To jamb or not to jamb: Evaluating cross passage permanent support systems

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ABSTRACT: This paper explores design considerations for cross passage permanent support systems, comparing the use of jambs versus lintels. Focusing on the City Rail Link in Auckland, which employs jambs, the study examines the associated benefits, such as enhanced structural support and improved load distribution. However, the incorporation of jambs introduces challenges, including installation complexities, maintenance issues, and potential access restrictions within the tunnel system. The paper highlights specific design and execution challenges faced during the City Rail Link project. It also discusses the advantages of lintel designs, which may offer improved flexibility and simplified construction, while emphasising the need for structural stability and safety. Through an analysis of the trade-offs between jamb and lintel designs, the findings aim to inform best practices for future urban tunnelling projects, contribute to discussions on optimal design strategies that enhance operational efficiency and construction safety in the future.

1 INTRODUCTION

1.1 *Project Background*

The City Rail Link (CRL) is the largest transport infrastructure project ever to be constructed in New Zealand's. CRL is a 3.45km twin-tunnel underground rail link up to 42 metres below the city centre. It will transform the downtown Waitematā Station (Britomart) into a two-way through-station that better connects the city's rail network.

It includes a redeveloped Maungawhau Station, where CRL connects with the North Auckland (Western Line) and new underground stations - one midtown underneath Albert Street called Te Waihorotiu Station and Karanga-a-Hape Station just off Karangahape Road with entrances at both Mercury Lane and Beresford Square.

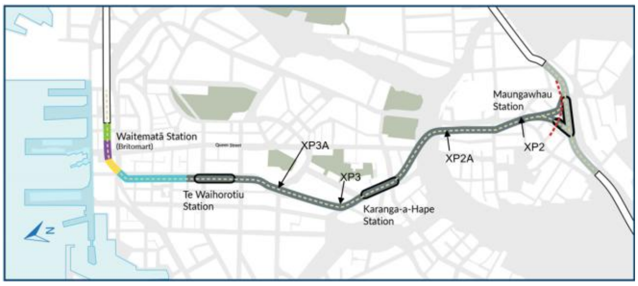

Figure1. City Rail Link Contract C3 Alignment and Station Location Plan

The Link Alliance is delivering the main works including three new stations, twin tunnels, rail systems and work at the existing Waitemata Station (Britomart) to accommodate the new rail connection. Link Alliance comprises City Rail Link Limited, Vinci Construction Grands Projets, Downer NZ Ltd, Soletanche Bachy International NZ Limited, WSP (NZ) Limited, AECOM New Zealand Limited and Tonkin + Taylor Limited[i].

There are two bored tunnel cross passages between each of the stations. The cross passages between Maungawhau Station and Karanga-a-Hape Station were labelled XP2 & XP2A and the cross passages between Karanga-a-Hape Station and Te Waihorotiu Station were labelled XP3 & XP3A in Figure 1. The spacing between the cross passages was determined following a fire life safety assessment which is beyond the scope of this paper. All cross passages on CRL were constructed with jambs.

1.2 *Definitions*

The elements that form cross passage permanent support are lintels, jambs, collar and side walls (Figure 2). These elements are defined as:

- Lintels: These are horizontal structural elements that span the openings above cross passages. They bear the load from the tunnel segments and help distribute it evenly across the support system.
- Jambs: The vertical supports that frame the sides of the lintels. Jambs effectively act as columns and carry vertical loads and bending.
- Collar: The section immediately behind the segments that receives the load from the lintel and transfer loads to the side walls
- Side walls: The elements that support the collar.

