

# Durability and detail design - the result of 15 years of systematic improvements

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## Abstract

Most weather exposed wooden structures do not fail due to structural errors but due to decay of essential parts of the carrying system. To avoid further substitution by concrete and steel, wooden structures must be built for a service life of 25-50 years. Chemical wood preservation being increasingly criticized, it was necessary to rethink environmentally less harmful possibilities. By following old and proven design principles, a number of essential constructive details were developed and tested. Service life of exposed wooden structures can be comparable to other building materials. With a minimum of maintenance, there is no quick failure mechanism to destroy a covered bridge. As wood reacts quickly to adverse influences, shorter maintenance intervals are recommended for exposed wood structures to keep repairs, if needed, easy and cheap - a feature substitute materials cannot offer. The quintessence of fifteen years of supervision of pilot structures is being presented to enhance the awareness of designers as well as craftsmen for the importance of proper detail design for the durability.

Keywords: bridge, durability, design, detail, exposure, preservation, wood, weathering

## Introduction

Exposed wooden structures have a long tradition in all countries where timber has been readily available as construction material. In Europe the oldest exposed wood constructions still in service today date back to the 11th century (1). In Switzerland alone about 250 covered bridges are still in good working condition, and many more would be around, had they not been carried away by floods or burned down for strategic reasons during the innumerable wars of the last 500 years.

Of all the wooden structures that have disappeared with time, only very few failed due to structural errors, but most of them degraded progressively as a consequence of decay by fungi. (Termites are beyond the considerations of this paper.) Nevertheless much engineering effort is still being invested to optimize the structure itself, but only little research work goes into finding better ways to prevent the decay of structural parts.

For the last 15 years a project team of EMPA has concentrated its efforts on extending the service life of weather exposed wood structures. The first pilot structure of this program was built in 1979. For each of the following projects, the experiences gained on the previous ones were systematically included in the planning phase, until approx. 40 structures could be included in the supervision program. Every structure is visited periodically by an experienced specialist, and developments are being recorded during its entire service life.

## Failure mechanism of weather exposed wood

The following (known) sequence leads ultimately to the failure of weather exposed wood members.

Cause	Effect
sunshine →	wood shrinking
internal stress→	longitudinal cracks
rain →	water into cracks
swelling →	cracks get deeper
etc.	etc.
deep cracks →	moisture stays
moisture stays→	fungi develop
fungi action →	internal decay
strong decay →	loss of strength

The speed of decay depends on exposure and a number of climatic factors. Often damage goes unnoticed until major repairs are necessary.

### Measures to extend service life

To extend service life, the above chain of events must be interrupted at some point, either by

- *preventing the development of cracks and delaminations*: Protecting the essential members of the structure from heating up, by providing sunshields and possibly a surface treatment of an appropriate color (not too dark), or

- *stopping water from entering the fissures*: Covering the cracked surfaces where rain could enter, or

- *poisoning the fungi*: Applying pressure treatment all the way down to the bottom of the deepest potential cracks. Considering the difficult penetration in the usual construction wood (softwoods), one cannot count on it for larger cross sections.

### Consequences for design

The major risk factors for the supporting elements are rain and direct sunshine, but not the changes of ambient moisture.

The most effective weather protection is a good roof which covers the entire structure. Such a roof is costly and reduces the design load, and many bridges were built without. In our climate it is then a matter of 5-15 years until decay makes such structures unsafe for their design load and they must be repaired. Such short service lives are normally not acceptable and have brought wood as bridge

material into disrepute for a long time in many parts of the world.

As steel and concrete became cheap and readily available, these became the materials of choice for bridge construction, even for minor crossings where wood would have performed perfectly well. For many decades new wooden bridges were therefore out of discussion, except for temporary crossings or in remote areas with difficult access.

## Rediscovering wood for exposed engineering structures

In the aftermath of the first oil crisis of 1973 public awareness for "ecological thinking" and "green ideas" made it attractive for decision makers (politicians) to resort to "natural materials" for all kinds of applications - and wood took much benefit of this trend.

