Shelly Beach Overbridge Modification, Auckland

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SYNOPSIS

Shelly Beach Overbridge is located on one of the busiest motorways in New Zealand on the southern approach to the Auckland Harbour Bridge. With over 100,000 vehicles passing below this bridge every day in each direction, increasing the span to accommodate motorway widening presented a unique challenge.

Cutting the bridge in half and sliding onto a new pier, with infilling and strengthening of the bridge superstructure, provided a cost effective and robust solution to this challenge. This paper describes how the design concept for modifying the bridge was developed and successfully carried through to construction.

1 INTRODUCTION

Shelly Beach Overbridge is located on the Auckland motorway just south of the Auckland Harbour Bridge and carries a southbound off-ramp over the motorway on a high skew. Extension of the outside traffic lane on the Auckland Harbour Bridge past Shelly Beach Overbridge was dependent on relocating the northern pier of the existing bridge so that the new traffic lane and widened shoulder could be located on the outside edge of the existing southbound carriageway.

It was a project requirement to modify the bridge whilst keeping the motorway open to traffic. Over 100,000 vehicles travel daily in each direction on this section of motorway, which is one of the busiest in New Zealand and the main arterial route from the north into Auckland.

Opus International Consultants were awarded the project by Transit New Zealand in October 1999, and developed an innovative construction method that gave a cost effective and robust solution, which also allowed the original appearance of the bridge to be preserved. This paper describes the problem faced, and outlines the constraints, design processes and how the solution was developed. Construction was completed and the bridge re-opened to traffic in January 2001.

2 ISSUES AND CONSTRAINTS

2.1 The Lane Extension Project

The project objective was to extend the outer traffic lane on the Auckland Harbour Bridge past the Shelly Beach off-ramp, in order to improve the efficiency and safety of the motorway network. It is intended that eventually the lane extension will form part of a dedicated lane for buses and high occupancy vehicles that will link the north shore area of Auckland with the central business district. The current project terminates about 150 m south of Shelly Beach Overbridge.

2.2 Site Constraints

The constraints that influenced the design solution, were:

- Motorway geometry
- Forward visibility for the lane extension
- Traffic safety
- Restrictions on motorway and off-ramp closures
- Form of the existing bridge
- Aesthetics
- Materials
- Services on the existing bridge and alongside the motorway
- Ground conditions
- Construction budget

These factors are discussed below.

2.3 Highway Geometry and Forward Visibility

The motorway was to be widened to provide an additional 3.5m wide traffic lane and 2.5m shoulder on the outside the edge of the existing carriageway.

Forward visibility was a significant issue at the bridge site due to the tight curvature of the motorway at this location, and a project objective to increase the sight distance on the inside of the curve to suit a design speed of 100 km/hour. To achieve this the existing bridge pier needed to be moved back 10 m on the bridge centreline.

2.4 Traffic Safety and Motorway Closures

Safety of road users had to be ensured at all times and closure of the motorway was limited to night closures, with traffic from one carriageway diverted onto the other carriageway via openings in the median barrier, and the operation of a “contra-flow” system. This had not previously been undertaken at this location on the motorway system. Two night closures of the southbound carriageway were permitted by Transit New Zealand.

Closure of the off-ramp over Shelly Beach Overbridge was allowed because traffic using the off-ramp from the motorway could find alternative routes. Discussions with Transit New Zealand during the early stages of the design process, confirmed that a closure of six weeks would be acceptable. Construction was subsequently timed to allow this closure to take place over the Christmas and summer holiday period, when traffic flows on the Auckland motorway system are at their least.

2.5 Form of Existing Bridge

Constructed in 1959 as part of the Auckland Harbour Bridge project, the existing bridge had four spans and a reinforced concrete ‘T’ beam superstructure. Three main longitudinal beams were provided. These were continuous, and of variable depth to a parabolic profile. The two centre spans over the carriageways were 31.4 m and the side spans 24.4 m, to give an overall length of 111.6 m. The bridge carried two traffic lanes and had a footway on the eastern side, with an overall width of 10.2 m.

Photo 1 shows a view of the existing bridge from the north, on the inside of the proposed widening.

