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Renfrew Bridge – Glasgow’s First Swing

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Introduction

This paper presents the design and construction of a new movable bridge in Glasgow, Scotland and the unique challenges and solutions addressed through a focus on efficiency throughout the project lifecycle. The design centered on creating lightweight movable bridge spans in order to limit the amount of material required to construct the bridge as well as to give the design-build team the maximum amount of flexibility to deliver and transport the end product.

Project Description

The Renfrew Bridge is located in Glasgow, Scotland and includes the design and construction of the first movable road bridge across the River Clyde. Connecting Renfrew to Clydebank and Yoker, this project has been a centerpiece of the £117 million Clyde Waterfront and Renfrew Riverside (CWRR) Project which aims to reconnect the communities across the water. This new route will reduce congestion and shorten journey times, improve public transport reliability, and enhance the connection between places of work, local hospitals, education centers, Glasgow Airport, and the Clyde waterfront. Attracting new developments to the riverside and providing better access to the Advanced Manufacturing Innovation District Scotland (AMIDS), thousands of new jobs will be created. With two carriageways and two footways that support cyclists in both directions, this structure provides a 90-meter wide by 7.81-meter high channel clearance when the bridge is in the closed position, shown in Figure 1 and Figure 2. In the open position, the bridge provides an unlimited vertical clearance for channel traffic. The project is being delivered by a joint venture design team of Hardesty & Hanover (H&H) and Roughan & O'Donovan (ROD) of Dublin, Ireland and a joint venture construction team of Hollandia Infra of Rotterdam, Netherlands and Iemants of Antwerp, Belgium. The Renfrew Bridge is scheduled to be completed for use in late 2024.

This 184-meter double-leaf cable-stayed swing bridge features an asymmetric or "bobtail" arrangement with 65-meter forward spans and 27-meter back spans, actuated by a slewing bearing with a planetary gearbox arrangement. Swing spans pivot about a vertical axis, typically on a bearing supported on a central pivot pier. While the motion is simple, the mechanisms to operate and support the span in all conditions are complex and require consideration of wind and operational loads, live loads, thermal changes, and all associated deformations.

