

INCREMENTAL LAUNCHING OF RAILWAY ARCH BRIDGES

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SUMMARY

Incremental launching is a convenient method of constructing railway arch bridges with stiff decks in highly urbanized areas. Different launching options are shown based on the construction of a railway bridge over Grabiszyńska Street in Wrocław. The article covers a description of the essential process elements, the different procedures implemented, factors that influenced the selection of solutions for assembly and transport of the spans to the construction site. The study contains a number of post-construction conclusions regarding the successful preparation and implementation of process documentation.

Keywords: *Construction process, steel, incremental launching, assembly, transverse slide over, urban area.*

1. INTRODUCTION

Incremental launching is one of the commonly used methods for railway arch bridge construction. The main advantages of this solution are associated with the execution of works while maintaining rail traffic continuity, on site conditions and areas adjacent to the construction site. Unlike other ways of erecting arch bridges, such as: construction using fixed scaffolding or multi-stage assembly of segments at the final location, the launching method allows for the carrying out of much of the construction works away from the final location and limits interferences to the obstacle. Depending on the site topography, soil and water conditions and type of structure, one can flexibly choose support types for structures launching. The Designer has a full range of options – from continuous sliding tracks, through individual supports on scaffolding or shallow foundations, to high tower structures on a deep foundation directly in a waterway. In special cases one can also use mobile methods, such as ballasted floating supports.

The large diversity of different process types of launching determines the need for the Designer to take into account material and equipment resources of the Contractor, including the preparation of comparative analysis of support options, location of assembly stations and launch routes. The most commonly used options take into account simple movements of the structure, which reduces the cost of the process and duration of the launching. An example of an exception to this rule is the railway bridge over Grabiszyńska Street in Wrocław. Located within a dense urban network, complicated railway track layout and the necessity to maintain continuous railway, vehicle and except for short periods of time, also tram traffic under the structure forced the Designer to apply an individual approach to each one of the constructed spans. This generated the

need to apply multiple types of launching and implementations. The experience gained in the process of the design and construction of the railway bridge over Grabiszyńska Street is the basis for the multilevel analysis of the launching process in terms of shaping the system, staging the works, selection of means of transport, development of process elements and the implementation process.

2. CONSTRUCTION OF THE VIADUCT OVER GRABISZYŃSKA STREET IN WROCLAW

2.1. Location of the structure

The bridge is located over Grabiszyńska Street in the south-west part of Wrocław, at the intersection of Grabiszyńska and Manganowa Street. Three railway tracks are located on the embankment:

- track no. 1 of Line No. 271 (E59) Wrocław – Poznań, horizontal curve on the structure,
- track no. 2 of Line No. 271 (E59) Wrocław – Poznań, transition curve on the structure,
- track no. 1 of Line No. 273 Wrocław – Szczecin, in straight line on the bridge.

Grabiszyńska Street - which runs under the bridge - connects the city centre (Legionów Square) with a suburb of Oporów. The street is a double carriageway, with two lanes each, separated by a two track tram line located on a dedicated track between the carriageways and non-standard pedestrian walkways near the abutments. The road is not fitted with crash barriers. The curvilinear course of Grabiszyńska Street under the railway bridge was forced by the necessity to fit in a limited clear span between abutments of the existing bridge. The horizontal clear span was 22.11 m, vertical was 4.51 m.

The project took place in a highly urbanized area, on one of the arterial roads of the city of Wrocław. This is reflected in a dense network of utilities located under the bridge. Their location (shown in Fig. 1) had a direct influence on the design of the construction supports.

