Puente sobre el rio Slaney – Diseño y construccion
The River Slaney Bridge – Design & Construction

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ABSTRACT

The River Slaney Bridge is a 150 m long, 3-span steel composite bridge which carries a new national road over two access roads, a railway line and the River Slaney. The bridge is a key structure on the M11 Gorey to Enniscorthy PPP scheme which comprises 28 km of motorway.

The structure has a span distribution of 42.5-70-42.5 and its made of girders with a constant depth of 2m with a 250mm concrete deck represent a very slender structure with a span to depth ratio of 31, which was driven by the clearance requirements over the railway and the highway alignment.

This paper summarizes the key aspects of the design and construction.

RESUMEN

El Puente sobre el rio Slaney tiene una longitud de 150 m y consta de 3 vanos con una sección mixta de hormigón y acero. El Puente soporta una autopista de dos carriles por dirección y salva el rio slaney además de una línea de ferrocarril y dos caminos locales. El puente es una estructura clave en el proyecto de la autopista M11 entre Gorey y Enniscorthy en Irlanda que tiene una longitud total de 28 km.

La estructura, con una distribución de vanos de 42.5-70-42.5 y vigas metálicas de 2 m de canto sobre las que se apoya una losa de 0.25 m, presenta una gran esbeltez (L/31) que estaba motivada por el galibo sobre el ferrocarril y el trazado de la carretera optimizado para disminuir la altura de los terraplenes.

KEYWORDS: road bridge, steel composite, web breathing
PALABRAS CLAVE: Puente de carretera, estructura mixta, deformaciones de alma

1. Project Background

The River Slaney Bridge has been designed and constructed as part of a large highway project in the south east of Ireland, referred to as the M11 Gorey to Enniscorthy PPP Scheme. The bridge is one of the main structures on the road scheme and carries a national road (N80) over the River Slaney and a railway line, in addition to minor roads.

The project has been procured as a Private-Public Partnership (PPP) scheme. The origin of the project began prior to the economic crisis that hit Ireland during the period 2008 to 2014. This resulted in a significant delay between the initial planning of the project and the contract award for the construction and operation.
In October 2015 the PPP Contract was awarded to Gorey to Enniscorthy M11 PPP Limited, a

consortium consisting of BAM PPP PGGM Infrastructure Coöperatie U.A. and Iridium Concesiones de Infrastucturas S.A.

The M11 mainline opened to traffic on the 18th July 2019.

Figure 1. M11 Gorey to Enniscorthy Scheme

The new bridge is located on the N80 link road, where the road crosses the River Slaney and the railway line.

Figure 2. River Slaney Bridge during construction

At this location the area surrounding the river is a flood plain during wet periods, and thus suitable measures needed to be taken to ensure that the bridge and the road embankment did not results in unwanted negative flooding effects.

As the bridge had already been subject to a detailed design stage as part of the planning process with TII and Irish Rail, the requirements for the bridge was highly specified within the contract and there was limited scope for significant revisions to the design. Hence the general arrangement was pre-defined in terms of the main dimensions such as span lengths, cross sectional width and structural depth.

2. Detailed Design

2.1 Bridge General Arrangement

After award of the PPP contract, ARUP were responsible for the detailed design of the bridge. This required a full analysis of the bridge to demonstrate the dimensions and configuration as stipulated with the contact complied with the design requirements for the project.

The structure consists of a 3-span composite steel plate girder bridge, with a main span of 70 m, supported on pot bearings at all support locations. The abutments consist of reinforced earth walls with in-situ concrete abutment galleries. A buried skeletal reinforced concrete structure on bored piles supports the superstructure independently of the reinforced earth wall. The intermediate supports consist of bored cast in-situ concrete piles with in-situ concrete pile caps. The superstructure is made of fabricated steel plate girders (S355) with a 250mm concrete deck including permanent participating precast concrete formwork.