In Europe, Switzerland has been on the forefront of this development and started to combine wood with the new technologies available, in order to obtain performing engineering structures. Such new technologies were f.ex.:

### Moisture resistant (resorcinol) glues

However, it took only a few years to discover that moisture resistant glueing did not mean weather resistant structures. The wood was still subject to decay and depending how good or poor the detail design was, it took from 2-8 years for structural damages to become apparent.

This spoke once more against wood, unless decay could be prevented effectively.

### Pressure treatment of sawmill stock - the weatherproof glulam

In a next step the phenolic glues were used to assemble pressure treated boards. The main softwood in Switzerland being spruce, the penetration was not sufficient, unless it was improved by incising the timber before treatment - a process quite common in North America.

Earlier attempts to assemble creosote treated boards had been successful (2), but nowadays the only accepted treatments were waterborne CCF- and CCB-salts. (For environmental reasons Switzerland had banned CCA and PCB already much earlier.) A number of manufacturing problems still had to be resolved, such as glue application rates, temperature, pressing time, wood MC etc., but eventually a "weatherproof glulam" was being manufactured, which opened again competitive chances for wood as weather exposed structural material.

Now the durability of the wood was given by the chemical preservation of the entire cross section, and design became occasionally negligent again. In some cases a few years of exposure were enough for first symptoms of decay to appear. Obviously preservative concentrations were not always sufficient to prevent the growth of wood destroying fungi.

The practical conclusion was that chemical preservation in such an application could only *postpone* the decay of sawn timber for quite some time, *but not prevent it for sure*.

### **Environmental considerations**

For proper gluelines the boards have to be planed shortly before glueing. On pressure treated boards, this additional manufacturing step removes the best treated layers. As environmental concerns grew further, the industrial production of these weatherproof glulams was increasingly handicapped by the growing pile of chemically soaked shavings to be disposed off.

Today, in view of the other pressures against chemical treatments, the use of these weatherproof glulams must be restricted to special cases where no other method of preservation will suffice - or their manufacturing will be banned by regulations.

It is still our conviction that *chemical preservation must be maintained* as a back-up or auxiliary measure at critical spots and where no other means of preservation will work, but it *should never be a substitute for poor design*.

### **Detail design - an essential feature of durability**

Wood constructions have the great advantage that practically any element can be repaired or replaced - a feature unthinkable of concrete structures. However, such an exchange may be a demanding task. Therefore avoiding a replacement by protecting major structural parts from adverse weather conditions is by far preferable. This is what proper detail design is all about.

The principle of preservation by design is quite simple - and has been known for long: *Keep water away from structural wood members*.

Traditionally the result was a large roof. On the other hand wood may get temporarily wet without taking harm. Therefore covering only the spots where water gets trapped and cannot dry, i.e joints, cracks, endgrain wood etc., should work as well.

The design of construction details to achieve this is an essential part of the planning work. For an articulate designer with a good material knowledge much of it is simple common sense. (Unfortunately) there is nothing spectacular to it, but the return on the investment is excellent.

### **Conception of structures**

Bridges, where the deck is placed above and is protecting the supporting structure from weathering, have demonstrated a better state of preservation than those where the deck was between or below the carrying structure.

The conception of a bridge depends on many factors and is often given by topography, required waterway clearance, load, appearance etc. The decision is taken already at a very early planning stage, but can have - other factors being equal - a decisive influence on the long-term behaviour of the structure. Ideally the advice of a wood expert should be already included at that early stage.

The less the structure protects itself, the more effort must be invested in protecting the individual endangered parts. Much of this can be done at the drawing board, assuming the engineer is responsive to the needs and limits of the construction material - and keeps in mind that full sun exposure is at least as dangerous as direct rain.

### **Execution of structures**

Other detail measures cannot be drawn up on a blueprint, but are simply part of good craftsmanship. Accordingly, they must be worked out, in the workshop or on site, by craftsmen knowing their working material and how to handle it.

Wood may get wet, as long as it can dry afterwards. The so-called "intelligent details" must

- provide protection from rain and sun,
- channel liquid water away quickly
- allow wet areas to dry out more easily

As trivial as this may sound, it is not always easy to achieve these features in practice and they must usually be custom-fitted to each new project.

### **Future possibilities**

The development task goes. Much work is going into combining wooden carrying structures with concrete bridge decks, or taking advantage of high strength fiber reinforcements, etc.

