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## TECHNICAL TOUR Timber Bridges in Switzerland



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# State of conservation of unprotected timber footbridges in Central/Northern Italy

*Alberto Cavalli[1], Marco Esposito[2], Marco Togni[3]*

## Summary

12 timber foot-bridges, different for age, dimensions, structure, exposition, were investigated and monitored by means of the visual inspection, to check their structural health and state of conservation. The bridges were unprotected against weathering; all of them have been directly exposed to weather. The bridges were studied and then subjected to a visual inspection for assessing their state of conservation and for verifying the design details in relation to the correct governing of moisture. The visual inspections revealed some important lack in the durability design, leading to premature wood-decay problems in the 100% of the cases, namely the water "traps" due to contact surfaces between timber members or steel-to-timber and the horizontal timber elements with no physical protection. Without a maintenance program and the repetition of the visual inspection, the shortening of the service life can be avoided only with some accurate remote long-term monitoring operations.

**Key words:** design for durability, visual inspection, service life, remote monitoring.

## 1 Introduction

In Italy, during the last twenty years, many timber bridges have been built, due to the renewed interest on wood, because of environmentally friendly and, into natural landscapes, particularly respectful. Wooden pedestrian bridges in Italy are typically short span bridges; rarely, dimensions can be relevant. Most part of recent bridges are directly exposed to weather because uncovered. For Eurocode 5 [1] it means that structure component have to be assigned to the service class n. 3. In other Countries, where timber structures were used extensively also for vehicle bridges, e.g. in U.S.A. [2], there is also an attention to avoid, if possible, directly exposed parts, designing and building mainly covered bridges [3]. An uncovered bridge would last shortly, especially if the design for durability is poor and it has not been able to avoid moisture problems and subsequent biological degradation [4]. Differently the use of more durable material is necessary: naturally durable timber (e.g. hardwoods in Durability classes n. 1 or 2 [5], or softwoods in class 3 [5]), treated timber (by means of deep impregnation with chemical preservatives), or recent products with a conferred durability by means of industrial processes (e.g. Accoya®, Kebony© etc.), can increase the service life, although for a limited time [6]. Where natural wood is used, surface treatments, differently from pressure treatments, are not enough to change the wood properties and to better the characteristic durability. To preserve the structures from a fast ageing and from failure/rupture, a planned maintenance schedule is needed ([2],[3],[4],[7],[8],[10]) and sometime restoring interventions [9],[10] cannot be avoided, bearing in mind that if a wooden bridge has been neglected too long, it could not be good candidate for rehabilitation [6],[11].

The study concerns 12 pedestrian timber bridges, without any covering wooden boards, (subjected to a periodic change), or with limited metal flashings, but no roof. The aims of the paper are:
- checking of their conservation conditions;
- assessing of the eventual decay level;
- verifying the design details in relation to the correct governing of moisture.

## 2 Material and methods

The 12 footbridges are located in Central and Northern Italy, in three different Region: Emilia-Romagna, Tuscany and Trentino. The bridges are different for building year, dimensions, shape of the structure, exposition, latitude and altitude. The most important characteristics and the images are listed in Table 1. The wooden structural components are made of conifers glulam beams, namely made with Norway spruce and/or silver fir (*Picea abies* Karst. and/or *Abies alba* Mill.). The bridges are on a stream or a river, in two cases only, on road.

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*Table 1 – Timber footbridges location, functions, dimensions and age of building (span: S=small <20m, M=medium 20m<X<60m, L=large >60m, age of building: R=recent <10 years, A=aged >10 years).*

