Urban Growth NSW
Lachlan's Line
Structural Concept Report

Revision 1 | 28 October 2014

LACHLAN'S LINE
MACQUARIE PARK

Job number 234008

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Job title	Lachlan's Line		**Job number** 234008
Document title	Structural Concept Report		**File reference**
Document ref			

Revision	**Date**	**Filename**	141028 Planning Concept Report – Lachlan's Line.docx		
Issue	28 Oct 2014	**Description**	Rev 1		
			Prepared by	Checked by	Approved by
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		Signature			
		Filename			
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1 Introduction

Arup, in conjunction with Sydney architects KI Studio, were tasked by Urban Growth NSW to propose an alternative bridge typology and alignment for Lachlan’s Line. The intent was to develop a more exciting and unique crossing whilst still providing a functional, cost-efficient, yet highly visual link between the M2 Site and the portion of Delhi Road adjacent to North Ryde Train Station.

A number of alternatives were proposed through this period, with the selected concept an innovative double helix with spiralling chords. The helical diameter and chord geometries have been modulated based on parametric structural optimisation principles to produce a highly efficient, yet sculptural, structure.

The redeveloped proposal commences at the Delhi Rd footpath, rises out over the M2 towards the North-East corner of Bundarra Reserve, where it swings north, spanning over Delhi Road and connects to the M2 site on a landscaped embankment developed by KI Studio in conjunction Aspect Studio and Urban Growth NSW.

