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Glasgow Central station: a new bridge, track and platforms

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Glasgow Central station is one of the busiest railway stations in the UK outside London, with approximately 38 million people using it each year and an average of 1100 trains per day. The original station was opened by the Caledonian Railway in July 1879 and comprises a labyrinth of masonry and brick arches linked by vaulted arches and supported on substantial masonry piers founded in alluvial deposits. In 2009, as part of their continued commitment to improve rail services in Scotland, Network Rail commissioned the construction of two new tracks into the station, the first for 100 years. This presented a significant engineering challenge as the proposed alignment for the new tracks squeezes through the existing narrow masonry arch entrance structure, runs above a line of vaulted arches, which house a nightclub, theatre and restaurant, and is carried over the existing short-stay car park and ramp on a new reinforced concrete bridge. The new structures had to be supported on the existing Victorian infrastructure, demanding innovative, practical design solutions and skilful construction techniques to enable them to be built quickly and safely in a confined, busy public place.

1. Introduction

In 2009, as part of its continued commitment to improve rail services in Scotland, Network Rail commissioned the £170 million Paisley corridor improvement project to enhance the capacity of one of its busiest railway routes. The works include an increase in the number of lines, from two to three, between Shields Junction and Paisley Gilmour Street, an extension of an existing loop at Elderslie as well as the associated signalling and overhead lines and two new tracks into Glasgow Central station, the first for over 100 years (Figure 1).

2. Glasgow Central station

Glasgow Central station is one of the busiest railway stations in the UK outside London, with approximately 38 million people using it each year and an average of 1100 trains per day. It has grade A, category A listed status and is the northern terminus of the west coast main line.

The original station was built on the site of the seventeenth century settlement of Grahamston, 'Glasgow's forgotten village' and was opened by the Caledonian Railway in July 1879 (Figure 2). However, by 1900 the station was found to be too small to accommodate the increasing passenger numbers and between 1901 and 1905 the original station was extended to accommodate 13 platforms (Figure 3).

The station is built on two levels comprising a labyrinth of masonry and brick barrel arches, linked by vaulted arches, supported on substantial masonry piers founded in variable alluvial deposits. The rows of arch structures are interrupted by a steel bridge at Midland Street and the famous steel, glass-walled bridge at Argyle Street, which is known locally as the 'heilliman's umbrella' (highlandman's umbrella) because it was used as a gathering place for visiting highlanders. Additional major steel bridges convey the approaches to the station over the adjacent River Clyde and the Broomielaw.

The spacious station concourse contains shops, a ticket office and catering outlets, while the building itself incorporates a large number of shops and restaurants, particularly along Union Street.

In the early 1970s a disused area in the middle of the concourse was turned into a short-stay car park with an exit ramp to Oswald Street below.

Following a terrorist incident at Glasgow airport in June 2007, concern was expressed that the short-stay car park was also vulnerable to this type of incident. This, together with an ever increasing demand on the rail network, provided the catalyst for Network Rail to start the procurement of the project.

3. Procurement of the project

The Paisley corridor improvement project was originally conceived as part of the Glasgow airport rail link. Although the airport link was cancelled, the main line improvements give

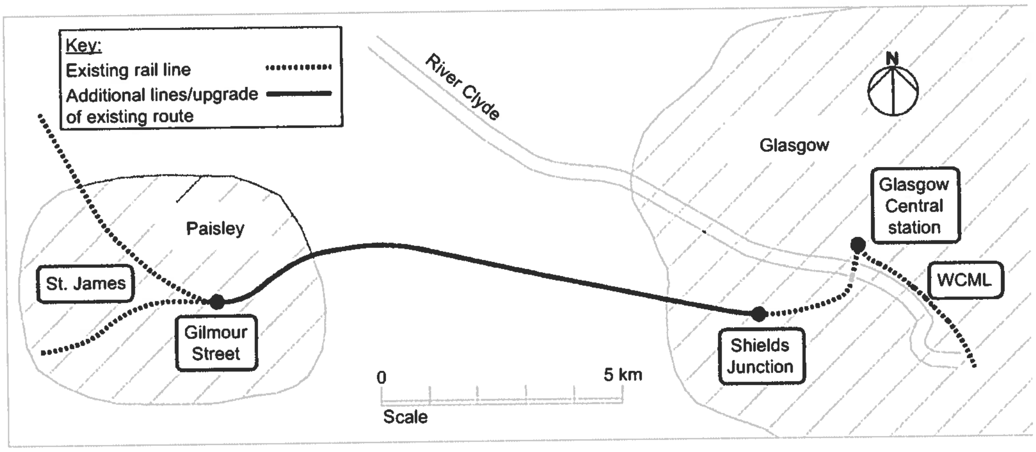

Figure 1. The Paisley corridor. WCML = west coast main line

wider benefits and Network Rail was still committed to upgrading the capacity of Central station and improvements to the rail network.

Therefore, in January 2009 Network Rail invited tenders for a design and build contract to procure the two new tracks, bridge deck, platforms with associated overhead line equipment (OLE) and signalling.