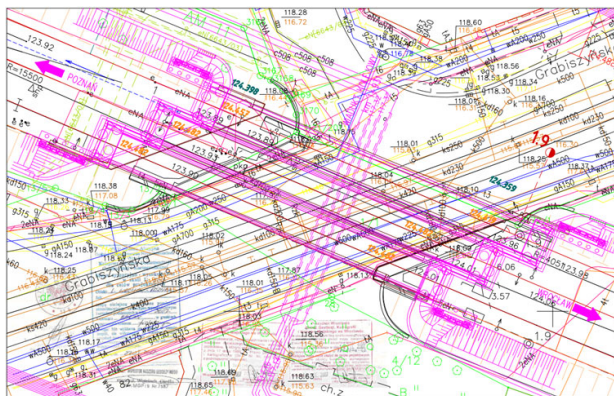


Fig. 1. Location Plan showing proposed structure

2.2. Bridge prior to refurbishment

The structure of the demolished railway bridge was a simply supported single-span truss. Two parabolically shaped upper chord steel truss spans were joined together with rivets. The two-track span, located to the west, had a design span of $L_T = 36.18$ m, while the single-track east span had a design span of $L_T = 35.92$ m. The structures had a taper angle of 44° , no bracings of the upper chords, a deck based on steel trough plates and an N type cross brace (brace-post).

2.3. Design process

2.3.1. Design assumptions

A number of assumptions were made at the concept design stage, which affected successive stages of the project. The horizontal clearance of the bridge had to take into account the possible future renovation of Grabiszyńska Street. It was decided to line up the bridge supports with the building lines of Pereca and Wysoka Streets. Structural and construction process solutions had to limit to a minimum traffic hindrances on Grabiszyńska Street and take into account the conditions necessary for related railway work scopes, including staging of works on the railway tracks, overhead lines and resulting track closures. In the course of the design process it was established that separate spans and supports must be provided for each one of the three tracks to allow for the location of narrow assembly stations on the embankment, in the area behind the abutments. The steel structure of the spans was to be initially prefabricated at a steel workshop and then assembled on site. For the purpose of reducing earthworks and limiting disturbance to railway traffic on active tracks it was decided to protect the not yet rebuilt abutments with sheet pile walls.

2.3.2. Basic technical parameters

A single span arch bridge with stiff deck, simply supported on separate supports for each track was adopted at the concept design stage. The side elevation of the bridge is shown on Fig. 2. The steel structure of the spans was selected as welded (also with respect to assembly joints). The superstructure comprises of a deck with a main box girder reinforced by the arches, steel rod hangers and orthotropic roadway with trough stringer ribs and cross beam girders. The spans are placed on spherical bearings. Pile supports are made of reinforced concrete large diameter piles with a monolithic cap. The wing-walls are parallel, monolithic, on reinforced concrete foundations, with renovated sandstone coping. The superstructure is made of S355J2+N structural steel, fittings of S235JRG2 steel. The abutments and their foundations are made of C25/30 W8 F150 concrete and A-IIIN RB500W reinforcing steel.

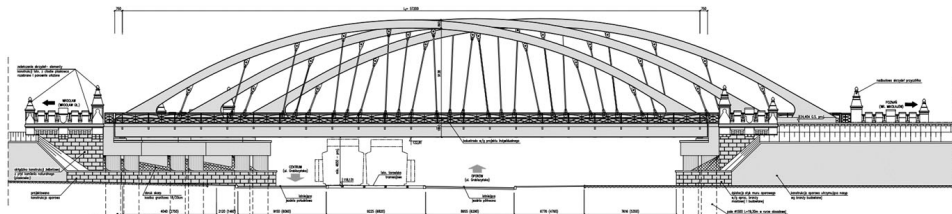


Fig. 2. Proposed bridge. Side elevation.

Table 1. Basic parameters of the proposed bridge.

Parameter	Symbol	Value [m]
effective design span	L_T	57.200
span length	L_C	58.700
span height	H_C	11.925
structural height of line no.1	H_K	1.553-1.605
structural height of line no.2/no.3	H_K	1.553
cross beam span	-	2.600
stringer span	-	0.620
intertrack span	B	2x6.000
horizontal clearance under the bridge	B	33.43
vertical clearance under the bridge	H	4.650

2.3.3. Choice of the assembly process

The decision process regarding the location of the span's assembly stations and assembly methodology was based on the fulfilment of time constraints imposed by the staging of track works with the possibility of tramway and single lane road closures of Grabiszyńska Street for short periods of time only. In addition, during the design stage space constraints had to be addressed, such as: railway site boundaries, existing and proposed elements of railway infrastructure (including overhead line gantries and piers), location of existing underground utilities in the area of the temporary supports and mobile crane, adjacent buildings, access roads, lack of a central reserve on Grabiszyńska Street, as well as the narrow railway embankment set in a horizontal curve. The necessity to make allowance for other construction works in the area adjacent to the bridge was taken into account as well (i.e. construction of a retaining wall on the city centre side of the embankment). Difficulties with site access for construction equipment was minimized, as well as the necessity to temporarily support the tram overhead network. Significant to note was also the higher elevation of the proposed spans in regard to the existing structure.