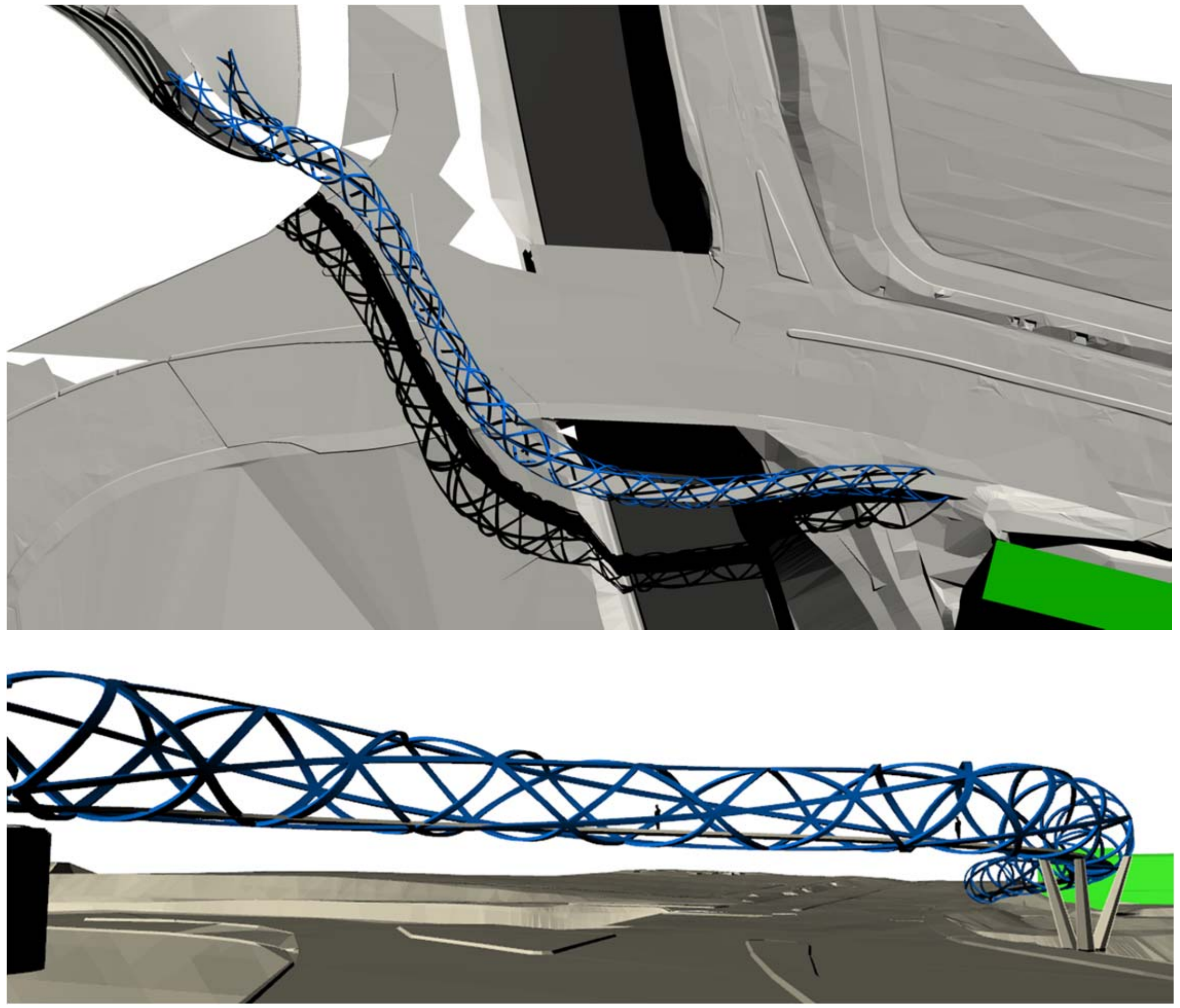

Figure 1: Bridge Form & Alignment

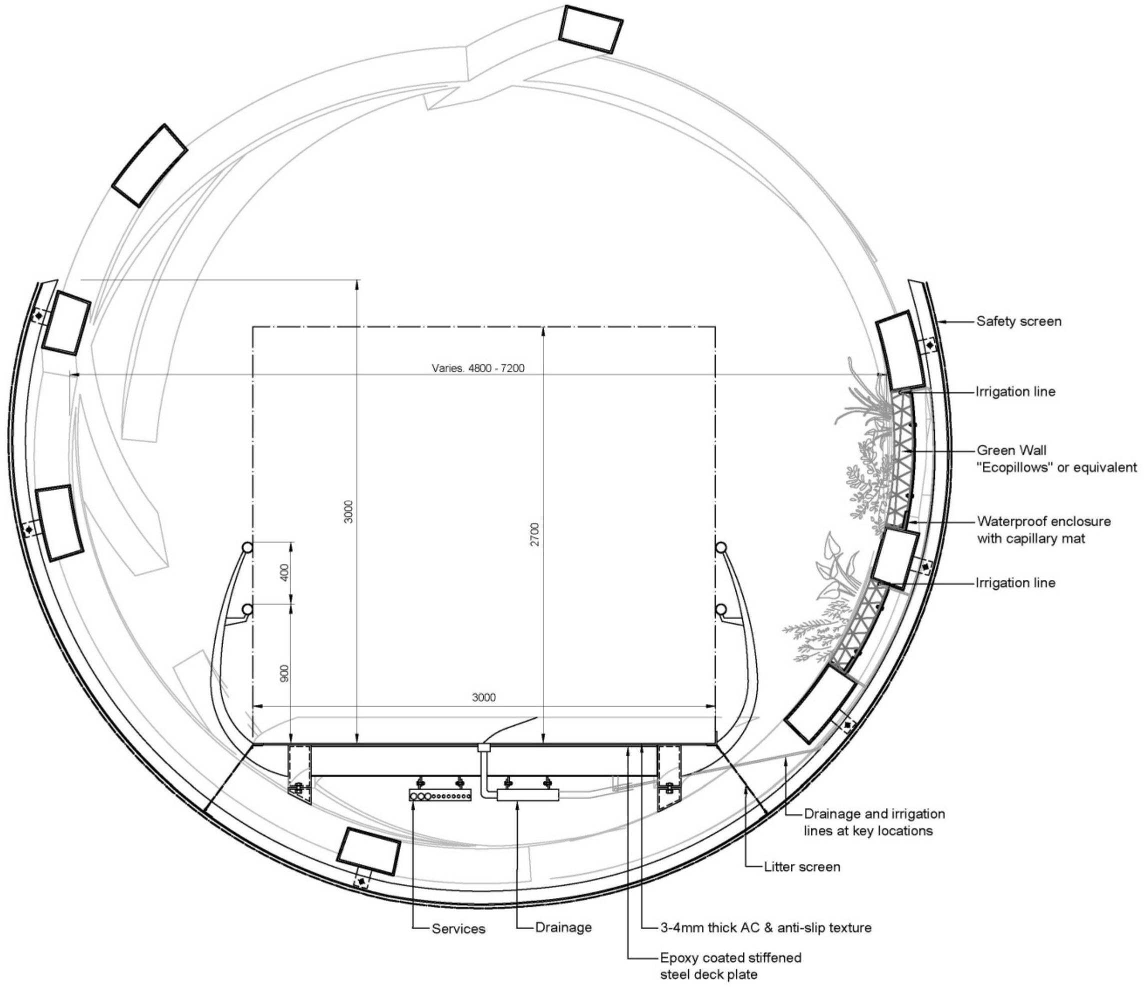

Figure 2: Typical Cross-section

This report summarises the end result of the revised concept design phase and should be read in conjunction with the Structural Drawings, see Appendix 2, as well as the Urban Design Report prepared by KI Studio.

2 Technical Criteria

The bridge and its approach ramps have been designed in accordance with AS5100, AustRoads, and the RMS standards and requirements as provided to date.

2.1 Geometric Constraints

- Maximum gradient 1:14 in accordance with the Disability Discrimination Act (DDA) and AS1428.1;
- Trafficable width 3.0m clear. Defined as a result of a study of existing Sydney pedestrian and cycle bridges, see Appendix B for report;
- Clearance to Delhi Road = 5.5m from top of road surface to underside of structure. Additional 130mm allowance for bridge deflection and erection tolerance; &
- Support piers located to comply with AustRoads and AS5100.

2.2 Structural Loads

- 4kPa live loading as per AS5100. Allowance for concentrated load from maintenance vehicles;
- Allowance for balustrades, cladding, and throw screens. 100kg / linear metre / side;
- Allowance for bridge services (lighting and hydraulics);
- Allowance for 100 kg / linear metre for trunk services. (additional to bridge lighting and hydraulic services); &
- Allowance for 2x small lightweight advertising hoardings (80 kg/m2 on elevation).

2.3 Structural Performance

- Design life: 100 years;
- Strength and serviceability performance in accordance with AS5100;
- Maximum deflection = span/300 under variable loads only (Trunk Services and Live Load). Permanent loads will be pre-cambered out (Structural Self Weight, Balustrade, Throw screens and Bridge Services);
- Maximum footfall response = response factor RF60 for external footbridges under a maximum footfall frequency of 2.5 steps/second; &
- First mode of lateral frequency = >1.5Hz to control lateral synchronous excitation.

2.4 Materials & Construction

- Structure: Structural Steel Grade 400. Painted.
- Deck: Steel plate with non-slip epoxy coating. Alternative: Stainless steel Duplex 2205 with non-slip and non-reflective finish;
- Piers: Reinforced concrete: S50, S65. Piers may be of precast or of insitu construction;
- Piles, piles caps, footings, and abutments: Reinforced concrete S40/S50;
- All structural steel fully welded. No bolted connections in accordance with RMS requirements;
- No permanent tension across bearings in accordance with RMS requirements;
- Constructions sequence developed to minimise impact or closures (partial or full) of Dehli Road, Epping Road, or the M2; &
- Staging area on M2 site for field assembly (welding) of prefabricated segments into maximum size elements for final erection sequence.

3 Parametric Alignment Analysis

3.1 Alignment Optimisation

The bridge alignments and approach ramps have been optimised using a parametric script to ensure all approach ramps rise and fall at the maximum allowable gradient, ensuring minimum total bridge length. Starting at Delhi Road the alignment swings south, out and over the M2. The bridge structure climbs at a maximum gradient of 1:14 before reaching the NE corner of Bundarra Reserve. The alignment then heads north just passing over the minimum clearance zones for Delhi Road before landing at the high point of the public park.

The deck sits wholly within the structure and is not integral with the performance of the primary structure. This allows the ramp form and gradients to be adjusted without compromising the structural form and performance, whilst providing compliance with both DDA and RMS maximum gradients. The ramp gradients are at a maximum of 1:14, but reduce to 1:33 and flat across the Delhi Rd span. The script allowed us to experiment with many ramp forms plus also graphically plot the gradient. A summary of the parametric alignment studies is shown in Figure 3 and Figure 4.