The new terminus platforms are 150 m long. The horizontal alignment of the associated tracks includes a curve with a radius of 300 m. The proposed route squeezes through the imposing masonry arch entrance structure, continues above a line of vaulted arches, which house a theatre, nightclub and restaurant, and finally crosses a new bridge structure that spans the void left by the removal of the short-stay car park and exit ramp (Figure 4).

The conditions of contract were Network Rail NR9 (based on ICE design and construct conditions of contract) and the new tracks had to be operational by 10 May 2010; any overrun attracting significant financial penalties.

Balfour Beatty Civil Engineering Ltd. was one of three contractors invited to tender and it duly appointed Scott Wilson, now URS, as its designer, thereby continuing the successful partnership, which was formed in the early 1990s during the development of the procurement of civil engineering projects in Scotland by design and build.

Figure 2. Construction of the arch support structures c. 1878

Figure 3. The station c. 1910 showing the future location of new platforms 12 and 13

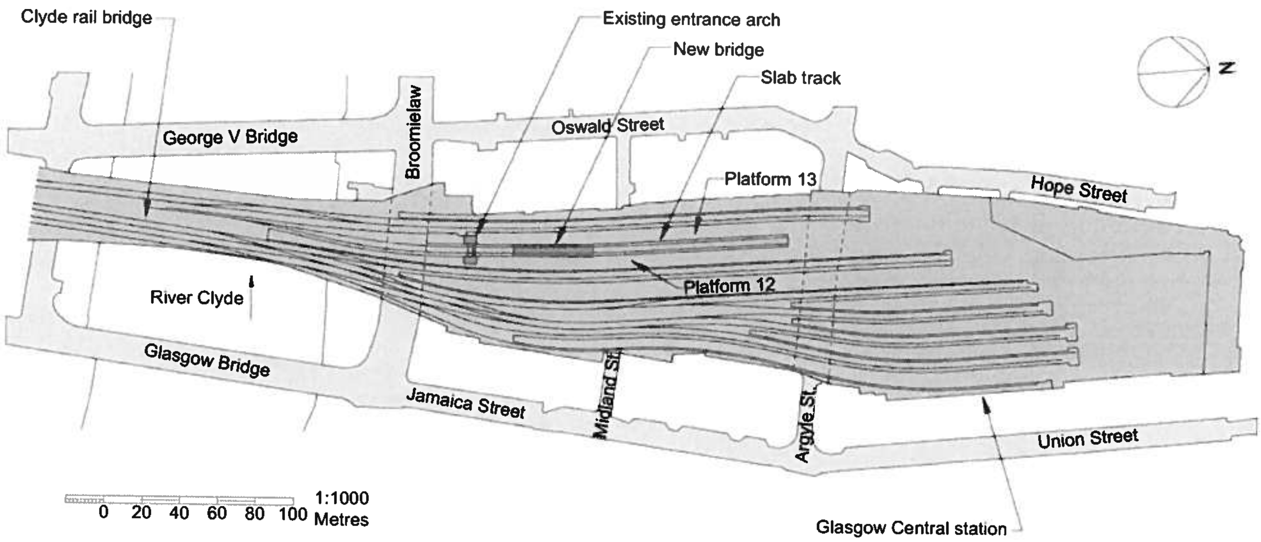

Figure 4. Plan layout of the station

4. Tender design

The tender documents were issued in January 2009, with a return date of April 2009. This relatively short timescale required intensive effort and skilful coordination of the multidisciplinary team to deal with the often conflicting requirements of preparing an accurate tender design, identifying and quantifying the risks, but also delivering a winning tender that could be completed satisfactorily and profitably.

The preliminary design, prepared by Network Rail's consultant and recorded on the form A, indicated that the new bridge and its reinforced concrete piers were to be supported by steel-dowelled connections to the ends of the existing masonry arch piers, which had never previously supported rail live loading. However, arch structures are difficult to assess accurately and there is no prescribed method in the codes for calculating the capacity of dowels in masonry. These issues were identified by the team as the critical design risks on the project.

Therefore, in order to eliminate these risks completely, Balfour Beatty and URS developed an alternative proposal, which used mini-piled foundations constructed in the station undercroft area, thereby separating the new structure entirely from the existing Victorian edifice.

Unfortunately, despite obtaining the necessary technical approval from Network Rail, the proposal had to be abandoned due to potential legal problems with the leasing agreement for the space beneath the arches. Therefore, other alternatives were evaluated, but eventually the principle of a dowelled support was accepted by the team.

Consequently, as anticipated, the number, size and capacity of the dowels became a critical item in the construction planning and programming. There is a lack of guidance relating to the design of dowels in masonry at ultimate limit state, especially in this situation where large dynamic loads require to be transmitted. Nevertheless, a preliminary design was undertaken to estimate the number and size of the dowels using a suitably conservative value for the strength of the masonry. However, the team realised that this matter would require further research during the detailed design stage to optimise the tender design and refine the construction programme.

During the tender process, a number of other modifications to the conforming design were proposed and accepted by Network Rail. These included an in-situ reinforced concrete deck slab for the new bridge structure instead of the conforming design of prestressed beams, to facilitate construction within the confines of the site. In addition, a reinforced concrete propping slab was introduced spanning between the footings of the new columns.

