*Andrew Lawrence*
*Associate*
*Arup Technology & Research*
*London, United Kingdom*

# Building bridges - from Scandinavia to the USA

## Bauarten – von Skandinavien bis Nordamerika

## Sistemi di costruzione – dalla Scandinavia all'America settentrionale

**Document in English**

# Building bridges - from Scandinavia to the USA

## 1 Introduction

The author has recently completed a study tour of timber bridges in Norway and the United States on behalf of the UK Institution of Structural Engineers, with a view to encouraging the use of more timber bridges in the UK. The paper will discuss the typical construction forms and details employed in each country and will compare the approaches to durability and design life. The author is also involved in assessing the potential for the use of acetylated timber in bridge construction, which offers a new approach to the preservation of timber without the use of potentially toxic preservatives, and reference will be made to the acetylated timber bridge which is currently under construction in Holland.

The majority of the bridges surveyed in both Norway and the United States were road bridges, all designed for heavy vehicle loads, and some on relatively busy roads. . The Norwegian bridges have all been built since 1996 as part of the Nordic Timber Bridge Programme, while most of the American bridges visited were built since 1989 under timber bridge programmes sponsored by the Federal Highways Administration and the USDA Forest Service.

### 1.1 Why timber

Many of the timber bridges in both Norway and the USA are replacements for previous bridges; use of timber allows rapid installation and avoids additional load onto existing foundations. Similarly in the US, concrete decks on steel bridges are often replaced in lighter-weight timber, enabling the live load capacity to be increased.

The use of timber bridges in Norway continues to be heavily promoted by the Roads Administration on environmental grounds, but only where timber can be shown to be cost competitive with other materials.

While many of the recent American timber bridges were built under Federal subsidy, several states are continuing to use wooden bridges, because they are relatively low cost (approximately Euro 1600/m³ excluding erection costs), low-tech and can therefore be installed and maintained by their own teams.

# 2 Structural Design

## 2.1 Structural Form

The Norwegian bridges have all been built by Moelven, and generally follow similar principles with stress-laminated decks spanning between steel U frames which restrain out of plane buckling of the main structural timber arches (Figure 1). Clear spans up to 70m have recently been achieved (Figure 2).

*Figure 1: Typical construction of Norwegian bridges showing stress-laminated deck spanning between steel U frames supported off the main arches*

*Figure 2: Tynset Bridge, Norway*

The American bridges are generally shorter simply supported spans, either stress-laminated, or more commonly comprising glulam deck panels spanning between longitudinal glulam beams (Figure 3).

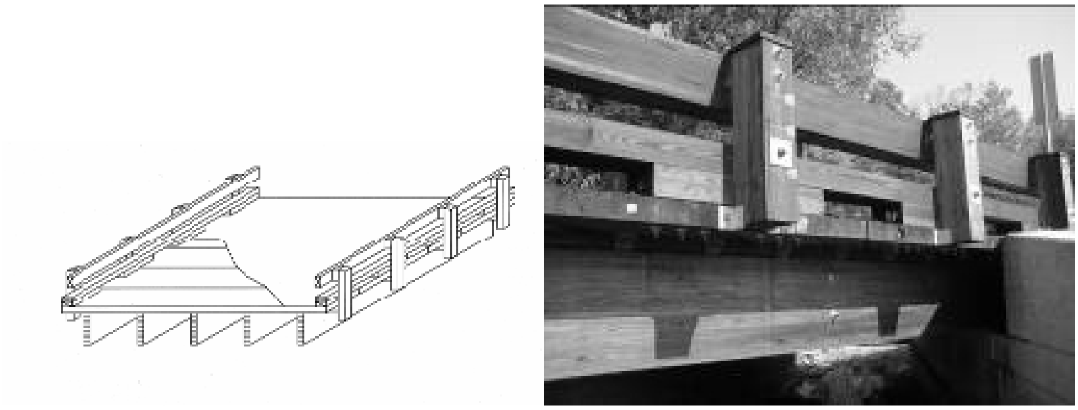

*Figure 3: Common American bridge with glulam stringers and transverse glulam deck*

