Friulian Journal of Science **14.** 2010, 93-109

# The "Ponte di Muro" bridge on a disused railway line at Dogna, Udine, and its recent conversion to cycle use

ALESSANDRO COCCOLO*

**Abstract.** This article illustrates the rail-to-trail conversion of a truss bridge known as "Ponte di Muro", located near the village of Dogna in the Julian Alps. The bridge was part of the disused Pontebbana railway line which has now been converted to accommodate the new "Alpe Adria" cycle trail. The paper includes a short history of the railway line, with particular reference to the bridge, the main technical details of the project and a description of the different phases of its execution.

**Key-words.** disused railway line, cycle route, metal bridge.

## 1 The Pontebbana railway line

*1.1. Historical outline. The line.* The historians of the railway network which has been crossing the Alpe-Adria region for the last hundred and fifty years have produced over the decades a large and well-detailed body of research, also serving as a precious and comprehensive technical bibliography.

A contemporary of the famous Austrian lines "Transalpina" (Trieste-Jesenice-České Budějovice) (AA.VV. 1996, Petronio 1997) and "Südbahn" (Trieste-Semmering-Vienna) (Rampati 2002, AA.VV. 2007), the Pontebbana railway line between Udine and Pontebba (Bortotto 1979, Roselli 1979, AA.VV. 2006) deserves an important place in 19th-century railway engineering, also by virtue of its spectacular and audaciously-accomplished crossing, by its 5th section, of the orographically complex "Canal

* CP Ingegneria, via Roma, 274, 33013 Gemona del Friuli (UD), Italy.
E-mail: alessandro.coccolo@pec.gruppocp.it

del Ferro", the narrow and rugged valley of the River Fella between the villages of Chiusaforte and Pontebba.

The construction of the line was approved by Law no. 896 of 30 June 1872, following am agreement signed by the Italian Government and Rome Banca Generale on the previous 6 May. It was designed by engineers Cesare Bermani and Lodovico Richard on the basis of a feasibility study written in 1857 by Alessandro Cavedalis. The construction phase, supervised by engineer Giuseppe Oliva, took place between 1873 and 1879 (Marinelli 1894) and was divided in 5 sections: Udine-Gemona, Gemona-Stazione per la Carnia, Stazione per la Carnia-Resiutta (7900 m), Resiutta-Chiusaforte (8102 m), Chiusaforte-Pontebba (12058 m of which 4311 m curvilinear, with two crossings of the River Fella by daringly-designed metallic bridges)[1]. The construction of the 4th and 5th sections, conducted roughly between 1877 and 1879, completely changed the life of the population of the valley, who contributed to the greater part of the 3000-strong workforce.

The first train pulled in at Pontebba railway station, by the Austria-Italy border, at 3 pm on 12 July 1879, while the line was officially opened on the following 25 July, when regular Udine to Pontebba services started. On the other side of the border, the construction of the "Rudolphsbahn" line, linking Pontebba/Pontafel to Tarvisio and to the Austria-Hungary network (24.9 km), started off only in April 1877. However, due to the more favourable orographic situation of the Fella valley between Pontebba and Camporosso, work was completed by October 1879. The international line Udine-Pontebba-Tarvisio was officially dedicated on 30 October 1879, and the event was largely reported by the press (Roselli 1979).

A crucial turning point in the development of the line was the replacement of steam with electric traction, as part of the electrification plan

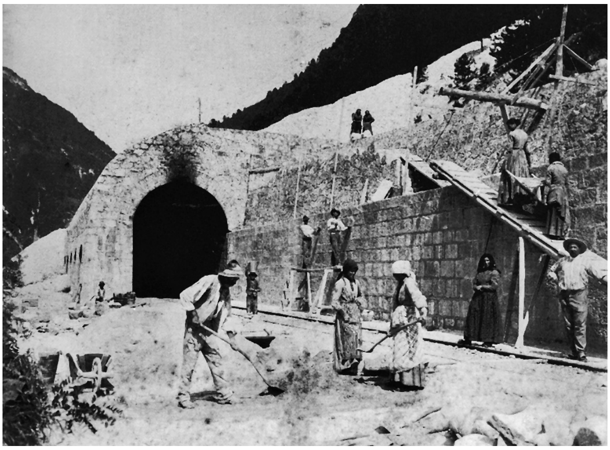

Figure 1. Workers engaged in the construction of a tunnel (archive Sorgato A. & Brusadini S.).

of the Italian railway network launched by the Fascist regime in 1932-1933. The first electrically-powered train ran on the line on 16 September 1935, while the official inauguration ceremony took place on the following 28 October. The estimated cost of electrification was of around 1 million lire per kilometre. During electrification work the line was substantially refurbished: the tracks, the metallic beams of bridges, the blockage and signalling apparatuses were radically modernized (Bortotto 1979).

In its original version (Udine-Pontebba) the Pontebbana rail line had a length of around 68.3 km with a maximum gradient of 1.6%, and was classified as a 2nd-grade, single-track line, with a capacity of 60 axes.

The length of the line became of 93.2 km at the end of World War I when it merged with the Pontafel-Tarvis line, and the gradient rose in parts of the line to 2.2%.

