

Unique Cable Stayed Bridge for Shopping Centre

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SYNOPSIS

The new Westfield Shopping World development at Bondi Junction, Sydney, comprises major shopping blocks located on either side of busy Oxford Street which are linked by an underground multileveled structure located beneath the street. The development conditions required that at least two traffic lanes plus provision for pedestrians and existing services be maintained at all times during construction.

This paper focuses on special features of the adopted bridge option, constructed to meet the development conditions. It describes the reasons behind the need, structural options considered and the design and construction features of the innovative cable stayed solution that was incorporated into the final building structure.

1. INTRODUCTION

The new Westfield Shopping World development at Bondi Junction, Sydney, is one of the most ambitious projects undertaken to date by the multinational Westfield Group. This AU\$1 billion shopping and entertainment complex consolidates three existing retail sites to establish 104,000 square metres of retail space in the heart of one of Sydney's most affluent areas. The major shopping blocks located on either side of busy Oxford Street were required to be linked by an underground multileveled structure passing beneath the street to create the

consolidated area. The development conditions required that at least two traffic lanes plus provision for pedestrians and existing services be maintained at all times during construction of the basement structure and that the street be re-opened to traffic in its original form on completion of building construction.

Initially, conventional steel and concrete type bridge decks spanning approximately 52m across the excavation required for the basement construction were considered for accommodating the vehicular and pedestrian traffic as well as the services. The intention being to construct the bridge structure on top of the existing road surface while temporarily deviating one lane of traffic. Supporting this structure at intermediate points other than at the two deck ends was not possible as excavation into the underlying sandstone had to be completed before foundations and support columns for the building structure could be constructed. A steel type truss superstructure of varying configuration was initially considered. It would have to be a “through type truss” that would extend above road level so as not to interfere with building construction below road level. Although a steel type structure that could span the full 52m was optimized and met the project requirements, it had disadvantages in that cost was high. In addition, it had to be discarded after use which was anticipated to be for only about six months. A concrete superstructure was also considered but had similar disadvantages to that of the steel option, as well as being much heavier and more difficult to remove. A slab type deck was not structurally achievable. As these solutions were not ideal, consideration was given to an alternative option.

To overcome the aforementioned problems Austress Freyssinet initiated a unique solution that incorporated the roof of the permanent structure and temporarily supporting it with stay cables until the remainder of the structure had been built up underneath. This solution would facilitate construction of the full excavation and then the multileveled basement structure without interference from any type of substructure support system, whilst maintaining a busy urban street open to vehicular and pedestrian traffic. This solution was made more economical by the presence of high level sandstone which avoided the need for costly temporary foundations for the stay cable masts.

The solution was readily adopted by the client as it presented many advantages including:-

- a) Significantly more economical than conventional type temporary bridges
- b) Faster to erect and dismantle
- c) Minimal use of temporary works
- d) No significant impact of the superstructure below ground level which would interfere with excavation.
- e) The two 0.45m diameter water mains could be incorporated into the permanent structure at the start. Other schemes required a separate structure.

2. BRIDGE DESIGN ASPECTS

To accommodate the required 6.4m trafficable width, pedestrian walkway and services, the deck had to be 11.0m wide and designed for standard bridge loading, refer to Figure 1. The width also had to be restricted so as to retain one lane of the existing road open to traffic during the initial construction stage. In the completed form and once incorporated into the final roof structure the required design live load was stipulated at 20kPa. It was found that this created a more severe action than that created by standard T44 bridge loading contained in the AustRoads Bridge Design Code. T44 loading was also determined to be more critical

than the bus loading that the bridge was expected to be restricted to during construction of the building works. The final proposal made after initial structural analyses that T44 loading be the design live load while acting as a cable stayed structure and then 20kPa once the slab was incorporated into the final roof structure, was accepted as the appropriate design live load.

