Optimizing the Interaction Between Permanent and Temporary Works in Balanced Cantilever Bridges

Joakim Dupleix, Florian Dieterle

CaSE International,
Brazil and Australia

Summary
This paper explores how the interaction between permanent and temporary works designs during the concept phase of bridge design can optimise project outcomes. The paper presents several case studies, including an analysis of various form traveller types for a balanced cantilever bridge and the impact of out-of-balance propping on the permanent design of such a bridge.

1 INTRODUCTION

Historically, complex bridge projects, requiring large construction equipment, often lacked consideration of the impact such equipment would have on the bridge structure during the permanent works design phase. The temporary works design was typically undertaken at a much later time than the permanent design, limiting opportunities for significant innovation and improvement in the construction method. This often resulted in sub-optimal construction techniques and increased cost.
This paper will discuss three Australian case studies of projects where the integration of temporary works and construction methods ultimately influenced and drove the permanent design of balanced cantilever bridge construction.

2 FORM TRAVELLER SELECTION

Long-span balanced cantilever bridges are often constructed using a cast-in-situ method due to the size of the segment near the piers, which are too heavy to be lifted using standard size lifting machines. Therefore, a travelling formwork system is typically used. These travellers are well-established and standardised systems, often designed and supplied internationally. However, these systems frequently require adaptation to local conditions, and when re-using an existing system, modifications must be carefully planned early in the process.

To ensure the delivery of an efficient system that meets project-specific needs, it is crucial to provide an accurate performance specification. This specification should address local access requirements, available cranage, efficient reinforcement installation, and the ability to achieve the typical one-week construction cycle per segment in a single pour.

As further elaborated by Meyer M (2018) [1], particular attention should be paid to:

1. The interaction between the form traveller and the permanent bridge works, including tie-downs and post-tensioning duct locations.
2. Crane requirements for both assembly and removal.
3. Interaction with the closure pour and the ability to re-use the formwork for closure.
4. Detailed consideration for reinforcement constructability.

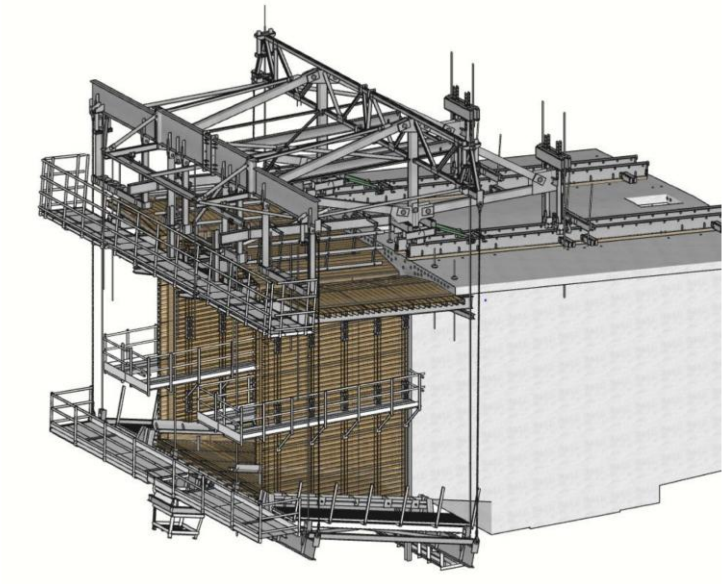


Fig. 1. 3D view of an overhead form traveller (CaSE, 2019)

Before balanced cantilever construction can proceed, a pier table must first be constructed using a separate formwork system. While there is an opportunity to reuse parts for the travelling formwork, careful and detailed planning is essential to avoid delays in the typical construction cycle of the form traveller.

Developing 3D models of the reinforcement provides significant benefits, including the ability to accurately check clashes, detail reinforcement bars when scheduling across different pours, and ensure adequate access around the large vertical walls. Once the 3D model is complete, it can be utilised to create a construction animation, allowing the sequence to be clearly communicated to all stakeholders.

Comentado [FD1]: @Joa
reo models?

Comentado [JD2R1]: I ca
much what to say about the

2.1 Form traveller types

The most common type of form traveller is the overhead form, where the main supporting structure, typically steel trusses, are placed above deck level (refer to Fig. 1 for illustration). This type of form traveller is popular because it is generally the most structurally efficient, resulting in a lighter system that imposes less stress on the permanent works. Additionally, overhead form travellers are widely available as standardised designs from various suppliers. From an operational point of view, they allow the launching operation to be performed from deck level, minimising the need for access below the structure.

