MacKays to Peka Peka Expressway (M2PP) Project

A Case Study

By Jamil Khan

Accelerated Bridge Construction in Seismic Areas: design detail of bridge piers
M2PP Expressway Project

Project Background

- 18km Long section of Expressway
- 17 Bridges to cross
  - Local roads
  - Expressway
  - Waterways

The Route
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Project Background

- Overpass Bridges (3)
- Underpass Bridges (2)
- Drain Bridge (1)
- Stream Bridges (3)
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Project Background

- 2 Span Overpass Bridges (2)
- 3 Span Overpass Bridges (2)
- 5 Span River Bridge (1)
- 5 Span Overpass Bridge (1)
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Project Background
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Challenging Environment

Ground Conditions

- The Expressway passes through Sand dunes and low lying inter-dunal deposits
- Peat deposits are present along alignment
  - Peat is very soft soil with very high organic content & highly compressible. These deposits are typically 0.5m to 6m thick
- Liquefiable loose sand and silt layers below GWT
- Founding layer of dense gravel sand for piles is about 20 ~30m below GL
Critical faults around the site:

- Ohariu Fault
  - Estimated MCE of M7.2
  - Return period – 2000 yrs
  - 1km from Peka Peka Bridge
  - 3km from Poplar Avenue Bridge

- Wairarapa Fault
  - Estimated MCE of M8.2
  - Return period - 1200 yrs
  - 27km from Poplar Ave Bridge
  - 30km from Waikanae River Bridge
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Challenging Environment (Cont)

Seismicity of the Area (cont.)

Comparison of Response Spectra

- Christchurch 1/2500yr
- M2PP 1/2500yr (liquefied)
- M2PP 1/2500yr (Near fault effects)
- M2PP 1/100yr event
- Auckland 1/2500yr event

Spectral Acceleration (g) vs. Displacement (mm)
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Multi-span Bridge Form

- Bridge Beams (Super T / SHC)
  - Installed as simply supported
  - Connected together via
    - Transverse post-tensioning (SHC beams)
    - Concrete topping slab (super T beams)

- Bridge Deck
  - Longitudinal direction - Bridge deck will slide over the abutments
  - Transverse direction - Deck will be restrained by shear keys

- Bridge Piers
  - Single or twin column, with precast crosshead beams
  - Supported by oversized large diameter bored piles
  - Resist total longitudinal inertia deck loads and
  - Share transverse seismic deck effects with abutments

- Bridge Abutments
  - The abutments are cast-in-situ concrete
  - Supported on steel H-piles
  - Resist only transvers seismic inertia loads of bridge deck.
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Accelerated Bridge Construction

- In the design and construction of M2PP multi-span bridges, a number of “Accelerated Bridge Construction” techniques adopted by following the principals of ABC
  - Use standard elements repeatedly
    - 2 column type, 1.5m and 2.1m
    - 2 Bored Pile size 2.1m and 3m
    - 2 type of piers
    - 3 types of crosshead beams
    - 2 types of beams, Super T and SHC
  - Eliminate an element or operation if possible to reduce the number of elements / operations
    - Pier supported on large dia mono pile, no pilecap
    - Column cage plunged on pile top, no 2nd stage pour
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Accelerated Bridge Construction

- Decouple or remove the dependency of elements on each other
  - Prefabrication of column and pile cage
  - Post-tension connection of column & crosshead
  - A short land span to separate MSE Walls and Abutment, so MSE wall can be constructed independently.

- Off-site pre-casting and prefabrication of reinforcement cage to improve the quality
  - Prefabrication of column & pile cage, abutment pile caps cage
  - Pre-cast bridge beams, crosshead beams, facia panels, facing panels, land span slabs etc

- Minimise confined space working at site
- Minimise working at height
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Multi-span Bridge Piers

- In an urban environment, piers are designed to:
  - Be aesthetically appealing
  - Occupy less space
  - Provide more light & room underneath bridge

- Types of pier adopted are:
  - Hammerhead pier (for 3 and more spans bridges)
  - Portal frame pier (for 2 span bridges)

- The components of piers are:
  - Monopile continuous with pier column
  - Pier column
  - Crosshead beam
  - Pier column & cross-head beam connection
  - Pier & deck linkage connection
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Bridge Piers Design

