m] Design resistance of the section for bending  $M_{c,Rdnet} = W_{net} \cdot f_{yp} / \sqrt{M_0}$

$|M_0| \leq M_{c,Rdnet}$   $|0.20| < 10.53$  **verified** (0.02)

$A_v = 12.25$  [cm<sup>2</sup>] Effective section area for shear  $A_v = h_p \cdot t_p$

$A_{v,net} = 10.30$  [cm<sup>2</sup>] Net area of a section effective for shear  $A_{v,net} = A_v - n_v \cdot d_0 \cdot t_p$

$A_{v,net} \geq (f_{yp}/f_{up}) \cdot A_v$   $10.30 > 8.00$  **verified**

$V_{pl,Rd} = 166.20$  [kN] Design plastic resistance for shear  $V_{pl,Rd} = (A_v \cdot f_{yp}) / (\sqrt{3} \cdot \sqrt{M_0})$

$|V_0| \leq V_{pl,Rd}$   $|3.23| < 166.20$  **verified** (0.02)

### 5.3. Right external plate

$A_t = 15.00$  [cm<sup>2</sup>] Area of tension zone of the gross section

$A_{t,net} = 12.40$  [cm<sup>2</sup>] Net area of the section in tension

$0.9 \cdot (A_{t,net}/A_t) \leq (f_y \cdot \sqrt{M_2}) / (f_u \cdot \sqrt{M_0})$   $0.74 < 0.82$  **verified**

$W = 37.50$  [cm<sup>3</sup>] Elastic section modulus

$W_{net} = 30.43$  [cm<sup>3</sup>] Elastic section modulus

$M_{c,Rdnet} = 7.15$  [kN\*m] Design resistance of the section for bending  $M_{c,Rdnet} = W_{net} \cdot f_{yp} / \sqrt{M_0}$

$|M_0| \leq M_{c,Rdnet}$   $|0.67| < 7.15$  **verified** (0.09)

$A_v = 15.00$  [cm<sup>2</sup>] Effective section area for shear  $A_v = h_p \cdot t_p$

$A_{v,net} = 12.40$  [cm<sup>2</sup>] Net area of a section effective for shear  $A_{v,net} = A_v - n_v \cdot d_0 \cdot t_p$

$A_{v,net} \geq (f_{yp}/f_{up}) \cdot A_v$   $12.40 > 9.79$  **verified**

$V_{pl,Rd} = 203.52$  [kN] Design plastic resistance for shear  $V_{pl,Rd} = (A_v \cdot f_{yp}) / (\sqrt{3} \cdot \sqrt{M_0})$

$|V_0| \leq V_{pl,Rd}$   $|-0.85| < 203.52$  **verified** (0.00)

### 5.4. Left external plate



$A_t = 15.00$  [cm<sup>2</sup>] Area of tension zone of the gross section

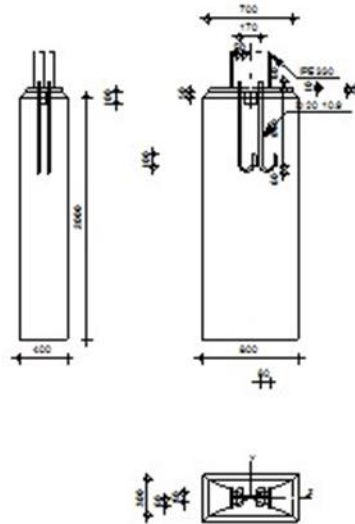
$A_{t,net} = 12.40$  [cm<sup>2</sup>] Net area of the section in tension

|  |  |  |
|--|--|--|
| $0.9 \cdot (A_{t,net}/A_t) \leq (f_y \cdot \square M_2)/(f_u \cdot \square M_0)$ | $0.74 < 0.82$                                | <b>verified</b>  |
| $W = 37.50$ [cm <sup>3</sup> ]   | Elastic section modulus                      |  |
| $W_{net} = 30.43$ [cm <sup>3</sup> ]   | Elastic section modulus                      |  |
| $M_{c,Rdnet} = 7.15$ [kN*m]  | Design resistance of the section for bending | $M_{c,Rdnet} = W_{net} \cdot f_{yp} / \square M_0$               |
| $ M_0  \leq M_{c,Rdnet}$   | $ 0.67  < 7.15$                              | <b>verified</b> (0.09)   |
| $A_v = 15.00$ [cm <sup>2</sup> ]   | Effective section area for shear             | $A_v = h_p \cdot t_p$  |
| $A_{v,net} = 12.40$ [cm <sup>2</sup> ]   | Net area of a section effective for shear    | $A_{v,net} = A_v - n_v \cdot d_0 \cdot t_p$                      |
| $A_{v,net} \geq (f_{yp}/f_{up}) \cdot A_v$                                       | $12.40 > 9.79$                               | <b>verified</b>  |
| $V_{pl,Rd} = 203.52$ [kN]  | Design plastic resistance for shear          | $V_{pl,Rd} = (A_v \cdot f_{yp}) / (\square 3 \cdot \square M_0)$ |
| $ V_0  \leq V_{pl,Rd}$   | $ -0.85  < 203.52$                           | <b>verified</b> (0.00)   |
| <b>Connection conforms to the code</b>   |  | <b>Ratio 0.64</b>  |