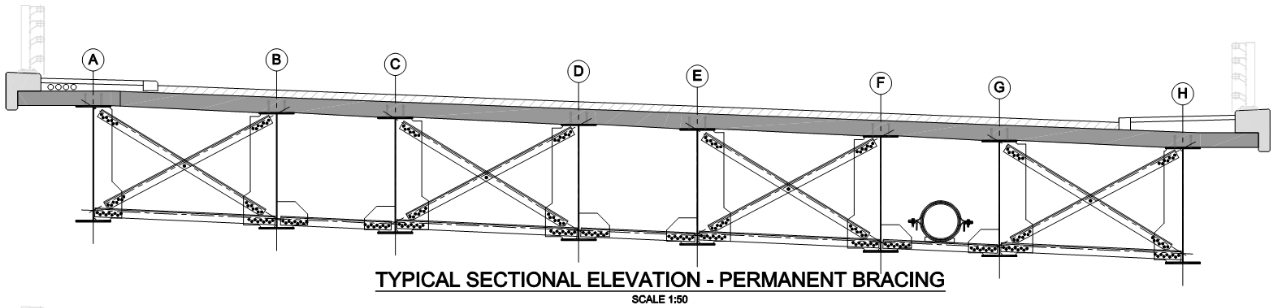

Figure 3. Superstructure Cross Section

The desired vertical alignment of the road and the presence of the river and the clearance envelope to the railway, resulted in a span to depth ratio of 31. This is relatively slender for a road bridge and resulted in the use of multiple pairs of braced I-girders.

The road alignment was such that the cross section of the road varied across the length of the bridge. This change was accommodated by a tapering deck geometry, achieved by arranging the braced pairs of girders with a varying gap between the pair. This lead to an optimisation in the design by keeping the geometry of the steelwork uniform and addressing the cross-section variation in the concrete deck.

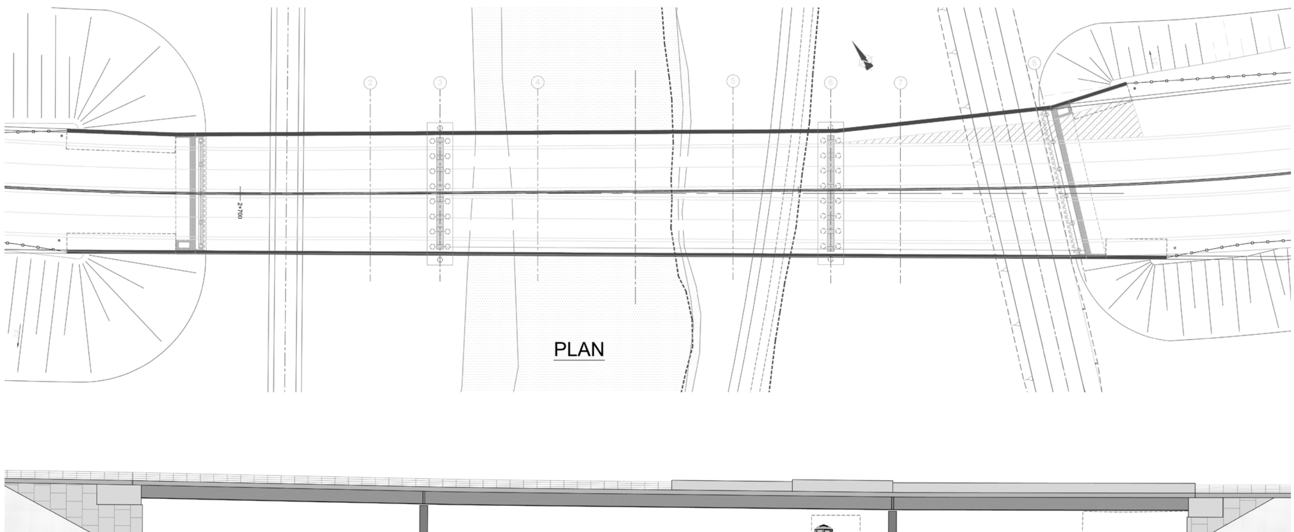

Figure 4. Overall configuration of the bridge

2.2 Structural Analysis

The structure including the foundations have been analysed in an integrated 3D finite element model.

A staged construction analysis has been undertaken due to the nature of the steel composite construction which is installed in stages, both in terms of the steelwork erection and the casting of the insitu concrete slab. The steelwork was first fabricated off-site (in Spain) and transported to the bridge location in pairs of girders which are braced using the permanent bracing members. Due to the live railway line, all the construction works at and adjacent to the railway needed to avoid any impacts on the operation of the railway.