- Design economy was achieved
  - Allowing the hinges in piles at depth
  - Both the pile yield, and column yield produce a plastic mechanism that has the strength and displacement capacity to achieve the seismic demands.
  - The different mechanisms form depending on the soils characteristics (upper bound vs lower bound etc.)
  - Columns are designed for:
    - Flexural demands and not for over-strength flexure capacity of piles
    - Over-strength shear due to Plastic Hinges in piles or columns
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Bridge Piers Design

- Potential Plastic Hinges (PH)
  - Ranges of soils used for all possible PH locations
  - Potential plastic hinges' that they occur either:
    1. At the base of the column when upper bound soil conditions are considered.
    2. At a range of depths (5m-12m) when lower bound conditions considered depending on shadowing effect etc
  - Plastic hinge region is designed for Over-strength shear.
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Bridge Piers Column Design

- The piers column are:
  - Octagonal shape at base
  - Followed by an architectural shape
    - Elongated hexagonal shape
    - Gradually change to rectangular at top.

- The piers column cage designed as:
  - Main structural steel cage
  - Secondary steel cage

- Main structural steel cage
  - Core cage detailed as circular shape
  - Provides flexibility and tolerance

- Secondary steel cage
  - Follows the architectural shape
  - Tie to main structural steel cage
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Bridge Piers Foundation Design

- Monopile continuous with pier
  - provides efficient support to piers
  - gives significant efficiencies in design and construction.

- Pier supported on large dia mono pile:
  - No pile cap

- Large diameter bored piles used
  - 3m dia piles for Hammered head pier
  - 2.1m dia piles for Portal frame pier

- We believe this is the 1st use of 3mφ bored pile in New Zealand.
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Pier Supported by Oversize Pile Shaft

- Two types of possible failure
  - The bars pull-out of the pile.
  - Pier pull-out of the pile.

- The horizontal forces due to prying action
  - Surrounding concrete
  - Transverse reinforcement.

- No guidance in NZ Standards

- AASHTO Bridge Design Code Adopted
  - Precast Bent System for High Seismic Regions
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Pier & Piles Detailing (Use of DH40 Bar Hoops)

- The top of pile shaft is designed for
  - Over-strength shear demands
  - Confinement demands
  - Horizontal force demands
    - Prying action of pier supported on an oversize pile shaft

- This led team to use
  - DH40 bars in bundle for longitudinal pile reinforcement (106 bars)
  - DH40 bars as hoop reinforcement

- We believe this is the first use of HD40 bars as hoops in New Zealand.
- Pile cage weights 60 tonnes
- Constructed 32 No piles safely & efficiently
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Bridge Piers and Pile Connection Design

- Column cage prefabricated
- 16T column cage plunged into the top of pile concrete

Advantages of this innovation are:
  - No pile cap
  - No 2nd stage concreting
  - No confined space working
  - Saving the project over $6M and 120 days.
  - Produced high quality piles and pile-column interface connections
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Crosshead Beam

- Inverted T cantilever reinforced concrete pre-cast beams
- Designed to remain elastic under all loading cases;
  - Operational loading
  - Construction loading and
  - Imbalance of live loads.
- Design for critical load cases was undertaken to NZS3101:2006 for flexure, shear and torsion at both SLS and ULS.
Corbel SLS design was undertaken using:
- The strut and tie methodology from BD21/01
- The ULS Design was undertaken to AS 5100.5-2004 Appendix D2.

The shear keys at each end of the crosshead are designed:
- For loading derived from transverse overstrength actions of the pier column.
- using strut and tie theory from Appendix A of NZS3101:2006
- Bearing stresses were assessed to section 16.3 of NZS3101:2006.
Colum - Crosshead Connection

- A Post-tension connection
- 6-56mm dia threaded stress bars was developed  
  - To reduce joint congestions
  - To increase construction speed
- The steel anchorage plates with screwed threaded stress bars were cast into the column.
- The crosshead was then lowered over the column with the stress bars passing through oversize ducts, and then stressing was performed.
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Column - Crosshead Connection

- The PT connection was designed to remain elastic under all load cases.
- The design ULS load case results from seismic inertia generated by overstrength of the pier column.
- The SLS design actions were derived from traffic out of balance loads.
- Losses due to creep and shrinkage were accounted for in accordance to NZS3101:2006 Cl19.3.4.
- Shear transfer at the column-crosshead interface was carried through shear-friction to NZS3101:2006 Cl7.7.
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Colum - Crosshead Connection

- This allowed rapid erection of the crossheads and prove to be the most cost effective solution.
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Linkage Reinforcement

- To restrain the bridge spans in the event of an earthquake.
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Linkage Reinforcement

- Conventional Linkage Bars
  - The linkage will yield extensively under the combined ULS action.