The remainder of the tender design complied closely with the form A design and tenders were duly returned in April 2009.

Following a tender clarification meeting with Network Rail, Balfour Beatty was awarded the contract in August 2009. Detailed design work started immediately.

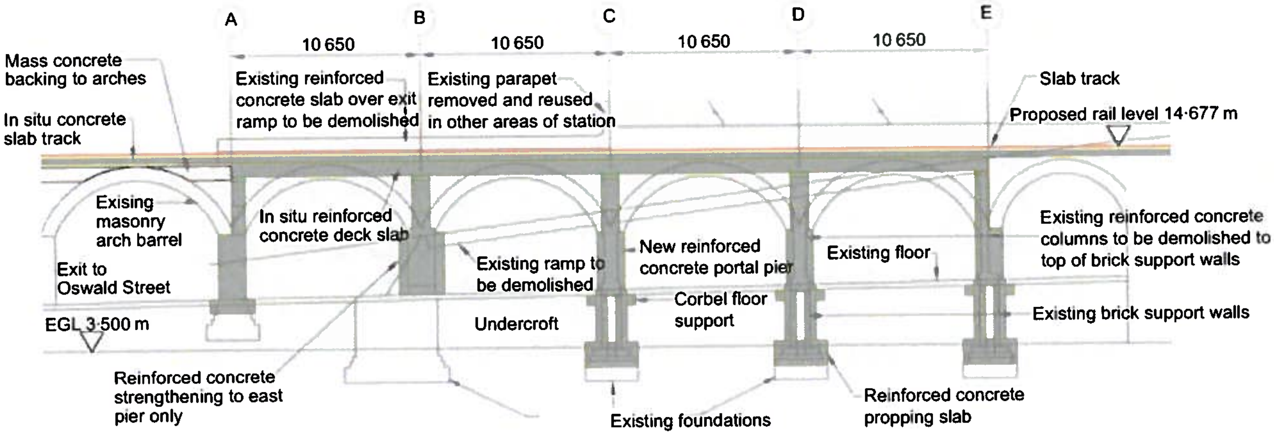

Figure 5. West elevation of new bridge (dimensions in mm)

5. Detailed design

5.1 Details of the new structures

The detailed design of the works was undertaken in accordance with the requirements of British Standard BS 5400 (BSI, 2000) for all combinations of vehicles running on railways in the UK, known as RU loading, supplemented by Network Rail's group and line standards.

The new bridge structure comprises a nominally 6100 mm wide by 800 mm thick, continuous, in-situ reinforced concrete slab with four equal spans of approximately 10 650 mm supported on robust, reinforced concrete portal piers. In turn, the portal legs are supported by stainless steel dowels, drilled and fixed into the existing masonry piers (Figures 5 and 6).

The design and detailing of the new pier supports was complicated. Not only did they need to support the substantial vertical loads from the deck of up to 4000 kN nominal per column, they also had to be detailed such that they could accommodate the numerous large-diameter steel support dowels. In addition, they had to suit the geometry of the existing arrangement of piers, walls and foundations.

Accordingly, the piers are rectangular in cross-section, being generally 1500 mm wide by 1000 mm deep, reducing at the existing arch springings to 1000 mm wide by 1000 mm deep at lines B, C and D and 750 mm wide by 1000 deep at gridlines A and E where the line of vaulted arches terminates. In addition, at gridlines C, D and E the pier is notched at the base to straddle an existing brickwork cross-wall, which supports the undercroft floor slab. At gridline A, where the original line of vaulted arches is interrupted, the portal pier is very similar to that at gridline E. The portal cross-heads are a substantial 1000 mm wide by 1500 mm deep.

Between the bases of opposing piers, a 3000 mm wide by 1125 mm thick reinforced concrete propping slab was introduced to form a frame with the columns and cross-head. The slab has several functions, primarily to provide continuity to the existing masonry pier footings and help resist shear failure of the soil under the toe. This arrangement enables the opposing pier foundations to act as one, minimising the increase in bearing pressures due to the loads from the new works. The propping slabs also restrain the ends of opposing masonry piers thereby providing a much more robust structure. Furthermore, the propping slabs introduce redundancy into the structural system by providing an alternative load path to the dowelled connections, although the design intends that load would be transmitted through the dowels.

In order to improve their effectiveness further, grouting was undertaken beneath the slabs post-construction. The measures taken to minimise settlements were extremely important in light of the variability of the prevailing ground conditions and the sensitivity of the continuous new deck and slab-track to settlement (Figure 6).

Although all pier portals were designed to be similar, not surprisingly, during excavation for the propping slab at gridlines A and B, unforeseen ground conditions were encountered that required a bespoke design for each foundation.