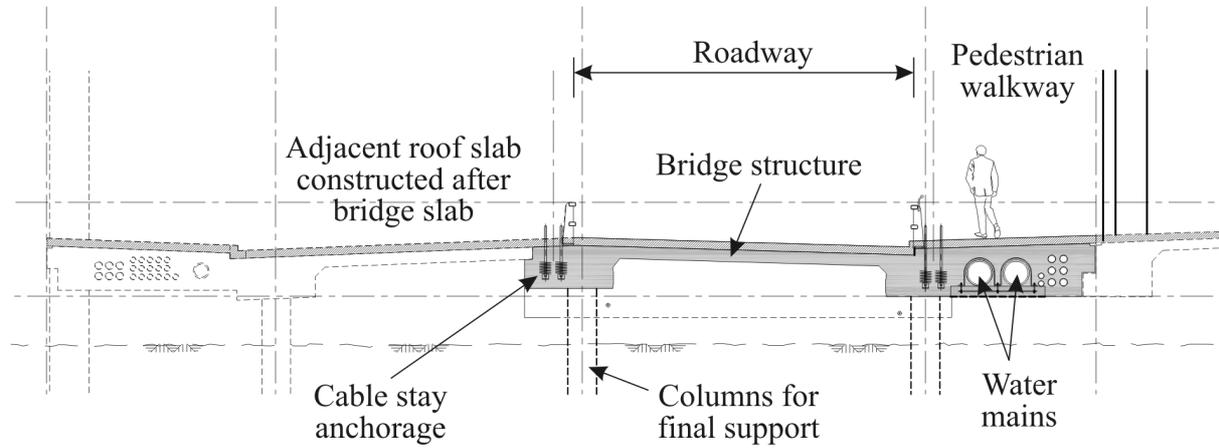


Figure 1: Deck Cross-section

The services to be accommodated in the deck included two large 0.45m diameter operational water mains as well as a number of electrical ducts. The bridge deck was designed to be temporarily supported by four pairs of cable stays during the construction period, which are anchored at the tops of four masts placed on the road approaches. The masts were restrained by back stays which were anchored to the bedrock through a pair of ground anchors located at each of the four anchorage points, refer to Figure 2.