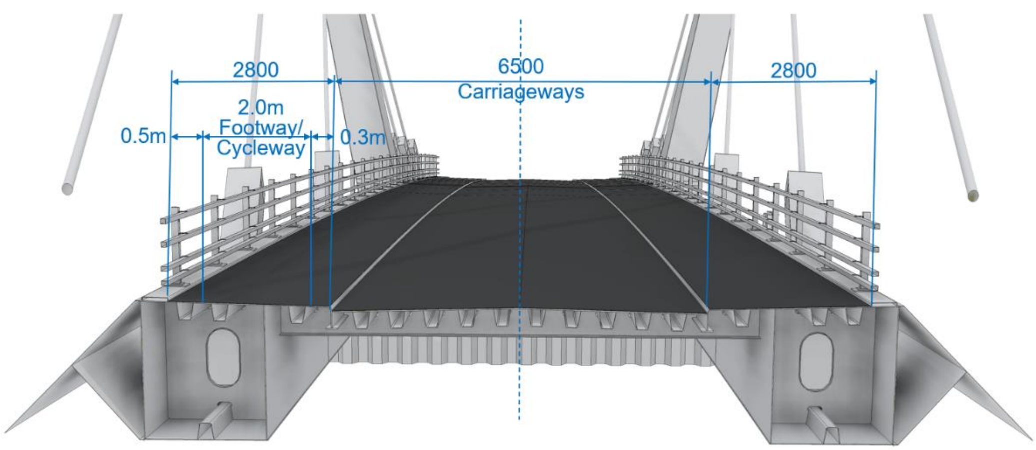

FIGURE 1: Renfrew Bridge Cross Section View

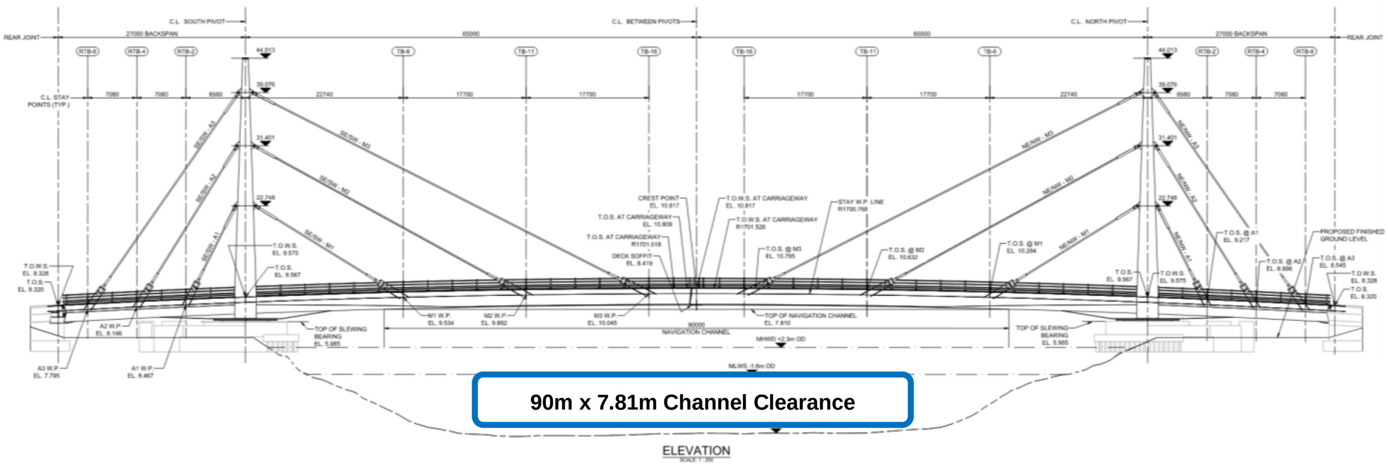

FIGURE 2: Renfrew Bridge Elevation View

Several fundamental aspects of this complex indeterminate structure are the end jacks or wedges to account for deformations and align the deck with the roadway, nose locks to maintain the deck surface continuity between spans, and a 6.7-meter diameter triple roller slewing bearing to provide moment restraint and stabilize the swing spans in both service and operation. The cable-stay design includes 3 forward stays and 3 rear stays with a radial rear joint and a 6-degree skew on the forward joint, allowing either span to be operated independently. This system provides structural efficiency and geometric control. Due to large thermal movements, the nose joint features a custom retractable modular joint in which hydraulic cylinders are actuated but position is maintained.

Lightweight Movable Bridge Design Features

In any movable bridge design, the weight of the span is integral to the kinematics of the structure. The Renfrew Bridge swing span leaves are comprised of a steel framework of welded elements balanced by a rear counterweight. This framework consists of main longitudinal load carrying elements (main girders) that support the floor framing system. The leaves are then supported on and pivot about the slewing bearing assembly, with a drum diaphragm to ensure load distribution from the framework to the bearing itself. The floor system consists of transverse beams that span between the main girders.

The orthotropic deck system consists of steel deck plates that are longitudinally stiffened by deck ribs, integral with the transverse beams. These ribs contribute to the bending resistance of the deck plate by acting as stiffeners and increasing the total cross-sectional area of the steel, allowing vehicular wheel loads to be distributed to the main girders and contributing to the structure's overall load-bearing capacity. While these features are also inherent of a concrete deck slab, the steel orthotropic deck is significantly lighter. This considerable reduction in weight extends to all elements of the structure including cables, towers, and piers. As a result, cost savings in mechanical elements can be made. While a steel orthotropic deck would have limited flexibility in construction when assembled on site, each leaf was fully fabricated in the shop and therefore this was not a concern when choosing the system.