This format also allows maximum reuse of existing steelwork, as most previously built travellers follow this design, further reducing the cost of equipment.

The second type of form traveller used in box girder construction is the underslung form. In this design, the main longitudinal structural system is located below the deck level and positioned on each side of the segment webs. Underslung travellers are commonly used for cable-stayed bridges, as they provide the necessary clearance for cables. However, they are also a viable alternative for box girders in situations where top-side access is critical, such as crane access for the installation of prefabricated reinforcement.

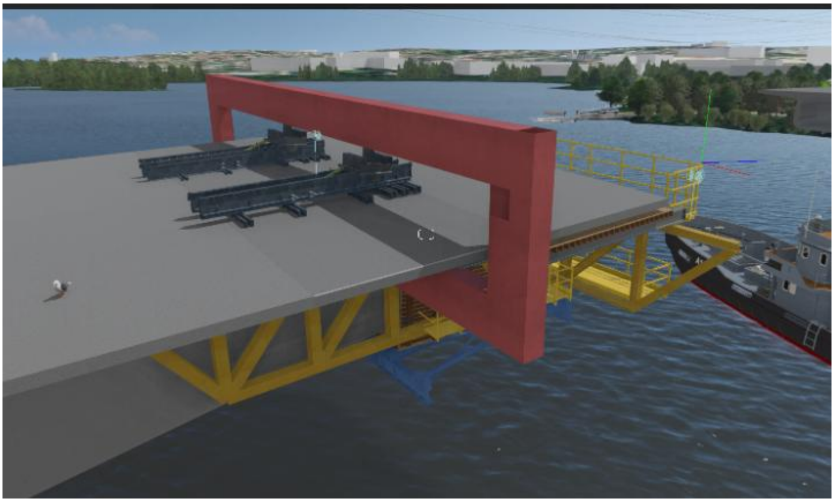


Fig. 2: Concept model of an underslung traveller (CaSE)

2.2 Case study

A recent case study illustrates the factors that can lead to selecting less common form traveller options. This project involved a three-span rail bridge, with a main span of 145 m and a deck width of 16.75 m. The bridge was planned to be built using form travellers due to the size of the concrete segments, which weighed up to 240t for the 8.5m deep sections.

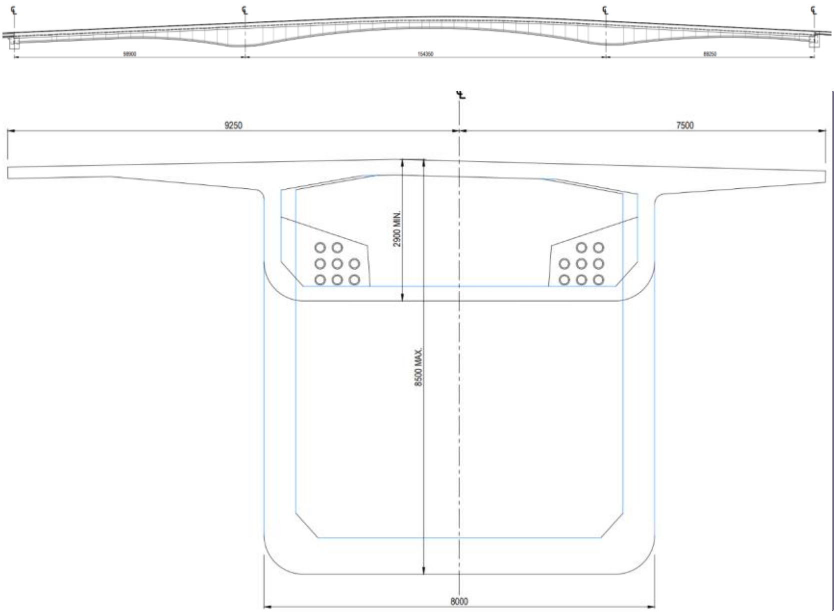
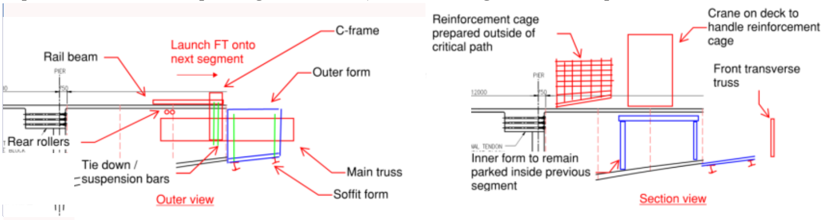