# Ligação do Pilar P3 aos Plintos

Página 1 de 7

|   |  |   |
|---|--|---|
|  | Autodesk Robot Structural Analysis Professional 2016   |  |
|   | <b>Fixed column base design</b><br>Eurocode 3: EN 1993-1-8:2005/AC:2009 + CEB Design Guide: Design of fastenings in concrete |   |



## X. General

Connection no.: 1

Connection name: Encastramento\_PilarP3\_Plinto

## XI. Geometry

### 1. Column

|            |                             |   |
|------------|-----------------------------|---|
| Section:   |                             | IPE 330                                   |
| $L_c =$    | 5.00 [m]                    | Column length                             |
| $\alpha =$ | 0.0 [Deg]                   | Inclination angle                         |
| $h_c =$    | 330 [mm]                    | Height of column section                  |
| $b_{fc} =$ | 160 [mm]                    | Width of column section                   |
| $t_{wc} =$ | 8 [mm]                      | Thickness of the web of column section    |
| $t_{fc} =$ | 12 [mm]                     | Thickness of the flange of column section |
| $r_c =$    | 18 [mm]                     | Radius of column section fillet           |
| $A_c =$    | 62.61 [cm <sup>2</sup> ]    | Cross-sectional area of a column          |
| $I_{yc} =$ | 11766.90 [cm <sup>4</sup> ] | Moment of inertia of the column section   |
| Material:  | S235                        |   |
| $f_{yc} =$ | 235.00 [MPa]                | Resistance                                |
| $f_{uc} =$ | 360.00 [MPa]                | Yield strength of a material              |

### 2. Column base

|             |              |                              |
|-------------|--------------|------------------------------|
| $l_{pd} =$  | 700 [mm]     | Length                       |
| $b_{pd} =$  | 300 [mm]     | Width                        |
| $t_{pd} =$  | 20 [mm]      | Thickness                    |
| Material:   | S235         |                              |
| $f_{ypd} =$ | 235.00 [MPa] | Resistance                   |
| $f_{upd} =$ | 360.00 [MPa] | Yield strength of a material |

### 3. Anchorage

The shear plane passes through the UNTHREADED portion of the bolt.

|                               |         |                    |   |
|-------------------------------|---------|--------------------|---|
| Class =                       | 10.9    |                    | Anchor class                            |
| $f_{yb}$ =                    | 900.00  | [MPa]              | Yield strength of the anchor material   |
| $f_{ub}$ =                    | 1000.00 | [MPa]              | Tensile strength of the anchor material |
| $d$ =                         | 20      | [mm]               | Bolt diameter                           |
| $A_s$ =                       | 2.45    | [cm <sup>2</sup> ] | Effective section area of a bolt        |
| $A_v$ =                       | 3.14    | [cm <sup>2</sup> ] | Area of bolt section                    |
| $n_H$ =                       | 2       |                    | Number of bolt columns                  |
| $n_V$ =                       | 2       |                    | Number of bolt rows                     |
| Horizontal spacing $e_{Hi}$ = |         | 170 [mm]           |   |
| Vertical spacing $e_{Vi}$ =   |         | 80 [mm]            |   |

#### Anchor dimensions

|         |     |      |
|---------|-----|------|
| $L_1$ = | 60  | [mm] |
| $L_2$ = | 640 | [mm] |
| $L_3$ = | 120 | [mm] |
| $L_4$ = | 100 | [mm] |

#### Washer

|            |    |      |           |
|------------|----|------|-----------|
| $l_{wd}$ = | 50 | [mm] | Length    |
| $b_{wd}$ = | 60 | [mm] | Width     |
| $t_{wd}$ = | 10 | [mm] | Thickness |

### 4. Wedge

Section: IPE 100

$l_w$  = 100 [mm] Length

Material:

$f_{yw}$  = 0.00 [MPa] Resistance

### 5. Material factors

|                 |      |                       |
|-----------------|------|-----------------------|
| $\gamma_{M0}$ = | 1.00 | Partial safety factor |
| $\gamma_{M2}$ = | 1.25 | Partial safety factor |
| $\gamma_C$ =    | 1.50 | Partial safety factor |

