Detailed Seismic Assessment and Seismic Improvements of Market Road Underpass

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ABSTRACT: A seismic improvement works were completed on Market Road Underpass (MRU) in Auckland. The bridge consists of three structures: The Underpass, the Motorway Off-ramp and the Rail Overbridge. In the NZTA's "Seismic Screening" of all state highway bridges MRU ranked 4th in its programme for further investigation and retrofitting. Assessment of seismic capacity of the bridge was completed by Opus in 2004 and 2008. The adopted benchmark event against which the performance of the bridge has been assessed is seismic shaking with a return period of 1000 years together with collapse avoidance under the 2500 year return period shaking. Seismic performance of the bridge under the above levels of shaking was determined to be inadequate, limited predominantly by the shear capacity of the beam-column joints and the abutment columns and stability of the unreinforced masonry pier common to the Underpass and the Rail Overbridge. Seismic improvement of the bridge was successfully completed in mid 2011 and included installation of new piles at one of the abutments, new auxiliary support at the critical pier common to the Underpass and the Rail Overbridge, strengthening of the pier beam-column joints, and installation of new shear keys at the Off-ramp. Works completed will improve the expected seismic performance of the bridge to the level required. Overall cost of the improvements was about NZ$1.5 million.

1 INTRODUCTION

Market Road Underpass is located on SH1N at RP 338/0.87 (Auckland). The bridge consists of three structures: The Underpass, the Motorway Off-ramp and the Rail Overbridge (Figures 1a and 1b). The Underpass and the Off-ramp are part of the State Highway network and are owned by the New Zealand Transport Agency (NZTA). The Rail Overbridge is owned by the Auckland City Council (ACC) and was not part of the strengthening programme.

From 1997 through to 2000 NZTA undertook a nation-wide "Seismic Screening" of all its state highway bridges. In terms of priority, the Market Road Underpass ranked 4th in its programme for further investigation and retrofitting. An initial assessment of the seismic capacity of the bridge was completed by Opus in 2004. As a part of the preparation of the Design Statement in 2008 further additional assessment was completed using a non-linear push-over displacement based analysis. Critical parts of the structure were identified and seismic improvement proposed. Site soil investigations were completed in 2009 to enable design of the improvements work. Detailed design and Contract Documents were completed mid 2010, a physical works contract commenced in August 2010 and construction was completed in June 2011.

2 DESCRIPTION OF THE BRIDGE

The Underpass is a four span monolithic, reinforced concrete structure, with span arrangement of 10.6 + 16.8 + 16.8 + 7.9 m. The deck is 19.2 m wide (kerb to kerb), continuous tee beam construction spanning between pier/abutment caps. Abutment D (common to the Railway Overbridge) is an unreinforced masonry wall. The deck is connected to the pier cap with reinforced concrete rocker supports. At the piers and the eastern abutment (Abutment H) the pier caps are monolithic with the columns and the deck. Each of the piers and Abutment H have four tapering columns, with each pair of columns supported on a separate shallow strip foundation beams. The Underpass was originally constructed with a longitudinal joint. During repairs to the bridge in 1995 the two superstructures were joined together.

The off-ramp has 7.3 m wide carriageway of a similar form to that of the Underpass. It comprises five continuous spans arranged 12.2 + 16.8 + 16.8 + 16.8 + 12.2 m. At the lower vertical retaining wall abutment, the superstructure is simply supported. The Off-ramp and the Underpass are separated by a 25 mm wide movement gap.

