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VIADUX PHASE 2, MANCHESTER

LISTED BUILDING STRUCTURAL REPORT

Project No 2209-01

March 2024

Rev: P03

V2B-REN-AA-XX-RP-S-00010

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Rev.	Description	Author	Checked	Date
P03	RIBA Stage 2	KG	PC	07.11.24
P02	RIBA Stage 2	KG	PC	21.03.24
P01	RIBA Stage 2	KG	PC	14.03.24

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EXECUTIVE SUMMARY

The proposed Viadux development is shown in figure 0.1. Phase 2 of the development comprises a 76 storey mixed use tower (Plot 2a) and a 22 storey affordable housing block (Plot 2b). The Plot 2a works also include refurbishment of the existing viaduct structure. The Viadux Phase 1 development was completion early 2024.

The existing Grade II listed viaduct structure encompasses the majority of the Viadux site. It was constructed between circa 1876-1879 and formed the approach to Manchester Central Station. The viaduct is of load-bearing masonry construction with segmental arches running east to west and pointed arches running north to south. These are supported on substantial masonry piers and abutments to the perimeter. Stability of the arches is reliant on balanced dead loading, and on minimising movement to the arches, piers, and abutments. All proposed works and alterations have been designed to respect this and to minimise the risk of damage.

The proposed structural alterations and works that could affect the existing viaduct include:

Plot 2a (76 storey mixed use tower)

- Core Opening
- Column Openings
- Drainage route penetrations
- Basement formation within the arches
- Ground settlements & viaduct movements
- Projecting pier removal to Albion Street elevation
- Parapet removal along Albion Street elevation
- Viaduct service yard level works
- Great Bridgwater Street abutment openings
- Great Bridgewater Street bridge deck removal

Plot 2b (22 storey affordable housing)

- Localised removal of existing masonry parapet

These works have been designed to minimise the impact and risk of damage to the existing viaduct structure. Where interventions are proposed these have been designed to maintain load-paths through the existing structure and minimise the loss of existing fabric. Many of the proposed structural interventions for Phase 2 are similar in nature to Phase 1. The knowledge and expertise gained on Phase 1 has been incorporated into the current proposals.

The new buildings have been designed to be structurally independent of the existing viaduct structure, avoiding overstressing of the existing viaduct, reducing the risk of damage, maintaining load-paths, and behaviour under thermal and loading effects.

The overall fabric loss to the existing viaduct structure, associated with the proposed Phase 2 structural interventions, has been assessed against the 2017 consented scheme. This demonstrates that the proposed loss of fabric is circa 693m^3 for Phase 2 versus 700m^3 for the 2017 consented scheme. This results in a 4% reduction in loss of fabric to the existing listed building.

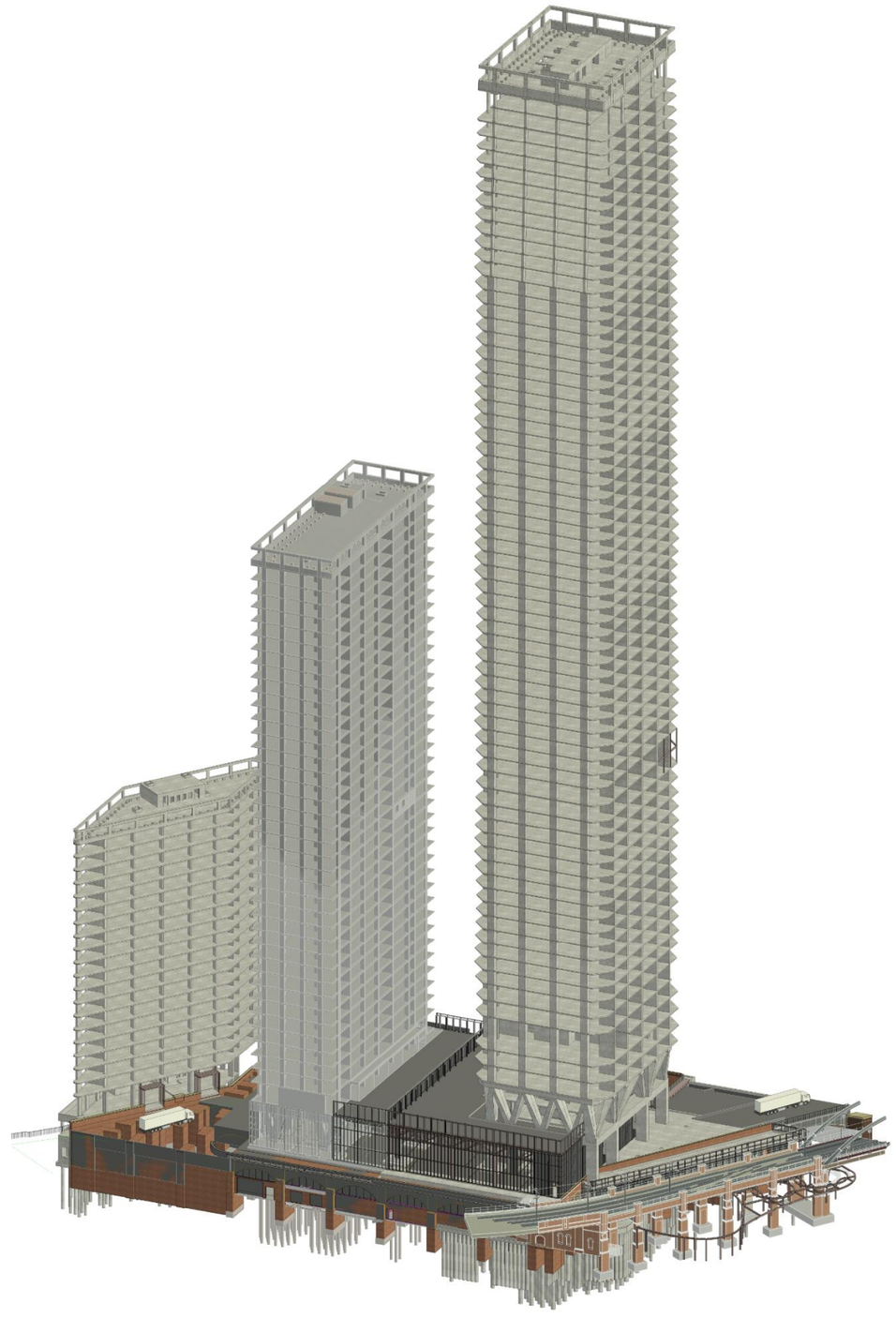


Figure 0.1 Viadux Phase 1 & 2 Development Isometric

1. INTRODUCTION

Renaissance have been commissioned by Salboy Central Limited to develop proposals to support Phase 2 of the Viadux development. This document provides an overview of the structural works for the proposed Viadux Phase 2 development that requires interventions to, or has the potential to impact, the existing Grade II
listed viaduct structure.

The existing viaduct structure, that encompasses the majority of the Viadux development site, was constructed between circa 1876-1879 by Midland Railway Company as part of the Manchester Central Station approach. The existing viaduct is of load-bearing masonry construction with segmental arches running east to west and pointed arches running north to south. These are supported on substantial masonry piers, and abutments to the perimeter. Refer to section 2 of this report for further details on the viaduct structure.

The proposed Phase 2 development is shown in Figure 0.1. The Phase 1 tower and podium works that are nearing completion on site are shown as opaque for ease of reference.

The structural alterations, and impact from the proposed new building, include the following:

Plot 2a (76 storey mixed use tower)

- Core Opening
- Column Openings
- Drainage route penetrations
- Basement formation within the arches
- Ground settlements & viaduct movements
- Projecting pier removal to Albion Street elevation
- Parapet removal along Albion Street elevation
- Viaduct service yard level works
- Great Bridgwater Street Abutment openings
- Great Bridgewater Street bridge daylighting

Plot 2b (22 storey affordable housing)

- Localised removal of existing masonry parapet

These are shown in figures 1.1 and 1.2. Reference should be made to Simpson Haugh drawings 10448-SHP-ZZ-B5D9-JC20-PL-00-001 and 10448-SHP-ZZ-B5D9-JC20-PL-01-001 for proposed demolition plans. An overview of the proposed alterations and mitigation measures to reduce the impact on the existing viaduct structure are presented in Section 3. This includes reference to the Phase 1 works where structural works are similar and help demonstrate the viability of the interventions.

The overall fabric loss to the existing masonry viaduct structure, associated with the structural interventions, is assessed against the 2017 consented office scheme and is presented in Section 4. This demonstrates that the proposed Phase 2 works result in a reduction in loss of fabric to the Grade II listed viaduct masonry structure.

