

APPENDIX Nº5

DESIGN OF BRIDGE ACCESSORIES

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1. OBJECTIVE

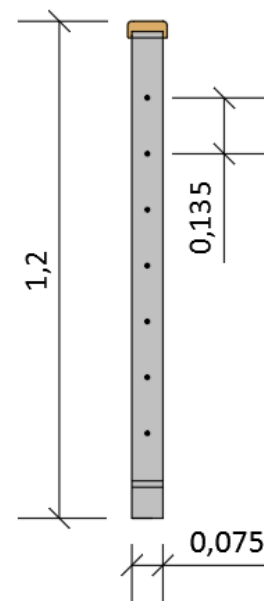
The purpose of this appendix is the definition and calculations regarding the bridge accessories, namely the railing, the deck surfacing and water drainage designed in accordance with the security requirements and standards for personal comfort.

2. RAILING

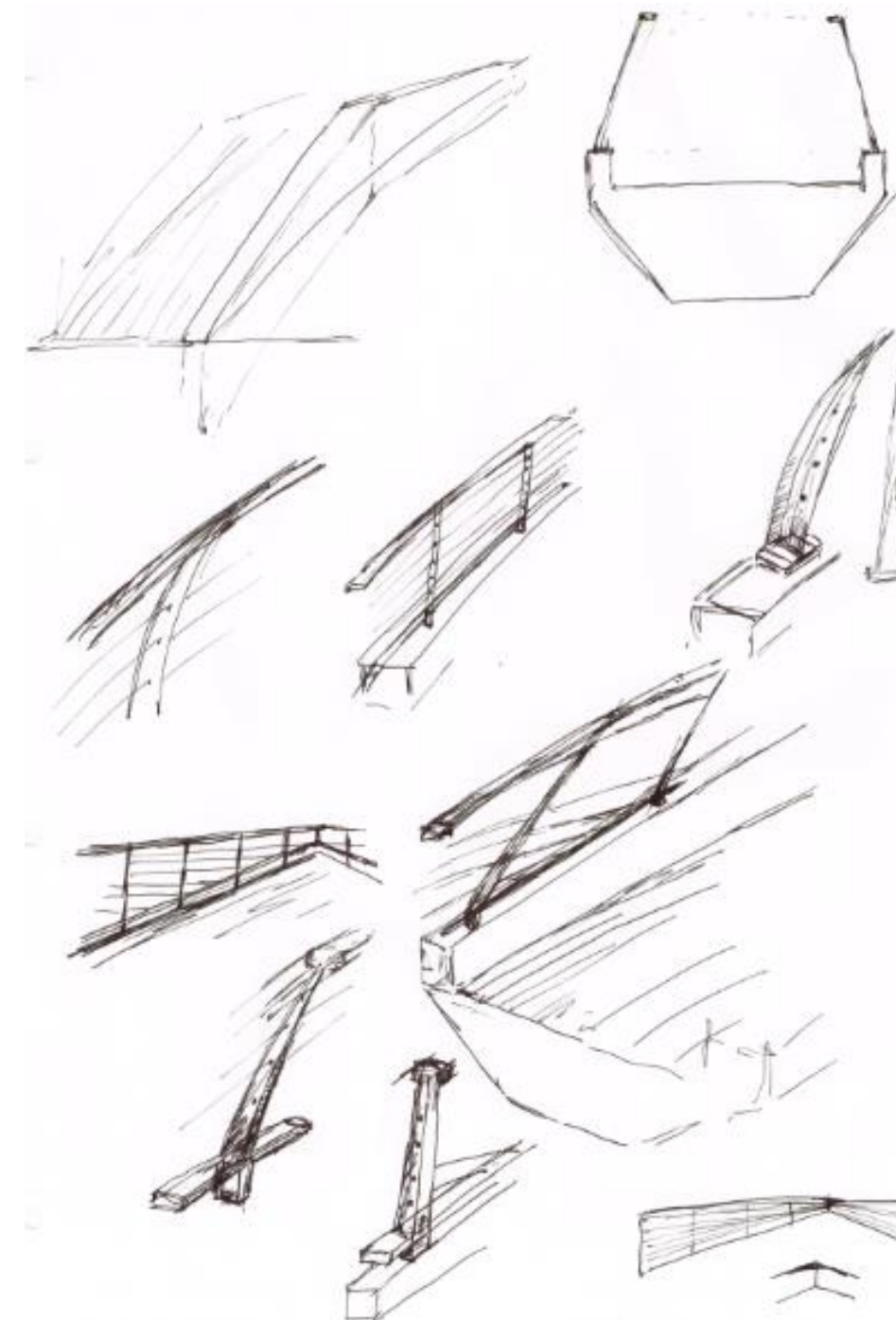
The specifications given by the IAP-11, article 4.1.7, regarding the horizontal pushing force on railings were considered for the following design.