The high volume of road traffic on Grabiszyńska Street as well as the importance of this artery for the city prevented the permanent location of supports for segmental assembly of the bridge structure over the street. The dead weight of the steel structure at about 237t prevented the assembly of the full spans with use of a mobile crane.

3. INCREMENTAL LAUNCHING DESIGN OF THE SPANS OVER GRABISZYŃSKA STREET

3.1. Initial principles of the Project

3.1.1. Staging of track works

One of the key aspects of the cooperation between different consultants at the design stage was the issue of organizing railway traffic operations during the construction of the bridge over Grabiszyńska Street. Two important railway lines run along the bridge and a complete closure of the lines would paralyze all north bound traffic from the city of Wrocław, generate huge financial losses and difficult to estimate social costs. The bridge is a part of branch outpost Grabiszyn, as shown on Fig. 3.

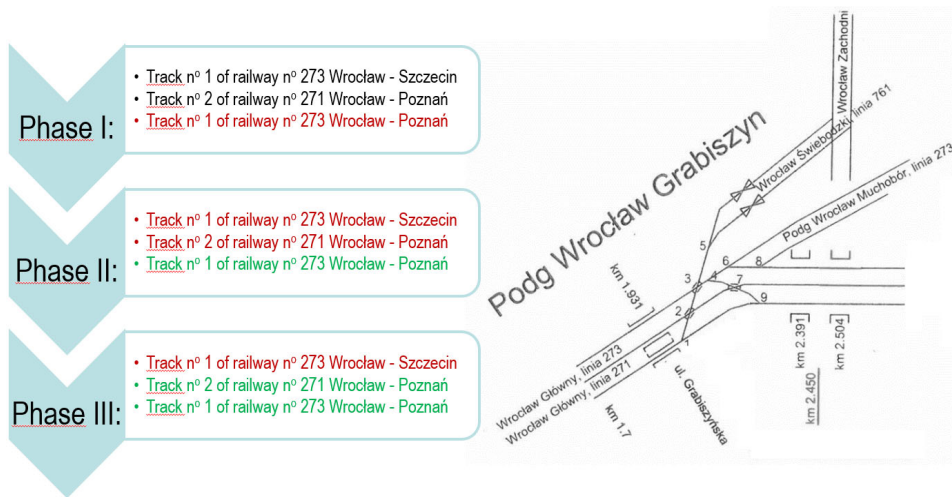


Fig. 3. Track layout diagram. Green indicates operational tracks, renovated, red – closed.

Separate stages of track closures were adopted for each span of the demolished structure. The structures replacing the two-track span were constructed simultaneously in two shortened stages. Railway traffic was resumed immediately after launching of the span on track no. 2 of Line No. 271, which generated an additional work stage.

3.1.2. Traffic organization of Grabiszyńska Street

Incremental launching of individual spans into position required approvals from the Roads Department, Traction Network Department and Public Transport Department. Due to the necessity to locate intermediate supports on the tramway it was necessary to close the tram lines and organize temporary bus transport. It was assumed that construction of the temporary elements on the road, launching of the structure, demolition of supports obstructing traffic and fixing of the tram traction to new spans could take no longer than a week. In the absence of alternative pedestrian routes, pedestrian traffic was maintained for the entire duration of construction works.

The angle of intersection between the road and the bridge differed significantly from the angle prior to reconstruction. The necessity to support the demolished structure at girder joints determined an out-of-parallel arrangement of axes of the supports to the bridge axis. For safety reasons it was necessary to close at least one traffic lane in each direction. After consultation a decision was made to close one of the carriageways completely and to reroute traffic in both directions to the other carriageways. The same problems aroused during the incremental launching of spans into their final position. The axes of the temporary supports were placed perpendicular to the launching direction, i.e. at approx. 45° to axis of the road. Complete closure of one of the carriageways allowed the Contractor easy access to temporary structures.