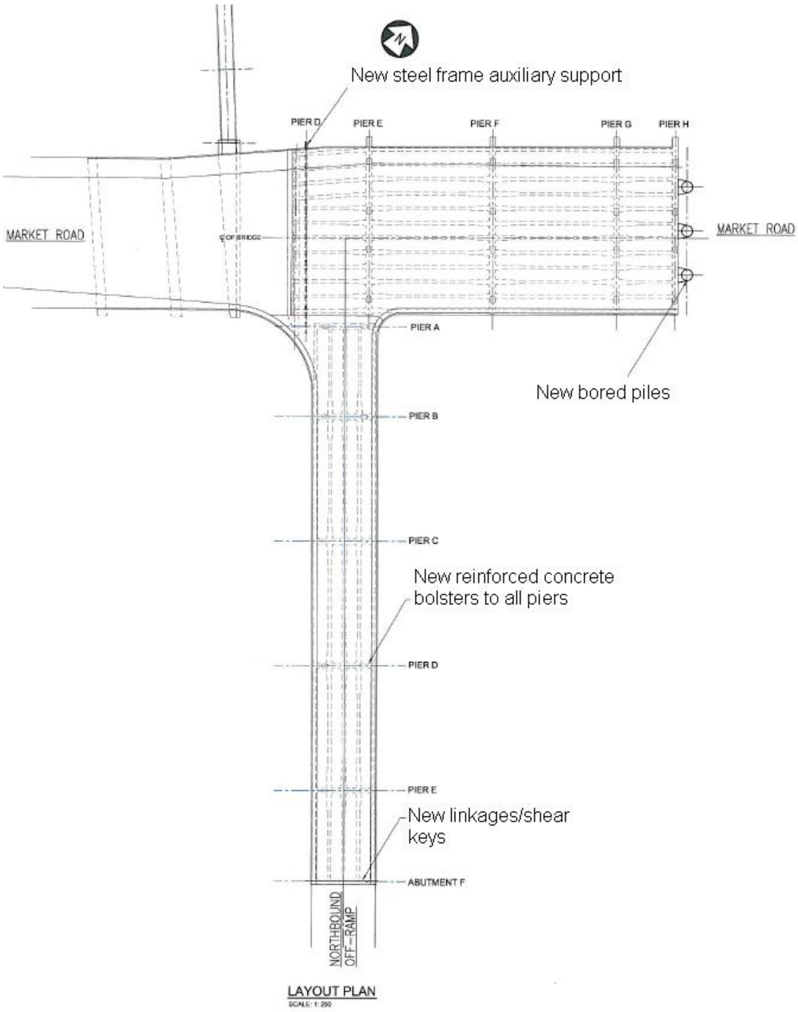

Figure 1a: Market Road Underpass – layout and proposed improvements locations

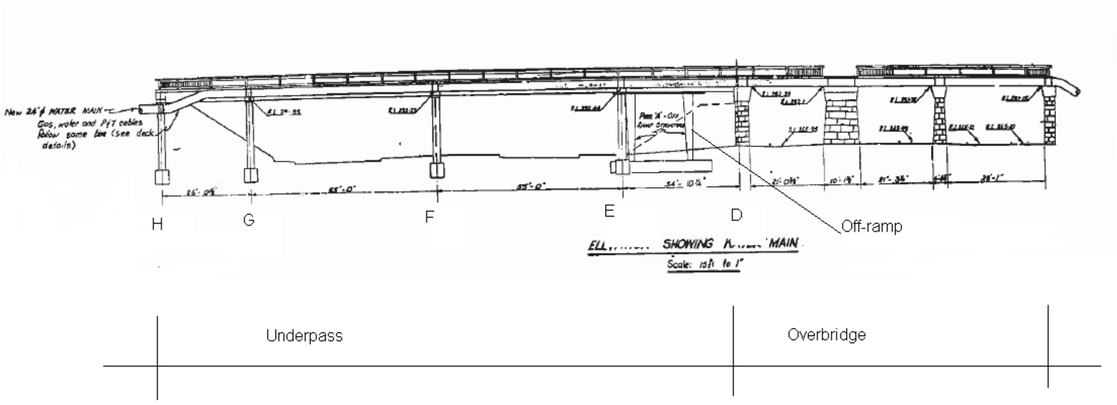

Figure 1b: Market Road Underpass – Elevation

Seismic forces in the Underpass longitudinal direction towards Abutment H are resisted primarily by the passive resistance of soil behind the Abutment H columns and partly by the bridge longitudinal frame. In the opposite direction loads are resisted primarily by the bridge longitudinal frame as the amount of resistance provided by the soil spill through embankment slope at abutment H is not very significant.

Seismic forces in the transverse direction will be initially transferred, via the continuous deck diaphragm, to Abutment H and Abutment/Pier D, other pier frames being significantly more flexible in this direction than the abutments. Once the capacity of the abutments is exhausted, the load would migrate towards the piers.