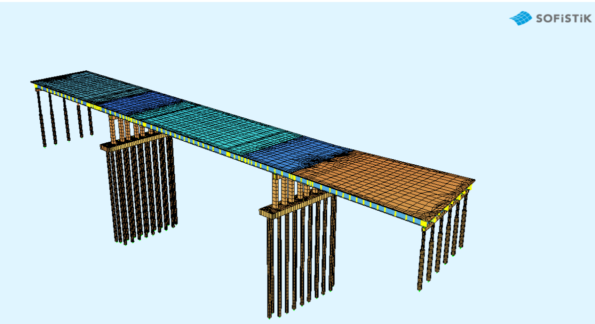

Figure 5. Finite Element Model

The installation of the steel girders and the concrete precast panels between the girders was undertaken during short possession periods. These were typically night-time closures of the railway, during which the steel girders where craned into position. An overview of the construction sequence as implemented in the model is shown in Figure 6 to 11 below.
There were two bolted splice connections at the main girders. These connections were executed as "air splices" without the use of additional temporary support elements. One of these splices was located above the River Slaney.

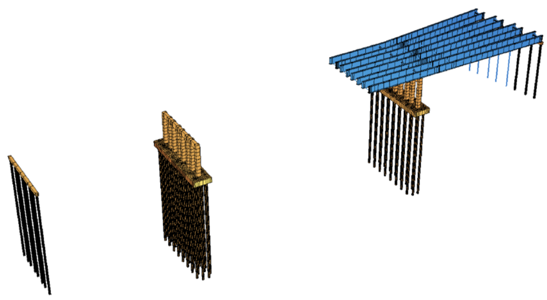

Figure 6. Steelwork Erection Stage 1

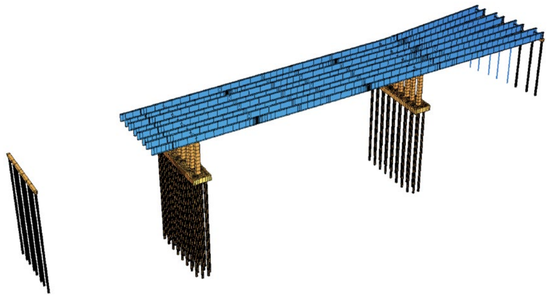

Figure 7. Steelwork Erection Stage 2

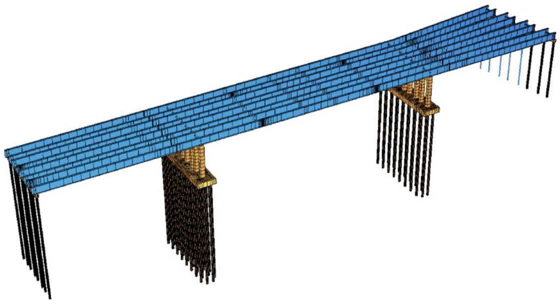

Figure 8. Steelwork Erection Stage 3

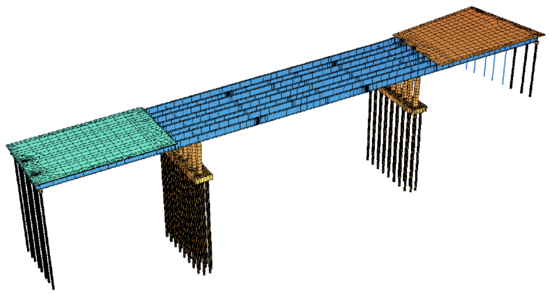

Figure 9. Concrete Pour 1 (Backspans)

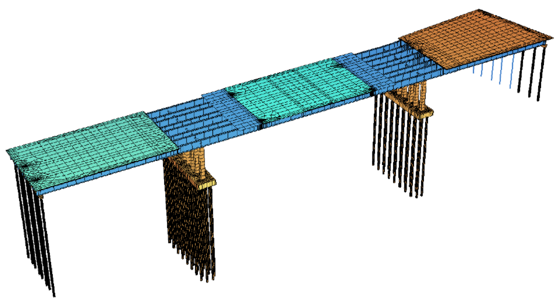

Figure 10. Concrete Pour 2 (Midspan – including sub-pour stages)