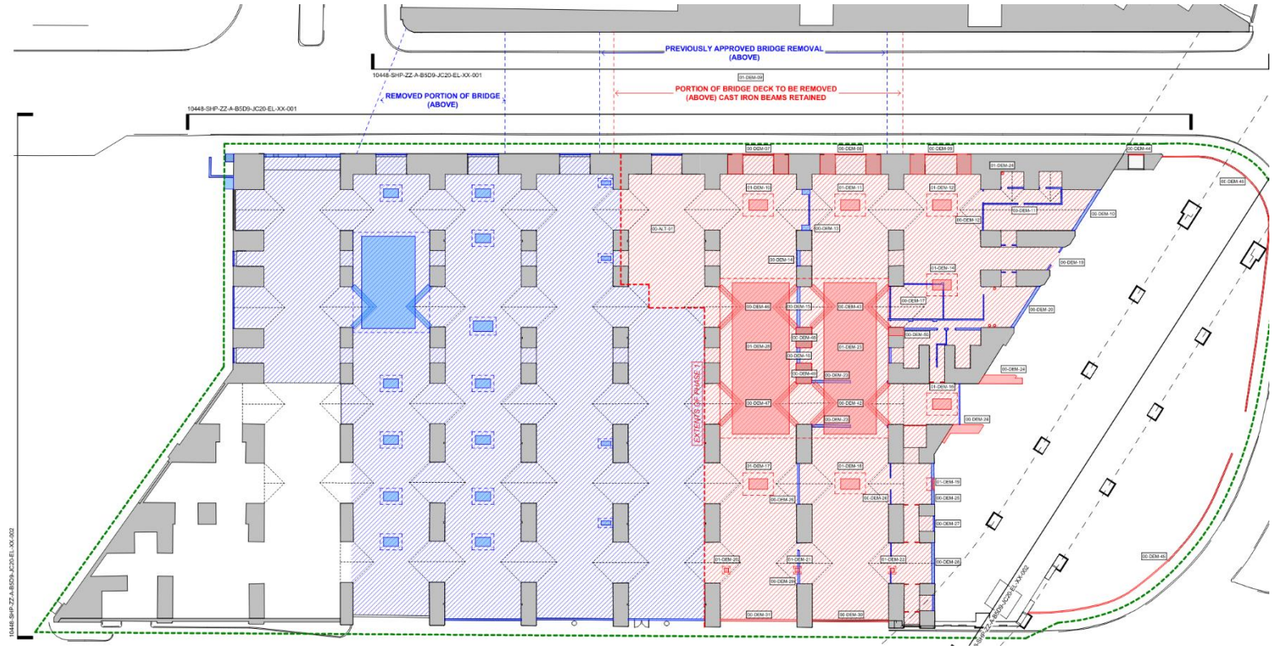


Figure 1.1 Viadux 2 Upper Level Intervention Works

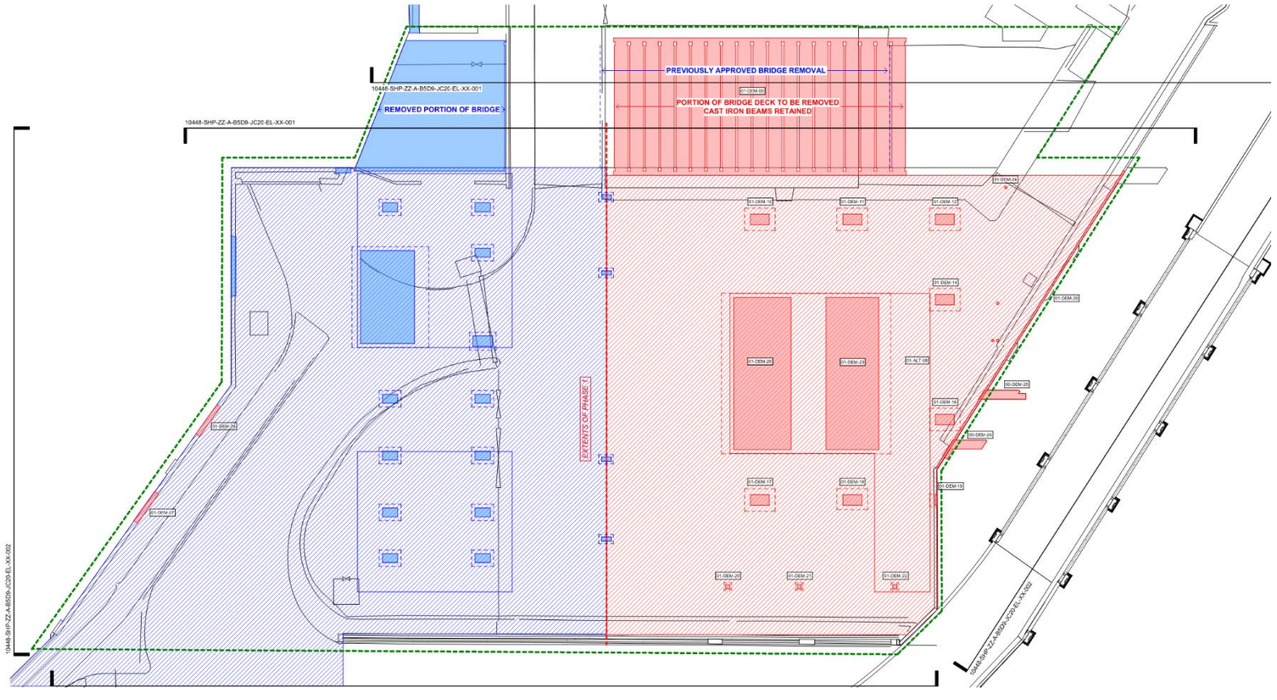


Figure 1.2 Viadux 2 Lower Level Intervention Works

2. GRADE II LISTED VIADUCT

2.1 Building Location

The viaduct structure is located in the city centre of Manchester (National Grid Reference: 383572, 397621 & Postcode M1 5NZ). The structure is bounded by Great Bridgewater Street to the north, Albion Street and the Metrolink to the east, Trafford Street and Deansgate-Castlefield Tram Station to the south, and the Hilton Hotel to the west. The overall site and development phases is indicated in Figure 2.1.

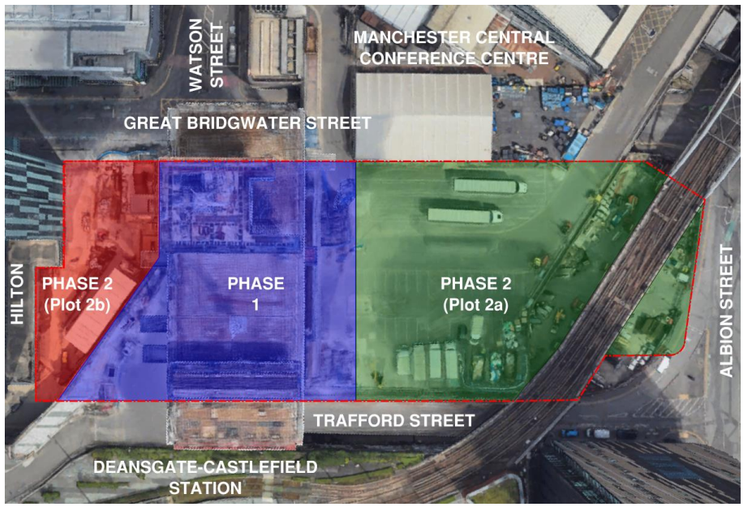


Figure 2.1 Site Location & Phasing

2.2 Building Listing & General History

The structure on the site forms part of the Grade II listing for 'Castlefield Railway Viaduct from G-Mex to Dawson Street', Historic England list entry 1292315. Reference should be made to Stephen Levrant Heritage Architecture reports for further details regarding the listing and significance.

The viaduct on the site was built as part of the approach to the former Manchester Central Railway Station (now Manchester Central Convention Centre). The station was designed by Sir John Fowler for the Cheshire Line Committee and prior to closure was operated by the Midland Railway Company. The Central Station and viaduct were constructed between 1876-1879. The former Central Station structure is Grade II* listed, with the viaduct arches and cast-iron bridge over Great Bridgewater Street Grade II listed.

The Manchester Central Station and viaduct structure on the site remained in use until 1969. Both buildings then fell into disuse.

The Manchester Central Station was converted in the 1980's to form the G-Mex conference centre. As part of these works various alterations were made to the existing viaduct on the Viadux development site, including:

- Raising the level of fill over the whole viaduct by circa 800mm to form a service yard.
- Construction of a new bridge link to the northwest corner of the viaduct to give access from Watson Street.
- Building two new precast concrete bridges above the Great Bridgewater Street cast iron bridge to connect the service yard to the access roads around the G-Mex.
- Removal of the fill from the cast iron bridge to Great Bridgewater Street and downgrading the load capacity.