Regarding chemical treatment, the efforts are geared at using *lesser quantities of chemicals*, by applying the preservative only where needed. This demands new application techniques, which are still in the experimental stage. Another pathway is being

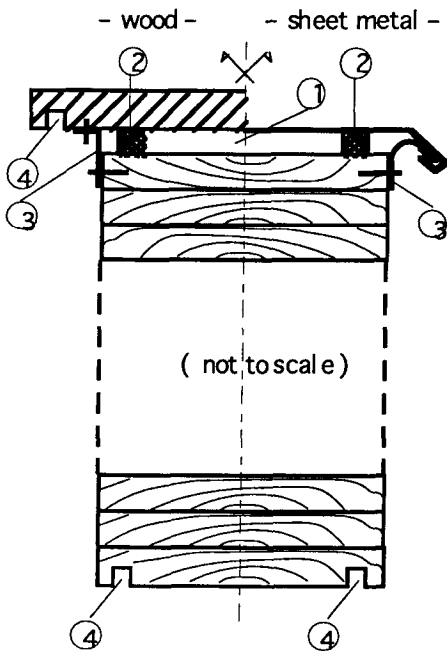
followed using *less toxic chemicals*, like boron, and finding ways to cope with their disadvantages.

*Unfortunately, wood is always a few steps behind concrete and steel in taking advantage of new technical possibilities!*

### Proven effective construction details

It was a learning by trial and error. Fifteen years of periodic supervision and improvements on approximately forty pilot structures have shown which details are most critical and how they could be protected without using chemicals. The quintessence of this work is the following set of recommendations. It applies to our moist, temperate climate, but will be helpful elsewhere as well.

**Exposed horizontal surfaces** - All horizontal (or slightly slanting) surfaces of structural elements should be protected from weathering, or they will invariably develop cracks where water can accumulate. Such surfaces must be protected with sheet metal covers or replaceable wood boards, which are properly attached, see fig. 1.



- ① air space
- ② spacer rods
- ③ weather protected attachment
- ④ drip ping groove

Fig.1: Covering horizontal top faces

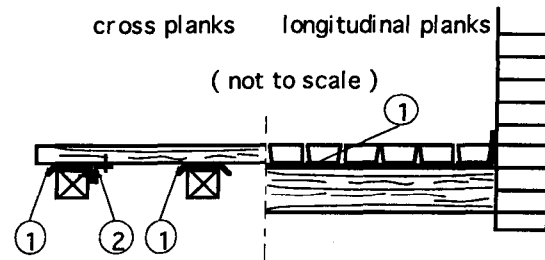
**Covers and their attachment** - In order not to puncture the top faces of wooden elements with screwholes, the fastening of planks and boards for bridge decks, handrails etc., (see fig.1).

- should always be from the protected side
- must permit unimpaired deformations
- provide an air gap

For a simple umbrella function, sheet metal or flexible roofing material can be very effective, but only until it is damaged or punctured. Properly installed wooden covers of sufficient width are just as effective, usually much cheaper, and less subject to vandalism.

Wooden covers will last 10-20 years - and with pressure treatment even longer. Replacement, if needed, is easy and cheap.

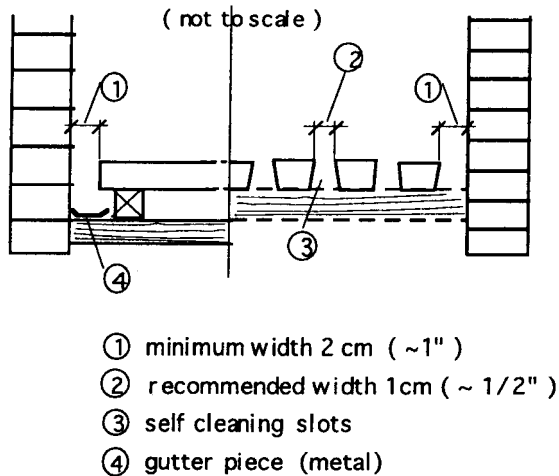
**Horizontal wood interfaces** - A waterproof barrier of tar paper or sheet metal must be installed to prevent capillary penetration of water into the lower members. Be careful not to puncture the separation layer, see fig.2.