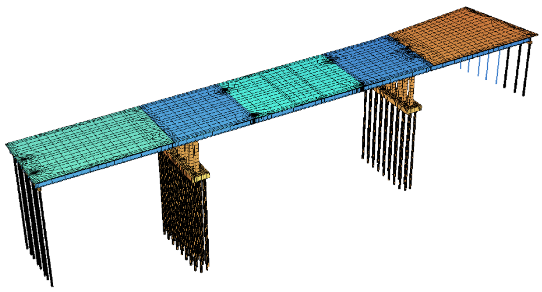

Figure 11. Concrete Pour 3 (Supports)

For this bridge no plan bracing was provided at the top of the steel girders, and thus the construction stage during which the wet concrete is loading the steelwork is one of the governing design situations for the steel girders. The analysis included a modal analysis of a pair of girders to check that the resistance to lateral torsional buckling was sufficient.

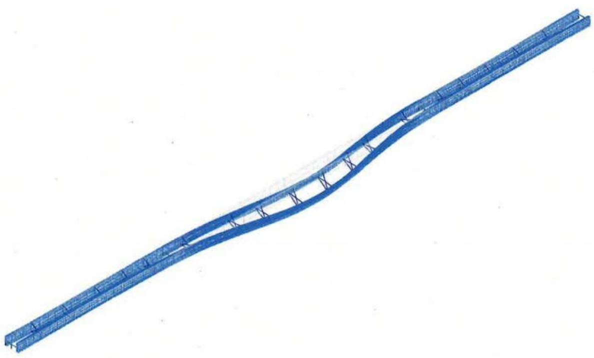

Figure 12. Lateral torsional buckling analysis

The global analysis and structural verification of the bridge was undertaken in accordance with the British Standards (BS5400) [1] and relevant road authority standards [2], rather than the Eurocodes. This was due to the fact that the contract design (pre-PPP contract award) had been undertaken prior to the implementation of the Eurocodes, upon which the various approvals had been granted. Thus, for the detailed design the same design standards were adopted. The global analysis provided the build-up of bending moments and shear forces in the steel and the steel composite sections. Typical outputs from the analysis are shown in Figure 13 and 14.

The resulting plate dimension of the steelwork is summarised in Table 1. It should be noted that the web is highly slender in the midspan and back span region of the bridge.

Table 1. Main Girder plate dimensions

Location		Plate dimensions (bxt)
Midspan	Top Plate	600x25mm
	Web	1930x10mm
	Bottom plate	800x45mm
Backspan	Top Plate	600x25mm
	Web	1945x10mm
	Bottom plate	600x30mm
Supports	Top Plate	600x 50mm
	Web	1890x20mm
	Bottom plate	800x60mm

These dimensions were the result of design refinement and an iterative analysis process. There are intermediate plate dimensions in the transitions between the locations above, not reported in the table above.

The webs are provided with 10mm thick vertical stiffeners on one side of the plate, at 2m centres.