During the 1990's further alterations were undertaken, including:

- Removal of the 1980's bridge link from Watson Street.
- Removal of the iron bridge over Trafford Street.
- Construction of a new access ramp from Albion Street.
- Construction of the Metrolink tram viaduct to the east with partial support taken from the existing viaduct.

As part of the Manchester Conference Centre operations an open mesh floor has been installed over the cast iron bridge to Great Bridgewater Street. A section of this was replaced with a composite steel frame in circa 2013 to provide a base for a large marquee. These later miscellaneous works interface with the 1980's alteration placed over the existing cast iron arches and abutments.

Works undertaken as part of the 2020's Phase 1 Viadux development included:

- Forming new columns openings within the crown of the existing viaduct arches.
- Forming a new opening through the viaduct arches for the tower core.
- Removal of the cast iron bridge over Great Bridgewater Street adjacent to Watson Street.
- Installation of an access stair and lift to the west corner with localised removal of the existing masonry parapet.
- Creation of public realm to the top of the viaduct linking Watson Street to Deansgate Station.

The original consented 2017 scheme for the Viadux development also included the formation of Spanish steps towards Watson Street that would have resulted in significant loss of the existing viaduct structure. New openings where also proposed to the Great Bridgewater Street abutment. To minimise the impact on the existing viaduct and associated loss of fabric the Client and design team altered the design allowing these works to be omitted.

The ground floor to the viaduct has been partially refurbished as part of the Phase 1 development. The remaining area is currently used for storage. The top of the viaduct is currently used as a service yard with HGV access for Manchester Central Conference Centre, and public realm where the new lift and stairs provide a link through to Deansgate-Castlefield Station.

2.3 Existing Structure

An isometric of the viaduct structure is presented in Figure 2.2.

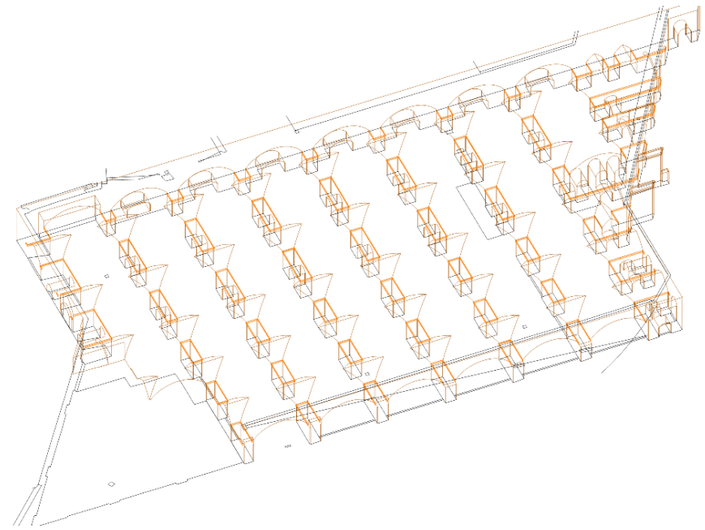


Figure 2.2 Isometric of Viaduct Arches

The structure is circa 125m long x 55m wide and circa 7.7m high. The topographical survey indicates that the ground floor level is circa 34.9–35.5m AOD and the service yard level is circa 43.0-43.4m AOD.

The viaduct structure top deck is formed with masonry arches of brick and lime mortar construction. 8 bays of segmental arches run east to west and span circa 9.15m between support piers and end abutments. 5 bays of secondary pointed arches run perpendicular to the main segmental arches and span circa 4.8m between piers and end abutments. The masonry arches spring from limestone skewbacks to the tops of the piers. The intersections between the main and secondary arches are formed with dressed limestone voussoirs (Figure 2.3). The arches are circa 590mm thick with a 240mm lower ring and 350mm upper ring.

The masonry piers supporting the arches are of solid brick construction. Investigation works indicate that these are founded into the weathered sandstone bedrock at circa 30m AOD. The larger piers and abutments include oval door openings as can be seen in figure 2.3.

Investigation and alteration works undertaken during Phase 1 confirmed the backing material to be masonry between the arches over the piers. The ballast fill level over the arches and backing was originally at circa 42.5m and provided 0.8m cover over the arch crowns. This level was raised to circa 43.2m during the 1980's conversion of Central Station, increasing the crown cover to circa 1.5m.



Figure 2.3 Undercroft Arches circa 1945
Historic England Archive ref: AA98/05434

Figure 2.4 shows the abutment wall with openings, and cast iron arch bridge over Great Bridgewater Street

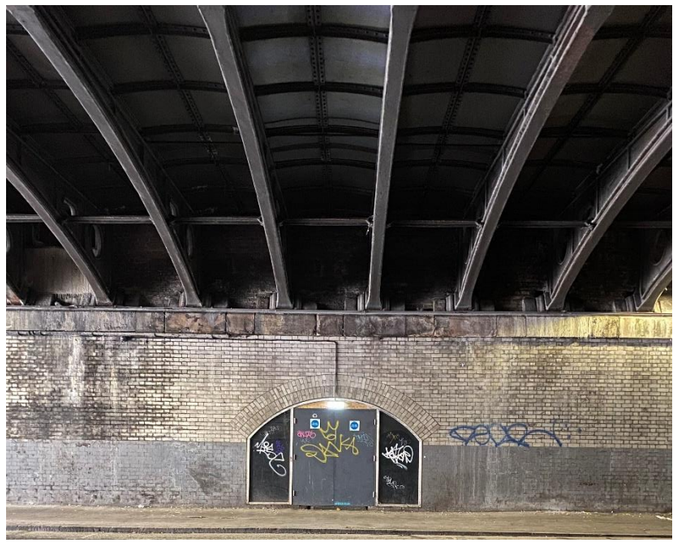


Figure 2.4 – Great Bridgewater Street Bridge & Abutment

The abutment wall along Great Bridgewater Street is circa 2.45m wide and is of solid masonry construction with localised opening. Works during Phase 1 confirmed that relieving arches are provided beneath the openings, with only the piers between extending to bedrock. A continuous limestone skewback along the abutment wall provides support to the cast iron arch bridge beam.

2.4 Structural Behaviour of Arches

To understand the potential structural impact of alterations to the existing viaduct structure, from the proposed Phase 2 development, it is necessary to appreciate how the arches, piers and abutment support and transfer loads applied to them.

Masonry arches behave predominately as compression structures as they have limited tension capacity. As load is applied externally to the structure a compression thrust line forms within the arch as shown in figure 2.5. As the applied load increases hinges are formed. Provided the thrust line remains within the arch, multiple hinges can be formed, with the structure remaining stable. If the thrust line passes outside of the arch section, or the masonry compressive capacity is exceeded, then the arch will fail.

Equilibrium of arches is therefore maintained by the rigidity of the supports and by providing sufficient compression with the arch under self-weight and dead loads. Removal of dead loads (fill etc,) or removing sections of fill creating unbalanced loads can reduce the precompression within the arch, reducing its load capacity. Structural alterations in both the permanent and temporary case must be carefully designed and constructed to ensure that the arch will remain stable and that the imposed load allowance capacity is maintained.

Figure 2.5 shows a typical failure mode for a single span arch under an applied point load and demonstrates the 4-hinge mechanism by which the arch resists loading. This is based on rigid support conditions.

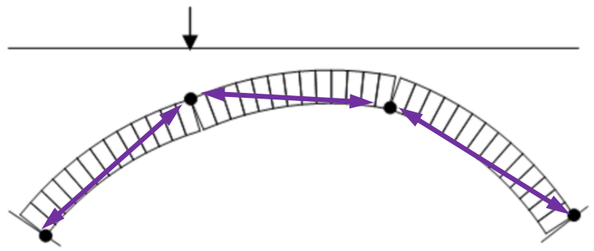


Figure 2.5 - Typical Single Arch Failure Mode

Multi-span arches behave in a similar way to single arches, however the arches interact, transferring thrust forces through adjacent arches and into the piers and end abutments. Figure 2.6 indicates the principles of how the arches interact when applied to a point load (vehicle wheels etc.). It is important to note that the arches either side of the loaded arch are pushed upwards by the thrust forces, which is counteracted by the weight of the masonry and fill above. Multi-span arches are therefore sensitive to unbalanced loading of both self-weight (differences in fill depth) and applied loads.