## 2.2 Deck design

The Norwegian stress-laminated decks generally use span:depths of about 20, with typical spans of 5m between U frames (Figure 1). Prestressing rods are spaced at 600crs and the initial prestress of about 1N/mm² is based on Canadian practice. Point wheel loads are assumed to be spread over a 600mm width of deck based on the Australian Codes. Since the decks are formed from sawn creosote impregnated planks, moisture contents generally start at 20%, and about 30% loss of prestress has generally been found to occur as this drops to the typical 12% in service moisture content. Rods are generally retightened one year after installation, and to date no further tightening has been necessary. Lateral vehicle loads are taken via an engineered steel connection (Figure 4) from the deck diaphragm back into the abutments below. The Norwegian Military Road Bridge (Figure 5) incorporates a concrete deck to avoid damage from tank caterpillar tracks.

*Figure 4: An engineered connection is used to resist lateral loads on the deck*

By comparison the American prestressed decks often use glulams rather than sawn planks. These start relatively dry and therefore tend to swell rather than shrink after installation, avoiding the need for re-stressing. Extensive load testing has been undertaken to investigate load spreading under point loads. Again initial prestress loads of 1N/mm² are used; lab tests suggests that stresses would have to drop to about 0.2 before any slip occurred.

*Figure 5: Norway – Military Road Bridge with concrete deck*

## 2.3 Main members

The Norwegian bridges generally rely on two horizontal glulams block-glued together for the main arch members (Figure 6). Joints are formed using multiple flitch plates with 12mm steel dowels. Such connections are based on those developed by Moelven for the Winter Olympic halls at Hamar and Lillehammer. For the bridges, the plates are inserted in full depth slots, to allow any water which might enter the joint to escape (Figure 7).

*Figure 6: Showing typical detailing of main arch and parapets in Norway*

*Figure 7: Typical connection detailing*

The American bridges generally use single glulam members. Economic methods of incorporating Kevlar reinforcement in the tension zone are also being developed to reduce structural depths.

## 2.4 Crash Barriers

The American crash barriers were originally designed based on static design loads, but many have now been proved by testing (Figure 8). Proven designs are published by the Federal Highway Administration.

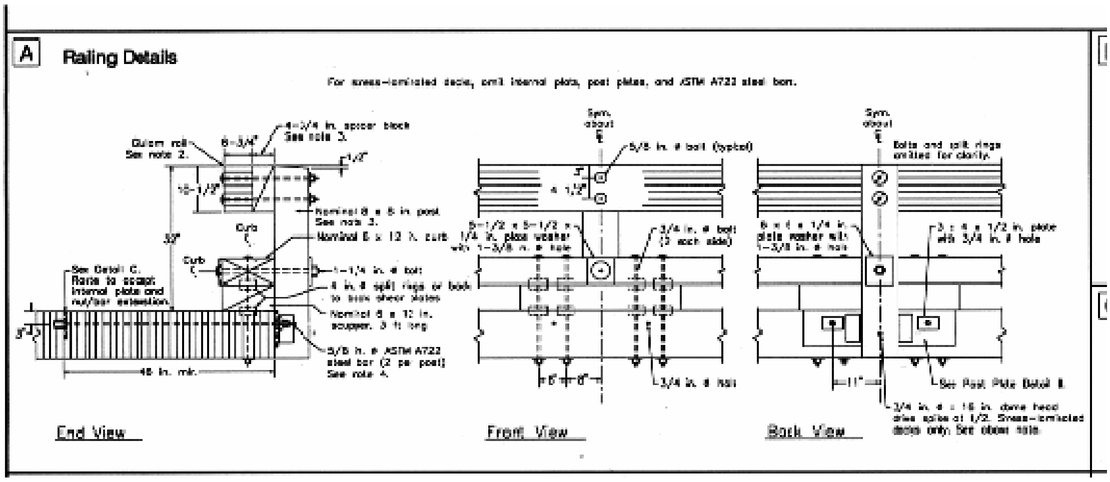


*Figure 8: Example of American crash tested barrier design*

## 2.5 Impact factors

Extensive testing undertaken in the USA suggests that the impact factor is similar with timber as other materials, although this is ‘hidden’ within the American codes which, to simplify design, conservatively take vehicle loads as long term, but ignore impact.