Photo 1: Existing Bridge from the North

The bridge deck was skewed at 47 degrees to the piers and abutments to suit the angle of the off-ramp as it crossed the motorway. The bridge deck had a 5% longitudinal gradient from south to north, and a 2.5% cross fall.

The main deck beams varied in depth from 2.5 m at piers to 1.1 m at midpsan, and at the ends of the bridge. The beams were 520 mm wide and the deck slab was 180 mm thick. Cross diaphragms were provided to the deck at each pier and at each end of the bridge.

Intermediate piers were supported on driven raked concrete piles. A cantilever abutment with spread foundations onto bedrock was provided at the southern end of the bridge and a piled bank seat type abutment at the northern end. The bridge was fixed longitudinally at the southern abutment and anchored for longitudinal seismic loads by an anchor block located in the approach fill behind the southern abutment.

2.6 Aesthetics

Transit New Zealand identified bridge aesthetics as a key driver in the bridge modification. The existing bridge had an attractive appearance with curved deck beams, clean lines and simple piers with horizontal feature grooves. The bridge was also highly visible, being located on the approach to the Auckland Harbour Bridge, and in close vicinity to the CBD.

2.7 Materials

The concrete to the superstructure was originally specified with strength of 31 MPa, but testing of cores indicated that the actual in situ strength was about 60 MPa. This higher strength was to prove beneficial to the design of the modification, and in particular for enhancing the shear capacity of the main beams.
The main reinforcement to the deck beams was a mixture of cold worked square twisted 1¼ inch bars to BS 1144: 1943 (1), with a yield strength of about 410 MPa, and round mild steel bars. Testing of reinforcement hardness confirmed that the yield strengths were in accordance with the original material specifications.

2.8 Services

Services on the bridge were an electricity cable, water main and sewer pipe suspended below the footway slab, to service the moveable barrier transfer station for the Auckland Harbour Bridge. Services were also located behind the southern abutment.

2.9 Ground Conditions

The site of the bridge has been reclaimed, and is overlain by 1 m to 2 m of silt, sand and fill material on top of a 3 m depth of loose hydraulic fill, and 1 m of remnant marine sand. Sandstone is encountered at 5.5 m to 6 m below ground level. Piled foundations were therefore envisaged for new substructures.

2.10 Construction Budget

The construction budget for the lane extension project was NZ$2.5 million, which precluded options to replace the bridge with a new structure.

3 OPTIONS

3.1 Preliminary Options

The options considered by the design team were:

- Tied-down cantilever beams to support the existing superstructure
- ‘C’ shaped pier to support the existing superstructure
- Cut, slide and infill the existing superstructure
- Extend the existing span using steel beams below the existing deck
- Replace half of the bridge with composite steel beam superstructure
- Replace the whole bridge deck with a new composite steel beam superstructure

These options were evaluated against the following criteria:

- Structural performance
- Aesthetics

- Seismic performance
- Buildability
- Traffic disruption/closures
- Geotechnical considerations
- Construction period
- Cost
- Risk profile

The option to cut and slide the existing bridge was selected because of its attractive appearance combined with acceptable cost and risk profiles. The “C” shaped pier option and the option to replaced half the bridge superstructure with composite steel beams were identified as close rivals, but were rejected on the basis of vertical clearance and higher construction costs. The tied-down cantilever beam option was not considered further as it needed a fascia to mask the cantilever beams, which would have significantly altered the appearance of the bridge and could have been a maintenance issue. It also relied on rock anchors for overall stability.

The cost of the cut and slide option was slightly higher than the tied-down cantilever option and the “C: shaped pier option, but it was still within the project budget.

The risks associated with Option C were carefully assessed before the final option selection was made. The use of well-proven construction techniques, which owed much to the technology used in the incremental launching of bridges, gave confidence that the risks associated with this solution could be managed within acceptable limits.