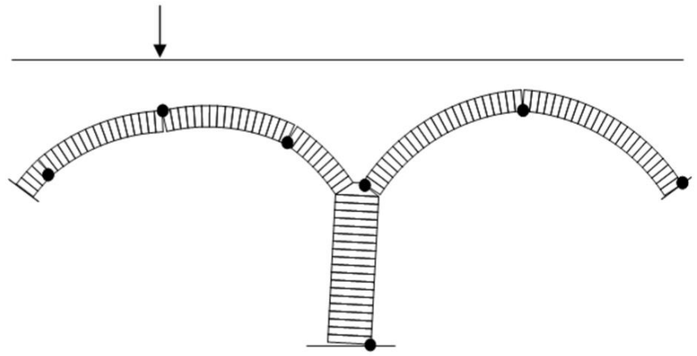


Figure 2.6 - Typical Multi-span Arch Failure Mode

To minimise the impact of the alteration works to the arches the proposals need to maintain the existing load paths. Where works require removal of sections of the arch, these are to be designed to allow thrust forces to funnel around the new openings. Care also needs to be taken to ensure that the removal of fill material and sections of masonry on adjacent arches to those being loaded is sufficient to maintain the stability of the multi-arch system.

The temporary stability of the arches is also critical where loads may become unbalanced, when forming the permanent works. Temporary propping between skewbacks to transfer the horizontal component of the arch thrust forces between piers, combined with centering to the intrados of the arch, is therefore recommended during the alteration works.

The lateral earth pressure against the piers and abutments is also critical to maintaining the stability of the arches as this helps resist the piers rotating under the horizontal forces and the arches spreading. Where deep excavations are required adjacent to piers and abutments, temporary propping will be required. This will need to be designed to resist the horizontal component of the arch thrust and earth pressure due to out of balance loading on the piers. Where basements or deep foundations are to be formed these need to be designed to transfer any horizontal forces acting on the abutments or piers.

3. PROPOSED STRUCTURAL INTERVENTIONS

This section describes the proposed structural works associated with the Viadux Phase 2 development that will affect the existing Grade II listed Viadux structure. This section of the report should be read in conjunction with the Simpson Haugh Architects demolition drawings. The design proposals have been developed in close collaboration with the Architect and Heritage Consultants to minimise the impact and loss of existing fabric to the existing listed structure.

Where structural intervention works are required, these have been developed and located to minimise the impact on the existing viaduct structure and load paths. Consideration has also been given to how the works will be constructed. Where feasible the temporary works have been incorporated into the permanent works to minimise the extent of movement during construction and reduce the risk of cracking and damage to the existing structure.

The column openings, core opening and foundations works are similar to those implemented during the Phase 1 development. Movement monitoring during the works was in line with the initial design assumptions, with no significant distress caused to the existing structure. Where feasible the Phase 2 works have been developed following the same principles for the design and construction as these have been shown to be successful and buildable.

Movement and vibration monitoring will also be undertaken during the structural alteration works. Movement monitoring will also be undertaken during construction of the 76-storey tower. The proposals for vibration and movement monitoring will be developed in detail during RIBA Stage 4 (technical design).

In addition to the main structural intervention works, general repairs will be undertaken to the structure, including repointing, brick repairs, and stone repairs. Reference should be made to the Heritage Architects details.

The Phase 2 development includes structural intervention works as outlined below and discussed in further detail within this section. The impact of the proposed tower development is also considered, :

Plot 2a (76 storey tower)

- Core Opening
- Column Openings
- Drainage route penetrations
- Basement formation within the arches
- Ground settlements & viaduct movements
- Projecting pier removal to Albion Street elevation
- Parapet removal along Albion Street elevation
- Viaduct service yard level works
- Great Bridgwater Street Abutment openings
- Great Bridgewater Street partial bridge deck removal

Plot 2b (Affordable housing)

- Localised removal of existing masonry parapet

3.1 Core Opening

A circa 17.3m x 18.2m opening is required on plan through the existing arches to allow for the core to the 76-storey tower to pass through. This requires a circa 20.2m x 19.2m propped ‘picture frame’ to be installed as described below.

The tower stability system incorporates outriggers and a transfer belt truss to minimise the core size and associated opening through the existing structure. The core has been located to sit centrally between existing viaduct piers. This limits the size of opening and associated loss of the masonry arches. It also allows the existing limestone skewback and supporting piers to be maintained. The tower structure and new opening within the viaduct are structurally independent of the existing viaduct structure, with a 75mm movement joint provided to allow for construction tolerance and differential movement.

To form the core opening, whilst maintaining the stability of the arches, a composite steel and reinforced concrete horizontal ‘picture frame’ with cross props is to be provided as shown in Figure 3.1.

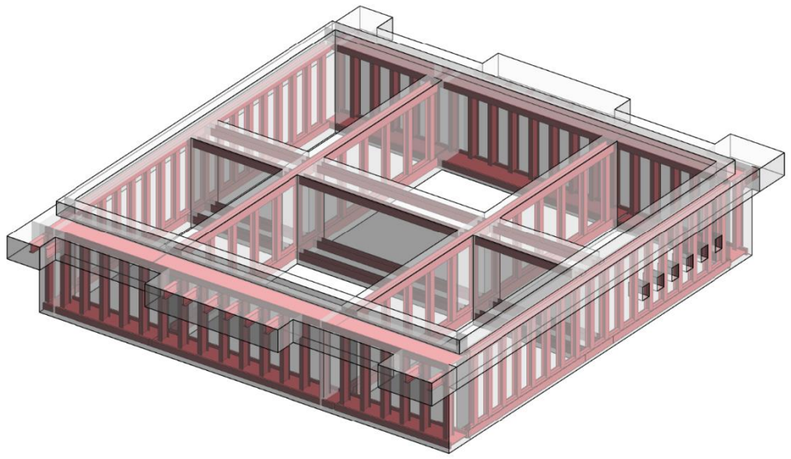


Figure 3.1 Core Opening ‘Picture Frames’

The frame is designed to transfer the horizontal thrust forces from the existing arches around the new openings, so the load paths through the existing structure are maintained. A section through the core opening is shown in Figure 3.2.

The weight of the new ‘picture frame’ partially replaces the weight of fill and masonry being removed. This minimises changes in loading on existing piers and abutments, maintaining overall stability of the viaduct. At RIBA Stage 4 a details assessment of the picture frame and viaduct movements, associated with the tower construction, will be undertaken. The final detailing and construction methodology and sequencing will be developed to minimise the risk of differential movement and cracking to the existing viaduct structure.

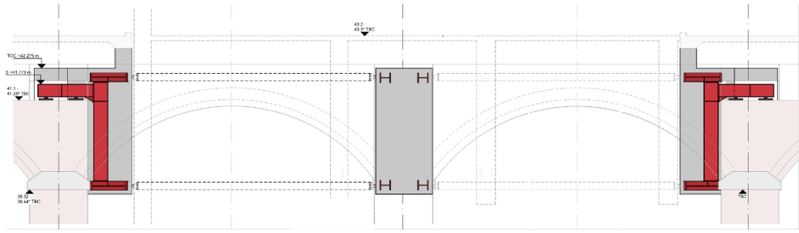


Figure 3.2 Core Opening Section

To minimise horizontal spreading of masonry arches adjacent to the new opening the same construction methodology as adopted on Phase 1 (Figure 3.3) is to be used. The horizontal steel frames are provided at skewback level and above the top of the arches. These are connected with vertical steel ‘needles’ and intermediate horizontal propping. This configuration allows the arch loads to transfer across the new frames. The masonry arch is then carefully demolished, and the new steel frame concrete encased, prior to removal of the temporary propping.

The composite picture frame is designed to limit horizontal movements to circa span/1000 (10mm) to minimise the risk of cracking to the adjacent arches and ensure the require load capacity of the viaduct service yard is maintained. These deflection limits were adopted on Phase 1 with no signs of significant movement or cracking around the new core openings.



Figure 3.3 Phase 1 Core Opening

3.2 Column Openings

To support the tower and podium above the viaduct new structural openings are required for 9No. 1.25m x 2.25m mega columns and 3No. 0.55m x 0.55m composite columns. A small section of viaduct to the Albion Street elevation also requires removal to allow for one of the mega columns. As with the core opening the structural frame to the new tower has been designed to minimise the number and size of openings through the existing viaduct structure.

The mega columns have typically been located centrally between existing piers, so the openings are through the crown of the segmental arches. This allows horizontal reinforced concrete ring beams to be formed within the existing masonry arches. This minimises the loss of fabric and reduction in dead loading. Localised increase in stresses, associated with funnelling of loads around the new opening, are also contained within the new reinforced concrete ring beam. This maintains the existing load path and stress levels within the existing structure. Figure 3.4 shows a section through a typical column penetration and is the same as adopted on Phase 1.