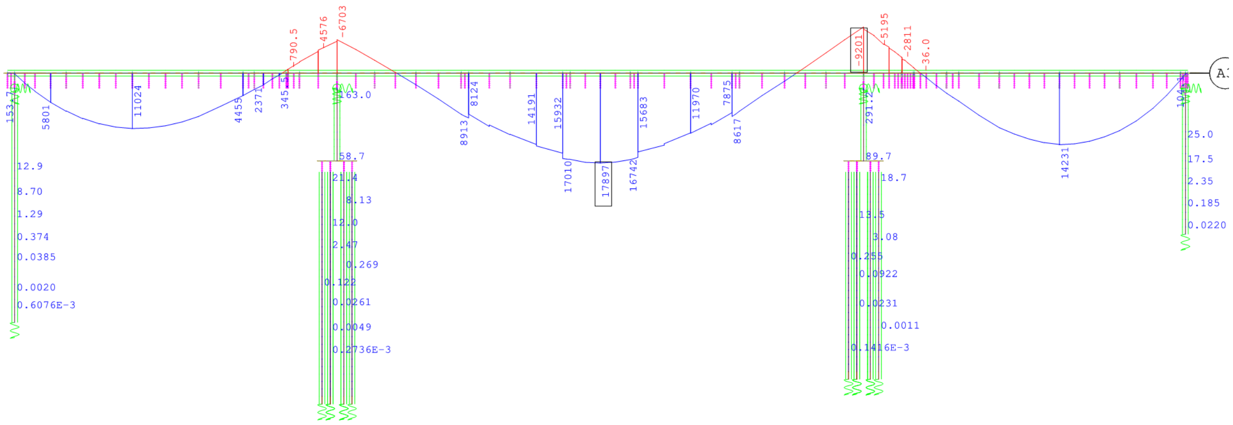

Figure 13. Typical Bending Moment Diagram

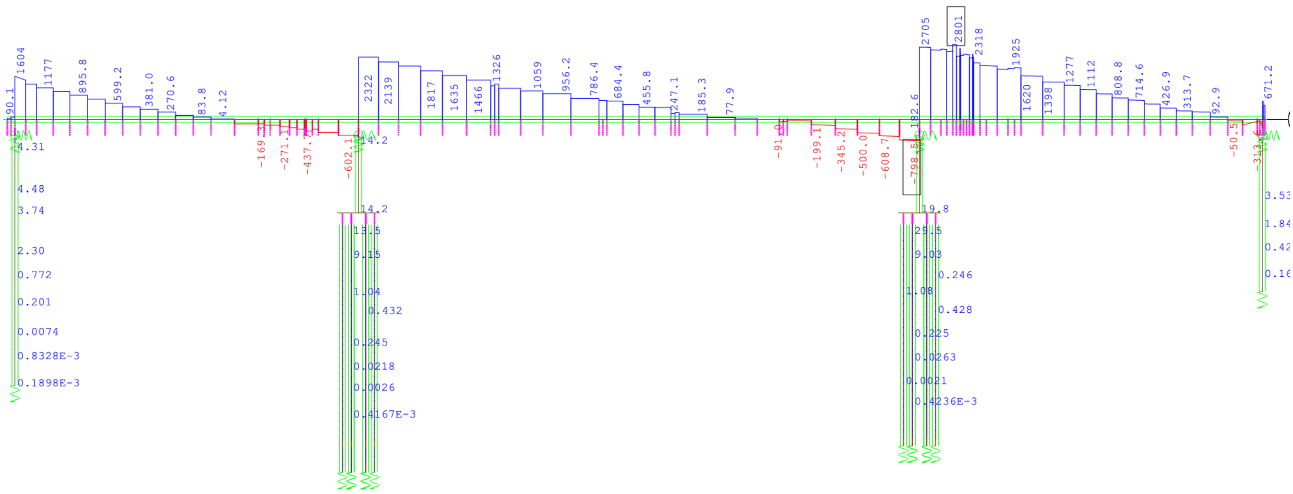

Figure 14. Typical Shear Force Diagram

The concrete deck slab consists of a combination of permanent participating formwork in the transverse direction and an insitu concrete topping. The slab is made composite with the steel girders using conventional shear studs at the top flange of the main girders.

Figure 15. Concrete formwork at bridge deck

3 Construction

3.1 Trial Erection and pre-camber

The detailed design included the calculation of the pre-camber to be adopted during the fabrication of the main girders. The target geometry was based on the permanent situation 1 year after construction (including creep and shrinkage effects). In the fabrication yard, prior to delivery of the steelwork a trial erection was undertaken to demonstrate how the bridge would be erected. As part of this process the pre-camber shape in the fully erected stage was compared with the theoretical shape and found to be in close agreement. Subsequently, on site after completion of the bridge, prior to installation of the asphalt surfacing the measured geometry was in close agreement with the target shape, and thus only minimal amounts of regulation wearing course needed to be applied.

Figure 16. Beams at fabrication yard

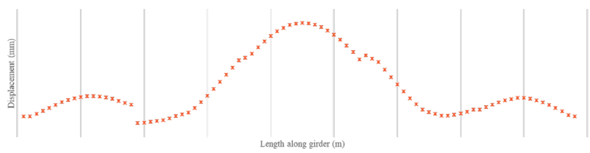

Figure 17. Pre-camber shape of fabricated beams

3.2 Steel Erection works

The main steel girders where lifted into position using cranes. The sequence of construction is described in Section 2. The largest lifting operation was the installation of the beams over the river, which involved a tandem lift, with a crane positioned either side of the river. During the works over the railway, the railway was closed for short time, in a planned possession period. The steelwork was lifted in pairs to maximise the stability of the elements during erections. At the outer girders, cantilever formwork was attached prior to installation operations to minimise the risks of working at heights.

