Proceedings of the IASS 2024 Symposium
Redefining the Art of Structural Design
August 26-30, 2024, Zurich Switzerland
Philippe Block, Giulia Boller, Catherine DeWolf,
Jacqueline Pauli, Walter Kaufmann (eds.)

Structural and constructive resolution of eccentric structural wire model for West Gate tunnel Melbourne.

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Abstract

In March 2024, Lanik is manufacturing the single-layer structure for the West Gate Tunnel in Melbourne. This project, among others, involves the participation of TTW Engineering and features a free-form skin designed for a cooling tower intended to be topped with an opaque enclosure. Typically, free-form single-layer mesh structures are designed to create skylights where the enclosure is made of glass. In such cases, silicone front sealing is commonly used as the sealing system, ensuring that the glass separation axes do not intersect at the nodes. Consequently, the primary design wire model usually corresponds to the axes of the structural bars, resulting in eccentricities between the enclosure axes.However, for this project, the opaque enclosure does not permit eccentricities between edges, necessitating the use of the enclosure as the primary wire model. Due to the geometry, this implies that the axes of the structural bars no longer intersect in space, causing eccentricities that must be considered in the calculations since they induce rotational moments at the nodes. Besides the structural challenge posed by these eccentricities, the construction solution must also accommodate these eccentricities at the nodes. This paper describes how the structure has been resolved, taking into account the eccentricities both in terms of structural analysis and construction solution using Lanik's SLO system.

Keywords: Eccentric, wire model, West Gate tunnel

1. Introduction

The West Gate Tunnel is a significant infrastructure project aimed at providing an alternative road route to the existing West Gate Bridge in Melbourne. The South Outbound Ventilation Facility pertains to the tunnel dive structure located at the southern end of the new tunnel. This Ventilation Facility is responsible for exhausting gases from within the tunnel, thereby maintaining a high-quality air environment.

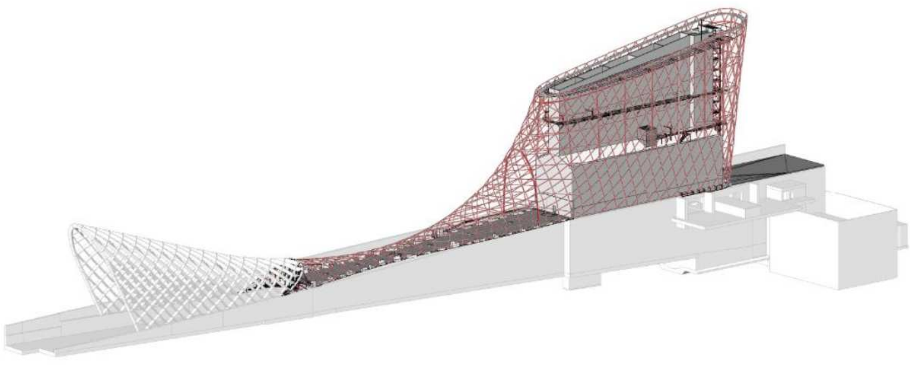

Figure 1: General view of the full Facility

The scope of work for Lanik in this project encompasses the engineering, production, and construction of the steel frame structure.

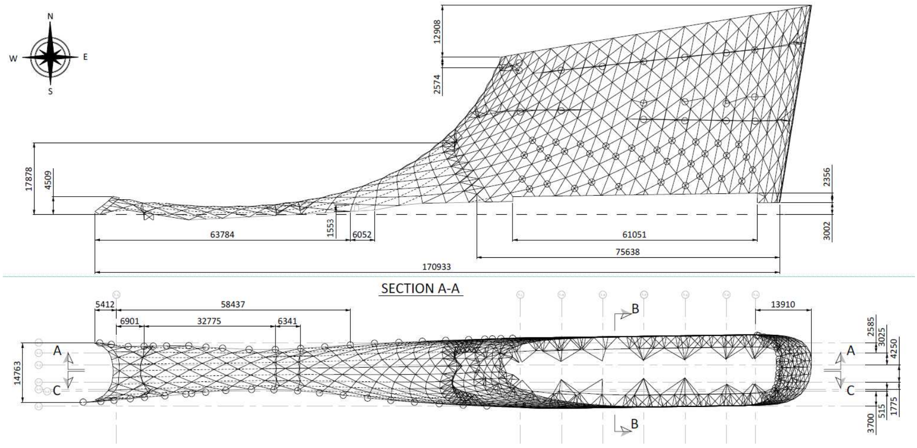

Figure 2: steel frame structure

This structure is designed using the SLO system and is covered with aluminum cladding..