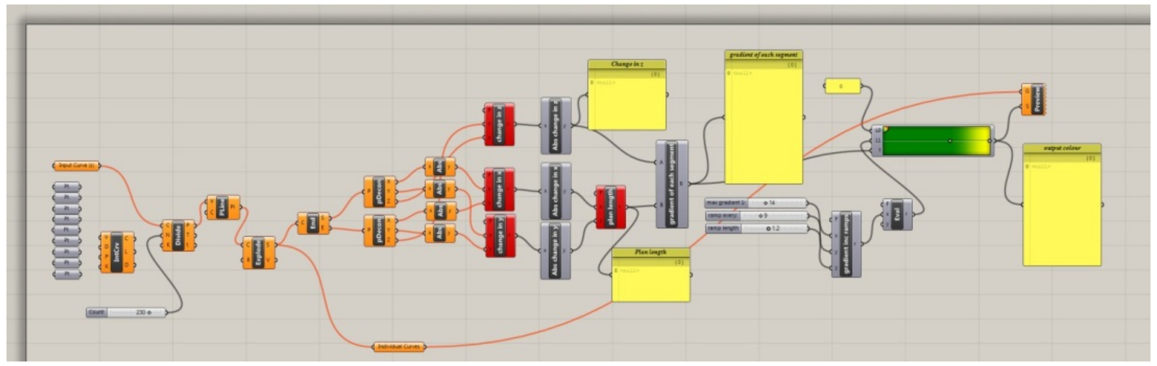

Figure 3: Custom Gradient Analysis Script

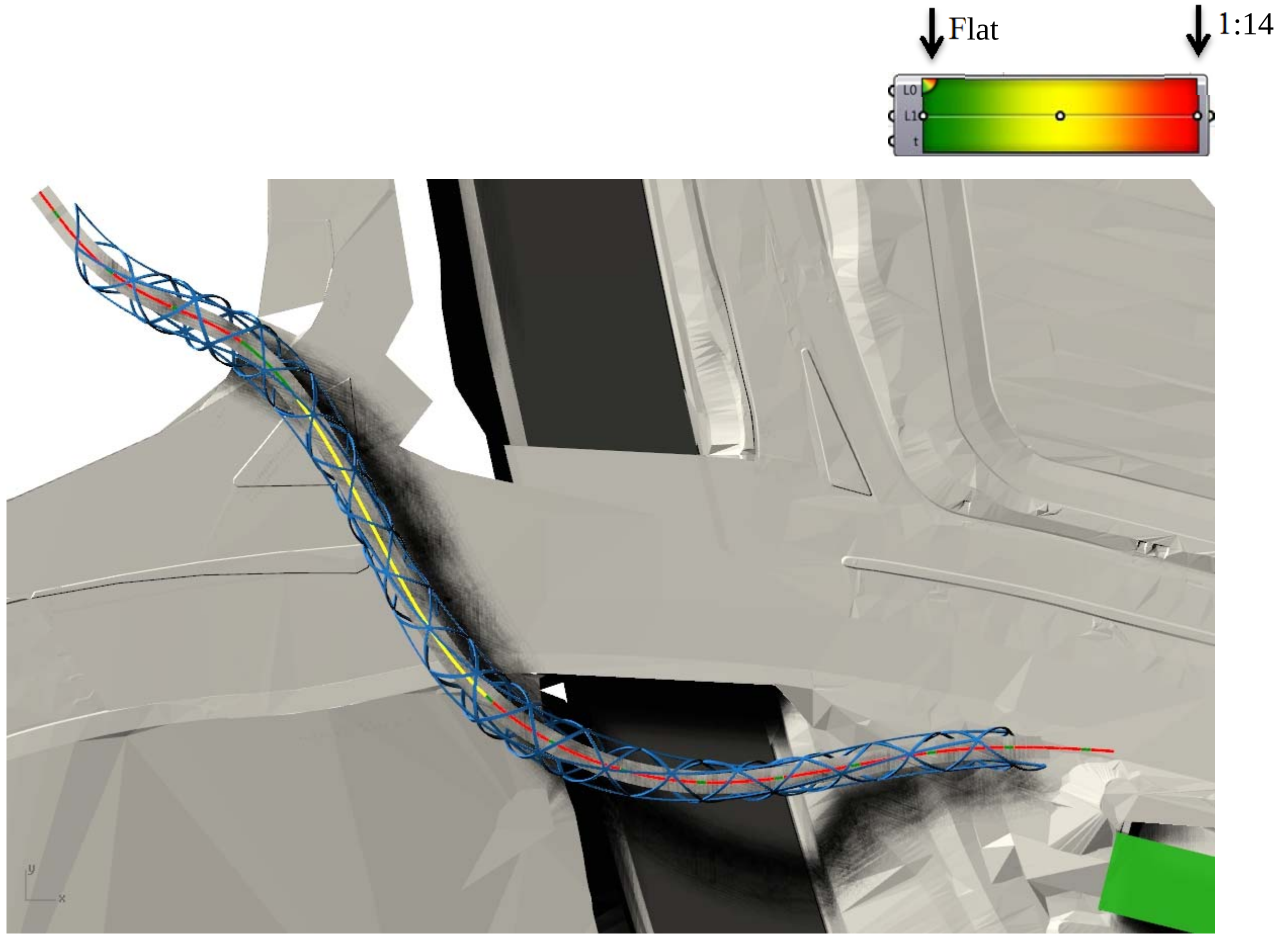

Figure 4: Gradient Analysis Graphic

The alignment is driven by minimising spans and overall bridge length, and hence keeping the structure lean. An option to support the Delhi Road span on the intermediate traffic island was explored, but feedback from RMS and the existing in-ground services made this option potentially more costly than spanning directly to the M2 site.

The alignment starts at the southern pavement edge near North Ryde station and swings south to the start. The structure rises continuously and spans the shortest distance across the M2 before swinging north as it crosses the North East corner of Bundarra Reserve. The helical truss levels as it passes over Delhi Road and heads directly towards the M2 site, keeping spans to a minimum. The alignment curves to sit parallel with the M2 site concept design terminating on a raised landscaped embankment.

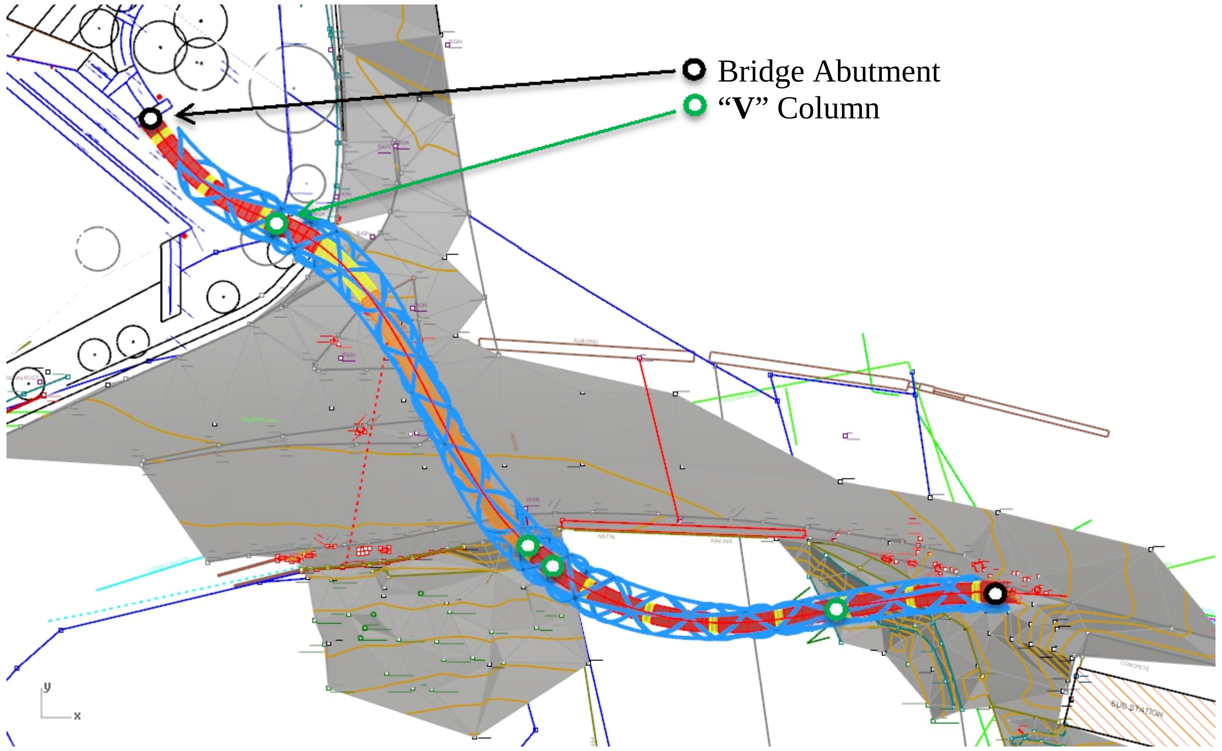

Figure 5: Final Bridge Alignment

3.2 Column Locations

Station Abutment

The foundations/abutment at the eastern end are located to minimise impact on existing in-ground services and avoid easements.