Construction costs were of 440,000 lire/km for the Italian portion, and of 430,000 lire/km for the Austrian portion. However, if we break down the costs between the first three sections of the line (Udine-Resiutta) and the last two (Resiutta-Pontebba), it appears that the 4th and 5th sections had a much higher cost per kilometre, equal to around 850,000 lire/km.

**Main features.** If on one hand the Pontebbana line was, on the whole, characterized by a relatively modest transport capacity, as is to be expected by a mountain railway, on the other its individual structures (bridges, viaducts, tunnels, retaining walls,

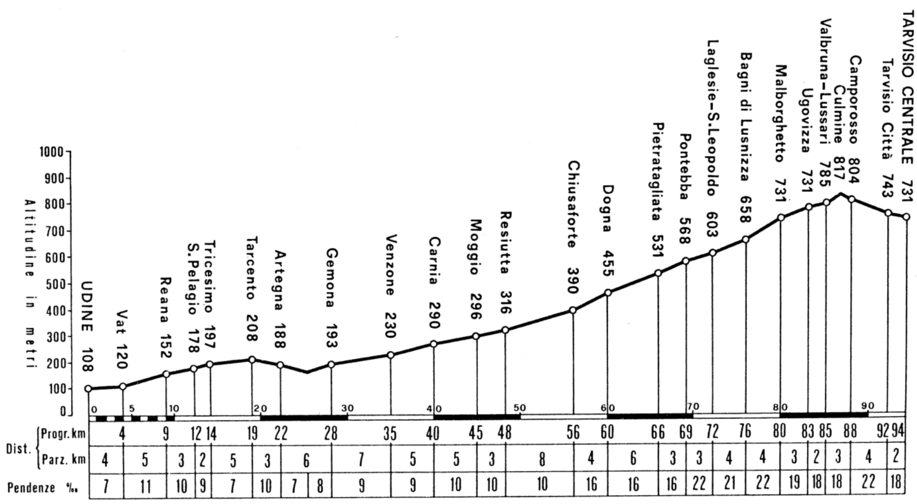


Figure 2. The longitudinal profile of the Udine-Tarvisio line (Roselli 1979). The gradient is indicated in the bottom row, the top row shows the progressive distance measured from Udine station.

Table 1. Types of structures in the original Udine-Pontebba line (Roselli 1979).

| *Type of structure* | *number* | *total length [m]* |
|---|---|---|
| Bored tunnels | 28 | 5,673 |
| Artificial tunnels | 5 | 565 |
| Masonry bridges and viaducts | 16 | 1,551 |
| Steel bridges and viaducts | 11 | 820 |
| Retaining walls over the structure | | 12,592 |
| Retaining walls under the structure | | 3,180 |

bank protection structures, all of which were abundantly represented in the mountainous portion of the line) were, and still are, a remarkable engineering feat.

Table 1 summarizes the many different structures comprised in the original Udine-Pontebba line and which were mostly concentrated in its 3rd, 4th and 5th sections.

Stations and crossing keeper's cottages display very different architectural features depending on whether they originally belonged to the Udine-Pontebba or Pontafel-Tarvisio lines. In the former case, they are built in a typically northern-Italian style with a small eaves overhang and have an altogether more anonymous appearance; in the latter case, they are very Alpine-looking and characterized by a large use of exposed stone (Bortotto 1979). Metallic bridge designs, on the other hand, following the extensive modernization work carried out on the line in the first half of the twentieth century, precisely correspond to the rigorous

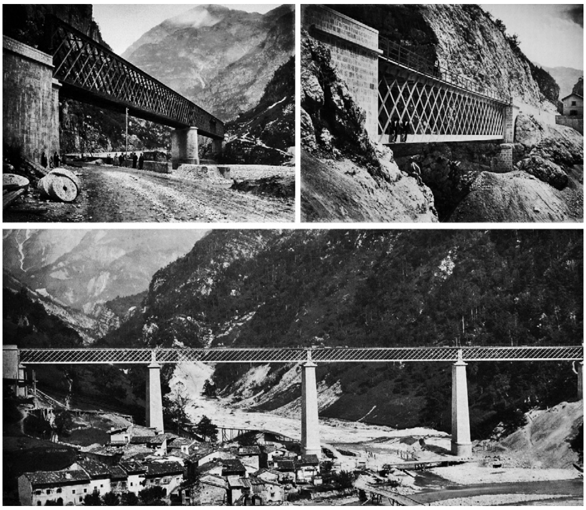

Figure 3. Examples of some of the original structures of the line (AA.VV. 2010). Top right, the bridge on the River Fella at Chiusaforte, top left the bridge over the Rio Potocco. Bottom, the spectacular viaduct over the River Dogna, which tragically collapsed in 1968. As shown by the photographs, the same truss design was used with all structures. In the 1930s when the line was electrified and structurally reinforced, existing beams were replaced and standard Italian Railway designs were adopted depending on span lengths.

