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NEBY BRU: ONE FOOTWAY, THREE WAYS OF SUSTAINABILITY

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ABSTRACT: Degree of Freedom, in collaboration with the municipality of Tynset, has developed the detail design of a pedestrian bridge that will join the neighbourhood of Neby with the rest of the city, crossing the river Glåma. This project had a limited budget, so the design stage has been influenced by the materials optimization, the use of local resources and suppliers and the consideration of conventional constructive methodologies. The bridge was opened to pedestrian traffic in May 2020. This text describes the main characteristics of the structure and the methodology considered in the design.

KEYWORDS: Footway, cable, suspension, timber, steel, truss, sustainability, social, commitment

1 INTRODUCTION

Degree of Freedom has collaborated with the Municipality of Tynset (Norway) in the design of a pedestrian bridge crossing the river Glåma.

The original idea of the design was to create a light pedestrian timber bridge integrated in the natural environment and landscape where it is placed.

The new suspension footbridge will reconnect the neighbourhood of Neby with the rest of the city of Tynset, laying on the foundations of an old bridge destroyed during the World War II.

Given the social approach of the project, it has been decided to use local resources and suppliers, seeking their collaboration when providing their services: from the cables, which are provided by a Norwegian company, to the steel plates, which are delivered by a local workshop.

The bridge will also be constructed by local people and using technology available in the area, which has largely conditioned the conception of the construction process.

Since the design process, the economy of the project has been considered by optimizing the materials as much as possible.

Figure 1: *View of the Neby pedestrian bridge*

2 DESCRIPTION OF THE STRUCTURE

The Neby Bru is a suspension bridge, consisting in a continuous timber truss deck with steel diagonals, suspended from catenary cables by means of vertical hangers. There are towers at each riverbank, plus two intermediate towers supported over two existing isles. The bridge is then divided into three spans approximately 30m, 33m and 30m long, respectively.

The deck has a minimum horizontal clearance of 1.5m between handrails, which is extended up to 5m at the central towers to create a balcony. The balcony makes the top and bottom chord truss to be discontinuous at the central towers since top chord is stopped. An extra diagonal hanger connected to the central towers is then required in order not to overload the bottom chord adjacent to the balcony (refer to Figure 4).

The bridge main structural elements are described in the following sections.

2.1 MAIN CABLES

The bridge has two main cables 6x36 IWRC with 36mm nominal diameter, parallel in the longitudinal direction of the bridge, suspended from the towers and anchored to concrete anchorages blocks.

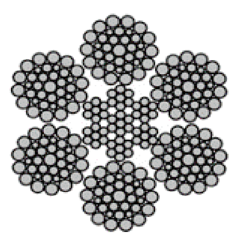

Figure 2: *Main cables section*

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Main cables rest over the four towers though steel saddles bolted at the top of the towers.

2.2 TOWERS

The towers on the river sides are composed by two timber columns and two lintels joining the top of them.

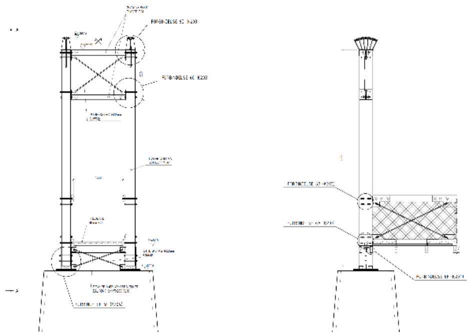

Figure 3: *Extreme towers*

For the towers in the central piles, in order to provide them with more stability they are designed with an A shape.

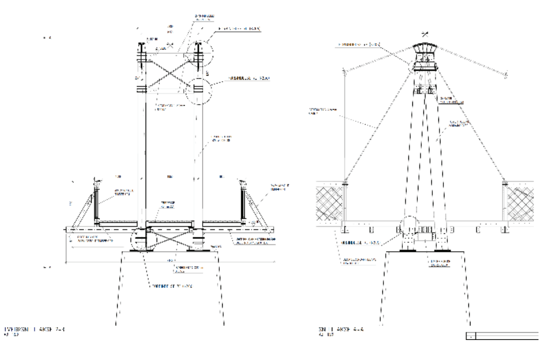

Figure 4: *Intermediate towers*

The height of the towers has been calculated assuming a ratio span/height = 5.25 which has been proved to work fine for this type of bridges. Then considering the central span we have:
H_{towers} = 33/5.25= 6.30 m

2.3 VERTICAL HANGERS

Vertical hangers are 16mm steel bars suspended from the main cables, supporting the bridge deck at a spacing of 33/12 = 2.75m.
Hangers are connected to the main cables though clamps and fork sockets.
The bottom meter portion of the hangers is threaded to be able to adjust the deck levels (adjusting nuts) at the required level in every construction stage.