3.2 The Preferred Solution

The final layout of the cut and slide option is shown in Figure 1. Key features of this solution are:

- Increase of the northern main span to 41.4 m after cutting the span and sliding the bridge deck onto a new northern pier and abutment
- Infill of the bridge deck and beams at midspan using in situ reinforced concrete lapped onto the existing reinforcement
- Strengthening of the main deck beams at the northern and central piers using a system of bonded steel plates located on the sides of the concrete beams
- A new tapered pier located at the back of the shoulder to meet the forward visibility criteria for the motorway
- A new northern abutment cap beam located at the top of the embankment
- Seismic strengthening of the bridge to increase its longitudinal seismic capacity using rock anchors tied to the southern abutment
- Replacement of the crib wall by a soil nailed wall located behind the visibility sight line

This solution also allowed the attractive appearance of the existing bridge to be preserved.

Figure 1: Elevation of Completed Bridge for Cut and Slide Option

4 STRUCTURAL ASPECTS

4.1 Construction Method

The construction method developed for the bridge cut, slide and infill method is shown in Figure 2. The key features are:

- Provision of temporary runway beams to support the sliding bridge as it is moved between the existing and new piers and abutments
- Temporary stayed cables to support the cantilever beams and control bending moments and deflections in the beams
- Sliding of the bridge on temporary skates with teflon/stainless steel sliding surfaces (similar to incremental launching)
- Temporary decking to protect the motorway so that cutting, sliding and strengthening of the bridge deck could occur above live traffic
- Longitudinal jacking of the bridge using a ‘failsafe’ system
- Side restraints at the existing pier and abutment to control lateral movements
- The use of high pressure water-jetting to remove concrete from the existing beams so that damage to the existing concrete and reinforcement could be avoided.

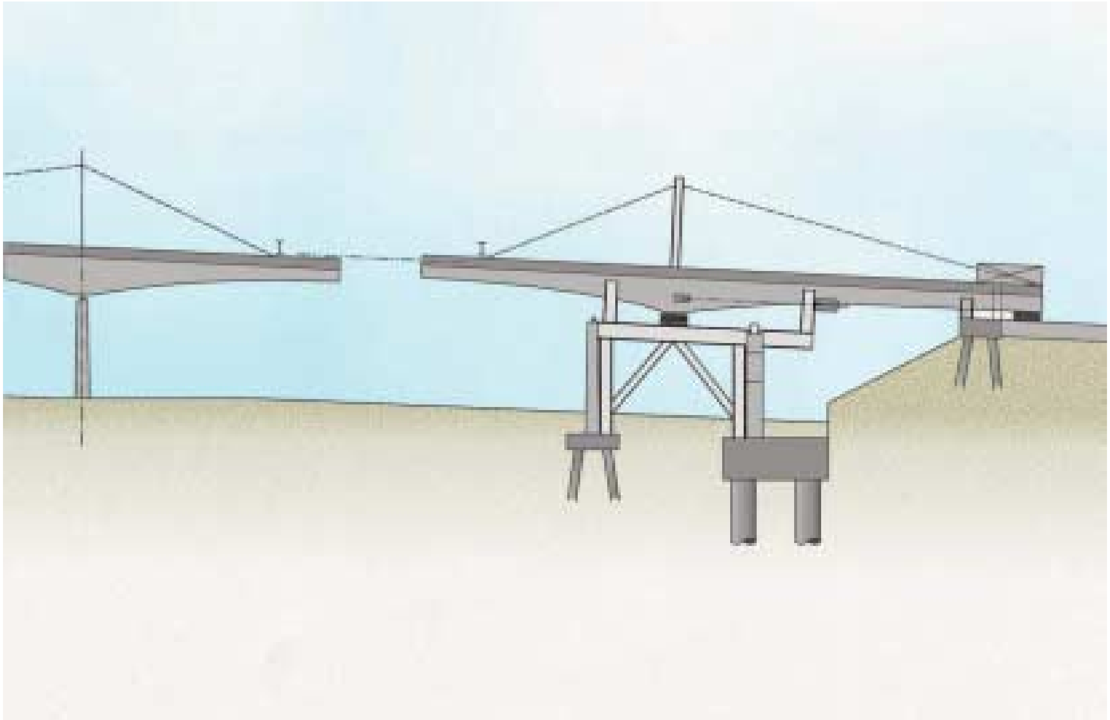

Figure 2: Construction Method

Photos 2 and 3 show the bridge during the sliding operation, and in particular the temporary decking and runway beams.