2. Description of the problem

Single-layer structures are often covered with glass. When using glass with silicone front sealing, a certain eccentricity between glass joints is permitted, as illustrated in Figure 4.

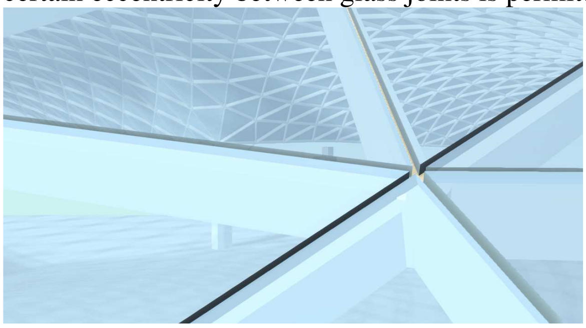

Figure 3: single layer covered by glass

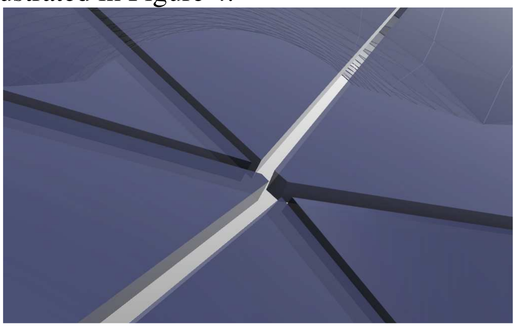

Figure 4: eccentricity between glass joints

This eccentricity between cladding panel joints occurs if the wire model used as the basis of design is located at the structural axis (see Figures 5 and 6) and if there is simultaneously a twist angle between members (see Figure 7).

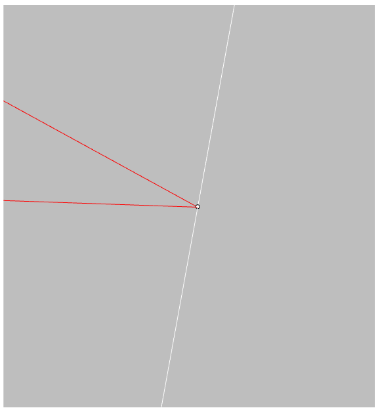

Figure 5: wire model

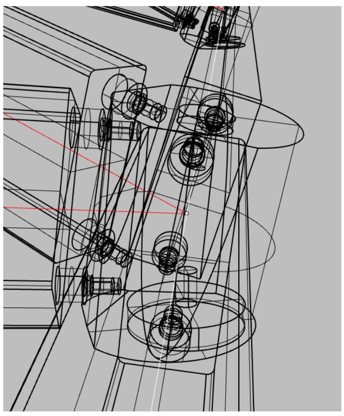

Figure 6: wire model at structural axes

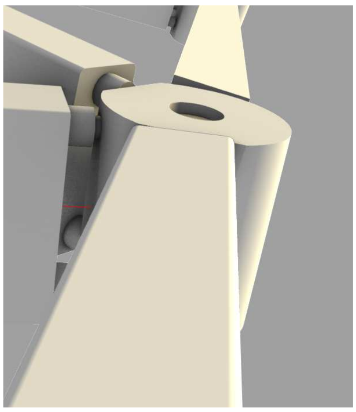

Figure 7: Twist between members

In this West Gate Tunnel project, the aluminum cladding does not permit eccentricities at the joints between panels. The joints must intersect at a single point at the nodes. In other words, the cladding axes must intersect in space and not overlap as can occur with glass joints.

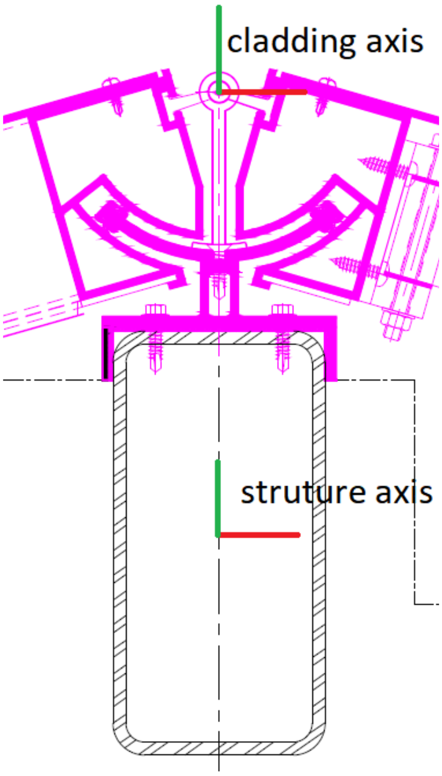

Figure 8: aluminium clading joint detail and location of structural and cladding axis

Since the cladding axis must intersect at nodes and twist angles cannot be avoided in a free-form structure, the wire model must align with the cladding axis. Consequently, the twist angles introduce eccentricities between structural axes. The construction system must accommodate these eccentricities, and the calculation must include bending efforts at the joints due to the combination of axial forces and eccentricities.