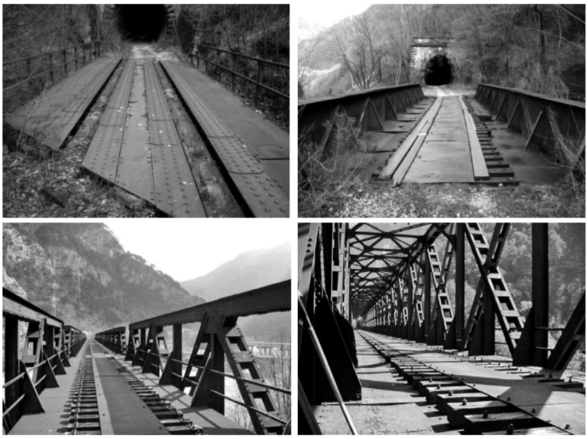

Figure 4. Examples of metallic bridges on the Pontebbana rail line (years 2007-2008). Top left, the small bridge over Rio Confine with twinned girders (on the municipal border between the villages of Dogna and Pontebba). Top right, the bridge on Rio Pontuz with plate girders (Dogna). Bottom left, the pony truss bridge “Ponte Peraria”. Bottom right, the through truss bridge “Ponte della Chiusa” (Chiusaforte).

standardization which had been imposed at the time by the Italian national railway company, *Ferrovie dello Stato*. Accordingly, four bridge designs were used on the line, depending on the length of the span:

– girder bridges with twinned girders, for modest spans;
– plate girder bridges, for longer spans;
– truss bridges with the deck sitting on top or at the bottom of the truss, and unconnected sides (*pony trusses*), for very long span;
– truss bridges with the deck sitting on top (*deck truss*) or at the bottom (*through truss*) of a box truss, also for very long span.

It is not easy to single out an individual structure as the symbol of the Udine-Pontebba line. In my opinion, there are two bridges that could aspire to such title: the iron viaduct on the River Dogna (progressive distance 60 km + 986 m from Udine) and the “Ponte di Muro” (Masonry bridge) situated a few miles more to the north (prog. dist. 63 km + 868 m from Udine).

The Dogna bridge collapsed a few years before its one hundredth anniversary on 16 September 1968, when the river overflowed with disastrous results. It was replaced by a much more anonymous structure in prestressed concrete with five spans instead of the original four (Bortotto 1979). A description of that tragic event lies beyond the scope of this article; in fact, an adequate discussion of the history of the Dogna bridge would call for a separate treatise, also in consideration of the structural damage that it suffered from allied bombing raids in 1944-1945 (D’Aronco 2008) and from an act of sabotage by the retreating German army in May 1945, when one of its two metallic central spans was destroyed (AA.VV. 2006).

The “Ponte di Muro”, on the other hand, has survived unscathed. Towering 40 metres high above the river bed, it has lived through ruinous floods, two world wars and an earthquake, finally having to bear the humiliation of being abandoned on 12 July 1995, when the 5th section of the Pontebbana line was closed to traffic. On account of this, and also on the basis of the information detailed in the following chapters, it could well be awarded the title of "Symbol of the Pontebbana line".

*1.2. The Ponte di Muro bridge. Technical characteristics.* The bridge stands between the northern portal of the first "Ponte di Muro" tunnel (330+16=346 m) and the southern portal of the second "Ponte di Muro" tunnel (365 m). It constitutes the third and final crossing of the River Fella within the "Italian" section of the Pontebbana line, after the bridge at locality "Peraria" between Resiutta and Chiusaforte and the bridge at locality "Sclusa", just outside the village of Chiusaforte.

Technically, "Ponte di Muro" can be classified as a five-span viaduct bridge. The central, metallic span is rectilinear with a net opening of 69.2

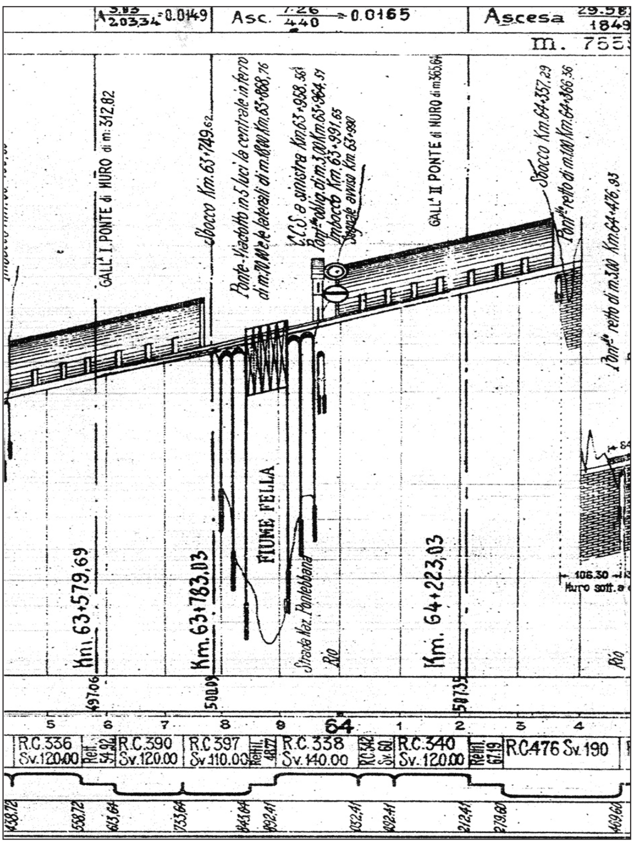


Figure 5. Profile of the rail line by the bridge "Ponte di Muro" (documentation dated 1940, *Ferrovie dello Stato* archive). The drawing shows a 1,65%, gradient for this segment of the line, a tunnel at either side of the bridge and a continuous succession of bends.