While designing the railing it was necessary to deal with the problem of the unavoidable longitudinal slope of the deck, which would result in a much higher balustrade at the ends if constructed straight. Therefore, it was created with the same slope as the deck, maintaining the same height throughout the whole length of the bridges and generating a bend in the middle. This intentional change in direction is solved by smoothing out the sharp timber elements, creating a gentle transition. In addition, the inclination of the railing emphasizes the triangular shape of the bridge.

The changing shape of the cross-section defines the height of the vertical posts, and though not allowing the use of prefabricated standard elements, they guarantee a unique design. The posts were designed to be straight, keeping the simplicity and the rectilinear, triangular shape uninterrupted.



2.1 Dimensions of the railing at the ends of the bridges



2.2 Study of alternative designs

With lowering height of each post, the distance between them increases, creating the appearance of the bridges “stretching” towards the center and resulting in a less intense look. In addition, the welding connections are stronger because of the gradual reduction of the load bearing width for posts with higher lever arms.

The slope of the railing made it more logical for the steel cables to run radially towards the center, rather than with no inclination. In the case of the bigger bridge, they come to a stop a few meters away from the middle to facilitate their installation, thus creating small triangular gaps on both sides, which soften the view of many lines accumulating in one point. As for the smaller bridge, the highest point is far lower, so the cables run towards the center meeting in the middle.

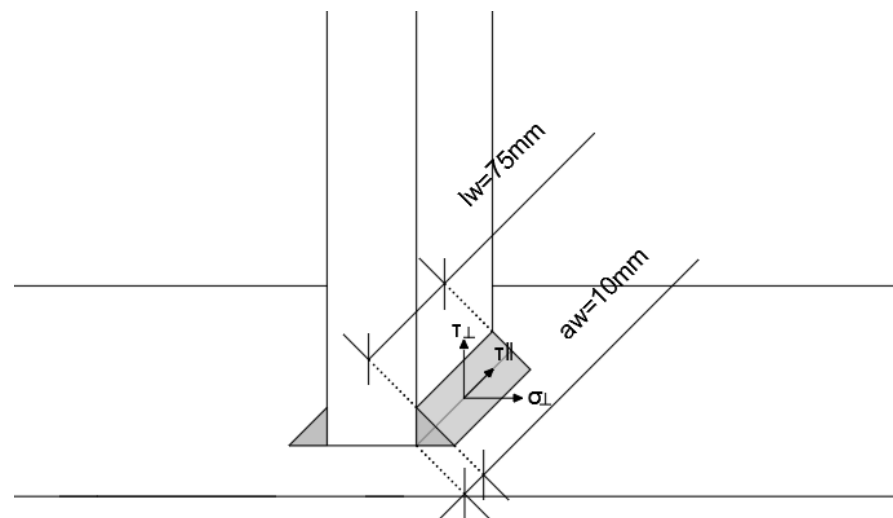
The lower part of the railing, inclined in the same manner as the main structure, intentionally marks the boundary between the latter and the whole support.

A 6cm space was left between the highest point of the lateral steel structure and the handrail for aesthetical reasons, resulting in an overall height of 1,20m, which complies with the minimum safe height. Furthermore, the distance between the cables should not be longer than 15 cm, which was also followed, with the longest gaps amounting to 13,5cm at the ends of the bridges.