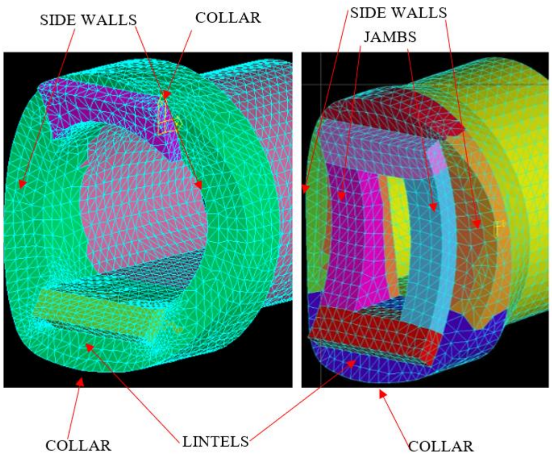

Figure 2. Cross passage permanent support definitions

2 A REVIEW OF THE BASICS

2.1 *Load transfer mechanisms*

The vertical load from the segments must ultimately be transferred into the side walls of the collar to find an equilibrating reaction from the bottom segment load or the ground (Figure 3). The load from the segments is usually considered to be uniform at the top and bottom of the opening so the most direct load path is provided by the jamb system.

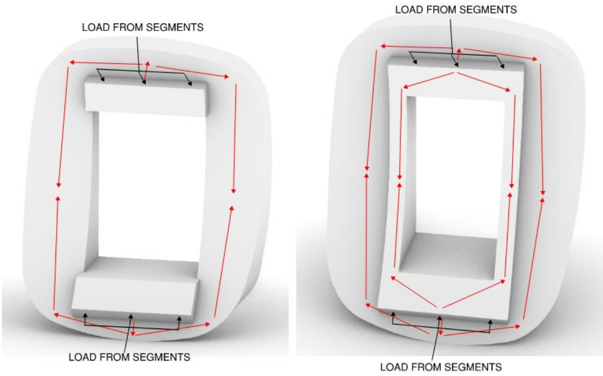

Figure 3. Load transfer mechanisms with no-jamb and jamb systems

For lintel only systems, given typical span and depth ratios, it can be designed using a strut and tie approach, with the primary design action being the axial load from the segments (Figure 4). The vertical load is subsequently transferred back to the collar along with the associated torsion. These actions are in turn is transferred to the side walls. Both systems require ground loads to be considered on the collar and side walls.

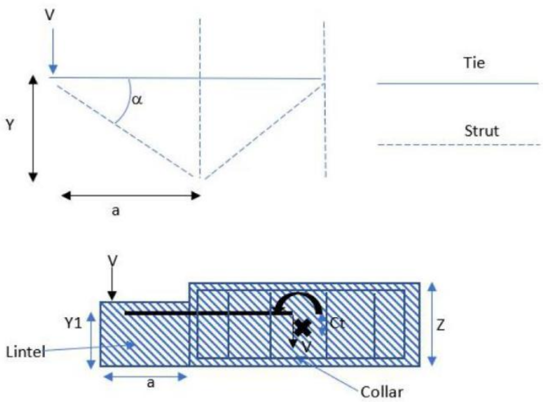

Figure 4. Strut and tie model and lintel collar transfer mechanism

2.2 Global Behaviour

The global behaviour of the permanent support systems is more readily comprehensible in the absence of jambs. In a no-jamb configuration, the segments exhibit a squeezing action that induces a tendency to close in towards the opening. This phenomenon results in the collar flexing and moving in both vertical and horizontal planes (Figure 5). Consequently, the ground must effectively resist these movements unless the cross passage lining is explicitly designed to provide additional restraint to the collar. If the ground cannot restrain the movements or there isn't a suitable movement joint between the collar and the cross passage lining, the dynamics of movement may compromise the structural integrity and stability of the cross passage.

In contrast, when a jamb system is implemented, movements are better accommodated and restrained due to the presence of a stiffer support structure surrounding the opening. This stiffness contributes to a more direct load path, which efficiently transfers the forces from the segments into the jambs. As a result, the design enhances the overall stability of the support system by mitigating lateral and vertical displacements.

In essence, a no-jamb system presents challenges that necessitate careful consideration of ground resistance and the adequacy of the cross passage lining. However, these risks are not insurmountable especially in favourable ground conditions. The incorporation of jambs leads to a more secure and resilient structural solution. This distinction is critical for designers when determining which support system best meets the demands of the project in question.