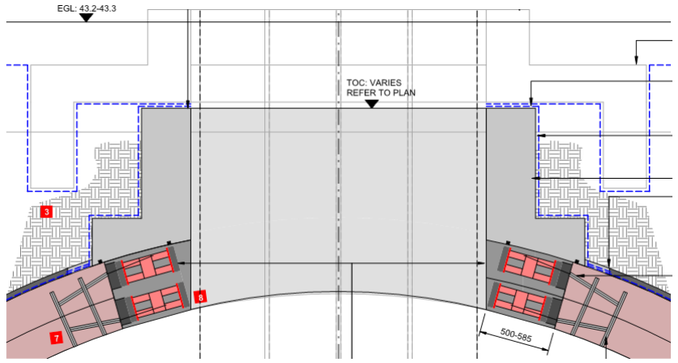


Figure 3.4 Typical Mega Column Opening

One of the mega column punches through a point arch as shown in Figure 3.5. For this opening a reinforced concrete ring beam is adopted. Due to the proximity to the end of the viaduct a reinforced concrete bridging slab is also adopted, allowing the end section of pointed arch to be retained. The bridging slab is localised to the area directly around the new opening so that the existing structure is still able to move under loading and temperature effects.

For the three composite columns, the structural openings are smaller and offset through the pointed arches. One opening is also close to the limestone rib that is formed between the pointed and segmental arch. For these smaller openings a steel sleeve collar solution is proposed as shown in Figure 3.6. This solution minimises the openings through the existing masonry arch and allows the limestone rib to remain intact.

All columns through the arches are structurally independent from the existing structure with a 75mm movement joint provided to allow for construction tolerance and differential movement.

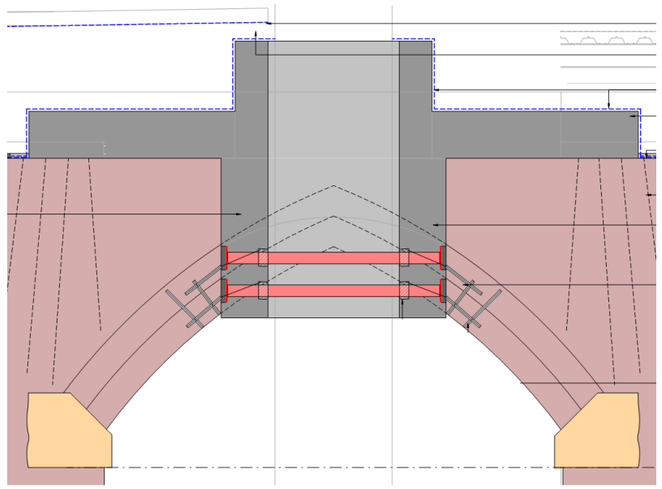


Figure 3.5 Mega Column Opening to Pointed Arch

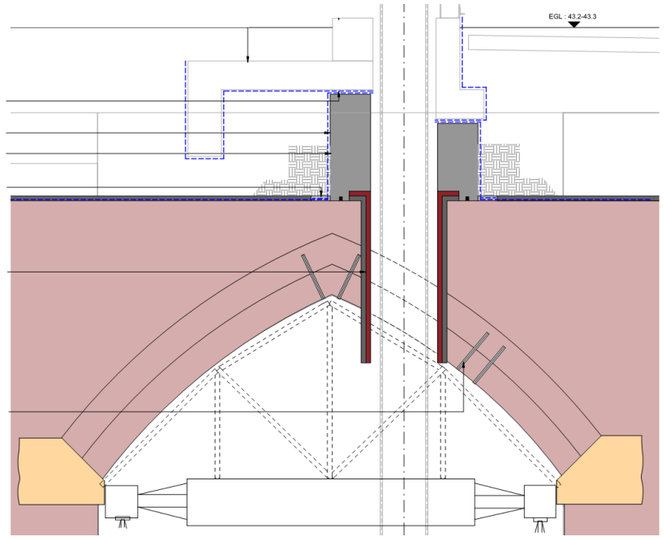


Figure 3.6 Composite Column Opening to Pointed Arch

To minimise movement to the existing structure, and maintain the existing load paths, the new openings to the Mega columns will be formed using the same approach as Phase 1 (Figure 3.7). This adopts the 'Pynford Stool' technique with steel stools installed, prior to cutting out the masonry and constructing the reinforced concrete ring beam. Once the ring beam has gained full strength the central section of masonry is then removed to form the new opening. This approach was successfully adopted on Phase 1 with no significant movement or cracking to the existing structure.



Figure 3.7 Phase 1 Mega Column Opening Construction

One of the mega columns clashes with the end of the viaduct on the Albion Street elevation. At this stage it is proposed that this section of viaduct is carefully cut out and a stainless steel restraint frame installed as shown in figure 3.8. This plate minimises the loss of existing fabric.

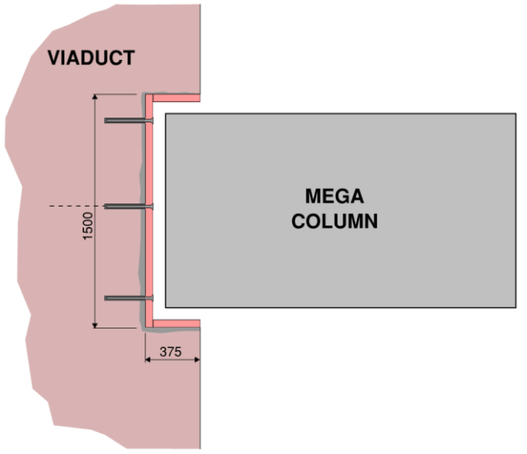


Figure 3.8 Albion Street Localised Viaduct Removal at Mega Column

During RIBA Stage 4 (Technical Design) option will be investigated to see if it is feasible to reduce the mega column locally to avoid the localised removal of the viaduct. However, at this stage it should be assumed that the section will have to be locally removed as shown above.

3.3 Drainage Route Penetrations

Three penetrations are required through the arches to connect the drainage between the service yard and ground floor levels. The penetrations are located adjacent to the existing piers and away from the ribs between the segmental and pointed arches. To minimise the opening a steel sleeve solution is proposed as shown in Figure 3.8.

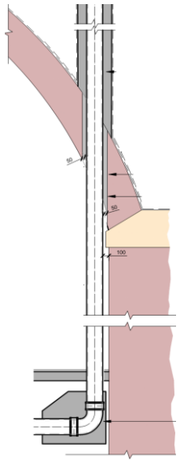


Figure 3.8 Service Opening

A drainage route is also required at high level through the Great Bridgewater Street abutment to provide drainage to the deck of the cast iron bridge over great Bridgewater Street. The details for this are to be developed but is likely to take the form of a circa 200-250mm core from bridge level to below the existing arches.

3.4 Basement Formation within the Arches

The ground investigation on the site indicates weathered sandstone at circa 4.5-6.0m depth, with drift deposits and made ground above. Site investigation works to Phase 1 verified that the existing viaduct piers are founded at circa 5m below ground level into competent bedrock. A site investigation is to be undertaken to verify the depth of pier foundations to Phase 2.

The tower superstructure has been designed to minimise the weight of the building and to help distribute the high building loads over the building footprint. The aim being to smooth out the ground settlements beneath the building core and associated impact on the listed viaduct structure.

Outriggers and a belt transfer truss have also been adopted to distribute the building loads into the mega columns around the perimeter of the building and away from the core. A basement has also been adopted to partially offset the weight of the tower and provide stiff foundations to help distribute the high core loads.

Due to the magnitude of foundation loads from the tower a piled raft is proposed with piles socketed circa 10-15m into the bedrock and the raft formed within the top of the weathered sandstone. A basement is also provided. The foundation solution has been developed to minimise overall settlements that will affect the existing viaduct and surrounding structures

The foundation raft and basement are to be formed within the arches as indicated in figure 3.10.

