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Portrack, Scotland—a major railway realignment

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Crossing the volatile River Nith at Portrack in Dumfriesshire has presented railway engineers with severe problems for over 150 years, at least one previous attempt having been destroyed in a flood. Despite ongoing maintenance and repairs, the existing 11 span wrought iron structure, which carries the increasingly important Glasgow and South West Scotland line over the river, needed urgent replacement to reduce long-term costs and improve the safety and efficiency of the route. Carillion Rail and Scott Wilson Scotland carefully evaluated a number of options before recommending a realignment of the railway, which involved the replacement of two viaducts. Working in an environmentally sensitive location, adjacent to a 'live' railway and to a tight deadline required a tremendous amount of planning, cooperation and ingenuity by all parties; even the local estate owner became the project's architectural advisor. The centrepiece of the scheme is a spectacular 90 m curved truss-girder crossing the river, which was erected using the world's largest mobile crane. The meticulous planning and teamwork paid off with the construction of the entire project being completed on time, within budget and without disruption to the railway.

1. LOCATION AND HISTORY

Portrack Viaduct is located in an attractive rural setting 8 km north of Dumfries in Scotland. It carries the Kilmarnock to Gretna line (G&SW) over the River Nith and its extensive floodplain (Fig. 1). The river level varies dramatically throughout the year, from the normal steady flow in the central channel to severe flood conditions when the entire plain is inundated.

The double-track, non-electrified line is a major freight (coal) and passenger route, and it is of strategic importance as a diversion for the West Coast Main Line between Carlisle and Glasgow.

Access to the site on the north side of the river is via narrow unmetalled farm tracks through the private Dalswinton estate, close to the A701 near Lochabriggs. On the south side, access is gained from the A76, again using farm tracks through the Portrack private estate and gardens.

The line was originally opened in 1848, the bridge over the river having an overall length of approximately 120 m. Unfortunately, the bridge did not survive very long, being washed away in the great flood of December 1848. Therefore a longer replacement viaduct was constructed on the same alignment with an increased flood-flow conveyance. Later, in 1852, modifications to the profile of the riverbanks further increased the capacity.

This structure remained until 1875, when the existing bridge, which was built off-line and slightly to the west of the previous crossings, replaced it, increasing still further the clearance and flood-flow conveyance. Despite this, over the years, the power

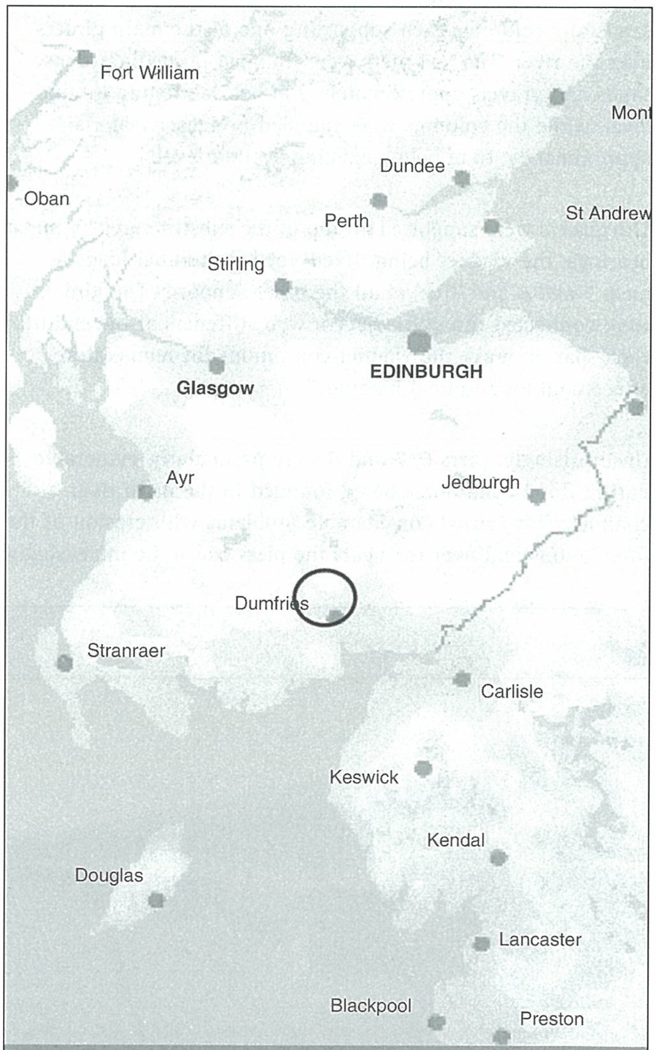

Fig. 1. Location

of the river in spate has continued to cause the structure problems, particularly with regard to scour of the pier foundations in the main river channel. As a result, throughout its life, a continuous programme of expensive repairs and strengthening of the substructures has been necessary. Also during this period, the timber deck has been renewed, the bearings replaced and remedial works carried out on the cross-girders and bearing stiffeners.

Nevertheless, the viaduct remained in service until December 2003, when it and an adjacent bridge, Lower Portrack Viaduct, were replaced as part of a major realignment of the railway, which is the subject of this paper.