Conventional Linkage Actions

Additional Actions
- Geometric Elongation
- Bending of linkages

Potential Localised Yielding

Delta Geo, Vert

Delta Geo, Hrz
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**Linkage Reinforcement**

- **Linkage Strands Alternative**
  - 15.2mm strands individually sheathed in a HDPE duct
  - Use of strand reduced flexural stresses in the linkage to a negligible value
  - Debonding increased significantly to control the strains in the linkages that develop due to geometric elongation
  - The strands are flexible enough to accommodate the rotations and axial extension without yielding/failing (both ULS and MCE).
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Bridge Beams

- Pre-cast pre-tension Bridge Beams
  - 650 / 900 Single Hollow Core Beam
  - 1225 / 1825 Super T Beams
- Designed as partially pre-stress elements
- 1825mm Super T beam
  - Beam length 38m
  - Beam weight 88T
  - 56 numbers of 15.2mm strands
  - Jacking force 75% of Pu
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New Zealand’s First 1825 Super T Bridge Beam

Kiwis can do

Even PM John Key and MP Nathan Guy were impressed!

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Expansion Joints

- The key considerations for an appropriate joint are:
  - Initial cost
  - Long term durability
  - Design performance

- NZTA has a strong preference for single seal joints

- In past single seal joints have provided very good long term services.

- A risk based approach adopted to gain the benefit of single seal joints.
  - List the efficiencies in construction and maintenance
  - Highlight the compromise in the design requirements.
  - List the possible risks for the Agency
  - Request for departures from Bridge Manual
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Expansion Joints, Departures from BM

- The maximum width of opening < 85mm
  - \( \Delta_{TP} + \Delta_{SG} + \Delta_{GAP} < 85\text{mm} \)
- Minor EQ return factor for expansion joints is \( R_s = 0.39 \)
  - \( R_s = \frac{R_u}{4.23} \), compare to \( \frac{R_u}{4} \) as suggested in BM 3\textsuperscript{rd} Ed.

<table>
<thead>
<tr>
<th>Bridge</th>
<th>Joint Type</th>
<th>Rs</th>
<th>SLS2 Event (AEP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waikanae River Bridge</td>
<td>Multi seal</td>
<td>0.50</td>
<td>1/100</td>
</tr>
<tr>
<td>Raumati Road Bridge</td>
<td>Multi seal</td>
<td>0.50</td>
<td>1/100</td>
</tr>
<tr>
<td>Poplar Ave Bridge</td>
<td>Single seal</td>
<td>0.50</td>
<td>1/100</td>
</tr>
<tr>
<td>Peka Peka Road Bridge</td>
<td>Single seal</td>
<td>0.50</td>
<td>1/100</td>
</tr>
<tr>
<td>Kapiti Road Bridge</td>
<td>Single seal</td>
<td>0.42</td>
<td>1/60</td>
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<tr>
<td>Wharemauku Stream Bridge</td>
<td>Single seal</td>
<td>0.40</td>
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<tr>
<td>Te Moana Road Bridge</td>
<td>Single seal</td>
<td>0.39</td>
<td>1/45</td>
</tr>
</tbody>
</table>
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Conclusions

- The high seismicity, challenging soil conditions and urban environment presented unique challenges to the Alliance team
- A number of Accelerated Bridge Construction (ABC) techniques has been adopted:
  - To improve construction efficiencies
  - To make the safe working environment
  - To achieve the good quality product.
- Displacement-based methods allowed for structures to be designed to more realistic levels of performance.
- Collaboration between designers and constructors enabled the use of a number of Accelerated Bridge Construction techniques for the multi-span bridges design.
- Innovation happens when the client, designers and constructors collaborate to put existing concepts together in a new way.
- By pushing to find ABC solutions in the design and construction of M2PP bridges, we have achieved significant construction efficiencies and savings.
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- The author would also like to acknowledge the contributions of other Alliance partners and suppliers in the development and implementation of the Accelerated Bridge Construction approaches taken on this project.