At gridline A, old brickwork foundations from the former Grahamston settlement were unearthed. Their presence had caused the existing masonry pier foundations to be constructed at different heights and propped by a cross-wall. This necessitated a quick response to enable Balfour Beatty to maintain progress. A local site investigation and survey was undertaken, followed by a complete redesign of the foundation, comprising a 750 mm deep

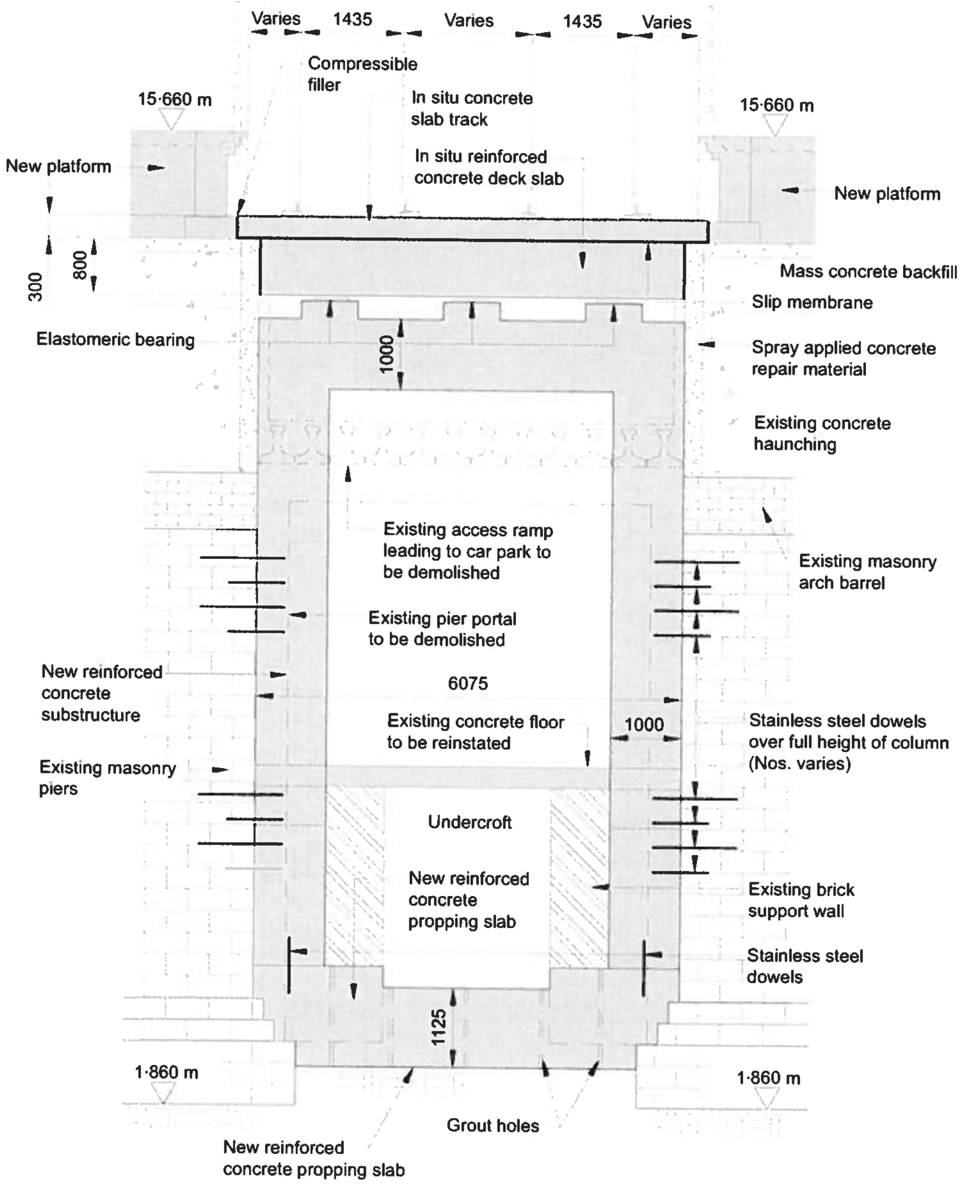

Figure 6. Cross-section at pier C (dimensions in mm)

by 2500 mm wide slab cast on excavations backfilled with mass concrete. The new design included a very precise and carefully staged construction sequence to ensure the masonry piers, cross-walls and excavations remained stable throughout construction.

At gridline B the existing masonry foundation and abutment wall, which supported the car park access ramp, had to be incorporated in the new foundations. The size of the existing structure severely reduced the space available for the dowels, so it was partly demolished and a new propping slab designed, supported on the masonry substructure.

The new deck is supported at each pier by three elastomeric bearings of relatively low shear stiffness to minimise any horizontal effects applied to the substructure in general and the dowels in particular. The design enables the bearings to be inspected and replaced if necessary during future maintenance programmes.

The deck's short, stiff span arrangement gave rise to potentially significant bending moments due to relatively small differential settlement of the supports. The deck slab was therefore made as slender as possible, resulting in a very dense reinforcement design.

Finally, Network Rail had specified that slab-track be adopted for the rail support system in the station rather than conventional ballasted track. URS designed a 340 m long section of 300 mm thick in-situ, reinforced concrete slab-track to convey the new tracks over the existing station structures, the new bridge and into the station. The overhead lines (OLE) and signalling completed the new lines 12 and 13.

6. Design challenges

Due to the nature and location of the works, the design was challenging. The design had to comply with the Standards, but at the same time, be quick and practical to build without compromising either the integrity of the existing, aged structure or the safety of the public and workforce. Access to the work area was severely restricted by the live railway lines and the surrounding building structures.