3. Constructive solution

The construction system employed in this project is the SLO system, developed by Lanik [2]. It utilizes a solid node where two ORTZ bolts are anchored for each bar.

The relative position of a bar connection, referenced to the local axes, is determined by three coordinates:

- Orientation: This angle is formed by the projection of the bar's axis onto the tangent plane at the corresponding node, relative to a specified reference direction on that plane.

- Elevation: This angle is formed by the axis of the bar with respect to the aforementioned projection.

- Distortion (or twist): This angle represents the deviation between the node's axis and its projection onto the bar's primary plane of inertia. This deviation arises because, generally, the normal vectors assigned to the endpoints of a bar are not coplanar. The primary plane of the bar typically lies in an intermediate position between both nodes. (In specific cases, such as on surfaces like a spherical segment where all normal vectors pass through its center, this distortion angle is zero).

The SLO system and the manufacturing process for its nodes have been meticulously designed and developed to adhere strictly to the specified angles. These angles, particularly the Distortion (or Twist) angle, are detailed in figures 9 and 10.

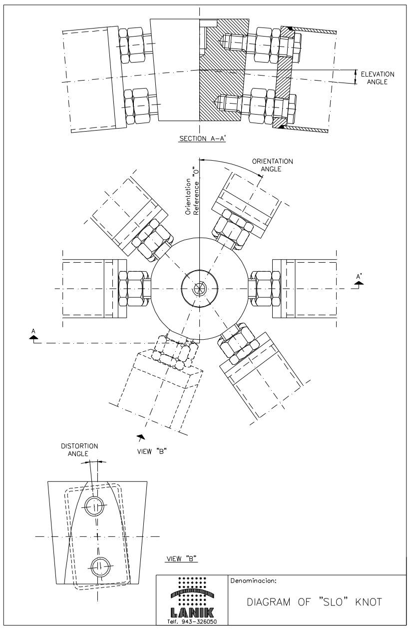

Figure 9: Main angles at SLO node

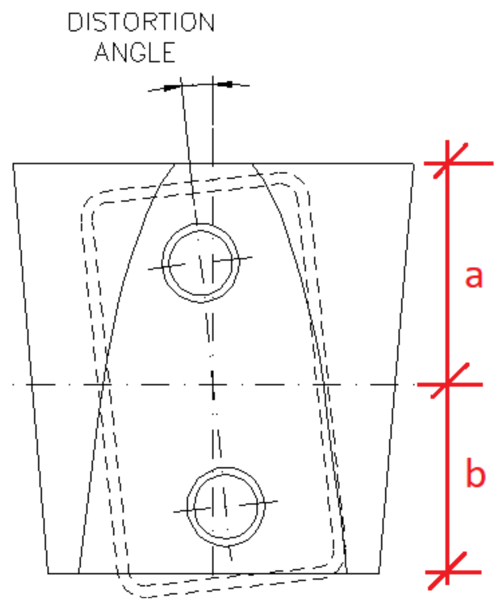

Figure 10: Distortion (or twist) angle at SLO node

The drilling machines utilized for manufacturing SLO nodes offer flexibility in positioning screws anywhere on the connection face or chamfer. This capability allows accommodation of the twist angle for each bar joined at a node. Geometrically, the center of rotation for the twist angle can be situated at any height, as the screws can be placed at any position on this plane. Typically, the center of rotation coincides with the structural axis, but not necessarily with the node's center, which may vary slightly in elevation ($a \neq b$ in figure 10) due to various factors.

The software employed for automated geometric node definition is GOOSE [1]. This software enables applying a specific eccentricity to bars in the direction of their orientation angle. In practical terms, bars can be displaced vertically along their orientation vector, allowing their axes to deviate from the wire model.

By combining these capabilities—flexible node center placement and bar displacement along their orientation vectors—the wire model used can be positioned at an offset distance from the structural elements.