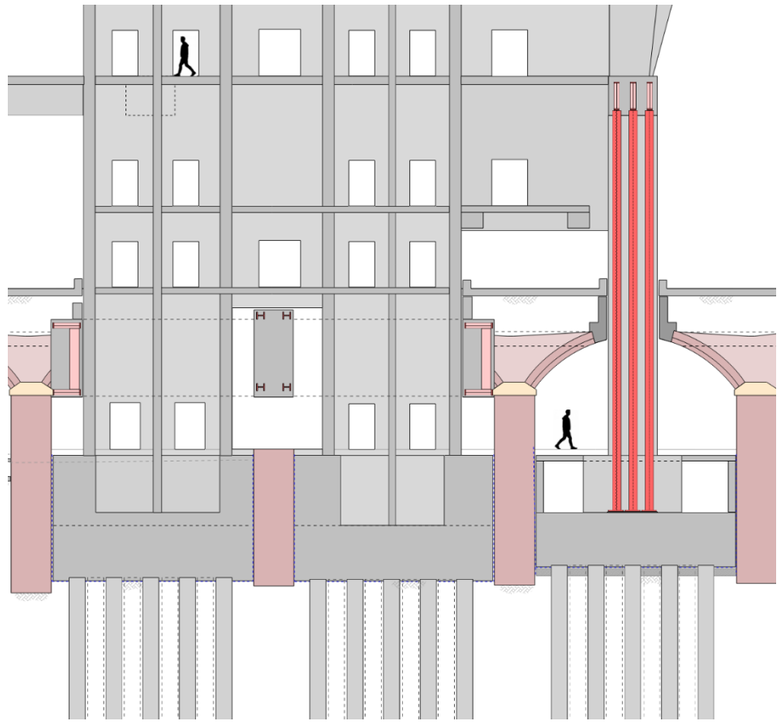


Figure 3.10 Foundation & Viaduct Section

To prevent the transfer of vertical loads into the existing viaduct piers a continuous vertical slip membrane is to be provided between the new and existing elements.

The viaduct piers and abutment rely upon the ground around them for lateral support to resist horizontal thrust forces from the arches above and out of balance earth pressures, where ground levels differ between pier faces. To resist and transfer these horizontal forces the new ground floor slab and basement raft will be cast tight to the existing piers.

During construction horizontal propping will be required to restrain the piers against movement and transfer the horizontal loads in the temporary case. Figure 3.9 shows the principles adopted during Phase 1 of the development. Due to the increased depth of excavation two layers of propping may be required, however, this will be assessed during RIBA Stage 4 (Technical Design) once the final excavation depths and depths of existing viaduct piers are known.



Figure 3.9 Phase 1 Pile Raft Construction with Propping

3.5 Ground Settlements & Viaduct Movements

To understand the magnitude of settlement to the existing arches associated with the construction of the tower A2 geotechnical engineers have undertaken a preliminary settlement assessment.

The settlement plot (Figure 3.11) is for the dead and imposed loads on the tower and predicts circa 25mm maximum settlement. This is within acceptable limits and not of structural concern. To understand the risk of damage to the existing viaduct due to ground settlements the differential deflections (Δ) need to be considered. These deflections induce tensile strains (ε) within the structure, which can be compared against the 'Burland' acceptance criteria in BRE Digest 251 'Assessment of damage in low-rise buildings' and 'Settlement of buildings and associated damage', Burland and Wroth, 1975.

A detailed settlement and damage assessment is to be undertaken at RIBA Stage 4 (Technical Design) and will include detailed modelling of the existing structure to understand the tensile strains. However, at this stage the strains associated with settlement can be estimated, based on the deflection ratio (Δ/L) and building element height (H), using Burland and Wroth.

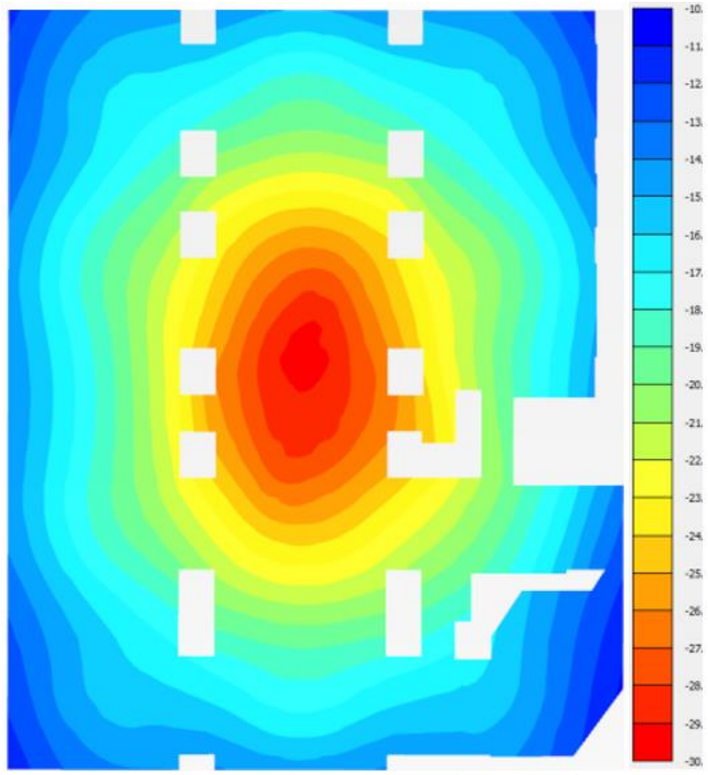


Figure 3.11 Primary Ground Settlement Assessment

As the masonry structure has limited tensile capacity the deflection ratio limit to strain limit can be approximated to $\Delta/L = 0.5\varepsilon$ for L/H = 1 and varying linearly up to $\Delta/L = 1.0\varepsilon$ for L/H>6.

Conservatively assuming a building height H = 2.5m, to reflect the maximum height of the arch and masonry backing, and a differential settlement length L>15m the approximate deflection ratios for a given strain can be estimated as presented in table 3.1.

Risk Category	Max Tensile Strain[1] ε (%)	Degree of Damage	Approx Crack Width (mm)	Deflection Ratio limit[1] (Δ/L)
0	0.05	Negligible	<0.1	1/2000
1	>0.05-0.075	Very Slight	0.1 to 1	1/1300
2	>0.075 -0.15	Slight	1 to 5	1/650
3	>0.15 – 0.30	Moderate	5-15	1/330
4	>0.30	Severe	15-25	>1/330
5		Very Severe	>25	

[1] For hogging Burland & Wroth recommend the ε and Δ/L limit is halved

Table 3.1 'Burland' Acceptance Criteria

These deflection ratios are considered conservative as the viaduct structure is constructed with non-hydraulic lime mortar, which is flexible, compared to the cement mortars the limits are based on.

Figure 3.12 shows the principles adopted in estimating the deflection ratios. Based on the preliminary settlement assessment the deflection ratios are circa:

Segmental Arch Direction

- Sagging Δ = 16mm, L = 31m Δ/L = 1/2000
- Hogging Δ = 12mm, L = 22m, Δ/L = 1/1833

Pointed Arch Direction

- Sagging Δ = 16mm, L = 38m, Δ/L = 1/2375
- Hogging Δ = 10mm, L = 20m, Δ/L = 1/1830.

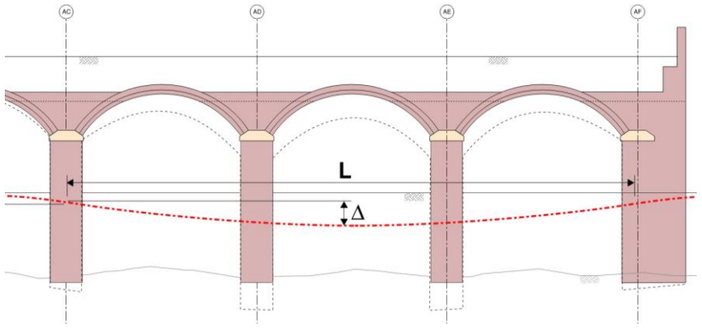


Table 3.12 Deflection Profile Parallel to Segmental Arches

Using the above acceptance criteria the maximum sagging strains are estimated to be circa ε = 0.05%, indicating Risk Category 0 - Negligible Damage. The maximum hogging tensile strains are anticipated to be circa ε = 0.06%, however for hogging the limit is halved, indicating Risk Category 2 - Slight Damage.

For Grade II listed building Slight to Moderate Damage is permitted provided remediation of damage is addressed. Slight Damage is likely to include fine cracking that is visible and requires localised repointing and this will be allowed for within the repair works.

Given the three-dimensional nature of the structure and risk of slight damage a detailed settlement assessment is to be undertaken at RIBA Stage 4. If the risk category is found to exceed the slight criteria, then additional remedial works may be required. If this is found to be the case proposals will be developed at RIBA Stage 4 for the review and approval of the Conservation Officer.

As a comparison the predicted settlements for the 42 storey tower on Phase 1 were 12mm overall with 6mm differential settlement between the segmental arch piers and 3mm to the pointed arch piers with a deflection ratio of Δ/L = 1/2500-3000. Movement monitoring on site recorded comparable values verifying the accuracy of the settlement assessment. No significant movement or cracking have been observed to the existing arches or piers following completion of the building.