M2 Eastern Pier

The “V” column supporting the eastern end of the M2 span is located at the top of the embankment and is well clear of any traffic on the M2. The stability of the existing embankment and ability to construct the pier through access from Delhi Rd has been considered. This pier location would be removed with any future widening of the M2. Refer Section 6.

Central Pier – Bundarra Reserve

The central abutment for the main spans sits in the North East corner of Bundara Reserve and at the lower end of a steep embankment which drops from the Delhi Road pavement above. The embankment gradient is greater than 1:4 therefore, in accordance with Austroads, a barrier protection system is needed.

Both “V” columns are located to ensure minimum 1.0m clear from front face of column to front face (road side) of barrier. By using a pair of columns instead of a single “V” end fixity of the Delhi Road span is maintained. This allows for the M2 span to be temporarily removed if the M2 were to be widened by adding additional lanes on its eastern flank.

M2 Site

In accordance with AustRoads columns located to ensure minimum 4m clearance from front face of column to Delhi Road kerb.

3.3 Vertical Clearance

The bridge achieves a 5.5m vertical clearance from the underside of the bridge to top surface of Delhi Road in accordance with both AS5100 and AustRoads. Vertical clearances for the M2 span are easily achieved due to site topography.

4 Structural Design

4.1 Form & Materiality

The structural tube widens and narrows at key locations to enhance the structural performance of the bridge. At the mid spans the bridge is at its narrowest, 4.8m in diameter, keeping load away from these sensitive areas and providing minimum depth for road clearance. Towards the support piers the tube diameter increases, to a maximum 7.2m diameter, deepening the structure through the highly stressed hogging zones optimising its structural function as a continuous structural element. This additional width has the secondary benefit providing space for seating.

The deck structure is secondary, and is supported lightly from the structural tube – which has no reliance on the deck for strength, stiffness, or buckling restraint. This allows full flexibility in deck geometry, material, and maintenance without compromising the primary structural form and performance.

Given the complex geometries involved steel is the natural material choice. Each member within the tube is a warped steel box beam. The dimensions and plate thickness of the elements are smoothly adjusted in parallel with the geometry based on structural strength requirements – optimising performance and minimising steel tonnage. Plate thickness is minimised at field splice locations to minimise time and maximise quality.

Three members cross over at each truss intersection point on a pure structural geometry, two helixes and one chord resulting in a 6 pronged star for each node. For each node the detailing remains the same, with one chord element and two helixes passing through.

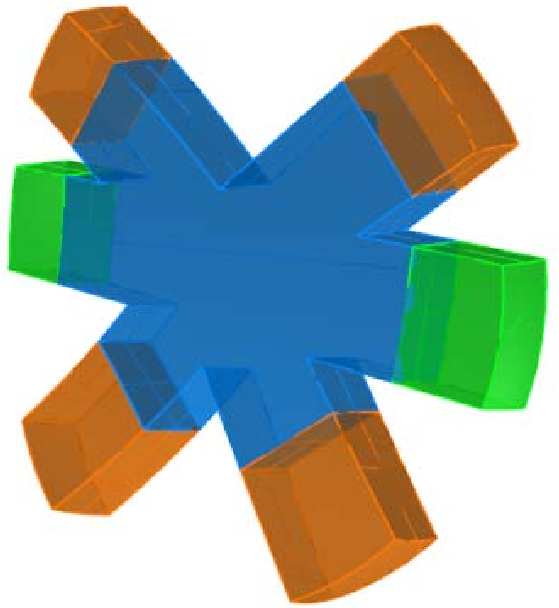

Figure 6: Typical 6 member node

4.2 Parametric Design

The structure was modelled parametrically within Rhino using Grasshopper software to help experiment with varying truss geometries and was used to optimise the design both structurally and architecturally. Each version was analysed as we progressed to ensure the impact of each variable was fully understood.

The parametric model will continue to yield benefits during both design development and detailed design phases. We intend to use the parametric model to explore varying helix angles, view corridors, tube depths and section properties to name a few. The parametric workflow could be then further extended and used during the construction phase, with fabricators using it to help improve the shop drawing and fabrication process with the team using a "one model" environment – improving the quality of the final outcome.

The optimisation and structural analysis packages were linked creating a custom, fluent and parametric work stream as shown in Figure 7.

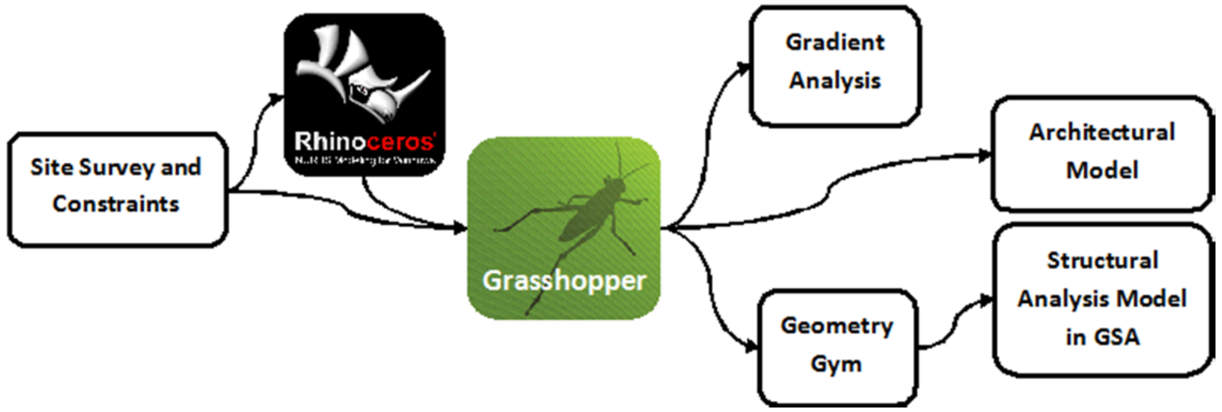

Figure 7: Parametric workstream representation

An isometric view of the final structural analysis Oasys GSA model is shown in Figure 8 with varying section sizes represented by colour. Multiple box beam properties were experimented with to find the optimum section size. Each colour represents a different box beam property, although only the plate thicknesses are varied, the outer box beams dimensions remain constant at the optimum 400mm wide x 250mm deep other than the pink elements which are larger in size to control dilation at the support location.