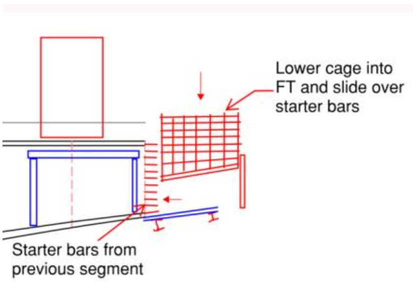
Fig. 3: Generic bridge design drawings

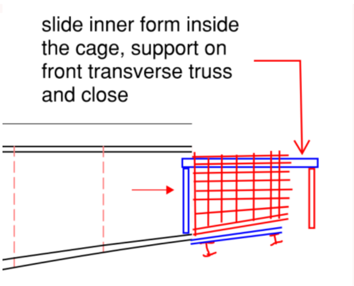
Comentado [FD3]: drawings here. i needed an Acrow. as its not so essenti
Comentado [FD4R3]: Alt similar box section
Comentado [JD5R3]: Th
Comentado [FD6R3]: ye without reference nor appro
Comentado [JD7R3]: Bru think?

The delivery team faced a critical decision: whether to use an overhead or underslung form traveller. The main driver for choosing an underslung solution was the potential to accelerate the rebar installation process. With the deck largely free of the structural steel associated with overhead travellers (except for the C-frame suspending the traveller), the following solution was possible:



Step 1





Step 2 ***Step 3***

Reinforcement cages could be prefabricated off the critical construction path, away from the form traveller. These prefabricated cages could then be craned directly into position within the traveller. The inner tunnel form would simply need to move the cage and be closed, allowing the segment pour to proceed. This method significantly reduced the construction cycle for each segment.
However, as previously mentioned, the underslung form traveller presented several challenges:

- A more complex design requiring a specialist team to define performance criteria and design the structure.
- A non-standard design, limiting the opportunity for reuse on future projects.
- A heavier structure, approximately 10-20% heavier, primarily due to the C-frame surrounding the segment wings, which is less structurally efficient
- Less favourable load transfer into the permanent works, as the main structural elements are offset from the segment webs.

Comentado [FD8]: Good table as that makes the TG ment is built or locked in, sc methodology “locked in” by or there could be an accide

Comentado [JD9R8]: I ha the pier

Comentado [FD10]: This for the competition

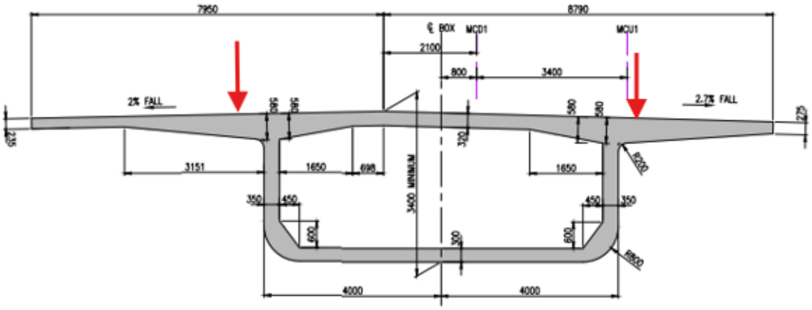


Fig. 4: Reaction force at the form traveller tie-down position connected to the permanent works.

By identifying these constraints during the conceptual stage, the permanent works could be evaluated, and the impact quantified in terms of additional design requirements. This assessment was then compared against the potential time savings from reducing the construction program. Ultimately, the decision was made to use an underslung form traveller for construction.

3 OUT OF BALANCE RESTRAINT SOLUTIONS

Balanced cantilever bridges constructed on bearings always require a temporary out-of-balance restraint solution until the cantilever is completed and connected to the opposite side. However, during cantilever erection, the forces at play and the potential for unbalanced situations - such as the accidental segment drop load case mentioned in AASHTO LRFD Section 5.12.5.3.2 [2] - can generate significant moments at the pier. These moments are often substantial enough to govern the pier design.

3.1 Typical solution

The temporary moment connection between the pier and the deck is typically achieved in two ways:

- Jacks on the pier head with post tensioning tendons that are nailed to provide the necessary clamping force.
- Props, either inclined or vertical, positioned below the first or second segment of the cantilever, significantly increasing the horizontal lever arm between the positive and negative support positions.