| N | *place: municipality and Region ( )* | *geographic coordinates and altitude* | *crossing over on a* | *span* | *age* | *shape snapshot* |
|---|---|---|---|---|---|---|
| 1 | Bedonia (Emilia-Romagna) | 44°30′06″ N 9°37′49″ E 544 m | river | S | A |  |
| 2 | Barberino di Mugello (Tuscany) | 43°59′23″N 11°14′42″E 270 m | river | M | R |  |
| 3 | Campitello di Fassa (Trentino) | 46°28′37″N 11°44′29″E 1448 m | river | M | A |  |
| 4 | Cerreto Guidi (Tuscany) | 43°45′42″N 10°52′37″E 38 m | river | S | R |  |
| 5 | Empoli (Tuscany) | 43°42′52″N 10°55′20″E 28 m | road | M | R |  |
| 6 | Fontanazzo – Mazzin (Trentino) | 46°28′04″N 11°43′52″E 1372 m | river | M | A |  |
| 7 | Fucecchio (Tuscany) | 43°43′14″N 10°48′45″E 25 m | river | S | R |  |
| 8 | Lamporecchio (Tuscany) | 43°49′00″N 10°54′00″E 56 m | road | S | R |  |
| 9 | Milano Marittima – Cervia (Emilia-Romagna) | 44°16′41″N 12°20′53″E 7 m | river | M | A |  |
| 10 | Rimini (Emilia-Romagna) | 44°03′54″N 12°33′04″E 10 m | river | L | A |  |
| 11 | San Giovanni alla Vena - Vicopisano (Tuscany) | 43°41′02″ N 10°34′14″E 11 m | river | S | R |  |
| 12 | Vicopisano (Tuscany) | 43°41′00″N 10°35′00″E 12 m | river | S | R |  |

To outline the main characteristics of the bridge their spans are divided in 3 clusters: small (S) for spans shorter than 20 meters, medium (M) for spans between 20 and 60 meters, and large (L) where the spans overcome the 60 meters. Only 1 bridge has a "large" span: the pedestrian bridge n. 10, characterised by a 90 m span. Bridges were differently grouped for age: bridges inspected within 10 years from the construction are marked as recent (R) and the other one as aged (A).

The bridges were investigated by means of the visual inspection [12], with the aim to check their structural health and the state of conservation. In some cases the inspections were repeated with the purpose to keep the structures monitored. The on-site inspection is the core strategy for a correct and complete examination [13]; it was carried out by means of simple tools (hammer, gimlets, screwdrivers, etc.) without employing any instrumental tests (e.g. static/dynamic hardness, free/forced vibration frequency, ultrasounds speed, etc.). Purposes of the examinations were the coarse estimation of the general health of the structures; the precise and punctual assessment of each timber member and joint, based on non-destructive devices, is not the goal of this paper.

For each bridge some important aspects concerning the durability were highlighted, linking, where possible and visible, effects to causes, and, concerning the conservation assessment of the wooden structure, associating context information (environment, functions, etc.) with the outcomes of the on-site inspection.

## 3 Results and discussion

The visual inspections revealed some important lack in the durability design, considering that the bridges are uncovered. Summarising results are shown in Table n. 2 and 3.

The 100% of studied bridges is characterised by some water "traps", which could be better defined as moisture "traps", i.e. some wooden surfaces which can be wetted by free water (rainfall) but that cannot dry quickly because not airy. Moisture "traps" found on the bridges were different for dimensions, water collection, moisture holding and so for the potential risk of decay by fungi and future impacts. The moisture "traps" in the joints were the most dangerous, while the contact surfaces between beams could be less critical (easier drying), but also to be avoided. None of the investigated structures was designed considering the possibility to build airy connections. The contact surfaces between steel plates and timber, to be considered as dangerous moisture "traps" in rainfall exposition, influenced by the holes containing the mechanical connection (bolts, pin, etc.), often cannot be avoided or reduced because contact is needed for load carrying. Water wets all the contact surfaces and fills the gaps. The high moisture content is maintained for long time, in absence of ventilation and because the metal plates or connectors are not porous, so they do not allow water to move and to escape. Year after year this condition makes certain the degradation by fungi.

10 bridges (83%) were built with some horizontal structural members, not covered: without metal flashings or other protections. Decks are not considered in the visual inspections, because typically they are subjected to a periodic replacement. 2 bridges (n. 4 and 5) are built with curved glulam beams, so really there are not horizontal surfaces on the main structural elements, although the small slope cannot be considered enough to avoid stagnation, and not so safe against fungi, for the long period.

*Figure 1: Timber-bridge n. 9. Fruiting bodies of brown-rot fungi, close to moisture trap (hole, bolt and washer).*

5 bridges (1, 3, 6, 9, 10 - 42% of the total) were already showing a decay by brown-rot fungi; concerning the diffusion on timber members, decay was localised only in some specific timber members in bridges 1, 6 and 10, but with important local wood degradation and some easily visible fruiting bodies (Table 2, decay column, bridges n. 1, 6 and 10), showing the good development of the alteration organisms, while in bridges 3 and 9 the degradation was very severe and diffuse. All the 7 remaining footbridges were recent (R in Table 1) and so no sign of decayed wood was present. Nevertheless it has to be noted that the low durability of the wood of the beams (Norway spruce and silver fir are in the Durability class n. 4= low durable [5]) to the fungi alterations, expose them to high risk of decay: we can hypothesize that the decay will appear soon.