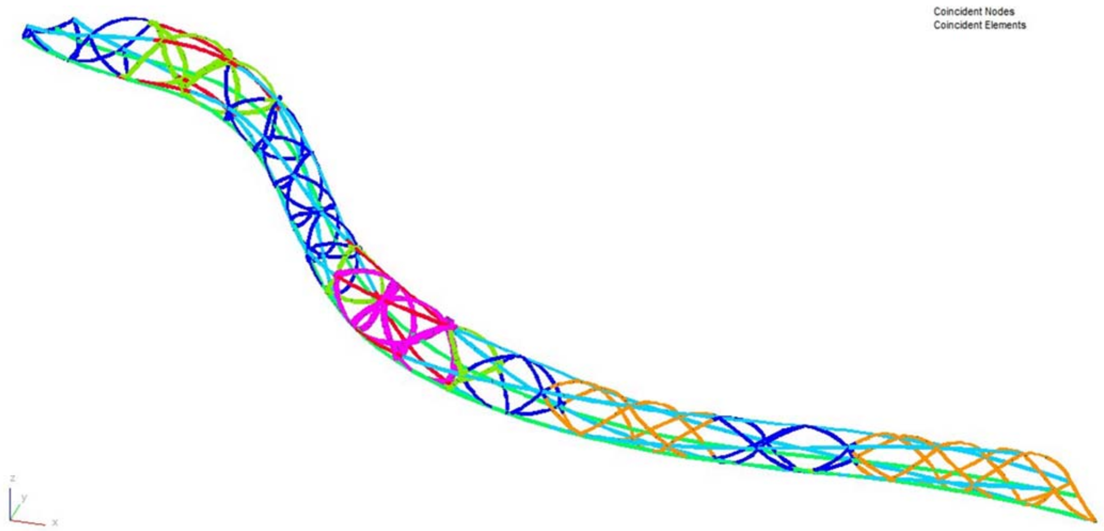

Figure 8: GSA structural analysis model isometric

The Grasshopper to GSA model link allowed us to run a series of analysis cases testing and optimising the bridges serviceability (SLS) and ultimate limit state (ULS) performance. A summary of these results follows with the ULS cases covered first.

4.3 Ultimate Limit State (ULS)

4.3.1 Strength Analysis

Due to the efficient form the majority of the elements within the bridge were sized for strength using the parametric workflow. Results from the ultimate limit state (ULS) analysis for the Delhi Rd span are shown below in Figure 9 and Figure 10.

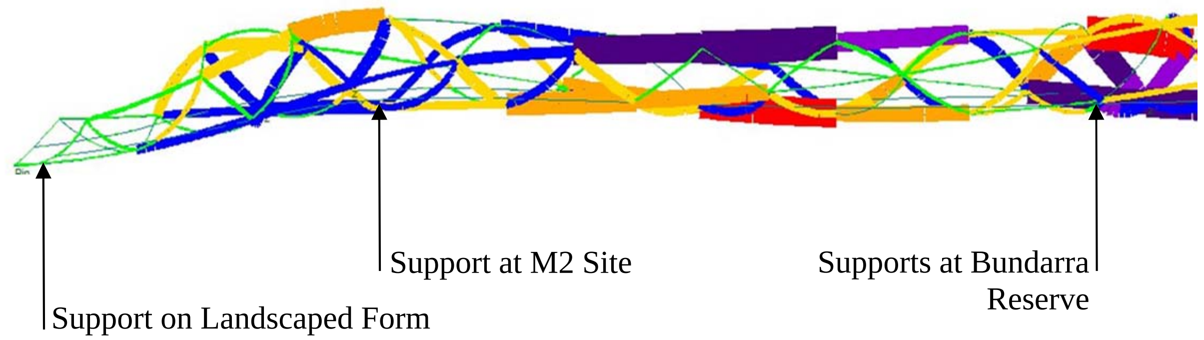

Figure 9: Axial forces under ULS case 1.1SW + 2.0SDL + 1.8LL

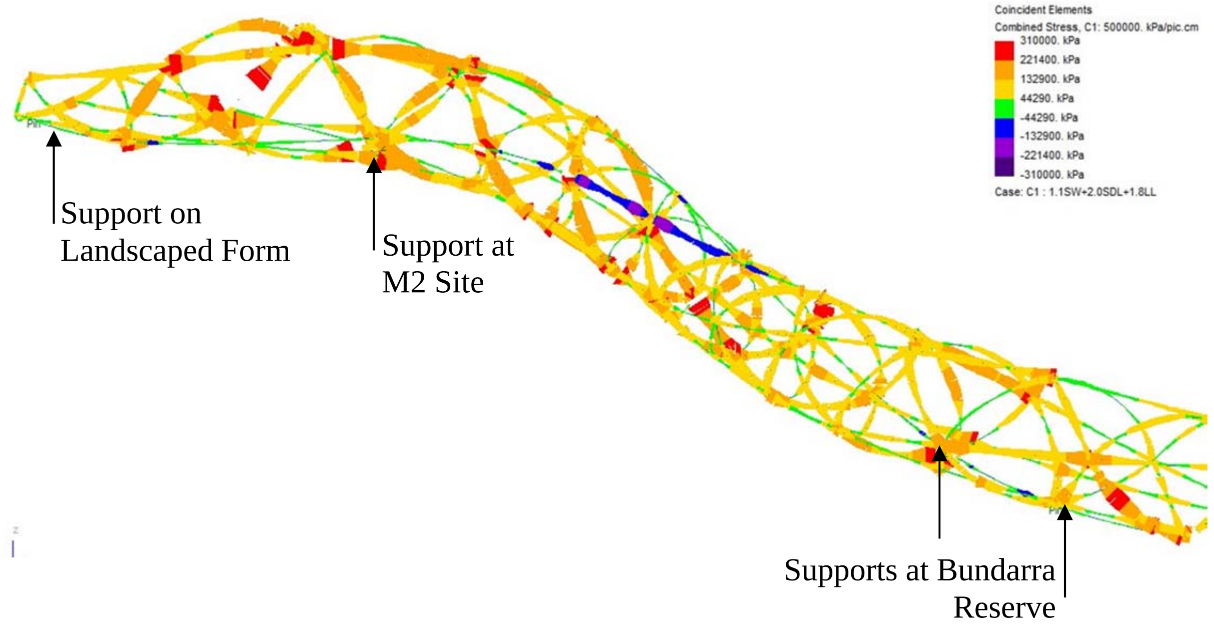

Figure 10 Peak fibre stresses ULS case 1.1SW + 2.0SDL + 1.8LL

4.3.2 Global Buckling

Under a linear global buckling analysis the first mode shows the top chord buckling at the Delhi Rd mid-span location. This particular mode is shown below, in Figure 11.

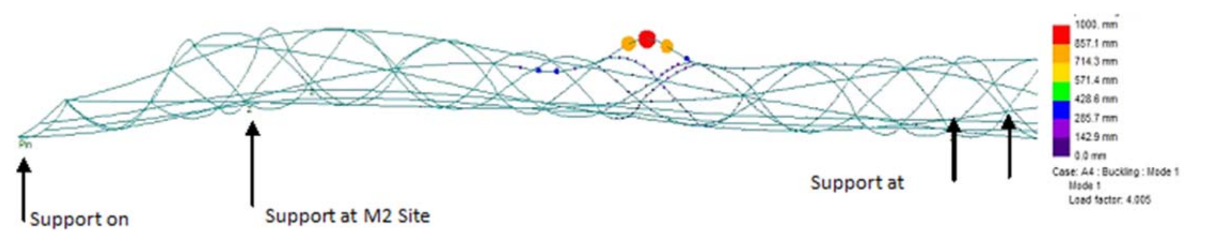

Figure 11: Global Buckling Analysis First Mode Buckling Factor = 4.0

4.4 Serviceability Limit State (SLS)

4.4.1 Vertical Footfall

Vertical vibration due to pedestrian footfall has been analysed based on the following criteria:

- Input walking frequency: 1 to 2.5Hz
- Footfall (walker) mass: 76kg
- Damping: 0.5%
- Target Response factor: R < 60 for external footbridges

Results of a global dynamic analysis based on zero live load form the basis of this calculation.