Unsurprisingly, therefore, this project presented a number of unusual design problems:

- the integrity and strength of the existing masonry, vaulted arches subjected to railway live loading
- the transfer of loads from the new deck structure to the existing masonry piers by steel dowelled connections
- articulation of the new deck and the transfer of horizontal railway live loads
- stability of the barrel arch foundations under eccentrically applied loading from the new deck
- design of the slab-track and rail support system
- the design of a significant opening in a masonry arch.

6.1 Existing vaulted arches

Of immediate concern was the possible deleterious effect of live railway loading on the existing structures, particularly the vaulted arches. The behaviour of vaulted arches is notoriously difficult to quantify due to the variable flexibility of the supports, contribution of the backing material and the uncertainty and variability of the internal structure. Notwithstanding these problems, URS developed a finite element model of a representative section of the barrel and vaulted arches to evaluate the effects on them of the increase in the applied loading (Figure 7). The results were used to assess the structure under permanent and live loading. Also, they enabled a comparison to be made with the actual observed performance of the particular structure and that of similar structures carrying railway live loading elsewhere in the station.

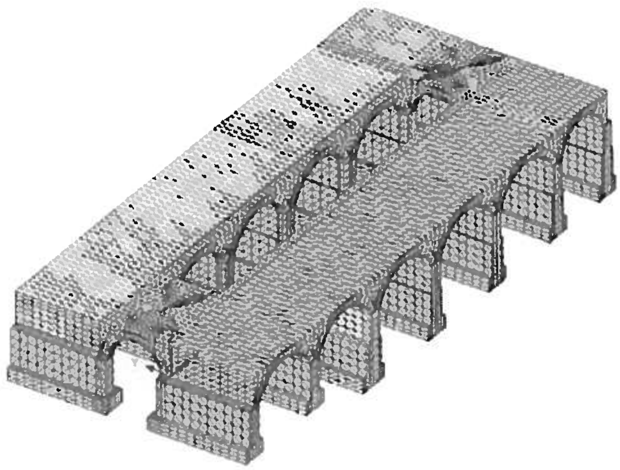

Figure 7. Finite element model of a representative section of the vaulted and barrel arches

In light of the numerous variables specified in the non-linear analysis of masonry, parametric sensitivity studies were undertaken to gain confidence that the variables selected were appropriate. The existing vaulted arches had been effectively 'load-tested' with the dead weights applied to them since construction and had remained in very good condition, with almost no evidence of cracking. This 'load-test' was used to verify the material properties chosen for the finite element model. In light of the novel nature of the analysis, a category III check was undertaken to confirm the RA8 assessment rating justified by the analysis.

Using this approach, the designer was able to confirm to Network Rail that its existing infrastructure would indeed be able to support the proposed new loading without suffering any adverse effects.

6.2 Dowelled supports

The support of the new reinforced concrete deck structure presented further design concerns. The new bridge pier portals had to be supported by large stainless steel dowels drilled and fixed into the ends of the existing masonry piers. Not only was a large number of dowels required, but there is also no definitive method for calculating their shear capacity, particularly in masonry. Therefore URS researched numerous technical publications on the subject before adopting a method based on the ultimate limit state design of dowels in concrete, as described in the CEB/FIP model code (CEB-FIP, 1990). However, the document gave no guidance relating to ageing masonry, so the designers developed an approach combining the requirements of British Standard BS 5628 (BSI, 2005) with the requirements for dowels in concrete. In excess of 25 cores were taken from the piers to enable axial and diametral tests to be undertaken, which demonstrated that the masonry had a characteristic compressive strength of approximately 14 N/mm^2. This value was adopted for the design as it exceeded the minimum strength requirements for the applicability of the CEB/FIP model code.

The coursing of the masonry piers was fairly regular, with an average course height of approximately 300 mm. The regular nature of the coursing, together with the pattern of the blocks, enabled the horizontal edge distance requirements specified in the CEB/FIP code to be achieved. The edge distance to vertical mortar joints within the mass of the masonry piers was limited to three dowel diameters from the circumference of the dowel. At the edges of the piers, the dowels were located to achieve the maximum possible edge distance, without compromising the above criterion for vertical internal mortar joints.

However, the course depths were not sufficient to comply with the advised vertical edge distance requirements. This was considered to be acceptable as the top and bottom edges of each masonry block were constrained by a mortar layer and the adjacent course of masonry. Generally, the dowels were positioned at approximately two-thirds of the height of a block. The dowel locations were also restricted by the vertical reinforcement in the portal pier legs. This necessitated the agreed adjustment of some of the dowel locations on site.