For both the railing and the steel cables the chosen material is stainless steel AISI-304, which guarantees durability, resistance to oxidation, as well as a matching appearance with the rest of the bridges' steel elements. The wooden handrail on the contrary gives the structure a finishing touch, while harmonizing with the wooden deck surface and providing a support that maintains a stable temperature regardless of the weather conditions.

The welded connections between the posts and the main structure can resist a horizontal force of 1,5kN/m. The necessary weld seam was calculated as follows:

First assumption of the weld seam dimensions:



2.3 Weld seam dimensions and acting stresses

The horizontal force per meter is multiplied by the load bearing width of a post, which is different for each one, due to the changing separation between them. This force generates a moment corresponding to the lever arm. These actions create the following stresses in the weld seam:

$$\text{Shear stress: } \tau_{\parallel} = \frac{F}{lw * \sum aw}$$

$$\text{Normal stress: } \sigma_{\perp} = \tau_{\perp} = \frac{Myd}{\frac{lw^2}{6} * \sum aw} * \cos(45)$$

$$\text{Resulting stress: } \sigma = \sqrt{\sigma_{\perp}^2 + 3 * (\tau_{\perp}^2 + \tau_{\parallel}^2)} \leq \sigma_{Rd}$$

$$\text{Reference stress (for S275): } \sigma_{Rd} = \frac{fu}{\beta_w * \gamma_{M2}} = \frac{43 \frac{kN}{cm^2}}{0,8 * 1,25} = 43 \frac{kN}{cm^2}$$

The results for each post, counting from the ends to the middle, are summarized in the following tables:

33m Footbridge								
Post	b [m]	h [m]	F [kN]	M [kNcm]	$\tau_{\parallel}$ [kN/cm ²]	$\sigma_{\perp}$ [kN/cm ²]	Resulting stress [kN/cm ²]	Reference stress [kN/cm ²]
1	0,50	1,200	1,13	135,00	0,08	5,09	10,18	43
2	1,10	1,133	2,48	280,42	0,17	10,58	21,15	43
3	1,30	1,053	2,93	308,00	0,20	11,62	23,23	43
4	1,50	0,960	3,38	324,00	0,23	12,22	24,44	43
5	1,70	0,853	3,83	326,27	0,26	12,30	24,61	43
6	1,90	0,733	4,28	313,36	0,29	11,82	23,64	43
7	2,10	0,600	4,73	283,50	0,32	10,69	21,39	43
8	2,30	0,453	5,18	234,43	0,35	8,84	17,69	43
9	2,65	0,293	5,96	174,70	0,40	6,59	13,19	43
10	2,90	0,100	6,53	65,25	0,44	2,46	4,98	43

16m Footbridge								
Post	b [m]	h [m]	F [kN]	M [kNcm]	$\tau_{\parallel}$ [kN/cm ²]	$\sigma_{\perp}$ [kN/cm ²]	Resulting stress [kN/cm ²]	Reference stress [kN/cm ²]
1	0,50	1,200	1,13	135,00	0,08	5,09	10,18	43
2	1,10	1,113	2,48	275,47	0,17	10,39	20,78	43
3	1,30	1,008	2,93	294,84	0,20	11,12	22,24	43
4	1,50	0,885	3,38	298,69	0,23	11,26	22,53	43
5	2,20	0,745	4,95	368,78	0,33	13,91	27,82	43
6	2,80	0,500	6,30	315,00	0,42	11,88	23,77	43

lw [mm]	75
aw [mm]	10

Due to its unconventional, symmetrical appearance the railing maintains the bridges' unique and elegant aspect. By connecting both structures and the island in the middle in the same manner, the effect of continuity is achieved and the flowing movement of the cables accentuates the designed shapes.