Figure 18. Installation of girders over river

During each stage of the steelwork erection sequence the main girders were made continuous by the installation of prestressed bolted connections at the site splice locations.

Figure 19. Completed erection of steelwork

Figure 20. Steel girders with deck in place

3.3 Concreting and Finishing works

Subsequently the permanent formwork was placed in between the steel girders and the insitu concrete pours were undertaken in accordance with the specified deck pour sequence. After completion of the concrete deck, the upper surface was provided with bridge deck waterproofing.

The structure was a key element in the overall construction programme for the roadworks as it was designed to be used as a haul road to facilitate the overall construction works. During this phase a temporary haul road was constructed on the bridge.

Figure 24. Bridge with temporary haul road

As the bridge crosses the railway line, high containment parapets (H4a) are provided over part of the bridge. The parapet including cladding was installed after the main structural components were completed.

Figure 25. Bridge parapets

4 Post-Construction

During the final stages of the construction, distortions in the web panels were observed, which has led to investigations with respect to web breathing.

Web breathing is a form of local buckling which can occur in slender webs, which, when subject to variable loading from traffic experience out-of-plane deformations. This phenomenon can impact the fatigue performance of the webs.

The web panels are classified as slender. The height and length of the web panel is equal (2m) and the web has a thickness of 10mm. Thus, visible distortions in the web plate are not unexpected and the slenderness of the web panels has been considered in the structural verifications.

Prior to opening of the bridge, a number of investigations were undertaken to confirm that there were no structural safety issues associated with these visual distortions.

As web breathing is not considered in BS5400, reference has been made to IS EN 1993-3 [3]. A static load test was undertaken, which demonstrated that the vertical stiffness of the bridge was consistent with the design. Accelerometer measurements showed that the natural frequency of the bridge was similar to the theoretical value.

Figure 26. Visual distortions in web panels

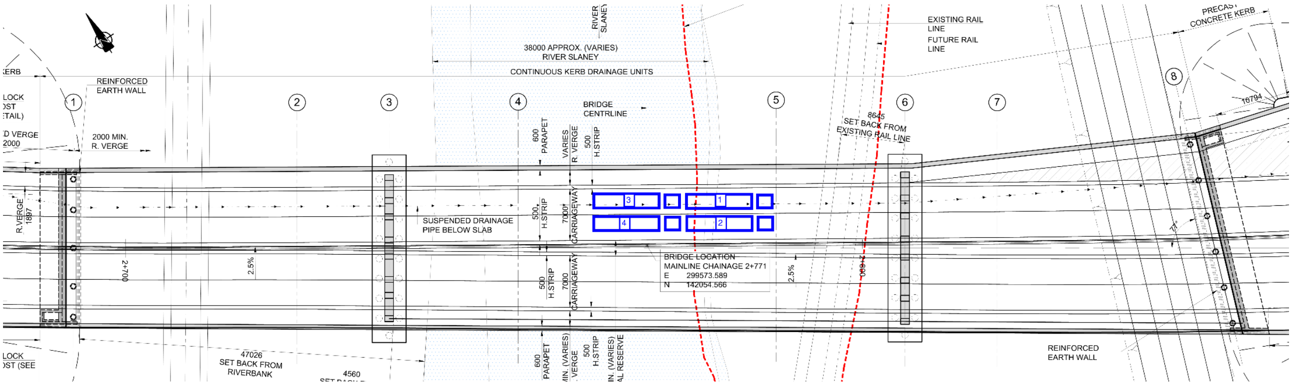

Figure 27. Position of trucks during load test

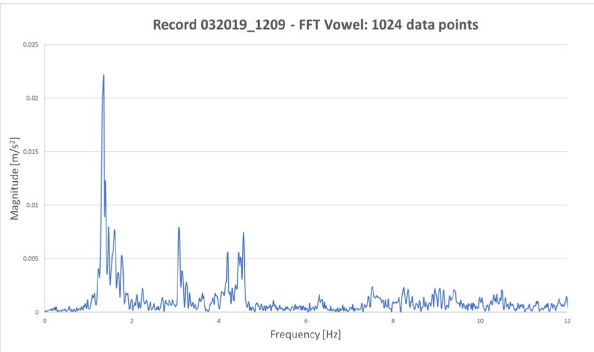

Figure 28. Accelerations plotted as function of frequency

A local FE analysis has been undertaken to assess the likelihood of local buckling of the web panels and the change in behaviour during the various stages of construction.