The response is calculated in accordance with SCI (Steel Construction Institute of Great Britain) publication `Design Guide on the Vibration of Floors' and AS2670.1

Performance values are defined as a multiplier on the vibration level that is the average threshold of human perception ie a multiplier or 'response factor' (RF) of 1 is the level of vibration that an average person can just barely perceive.

The footfall results are shown in Figure 12 as contoured response factors.

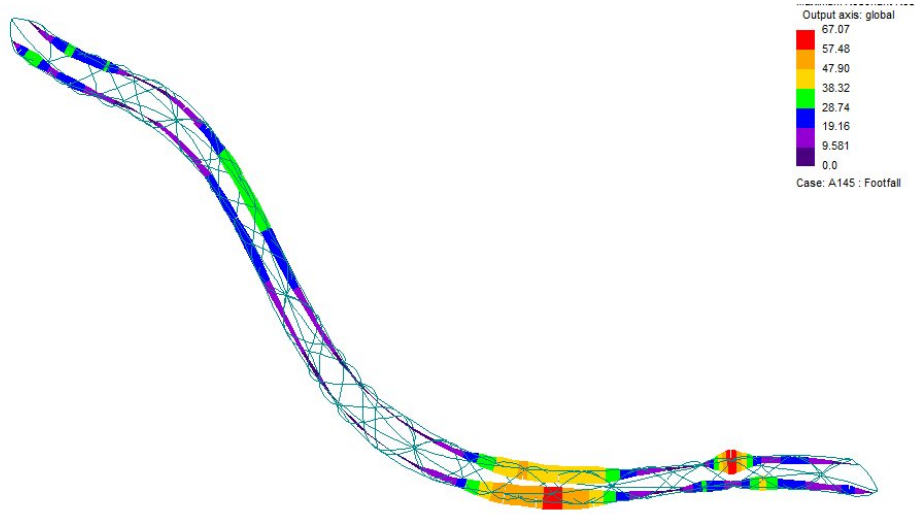

Figure 12: Footfall Response Factor RF=67 (peak)

4.4.2 Lateral Synchronous Excitation

Lateral synchronous excitation due to pedestrian walking in crowd conditions is generally prohibited if the first lateral mode of vibration of the deck structure, fh, is greater than 1.3Hz, with the frequency calculated under an additional applied mass equivalent to a live load of 1kN/m2 representing 1.5 persons/m^2. The majority of current design codes, included AS5100, provide a target minimum of 1.5Hz to allow for modelling and construction variations.

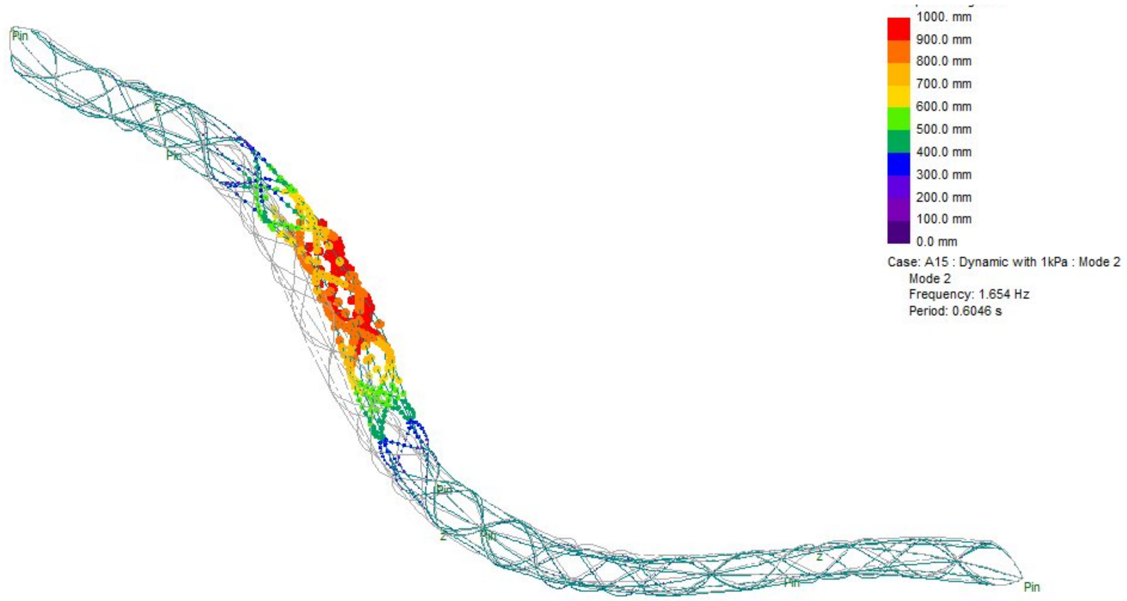

Figure 13: First Lateral Mode of Vibration under 1kPa LL = 1.6Hz

As shown in Figure 13 above the first mode of lateral vibration = 1.6Hz, above both performance minimum and code requirements.

4.4.3 Vertical Deflection

The known dead loads (self-weight, deck, cladding) of the structure will be pre-cambered out. By pre-cambering the bridge we eliminate any deflections associated with the known dead loads, leaving the as-installed bridge sitting at design intent level. This leaves only the variable trunk services (1kN/ linear metre), signage, and live loads to consider during for in-service deflection. Results of this analysis are shown in Figure 14 for the Delhi Rd span.

Figure 14: Vertical serviceability displacements under trunk services and LL

The maximum vertical displacement of -75mm can be accommodated and will not encroach into the Delhi Road clearance zone.

5 Construction Sequence

The proposed construction sequence relies heavily upon prefabrication to minimise the time and costs associated with site works near two major roads. Splice and construction joints are located at inflection points to minimise splice welding requirements.

It is intended to provide a staging area on M2 site for field assembly (welding) of prefabricated segments into maximum size elements for final erection sequence

A brief four step construction sequence is described below in Figure 15 to Figure 18.

Stage 1 – Complete all in-ground works. Construct supporting structures and bridge abutments.