The primary structural support for the superstructure utilizes a cable-stayed system. Compared to a traditional truss or girder span, this system reduces the weight of the swing span by supporting the bridge deck and therefore minimizing the amount of material required. The cables efficiently transfer load to the supporting pylons, allowing for a slimmer and lighter design. An additional advantage of this system is inherent in the stays themselves as each cable can be individually tensioned, ultimately driving the deflections of the span to the desired shape.

Value of 3D Design Coordination

In order to deliver a complex long-span structure, preconstruction planning is critical. Using the modern tools at our disposal, certain challenges were able to be overcome. The project's owners were located in Glasgow, the design teams were located in New York, Florida, London, Dublin, and Austria, and the fabrication teams were located in Rotterdam and Antwerp. The language and geographic barriers of this both real and virtual workplace emphasize the key role that communication plays in the success of projects.

Although traditional two-dimensional (2D) drawings and sketches were circulated amongst the teams as formal contract drawings and communication, three-dimensional (3D) models and views were critical to maintaining a strong understanding across all groups. To achieve this, the design team detailed nearly all steel plates and mechanical components of the bridge superstructure in 3D to Level of Development (LOD) 400 to ensure that the fully welded steel structure was fabricated as intended. The design CADD model was created in Autodesk Inventor and the global structural analysis model was developed in MIDAS in parallel. Local stress shell analysis was performed using MIDAS and LUSAS. As shown in Figure 3, 3D .step files, 2D and 3D .dwg files, and Trimble connect links were utilized for model progress coordination.

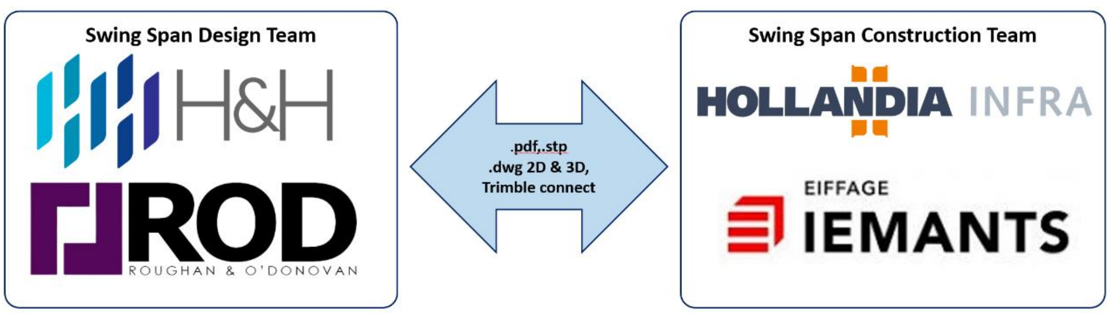

FIGURE 3: CADD File Workflow During the Design-Build Process

Since the detailing of the bridge was fully developed in 3D, after substantial design completion, the swing span fabricators were able to use the design model to create their preconstruction methodology (see Figure 4) in order to coordinate and convey their fabrication and weld preferences for construction of the superstructure. This workflow in the design-build process prevented a significant amount of rework as fabrication and detailing decisions could be made prior to the typical 100% design completion.

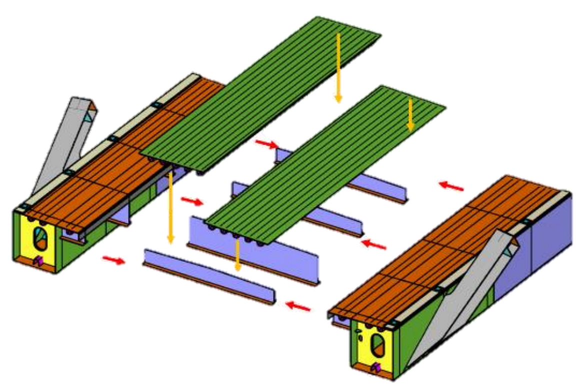

FIGURE 4: Fabricator's Preconstruction Methodology

The Renfrew Bridge had many specific details that benefited from this workflow. Compared to traditional concrete decks, orthotropic deck systems require a higher level of detailing as you cannot rely on discrete zones such as haunches to account for tolerance differences. The steel deck runs the entire length of the bridge and incorporates both transverse and vertical roadway profiles. Due to the bridge's double-leaf swing design, traditional orthogonal deck joints were impractical. The rear deck of each leaf follows a radial curve, while the forward ends are set at a 6-degree skew angle. These design features are inherently sensitive to the varying rates of elevation change at the crucial movable bridge interaction points.