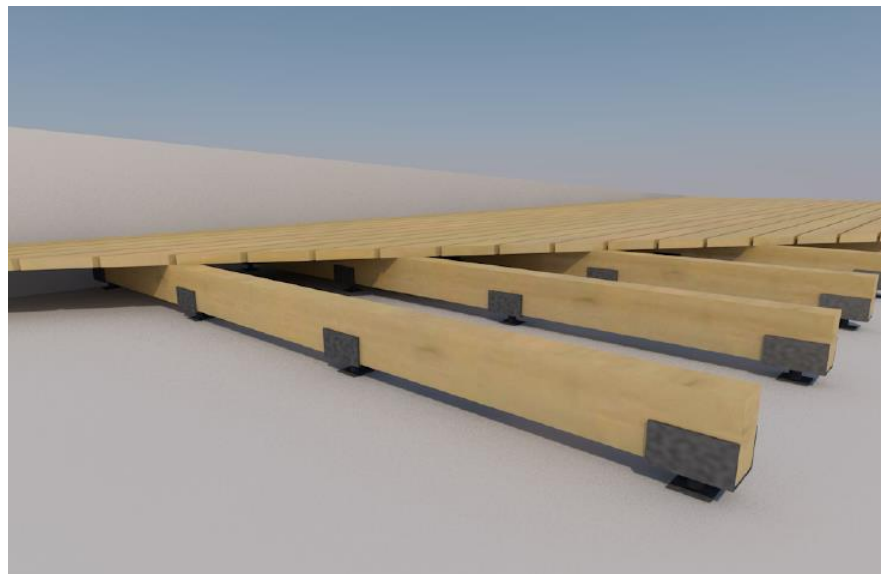
3. LIGHTING

Considering the fact that the footbridges are located in a rural area, and the hiking path, which they connect, is used mainly in daylight, there is no need for illuminating nor marking the way.

4. DECK SURFACING

The construction of the surfacing and the drainage had to be considered simultaneously to achieve a flawless and coherent waterflow. Since timber is a renewable resource, fits very well in the rural environment, weights little and complements the steel structure, it was chosen as material for the deck. As it was determined to carry out the drainage underneath the walking surface, it was clear that a raised construction was needed. As a result, the deck consists of longitudinally laid slats screwed onto transversally laid beams, which are placed on steel bearings welded to the steel construction. Pine timber was chosen as an adequate timber type, considering its outstanding performance in external conditions and strength.

Placing the beams with the dimensions 9x9x199cm, every 0,5m results in 66 beams needed for the bigger bridge, 32 for the smaller one. As for the slats, their dimensions are 9,5x2,1x300cm which results in 209 for the bigger bridge and 105 for the smaller one.