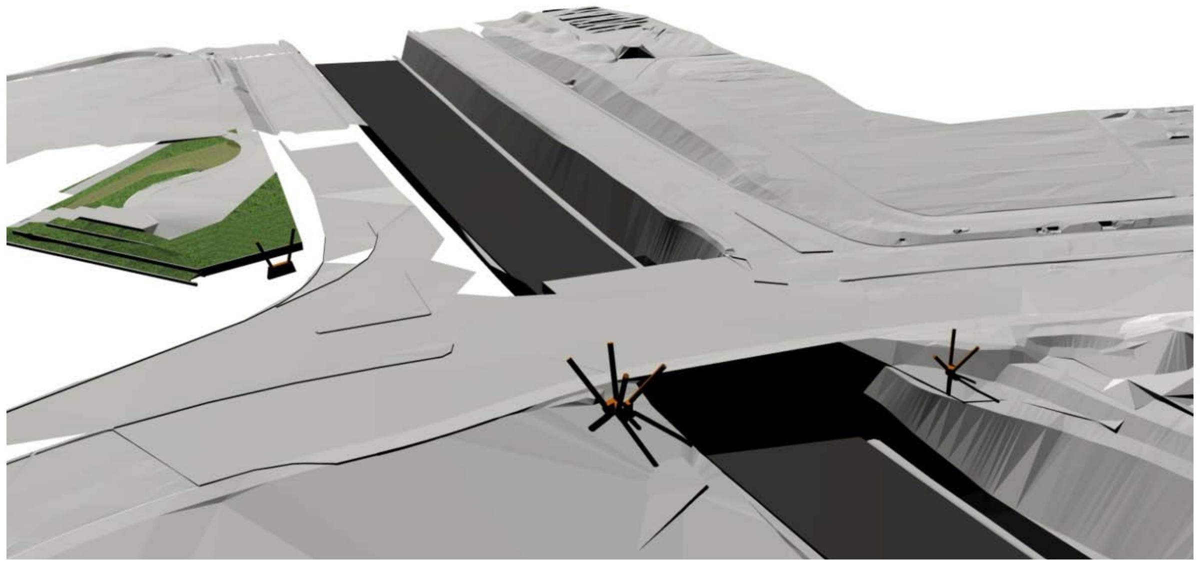

Figure 15: Construction Stage 1

Stage 2 – Combine prefabricated portions into a single assembly. Lift in central portion of Helix. Deck, balustrades and screens included.

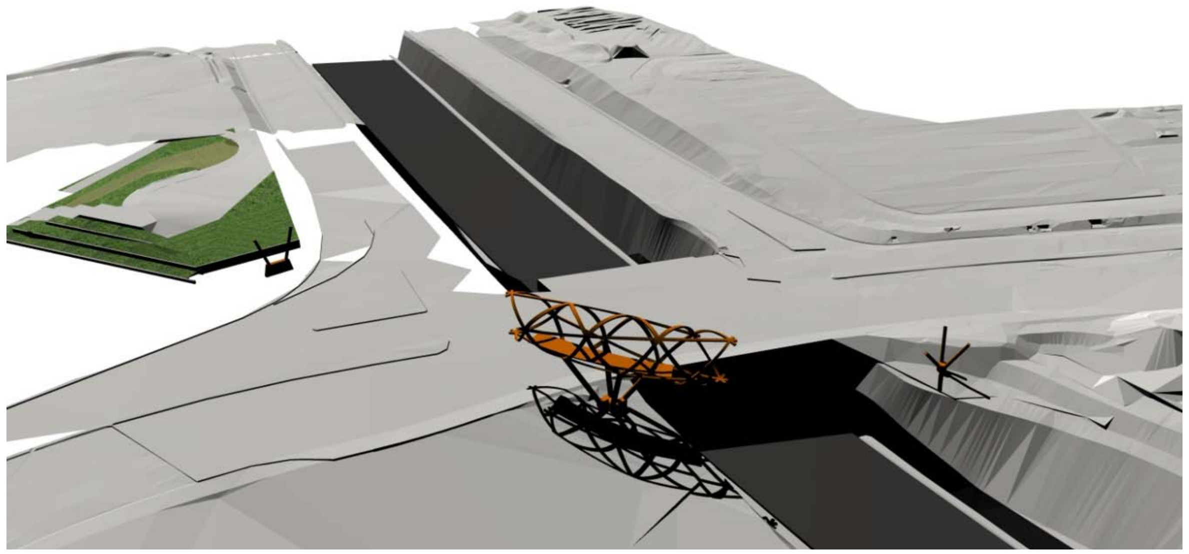

Figure 16: Construction Stage 2

Stage 3 – Combine prefabricated portions into single assemblies. Lift in Delhi Road and M2 Site approach ramp assemblies. Deck, balustrades and screens included.

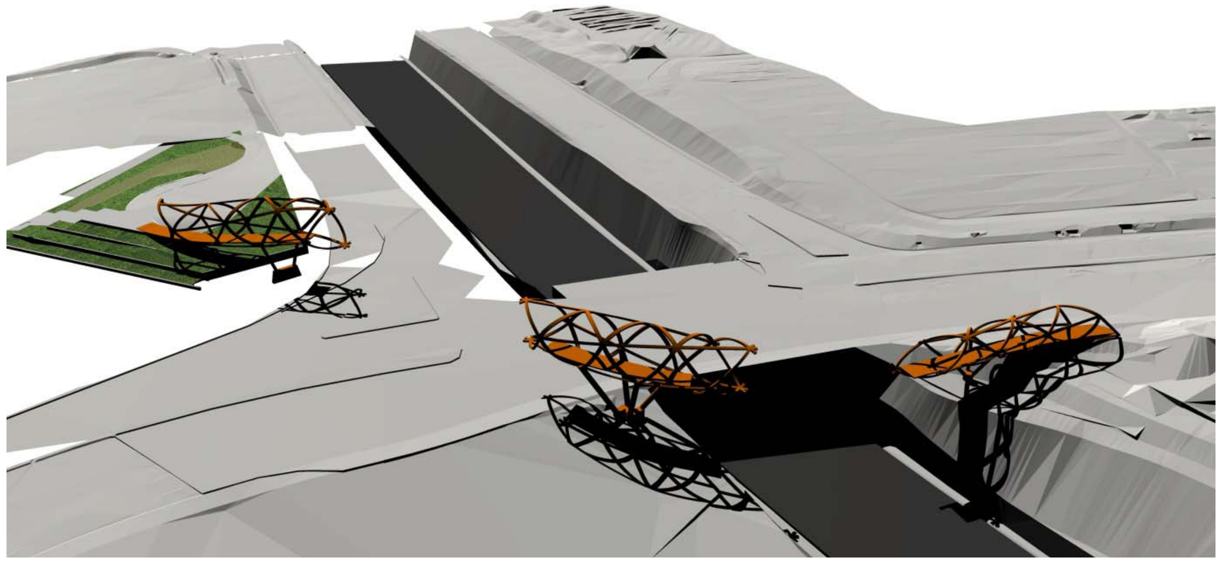

Figure 17: Construction Stage 3

Stage 4 – Combine prefabricated portions into single assemblies. Lift in central spans, temporary propping not required. Deck, balustrades and screens included.