# 3 Durability

## 3.1 Generally

The Norwegian bridges are designed for an 80 year life, which is achieved through a combination of a bitumen membrane on the deck, capping to end grain and horizontal surfaces (Figure 6) and preservation (both before gluing with a water based preservative, combined with creosote impregnation of the finished glulam). In recent bridges capping has also been introduced to diagonal members, due to the development of fissures in the upper surface of the diagonals. Preservation of the individual laminates is intended to provide protection in the event of water penetration into deep fissures. Monitoring has shown that the internal moisture content of the members and deck generally reaches 10-12% after 1-2 years, considerably lower than the predicted equilibrium moisture contents for the climates in question, although the reason for this is not yet fully understood. As a consequence only a partial downgrade on the dry E value is taken in serviceability calculations. Where the members are too large for a creosote treatment tank, sacrificial protection (louvres) are instead used to protect the vertical faces (Figure 9). Capping is generally omitted to members which are easy to inspect and replace such as the plan bracing.

*Figure 9: Where members are too large for the treatment tank, full physical protection is provided*

The American bridges rely primarily on oil based preservative treatment (formerly creosote, now pentachlorophenol) oil based being chosen to avoid the fissuring that will occur during drying after treatment with water based preservatives. While deck membranes and capping are generally recommended by the bridge designers and manufacturers, in practice these are often omitted by the local county clients whose own teams will usually install and maintain the bridges. The structural members are generally protected by the deck, so any problems due to lack of capping and membrane would at least be limited to secondary members such as the deck and crash barriers, although no significant problems have been recorded to date. On low volume roads in the US a 50 year design life is generally required, and this is consistent with the figures quoted in American publications such as the USDA Forest Service Timber Bridge Manual. Stringers are designed based on dry stresses, whereas wet stresses are taken for the deck.

Both Norway and the US are increasingly seeking to reduce the retention levels of preservative, to reduce the subsequent leaching of the excess solvent in hot weather.

## 3.2 Protection to decks

Both the Norwegian and American bridges exhibited cracking to the wearing surface. In the American bridges with glulam panels this generally occurred at the joints between the panels (Figure 10), even where stiffeners had been introduced to promote load sharing, and thus seemed to be primarily related to omission of the membrane leading to wetting of the upper surface of the deck causing hogging; hogged panels will deflect under load leading to cracks at the panel joints.

In the Norwegian stress laminated decks, cracking generally occurred over the steel U frame supports. It is not known whether the bitumen membrane below the asphalt was also damaged.

*Figure 10: Cracking to wearing surface over joints between glulam deck panels*

## 3.3 Acetylated timber

This relies on replacement of the water within the cell walls with acetyl groups (derived from acetic acid). The process is most effective with used on a permeable timber such as Radiata Pine (in which full depth penetration can be achieved on 100thk members). Long term field tests suggest better than Class 1 durability, and very low moisture movements because the timber is swelled back to its green volume during treatment and thus little further swelling is possible. Commercial production started in March, with a single facility in Holland although more are planned. Two 40m span roadbridges are also under construction using the material (Figure 11).

*Figure 11: Model of acetylated timber bridge under construction in Holland*

## 3.4 Inspection & Maintenance

In the USA, limited visual inspections are carried out every 2 years. There is also a move to start including intrusive inspections and long term remote monitoring to check for internal decay. While some counties have high standards of maintenance and inspection (eg: field treating any fissures), in other counties blocked outlets and water ponding on the decks (Figure 12) and suggest that little or no maintenance is being undertaken.

*Figure 12: Omission of membrane and poor maintenance allow ponding on the glulam deck panels*

## 4 Conclusions

While capping and membranes are often omitted in the USA this may well be acceptable given the shorter required design lives compared with Norway. Cracking of asphalt finishes appears to remain an issue for timber vehicle bridges in both countries.

Overall there is no doubt that preserved timber bridges can achieve good design lives, given robust detailing and adequate maintenance. With the increasing restrictions on the use of preservatives, acetylated timber may provide a suitable alternative to the combination of untreated timber combined with physical protection, that is now favoured in Germany.