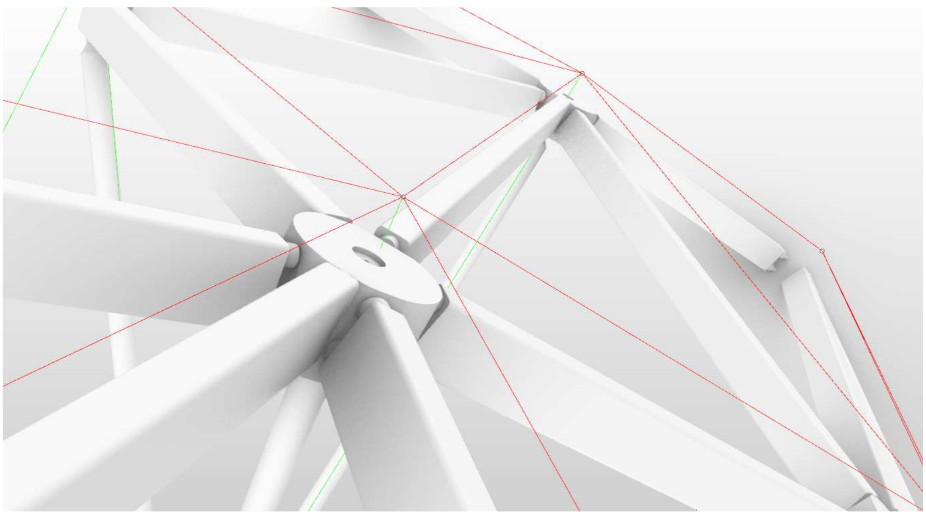

Figure 11: Wire model located at a certain offest distance to the structrual members

The offset depicted in Figure 11 is achieved by displacing the bars along their orientation vector (which lies within the main plane of inertia) and displacing the nodes along their orientation vector (average of the normal vectors of the 6 adjacent panels). As a result, in certain instances, the screws are notably shifted away from the center of the connection planes, and the structural axes no longer intersect between them.

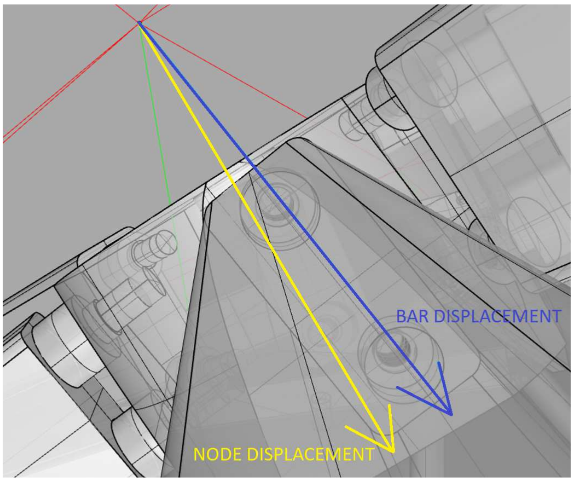

Figure 12: node and bar displacements

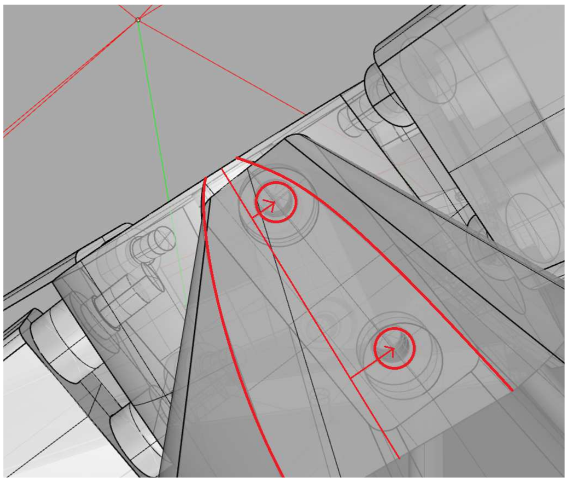

Figure 13: Non centered screws

As depicted in Figure 13, the automatic resolution of nodes by GOOSE accommodates the displacement of bars and nodes, ensuring that connection screws are correctly positioned within the chamfer of the node. From GOOSE's perspective, mathematically, there is minimal distinction between this offset case and any other scenario without offset. Therefore, the constructional aspect of this issue is effectively addressed using the SLO system generated automatically by GOOSE.

4. Structural calculation solution

Once the constructive solution is defined, it must be correctly simulated in the calculation model.

In this case, the displacements done to the bars promotes certain eccentricities between structural axes. In the calculation model, the strategy adopted is to create a new master point displaced along the orientation vector of the nodes, and one slave point for each structural member end. This generation is done inside GOOSE (Rhino plugin) using grasshopper to create the new points.