*Table 2 – Exemplification of the main problems discovered on timber footbridges and relative images. Selected bridges characterised by incoming decay.*

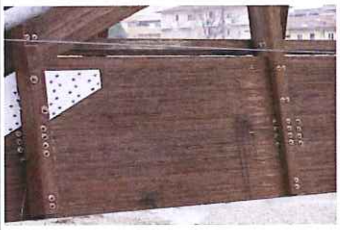
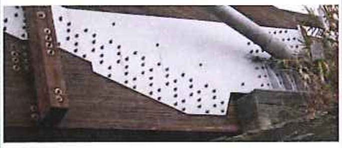
| **N.** | ***uncovered horizontal surfaces in load-bearing glulam components*** | ***moisture traps*** | ***decay: diffuse in* 3 e 9 *localised in* 1, 6 and 10** |
|---|---|---|---|
| 1 |  |  |  |
| 3 |  |  |  |
| 6 |  |  |  |
| 9 |  |  |  |
| 10 |  |  |  |

*Table 3 – Exemplification of the main problems discovered on timber footbridges and relative images. Selected bridges without decay.*

| **N.** | ***uncovered horizontal surfaces in load-bearing glulam components*** | ***moisture traps*** | ***decay: expected* [E] (2, 4, 5, 7, 8, 11, 12); *unexpected (none)*** |
|---|---|---|---|
| 2 |  |  | E |
| 4 | None, excepted deck (extrados covered by metal flashing) |   | E |
| 5 | None, excepted deck (extrados covered by planks) |  [a] | E |
| 7 |  |  | E |
| 8 |  |  | E |
| 11 |  |  | E |
| 12 - Vicopisano (Tuscany) |  |  [b] | E |

*[a] The deck, made of planks, is open to rain: water can come down along the surface of the structural timber member.*

*[b] The bridge is characterised also by a design and mounting error. The main horizontal beams are notched and consequently broken longitudinally for the tension perpendicular to the grain.*

## 4 Conclusion and future work

The study on twelve pedestrian bridges in this work shows the importance of the "design for durability" on timber load-carrying structures without shelter, for their longer duration. According to the results, the primarily required action is the visual inspection, which allows to identify possible problems: incorrect details design, water traps, poor ventilation, incipient decay etc., in an easy and cheap way.

The use of not naturally durable timber species and the lack in design and maintenance caused a premature ageing of the structures, determining the poor state of conservation for all the bridges older than 10 years at the time of inspection: evident decay due to brown-rot activity were found in correspondence of moisture traps and horizontal members not protected.

For the other bridges, presenting similar design, but with age less than 10 years, the decay could be present at early stages (still not detectable) and it will be expected soon.

To face hardly the lack of the "design for durability", a long time monitoring program is needed. Such a program can be intended as the repetition of the visual inspection: some periodic assessments of the bridge for the control of its state of conservation. Differently a remote monitoring" (RM) [14], is to be set for checking some conditions of the timber components: principally moisture content, for preventing decay, and deformations, to assess possible overloads or malfunctioning on structural joints.

The results of RM may guide the maintenance operations and, if need, the restoring interventions. The monitoring can be also used as a real time system to alert, in case of risk, for structures and people. Although RM programs could seem an innovative approach for the footbridges, the first monitoring experiences on timber bridges have been developed during the nineties in North America by the *"Timber Bridge Initiative"* for the evaluation of structural health of those structures [15]. The Forest Product Laboratory developed some remote monitoring systems to be adaptable for different kinds of timber bridges. Many solutions of RM are still adopted for the monitoring of bridges [16],[17],[18],[19],[20], for the assessment of their safety and structural reliability.

The monitoring is the only system for giving the possibility to check continuously the state of conservation and to prevent some irreversible decay of wood/ timber members/joints, by means of specific interventions, promptly guided by the data collected from repeated visual inspections or continuous sensors monitoring.

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