Photo 2: Bridge Sliding Showing Runway Beam

4.2 Strengthening of Main Beams

The structural design was carried out to the Transit New Zealand Bridge Manual (2).

The design was developed on the basis of strengthening the main reinforced concrete beams using a system of bonded steel plates. These were to be installed to the sides of the existing beams to provide enhanced flexural capacity in the hogging zones over the piers. This avoided plates being located on the top surface of the beams, where they would have been vulnerable to corrosion.

The system of bonded steel plates was designed to the United Kingdom Department of Transport Standard BA 30/94 (3). As shown in Figure 3 below, 600mm wide x 10mm thick plates were proposed on each side of the main beams over the main piers, where the bending moments increased by 42% due to the increase in span length. It was proposed to bond the plates to the concrete beams using epoxy adhesive, with bolted fixings provided to locate the plates and to resist “peeling” effects.

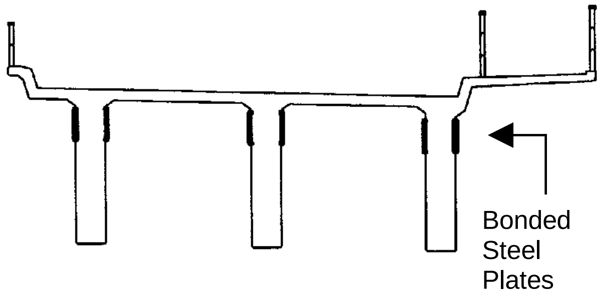

Figure 3: Typical Cross Section of the Strengthened Bridge Deck.

Analysis of the existing beam sections indicated that they had spare capacity in bending due to the high yield strength of the square twisted reinforcement. Consequently, the bonded steel plates only needed to provide an additional 15% capacity, which was within the capability of this technique.

Photo 3: Bridge Sliding Showing Temporary Decking

Alternative designs for the bridge modification were encouraged in the tender documentation to promote innovation and cost/time savings by the Contractor.

An alternative tender was subsequently accepted that utilised a post-tensioning system to strengthen the bridge deck, by providing external prestressing in lieu of the bonded steel plates. The prestressing also supported the cut beams during construction and the temporary stayed cables were therefore not required. The alternative tender gave only a small cost saving, but significant advantages in construction timing. The appearance of the completed bridge was also improved as the bonded steel plates were omitted from the outside of the bridge beams.

4.3 Shear Capacity

The original bridge drawings indicated that a critical shear zone existed towards the midspan section of each beam. In this area the shear reinforcement reduced markedly, with insufficient capacity to cater for the increased shear forces that would occur with the lengthened span.

This required the deck beams to be broken out for an additional 3m length beyond the 10 m infill section. This allowed a new beam section with adequate shear capacity to be constructed. Conveniently, the additional 3 m length of new beam allowed an arrangement of staggered laps to be provided for the main beam reinforcement splices.

4.4 Beam Splices

The main beams were heavily reinforced in the vicinity of the proposed splices with four layers of 1¼ inch diameter square twisted bars in the bottom face of each beam. Lapping of these bars with 40mm diameter bars from the new infill section required careful detailing to allow four bars in each layer to be made continuous through the splice, to meet the required bending capacity.

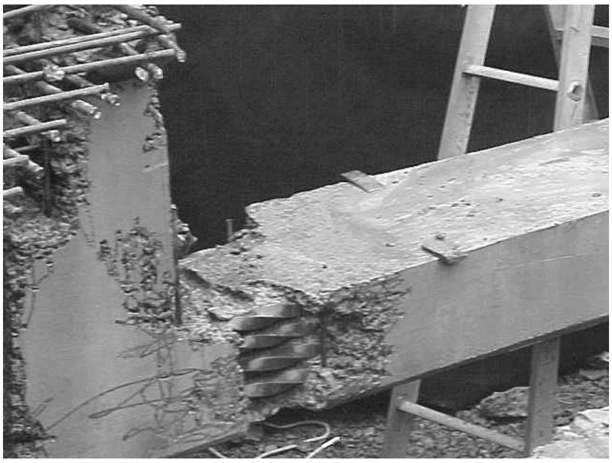

Photo 4: Breaking Out Beam Reinforcement

Photo 4 shows breaking out around the main square twisted reinforcement in the bottom of the main beams.