2. UPPER PORTRACK VIADUCT

The viaduct was of riveted, wrought iron construction and was almost 200 m long, comprising 11 simply supported spans with measurements of 12·1 m (one span), 20·1 m (eight spans), 13·7 m (one span) and 9·7 m (one span). The twin main girders, which were 1·62 m deep and spaced 4·88 m apart, supported 'fish belly' cross-girders, which in turn supported the longitudinal timber deck and ballasted track. The substructures comprised conventional masonry abutments end supports together with ten intermediate piers, which were of two separate types of construction (Fig. 2). Piers 1, 2, 3 and 10 were masonry leaf piers supporting both main girders over the floodplain, whilst piers 5 to 9 comprised discrete cylindrical sandstone columns, each supporting one of the main girders over the river. The leaf piers were founded in medium-dense sands and gravels approximately 3 m below existing ground level, while the columns were founded in denser material approximately 10 m below existing ground level.

The girders were supported on top of the substructures by metal bearings, the viaduct being 'fixed' for longitudinal loads at piers 5 and 6 and 'free' at all the other supports. The girders were connected through adjacent web stiffeners at the end of each span to make the viaduct continuous for temperature effects and longitudinal loading.

Unsurprisingly, piers 6, 7 and 8 were particularly vulnerable during flood conditions, being founded in the main river channel. This caused considerable problems with erosion of the foundations and over the years the piers had to be increasingly protected against this potentially catastrophic effect by the construction of concrete 'skirts' and rock armouring. These works were successful in attenuating scour of the pier foundations, but unfortunately they had a detrimental effect on the articulation of the structure and the river regime.

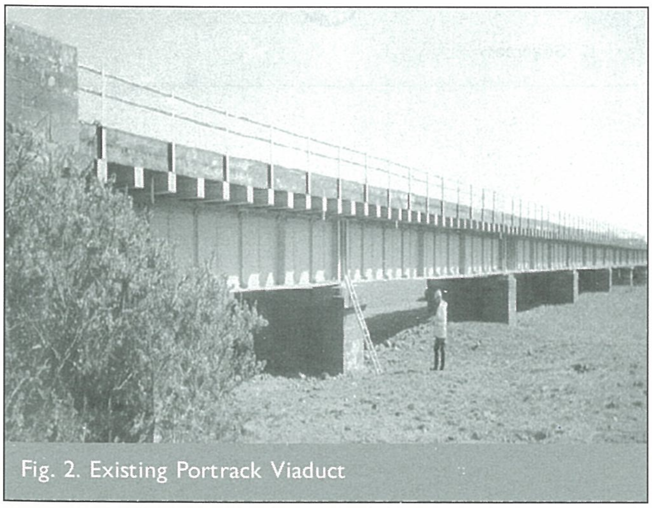
Fig. 2. Existing Portrack Viaduct

3. ASSESSMENT OF THE VIADUCT

During one of their regular routine inspections, Railtrack (now Network Rail) identified that despite ongoing repairs and strengthening works, the structural problems at the supports had become significantly worse since their last inspection.

Therefore in early 2000, as part of their commitment to maintain the safe and efficient operation of the railway, Railtrack commissioned Carillion Rail, through their cooperative structures framework contract, to investigate the problem. In turn, Carillion appointed Scott Wilson Scotland Ltd as their designer, thus reforming the team that had worked together so successfully on previous major rail bridge projects.

A simple monitoring regime was immediately installed on the structure, designed to identify any adverse trends in the movement of the substructures and alert the team to any increase in the width of the existing cracks.

The team then identified a programme of investigative work to be carried out. This included a search of the drawing archives, a preliminary ground investigation contract and a detailed site inspection of the structure.

The site inspection confirmed that the substructures were generally in a poor condition, particularly river piers 6, 7, 8 and 9, the north abutment, and pier 1, which was severely cracked and exhibiting signs of foundation failure. Furthermore, it was observed that the bearings, which were installed circa 1959, were seized and therefore unable to function properly.

The ground investigation confirmed that the area consists of medium-dense to dense sands and gravels with occasional boulders, overlying bedrock at 20 to 22 m depth, thus corroborating the information shown on the archive drawings. The investigation also revealed a lens of softer material beneath the foundations of pier 1.

After careful consideration of all the available information, it was proposed that the inadequacy and malfunctioning of the bridge's articulation arrangements were probably the initial cause of the distress at the supports, which was now being exacerbated by the increased frequency of heavy freight train loading. Therefore it was agreed that the behaviour of the bridge should be analysed using current standards, with the object of quantifying the theoretical forces applied to the structure, particularly those due to traction and braking of the trains and restraint of the thermal movements of the deck.

Consequently, a two-dimensional model of the bridge was constructed, which included an approximation of the stiffness of the founding material. The results of this study confirmed the suspicion that in its current state, with 'lock-up' of the bearings, the substructures were being subjected to loading well in excess of that for which they were designed. Furthermore the study revealed that re-articulation of the bridge using modern bearings and load-transfer devices in an attempt to share out the large longitudinal forces served only to refocus the overload. The study also confirmed that the bridge's faulty articulation was contributing to the distress of pier 1, which had been initiated by the presence of the soft material beneath the foundations.

4. REMEDIAL WORKS

A report of the findings was promptly prepared and after careful consideration of the conclusions, Railtrack commissioned Carillion to replace pier 1, repair the north abutment and temporarily strengthen the other substructures. It was agreed that it would not be economic or practical at this stage to attempt to repair the unsatisfactory articulation of the bridge.