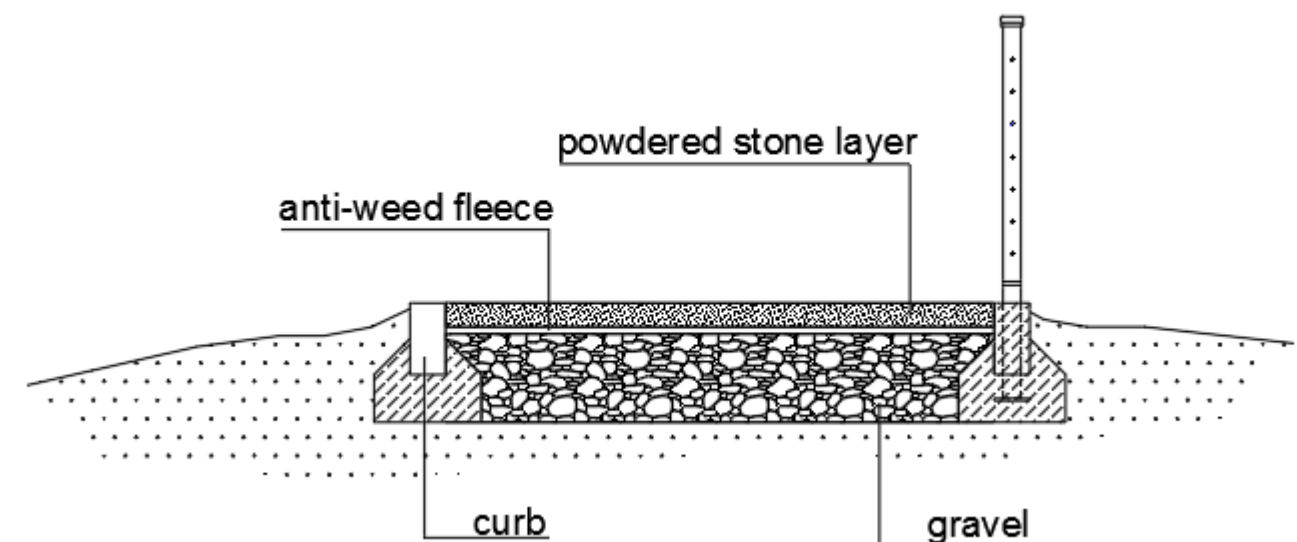


4.1 Construction of the deck surfacing

There are four bearings for each beam – two at the ends and two in the middle. Assuming the payload of $5 \frac{kN}{m^2}$ and considering that the middle bearings have a larger load bearing width of roughly 0,67m, they support a load of $0,67m * 0,5m * 5 \frac{kN}{m^2} = 1,675kN$.

To achieve a coherent link between the footbridges and the paths, there is a 1m long rolled-stamped concrete layer at each end above the abutments.

The path on the island and the access paths to the footbridges consist of a powdered stone layer on gravel with an anti-weed fleece in between. Additionally, there are cobblestones on both sides fixed in a concrete bed to mark the margins of the paths and allow the installation of the railing on the island, as showed in the following sketch:



4.2 Construction of the path on the island

5. DRAINAGE

As mentioned, the drainage was designed with the idea of the water flowing underneath the walking surface, with timber allowing the rain to pass through its openings.

The first step was to calculate the reference flow rate based on the specifications given by the norm “5.2-IC Drenaje superficial” and the document “Máximas lluvias diarias en la España Peninsular”, with the following results:

- Daily precipitation (Pd) in the considered location for a return period of 50 years:

Coefficient of variation: $C_v = 0,39 \rightarrow$ Amplification factor $Y_t = 2,083$

Average annual value of the maximum daily precipitation: $\bar{P} = \frac{40\text{mm}}{\text{day}}$

Daily precipitation: $P_d = Y_t * \bar{P} = 2,083 * \frac{40\text{mm}}{\text{day}} = \frac{83,32\text{mm}}{\text{day}}$

- Concentration time (T) for the length $L = 16,5\text{m}$ and slope $I = 2\%$:

$$T = 0,3 * \left(\frac{L}{I^{(1/4)}} \right)^{0,76} = 0,3 * \left(\frac{0,0165}{0,02^{(1/4)}} \right)^{0,76} = 0,02787 \geq 0,0833 \text{ h}$$

- Average precipitation intensity I_T :

$$\frac{I_1}{I_d} = 10$$

$$I_d = \frac{P_d}{24} = \frac{83,32\text{mm/day}}{24\text{h}} = 3,47\text{mm/h}$$

$$I_T = I_d * \left(\frac{I_1}{I_d} \right)^{\left(\frac{28^{0,1} - T^{0,1}}{28^{0,1} - 1} \right)} = 3,47\text{mm/h} * 10^{\left(\frac{28^{0,1} - 0,0833^{0,1}}{28^{0,1} - 1} \right)} = 124,96\text{mm/h}$$

- Run-off coefficient C:

$$C = \frac{\left(\left(\frac{P_d}{P_0} \right) - 1 \right) * \left(\left(\frac{P_d}{P_0} \right) + 23 \right)}{\left(\left(\frac{P_d}{P_0} \right) + 11 \right)^2} = \frac{\left(\left(\frac{83,32}{1} \right) - 1 \right) * \left(\left(\frac{83,32}{1} \right) + 23 \right)}{\left(\left(\frac{83,32}{1} \right) + 11 \right)^2} = 0,9838$$

- Drained surface area A:

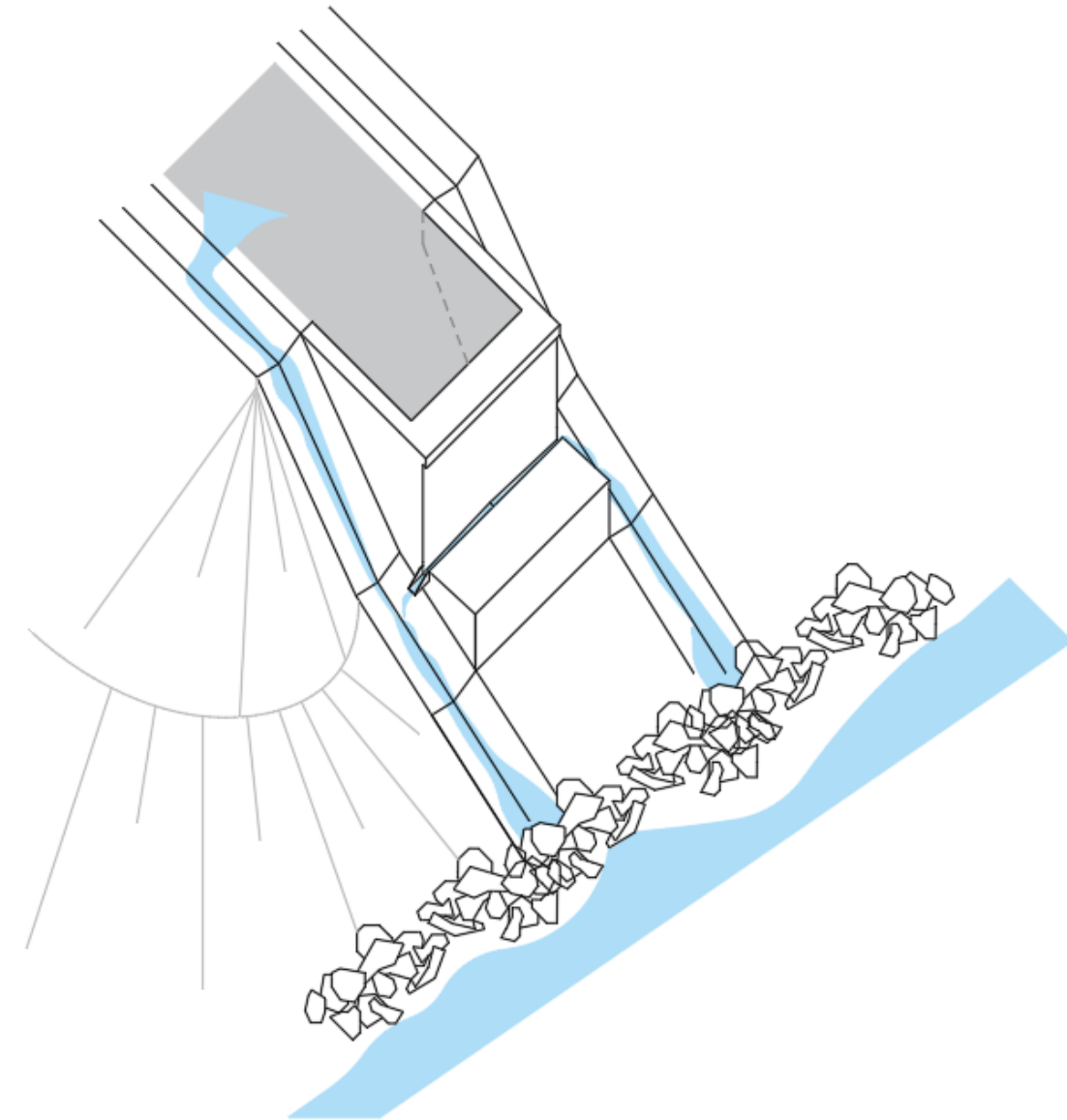
$$A = 16,5\text{m} * 2\text{m} = 33\text{m}^2$$

- Reference flow rate Q:

$$Q = \frac{C * A * I_T}{3000} = \frac{0,9838 * 33\text{m}^2 * 124,96\text{mm/h}}{3000} = 1,3523\text{l/s}$$

To achieve an adequate drainage, it was decided to let the water that accumulates at the ends of the footbridges flow along the side of the footing, landing in a designated, integrated gutter, which transports it away from the foundation and onto cobblestone beds placed on each side and from there towards the river.

For the mentioned flow rate, it was calculated that an area of 5x5cm with a drainage capacity of 1,96l/s was sufficient.



5.1 Sketch of the drainage concept