The position of the existing beam reinforcement was identified as an important factor in the success of the proposed method, as there was little space available to relocate lapping bars, in the event that existing bars were out of position. In practice, the existing bars had been accurately constructed, and few problems were experienced during construction.

4.5 Substructures

Construction of the pier required bored piles to be located clear of the main deck beams to allow sufficient headroom for the piling rig. 1.5 m diameter piles were provided at each corner of the rectangular pile cap. Piles are founded in sandstone at a depth of 12 m below ground level. The new northern abutment is also supported on 1.5 m diameter bored piles founded in bedrock.

The existing bridge deck was supported on steel rocker bearings. These had been fabricated in the form of rectangular boxes under each beam to allow the bridge to move longitudinally under temperature and seismic loads. Transverse loads were transmitted through the bearings to the substructures. The existing bearings were re-used at the new pier and abutment, after first being grit blasted and re-painted.

4.6 Construction Aspects

The contract was awarded to Contractor Fulton Hogan Civil Ltd in August 2000. Fulton Hogan developed a detailed construction methodology based on the concept outlined in the contract. They also commissioned the design of the alternative strengthening system to the main beams using external prestressing. The design was carried out during the early stages of the construction period by consultant URS New Zealand Ltd.

The cutting and sliding operation was undertaken after the new northern pier and abutment had been constructed. The 550 tonnes bridge section was slid on runway beams that were located between the old and new supports, and propped from ground level.

The bridge was jacked longitudinally using a "telescopic rack" system developed by Fulton Hogan, which provided a "fail-safe" restraint to prevent the bridge sliding out of control. Transverse guides were also provided to prevent the bridge sliding off the runway beams. The sliding operation was undertaken above the "live" motorway and took only about six hours to complete on a Saturday morning.

The temporary decking system was installed before any work started on the bridge superstructure during a temporary overnight closure of the southbound carriageway. The “contra-flow” system of traffic management used to divert the traffic was a first on this section of the Auckland motorway. The decking system allowed all construction activities on the bridge to continue above the live motorway traffic. The driving public had little idea of what was going on above their heads, once the decking and side screens were in place.

High pressure hydro-demolition techniques were specified to ensure the concrete around the heavily congested main reinforcement bars could be broken out without risk of damage to the bars. The very high strength concrete in the bridge made hydro-demolition difficult to achieve in practice and some conventional demolition techniques were used for non-critical areas.

The lane extension project was completed in six months with the overbridge closed for six weeks whilst the bridge was cut, slid and strengthened. The completed bridge was re-opened to traffic one week earlier than planned, in January 2001, with the closure of the off-ramp being timed to coincide with the quieter road conditions over the Christmas period. It was also planned to occur at the same time as work on the Harbour Bridge, to minimise impact on road users.

5 CONCLUSIONS

The modification of Shelly Beach Overbridge provided a considerable challenge to the design team to find a solution that would meet Transit New Zealand's objectives and keep within the project budget. At the same time the operation and safety of the motorway could not be compromised by construction activities.

This led to the development of a unique and innovative solution that has been successfully taken through to construction. This project demonstrates the versatility of concrete as a structural material and how an existing structure can be modified to meet the changing needs of the highway network.

The cut and slide concept has provided a robust and economical solution to a complex structural problem. Furthermore, the attractive appearance of the original bridge has been preserved, and the effects on the operation and safety of the motorway have been minimal.

Photo 5 shows the completed bridge after opening.

Photo 5: The Completed Bridge

The project was recognised by the Association of Consulting Engineers, New Zealand in 2002 by the Award of Merit for Engineering Excellence.

6 REFERENCES

1. British Standards Institution, BS 1144: 1943 – Cold Twisted Steel Bars for Concrete Reinforcement.

2. Transit New Zealand, Bridge Manual, 2000.

3. Department of Transport, UK, Advice Note BA 30/94 - Strengthening of Concrete Highway Structures Using Externally Bonded Steel Plates, 1994.