The replacement of the north pier was the most significant challenge. After considering various options it was decided that the most appropriate solution was to isolate the existing pier by enveloping it in a reinforced concrete 'jacket' supported on minipiles. A gap was detailed between the existing and new piers to prevent structural interaction (Fig. 3). The new pier was designed to be capped during a possession of the line with a precast concrete plinth supporting new bearings. Railtrack accepted this proposal, and a full detailed design was duly prepared.

Meanwhile the repairs to the other supports, which comprised a combination of resin injection to the cracks, steel banding and scour protection works, were also detailed. As part of this work the opportunity was taken to assess the main girders, which surprisingly were found to have a very low live load capacity. Railtrack's term assessment consultant quickly confirmed this. The conclusions of their assessment report advised that full line loading could only continue to be accommodated if the structure was closely monitored and a number of other measures implemented and investigated. These included speed restrictions, actual stress measurements, single-line working, propping and testing. These measures would have improved the assessed capacity of the girders, but would not have provided a satisfactory long-term solution to the structure's chronic problems.

Therefore in order to maintain the safe working of the line, reduce the cost of maintenance and improve the efficiency of this increasingly important freight route, Railtrack decided to commission a feasibility study to investigate the options for improving the structure.

In the meantime a temporary speed restriction (TSR) was immediately imposed by Railtrack, reducing the line speed from 70/40 (70 mph for passenger trains and 40 mph for freight trains) to 40/20.

5. THE FEASIBILITY STUDY

In June 2001 Railtrack extended Carillion's brief to undertake a feasibility study of the options for strengthening the bridge to modern standards or replacing it completely. The study was required to take into account the condition of the existing structure, the disruptive effects of each option, environmental implications, safety and cost (including the cost of future maintenance).

Initially the study concentrated on the techniques available for strengthening and refurbishing the existing structure as it was felt that this might be the most attractive option economically. The traditional method of strengthening wrought iron plate girders by the addition of steel plating was considered, together with the modern equivalent of using composite materials bonded to the existing metal. However, testing of the wrought iron showed it to be of variable quality with widespread areas of corrosion and therefore not suitable for welding. Plate bonding of railway bridges using composites is currently being developed and was not accepted by Railtrack for use on mainline bridges. This information made strengthening work highly unpredictable, particularly in the long term, and therefore very unattractive.

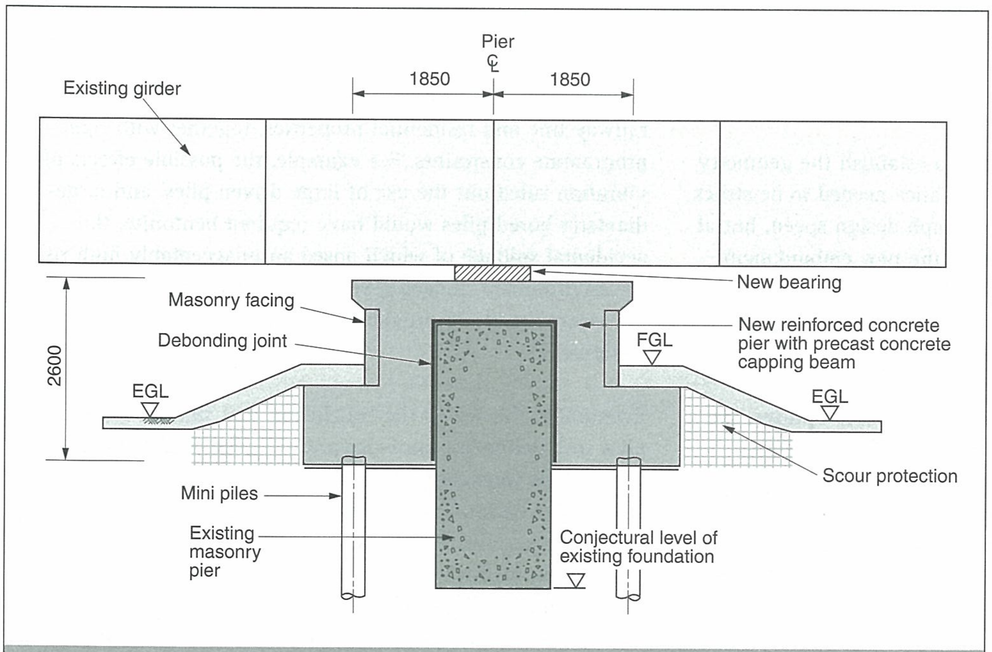

Fig. 3. Pier 1 repairs (all dimensions in mm)

Furthermore, from the previous analytical work it was recognised that it would be necessary to strengthen or replace the majority of the substructures, particularly the river piers, together with all the bearings, to guarantee the long-term viability of the structure.

As the study progressed it was apparent to the team that repairing the structure had a number of serious disadvantages. These included safe-working implications, major and prolonged disruption to the operation of the railway, the efficacy of any repairs to a nineteenth-century wrought-iron structure and the continued obstruction to the river's natural flow. Furthermore, a repair strategy would not completely eliminate the inherent defects in the structure.