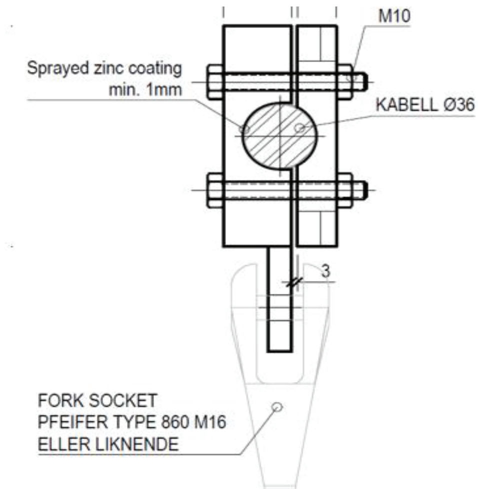

Figure 5: *Hangers clamp and fork socket*

2.4 TIMBER TRUSS DECK

The timber frames form two vertical trusses connected between them at the bottom by another horizontal truss that gives lateral stiffness to the bridge to resist loads in the gravity direction but also lateral forces from the wind. These three trusses form an open U-shaped section, so the top chord is also the handrail.
The following pictures show the preliminary design for a typical module of the bridge deck, which would be repeated every 2.75m.
The bridge deck will be ensembled in double and single 2.75m modules to facilitate the construction sequence.

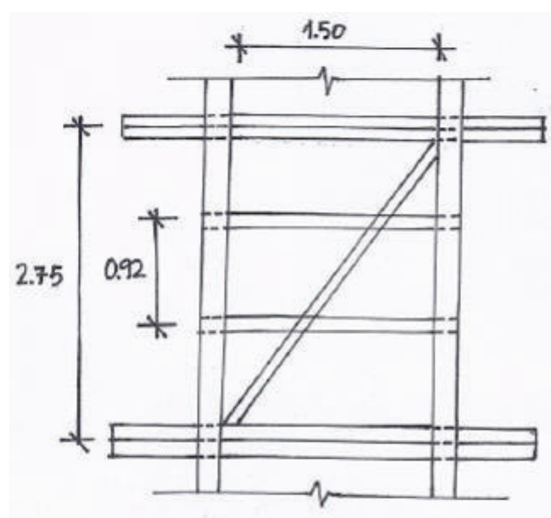

Figure 6: *Truss plan view*

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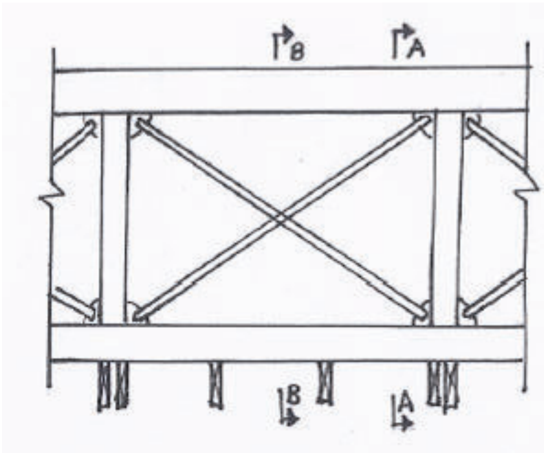