In the Off-ramp the seismic forces towards Abutment F are resisted primarily by the passive resistance of the soil behind the abutment. In the opposite direction loads are resisted primarily by the rocking/sliding capacity of the Abutment F wall and the Off-ramp longitudinal frame action.

In the transverse direction the seismic forces are resisted by the Abutment F wall and the pier frames.

3 DETAILED SEISMIC ASSESSMENT

The adopted benchmark event against which the performance of the bridge has been assessed (i.e., the “design” event in terms of the Bridge Manual) is seismic shaking with a return period of a 1000 years. This event has also been adopted as the target minimum level of performance to be sought for the retrofitted bridge, together with collapse avoidance under the 2500 year return period shaking.

Detailed seismic assessment completed revealed that the existing structure of the Market Road Underpass is deficient in its capacity to resist seismic loads imposed by the design event. The seismic performance was determined to be limited by:

- Shear capacity of the beam-column joints, flexural capacity of the top of pier columns in the longitudinal and transverse frames, and torsional capacity of pier cap beams in the Underpass and Off-ramp structures.
- Shear capacity of the Underpass Abutment H columns.
- Capacity/stability of unreinforced masonry pier D, the pier common to the Underpass and the Rail Overbridge.
- Capacity of the shear dowels and back wall of the Off-ramp abutment.

Figure 2 shows reinforcing details of the beam column joints in the typical pier frame. Such details do not provide for an adequate mechanism to form to transfer forces through connections between columns and cap beams.

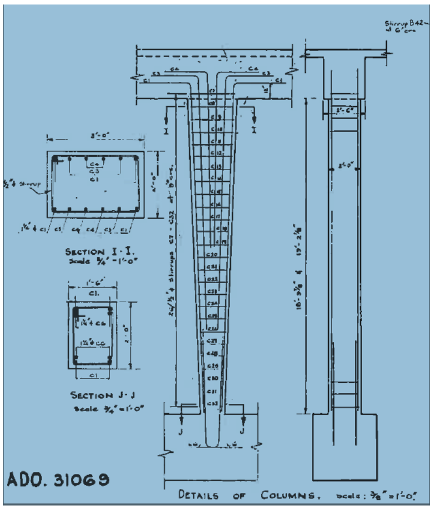

Figure 2 – Reinforcing detail of the Underpass Pier frame column and beam–column joint.

There were also potential problems associated with:

- Central barriers of the motorway effectively shortening the unrestrained height of the Underpass pier columns
- Potential damage to the existing water main supported by the Underpass, which is constructed without flexible joints, making it vulnerable to differential movement between the supporting structures.

4 SEISMIC IMPROVEMENTS

Seismic improvements proposed and subsequently designed for the Underpass included the following:

- Construction of three large diameter cantilever piles at the Underpass Abutment H. These were designed to limit seismic movements in bridge longitudinal and transverse directions, reducing the demand on the existing pier frames, abutment columns and capping beam to below their capacities. As a result, strengthening of the abutment piles and pier frame beam-column joints was not necessary. Strengthening of the piers, which would be similar to that completed on the Off-ramp discussed below, would have incurred significant traffic management costs. Less movement would also reduce the risk to the existing watermain supported by the bridge.
  To increase their stiffness new piles they are provided with permanent steel casing which extends to the bedrock. This casing is not required for strength. The piles were designed to cantilever from the bedrock and do not rely on the lateral support provided by the scoriaceous basalt layer above the bedrock. This way, grouting between the outer steel casing and the over-bored hole through the scoriaceous basal layer, the effectiveness of which could be questionable, was not required. Only the top few metres from the ground surface were grouted, as discussed below.
- Construction of a new structural steel auxiliary support at Pier D. The new structural steel frame will provide a secondary support, both for gravity and lateral loads to this end of the Underpass should the stone wall pier become damaged during seismic shaking. This support was designed to provide gravity support for the dead load of the bridge and emergency traffic only. A more robust permanent solution would have to be provided to enable full traffic load following a major event.

Seismic improvements of the Off-ramp included the following:

- Installation of new linkage bar/shear key assemblies at the bottom abutment to provide a reliable load path for seismic loads by bypassing the existing strength deficient shear dowels and protecting the abutment back wall from damage.
- Construction of reinforced concrete bolsters at the top of pier columns. These bolsters have a multiple effect on the seismic capacity of the pier frames; they increase the shear capacity of the beam-column joints and torsional capacity of the capping beam and also push the potential plastic hinge zone further down the column, away from the reinforcement anchorage zone.