3.1.3. Remaining associated disciplines

An important challenge for the design team was the connection of works on the bridge construction to the surrounding structural work. The design required for the bridge wing-walls to be continued in the form of retaining walls constructed ahead of the bridge engineering works. The positioning of the foundation cap beams directly below the assembly station of span no. 1 was the basis for a complex analysis for the selection of position, type and function of temporary supports.

The track system was implemented in stages and there was a need to support the overhead line network to newly built support elements. Some of the gantry structures limited access to assembly stations from the top. The solution to this problem was the staging of works, taking into account separation of the function of specific stations and allowing for the transport of partially merged structures between the stations. As a result, only the bridge deck and main girders were assembled under traction gates.

3.1.4. Adjusting assembly methodology to suit abutments construction conditions

Construction works on the abutments took place at the same time as the assembly of steel structure. The area required for the excavation was secured with anchored steel sheet pile wall sections, supplemented by capping beams and struts in the corners. During the execution of works on track no. 1 of Line No. 271, a vehicle circulation area for heavy equipment and access road to the embankment from the side of the city centre was allocated in the area behind the abutments. For this reason, the location of the assembly station was further limited by the gauge of track no. 2 of Line No. 271, the face of the retaining wall and the edge of access road embankment. The access road was a fixed point – its location was dictated by the adjacent garage buildings.

3.2. Phase I – assembly of span no. 1

3.2.1. Assembly station

For the purpose of assembling and launching of span no. 1 an assembly station was constructed, located on the slope of the embankment, parallel to the tangent of the horizontal curve of track no. 2 of Line No. 271. For this reason, the position of the assembled span was out of alignment with the final centre line of the structure. This fact required for design of the temporary supports for both the incremental launching and a rotation relative to a point away of the assembly station, which in practice meant adapting it for a transverse launching of the end of the span along the circular curve. The station was approx. 22 m away from the face of proposed abutment to allow for 8 m wide technological drive. The total distance the superstructure had to move was 82 meters, which included the initial push, rotation of the span to the next starting position and the final launch over Grabiszyńska Street.

Shipping elements constructed in accordance with Fig. 4 were transported to the site by road and placed in position using a mobile crane with max lifting capacity of 200t. Installation of the crane was a separate issue and required a study of ground load bearing capacity and introduction of protective measures of the gas lines located under this area. Works which were in collision with the railway gauge were allowed only during scheduled night traffic breaks.

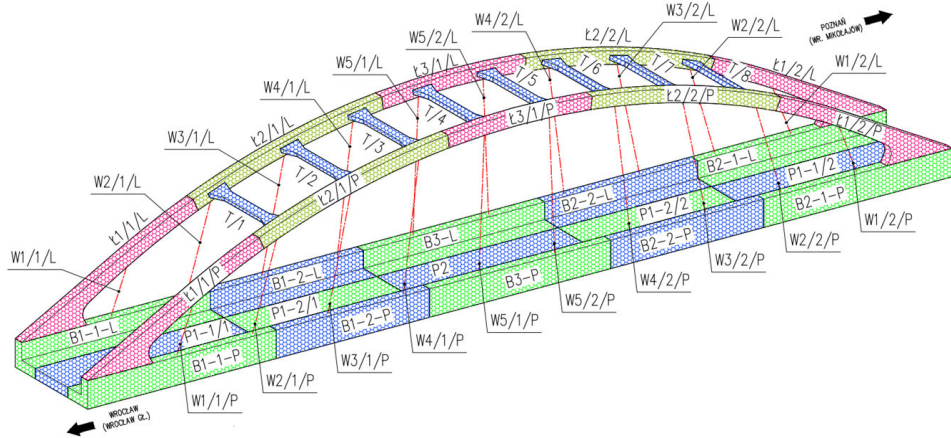


Fig. 4. Diagram of subdivision of the structure into easy to transport elements.