Figure 7: *Truss elevation*

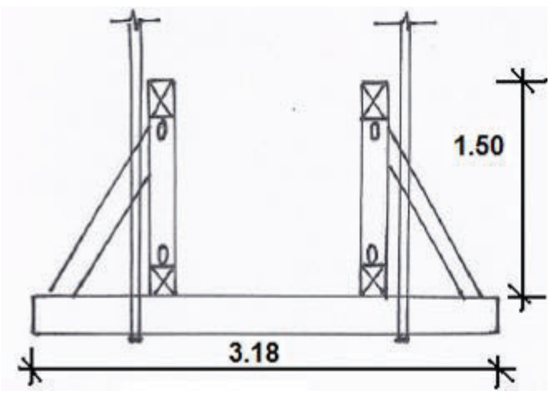

Figure 8: *Truss section A-A*

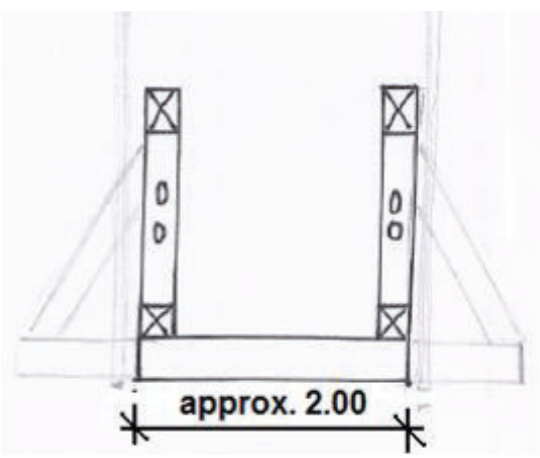

Figure 9: *Truss section B-B*

2.5 CONCRETE ANCHORAGE BLOCKS

Concrete anchorage blocks are located on both river sides, they are capable to resist the forces from the main cables.

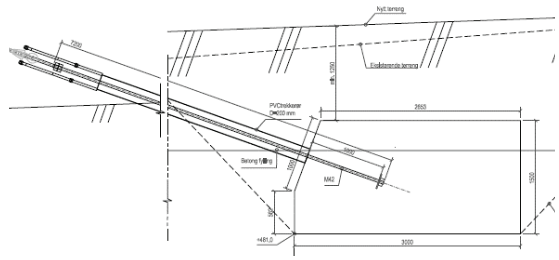

Figure 10: *Anchorage block*

3 BRIDGE ERECTION SEQUENCE

Bridge erection takes a leading role on the conception and design of the bridge as the construction sequence needs to use conventional methods able to be undertaken by the available local resources in Tynset.

It is assumed that the bridge will be erected following this simplified procedure:

1) Erect the supports (towers) over the concrete foundations (piers, abutments).

2) Hang the main cables from the supports and adjust it to have the required shape.

3) Hang the double modules from the hangers.

4) Erect the balconies modules, hanging them from the hangers and connecting them to the towers.

Figure 11: *Bridge erection (central span)*

5) Prestress the hangers (by adjusting nuts) to bring each module to the same vertical position (horizontal). Truss diagonals are not fixed during these phases (not taking loads).

6) Join the single modules by assembling on site the gaps between them.

7) Stretch all diagonals (by adjusting nuts), so they take just zero efforts.

8) Install horizontal bracing elements (steel L profiles).

9) Install deck floor except at modules adjacent to balconies.

10) Rise the deck (creating a parabolic shape) prestressing the hangers (by adjusting nuts)

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11) Prestress end cables at the same time as previous phase (by adjusting anchorage element) to bring the extreme towers to the vertical position
11) Install remaining deck floor
12) Stretch non-tensioned diagonals, so they take just zero efforts
13) Install and adjust balcony ties, so they take just zero efforts.
The bridge construction sequence as detailed above has been included in the FEM model, so the accumulated loads and deformations of the bridge elements are considered.

Figure 12: *Bridge erection (lateral span)*

4 DESIGN CRITERIA

4.1 MATERIALS

4.1.1 TIMBER

The bridge main material is timber. Its strength, light weight, and energy-absorbing properties make it highly desirable for bridge construction. Main advantages of using timber as principal construction material are detailed below.
DURABILITY: Wood is inherently very durable when properly protected against rotting, shrinking, twisting, insect attack and everyday exposure to the elements. Properly treated timber will not crumble like concrete, will not rust like steel and can be used in any environment regardless of climate. Wood is not damaged by continuous freezing and thawing and resists harmful effects of de-icing agents, which cause deterioration in other bridge materials.
LOW MAINTENANCE: wood treated with preservatives requires little maintenance and no painting.
COST COMPETITIVE: From an economic point of view, wood is competitive with other materials on a first-cost basis and shows advantages when life cycle costs are compared.
QUICK CONSTRUCTION: Design constraints of using steel or concrete will slow down the installation process, whereas timber is a readily available resource and installation is quicker. Timber bridge construction can occur in any weather conditions, without detriment to the material.
Both solid timber and glulam are used in Neby pedestrian bridge. Glulam, an engineered timber product, provides greater strength than solid timber for longer span applications.
Glulam is manufactured by laminating individual pieces of sawn lumber together with waterproof structural adhesives.
GL 30c: Used in bridge towers and in bottom chord and transversal beam of balconies area.
$f_{m,g,k}$ = 30 N/mm² (bending strength)
$f_{t,0,g,k}$ = 19.5 N/mm² (tensile strength)
$f_{c,0,g,k}$ = 24.5 N/mm² (compression strength)
$\rho_{g,\ mean}$ = 430kg/m3
C24: Solid timber used in deck structural elements (transverse beams, vertical and diagonal posts, top and bottom chords)
$f_{m,k}$ = 24 N/mm² (bending strength)
$f_{t,0,k}$ = 14.5 N/mm² (tensile strength parallel)
$f_{c,0,k}$ = 21 N/mm² (compression strength parallel)
$\rho_{g,\ mean}$ = 420kg/m3