With this in mind, complete replacement started to become a more attractive solution. Several options were considered, including both on-line and off-line alternatives, and outline schemes prepared. The team carefully considered the advantages and disadvantages of each option. It was clear that building a new viaduct on the existing line had little merit as it would be more disruptive and expensive than repairing the existing viaduct. Therefore the team began to investigate an off-line solution in more detail. Several alignments were considered, together with a number of different forms of construction. All the options had the obvious advantage of providing the client with a new structure designed to modern standards. Furthermore, disruption to the operation of the line during construction would be minimised, the obstructions in the river could be removed and construction would be relatively easy and safe. However, it was recognised that the proposal had a number of potential problems that would have to be resolved. Theses included possible objections, particularly by the local landowners and organisations representing the fishing interests, the need for planning consent, the formation of extensive new embankments and the construction of a second major bridge further down the line at Lower Portrack.

Nevertheless, after further consideration and careful costing of the options by the team, the preferred solution that clearly emerged was the construction of a new structure, off-line and as close as practically possible to the existing viaduct. This offered Railtrack the best value for the improvement of the line and long-term operation of the railway, and it provided the best combination of cost, speed and flexibility during construction with minimal disruption to the operation of the railway.

6. THE DESIGN APPROACH

In late 2001 Railtrack took the decision to replace the viaduct as a matter of urgency. Immediately the contractor prepared a 'fast-track' programme for the design and construction of the realignment, which showed that the new line could be operational by December 2003.

With this in mind, the first task was to establish the geometry of the realigned permanent way. A balance needed to be struck. The new line had to achieve the 100 mph design speed, but at the same time minimise the length of the new embankment without compromising the lateral clearance necessary to ensure failsafe working conditions and reduce the effects of construction activities on the existing bridge supports.

Eventually after the appraisal of several possible options, the new alignment was fixed 20 m to the east of the existing bridge, resulting in an overall length of 1600 m between tie-ins. (Coincidentally, during construction of the new works, aerial photographs of the site revealed that the 'new' alignment had unwittingly returned the track to the original alignment constructed in 1848.)

At Upper Portrack Bridge, the desire by all concerned not to impede the flow of the river led to an early decision to cross the main river channel with a single span, and limit the number of approach spans. In addition a shallow construction depth was required to maximise the clearance above the highest recorded flood level. These considerations led naturally to the choice of a 90 m long main span, with the piers set well back from the river bank, complimented by three continuous 30 m long approach spans. The team quickly evaluated a number of possible bridge types, but it was soon obvious that the types of construction traditionally used by railway engineers were the most appropriate at this location; these being a steel truss girder for the main span, and steel 'half-through' girder construction—the deck being located within the lower half of the plate girders—for the approach spans. Steel construction is admirably suited to this particular location, as it allowed the contractor to transport the truss to site in relatively small sections for assembly prior to erection. It can also be erected quickly, which is of major significance when working next to a live railway line.

Finally, in order to complement the clean appearance of the steel superstructure, it was decided that the substructures would comprise simple reinforced-concrete abutments and discrete reinforced-concrete circular piers.

The existing Lower Portrack Bridge is a four-span masonry arch structure. It was easily agreed that a single-span, steel 'half-through' girder superstructure supported on reinforced-concrete abutments and wing-walls was the most appropriate form of construction for the replacement bridge.

Following acceptance of the proposals by Railtrack, preliminary designs were undertaken to establish approximate member sizes, overall weights and foundation loads. This information was vital for the ensuing discussions with steelwork fabricators, erection specialists and piling contractors.

The prevailing ground conditions at the site dictated that both of the new structures had to be supported on piled foundations. Extensive consultations with specialist piling contractors were undertaken, and all the appropriate types and methods considered. The type of pile that would succeed was limited by poor access to the site, the prevailing ground conditions, environmental considerations, proximity to the existing live railway line and residential properties, together with tight programme constraints. For example, the possible effects of vibration ruled out the use of large driven piles, and large-diameter bored piles would have required bentonite, the accidental spillage of which posed an unacceptably high risk to the environment. Indeed several contractors advised that that they were unable to provide workable solutions with their equipment.

Eventually, this led to the conclusion that smaller-diameter piles installed using mini-rigs and founded in the dense sands and gravels were the most appropriate solution. Two piling contractors each offered a piling system that they considered to be appropriate for the conditions; a 323 mm diameter minipile, founded on bedrock and formed initially by drilling and completed by bottom driving of the casing; and a 600 mm diameter continuous flight-augured (CFA) pile installed by a segmental-augur rig, and founded in the dense sands and gravels. Both types had advantages—the smaller pile would be better able to deal with the boulders and quicker to install while the larger pile would have a much greater lateral load capacity, which was significant in reducing the overall number of piles required. It was therefore decided to undertake a trial installation and a vertical and horizontal load test of both techniques. In addition, the contractor conducted an extensive probing survey of the likely pile positions to evaluate the risk caused by the presence of boulders.

During testing the drilled minipile experienced difficulty dealing with the high groundwater pressures at depth, while the CFA pile performed satisfactorily. Therefore the CFA pile was selected as the preferred piling technique at this location on the basis of cost and practical installation.

6.1. Environmental considerations

The site is set amid the gently rolling curves of one of Scotland's great pastoral landscapes, which is home to a wide variety of flora and fauna including protected species such as otters. Furthermore it straddles two private estates and parkland of national importance.

Also, the Nith is the largest of the Solway rivers, and as the area's most important game-fishing amenity, it is an important contributor to the local economy. The existing viaduct's piers and scour protection works were a severe impediment to the passage of migratory fish.