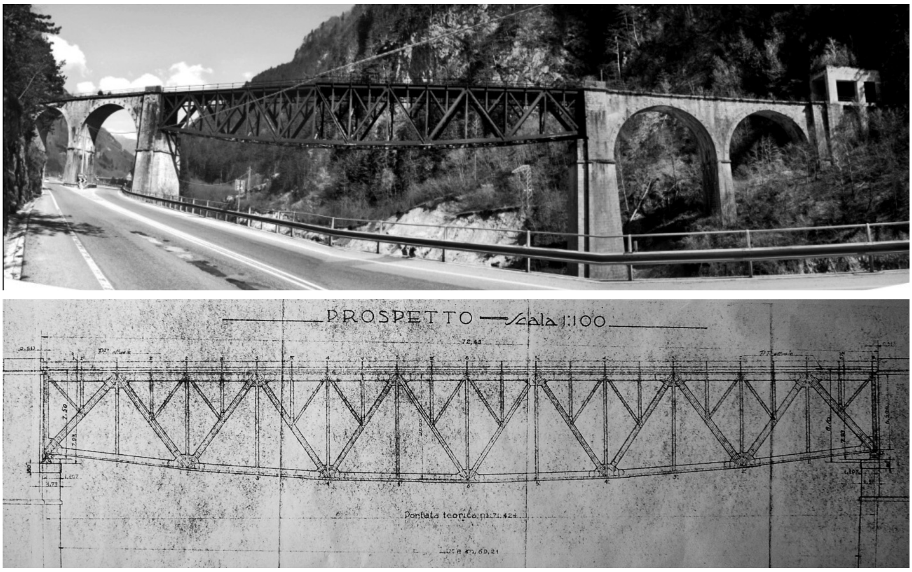


Figure 6. Top, the structure prior to conversion in 2007. Bottom, an original drawing of the elevation of the metal span, constructed in 1933 when the line was electrified and structurally reinforced (*Ferrovie dello Stato* archive). The drawing shows an increase in the total section of the span, with a subsequent improvement in its structural resistance capacity, at the mid-point of the bridge. The change was necessary because of the increased train load and was obtained by designing a truss box with arched lower longitudinal beams.

m and a distance of 71.4 $m^2$.between the abutments. The side spans, two for each side, are planimetrically curvilinear and made of brick, with arched spans of 18 m each[3].

The central span features an under-deck truss. In its final configuration, it was constructed by coupling, using cross-girders lying at a distance of 297 cm, two truss panels with a lower curvilinear profile, at a distance between them of 4.5 m. Under the rails and parallel to them, there are rail bearers lying at a distance of 1.75 m between them and interrupted at the intersection with every cross-girder.

The structure was built in approximately 1878-1879. However when the first train ran on the line on 12 July 1879, the bridge was far from being complete! An agreement between the Italian and Austrian governments had in fact anticipated the date of the opening of the line, but as the central metal structure was not yet available, a complex wooden structure was hastily erected, to be later removed (with an obligation not to disrupt train services) once the final structure was finally in place.

The wooden structure was tested only at the beginning of July 1879, immediately before the official inauguration. This is how the news was reported by Marinelli (1894).

Figure 7. The construction of a temporary wooden structure in June 1879 (AA.VV. 2010).

"... Behind the construction of this bridge lies a story that is truly a credit to Italian engineering. Owing to a special arrangement between the Austrian and Italian governments, it was resolved that the line should be open for traffic before the date previously assigned to the General Contractor and consequently to the sub-contractors. With a little good will, work along the line was completed according to the new more stringent timelines, but the afore-mentioned bridge, whose construction had always been considered one of the most difficult problems ever encountered in railway history, was still unfinished, on account of the ruggedness of the terrain, of the height over the river bed, of the length of the central span, of the very inconvenient access (the bridge is adjoined by a tunnel at either side) and also on account of the gradient which is, at that particular point, not lower than 16 per 1000. In order to meet the new deadline, in the impossibility to have the metal span ready by that date, the Contractor adopted the expedient of building a temporary wooden bridge, which was erected in two months at an expense of 61,000 lire and which proved to be stable enough for the line to be opened for traffic on 25 July 1879. Meanwhile work continued on the permanent metal structure, which was assembled in the maze of wooden beams that supported and formed the temporary bridge, and all the while at a height of 40 metres above the river bed, almost suspended over the heads of the workers, the trains were providing a regular service, albeit at a justifiably low speed. Moreover, work had to be carried out in such a way that service should not be interrupted even while the metallic span was finally put in place. And in actual fact the result was achieved, without damages or suspension of service… The total cost of this beautiful structure (not including the expense of the temporary bridge) rose to 545,755 Italian lire, of which 125,755 for the metallic part."