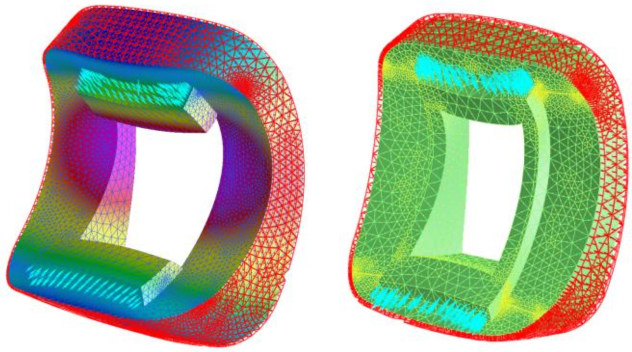

Figure 5. Global behaviour of a no-jamb system and jamb systems

4 DDITIONAL PERMANENT SUPPORT OPTIONS

4.1 *Shear keys*

Shear keys facilitate load transfer, improve stability, and alleviate potential movement between the segments. They have been used successfully in temporary support to facilitate the construction of openings in the segmental linings of large diameter TBM tunnels (Chau et al., 2023).

Shear keys act as mechanical interlocks between adjacent segments, and they help to distribute the axial forces in the segments around the opening. When used in conjunction with either of the jamb or no jamb systems, they would act to reduce the load taken by the lintels and jambs.

However, when incorporating steel shear keys into the design of a permanent support system, several factors would have to be assessed. These include but are not limited to:

1. The long-term durability of the shear key. Steel is commonly used due to its acceptable mechanical properties Protective coatings may need be applied to enhance corrosion resistance, particularly in moist or chemically aggressive environments.
2. Construction tolerances and ring roll if the shear keys are cast into the segments
3. Coring and reinforcement clashes as well construction logistics challenges associated with installation after the ring build.

Given these factors and the relatively low magnitude of the axial forces in a metro tunnel compared to a road tunnel shear keys were not adopted on CRL.

4.2 *First stage concrete (FSC)*

The track bed first stage concrete was used as a flexible strut both in the temporary and permanent case on CRL. This resulted in no temporary lintel having to be lifted and fixed in place before the opening of the segments (Figure 6). Moreover, it resulted in a more rigid permanent support system for the cross passages and additional load sharing between the segments either side of the opening and the collar.

On CRL analysing the effect of the first stage concrete in the permanent case involved carrying out a construction stage analysis calculation where temporary support elements (bicones in this case) are ‘switched off’ and the permanent support is wished into place. The analysis is then rerun, and sections were cut through each of the structural elements (1.2) to determine the design actions.

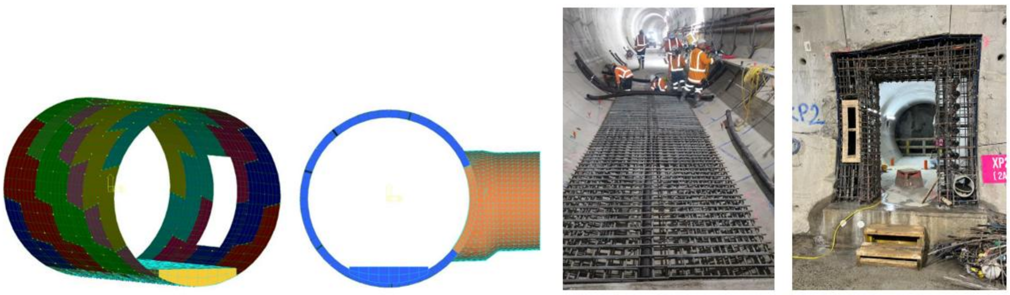

Figure 6. FSC Analysis models, FSC installed reinforcement, Segment opening without temporary lintels

5 CONSTRUCTABILITY

5.1 *Formwork and Reinforcement Detailing at Element Transitions*

Regardless of the chosen structural system, the formwork will likely need to be bespoke; in CRL's case, Liando formwork was utilized (Figure 7). Careful consideration must be given to the reinforcement detailing at the transitions between elements. Initially, the plan for CRL was to construct the permanent structure in a single pour; however, this strategy was adjusted to require two separate pours. Consequently, the introduction of couplers was necessary to effectively connect the flat invert with the curved sections, ensuring the integrity and continuity of the reinforcement across the junction (Figure 8). Non-contact laps were used to ensure continuity with the curved bars above the construction joint. In this instance the choice of a jamb system was beneficial as the side walls are generally lighter in reinforcement than no-jamb systems. Proper detailing at these transition points is critical for maintaining structural performance and durability requirements.