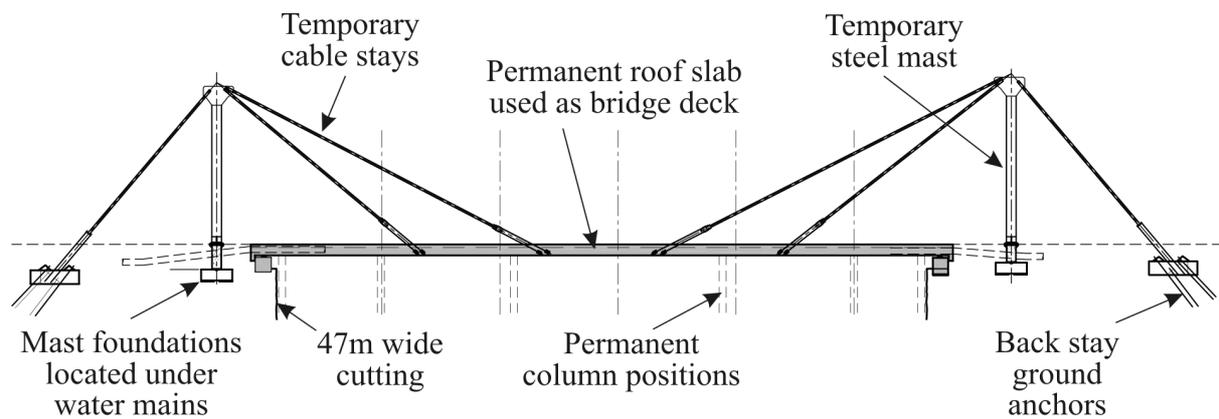


Figure 2: Longitudinal Deck Section

Design of the cable stay configuration had to optimize the location and size of cables as well as the reinforcing in the deck slab. Structural analysis of a computer model using variations in configuration identified the most ideal cable support points, refer to Figure 2. The critical aspect for optimum cable support location turned out to be the restriction of bending actions in the deck slab. These optimum cable support points however, turned out to not coincide with the final support points once the deck slab was incorporated into the final structure. Final support had to be located at fixed column locations that were determined by architectural requirements and could not be altered, refer to Figure 2. This variation in points of support creates a large reversal in applied bending actions to the deck slab. The magnitude of these resulting actions required that the slab had to be post-tensioned to effectively resist these actions. As the entire building slab into which the bridge deck is incorporated is post-tensioned, this requirement was in keeping with the global form for the rest of the project. However, the reversal in bending action could only be overcome by applying the post-tensioning in a largely concentric arrangement about the sections neutral axis, refer to Figure 3.

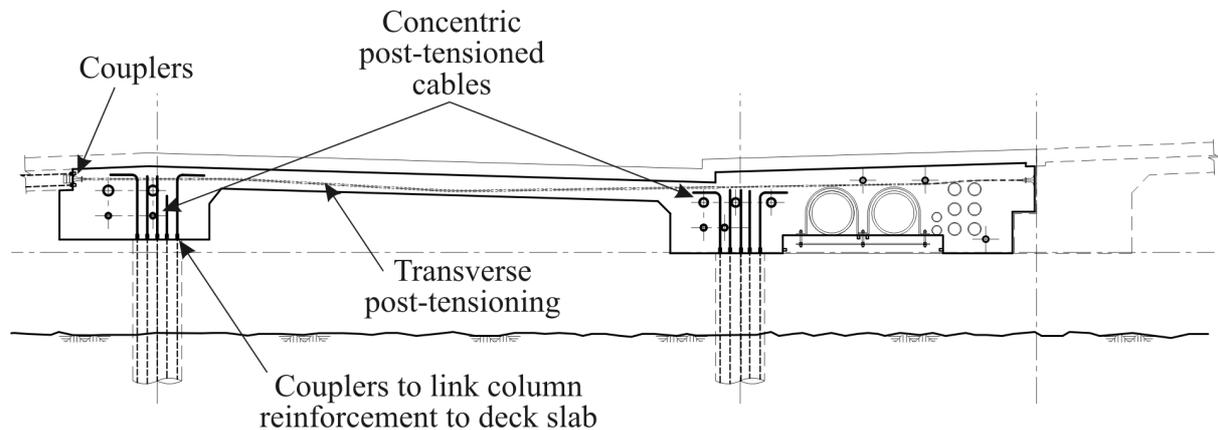


Figure 3: Deck Post-tensioning

The bridge deck slab was retained largely at the same section configuration as required for the other adjacent sections of slab that were not required to act as part of the initial cable stay structure. This ensured uniformity in the soffit appearance of the adjacent building floor slab. The longitudinal axis of the bridge deck extends for the full length of the building structure and thus only required linking to the adjacent future building slab in the transverse direction, refer to Figure 1. Transverse continuity with the final building structure was achieved on one side by using couplers to extend both transverse reinforcement and post-tensioned cables that were initially constructed into the bridge deck. On the other side, a halving joint support to the adjacent slab was provided. Transverse post-tensioning was retained at the level required for the design of the adjacent building floor slabs. The additional required bending capacity was supplemented by the addition of normal transverse reinforcement. To ensure that the two main longitudinal beams or ribs were effectively linked to each other by the thin deck slab, two regions of deck thickening or diaphragms were included that met with the Architects approval. These regions of increased depth were minimal and only marginally affected the deck soffit appearance locally. Structural analysis confirmed the necessity for these regions of increased stiffness.

The stay cables comprised conventional post-tensioned strand with only temporary protection in the form of uPVC sleeves. Connection to the deck slab was made by casting in a pair of rigid stress bars (Macalloy bars) that only extended far enough above the slab surface to accommodate a plate connection to the cable stay via a normal anchorage system used for anchoring 7 wire strands. Stays were extended to the mast heads where they were anchored off on conventional anchor heads. The back stays were similarly, also anchored off at the mast heads and extended down via stress bars to a reinforced concrete anchor block that comprised the ground anchor system, refer to Figure 2.