### 6. Spread footing

|       |      |      |                       |
|-------|------|------|-----------------------|
| $L$ = | 800  | [mm] | Spread footing length |
| $B$ = | 400  | [mm] | Spread footing width  |
| $H$ = | 2000 | [mm] | Spread footing height |

#### Concrete

|            |        |   |
|------------|--------|---|
| Class      |        | Usuario   |
| $f_{ck}$ = | 382.50 | [MPa] Characteristic resistance for compression |

#### Grout layer

|              |       |       |  |
|--------------|-------|-------|--|
| $t_g$ =      | 50    | [mm]  | Thickness of leveling layer (grout)                    |
| $f_{ck,g}$ = | 12.00 | [MPa] | Characteristic resistance for compression              |
| $C_{f,d}$ =  | 0.30  |       | Coeff. of friction between the base plate and concrete |

### 7. Welds

|         |   |      |                                  |
|---------|---|------|----------------------------------|
| $a_p$ = | 4 | [mm] | Footing plate of the column base |
| $a_w$ = | 4 | [mm] | Wedge                            |

## XII. Loads

Case: Manual calculations.

|                |        |        |                |
|----------------|--------|--------|----------------|
| $N_{j,Ed}$ =   | 526.48 | [kN]   | Axial force    |
| $V_{j,Ed,y}$ = | 0.13   | [kN]   | Shear force    |
| $V_{j,Ed,z}$ = | 0.88   | [kN]   | Shear force    |
| $M_{j,Ed,z}$ = | -0.31  | [kN*m] | Bending moment |

## XIII. Results

### 1. Tension zone

#### STEEL FAILURE

|  |         |                    |   |               |
|--|---------|--------------------|---|---------------|
| $A_b =$  | 2.45    | [cm <sup>2</sup> ] | Effective anchor area                   | [Table 3.4]   |
| $f_{ub} =$   | 1000.00 | [MPa]              | Tensile strength of the anchor material | [Table 3.4]   |
| $\beta =$  | 0.85    |                    | Reduction factor of anchor resistance   | [3.6.1.(3)]   |
| $F_{t,Rd,s1} = \beta * 0.9 * f_{ub} * A_b / \gamma_{M2}$ |         |                    |   |               |
| $F_{t,Rd,s1} =$  | 149.94  | [kN]               | Anchor resistance to steel failure      | [Table 3.4]   |
| $\gamma_{Ms} =$  | 1.20    |                    | Partial safety factor                   | CEB [3.2.3.2] |
| $f_{yb} =$   | 900.00  | [MPa]              | Yield strength of the anchor material   | CEB [9.2.2]   |
| $F_{t,Rd,s2} = f_{yb} * A_b / \gamma_{Ms}$               |         |                    |   |               |
| $F_{t,Rd,s2} =$  | 183.75  | [kN]               | Anchor resistance to steel failure      | CEB [9.2.2]   |
| $F_{t,Rd,s} = \min(F_{t,Rd,s1}, F_{t,Rd,s2})$            |         |                    |   |               |
| $F_{t,Rd,s} =$   | 149.94  | [kN]               | Anchor resistance to steel failure      |               |

#### PULL-OUT FAILURE

|   |        |       |  |                       |
|---|--------|-------|--|-----------------------|
| $f_{ck} =$                                      | 382.50 | [MPa] | Characteristic compressive strength of concrete                                | EN 1992-1-[3.1.2]     |
| $f_{ctd} = 0.7 * 0.3 * f_{ck}^{2/3} / \gamma_c$ |        |       |  |                       |
| $f_{ctd} =$                                     | 7.38   | [MPa] | Design tensile resistance  | EN 1992-1-[8.4.2.(2)] |
| $\gamma_1 =$                                    | 1.00   |       | Coeff. related to the quality of the bond conditions and concreting conditions | EN 1992-1-[8.4.2.(2)] |
| $\gamma_2 =$                                    | 1.00   |       | Coeff. related to the bar diameter   | EN 1992-1-[8.4.2.(2)] |
| $f_{bd} = 2.25 * \gamma_1 * \gamma_2 * f_{ctd}$ |        |       |  |                       |
| $f_{bd} =$                                      | 16.60  | [MPa] | Design value of the ultimate bond stress                                       | EN 1992-1-[8.4.2.(2)] |
| $h_{ef} =$                                      | 640    | [mm]  | Effective anchorage depth  | EN 1992-1-[8.4.2.(2)] |
| $F_{t,Rd,p} = \gamma_1 * d * h_{ef} * f_{bd}$   |        |       |  |                       |
| $F_{t,Rd,p} =$                                  | 667.46 | [kN]  | Design uplift capacity   | EN 1992-1-[8.4.2.(2)] |