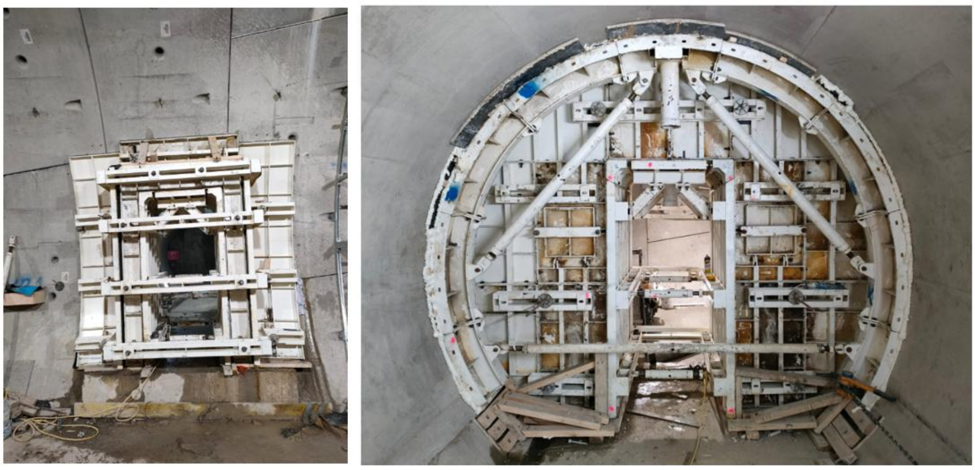

Figure 7. Liando formwork for the cross passage permanent support on CRL

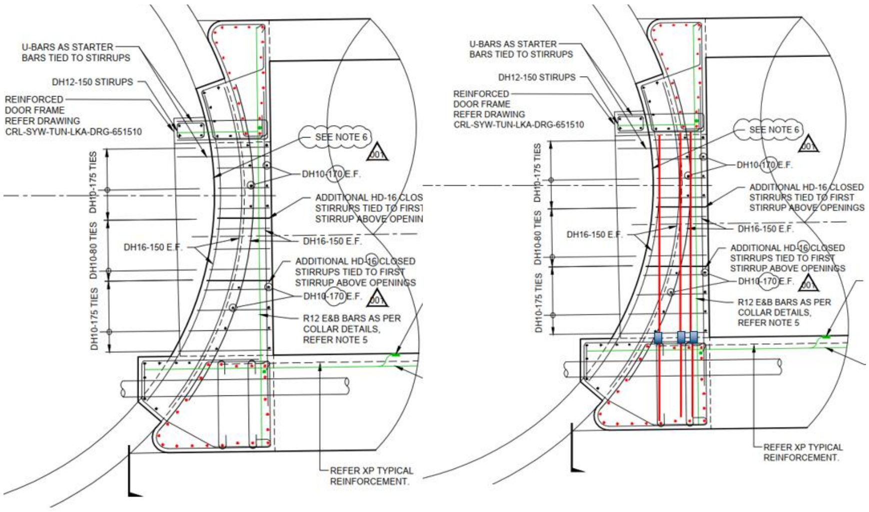

Figure 8. Original Reinforcement arrangement without couplers (left) and construction phase red-line mark up of couplers and starter bars

5.2 *Alliance considerations*

CRL was delivered through an alliance model, which enabled early contractor involvement and fostered enhanced collaboration among the alliance team. This approach facilitated informed decision-making that aligned with the project's objectives. A key result of this collaboration was the selection of jambs in conjunction with the first-stage concrete for the permanent support system. This choice led to a significant reduction in reinforcement requirements. This reduction not only improved structural efficiency but also lowered material costs. Additionally, the use of jambs simplified construction logistics throughout the lifecycle of both the temporary and permanent works. The clearer task delineation associated with implementing jambs and first-stage concrete enabled more efficient scheduling and resource allocation. Overall, the alliance delivery model contributed to a more effective design solution while enhancing the project's constructability.