Consequently, the team recognised that it was essential to the speed and success of the project that the proposed form of the new works and the chosen method of its construction had to minimise any risk to the environment. Furthermore, it provided an opportunity to vastly improve the river regime and thereby satisfy the aspirations of the interested parties, as well as being acceptable to Railtrack.

As a result, a comprehensive consultation exercise was undertaken with the landowners on both sides of the river, as well as the Scottish Environmental Protection Agency, Scottish Natural Heritage, the Royal Society for the Protection of Birds, Nith District Salmon Fisheries Board, the Historic Garden Society and the Planning Authorities to ensure all aspects of the proposed project would ultimately gain approval (Fig. 4).

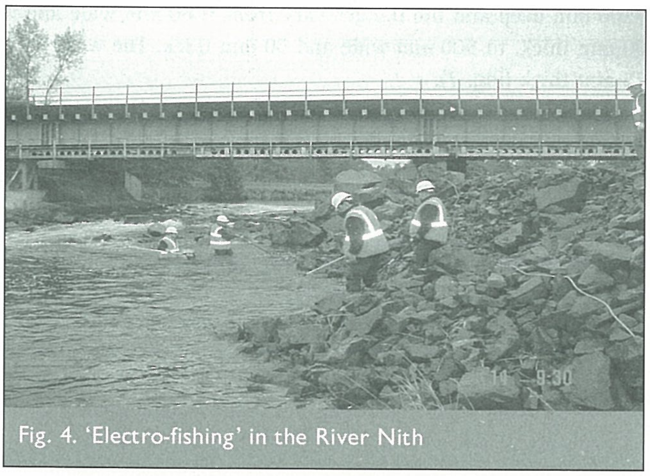

Fig. 4. 'Electro-fishing' in the River Nith

This strategy proved to be very successful and rewarding, resulting in planning approval for the scheme being granted without objection in spring 2002.

7. AESTHETICS

Due to its location, the appearance of the new viaducts was of particular concern. Coincidentally, the owner of Lower Portrack Estate, Charles Jencks, the renowned architectural critic and designer (who is a recent winner of the Gulbenkian Prize and author of numerous books including *The Garden of Cosmic Speculation* and *The Architecture of the Jumping Universe*), offered to join the team as an architectural consultant—an unexpected bonus for the project.

Having established the most appropriate form of construction for Upper Portrack Viaduct, the questions of shape, colour, proportion of parts and details, and how they relate to the context, became very important considerations to all parties.

Consequently after some intense debate, the first major decisions to be made were that the truss should have a constantly curved top boom and the top and bottom booms should comprise slender box construction to achieve the desired effect of simplicity of appearance with clean lines. Furthermore all other elements were to be proportioned with respect to each other and given gentle curves where they met.

The sweet curve of the trusses is not common in such construction, as invariably they tend to be fabricated from straight members; chords to a curve, and thus look clumsy. By contrast the new bridge flows smoothly from the horizon line, with the long approach of the tracks to either side swelling up in the middle effortlessly as a crescendo and falling away on the other side just as gracefully. In order to maintain the effects of proportionality and lightness, cross-members were needed to brace the top booms. These were given a size and density similar to the members on either side, such that when the bridge is viewed from any angle, there are three basic planes of steel (three screens of equal visual weight). This is key to giving the bridge overall sculptural unity.

Aesthetically it was important to simplify an already very simple form, so the walkway handrails were put behind the main truss diagonal members and given corresponding 'zigzag' supports. Nothing was allowed to interfere with the overall structural shape and purity of its members.

With regard to the colour of the bridge, after much consideration, red was chosen to contrast with the green of the pasture, the blue of the sky and the foamy dark of the Nith below. Here the particular shade chosen has a slight blue tinge making it quite sober, but when the sun strikes the structure and it is seen against a clear blue sky and the surrounding fields, the structure looks fiery and magnificent. To complement the superstructure, red concrete was specified for the supports, which were given a novel fluted relief and a straightforward massiveness.

By contrast, the new bridge at Lower Portrack is a simple structure, designed such that the views of the existing masonry arches and landscape are preserved. Careful attention was paid to proportioning the girders and detailing the concrete features and finishes. The colour scheme is identical to that of the larger structure, thus maintaining the 'red' theme.

A key element of the work on the site was to preserve some of the nineteenth-century structures and technologies, giving them new functions as part of the Portrack Estate gardens. Here there were opportunities. The existing four-arched bridge is faced in red sandstone and has affinities with ancient structures found in classical landscapes. For this reason and the way it frames the pastoral views beyond, it was decided to incorporate the bridge into the landscaping design. Cleaned and restored, it will support a series of small landforms, or 'moundettes', from which small trees will grow, connected by sections of girder retrieved from the existing viaduct. Thus a 'landscape train' will travel across the refurbished bridge, forming a beautiful transition point and frame for the garden.

Continuing towards the river there will be a longer landscape train constructed from the same elements, culminating in two larger mounds representing the 'engine', whence spectacular views of the new viaduct and the passing trains will be afforded.

Beyond this and cantilevering out over the river adjacent to the new bridge, there will be a pedestrian access bridge formed from parts of the existing viaduct, which will be stripped back, shorn of its tracks, cleaned and painted red. Thus as a simplified partial reconstruction it will become a literal memory of the past. Set next to the new bridge it will be a contrast of old and new technologies.