- ① sheet metal or tar paper (approx. 3 cm oversize on either side)
- ② weather protected attachment

Fig. 2: Waterproof separation between horizontal contact surfaces

**Vertical Ventilation slots and Drainage holes** - To be effective, they must be at least approx. 2cm (3/4 inch) wide - or they will plug up fast, particularly in forested areas, see fig.3.



**Fig.3: Quick draining and easy cleaning**

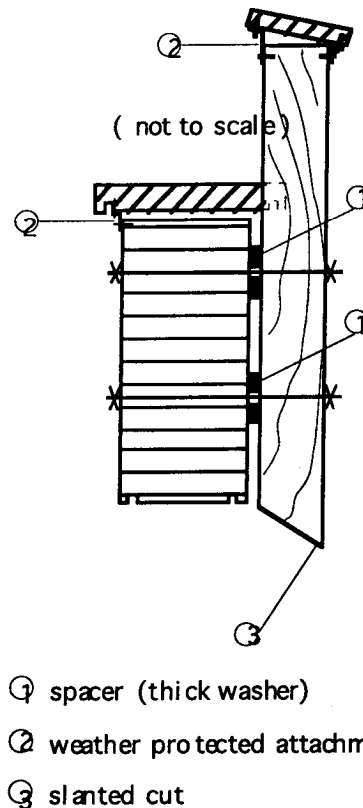
**Dripping grooves** - They are very effective on the bottom faces of rain exposed elements, such as large glulam trusses, but also handrails and cover boards, etc., see fig. 1 and 4.

**Exposed vertical surfaces** - of not replaceable elements, e.g. main faces of glulam trusses, should have at least a water repellent surface treatment or, for longer lasting, a protective cladding, particularly on the sunny side.

**Tightening of screws and bolts-** Quite often the lumber is used in a freshly sawn state and will shrink in service; glulams one the other hand are delivered dry (10-12 % MC) and will normally swell up to a service MC of up to 20 %.

Therefore, the fastening bolts of glulam elements should only be *tightened lightly* at the time of erection, or the swelling will cause crushings of the wood surfaces, which become capillary entry ways for water into the wood member.

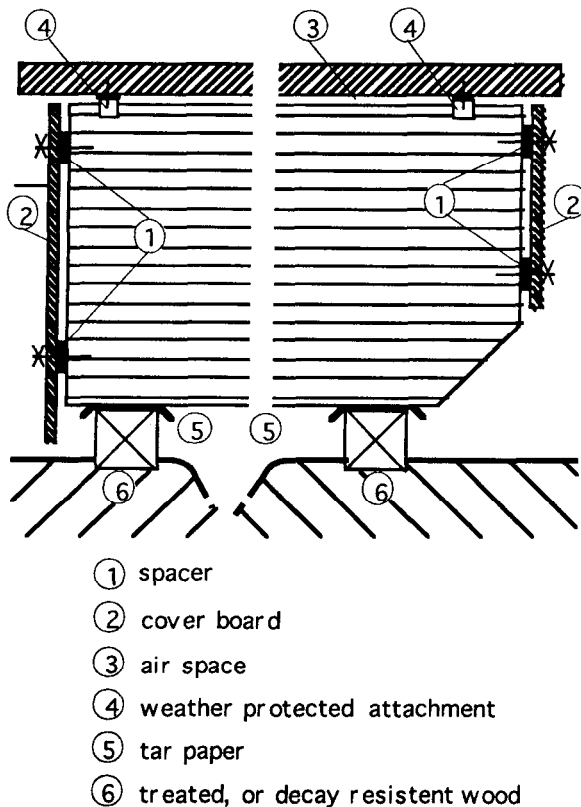
**Vertical wood interfaces** - As a rule, unavoidable contact areas should always be kept as small as possible to limit capillary penetration and encourage a rapid drying. To minimize the wood to wood contact, separate the surfaces with metal (or plastic) washers, see fig.4.



**Fig. 4: Minimizing vertical contact**

**Footings/Abutements** - see fig.5. Provide plenty of space around them. Prevent accumulation of dirt and leaves. Wood pieces in ground contact and in the splashing zone should be decay resistant or pressure treated, or made of galvanized steel. Minimize their size and number.