Each mast comprised a pair of braced columns located on the approaches, refer to Figure 4. Mast foundations comprised reinforced concrete footings and stub columns. Initially, the column bases were to be secured to the mast to restrain bending action. However, as the design progressed, the benefit (such as a reduced effective length and reduction of redundancy) of not restraining bending action resulted in the adoption of a column base that was effectively pinned. A simple detail comprising a bar placed into a half round recess formed in a base plate proved effective, refer to Figure 5.

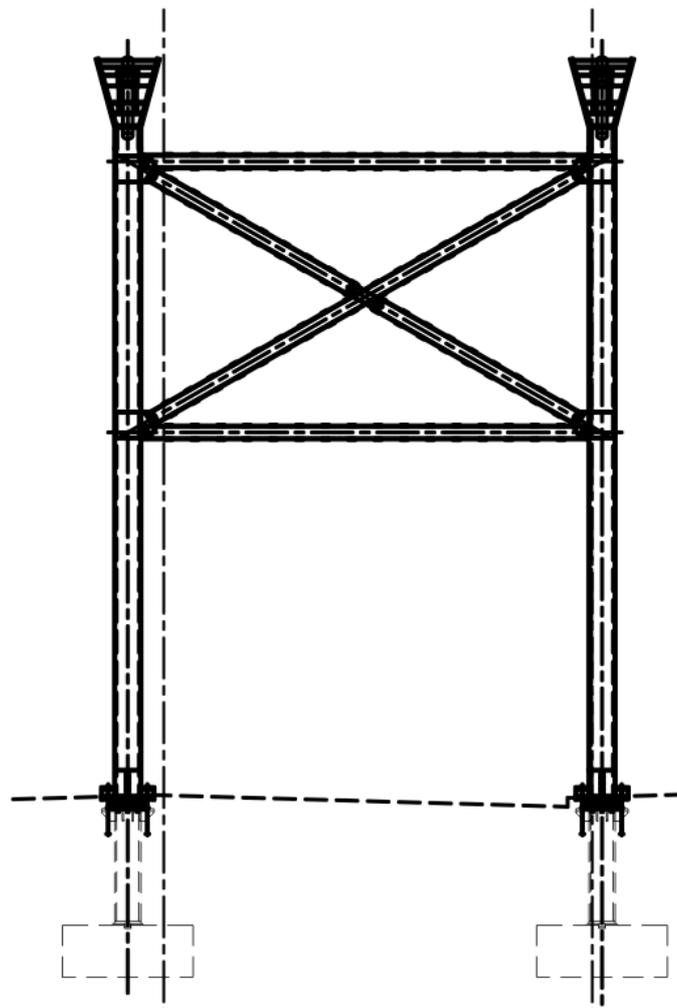


Figure 4: Elevation on Mast

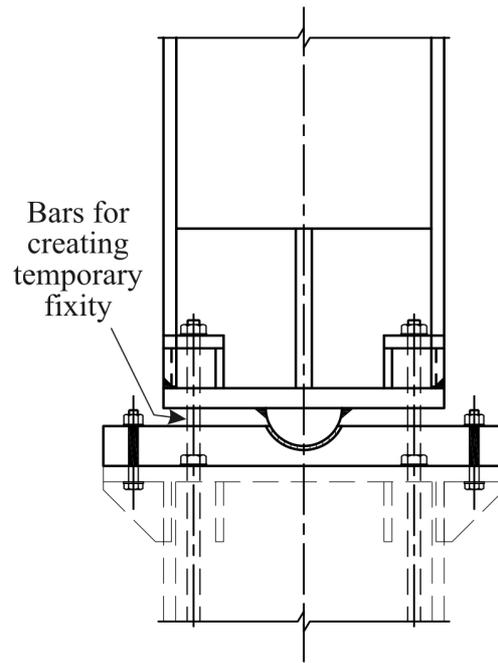


Figure 5: Mast Base Detail

The rock mass supporting the column bases was anticipated to move by as much as 35mm at the surface as excavation for the basement progressed and the rock relieved residual horizontal stresses. This anticipated movement had to be included in the structural analysis as well as included