Saw cutting of barriers on SH1 under Market Road Underpass was also completed to allow flexing of the columns over their full height during seismic shaking.

5 SITE INVESTIGATIONS

Soil investigation at Abutment H was required to confirm soil parameters to be used in the final design of the new piles.

The Market Road bridge site lies approximately midway between Mt Hobson and Mt St John, two volcanoes that erupted greater than 28,500 years ago as part of the Auckland Volcanic Field. The geology has been mapped at 1:50,000 as Auckland Volcanic Field lithic tuff (Kermode, 1992).

A total of three boreholes were drilled to assess the ground conditions and to develop a robust geotechnical ground model. One borehole to 15.6 m depth was drilled near the western abutment of the bridge and two boreholes were drilled adjacent to the eastern abutment to depths of 19.5m and 12.0m depth. The second of the two eastern abutment boreholes was drilled to specifically obtain strength data of the tuff layers. All boreholes encountered both stiff volcanic tuff soils and fractured basalt rock consistent with the geological setting.

6 CONSTRUCTION

Construction of the seismic improvement was carried out by Downer EDI Works Ltd under the supervision of Opus.

6.1 Bored piles at Abutment H

Three 1.5 m diameter reinforced concrete bored piles with 20 mm thick permanent steel casing were installed and tied to the eastern abutment of the Underpass. Structural checking was carried out to confirm that the deck had sufficient capacity to withstand the loading during the construction.

Boring of the concrete piles was carried out using a BG28 Bauerer Rig imported from Australia and specialized in drilling through hard rocks (Figure 3). The operational cost of a Bauerer Rig is three times higher than that of a conventional modified rig, but it has the ability to operate more efficiently and in a relatively smaller and tighter work space. This additional cost was offset by the lower cost for relocating existing services, which is typically very costly and disruptive. The use of this rig also enabled both directions on Market Road to be trafficable for the entire duration of the construction.

The first two to three metres were drilled using a clay auger to remove the subsoil. Once this depth was reached, a 1.8 m diameter temporary starter casing was installed into the hole using a ramming tool and drilling then continued with a 1.58m diameter drilling tool until the scoriaceous basalt strata was encountered. This necessitated a change to a rotary barrel to rotary core to the top of the vesicular basalt bedrock. Permanent casing was then installed to sit on the bedrock and drilling continued with a 1500 mm diameter core barrel through the inside of the permanent casing to achieve a 3m embedment. All three piles were in excess of 13m in length. Finally the top few meters of the over-excavated hole was grouted using high slump concrete and a low pressure pump while gradually removing the temporary 1.8 m diameter starter casing.

CCTV tests revealed a dry and clean base with no apparent fracture or sign of collapse in the socket wall (Figure 4).

Figure 3: Bauerer rig in action with the rotary barrel

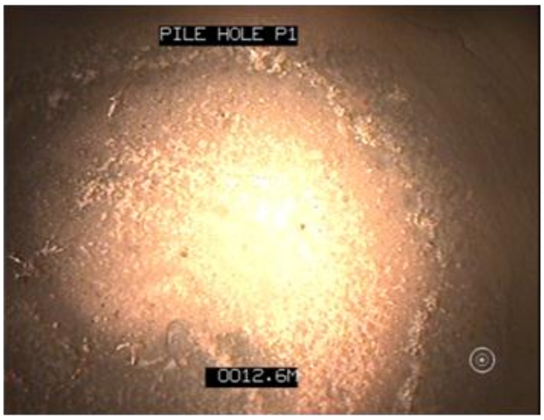

Figure 4: Pile base was dry and clean

On completion of the boring process, a pre-fabricated steel cage was lowered into each of the pile bored holes with plastic spacer wheels clipped to the outer spiral to maintain the 75 mm cover (Figure 5).

Figure 5: Lifting and lowering of pile cage into bored hole

Tremie type of mix was then pumped through a tremie pipe into the pile casing (Figure 6). Once the concrete had set, the annulus between the permanent casing and surrounding soil was grouted using a low pressure pump, to avoid segregation of the concrete and to ensure proper consolidation. The starter casing was extracted progressively to ensure all voids were filled and to minimise spalling of the surrounding soil.