The cable-stayed system is longitudinally asymmetric and battered in all three axes, requiring thorough tracking of 24 specific coordinates to ensure that the loads of the tie plates are properly balanced. As shown in Figure 5, diagrammatically expressing the coordinates and slopes of each individual stay cable and their supporting elements in 2D was complex. The utilization of the 3D design model expedited the precise geometric coordination of the orthotropic deck system, the cable-stayed system, as well as with other stakeholders responsible for designing coordinating elements such as the movable joint components and substructure.

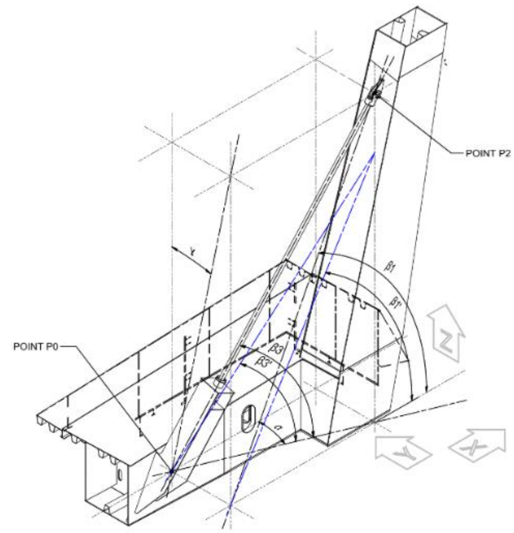

FIGURE 5: Cable-Stay Geometry Ordinates

A major advantage of having such a lightweight structure was the ability to use specialty but commercially available items rather than custom fabrications. For the center pivot support the Renfrew Bridge sits on a gear-driven slewing bearing normally used in the industrial crane industry. Traditionally on older swing spans, this center support system would consist of a large casted thrust bearing with balance wheels and right-angle reducers. In this set-up, hydraulic motors drive four pinions in a planetary arrangement to operate the span. As shown in Figure 6, the 3D model was used again here to coordinate the superstructure, substructure, and mechanical elements as well as detailing the confined space and material handling of the pivot area.