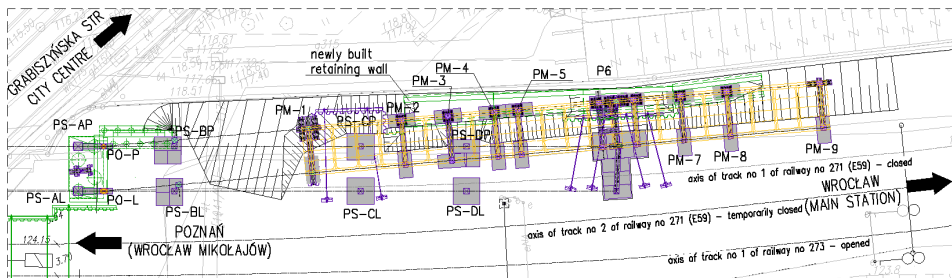


Fig. 5. Assembly station on the embankment on the city centre side.

3.2.2. Temporary supports

Temporary supports used during Phase I varied in terms of the type and elevation of foundations, type of connections and function. S355J2+N steel was the basic material used for construction of the support cap beams. The majority of connections were designed as bolted connections to speed up assembly and later dismantling of the elements. Positioning of the supports, which were part of the assembly station, is shown on Fig. 5. A summary of basic characteristics of the supports is shown in Tab. 2.

Table 2. Schedule of temporary supports used in Phase I.

Support ID	Function	Foundation	Structure
PS-AL/PS-AP	Incremental launch, assembly place	Fixed to the abutment	Foundation framework bolted to vertical support elements
PO-L	Lunching support at the rotation	Direct on road slabs	Support table of welded sections
PO-P	Rotation point	As above	As above
PS-BL/PS-BP/ PS-CL/ PS-CP/ PS-DL/PS-DP	Final incremental launch	As above	As above
PM-1	Joining of the bridge deck, initial incremental launching	Indirect on 4 steel pipes Ø508x4	Grid of welded sections
PM-2/PM-3/ PM-4/PM-5/ PM-7/PM-8/	Joining of bridge deck structure	Direct on road slabs	Grid of welded sections positioned on support cages ZBM90 / support table of welded sections
P6	Joining of the bridge deck, initial incremental launching, slide track during rotation, final incremental launch	As above	Grid of bolted sections positioned on support cages ZBM90 / sliding track of welded sections (see: Drawing No. 6.)
PM-9	Joining of the bridge deck	Indirect on 2 steel pipes Ø508x4	Grid of welded sections
PL-1/PL-2/ PL-3/PL-4	Joining of arch girders	Direct on road slabs or levelling course	Grid of bolted sections positioned on support cages ZBM90
PP-1/PP-2P	Final incremental launching	Direct on road slabs	As above
PP-2L	As above	Fixing to demolished abutment	Grid of welded sections
PP-3	As above	Fixing to constructed abutment	Grid of welded sections
PM-9	As above	Indirect on 2 steel pipes Ø508x4	As above

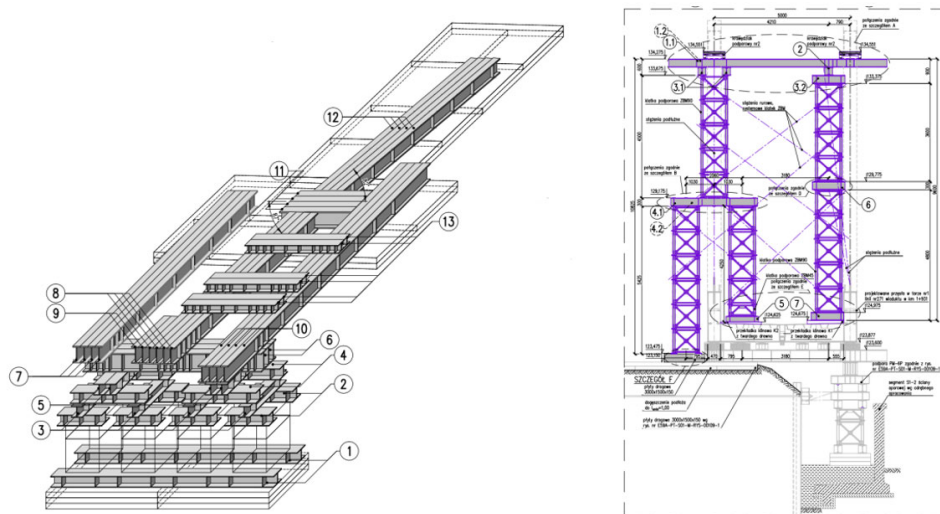


Fig. 6. Left: diagram of the multifunctional launching support P6, used at the assembly station for span no. 1; right: support for arch girders.