Down the middle of the bridge will be a pathway that diminishes in perspective, using a device aptly known as 'railroad track illusion': forced perspective. By diminishing all dimensions in plan and section, the sense of distance is exaggerated. The path will eventually culminate at the tip of the cantilever, from where beautiful elevated views of the river and the new bridge will be revealed.

Another path will descend between the new viaduct and the access bridge viaducts to an industrial waste garden formed using 'cast-offs' from the construction site including the old railway track. Some of the material will stay a natural rust colour and some will be painted red. The red concrete substructure of the bridges on each side, the red gravel and red planting will make this a visual symphony of 'rust'. Small touches of green will heighten the effect. This small, enclosed garden will end in a platform allowing low-level views of the river and bridges on each side to be enjoyed.

8. DETAILS OF THE VIADUCTS

The detailed design of both viaducts was undertaken in accordance with the requirements of British Standard BS5400,[1] supplemented by Network Rail's Group and Line Standards.

Opportunities for 'value engineering' were taken throughout the design; for example, the analysis of the structure for the calculation of fatigue forces in the transverse deck members and end bracing was undertaken in accordance with the method contained in Draft Eurocode 4 (Draft ENV 1994-2),[2] in which the deck slab is assumed to be cracked and its effective stiffness used, thereby simplifying the deck design. Also, the novel handrailing was formed from 'pultruded' glass-reinforced plastic (GRP) designed to American standards.

At Upper Portrack Viaduct, the main span over the river comprises twin, curved, through-truss girders, spaced 10·45 m apart supporting a composite steel and concrete deck plate. The span is 88·5 m between supports, with the top boom having a rise of 14 m and a constant radius of 85 m. Both the top and bottom booms of the trusses are formed from sealed fabricated steel box sections, the top boom being 1000 mm wide by 1000 mm deep and the bottom boom being 1000 mm wide by 1300 mm deep. The thickness of the plate varies between 35 mm and 45 mm.

The diagonal web members and cross-bracing are slim, fabricated 'I' sections, 1000 mm deep, which are butt welded to extensions of the top and bottom boom webs, thus cleverly forming a neat unobtrusive detail. Similarly the top transverse members, which also comprise fabricated I sections, are connected to extensions of the top boom flange plates.

The lower transverse girders are generally European wide-flange rolled steel beams (HE 900 B), apart from the end trimmers and immediately adjacent girders, which needed to be specially fabricated I sections provided with additional stub stiffeners and connecting plan bracing to resist horizontal load effects. The transverse girders are connected by bolted splices to stubs fabricated as part of the bottom booms. (Figs 5 and 6).

Approach spans are of continuous half-through construction, having three spans of 30 m, 30 m and 31·25 m. They comprise fabricated steel girders, connected by European wide-flange rolled steel transverse beams (HE 700 M) acting compositely with the reinforced-concrete deck slab. The main girders are 2500 mm deep and the flanges vary from 1060 mm wide and 60 mm thick, to 900 mm wide and 50 mm thick. The webs are 25 mm thick (Fig. 7).

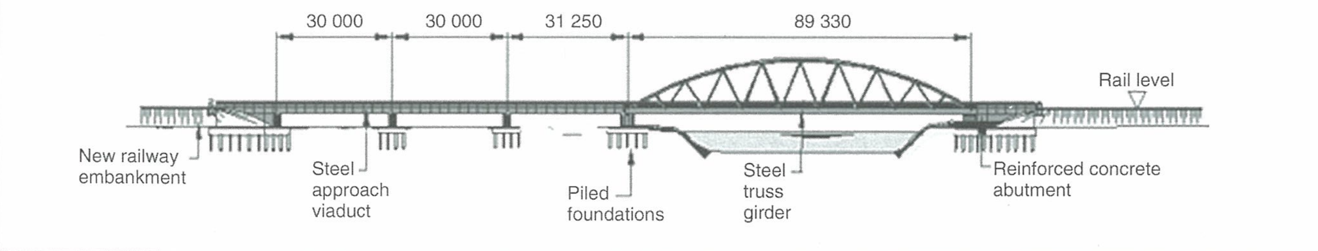

Fig. 5. Elevation of Upper Portrack Viaduct (all dimensions in mm)z

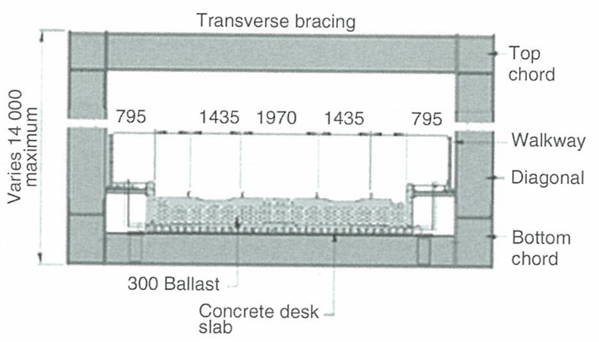

Fig. 6. Cross-section of truss span (all dimensions in mm)

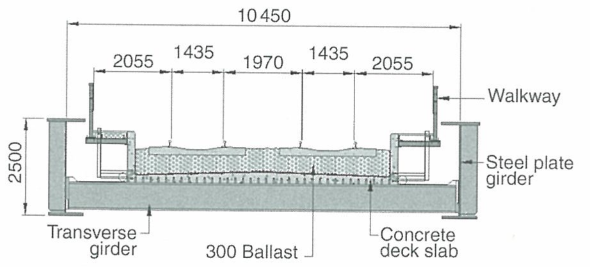

Fig. 7. Cross-section of approach viaducts (all dimensions in mm)

The reinforced-concrete deck slab, which runs the length of the viaduct and spans between cross-girders, is a minimum 200 mm deep and has 225 mm thick upstand walls forming a tray to contain the ballast and track. Transversely, the deck is connected to each cross-girder by shear studs to form a composite member. In addition the deck acts compositely with the bottom chords of the truss to provide the tie to the top chord.