#### CONCRETE CONE FAILURE

|  |         |                    |   |                       |
|--|---------|--------------------|---|-----------------------|
| $h_{ef} =$   | 210     | [mm]               | Effective anchorage depth   | CEB [9.2.4]           |
| $N_{Rk,c}^0 = 7.5 [N^{0.5}/mm^{0.5}] * f_{ck} * h_{ef}^{1.5}$  |         |                    |   |                       |
| $N_{Rk,c}^0 =$   | 446.38  | [kN]               | Characteristic resistance of an anchor  | CEB [9.2.4]           |
| $s_{cr,N} =$   | 630     | [mm]               | Critical width of the concrete cone   | CEB [9.2.4]           |
| $c_{cr,N} =$   | 315     | [mm]               | Critical edge distance  | CEB [9.2.4]           |
| $A_{c,N0} =$   | 5680.00 | [cm <sup>2</sup> ] | Maximum area of concrete cone   | CEB [9.2.4]           |
| $A_{c,N} =$  | 3200.00 | [cm <sup>2</sup> ] | Actual area of concrete cone  | CEB [9.2.4]           |
| $\gamma_{A,N} = A_{c,N} / A_{c,N0}$  |         |                    |   |                       |
| $\gamma_{A,N} =$   | 0.56    |                    | Factor related to anchor spacing and edge distance  | CEB [9.2.4]           |
| $c =$  | 160     | [mm]               | Minimum edge distance from an anchor  | CEB [9.2.4]           |
| $\gamma_{s,N} = 0.7 + 0.3 * c / c_{cr,N} \leq 1.0$   |         |                    |   |                       |
| $\gamma_{s,N} =$   | 0.8     |                    | Factor taking account the influence of edges of the concrete member on the distribution of stresses in the concrete | CEB [9.2.4]           |
| $\gamma_{ec,N} =$  | 1.0     |                    | Factor related to distribution of tensile forces acting on anchors  | CEB [9.2.4]           |
| $\gamma_{re,N} = 0.5 + h_{ef}[mm] / 200 \leq 1.0$  |         |                    |   |                       |
| $\gamma_{re,N} =$  | 1.00    |                    | Shell spalling factor   | CEB [9.2.4]           |
| $\gamma_{ucr,N} =$   | 1.40    |                    | Factor taking into account whether the anchorage is in cracked or non-cracked concrete                              | CEB [9.2.4]           |
| $\gamma_{Mc} =$  | 2.16    |                    | Partial safety factor   | CEB [3.2.3.1]         |
| $F_{t,Rd,c} = N_{Rk,c}^0 * \gamma_{A,N} * \gamma_{s,N} * \gamma_{ec,N} * \gamma_{re,N} * \gamma_{ucr,N} / \gamma_{Mc}$ |         |                    |   |                       |
| $F_{t,Rd,c} =$   | 138.94  | [kN]               | Design anchor resistance to concrete cone failure   | EN 1992-1-[8.4.2.(2)] |

### SPLITTING FAILURE

|   |          |                    |   |               |
|---|----------|--------------------|---|---------------|
| $h_{ef} =$  | 640      | [mm]               | Effective anchorage depth   | CEB [9.2.5]   |
| $N_{Rk,c}^0 = 7.5[N^{0.5}/mm^{0.5}] * f_{ck} * h_{ef}^{1.5}$  |          |                    |   |               |
| $N_{Rk,c}^0 =$  | 2374.91  | [kN]               | Design uplift capacity  | CEB [9.2.5]   |
| $s_{cr,N} =$  | 1280     | [mm]               | Critical width of the concrete cone   | CEB [9.2.5]   |
| $c_{cr,N} =$  | 640      | [mm]               | Critical edge distance  | CEB [9.2.5]   |
| $A_{c,N0} =$  | 19720.00 | [cm <sup>2</sup> ] | Maximum area of concrete cone   | CEB [9.2.5]   |
| $A_{c,N} =$   | 3200.00  | [cm <sup>2</sup> ] | Actual area of concrete cone  | CEB [9.2.5]   |
| $\square_{A,N} = A_{c,N}/A_{c,N0}$  |          |                    |   |               |
| $\square_{A,N} =$   | 0.16     |                    | Factor related to anchor spacing and edge distance  | CEB [9.2.5]   |
| $c =$   | 160      | [mm]               | Minimum edge distance from an anchor  | CEB [9.2.5]   |
| $\square_{s,N} = 0.7 + 0.3 * c / c_{cr,N} \leq 1.0$   |          |                    |   |               |
| $\square_{s,N} =$   | 0.77     |                    | Factor taking account the influence of edges of the concrete member on the distribution of stresses in the concrete | CEB [9.2.5]   |
| $\square_{ec,N} =$  | 1.00     |                    | Factor related to distribution of tensile forces acting on anchors  | CEB [9.2.5]   |
| $\square_{re,N} = 0.5 + h_{ef}[mm]/200 \leq 1.0$  |          |                    |   |               |
| $\square_{re,N} =$  | 1.00     |                    | Shell spalling factor   | CEB [9.2.5]   |
| $\square_{ucr,N} =$   | 1.40     |                    | Factor taking into account whether the anchorage is in cracked or non-cracked concrete                              | CEB [9.2.5]   |
| $\square_{h,N} = (h/(2 * h_{ef}))^{2/3} \leq 1.2$   |          |                    |   |               |
| $\square_{h,N} =$   | 1.20     |                    | Coeff. related to the foundation height   | CEB [9.2.5]   |
| $\square_{M,sp} =$  | 2.16     |                    | Partial safety factor   | CEB [3.2.3.1] |
| $F_{t,Rd,sp} = N_{Rk,c}^0 * \square_{A,N} * \square_{s,N} * \square_{ec,N} * \square_{re,N} * \square_{ucr,N} * \square_{h,N} / \square_{M,sp}$ |          |                    |   |               |
| $F_{t,Rd,sp} =$   | 232.30   | [kN]               | Design anchor resistance to splitting of concrete   | CEB [9.2.5]   |