More than fifty years later in 1934-34, when the line was modernized

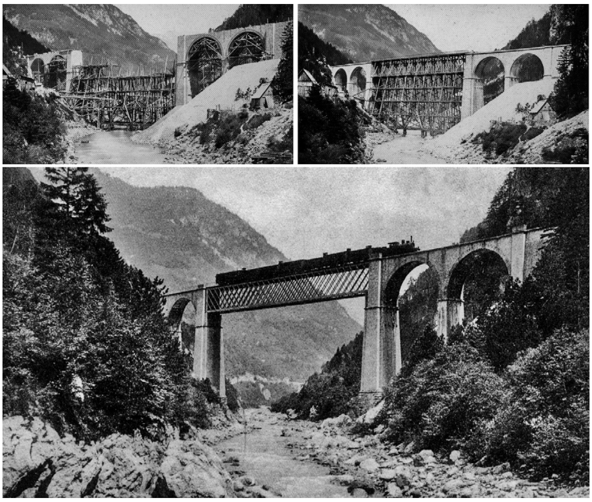

Figure 8. Top, phases of construction of the temporary wooden structure (June 1879) (AA.VV. 2010). Bottom, the metallic structure in operation (AA.VV. 2006).

and reinforced and the original metallic structure was replaced by a new and stronger span which could withstand increased train loads, another temporary wooden structure took centre stage at “Ponte di Muro”. Once again the operation was daringly carried out. A large scaffolding tower was built around the bridge; the metallic span that had to be replaced was positioned on rollers, moved to the side of the track, laid on top of the scaffolding and dismounted. With the same procedure, the new metallic span was put in place.

*The 1920 accident.* On 26 March 1920 a tragic railway accident took place at the “Ponte di Muro” bridge causing the death of twelve people, all of them Egyptian students who were travelling to the universities of Vienna and Berlin. The dynamic of the accident was impressive to say the least. Eight goods carriages standing unmanned at Pontebba rail station, a few miles to the north, suddenly began to move and proceeded along the main track of the line at a speed of almost 90 km per hour in the direction of Udine.

By a tragic coincidence, at the same time the express train to Vienna was travelling northwards at a an estimated speed of 50/60 km per hour, crashing head-on into the runaway train as it was crossing the bridge. At the time it was considered fortunate that the collision had taken place on the last pier of the northern semiviaduct rather than on the central span, which would probably not have withstood the impact. Another important factor in limiting the number of casualties was the reduced speed of the passenger train, which by a providential decision by the Chiusaforte station master, was drawn by a single

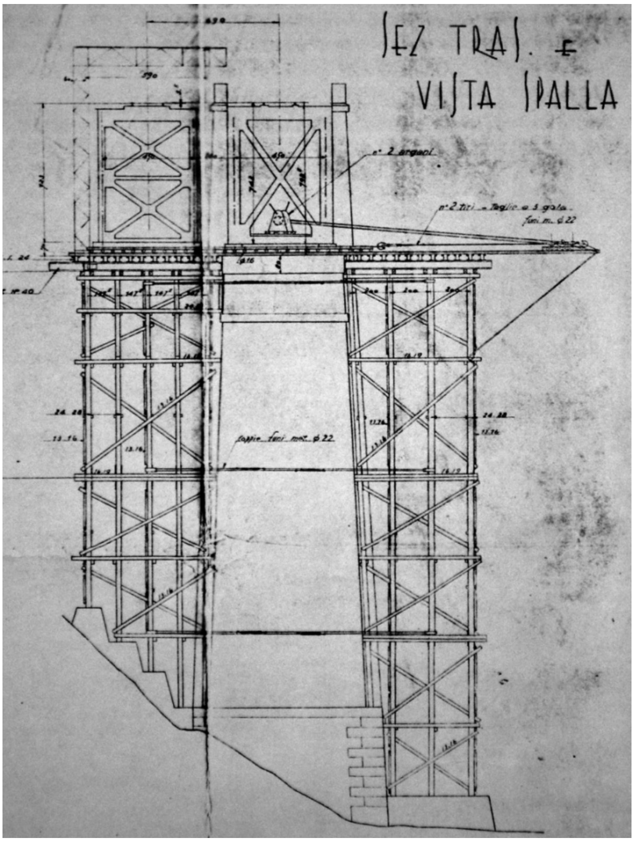


Figure 9. Cross section of the temporary wooden scaffolding erected to replace the original metallic span in 1934-35 (*Ferrovie dello Stato* archive). On the left the new, pre-assembled structure, in the middle the structure to be replaced. It was carried to the side with ropes and hoists until it was safely positioned on top of the scaffolding on the right, where it was dismounted.