3.6 Projecting Piers Removal to Albion Street Elevation

Two projecting piers in engineering brick are proposed to be removed. These piers are of solid masonry construction with blue engineering brick and are a later addition to the original viaduct structure (Figure 3.13). The removal of the piers will not affect the stability of the original viaduct structure. Where the pier has been toothed into the existing viaduct repairs will be required.



Figure 3.13 Albion Street Elevation Piers

3.7 Parapet Removal along Albion Street Viaduct Elevation

A single storey extension is proposed along the Albion Street elevation to provide an entrance for the new development and to extend the service yard above. The reinforced concrete frame for the side extension is to be structurally independent. At the interface the existing masonry parapet is to be removed and an indicative detail is shown in figure 3.14.

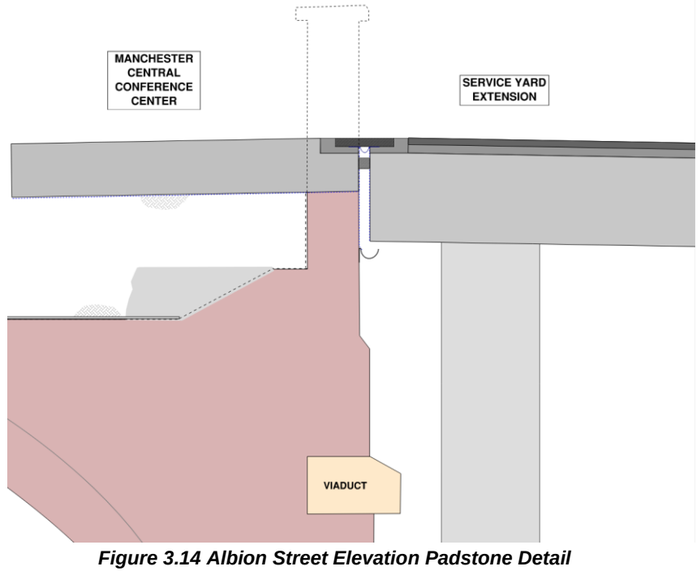


Figure 3.14 Albion Street Elevation Padstone Detail

3.8 Viaduct Service Yard Level Works

The service yard is covered with macadam paving with drainage gullies discharging into a below ground drainage system. Original asphalt waterproofing is also present over the top of the masonry arches which drained to downpipes recessed within the face of the piers. The asphalt and downpipe system are no longer effective, and the macadam and drainage system are of limited benefit. Water ingress through the masonry arches is an ongoing issue, with staining and efflorescence visible in large areas. If not addressed the water ingress will result in continued accelerated deterioration of the structure.

The proposal for building over the viaduct will provide protection from rainwater to most of the viaduct. To protect the external service yard area to the east of the tower a waterproofing system with a concrete apron over slab is proposed. To the elevated landscaped area along Trafford Street a waterproofing system and reinforced concrete planter and slab system is also proposed. This is to drain into a new sealed below ground drainage system within the fill material. The waterproofing specialist will detail the system to provide a continuous system to minimise the risk of further water ingress.

Reinforced concrete slabs are also proposed around the new columns and cores to provide support for vehicle restraint barriers.

3.9 Great Bridgewater Street Abutment Openings

The proposals are to enlarge the existing openings within the Great Bridgewater Street abutment following removal of the section of cast iron bridge above. The walls are circa 2.45m in width and of solid brickwork.

Figures 3.15 and 3.16 show the works to a typical opening. To maximise the new opening height, whilst avoiding the limestone skewback, it is proposed that the openings are formed with a series of steel ‘goal post’ frames supported on reinforced concrete spreaders. This solution allows the beam depth over the opening to be minimised, whilst also evenly distributing the loads around the new opening, avoiding localised overstressing of the existing masonry. The stiffness of the goal post frame also helps minimise beam deflections reducing the risk of cracking to the existing masonry and stone above.

Due to both the thickness of the abutment walls and loading from the masonry above, the proposals are to form the new opening in two stages. Figure 3.17 shows a typical cross section through the abutment wall. The first stage is to install the needles and temporary works to allow half the width of the wall to be carefully cut out. The reinforced concrete base and three of the steel goal post frames are then inserted and grouted into place. Once these have been grouted the temporary works are installed to the remaining half of the wall, followed by removal of the remaining masonry and insertion of the remaining reinforced concrete base and steel frames. The final construction methodology will be developed by the Main Contractor and their Temporary Works Designer.

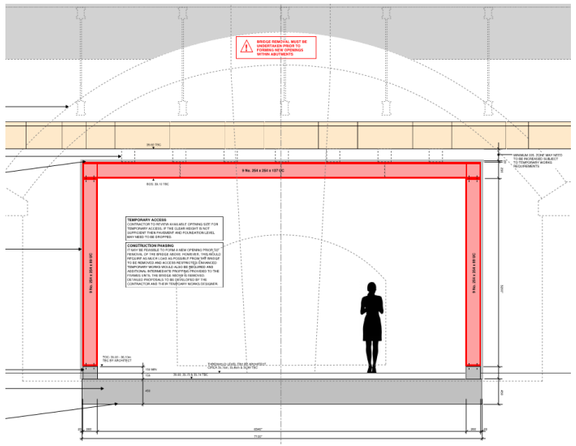


Figure 3.15 Great Bridgewater Street Typical Opening

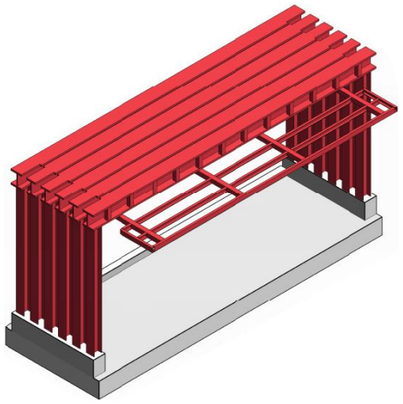


Figure 3.16 Typical Opening Frame Isometric

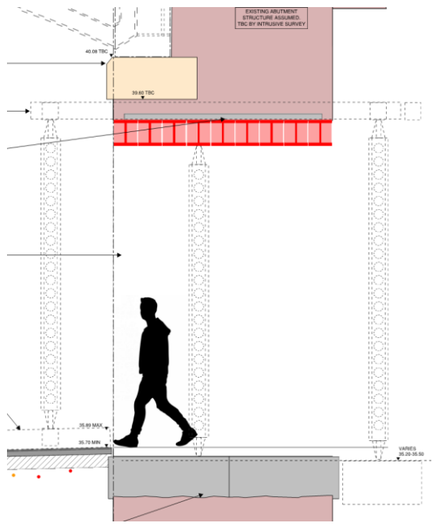


Figure 3.17 Great Bridgewater Street Typical Section

3.10 Great Bridgewater Street Bridge Deck Removal

The Phase 2 Viadux proposals include the removal of the bridge deck to the central section over Great Bridgewater Street.

The works include removing the original wrought iron buckle plate supported on the existing cast iron bridge beams. The existing cast iron bridge beams are to be retained. There is anecdotal evidence that some of the cast iron bridge beam may have cracked so all the beams will be inspected and repaired if found to be required.

On the Manchester Central Conference Centre side, the top of the abutment is to be extended with a reinforced concrete retaining wall as shown in figure 3.18. This is to be tied into the existing 1980’s redundant service duct. The base of the retaining wall is to be supported on the top of the viaduct and reinforced concrete infill panels between the existing beams to give a solid bearing. A movement joint will be provided between the existing beams and new infill walls to allow for differential movement. The wall and backfill partially replace the weight from removal of the bridge deck and does not adversely affect the existing masonry viaduct structure.