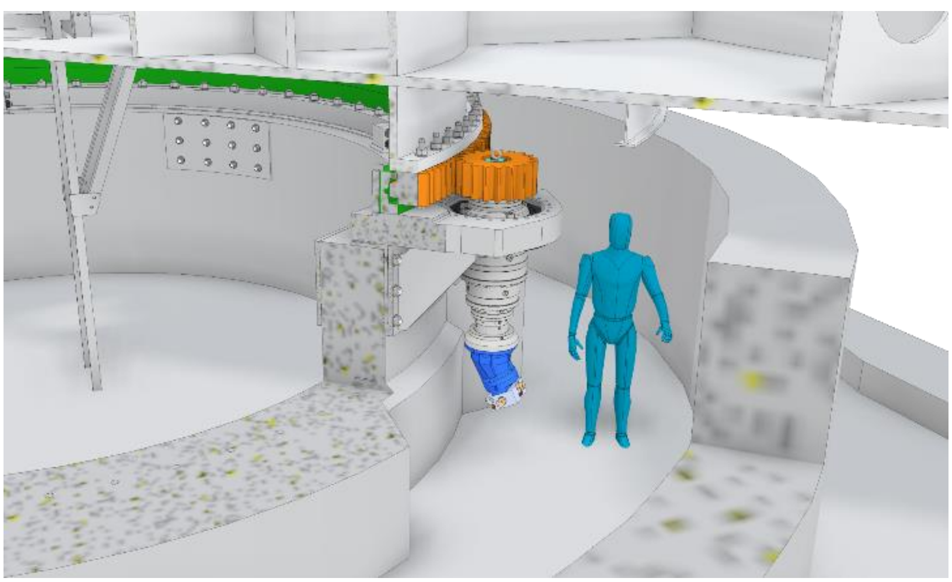
FIGURE 6: Slewing Bearing Gallery

Prefabrication Advantage

The ability to transport the swing span leaves in their entirety by Self-Propelled Modular Transporters (SPMTs), marine cranes, and barges was a further advantage of the lightweight structure. Each leaf was fully assembled at their respective fabrication shops rather than on site in Glasgow. This allowed for the fabrication of each span to progress concurrent to the progress on the job site which greatly expedited the overall schedule of the project.

This prefabrication eliminated the need for traditional bolted or welded field splices in the superstructure. All structural fabrication, priming, and painting was performed in controlled environments at the shops. Wind fairings were installed and counterweights were filled with heavyweight concrete and balance blocks prior to shipping. Additionally, nearly all mechanical, hydraulic, and electrical components of the leaf were installed, routed, fastened, and tested prior to delivery on site.

FIGURE 7: Fully Assembled South Leaf on Barge

For installation of the cable-stayed system, each stage of cable stressing required a specific deflection in the superstructure before advancing. Dead load at these discrete stages plays a significant role in the sequencing and therefore it was advantageous to perform substantial completion of the stressing prior to transporting the structure. 16 of the total 22 cable-stay stressing stages were able to be conducted at the shop. Performing this precise operation on land expedited the process, allowing surveyors flexibility in their set ups and the jack operators mobility to travel about the leaf without concerns of conflicting with other site operations.

Prefabrication planning also benefited the project safety as a majority of traditional over-water work could be eliminated. Heavy components and sub-assemblies were lifted and installed on land with factory cranes using the fabricator's own personnel familiar with the work. Skilled mechanical and electrical installers were able to be perform their specialty installation work in the controlled environment of the shop rather than the temporary and congested environment of the project site.

The 3D models used during the design and fabrication phases evolved into models used in the transportation planning of the project delivery. As shown in Figure 8, engineers responsible for the marine transportation were able to use the model for load balancing and shoring of the structure on the barges and SPMTs.

FIGURE 8: Transport Engineering Design

The prefabrication of the movable swing spans benefited both project costs and sustainability. This construction method significantly reduced the need for temporary infrastructure such as trailers, diesel generators, and sanitation facilities typically required for bridge projects. It also minimized large material handling and transport through residential areas. Additionally, the fully assembled spans were able to be installed on the pivot piers within a short amount of time, significantly limiting the cost of expensive marine cranes and water work. All these features greatly reduced the project's cost and carbon impact.

Conclusion

Overall, the specific design decisions and solutions chosen throughout the Renfrew Bridge project were successful in creating a lightweight movable bridge structure. While unusual, the ultimate combination of cable-stayed swing bridge with a fully welded steel orthotropic deck superstructure significantly lowered the weight of the movable span which allowed the structural, mechanical, and construction teams the flexibility to choose the most efficient ways to deliver the project.

The development of the design model in 3D allowed multiple stakeholders to leverage modern tools to coordinate their important geometric checks. This workflow facilitated a more efficient coordination between all teams as geometric changes were able to be performed rapidly and instances of rework were reduced. While a higher level of technical proficiency is needed for 3D delivery, it was proven to be an invaluable tool and is becoming a standard practice in the industry.

Hollandia Infra and Iemant's focus on prefabrication greatly improved the deliverable quality of the bridge superstructure and movable bridge components. The prefabrication process expedited the construction schedule, increased overall project safety, and reduced the carbon impact of the project. It is clear that proper coordination and planning allows for longer span movable bridges to be designed more economically and with more efficiency.