Supports PP-1, PP-2 and PP-3 were used primarily for the launching of the structure into its final position and were constructed in the street under the bridge and on the abutments, immediately before the final launching. Due to the considerable horizontal forces of up to 10% of the dead weight of the span, support PP-1 was anchored by stay cables to the existing abutment on the side of structure's launching. The location of temporary supports on the roadway was determined by the position of the underground utilities. District heating pipelines were safeguarded by spreading the load using several layers of road deck slabs. The maximum allowable span of the cantilever of the launched span was set at 22.1 m.

3.2.3. Launch station, initial launching of the span

Due to the two-stage launching process of the steel span (initial and final launching), it was necessary to shape the supports PS-AP and PS-AL in such a way as to allow for fulfilling of the role of both slide supports, as well as parts of the launch station (where retaining blocks with hydraulic jacks could be fixed). The upper part of the support was expanded to allow for the fitting of pull anchors in two positions, allowing for the pulling of the structure during the preliminary and final launching from only one point.

Completion of the assembly of the structure at the assembly station initiated the next stage of the works. Although the assembly of some temporary supports could run simultaneously with span's assembly process, the remaining portion of the works could only take place after the completion of span's assembly and demolition of temporary access road on the embankment. This was due to the fact that the temporary access road was located in the immediate vicinity of some of the temporary supports and maintaining its function during the launch process would be impossible.

The incremental launching process was controlled by the anchor points, fixed to selected cross beams. Small adjustments of the trajectory could be induced by using of two separate launching points.

3.2.4. Span rotation

The next step after moving the span from the assembly station to the support PO-P and PO-L (initial launching) was the rotation of the span into a position that allowed for the main launch. A plate with a centrally located hole was welded to the lower flange of the box girder so that a pin of sufficient strength could create a pivot for the steel span. A station for the fitting of a hydraulic jack was located on the other side of the assembly station and it comprised of an anchor block fixed to a steel capping beam of a sheet pile wall driven into the embankment. The centre of rotation of the span was positioned on support PO-P. The location of the pivot point was chosen so as to minimize the total number of component translation operations of the span from the assembly point to the final position.

3.2.5. Launching into final position

The next stage after completion of initial launching and rotation was the launching of the arch beam into its final position over Grabiszyńska Street (Fig. 7). This process required a number of additional steps. Firstly, it required the rehangng of the tramway's overhead lines. The next step required much more work. Due to a large distance to cover during incremental launching into the final position it was necessary to provide an intermediate temporary support, which - because of high volume of road traffic - could only be placed on the tram tracks, involving a couple-of-day closure of all tram services.



Fig. 7. Span no.1 during the launching process over Grabiszyńska Street (source: fotopolska.eu).

The large vertical and horizontal load, as well as a high density of underground utilities located near tram line, led to a necessity of spreading the load from the supports over a large area (using several layers of road deck slabs), the bracing of individual branches of the support, as well as the introduction of stay cables (fixed to the abutment on lower mileage side) that secured stability of intermediate support. Additional multi-segment steel temporary supports were provided on the old abutment on higher mileage side, which allowed for support of the span after the launching stage and setting on the bearings.

Additional elements, for the securing of the steel structure of the span, were struts fixed between box girders of the bridge deck and the arches. The struts were made of steel pipes. The hangers, which are slender and do not transfer compressive forces, would not be able to cope without additional struts. The maximum span of the steel structure's cantilever - before reaching the intermediate support on the tram tracks and the final support on the abutment - would cause such a deflection (change of span's geometry) which in turn would cause excessive compressive forces in the hangers. The use of struts eliminated the adverse impact of this force on the hangers, because the force was taken over by the pipe struts.