4.1.2 STEEL

S275J2: Used in connection plates and steel elements in the bridge deck (saddles and clamps)
f_y = 275 N/mm²
f_u = 390 N/mm²
S355J2: Used in steel rods (hangers and diagonals bars)
f_y = 355 N/mm²
f_u = 490 N/mm²

4.1.3 Concrete

B45: Used in the piers
f_{ck} = 45 N/mm²
B30: Used in concrete anchor block
f_{ck} = 30 N/mm²

4.2 LOADS

In addition to Self-weight, Superimposed dead load from the timber boards deck is set to 0.25kN/m^2. Parapet net attached to the handrail is treated separately as 0.05kN/m (each side). Permanent loads also include cable and hangers pre-stressing loads, modelled as temperature.
Uniformly distributed traffic load dependant on the loaded length has been considered, with a maximum UDL of 5kN/m^2 and a minimum of 2.5kN/m^2. With respect to horizontal loads, 10% of traffic vertical loads are considered longitudinally. When required, loads on pedestrian parapet were set to 1.5kN/m, vertical or horizontal.
Snow loads have been considered in combinations with just climatic actions as it cannot be combined with traffic loads.
Wind on deck is 0.6kN/m transversally, 0.3kN/m in the longitudinal direction and ±2.3kN/m in the vertical direction. Wind load in main cables has been set as 0.04KN/m and 0.02KN/m in hangers. Wind in towers is 0.57KN/m transversally and 0.19KN/m longitudinally.
Finally, thermal actions include ΔT expansion of 36ºC and contraction of 55ºC. For each situation, the unfavourable structural element (timber or steel) should have the extreme temperature, $\Delta T_{N,exp}$ or $\Delta T_{N,con}$, and the other element should have a reduction ΔT=15ºC in relation to the extreme temperature.

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4.3 FE MODEL

4.3.1 MODEL DESCRIPTION

A three-dimensional finite element model (FEM) was created to carry out the global analysis of the suspension bridge, consisting of frame elements modelling the main structural members and link elements modelling the connections between them, also considering the frame section offsets.

The global analysis allows the calculation of the whole bridge for determining the joint displacements and the internal forces at the different elements. This model was created and calculated considering the construction phases and two specific dates in the bridge life – at traffic opening (short term situation) and at infinite time (long term situation).

Deck truss chords, diagonals, transversal beams and bracings have been modelled using frame elements, placed at the centroid of the real element. These frame elements are interconnected at nodes by link elements, modelling frame section offsets and the stiffness of the connections between timber elements (Kser).

Piers have been modelled using frame elements and cables have been modelled using frame elements with no flexure stiffness.

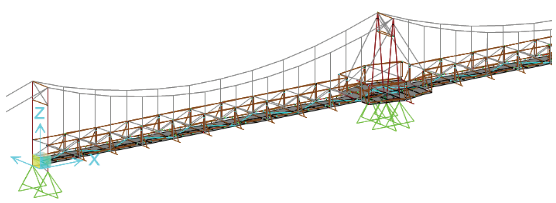

Figure 13: *View of the FE model*

Two different groups of support restraints have been defined in the model:

1) End cables and timber towers rest onto concrete anchorage blocks and concrete piers, respectively, though simply supported joint restraints (rigid).

2) Timber deck rest vertically and transversally onto all the timber towers, while it is longitudinally supported just onto the central timber towers. All these supports are modelled considering the stiffness Kser of the connections (flexible).

4.3.2 ANALYSIS METHODOLOGY

An analysis which captures the cable behaviour is crucial when evaluating a suspension bridge.

P-Delta effect is a very important contributor to the stiffness of suspension bridges, as the lateral stiffness of cables is due almost entirely to tension since they are very flexible when unstressed.

A non-linear analysis which considers P-Delta effect plus large-displacements has been set.