The weight of each truss is 376 t, and the total weight of steelwork in the viaduct is 1370 t.

The viaduct is carried over the river and its floodplain on discrete, circular, reinforced-concrete multi-faceted columns and abutments supported on piled foundations. The columns, which are 3500 mm in diameter beneath the truss and 2000 mm in diameter beneath the approach spans, are repeated at the end supports, where a transverse connecting wall and wing walls combine to form novel abutments. The substructures are supported on reinforced-concrete pilecaps and 600 mm diameter CFA piles up to 13 m long with a working load of 1100 kN.

The superstructure is supported on pot-type bearings. The truss is fixed at pier 4 to resist the large longitudinal forces due to traction and braking of the trains, together with other coexistent horizontal loads. The approach viaducts are similarly fixed at pier 3. At all other supports the superstructure is guided longitudinally. Proprietary expansion joints at both abutments and pier 4, provided with protection from the ballast, accommodate thermal movements of the viaduct.

Lower Portrack Bridge is of half-through construction comprising fabricated steel-plate girders connected by rolled-steel transverse beams supporting a composite reinforced-concrete slab. The bridge has a single 25 m span and is slightly skewed to the abutments, which are in reinforced concrete supported on CFA piles.

Girders are 2500 mm deep and are spaced 10·45 m apart. The top flange is 1100 mm wide by 80 mm thick, while the bottom flange is 1100 mm wide by 60 mm thick. The web plate is 25 mm thick.

The transverse girders are 356 × 406 × 340 rolled-steel universal column (UC) sections, which support a nominally 250 mm thick reinforced-concrete slab, formed using GRP formwork. Abutments and wing walls are traditional reinforced-concrete structures supported on piled foundations.

The superstructure is supported on 'pot' bearings, being fixed at the south abutment and longitudinally guided at the north abutment. A free sliding bearing is positioned at the centre of each end trimmer beam to limit live load deflection.

All the steel used to fabricate both superstructures is grade S355 to BS EN 10025 J2 or K2, and all bolted connections are made using 24 mm diameter high-strength friction grip (HSFG) bolts.

9. CONSTRUCTION AND ERECTION

As with all large civil engineering projects, particularly railway schemes, the method of construction is of fundamental importance and has a considerable influence on the design. In this case the construction period was relatively short, the site was susceptible to flooding and no disruptive possessions of the line were available.

Construction activities commenced on-site in March 2002 with the formation of the new embankments. They are of traditional cross-section with side slopes with a gradient of 1 in 2, constructed using rockfill won from the local Dalswinton quarry. A temporary conveyer belt supported on the existing pier foundations neatly solved the problem of transporting the material to the south side of the river, where access was particularly poor. Construction activities on the main bridge commenced in June 2002 with installation of the piled foundations (Fig. 8).

During construction a selected number of working piles were load tested and all the piles were integrity tested. Some piles had to be abandoned due to obstructions, but despite having to install replacement piles the CFA technique still proved to be the most economical solution.

Piling was quickly followed by construction of the reinforced-concrete pile caps and substructures. The use of minirigs and safe working methods allowed these operations to proceed quickly without disruption to the railway line.

Meanwhile the main construction challenge of the project, installing the truss span over the river, was addressed. The contractor considered all the standard methods: on-line launch, off-line launch, sideward slide and straight lift-in. Each option

Fig. 8. Piling operations for new foundations

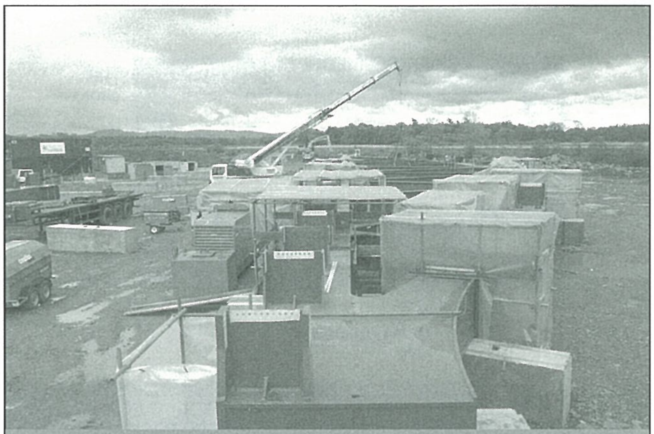

Fig. 9. Welding of truss girder sections

Fig. 10. Truss girder ready for erection

was carefully evaluated for speed, safety, cost and environmental effects. Ultimately, lift-in by a large crane was chosen by the contractor as the preferred option. It benefited from the fact that a large area was available on-site for the crane and layout of the steelwork. In addition (and very importantly), no temporary works were required in the river, and erection could be organised around normal 'rules of the route' possessions.