3.3. Phase II – assembly of span no. 2 and bridge deck of span no. 3, incremental launching of span no. 2

3.3.1. Assembly station A and B

The tight schedule of track closures and the lack of any additional time reserves required the assembly of two steel structures at the same time. For this reason, two assembly stations, arranged nonlinearly relative to each other, were constructed on the embankment. The relative nonlinear position was due to the layout of the railway tracks (tracks on a curve). Assembly station A, constructed as point supports, was located at an earlier point on the track and only served as a position to merge the deck of span no 3. This was due to the assembly station being located directly under the newly-constructed overhead line support gate. Moving a completely merged span under the gate (bridge deck, arch and hangers) was impossible. The second assembly station (noted B) was constructed as a continuous support, located at the higher mileage, between assembly station A and the abutment. Its centre line coincided with the destination centre line of span no. 3 (over Grabiszyńska Street). Assembly station B was used to assemble the entire span no. 2 and the assembly of the arches to the deck of span no. 3 (after the initial push from station A to station B). An additional function of station A was to use it as the continuous track for the final launch. The layout of both assembly stations is shown on Fig. 8.

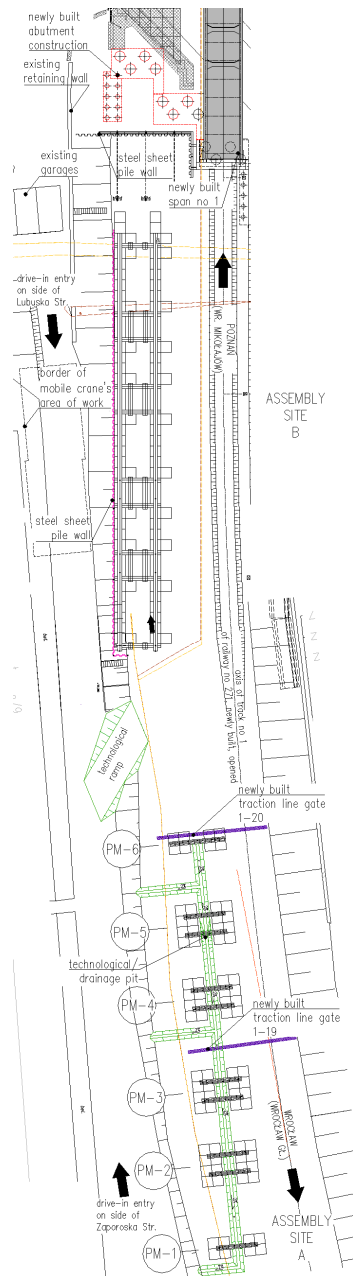


Fig. 8. Layout of assembly stations A and B.

3.3.2. Temporary supports

Additional supports were provided for the purpose of moving the structure of span no. 3 from assembly station A to station B, allowing for the reduction of the cantilever of relocated structure. Similarly to Phase I, supports were provided at newly built abutments, capable of transferring horizontal forces to the abutments (supports PS-I2, PS-J). Supports founded directly on the embankment were added in front of the abutment on the launch approaching side. On Grabiszyńska Street roadway, prior to the final incremental launching, braced with the abutment support structure PS-K was set on the tramway, as well as dual-purpose support PS-L (see Fig. 9) enabling also transverse sliding of span no. 2 into its final position. An important feature of support PS-L was the ability for its quick, partial dismantling to allow for the lowering of the span structure onto its final bearings. A complete list of temporary supports used in Phase II and III is shown in Table No. 3.

Table 3. Schedule of temporary supports used in Phase II and III.

Support ID	Function	Foundation	Structure
PM-A/PM-B/ PM-C/PM-D/ PM-E/PM-F/ PM-G/PM-H	Joining of the bridge deck and initial incremental launching of span no. 2	Direct on road slabs	Foundation of welded sections located cross wise to the centre line of the span
PS-I1	Final incremental launching of span no. 2 and no. 3	As above	As above
PS-I2	Final incremental launching and transverse slide over for span no. 2 and no. 3	Fixed to abutment	Foundation grid bolted to vertical support elements
PS-J	Final incremental launching of span no. 2 and no. 3	Direct on road slabs	Grid of bolted sections positioned on support cages ZBM90
PS-K	Final incremental launching	As above	As above
PS-L	Final incremental launching and transverse slide over for span no. 2 and no. 3	As above	Grid of bolted sections positioned on support cages ZBM90. Angle braces made of steel sections supporting structure on sheet pile wall.