The governing situation was found to be the wet concrete stage (Stage A in Figure 29 and 30). During this stage the neutral axis is towards the bottom flange of the girder, and in the sagging regions, a large portion of the web panel is subject to compression due to flexural action. This compression loading, in combination with shear, results in elastic buckling of the web panels. After hardening of the concrete slab, the neutral axis of the girders rises towards the top flange level, and hence the compression zone in the web panels is reduced. So, the tendency for elastic buckling is reduced and stabilisation occurs due to the increase of the tensile zone in the web panel. Hence the predicted out of plane displacements are found to be reduced during the service condition (Stages B, C and D in Figure 29 and 30).

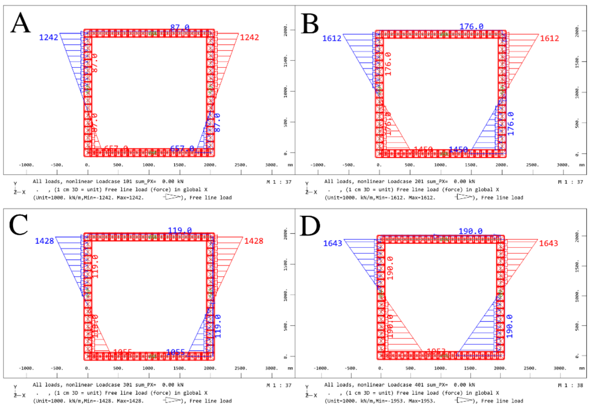

Figure 30. Applied bending and shear forces on web panel

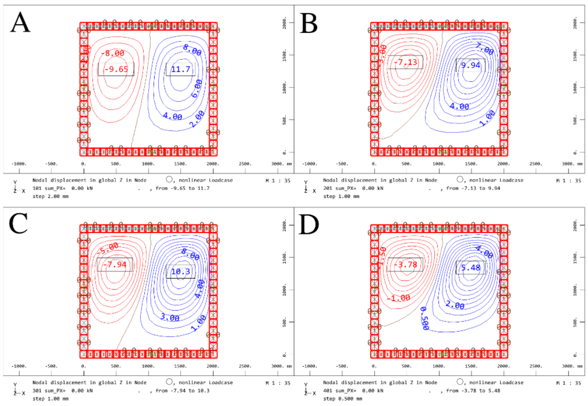

Figure 30. Out of plane deformations from elastic buckling analysis

There are proposals to undertake some monitoring of the bridge to ascertain whether web breathing is occurring under traffic loading. The monitoring will initially investigate the magnitude and distribution of out of plane displacements under a controlled load test situation and during a period of measurement under normal traffic conditions.

5. Conclusions

The River Slaney Bridge at the N80 crossing is a slender 3-span river bridge which has been highly optimised to achieve an efficient steel composite design.

The detailed design has taken a prescribed contract design and delivered a bridge which has been executed in a manner requiring minimal temporary works and little impact to the railway and river crossing.

While the web panels have visual distortions due to their slenderness, the design complies with the applicable design standards. Monitoring of the bridge is proposed to determine if there is any evidence of web breathing.

6. Acknowledgements

The Authors want to thank the main contractors BAM-Dragados, and the road authority TII, for the contribution throughout the design and construction stages of the project.

Finally, the Authors would like to acknowledge the proactive and positive contribution of the independent checker, Pondio Ingenieros, which was fundamental to achieve the value engineering required by the client and provided deep insight knowledge along the whole process.

References

[1] BS 5400 Part 5 Steel, concrete and composite bridges. Code of practice for design of composite bridges

[2] NRA BD 37/14 Loads for Highway Bridges

[3] IS EN 1993-2 Eurocode 3 - Design of steel structures - Part 2: Steel Bridges