### TENSILE RESISTANCE OF AN ANCHOR

$$F_{t,Rd} = \min(F_{t,Rd,s}, F_{t,Rd,p}, F_{t,Rd,c}, F_{t,Rd,sp})$$

$$F_{t,Rd} = 138.94 \text{ [kN]} \quad \text{Tensile resistance of an anchor}$$

### BENDING OF THE BASE PLATE

#### Bending moment $M_{j,Ed,z}$

|  |        |        |   |           |
|--|--------|--------|---|-----------|
| $l_{eff,1} =$  | 177    | [mm]   | Effective length for a single bolt for mode 1 | [6.2.6.5] |
| $l_{eff,2} =$  | 177    | [mm]   | Effective length for a single bolt for mode 2 | [6.2.6.5] |
| $m =$  | 32     | [mm]   | Distance of a bolt from the stiffening edge   | [6.2.6.5] |
| $M_{pl,1,Rd} =$  | 4.16   | [kN*m] | Plastic resistance of a plate for mode 1      | [6.2.4]   |
| $M_{pl,2,Rd} =$  | 4.16   | [kN*m] | Plastic resistance of a plate for mode 2      | [6.2.4]   |
| $F_{T,1,Rd} =$   | 524.15 | [kN]   | Resistance of a plate for mode 1              | [6.2.4]   |
| $F_{T,2,Rd} =$   | 270.85 | [kN]   | Resistance of a plate for mode 2              | [6.2.4]   |
| $F_{T,3,Rd} =$   | 277.87 | [kN]   | Resistance of a plate for mode 3              | [6.2.4]   |
| $F_{t,pl,Rd,z} = \min(F_{T,1,Rd}, F_{T,2,Rd}, F_{T,3,Rd})$ |        |        |   |           |
| $F_{t,pl,Rd,z} =$  | 270.85 | [kN]   | Tension resistance of a plate                 | [6.2.4]   |

### TENSILE RESISTANCE OF A COLUMN WEB

#### Bending moment $M_{j,Ed,z}$

|   |        |                    |   |                        |
|---|--------|--------------------|---|------------------------|
| $t_{wc} =$  | 8      | [mm]               | Effective thickness of the column web       | [6.2.6.3.(8)]          |
| $b_{eff,t,wc} =$  | 177    | [mm]               | Effective width of the web for tension      | [6.2.6.3.(2)]          |
| $A_{vc} =$  | 30.81  | [cm <sup>2</sup> ] | Shear area                                  | EN1993-1-1:[6.2.6.(3)] |
| $\square =$   | 0.90   |                    | Reduction factor for interaction with shear | [6.2.6.3.(4)]          |
| $F_{t,wc,Rd,z} = \square b_{eff,t,wc} t_{wc} f_{yc} / \square M0$ |        |                    |   |                        |
| $F_{t,wc,Rd,z} =$   | 279.87 | [kN]               | Column web resistance                       | [6.2.6.3.(1)]          |

### RESISTANCES OF SPREAD FOOTING IN THE TENSION ZONE

$N_{j,Rd} = 541.70$  [kN] Resistance of a spread footing for axial tension [6.2.8.3]

$F_{T,Rd,z} = \min(F_{t,pl,Rd,z}, F_{t,wc,Rd,z})$

$F_{T,Rd,z} = 270.85$  [kN] Resistance of a column base in the tension zone [6.2.8.3]