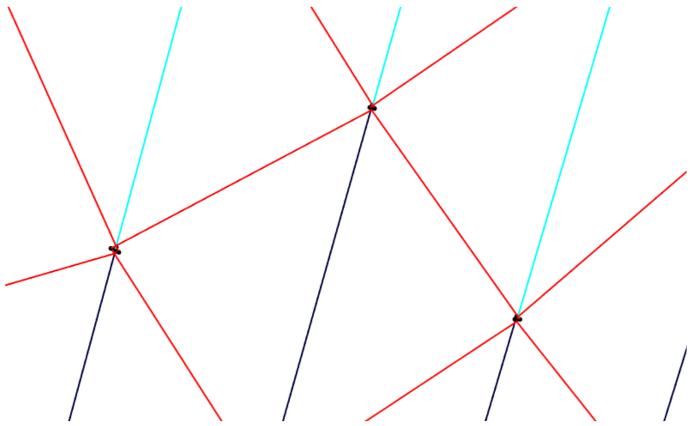

Figure 14: Eccentricities in the calculation model

To integrate these aspects seamlessly, "LINK type" elements have been incorporated into SAP2000. A link object establishes a connection between two points, i and j, which are separated by a length L. This linkage ensures that both nodes experience identical displacements and rotations.

Typically, in the absence of eccentricities, the SLO connection exhibits high flexibility along the secondary axis of inertia. For triangular meshes, the moment at the node in the weak axis is usually regarded as negligible. However, in scenarios with eccentricities, the moment in the weak axis can become significant. Hence, it becomes imperative to consider this moment in the combination of forces.

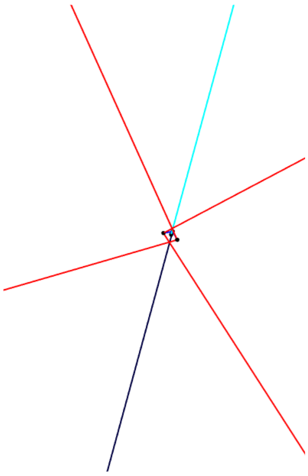

Figure 15: calculation model

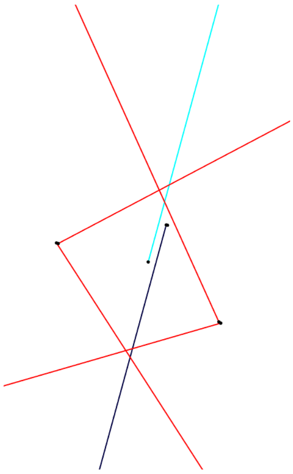

Figure 16: zoom view of a node

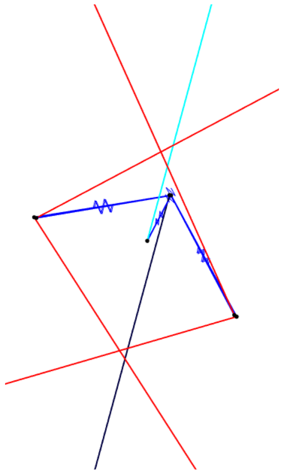

Figure 17: LINK type elements

The verification of bolted connections and beam sections includes consideration of bending moments resulting from a combination of eccentricity and axial force. These additional forces are directly extracted from the calculation software, which incorporates geometric eccentricities into the model.

Typically, when there are no eccentricities, the SLO connection exhibits high flexibility along the secondary axis of inertia, and any moment at the node in the weak axis is often negligible in triangular meshes. However, due to eccentricity effects, the moment in the weak axis can become significant and must therefore be accounted for in the combination of forces.

The standard bolt verification formulation in GOOSE does not inherently include this bending moment. Therefore, in such cases, verification is conducted using an Excel spreadsheet where the bending moment is added to the tensile and shear forces. The number of parameters involved in this verification is extensive and cannot be feasibly presented as an image in this paper.

5. Conclusion

The problem has been resolved through both constructive and structural means by implementing the SLO system and integrating new virtual nodes into the computational model. This approach ensures the project meets the stringent requirement of non-eccentricity between cladding axes. The SLO system's capability to handle geometric eccentricities and its integration with SAP2000 for comprehensive structural analysis have been instrumental. By incorporating bending moments alongside axial and shear forces in the verification process, accurate assessments of bolted connections and beam sections are achieved. This holistic approach, combined with supplementary calculations for bending effects, underscores the project's robustness in meeting design specifications and ensuring structural integrity.

References

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[2] J. Goñi and L. Irisarri, “Elastic-plastic behaviour of the SLO node for the second order calculation of the safety factor against global buckling in single layer structure”, *IASS Symposium*, Wroclaw, Poland, 2013.