**Endgrain wood** - of lumber and particularly of glulam must be protected from rain and mainly sunshine to prevent fissuring, see fig.5. Similarly exposed pile tops should be covered as well.



**Fig.5 Endgrain protection and minimizing ground contact**

## Implementation

To include these performing details in a project, some additional efforts are required during planning and execution. The major problem is to develop an awareness for the decisive importance of these features. Their implementation is often part of the finishing work and should be the trade mark of a well built project.

The additional costs involved are *negligible*, and the return translates into years of extension of service life.

## Surface treatments

Adequate surface treatments are an excellent supplemental way to protect exposed wood effectively. One purpose of a coating is to retard moisture exchange between the wood and the ambient surroundings. By dampening the natural moisture movements in the wood, the opening of cracks where liquid water can accumulate, is greatly reduced.

The subject of surface coating of wood cannot be treated exhaustively in this paper. (Further information can be taken from the extensive literature on the subject, f.ex. ref. 3).

### Practical hints

- For a good dimensional stability, water repellent (WRP-) surface coatings of a certain film thickness are needed. In literature at least 50 microns are recommended. The optimum thickness of a coating is also product dependent. The protection given by thicker coatings is better, but they demand more work for refinishing: Thin coatings can mostly be brushed off, whereas thick coatings must normally be scraped off or even sandblasted.

- In practice the following *formula* has demonstrated the longest renovation periods:

- \* One of two applications of a penetrating stain
- \* plus a good top coat of 50-80 microns, using a film forming product of good quality

- The color, mainly for sun exposed members, should not be too dark to avoid undue heating up of the wood, but still have enough pigmentation to prevent photochemical degradation of the wood surface below the coating.

- An intact surface coating works two ways: In one direction it is as a physical shield preventing liquid water from reaching the wood surface, and in the other direction acts as vapor barrier. As soon as the coating film is cracked, liquid water can seep below the coating and is then trapped in the wood by the vapor barrier. The MC can build up with time and eventually lead to decay.

A cracked coating can be worse than no coating at all, which should explain the need for repainting when cracks start to show.

- Pressure treated wood *does not need* an additional surface treatment. The natural graying of the wood is slower than for untreated wood, but leads eventually to the same appearance. However, surface coatings do reduce water uptake and moisture movements of the wood and thus can increase the service life of a weather exposed structure still further.

- Apart from esthetic considerations, the additional expense of a good surface treatment is offset by longer maintenance period. Like pressure treatment, it is an excellent supplemental measure to prolong the durability of exposed structures, but (once more) *should never be a substitute for poor design*.

## Maintenance and repair

No planning or execution is perfect and weather exposed wood reacts faster than steel or concrete to adverse influences. Therefore it is a good policy to check wooden structures already after a few years of service. Potential problems are then still small and can be easily remedied (5).

We cannot emphasize strongly enough the value of periodic checking and maintenance for the durability of exposed wooden structures. The work required will mainly consist of

- unplug and clean drainage paths for water
- repair covers and minor damages
- refinishing surface coatings before they have lost their effectiveness
- add covers where needed

Some of the details proposed are also very adequate for retrofitting existing structures when signs of decay can be noticed. Once water is prevented from getting into the endangered zones, the fungi will die off and the damage will be stopped.

Most of this maintenance work can be done by regular highways crews, occasionally assisted by a local carpenter or contractor.

Unfortunately, this aspect of control, maintenance and early repair, is often being neglected, postponed or not done knowledgeably. This may save some money in the short run, but end up costing a lot more with time. More important, however, is the fact that it is poor publicity for wood as bridge material.

## Conclusions and outlook

The best way to guarantee in the future the use of wood for weather exposed structures is by designing them for the longest possible service life.

Retrofitting existing structures before decay has done extensive structural damage can be an efficient way to extend service life at low cost.

By combining good detail design with the effective supplemental measures described, i. e. water repellent surface coating and chemical treatment where needed - but only there! - it is possible to equip

weather exposed wooden structures for a service life comparable to other construction materials - and still keep the advantage of wood as ecological material without disposal problems.

Following these guidelines wood has a great potential for weather exposed structures. Its main competitors, i.e. steel or concrete take a few years longer to show damages, but then, rehabilitation is usually difficult, expensive or not worth it at all.

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