## 2. Connection capacity check

$N_{j,Ed} / N_{j,Rd} \leq 1,0$  (6.24)  $0.97 < 1.00$  **verified** (0.97)

$e_z = 1$  [mm] Axial force eccentricity [6.2.8.3]

$z_{c,z} = 46$  [mm] Lever arm  $F_{C,Rd,z}$  [6.2.8.1.(2)]

$z_{t,z} = 40$  [mm] Lever arm  $F_{T,Rd,z}$  [6.2.8.1.(3)]

$M_{j,Rd,z} = 0.31$  [kN\*m] Connection resistance for bending [6.2.8.3]

$M_{j,Ed,z} / M_{j,Rd,z} \leq 1,0$  (6.23)  $0.99 < 1.00$  **verified** (0.99)

## 3. Shear

### BEARING PRESSURE OF AN ANCHOR BOLT ONTO THE BASE PLATE

#### Shear force $V_{j,Ed,y}$

$\square_{d,y} = 0.96$  Coeff. taking account of the bolt position - in the direction of shear [Table 3.4]

$\square_{b,y} = 0.96$  Coeff. for resistance calculation  $F_{1,vb,Rd}$  [Table 3.4]

$k_{1,y} = 2.50$  Coeff. taking account of the bolt position - perpendicularly to the direction of shear [Table 3.4]

$F_{1,vb,Rd,y} = k_{1,y} * \square_{b,y} * f_{up} * d * t_p / \square_{M2}$

$F_{1,vb,Rd,y} = 277.09$  [kN] Resistance of an anchor bolt for bearing pressure onto the base plate [6.2.2.(7)]

#### Shear force $V_{j,Ed,z}$

$\square_{d,z} = 4.02$  Coeff. taking account of the bolt position - in the direction of shear [Table 3.4]

$\square_{b,z} = 1.00$  Coeff. for resistance calculation  $F_{1,vb,Rd}$  [Table 3.4]

$k_{1,z} = 2.50$  Coeff. taking account of the bolt position - perpendicularly to the direction of shear [Table 3.4]

$F_{1,vb,Rd,z} = k_{1,z} * \square_{b,z} * f_{up} * d * t_p / \square_{M2}$

$F_{1,vb,Rd,z} = 288.00$  [kN] Resistance of an anchor bolt for bearing pressure onto the base plate [6.2.2.(7)]

### SHEAR OF AN ANCHOR BOLT

$\square_b = 0.25$  Coeff. for resistance calculation  $F_{2,vb,Rd}$  [6.2.2.(7)]

$A_{vb} = 3.14$  [cm<sup>2</sup>] Area of bolt section [6.2.2.(7)]

$f_{ub} = 1000.00$  [MPa] Tensile strength of the anchor material [6.2.2.(7)]

$\square_{M2} = 1.25$  Partial safety factor [6.2.2.(7)]

$F_{2,vb,Rd} = \square_b * f_{ub} * A_{vb} / \square_{M2}$

$F_{2,vb,Rd} = 62.33$  [kN] Shear resistance of a bolt - without lever arm [6.2.2.(7)]

$\square_M = 2.00$  Factor related to the fastening of an anchor in the foundation CEB [9.3.2.2]

$M_{Rk,s} = 0.29$  [kN\*m] Characteristic bending resistance of an anchor CEB [9.3.2.2]

$l_{sm} = 70$  [mm] Lever arm length CEB [9.3.2.2]

$\square_{Ms} = 1.20$  Partial safety factor CEB [3.2.3.2]

$F_{v,Rd,sm} = \square_M * M_{Rk,s} / (l_{sm} * \square_{Ms})$

$F_{v,Rd,sm} = 6.90$  [kN] Shear resistance of a bolt - with lever arm CEB [9.3.1]

### CONCRETE PRY-OUT FAILURE

$N_{Rk,c} = 300.10$  [kN] Design uplift capacity CEB [9.2.4]

$k_3 = 2.00$  Factor related to the anchor length CEB [9.3.3]

$\square_{Mc} = 2.16$  Partial safety factor CEB [3.2.3.1]

$F_{v,Rd,cp} = k_3 * N_{Rk,c} / \square_{Mc}$

$F_{v,Rd,cp} = 277.87$  [kN] Concrete resistance for pry-out failure CEB [9.3.1]