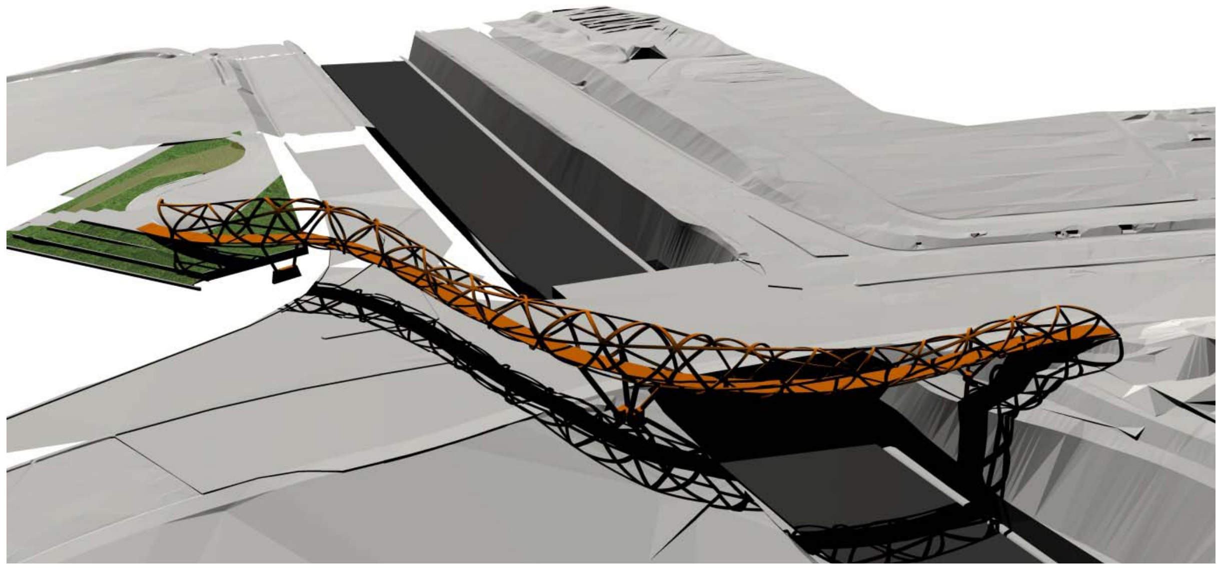

Figure 18: Construction Stage 4

6 Future Widening & Replacement of the M2 Span

Although not currently in the 20 year M2 plan, it is understood that there is provision for future M2 widening of the M2. The eastern embankment of the M2 may be pushed back towards North Ryde Station, widening the M2 by up to 3 lanes. In this scenario the M2 span of the bridge will need to be removed and replaced.

The central abutment has been design such that continuity to the Delhi Road span be can still maintained, even though the M2 span is missing. Under this scenario the bridge would naturally be closed to pedestrian traffic. Analysis model and result images are shown in Figures 15 and 16 respectively.

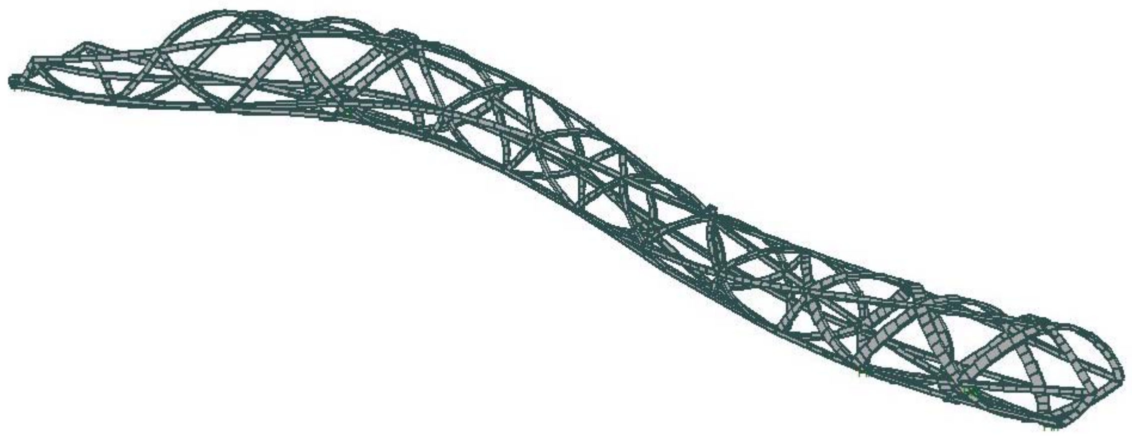

Figure 19: Analysis Model with M2 Span Removed

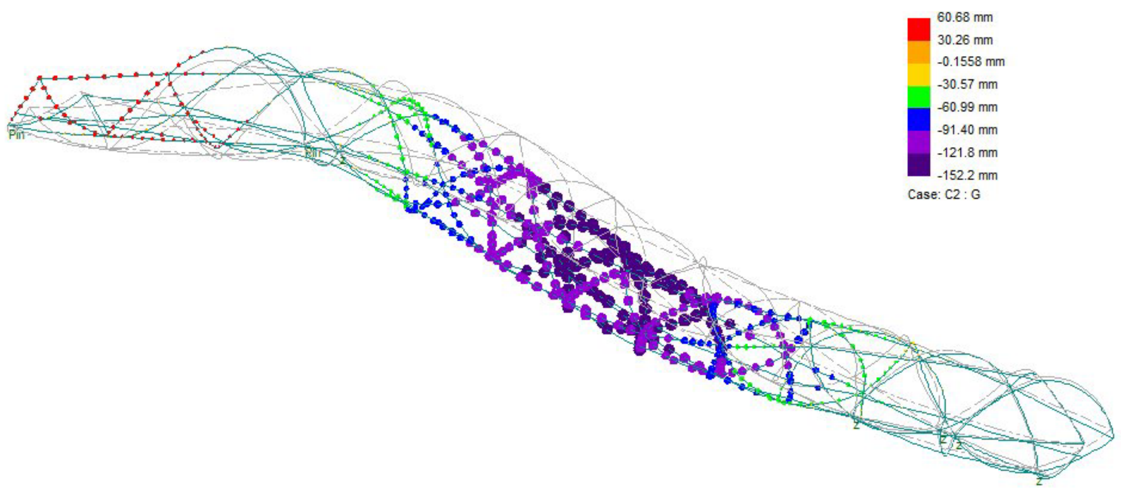

Figure 20: Delhi Road Deflection under Dead Load only

Figure 16 shows that, when compared to the complete bridge mid-span deflection of 154mm, the removal of the M2 span has hardly any influence on the deflection of the Delhi Road span. In this condition the bridge will still sit above the Delhi Road clearance zone.

7 Hydraulic Concept

The bridge is to convey the one in twenty year ARI storm (minor storm) via drains to prevent nuisance. Storms greater than a 1 in 20 ARI (major storms) will surcharge and overflow over the edges of the bridge onto roadways and plazas below.

The bridge drainage will consist of two systems;

- Interception: a grated trench on one side of the bridge that intercepts water run over the decks singular cross fall.
- Conveyance: 2 RHS channels conveying water collected by the respective interception system and transferred to this system. Transfer from the interception to conveyance system is via a DN50mm pipe.

At the M2 site provision has been made in the stormwater system for collection at the bridge abutment and conveyance to the new trunk drainage system.

At the eastern end connection will be made to the Delhi Rd trunk drainage system.

Appendix A

Preliminary Structural Drawings