in the design of the abutment/deck connection. Being a temporary cable stayed structure there was no need to provide expensive expansion joints. The deck end overhung the abutment beam and provided the necessary restraint to the approach fill. This integral deck/soil interaction provided the necessary restraint to lateral deck movement. The deck was supported on elastomeric bearings that could accommodate the vertical loads as well as the horizontal displacements. Should the approach restraint prove insufficient, horizontal anchor bars linking the deck and abutments that would become effective if movements exceeded a small amount of about 5mm, were included to provide additional restraint, refer to Figures 6 & 7.

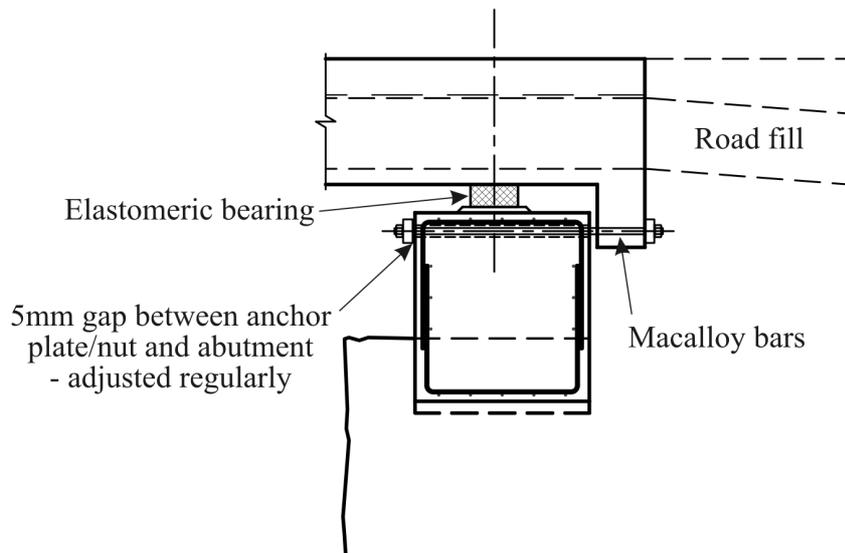


Figure 6: Abutment/Deck Cross-section

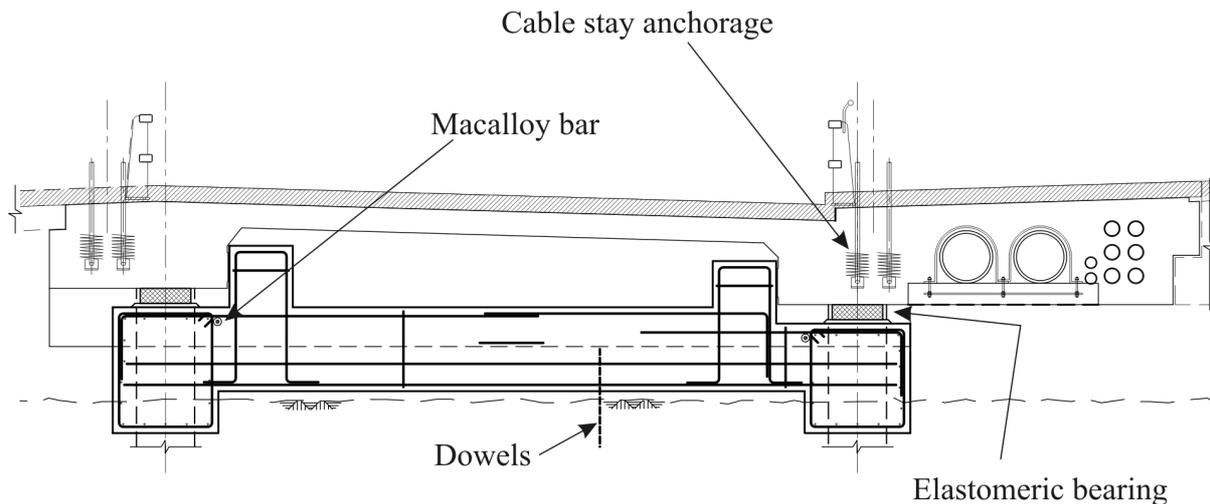


Figure 7: Abutment/Deck Elevation

An extensive dynamic analysis of the cable stayed deck proved that no special precautions to stabilise the superstructure were necessary.