### CONCRETE EDGE FAILURE

#### Shear force $V_{j,Ed,y}$

|                           |        |      |   |                 |
|---------------------------|--------|------|---|-----------------|
| $V_{Rk,c,y}^0 =$          | 672.36 | [kN] | Characteristic resistance of an anchor  | CEB [9.3.4.(a)] |
| $\square_{A,V,y} =$       | 1.00   |      | Factor related to anchor spacing and edge distance  | CEB [9.3.4]     |
| $\square_{h,V,y} =$       | 1.00   |      | Factor related to the foundation thickness  | CEB [9.3.4.(c)] |
| $\square_{s,V,y} =$       | 1.00   |      | Factor related to the influence of edges parallel to the shear load direction                                   | CEB [9.3.4.(d)] |
| $\square_{ec,V,y} =$      | 1.00   |      | Factor taking account a group effect when different shear loads are acting on the individual anchors in a group | CEB [9.3.4.(e)] |
| $\square_{\square,V,y} =$ | 1.00   |      | Factor related to the angle at which the shear load is applied  | CEB [9.3.4.(f)] |
| $\square_{ucr,V,y} =$     | 1.00   |      | Factor related to the type of edge reinforcement used   | CEB [9.3.4.(g)] |
| $\square_{Mc} =$          | 2.16   |      | Partial safety factor   | CEB [3.2.3.1]   |

$$F_{v,Rd,c,y} = V_{Rk,c,y}^0 * \square_{A,V,y} * \square_{h,V,y} * \square_{s,V,y} * \square_{ec,V,y} * \square_{\square,V,y} * \square_{ucr,V,y} / \square_{Mc}$$

$$F_{v,Rd,c,y} = 311.28 \text{ [kN]} \quad \text{Concrete resistance for edge failure} \quad \text{CEB [9.3.1]}$$

**Shear force  $V_{j,Ed,z}$**

|                           |         |      |   |                 |
|---------------------------|---------|------|---|-----------------|
| $V_{Rk,c,z}^0 =$          | 1857.31 | [kN] | Characteristic resistance of an anchor  | CEB [9.3.4.(a)] |
| $\square_{A,V,z} =$       | 0.34    |      | Factor related to anchor spacing and edge distance  | CEB [9.3.4]     |
| $\square_{h,V,z} =$       | 1.00    |      | Factor related to the foundation thickness  | CEB [9.3.4.(c)] |
| $\square_{s,V,z} =$       | 0.80    |      | Factor related to the influence of edges parallel to the shear load direction                                   | CEB [9.3.4.(d)] |
| $\square_{ec,V,z} =$      | 1.00    |      | Factor taking account a group effect when different shear loads are acting on the individual anchors in a group | CEB [9.3.4.(e)] |
| $\square_{\square,V,z} =$ | 1.00    |      | Factor related to the angle at which the shear load is applied  | CEB [9.3.4.(f)] |
| $\square_{ucr,V,z} =$     | 1.00    |      | Factor related to the type of edge reinforcement used   | CEB [9.3.4.(g)] |
| $\square_{Mc} =$          | 2.16    |      | Partial safety factor   | CEB [3.2.3.1]   |

$$F_{v,Rd,c,z} = V_{Rk,c,z}^0 * \square_{A,V,z} * \square_{h,V,z} * \square_{s,V,z} * \square_{ec,V,z} * \square_{\square,V,z} * \square_{ucr,V,z} / \square_{Mc}$$

$$F_{v,Rd,c,z} = 233.40 \text{ [kN]} \quad \text{Concrete resistance for edge failure} \quad \text{CEB [9.3.1]}$$

**SPLITTING RESISTANCE**

$$C_{f,d} = 0.30 \quad \text{Coeff. of friction between the base plate and concrete} \quad [6.2.2.(6)]$$

$$N_{c,Ed} = 0.00 \text{ [kN]} \quad \text{Compressive force} \quad [6.2.2.(6)]$$

$$F_{f,Rd} = C_{f,d} * N_{c,Ed}$$

$$F_{f,Rd} = 0.00 \text{ [kN]} \quad \text{Slip resistance} \quad [6.2.2.(6)]$$

**BEARING PRESSURE OF THE WEDGE ONTO CONCRETE**

$$F_{v,Rd,wg,y} = 1.4 * I_w * b_{wy} * f_{ck} / \square_c$$

$$F_{v,Rd,wg,y} = 3570.00 \text{ [kN]} \quad \text{Resistance for bearing pressure of the wedge onto concrete}$$

$$F_{v,Rd,wg,z} = 1.4 * I_w * b_{wz} * f_{ck} / \square_c$$

$$F_{v,Rd,wg,z} = 1963.50 \text{ [kN]} \quad \text{Resistance for bearing pressure of the wedge onto concrete}$$