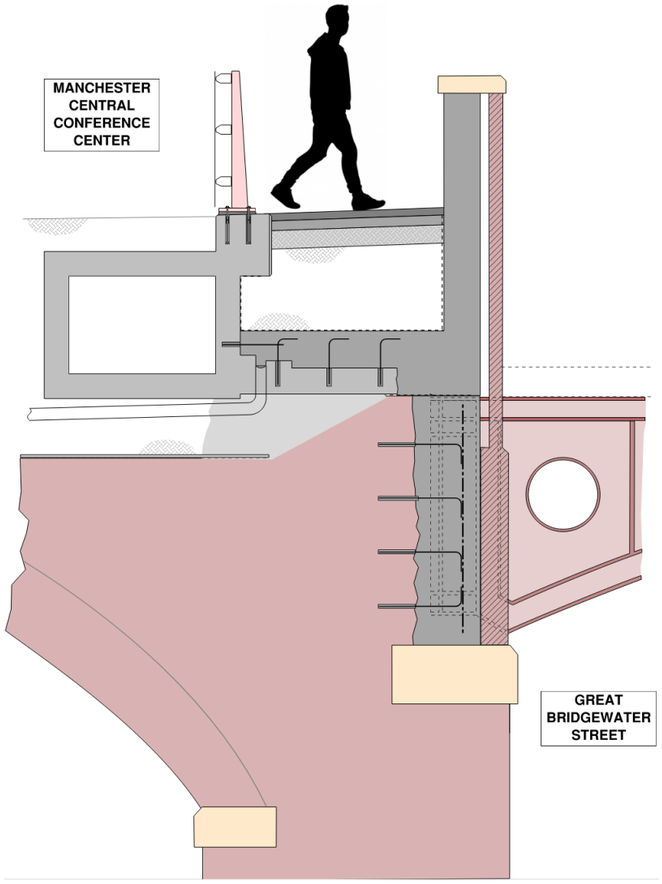


Figure 3.18 Manchester Central Viaduct Edge Detail

On the Viadux Phase 2 side of the bridge the reinforced concrete over slab and retaining walls, installed as part of the 1980's alteration works will be removed. The top of the abutment wall will then be extended with a reinforced concrete retaining wall as shown in figure 3.19. The base of the retaining wall is to be supported on the top of the viaduct and a reinforced concrete infill to give a solid bearing. A movement joint will be provided between the existing beams and new infill walls to allow for differential movement. The wall and backfill partially replace the weight from removal of the bridge and does not adversely affect the existing masonry viaduct structure.

To replace the horizontal restraint provided by the bridge deck new steel ties will be provided to stabilise the existing arches against buckling. The location and detail of these is to be developed at the next RIBA design stage following a detailed buckling analysis of the existing beams. Where feasible the existing holes within the top of the cast iron bridge beams will be utilised for fixing of the new tie elements. The existing bottom ties are to be retained.

The masonry viaduct structures to the Viadux site and Manchester Central Conference Centre are substantial with buttressing. They do not rely upon the cast iron bridge for propping. The removal of the bridge deck elements is therefore structurally acceptable.

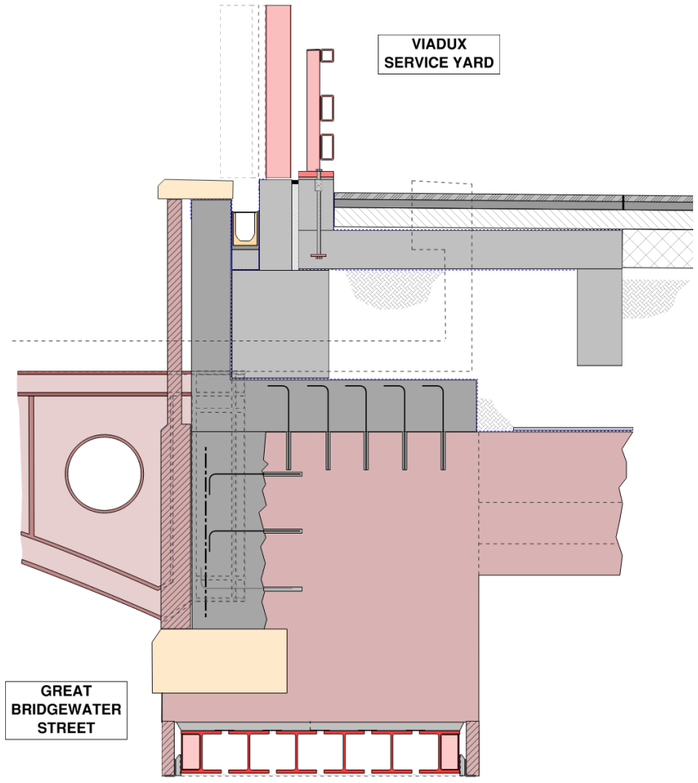


Figure 3.19 Viadux Phase 2 Edge Detail

3.11 Plot 2b Link Bridge

The Plot 2b building has been designed with the façade and structural columns offset from the existing viaduct. This provides clear separation between the new building and existing viaduct and allows the new foundations to be offset.

To connect the building to the public realm space to the top of the viaduct two link bridges are proposed (Figure 3.20).

The link bridges are to be reinforced concrete or steel and will be supported on bridge bearings to allow for differential movement between the existing viaduct and new structure. To form the link bridges localised areas of the existing masonry parapet wall will be locally cut down to allow for the installation of a reinforced concrete bearing plinth to support the new link bridges.

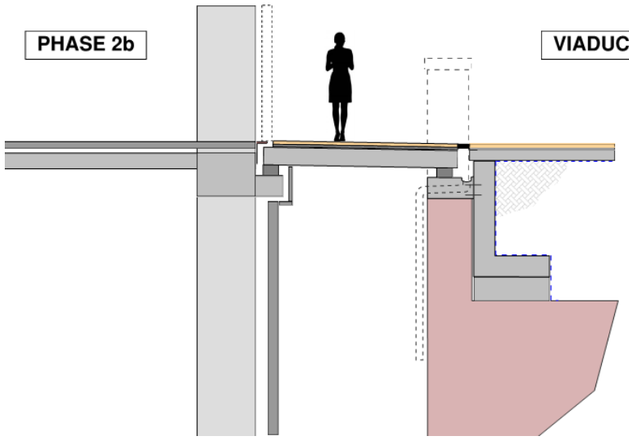


Figure 3.20 Great Bridgewater Street Typical Section

4. ASSESSMENT OF FABRIC LOSS

A comparison of the proposed Viadux Phase 2 development against the 2017 consented office development is presented below. This has been undertaken to understand the impact of the proposals and demonstrate that the Viadux Phase 2 proposals results in a circa 4% reduction in loss of fabric to the Grade II listed masonry viaduct structure.

4.1 2017 Consented Works

The previous office scheme for the site consented in 2017 was for an office development. The consented works included:

- Formation of openings through the arches for new columns
- Demolition of a substantial section of the viaduct end bay arch and abutment to allow for a new core
- Formation of opening through the Great Bridgewater Street abutments
- Removal of a section of the existing bridge deck and cast-iron bridge beam over Great Bridgewater Street

The loss of fabric for these works is summarised in Table 4.1.

Works	Volume (m^3)
Column Openings	9
Core Opening	533
GBS Openings	154
GBS Bridge Removal	24
Total	**720m^3**

Table 4.1 2017 Loss of Fabric

The above volumes are for loss of fabric to the existing masonry viaduct only and ignore the fill material over the arches and all demolition works below ground level. The removal of piers to the Albion Street elevations are also also ignored.

The above estimate is optimistic as loss of fabric associated with implementing the works was not included. In practice the loss of fabric would have been higher.

4.2 Proposed Viadux 2 Works

The extent of works for the proposed Viadux Phase 2 development that result in loss of existing fabric include:

- Formation of openings through the arches for new columns
- Formation of core opening within the existing arches
- Formation of service holes through the arches for drainage
- Removal of a section of the masonry parapet along Albion Street
- Formation of opening through the Great Bridgewater Street abutments
- Removal of a section of bridge deck over the cast-iron bridge beams to Great Bridgewater Street
- Localised removal of brick parapet for link bridges to Plot 2b

When compared to the 2017 consented works the Plot 2a column openings are larger due to the scale of the proposed tower. The core opening has been simplified and avoids demolition of the abutments and associated piers. The openings within the Great Bridgewater Street abutment are also slightly larger to reflect the works required in forming them and transferring loads. The above works also include the introduction of the link bridges to Plot 2b which was not part of the 2017 consented scheme.

The loss of fabric for these works is summarised in Table 4.2.

Works	Volume (m^3)
Column Openings	48.5
Core Opening	442
Service Holes	1.5
Albion St Parapet Removal	17
GBS Openings	172
GBS Bridge Arch Removal	0
Plot 2B Link	12
Total	**693m^3**

Table 4.2 Viadux Phase 2 Loss of Fabric

The above volumes are for loss of fabric to the existing masonry viaduct only and ignore the fill material over the arches and all demolition works below ground level. The removal of the Cast iron bridge over Great Bridgewater Street is also ignored.

4.3 Conclusion

The 2017 consented works result in a loss of fabric to the masonry viaduct structure of circa 720m^3. The proposed Viadux Phase 2 works results in loss of fabric of 693m^3. This equates to a circa 4% reduction in loss of fabric.

This reduction has been achieved by developing the new structural proposals to minimise the loss of fabric, and impact on key features, and by working in close collaboration with the Architect and Heritage Consultant. The structural alterations have also been designed to maintain the load paths within the existing structure, where feasible, and minimise the risk of damage