Applied cable stressing values varied between 29% and 45% of ultimate tensile strength and cables comprised between 10 to 40 strands. The cables on the pedestrian walkway side were substantially heavier mostly due to the additional concrete mass of the deeper slab in this region. Achieving the required initial prestress force, which varied for each cable, was a specific construction challenge.

Once the reinforced concrete columns of the basement structure reached the underside of the cable stayed deck slab, connectivity was achieved by coupling column reinforcement into sleeves previously cast into the deck slab and pouring a closure portion of column.

3. CONSTRUCTION ASPECTS

Construction work for the bridge began in September 2002 with the implementation of the traffic diversion to one half of Oxford St. The temporary tower footings commenced soon after and immediately presented more work than anticipated due to the presence of unexpected below ground services. The tower footings also had to be built around the existing water mains resulting in considerable detailed hand excavation. At approximately the same time the foundations for the back stays were commenced which involved excavation work (also around existing services), construction of the reinforced concrete foundation, casting in of the 4 no. x 40 diameter Macalloy bars on the North side and 6 no. x 50 diameter bars on the South side to be used as holding down bolts for the stay cable anchorages and installation and stressing of 2 no. x 9 or 21 strand ground anchors per foundation.

Once the tower foundations and the abutments were completed, construction of the roof slab of the permanent structure, that would initially act as the cable stayed bridge deck, was commenced by Westfield. The structure was cast directly onto the partially excavated rock with only minimal formwork required.

Once both the tower foundations and the bridge deck were completed the structural steel towers could be erected. The towers were erected using a 80t mobile crane over a period of two days. Once held vertical by the crane the holding down bolts were fixed and one strand each on the forestays and two strands each on the backstays were installed and stressed. Once the towers were in place the remainder of the strands were installed one by one and stressed individually to a predetermined sequence. However, due to the fact that the towers were a quite flexible element with a pinned base the temporary support and consequent stay cable stressing sequence became extremely important.

Considerable time was spent by both Connell Wagner and Austress Freyssinet in the construction engineering phase to develop a stay cable strand installation and stressing sequence which ensured the towers were always maintained close to vertical and not overstressed at any stage.

The basic stages of stressing were as follows:

- Once both towers were erected and the initial strands placed and stressed the remaining strands were stressed five at a time for the back stays followed by two at a time for the forestays.
- Each side of the tower was stressed simultaneously and when one cycle of strands were complete the stressing was moved to other tower.
- The removal of the towers at the end of the project followed the reverse sequence.

As the bridge deck was cast directly onto rock it was necessary to carry out all the cable stay stressing from the top of the tower which although on the one hand was convenient to have all anchorages in one location it meant a quite congested work area due to the small size of the tower masts.

The final loads in the cables ensured that the concrete deck lifted off the formwork by approximately 20mm. Once complete the traffic barriers and pedestrian safety screens were put in place and the bridge was ready for traffic. The traffic was diverted onto the bridge and excavation on the other half of Oxford Street and under the deck commenced. The bridge was

in service from January 2003 to October 2003 whilst Westfield carried out their excavation and built up the structure underneath.

During excavation phase the walls of the excavation moved in by approximately 20mm each side resulting in a reduction in load in the cables and a lowering of the deck midpoint by approximately 70mm. This was anticipated in the original construction sequence so flat jacks were used in the permanent columns to restore the deck to the required level before completing the permanent column connection.

Once this was done the adjoining roof slab was completed allowing traffic to be diverted off the bridge deck so that the stay cables and towers could be removed, which occurred over a period of four days. Minor road works were all that was required to recommission the deck for traffic use.

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