The permanent support design decisions did lead to some additional logistical challenges for the construction team. Firstly, the pours needed to be co-ordinated with a separate team within the Alliance. Additionally, the integration of services through the jambs required specific design checks on site to ensure the type and number of ducts were suitable to house the services (Figure 9).

Figure 9: Cross passage reinforcement and concrete after striking

5.3 *No jambs*

Eliminating the need for jambs can offer advantages in terms of constructability and access, particularly when addressing the secondary lining section between the collars. Without jambs, there is the potential for greater manoeuvrability of formwork through the temporary opening and potential for an additional service path for plant. In some instances, this may improve cycle times for cross passage construction. Additionally, not having jambs means that ducting does not need to be routed through the reinforcement, simplifying the reinforcement detailing

6 MAINTENANCE

The maintenance considerations are broadly similar for both systems with the lintel only system having fewer elements to maintain. In the case of CRL the permanent support was designed with minimal maintenance requirements during the 120-year design life.

7 CONCLUSIONS

7.1 *Summary*

This paper evaluates the design considerations for cross passage permanent support systems, focusing on CRL in Auckland, which employs jambs. It discusses the benefits of jambs, such as enhanced structural support and improved load distribution, but also highlights challenges including installation complexities and potential access restrictions. The analysis contrasts jamb and lintel designs, noting that jambs can lead to significant reductions in reinforcement requirements, improving material efficiency and lowering costs. Additionally, the paper emphasizes the advantages of not using jambs, including increased constructability, greater manoeuvrability for formwork, and simplified ducting without interference with reinforcement. Ultimately, the findings aim to inform best practices in urban tunnelling projects by weighing the trade-offs between structural robustness and construction efficiency.

7.2 *Selection of jambs on CRL*

Jambs were chosen on CRL primarily because they provide enhanced structural support and a more direct vertical load path, improving load distribution and increasing the overall robustness of the permanent support system. This approach reduces the reliance on the collar alone, resulting in better tunnel stability by accommodating movements and minimizing displacements. Additionally, the use of jambs allowed for a significant reduction in reinforcement requirements, improving material efficiency and lowering costs. Despite adding some construction complexity, jambs integrated well with the first-stage concrete and the alliance delivery model, simplifying construction logistics through early contractor involvement and effective collaboration.

7.3 *Comparison*

Aspect	No Jambs	Jambs
Load Path	Horizontal spanning + distributed hoop stress through collar.	Combined vertical (through jambs) and horizontal spanning + collar action.
Load Transfer	Lintel to collar- collar to side walls – side walls to ground (or equilibrating force from bottom lintel)	Loading split between lintel to jambs and lintel to collar.
Structural Redundancy	Moderate — relies on collar and tunnel lining integrity.	High — jambs provide an independent, direct vertical load path alongside collar support.
Tunnel Stability	Good, but more sensitive to deformation if collar installation or material behaviour is imperfect.	Very robust — tunnel lining integrity is well maintained through multiple load paths.

Construction Complexity	Simpler — fewer structural elements to install (no jambs).	More complex — requires precise jamb installation plus collar and lintel works.
Maintenance / Inspection	Easier — fewer elements; collar inspection is important.	Slightly more challenging — multiple elements must be inspected and maintained.
Access Impact (Tunnel Operations)	Better — no vertical elements (jambs) obstructing passageway.	Reduced — jambs may slightly restrict space inside cross passage.
Best Use Cases	In good ground, where construction speed, flexibility, and minimal intrusion are priorities.	Where maximum long-term structural robustness and reduced deformation are critical.

ACKNOWLEDGEMENTS

The author would like to thank City Rail Link Ltd for permitting the publication of this paper and Brandon Wang of Aurecon for his help with model generation.

8 REFERENCES

[i] https://www.cityraillink.co.nz/

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