3.3.3. Launching of span no. 2 and transverse slide

The structure of span no. 2 assembled at station B was in the first stage moved over the roadway (in line with track no. 1 of Line No. 273 Wrocław – Szczecin). An additional temporary support was located on the tramway of Grabiszyńska Street, similar to the one used for the construction of span no. 1. A sliding support which also fulfilled a role of pulling station was located on the capping beam at abutment no. 1. The support was made of steel sections in a multi-layered arrangement. Span no. 2 was designed for track no. 2 of Line No. 271 (E59) Wrocław – Poznań, but was slid over the roadway on the centre line of the adjacent track, so it was necessary to implement an additional

operation, a transverse slide. Two temporary supports were provided for the purpose of implementing the transverse sliding over the roadway. The first one was located at abutment no. 1. It was built in the form of a transverse sliding track made of connected HEB steel sections. Part of the sliding track was based on road slabs and supported directly on the railway embankment (in front of the abutment), while the other part was set on a multi-layered steel support on the abutment's capping beam. The second one was constructed as an extension of abutment no. 2. Part of the sliding track of this support was placed on the abutment's capping beam using a steel structure in order to obtain the required elevation of launch track, while its second part was supported on ZBM type cages. In the case of this support it was necessary to ensure an appropriate level of security, due to the presence of horizontal forces. It was decided to provide a retaining element transferring the horizontal force, which occurred as a result of friction on the slide bearing. The retaining element was made of a steel sheet pile driven into the ground.



Fig. 9. Span no. 2 during the transverse slide over on support PS-L into its final position on track no. 2 of Line No. 271.

3.4. Phase III – assembly of the arch girders and launch of span no. 3

3.4.1. Preliminary works

Similarly to Phase II, in Phase III of the construction works it was necessary to close the tram traffic to build a support PS-K. The other supports did not interfere with regular road traffic hence were not removed after the previous phase and were organized identically to the layout in the previous phase.

3.4.2. Final launch

After the assembly of the entire deck at station A, its push to station B and assembly of its arches and hangers, the launch of the structure to its final position took place. During this operation the same supports were used as for the launch of span no. 2.

4. GUIDELINES AND SUGGESTIONS

A designer, who undertakes the design of such an unusual work, should pay attention to the following:

- The necessity of continuous cooperation with the contractor of the works and taking into account the contractors guidelines and suggestions.
- The need for a very large number of workshop drawings of secondary elements such as, amongst others, supports for the arch shipping elements, launch stations, the pivot area (including platforms with worker access points), sliding bearings, pivot bearings, protection against uncontrolled movement of the span (side bumpers), serviceability limit state of the supports (stay cables, struts), the arch struts, etc.
- It is essential for the contractor to express his opinions and comments regarding feasibility of details, especially construction time (e.g. by introducing bolt connections)
- Often it is necessary to propose many options of individual drawings and incorporate many adjustments during the construction stage of individual tasks.
- The contractor must be informed of important aspects of critical activities (e.g. the moment when extreme loads will occur) and of risks such as for example the impact of wind speed and rainfall.
- It is necessary to point out to the contractor key assumptions concerning work safety by: identifying locations where presence of any personnel is forbidden; the appropriate connection of various positions and securing work areas; specifying of stages for which it is forbidden to apply additional loads to the structure, even with minor process components and so on.

5. SUMMARY

Implementation of such a complex project is time consuming and requires a great number of preliminary works to be carried out.

After being appointed to the design - but prior to commencement of the works - the Designer held a series of meetings with the Contract Engineer, the Contractor for assembly works, steel workshop, track designers, traction line designers, temporary traffic designers, representatives of the Municipality, City Roads Department as well as mobile crane and hydraulic stand jacks' operators. The stage preceding the design took several weeks and this is when the framework of the assembly methodology was established and a convenient time for the closing of vehicle and tram traffic was selected.

After completion of the preliminary stage it took about three months to complete the design, up until the commencement of the assembly. A team of seven people was involved in the design. The assembly process went very smoothly, without any unexpected surprises. The Contractor completed works within the time frames allocated in railway track closing schedule.