The ensuing design is for 50 mm diameter stainless steel dowels, with a 0·2% proof stress of 600 N/mm^2, resin-fixed into 65 mm

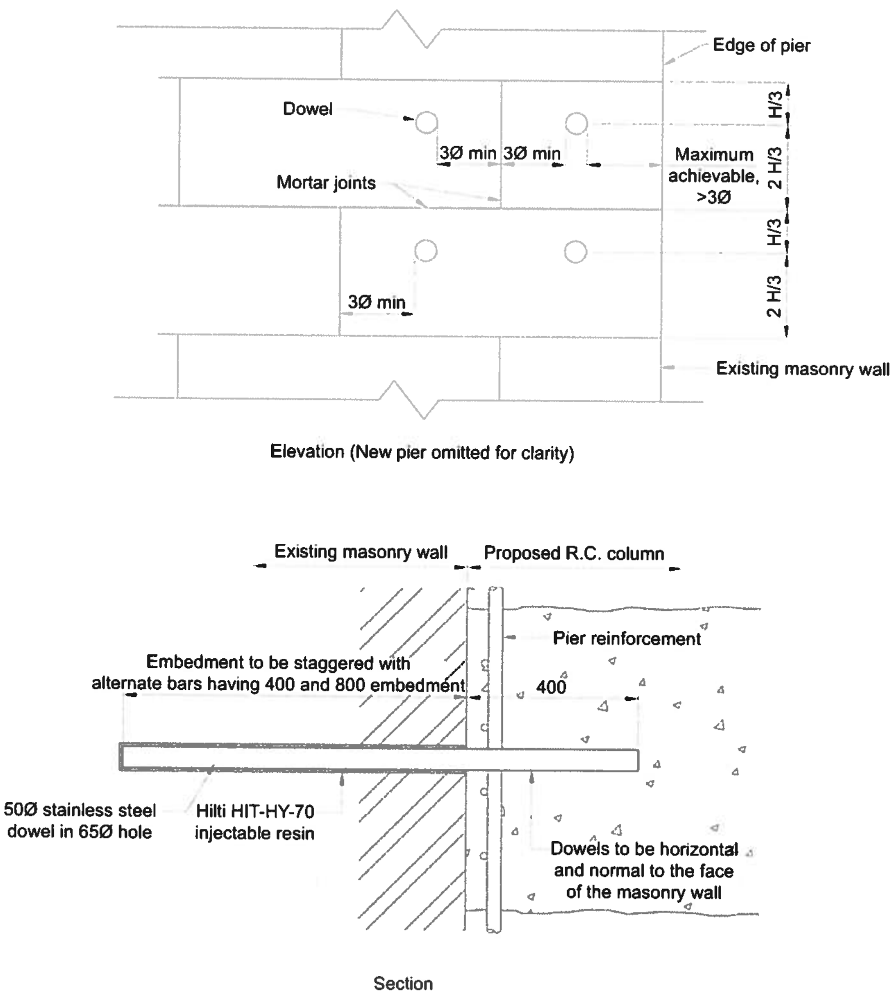

Figure 8. Dowel detail. R.C. = reinforced concrete (dimensions in mm)

diameter holes cored in the masonry. There are up to 44 dowels per column with staggered embedment lengths of 800 mm and 400 mm and a minimum spacing between dowels of 350 mm (Figure 8).

Large-diameter dowels were selected to minimise the number of holes needing to be cored; smaller dowels would have required significantly more dowels, thereby 'peppering' the masonry blocks with holes and possibly reducing the integrity of the structure. The larger diameter dowels allowed more load to be transmitted into the existing masonry piers at a higher level and consequently fewer were required in the congested undercroft area. This arrangement ensured that the vertical loads had the greatest possible height over which to dissipate through the masonry piers, thus further reducing undesirable bearing pressures beneath the foundations.

6.3 Cracks in masonry at pier B

During coring for the dowels in the masonry wall at pier B east, a number of cracks was noticed in the vicinity of the core holes. The extent of the cracks was ascertained by undertaking additional smaller cores, which showed the cracks were up to 1000 mm deep. This exceeded the masonry block depth and the lengths of the dowels, so remedial works were necessary.

It was considered unlikely that the cracking was due to the coring process itself, which was undertaken by a relatively light coring rig and had not produced significant cracking elsewhere. Also, previous testing of core samples had shown the masonry to be of good quality and strength. It was considered that the more likely cause was the demolition of the mass concrete abutment, which had supported the vehicle exit ramp, thereby removing a significant lateral restraint to the piers, resulting in some slight movement and cracking.

Several options for the remedial work were considered, before selecting a 'U' shaped reinforced concrete collar as the most appropriate solution. It was quickly designed and constructed as part of the new pier to contain the cracked section of wall. Plastic pipes were incorporated into the new column section at each dowel location during steel-fixing to facilitate accurate coring of the holes through the completed columns.

6.4 Articulation

The new bridge had to accommodate seasonal temperature movements, but also transfer large horizontal design loads, up to 2000 kN nominal due to traction and braking of the trains, from the track to the supporting structures. However, it could not be fixed to the new bridge piers as unmanageable, eccentric loads would have been applied to the dowel connections. The problem was resolved by separating the slab-track from the deck slab by introducing a simple yet effective slip membrane between them, comprising bituminous paint applied to a steel, float-finished concrete surface overlain by high-density polythene sheeting. This arrangement allows the deck to expand and contract freely beneath the slab-track during temperature changes, while the continuous, concrete slab-track transfers the horizontal loads to the adjoining arch structures, which in turn further spread the loads to the foundations. In addition, the elastomeric bearings supporting the new deck were deliberately selected for their low shear stiffness, thus ensuring that the difference in stiffness between the elastomeric bearings and the backing to the existing structures, combined with the slip membrane, isolated the new bridge and dowelled supports from significant horizontal loading.