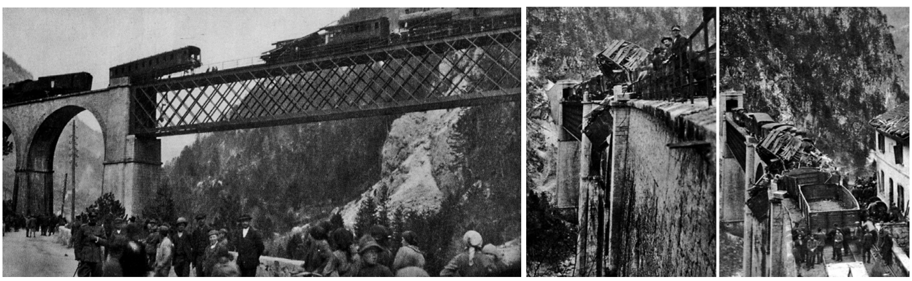

Figure 10. The railway accident in March 1920 (AA.VV. 2006).

locomotive. A greater traction provided by a second engine would have probably caused the train to derail, pushing it off the bridge.

*Present situation.* Having withstood the damages brought upon by bad weather, natural disasters and historical mishaps, miraculously ignored by

WWII Allied bombers (who attacked instead “Ponte Peraria” at Chiusaforte and nearby Dogna bridge), the bridge has survived until today in a remarkably good state of repair, particularly considering the total lack of maintenance since 1995 when the line was abandoned.

Before conversion work officially commenced, numerous preliminary inspections were carried out. The evaluation of the state of preservation of the protective paint on the bridge’s metallic structure, carried out in March 2010, was particularly important (Dorigo 2007).

On that occasion, it was assessed that the orange-coloured mono-component primer was in a good state of repair, with a thickness of around 200 micron across the entire structure. Paintwork, including the top coat in the classic RAL 8028 brown colour, presented an average thickness of 400 micron, and was rusted for around 5-10% of the surface. Below the plane of the rails, on the other hand, the top coat had peeled off for at least 10-15% of the painted surface, exposing the underlying primer paint.

In general the state of conservation of the structure, as evaluated by the 2007 survey, was regarded as acceptable, also in consideration of the fact that the bridge had been abandoned for twelve years, and the areas at risk of oxidation did not appear to be in need of immediate repair.

It was not considered necessary to assess the mechanical properties of the material by a Vickers hardness test, because the evaluation of the static characteristics of the existing structure could be banally conducted “by comparison” between railway-related and bicycle-related stresses, without having to establish the precise resistance level of the existing metallic structure.

Figure 11. Inside of the truss (the deck is on top). Paintwork on the lower parts of the truss has extensively peeled off, exposing the underlying orange-coloured primer (March 2007).

## 2. The conversion to cycle use

*2.1. General outline.* After a number of years when preliminary designs were presented and evaluated and the transferral of ownership of the line was finalized, the project of conversion of the Pontebbana line into the new “Alpe-Adria” bicycle trail finally got underway in 2007 when the final designs and working plans were produced. The project concerned the

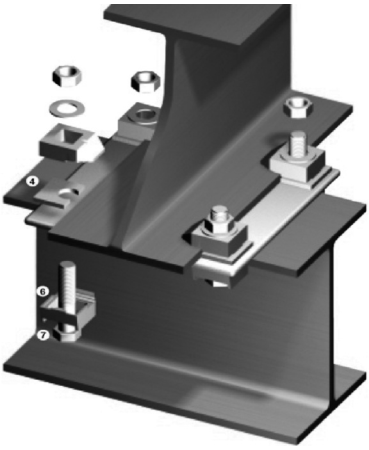


Figure 12. Girder clamps used to fix the new decking onto the existing load-bearing structure.

conversion of the entire 4th section and of part of the 5th section (from Resiutta to Dogna) of the line, probably the most complex and fascinating segment of the railway.

Right at the start of the planning stage, one of the most important design issues that were considered regarded the characteristics of the new decking that would replace the existing rail tracks on the metallic bridges, which were a precious historical feature that it was necessary to preserve.

The approach that was adopted aimed at finding solutions that were both respectful of the existing structures and as unobtrusive as possible, using features that were remindful of the original architecture (wooden sleepers, simple guardrails with three horizontal rails) and also very easy to remove, in order to facilitate future maintenance. For this reason we avoided solutions that required invasive techniques such as soldiering or bolting onto the original metal structures, preferring to use completely dismountable girder clamps.

The new decking for pedestrian and bicycle use was constructed by removing the existing wooden sleepers and the inspection walkways made of chequered sheets, thus exposing the underlying metallic structure (cross-girders and rail bearers). Three HEA180 longitudinal steel girders were then laid at a distance of 132.5 cm from each other, fixed to the original metallic structure by girder clamps. For ease of transport and mounting, the girders had a length of only two spans (i.e. connecting three cross-girders). These longitudinal members provided continuous support to glulam larchwood beams lying on top of them, having a standard 20x24 cm section and being laid at a distance of 50 cm, which support the new deck. This has been constructed with panels of structural metal grating (with 33x11 mm openings), which is less slippery than the traditional wooden boards, particularly when it rains. The deck was lined at both sides with metallic railings, higher than the usual pedestrian guardrails, made of metal posts and guards and furnished with wooden hand rails.