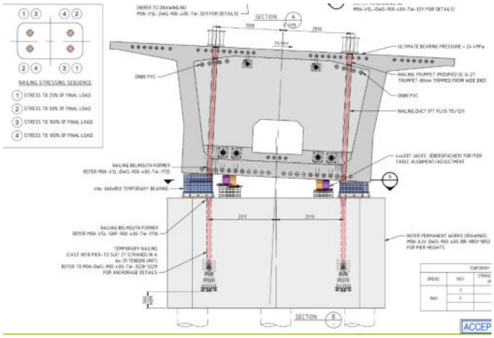


Fig. 5: Example of nailing tendons to secure pier segment on bearings

In both cases, hydraulic jacks are required to adjust the loads after each segment is erected.

The first option is generally more economical, but it is limited by the size of the pier, which could be narrow in the longitudinal direction. As a result, it is less suitable for long spans where the forces involved are large.

The second option has the challenge of installing and dismantling the props, especially when working over water with limited access. However, it is less « invasive » on the permanent works as it does not require space for the nailing tendons and temporary jacks. This allows for the possibility of a more slender and smaller pier column.

Comentado [VM11]: if you're thinking of changin instead of 'intrusive'

3.2 Case Study

This recent Australian project is a 6-span balanced cantilever bridge. The main spans were 77.75 m long.

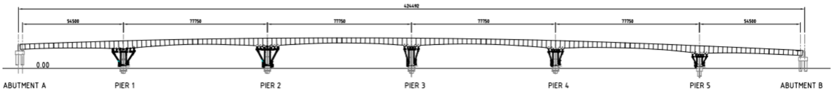


Fig. 6: Bridge elevation

Two piers are supported by bearings in their permanent configuration, while three other piers are monolithic. All segments, including the pier segment, were precast. A temporary works solution was required for the erection of the pier segments to restrain the piers on bearings during the balance cantilever erection. A steel solution was developed as follows:

- A base frame was installed on the pier pile cap.
- Heavy inclined props, modular to accommodate the varying pier heights, were placed under each segment web. These props formed part of a triangular frame, with a horizontal member designed to support the pier and first segment of the cantilever.
- The frames are horizontally tied back at the top against the pier, with stress bars positioned on the outside of the concrete column.
- The modular design and incorporated hinges allowed for the props to be dismantled efficiently. By lowering them and rotating around the lower pin connection, the props could be removed and then transported away by barge.

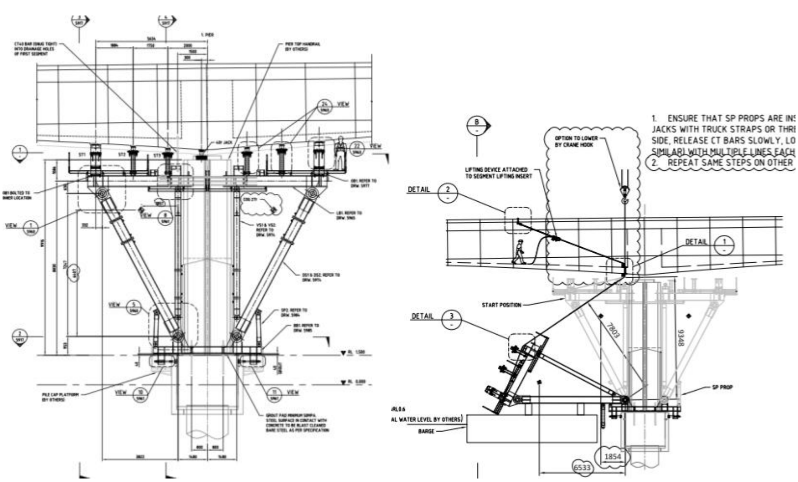


Fig. 7: Details of the propping solution and dismantling methods

This design, along with its careful planning during the permanent works design phase, allowed efficient construction while minimising impact on the pier segment diaphragm, thereby avoiding additional congestion.

Fig. 8: Photo of the propping solution during construction

4 CONCLUSIONS

These examples demonstrate that early planning of the critical construction phases for a balanced cantilever bridge allows for the permanent works to be adapted, ensuring the best possible project outcome. The authors encourage contractors and designers to closely examine these interfaces for challenging projects. The lessons learned from Australian bridge projects can also be applied to other concrete construction projects.

References

[1] Meyer M, Harridge S (2019), Bridge Deck Erection Equipment – A best practice guide, IABSE Working Group 6, Chapters 11 and 13, ICE Publishing, 2018, London

[2] AASHTO LFRD –BRIDGE DESIGN SPECIFICATIONS, 9th Edition | 2020