6.5 Slab-track

The design of the slab-track itself, although not innovative, nevertheless is the first use of this type of track support at Glasgow Central station. Concrete slab-track is a system whereby conventional sleepers and ballast supporting the rails are replaced by a continuous concrete base or precast sleepers cast into a concrete base. The resilience of the track is provided by proprietary fastenings that incorporate an elastomeric pad.

Unfortunately, the very tight construction programme did not allow sufficient time to incorporate precast sleepers, so URS designed an in-situ reinforced concrete slab. A detailed finite element analysis was undertaken to confirm the slab thickness, particularly in one localised area where it needed to cantilever over the existing barrel arches. The rails are fixed to the slab-track by proprietary VIPA-SP 11308 four hole, base plates spaced at 700 mm centres using 320 mm long, M24 preloaded studs grouted into post-drilled holes. The studs were designed by the manufacturer of the base plates for railway loading and fatigue effects as part of the proprietary system. However, URS designed the length of the stud to be cast into the slab-track to ensure that there was sufficient anchorage to resist the loads applied to the studs, including a substantial factor of safety on the design load. During the design, great care was taken in the setting out and detailing of the reinforcement together with the specification of the construction tolerances for each component to ensure that the track could be built and installed to the correct line and level without the need for very expensive and disruptive post-construction remedial work and without fouling the slab reinforcement (Figure 9).

The transition from the slab-track to the ballasted track outside the station is achieved using hardwood sleepers at 700 mm centres. The gradual change in support stiffness between the slab-track and ballasted track was achieved by varying the stiffness of the resilient pads beneath the VIPA base plates.

6.6 Opening in a masonry arch

The construction of the new waste compactor facility required the formation of a significant 1200 mm wide by 1700 mm long opening in an existing masonry barrel arch, which also

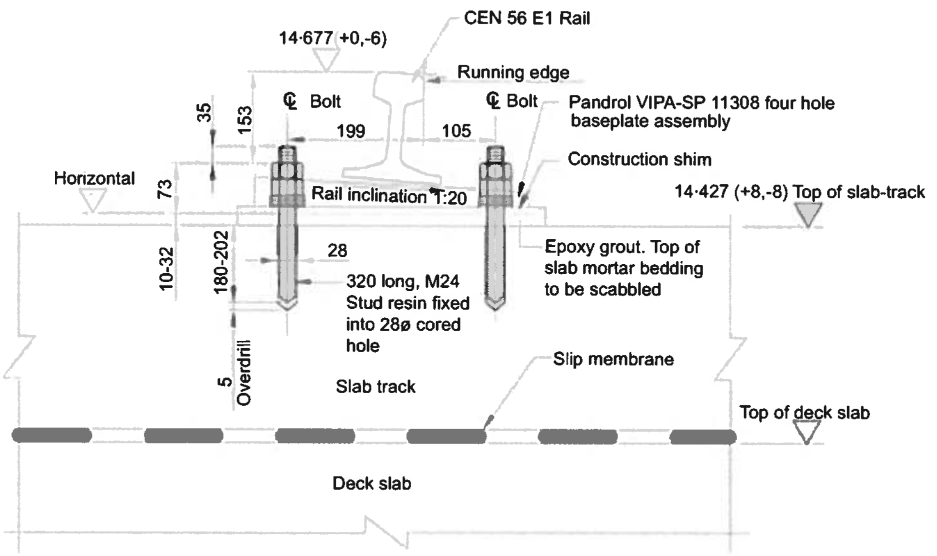

Figure 9. Slab-track base plate arrangement (dimensions in mm)

supported existing railway tracks. A number of alternative arrangements and methods of construction were evaluated. However, in order to eliminate the risk of weakening the arch, it was decided to provide a 500 mm thick in-situ, reinforced concrete internal arch lining, walls and foundations, which in effect replaced the existing arch as a structural element. The reinforcement was detailed to facilitate overhead construction and self-compacting concrete was used to allow the arch to be concreted without vibration. Any voids left between the masonry and concrete arches were grouted through small holes drilled in the masonry post-construction.

7. Construction

Construction activities in a busy railway environment are particularly difficult, especially when the site is at the heart of a major operational station. The track and platforms had to be constructed between current live railway tracks, on existing aged infrastructure and over a new bridge constructed in the middle of the busy concourse. This meant that the client, designer and contractor had to work together to ensure maximum efficiency and safety during construction.

The main civil engineering works to be undertaken were:

- demolition of the existing vehicle exit ramp and car park
- demolition of the existing platform 12 and associated buildings
- construction of a new bridge on the site of the existing short-stay car park and exit ramp
- construction of 340 m of slab-track
- construction of two new platforms.

Other works included:

- installation of associated track and switches
- extension of the OLE traction supply system
- relocation of the existing waste compactor facilities
- alterations to the station entrance area to facilitate disabled access.