*2.2. Structural analysis.* Structural analysis was performed by limit state verification using a partial safety factor design method. It is not important, however, to illustrate the analysis in detail as it makes reference to the application of the usual Building

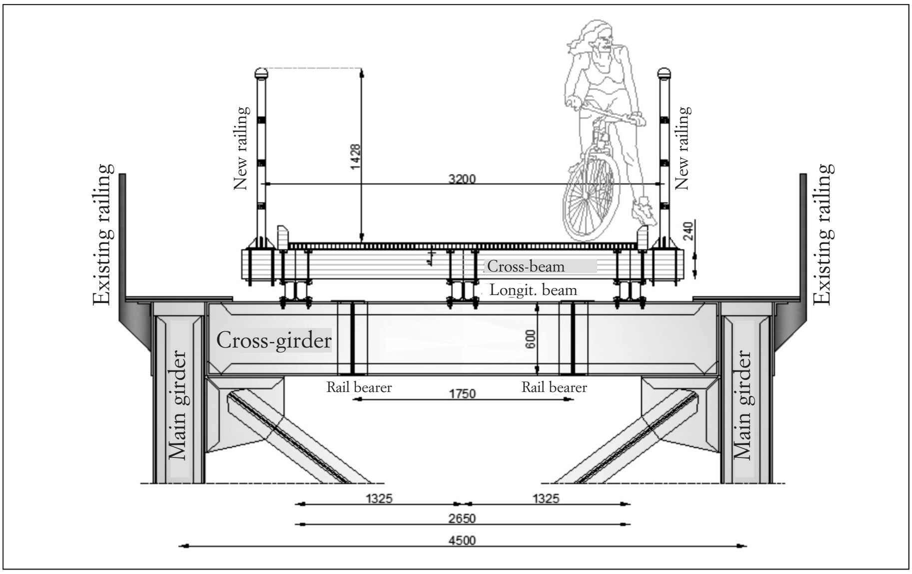


Figure 13. Typical cross section of the new decking, showing the wooden cross-beams being supported on three points.

codes and is of little scientific interest. Only some general information is given here, remembering that renovation was not aimed at the improvement or seismic reinforcement of the existing structure, which has not been modified in its static characteristics or subjected to an increase in loads following its conversion.

With regard to the probabilistic loads which have been estimated on the new decking, they consisted in a uniformly distributed pressure across the width of the structure having a value higher than 5 kPa. However we considered the possibility that the new decking should support the transit of a 3-axle service/emergency vehicle (ambulance, van) with a maximum weight at full load not higher than 250 kN (180 kN in total by the two rear axles).

The structural analysis of the new structure has been performed using simple static schemes, assuming that it was connected to the underlying steel girders through hinge constraints, created by the girder clamps linking cross-girders and longitudinal beams. The constraining reactions were later used in a simplified analysis of the underlying load-bearing structure, formed by the under-rail frame made of cross-girders and rail bearers.

In particular, the stress derived from the weight of cycle traffic has been compared with that obtained by loading a structurally significant portion of the under-rail frame by the railway loads prescribed by the guidelines no. 2711 of 1925 (*Ferrovie dello Stato* 1925), which are lower

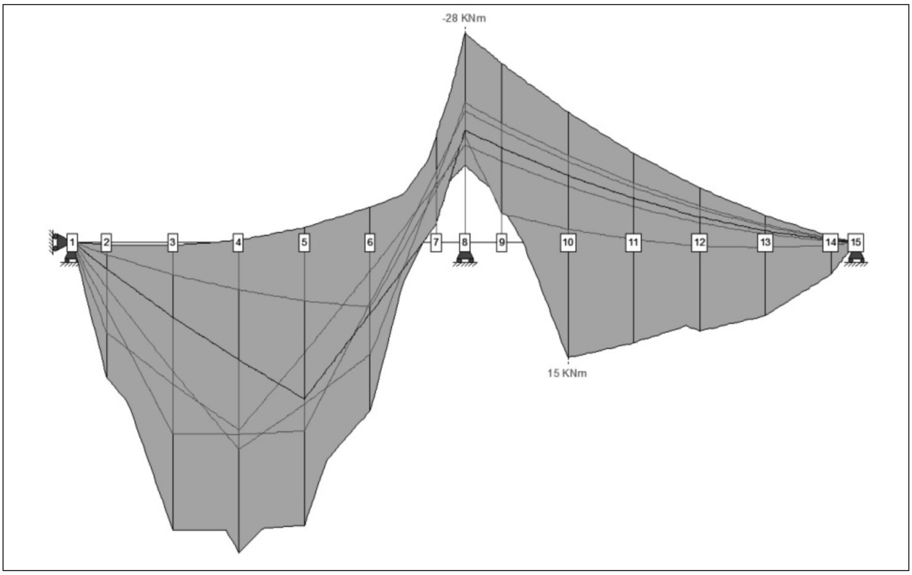


Figure 14. Envelope of the diagram of the bending moments generated in the central beam of the new decking (longitudinal view, two-span beam). The fragmented aspect of the polygonal chain is due to the discrete loads applied by the glulam wood cross-beams. The constraints represented in the figure are materially caused by the cross-girders of the bridge truss.