**SHEAR CHECK**

$$V_{j,Rd,y} = n_b * \min(F_{1,vb,Rd,y}, F_{2,vb,Rd}, F_{v,Rd,sm}, F_{v,Rd,cp}, F_{v,Rd,c,y}) + F_{v,Rd,wg,y} + F_{f,Rd}$$

$$V_{j,Rd,y} = 3597.58 \text{ [kN]} \quad \text{Connection resistance for shear} \quad \text{CEB [9.3.1]}$$

$$V_{j,Ed,y} / V_{j,Rd,y} \leq 1,0 \quad 0.00 < 1.00 \quad \text{verified} \quad (0.00)$$

$$V_{j,Rd,z} = n_b * \min(F_{1,vb,Rd,z}, F_{2,vb,Rd}, F_{v,Rd,sm}, F_{v,Rd,cp}, F_{v,Rd,c,z}) + F_{v,Rd,wg,z} + F_{f,Rd}$$

$$V_{j,Rd,z} = 1991.08 \text{ [kN]} \quad \text{Connection resistance for shear} \quad \text{CEB [9.3.1]}$$

$$V_{j,Ed,z} / V_{j,Rd,z} \leq 1,0 \quad 0.00 < 1.00 \quad \text{verified} \quad (0.00)$$

$$V_{j,Ed,y} / V_{j,Rd,y} + V_{j,Ed,z} / V_{j,Rd,z} \leq 1,0 \quad 0.00 < 1.00 \quad \text{verified} \quad (0.00)$$

**4. Welds between the column and the base plate**

$$\square_{\square} = 78.44 \text{ [MPa]} \quad \text{Normal stress in a weld} \quad [4.5.3.(7)]$$

$$\square_{\square} = 78.44 \text{ [MPa]} \quad \text{Perpendicular tangent stress} \quad [4.5.3.(7)]$$

$$\square_{yII} = 0.05 \text{ [MPa]} \quad \text{Tangent stress parallel to } V_{j,Ed,y} \quad [4.5.3.(7)]$$

$$\square_{zII} = 0.36 \text{ [MPa]} \quad \text{Tangent stress parallel to } V_{j,Ed,z} \quad [4.5.3.(7)]$$

$$\square_w = 0.80 \quad \text{Resistance-dependent coefficient} \quad [4.5.3.(7)]$$

$$\square_{\square} / (0.9 * f_u / \square_{M2}) \leq 1.0 \text{ (4.1)} \quad 0.30 < 1.00 \quad \text{verified} \quad (0.30)$$

$$\square(\square_{\square}^2 + 3.0(\square_{yII}^2 + \square_{zII}^2)) / (f_u / (\square_w * \square_{M2})) \leq 1.0 \text{ (4.1)} \quad 0.44 < 1.00 \quad \text{verified} \quad (0.44)$$

$$\square(\square_{\square}^2 + 3.0(\square_{zII}^2 + \square_{yII}^2)) / (f_u / (\square_w * \square_{M2})) \leq 1.0 \text{ (4.1)} \quad 0.42 < 1.00 \quad \text{verified} \quad (0.42)$$

**5. Connection stiffness**

**Bending moment  $M_{j,Ed,z}$**

$$k_{13,z} = E_c * \square(A_{c,z}) / (1.275 * E)$$

$$k_{13,z} = 64 \text{ [mm]} \quad \text{Stiffness coeff. of compressed concrete} \quad [\text{Table 6.11}]$$

|  |         |        |   |               |
|--|---------|--------|---|---------------|
| $l_{eff} =$  | 177     | [mm]   | Effective length for a single bolt for mode 2           | [6.2.6.5]     |
| $m =$  | 32      | [mm]   | Distance of a bolt from the stiffening edge             | [6.2.6.5]     |
| $k_{15,z} = 0.425 \cdot l_{eff} \cdot t_p^3 / (m^3)$ |         |        |   |               |
| $k_{15,z} =$   | 19      | [mm]   | Stiffness coeff. of the base plate subjected to tension | [Table 6.11]  |
| $L_b =$  | 250     | [mm]   | Effective anchorage depth                               | [Table 6.11]  |
| $k_{16,z} = 1.6 \cdot A_b / L_b$                     |         |        |   |               |
| $k_{16,z} =$   | 2       | [mm]   | Stiffness coeff. of an anchor subjected to tension      | [Table 6.11]  |
| $\lambda_{0,z} =$                                    | 1.50    |        | Column slenderness                                      | [5.2.2.5.(2)] |
| $S_{j,ini,z} =$                                      | 337.94  | [kN*m] | Initial rotational stiffness                            | [6.3.1.(4)]   |
| $S_{j,rig,z} =$                                      | 9930.60 | [kN*m] | Stiffness of a rigid connection                         | [5.2.2.5]     |
| $S_{j,ini,z} < S_{j,rig,z}$ SEMI-RIGID               |         |        |   | [5.2.2.5.(2)] |

## 6. Weakest component:

BASE PLATE - BENDING

**Connection conforms to the code**                      Ratio 0.99