The piles were tied to the abutment with RB32 Reid bars locked to the brackets (consists of two PFCs) installed at the front face of the abutment beam. The other ends of the Reid bars were held in position with an anchor plate (Figures 7 and 8).

Figure 6: Concreting using Tremie pipe

Figure 7: Anchor Plate holding the Reid bars at the pile end

Figure 8: Bracket at the front of abutment beam anchoring the Reid bars

6.2 New structural steel auxiliary support at pier D

A steel auxiliary support at Pier D consists of a 700 WB fixed to the bridge girder and supported by 200 UC columns and cross bracing and a 1200 x 1200 mm concrete footing.

The installation of the steel auxiliary support was preceded by removal of the soil against the existing basalt block wall, demolition of the wing wall and construction of the footing adjacent to the existing wall footing (Figures 9 and 10). There were concerns that this operation may affect the structural integrity of the wall and its footing. Preliminary potholes also revealed that the basalt wall was founded on a fractured basalt rock.

Figure 9: Soil leaning against the basalt wall prior to excavation

Figure 10: Existing wingwall to be demolished

To minimize the risk during the excavation process, construction of the new footing was carried out in three sections using Reid bars and Reid couplers to reduce reinforcement lapping lengths.

The initial concerns were realized when work had to be halted immediately after the discovery of cracks developing in the existing basalt wall during the first stage of excavation. A decision was made to first reinforce the wall with a combination of steel mesh and minimum 150 mm thickness of shotcrete prior to any further excavation (Figure 11). The rest of the footing was completed successfully without further incident (Figure 12). The existing wall was monitored regularly throughout the whole construction phase. Construction of the steel frame support was completed without major problems (Figure 13).

Figure 11: Staged construction of the footing and shotcrete wall

Figure 12: Final product of the shotcrete wall and footing

Figure 13: Completed auxiliary support

6.3 **Strengthening of the Off-ramp**

6.3.1 *Beam column joints*

Concrete bolsters were constructed in situ the beam-column joints of 10 piers. Due to the space constraints Reid bar reinforcement was used to tie the bolsters to the deck above (Figure 14). Rectangular sections of the deck were removed by saw-cutting to create pockets the Reid bar anchors (Figure 15). Steel plates supported by plastic shims were installed over the concrete pockets to allow traffic flow on the Off-ramp while the construction proceeded. Self-compacting concrete was used to ensure proper consolidation of the concrete as it was impossible to vibrate the concrete evenly during construction. The finished bolster is shown in Figure 16.

Figure 14: Bolster reinforcement

Figure 15: Anchors plate with threaded inserts in pockets prior to grouting

Figure 16: Finished bolster

6.3.2 *Shear keys at the Off-ramp abutment*

New shear keys were installed at the off-ramp abutment walls to anchor the bridge to the abutment (Figure 17). SHS and PFC sections were welded together and fixed to the girder beams and abutment walls with Hilti HAS Class 8 threaded anchor. To ensure that the existing concrete of the abutment and the Hilti anchors performed to the expectation of the designer, non-destructive pull-out tests were carried out on three of the Hilti anchors. The test results were satisfactory with no anchors showing signs of yielding and no visible damage to the concrete.

Figure 17: Shear keys at the Off-ramp abutment – working around existing services is always a joy

7 CONCLUSIONS

Detailed seismic assessments of the Market Road Underpass completed by Opus in 2004 and 2008 showed that the existing structure has insufficient capacity to resist the level of seismic shaking set by NZTA as a benchmark for its State Highway network. Damage and potential collapse of the bridge would cause major disruption to the traffic on this part of State Highway 1. Seismic improvements designed by Opus and successfully constructed by Downer EDI Works Ltd has improved the expected seismic performance of the bridge to the level required.

8 AKNOWLEDGMENTS

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REFERENCES:

Opus International Consultants Ltd, 2008, 2010, *Seismic Improvements Design Statement SH1N Market Road Underpass.*

Opus International Consultants Ltd, 2010, *Seismic Improvements SH1N Market Road Underpass Contract Documents.*

Kermode, L.O. 1992: *Geology of the Auckland Urban Area Scale 1:50 000, IGNS.*