The crane chosen for the lifts was the huge Sarens PC9600 (2000 t) crane, which is the largest mobile crane in the world. At the required operating radius of 54 m, and utilising 1000 t of 'superlift' counterweight, the capacity of the crane is 440 t.

With these facts in mind, precise plans were prepared to choreograph the position and movement of the crane, its superlift and the assembly area for the trusses, which were to be built horizontally in order to control on-site fabrication tolerances.

Rowecord fabricated the steelwork, valued at £2·2 million, at their works in South Wales. Due to the size of the structure, a trial erection was not practicable, and therefore special measures were taken during fabrication to achieve the accuracy necessary to ensure fit-up on site. On completion of the steelwork, a glass-flake epoxy paint protection system was applied.

Back on site, temporary concrete supporting plinths were constructed to support the truss sections, which ranged in weight from 22 to 32 t, and were delivered to site by road. Over the ensuing ten weeks, the truss sections were butt-welded together under carefully controlled conditions, and the paintwork was completed (Fig. 9). At this point one of the trusses was 'weighed' using a five-point jacking arrangement located on the temporary supports. This confirmed the calculated weight of the truss at 376 t. The 'all-up' lift weight was 415 t, which included temporary scaffold to the top and bottom booms and the lifting tackle.

Next, during two midweek overnight possessions of the line, both trusses were raised to the vertical and temporarily propped (Fig. 10). During subsequent weekend possessions, in what is believed to be the largest lift ever undertaken on the UK rail network, the crane effortlessly swung each truss out over the river and landed them on top of the substructures (Figs 11 and 12). Over the following two weeks, the top and bottom transverse members were bolted in position, thus connecting the trusses together (Fig. 13).

Following this, the erection of the approach spans, comprising a grillage of main girders and cross-girders, was speedily carried out using bolted connections and splices, without any further disruption to the railway.

Fig. 11. Erection of truss girder

Fig. 12. Truss girder erected over the River Nith

Fig. 13. Aerial view of truss

Construction of the concrete deck slab followed immediately (Fig. 14). It was supported on permanent formwork spanning between cross-girders and poured in two sections, followed by spray-applied waterproofing complete with protective boards and installation of the deck drainage system.

The cantilevered walkways, which comprise steel brackets supporting GRP flooring and handrailing, were then attached to the deck upstands. A services cable trough was provided beneath each walkway.

Fig. 14. Construction of concrete deck slab

Fig. 15. Lower Portrack Viaduct

All these operations were carried out using small plant positioned on the concrete deck slab, thus ensuring safe working operations near the live railway.

Construction of Lower Portrack Viaduct commenced in January 2003 with the installation of the CFA piles. It proved to be a slow operation, with a need to provide substantial temporary support to the foundations of the adjacent existing bridge, which were continually monitored throughout. The substructures were constructed during the spring and summer, followed in September by erection of the main girders using a 400 t mobile crane during an overnight possession of the line. Then, over the next four weeks, the reinforced-concrete deck slab was constructed and the drainage system, waterproofing, joints and handrailing were installed using small plant and failsafe working methods (Fig. 15).

Throughout the construction programme, as each section of the realignment was finished and made available, the ballast and new track were promptly laid. The latter comprised FB CEN60 continuous welded rail supported on concrete sleepers.

Finally, during a possession of the line over the 2003 Christmas holiday, the track tie-ins were completed and the realignment opened for service (Figs 16–18).

Land reinstatement, demolition of the old bridge and completion of the accommodation works were undertaken during the summer of 2004. The overall cost of the project is

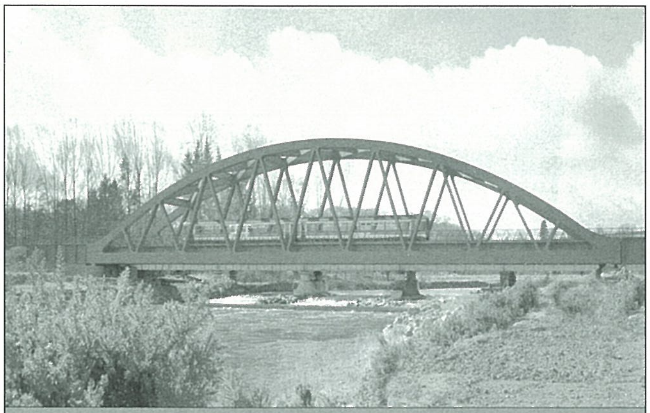

Fig. 16. Eastern elevation of truss span

Fig. 17. Full line speed

£15 million, including client costs, and from inception to completion the entire scheme took a little over two years.

10. CONCLUSIONS

The realignment of the railway line at Portrack , including the replacement of two major viaducts, is a remarkable success story and is a testimony to the exemplary planning, teamwork, skill and ingenuity of all those concerned.

The project was undertaken with the utmost regard for and sensitivity to the local environment and was delivered to the client's complete satisfaction, on time, within budget and to the highest levels of safety and quality.

Fig. 18. The completed realignment

It has resulted in a substantial improvement in the operation and efficiency of this important, strategic railway route, thereby demonstrating the industry's commitment to upgrading the rail network.

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REFERENCES

1. British Standards Institution. *Steel, Concrete and Composite Bridges*. BS 5400, BSI, London, 1988.
2. British Standards Institution. *DD ENV 1994–2, Eurocode 4: Design of composite steel and concrete structures, part 2, Composite bridges*. BSI, London, 2001.

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