Unsurprisingly, bearing in mind the location, there was a number of major constraints imposed by Network Rail, which influenced the sequencing and programming of the works:

- Existing platform 12 could not be closed until 24 December 2009.
- New platforms 12 and 13 had to be operational by 23 May 2010 to meet the summer timetable change.
- The existing car park had to remain open until 30 September 2009.
- All other platforms had to remain operational throughout the works.
- Access to the site was by means of the existing car park entrance, which had a 3 t weight restriction and severe geometrical constraints.
- Only one disruptive possession of the tracks was planned (from 25 to 27 December 2009).
- Work above the Arches Theatre, restaurant and nightclub was restricted to January and February 2010.
- The works were required to be integrated with the NRI signalling contractor.
- Designs had to be developed from form A to form B and

approved by Network Rail before any construction could begin.

These constraints made the preparation of a construction programme very difficult and significantly reduced the opportunity to mitigate risk by arranging to undertake some activities early.

While the form B designs were being developed, Balfour Beatty prepared to start the demolition works.

First, a substantial site boundary hoarding was erected within the station concourse to delineate the area of the works and minimise the interface with passengers and Network Rail station personnel. This created a sterilised area, which allowed work to progress uninhibited as well as maintaining public safety.

The car park surfacing and precast concrete slabs were then removed exposing brickwork upstand walls supported off the barrelled and vaulted arches below. These were demolished and all materials were removed from the site for recycling by way of the exit ramp, thereby ensuring minimal interface with the public.

Next, the exit ramp itself was addressed. It comprised precast concrete 'I' beams with an in-situ concrete infill. Balfour Beatty's initial plan had been to support the beams temporarily, cut them into sections and then remove them off site using a crane during rules of the route possessions. However, having successfully managed to recycle the material from the car park, the site team proposed the use of an excavator fitted with hydraulic crusher jaws, known on site as a 'muncher', to break up the beams and concrete. This required significantly less temporary works and reduced the difficulties in removing the slabs as well as providing good material for recycling (Figure 10).

Figure 10. Excavation of the existing access ramp

On completion of the demolition phase, a concrete screed was applied to the exposed masonry, followed by the construction of the new bridge. Whenever possible, to accelerate production, column and beam reinforcement were prefabricated at ground level and then lifted into position. The holes for the support dowels were drilled using a diamond coring machine and fixed into place with injectable, resin mortar. The formwork for the in-situ slab was supported on traditional falsework, the slab itself being constructed in stages. Access for plant and materials was contained at the undercroft level to minimise the interface with the public and station staff.

Full use was made of the one planned disruptive possession over Christmas 2009. The existing track and OLE were removed and excavation of the existing platform began. Once again the challenge of access and disposal of arisings was solved by using the undercroft. All the excavated materials were taken away and recycled on the adjacent M74 project.

Platform wall construction was a standard brick and block construction with 'Bison' slabs used to span the void between the new and existing walls. Coping stones and tactile slabs were then installed and the platforms resurfaced to tie in with the existing concourse.

The rail and OLE alterations were a further challenge being located in such a busy station. Balfour Beatty Rail acted as a subcontractor and carried out the majority of the permanent way design including the ballasted track, switches and crossings, buffer-stops and the track alignment.

In February 2010, once the new bridge deck had been completed, the permanent way installation was started, comprising 200 mm of plain line-ballasted track, 340 m of slab-track, two adjustment switches, four shop glued insulated block joints and two buffer stops. Construction was carried out unrestricted within the 'sterilised' area and during possessions of the line elsewhere (Figure 11).

As in all design and build projects, construction of previously approved designs was ongoing while the remainder of the design was in production. This required the cooperation of all parties to ensure that the interdisciplinary design reviews and form B approval process progressed smoothly in order to meet the agreed construction programme.

Another pleasing aspect of the project was the safety record. Throughout the design and construction process in this potentially hazardous environment, the whole team embraced

Figure 11. Construction of slab-track

Balfour Beatty's 'zero harm and make safety personal' initiative, resulting in no accidents or lost time on the site.

8. Conclusions

The scheme is a truly multidisciplinary design and build project, skilfully constructed in a sensitive railway environment. It was a challenging project as it required major demolition works and the construction of a substantial new railway bridge, supported on existing Victorian masonry arches, without causing any damage to the existing infrastructure or disruption to the operation of the station and the businesses underneath. In addition, the design and construction had to be practical such that the works could be built safely and efficiently on a confined site in a busy public place with severe access restrictions.

Despite the extremely tight timescales, the numerous constraints and the many engineering challenges, the works proceeded smoothly and the new platforms were brought into operation as planned in May 2010 (Figure 12). Undoubtedly, a major contributor to the project's success has been the team approach adopted by Network Rail, Balfour Beatty and URS. By working from a single site office the management of the individual organisations collaborated to the overall benefit of the project. As a result, unforeseen problems on site as well as contractual issues, when they arose, were dealt with effectively and professionally.

Figure 12. 'The first train'

The project has provided a welcome and necessary increase in the capacity of Scotland's busiest railway station and the predicted number of passengers has already been surpassed.

Its success and timely completion is a testimony to the organisation, skill, teamwork and cooperation of all the parties and individuals involved.

Acknowledgements

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