In addition, the erection sequence is also fundamental in this kind of structures, as the operations carried out at each stage affect the shape of the cable, and therefore, the distribution of axial forces.

A stage construction analysis is carried out to evaluate the effects of the permanent loads by considering the erection sequence. The following analyses, which consider the effects of the different combination of variable loads, start from the results of this initial analysis.

Two different stage construction analysis are set, depending on the limit state which is evaluated (SLS/ULS).

In accordance with Premissedokument, as the distribution of member forces and moments is affected by the stiffness distribution in the structure, two different stiffness must be considered when modelling the timber elements. This leads to two design situation (short-term and long-term), where the elasticity modulus (E), the shear modulus (G) and the slip modulus (K_{ser}) are divided by a factor 3 when evaluating the long-term situation.

4.4 RESULTS

4.4.1 SLS VERIFICATIONS

In accordance with Eurocode 5, deflections should be limited under characteristic traffic loads to L/200 = 150mm. The maximum vertical sag occurs at midspan of every span for the different loading conditions considered. Maximum vertical deflection is 124mm, under the L/200 limit.

The main results of the modal analysis carried show that the 1st relevant lateral mode is 2.34 Hz and the 1st relevant vertical mode is 3.48 Hz. It is checked that, in accordance with the frequency range classification given by SETRA, the footbridge has a low risk of resonance for standard loading situations, both for vertical/longitudinal vibrations and for transverse horizontal vibrations.

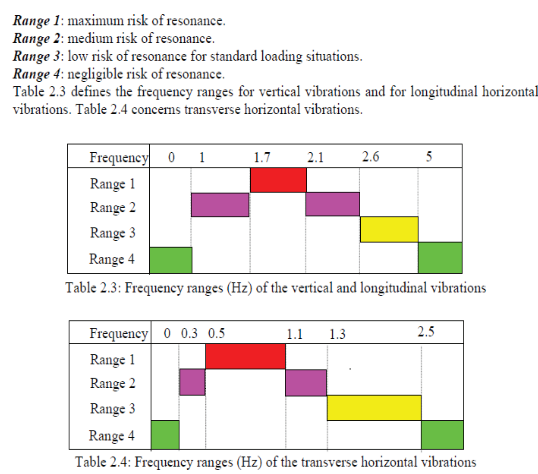
Range 1: maximum risk of resonance.
Range 2: medium risk of resonance.
Range 3: low risk of resonance for standard loading situations.
Range 4: negligible risk of resonance.
Table 2.3 defines the frequency ranges for vertical vibrations and for longitudinal horizontal vibrations. Table 2.4 concerns transverse horizontal vibrations.

Table 2.3: Frequency ranges (Hz) of the vertical and longitudinal vibrations

Table 2.4: Frequency ranges (Hz) of the transverse horizontal vibrations

Figure 14: *Frequency ranges given by SETRA*

4.4.2 ULS VERIFICATIONS

The tension in the cables varies during the life of the structure due to the long-term timber effect and to the temperature variation. The maximum values calculated are 270 kN for the main cables, 20 kN for the hangers and 100KN for the vertical truss bracing.

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The timber sections of the bridge deck and towers and the connections between the different timber frames have been post-processed in order to check its capacity.

As expected, there is compression at top chord and tension at the bottom chord under vertical loads. In order to make the top and bottom chord profiles more effective and avoid increasing their size, the prestress of the hangers was used to create a precamber of the bridge that produces the opposite effect to the chords than the expected under normal loading condition (top chord is thus pre-tensioned and the bottom chord is pre-compressed). By this, they can resist a greater UDL, similarly to the prestress concrete theory.

All timber connections are designed with steel plates and bolts. They have been evaluated separately in order to optimize the number of bolts and the steel plates.

5 CONCLUSIONS

The design of Neby pedestrian bridge has been undertaken considering that it is a social project with a limited budget that is being built by local people. This makes material optimization more important than the duration of the construction period.

Timber quantities have been optimized by using the precamber of the truss to compress the bottom chord and tense the top chord, so they become more effective under normal loading condition.

An optimization of the connections has been considered by evaluating any connection separately, so the utilization is close to 1.

It has been decided to use local resources and suppliers, as well as local people to build the bridge with technology available in the area.

The use of wood as the main building material of the bridge, enhance the local industry and contributes to an environmental benefit.

Thus, it can be said that the Neby Bru project generates a clear social commitment, promoting sustainability from three different points of view: economic, environmental, and social.

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