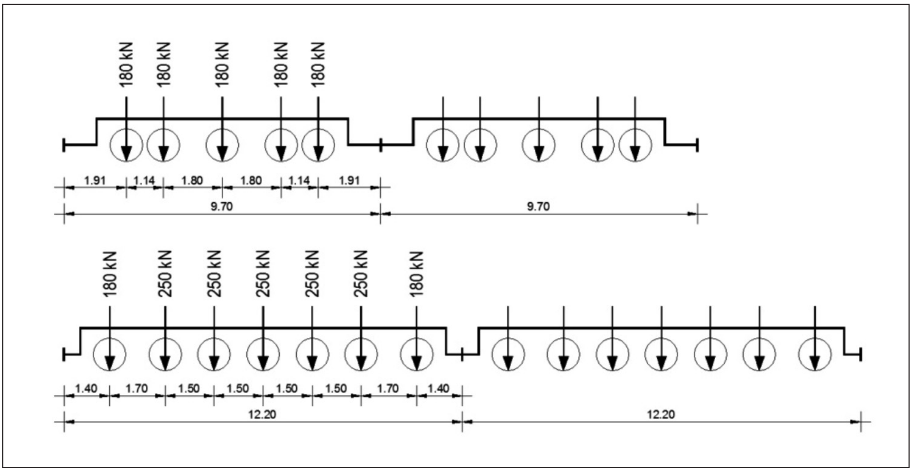


Figure 15. Loading diagrams contained in historical documentation published by *Ferrovie dello Stato*, with indication of the load applied by each axle. Top, the two locomotives which were presumed by guidelines no. 2711 of 1925. Bottom, the higher loads presumed by guidelines no. 2715 of 1945.

than those of the successive guidelines no. 2715 of 1945 (*Ferrovie dello Stato* 1945) and therefore implicitly defining the minimum resistance capacity of the structure, to be compared with the new loads caused by cycle traffic.

Despite having a predictable result, this verification was necessary for bureaucratic reasons, since the rail-to-trail conversion formally involved a change in the use of the structure.

*2.3. The construction stage.* The re-design of the bridge truss with the removal of rails and sleepers and the construction of a new decking took place in Winter 2007-2008, while the conversion of the rest of the line was completed in 2010. In this case, the rail tracks were removed and the ground was covered in asphalt concrete, which was also laid on the four side spans of the "Ponte di Muro" bridge.

The decision of using simple and independent structural elements and easily assembling them with bolts and clamps has proved to be a very convenient one, cutting construction time and limiting safety hazards (particularly considering that the building site was 40 metres above the ground). Regarding this, the choice of maintaining the original railings has permitted the instalment of two lifeline ropes to which workers were continuously harnessed. This was particularly important in the delicate phase when sleepers and inspection walkways were removed and the new decking was put in place.

Finally, a curious discovery was made during the renovation of the bridge's southern-most span: an old mine shaft covered by ballast and hidden inside the central pier. It has not been possible to date the cavity, which may have been dug at the same time as the rest of the structure, or excavated during WWI or at the same time as the fortifications emerging from the rock at the southern end of the bridge. Incidentally, these fortifications are not included in the military description of the defensive line known as Vallo Littorio (Bernasconi

Figure 16. Construction of the new decking. Top, removal of railway sleepers and inspection walkways. Bottom left, the new cross-beams made of glulam larch-wood. Bottom right, the finished decking. As shown by the photographs, employees wore safety harnesses attached via a shock absorber to the life lines at the sides.

Figure 17. Left, the two southern spans as they were constructed (AA.VV. 2010). Right, the mine shaft discovered inside the central pier.

& Muran 2009), built by the Italian army before its entry into WWII. Despite these uncertainties, it was decided to preserve a visible sign of the presence of the shaft by bringing it to the level of the tarmac and closing its opening with a simple plate.

**3. Conclusions.** The article has described of the process of rail-to-trail conversion of “Ponte di Muro”, a viaduct bridge with a masonry-and-steel structure located near the village of Dogna (Udine), part of the disused “Pontebbana” railway line. Following the conversion of the railway line into the new “Alpe-Adria” bicycle trail, the old bridge has recovered its former function as a crossing of the River Fella: a function it had lost in 1995 when the old line was replaced by a new two-track, in-trench railway, effectively blotting out the rugged terrain that the bridge had masterfully conquered at the end of the 19th century.

In the place of the old rails and sleepers, the bridge’s steel truss structure now accommodates a new pedestrian and cycle deck: light, easily maintained, and above all respectful of the environment and of the existing architecture. We hope that the new lease of life that has been gained by the bridge and more generally by the rail line through their conversion into a bicycle facility could effectively contribute to an ecologically-sustainable re-launch of these border lands, so harshly affected by historical events and by complex and sometimes not very sensible choices of infrastructural development and tourism planning.

[1] Some authors divide the line in four sections, considering the segment between Resiutta and Pontebba as a single section.

[2] Data obtained from the original *Ferrovie dello Stato* drawings regarding the replacement of the bridges’ metalwork carried out in 1933.

[3] Span lengths were correctly reported by Marinelli (1894). AA.VV. (2006) erroneously gives a net span of 14 m.

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