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65 YEARS OF PRESTRESSING CONCRETE IN NEW ZEALAND BRIDGES

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SUMMARY

Prestressing has played an important role in extending the span capability and economy of concrete bridges. The history of bridge construction in New Zealand has proved that prestressed concrete is an excellent material for constructing bridges and Kiwi engineers made considerable early use of prestressed concrete in bridge construction. Kiwi engineers love new ideas and embrace new technologies. New Zealand bridge engineers, from the early days, were not afraid to take on the challenge of working with new and innovative materials.

INTRODUCTION

Prestressed Concrete is one of the most cost effective and durable construction materials and can provide many advantages over other materials. Originating in France, prestressing in bridge construction was introduced in early 1950's. In the United Kingdom, the first major prestressed concrete road bridge was the replacement for Northam Bridge[24], Southampton in 1954. Walnut Lane Bridge in Philadelphia completed in late 1950, is considered the first prestressed concrete bridge in the USA[25].

It is remarkable that New Zealand, as a remote country at the end of the world, made considerable early use of prestressed concrete in bridge construction. IPENZ's records indicate that in 1954 the Hutt Estuary Bridge[18] used post-tensioned prestressed concrete for the first time in New Zealand. Upper Hutt City Council also claims their Bridge Road Bridge B8/1, built in 1954 over the Akatarawa River, was the first prestressed bridge in New Zealand[17]. As one can see, Kiwi Bridge engineers were keeping up with UK and USA engineers in adopting this new technology.

This paper provides a journey of the last 65 years through the developments of prestressed concrete bridge construction in New Zealand, recognising and celebrating some of the notable achievements of our pioneer bridge engineers and constructors. The journey of the last 65 years is broadly grouped into three eras:

- Adoption Era, 1953-1962, engineers adopted prestressing technology in bridges.
- Golden Era, 1963-2002, engineers pushed for innovations and scale in bridge designs.
- Refinement Era, 2003- Today, engineers focused on better understanding the behaviour of prestressed concrete and improving performance.

ADOPTION ERA FOR PRESTRESSED BRIDGES IN NEW ZEALAND (1953-1962)

Prestressed concrete was virtually unknown in New Zealand before 1952. Kiwis began using prestressed concrete in bridge construction from about 1953, and soon it became a preferred material for bridge construction. In 1956 New Zealand bridge engineers had built Waitaki River bridge, the longest bridge the world (at that time), using precast, pre-tensioned I-Beam.

By 1960, prestressed concrete became one of the foremost bridge-building materials for medium span bridges. Prestressing techniques were mainly used in precasting components (largely beams) in factories. The Ministry of Works (MoW) produced standard beam designs to make factory manufacture easier. At the same time, bridge designers were making intensive efforts to apply prestressing to continuous-span, cast-in-place superstructures; for example, prestressed concrete box girder bridges. Cobham Bridge over Wanganui River on the State Highway 3, was constructed in 1962, is the first cast-in-situ prestressed concrete box girder structure in New Zealand.

In the following section we have listed some examples of prestressed concrete bridges from this adoption era of prestressed concrete bridges in New Zealand, to recognise and celebrate some of the more notable achievements of New Zealand bridge engineers in adopting the prestressed concrete.

Bridge Road Bridge B8/1, Upper Hutt

In 1954 Hutt County Council upgraded the smaller of the two Black Bridges (that crossed the Akatarawa River) in order to continue to provide Bridge Road residents with vehicle access. Two new prestressed concrete deck spans were built over top of the old wooden bridge, but remained supported by the original 1881 pier. The old wooden trusses and the original decking were then removed. Figure 1 shows the way this bridge was when it was re-opened after its 1954 upgrade. The wooden tresses at the side hadn't been removed yet, but one can see that the concrete decking was sitting above them. The pre-tensioned beams were 'T' beams with a combined deck slab that was joined by insitu stitches between each beam. On Thursday 29 October 2015, the central pier (old 1881 pier) settled due to scouring under the foundation and the bridge partially collapsed, it was a sad loss for our engineering heritage when this first prestressed bridge was demolished and replaced with a single span weathering steel bridge.

Figure 1. Bridge opening 1954 Figure 2. Central Pier failure 29 October 2015

Hutt Estuary Bridge

The Hutt Estuary Bridge, completed in 1954, was New Zealand's first substantial bridge with a prestressed concrete superstructure[1,18]. At the time of its construction this road bridge was widely regarded as a significant New Zealand engineering project.

The Hutt Estuary Bridge is a two-lane road bridge consisting of five 32m spans and 9m approach spans at each end. It was designed with a pedestrian walkway on the South side, and a serviceway on the opposite side carrying water pipes and other services, across the

Hutt River. The bridge's parabolic profile was a design feature to allow for the required flood clearances.

Figure 3. Hutt Estuary Bridge

Figure 4. Hutt Estuary Bridge construction

Waitaki River Bridge – South Canterbury

The Waitaki River Bridge in South Canterbury, comprising 30m spans, 906m long and carrying two lanes of traffic, was built in 1956. It has reinforced concrete pile caps supporting twin cylinder columns at 4m centres. The superstructures comprise precast, pre-tensioned I-beams with a reinforced concrete slab. At the time of its construction, it was considered as one of the world's longest bridges using precast pre-tensioned and I-beams.

Figure 5. Waitaki River Bridge

Figure 6. Waitaki River Bridge construction

Victoria Park Viaduct

The Victoria Park Viaduct is a major motorway viaduct carrying the Auckland Northern Motorway (SH1) over Victoria Park in Auckland. Construction began in 1959 using post-tensioned precast beams and the bridge opened on 5 April 1962. The overall length of the bridge is about 630m.

Figure 7. Victoria Park Viaduct

Figure 8. Victoria Park Viaduct construction

Cobham Bridge, Whanganui

Cobham Bridge over the Whanganui River on SH3, was designed by the MoW and constructed in 1962 and is the first cast-in-situ prestressed concrete box girder structure in New Zealand. The 275m long bridge comprises 9 spans. The first three spans from each abutment are composed of four 27.4m post-tensioned precast concrete I-beams with a composite insitu concrete deck. The fourth span of 32.9m, from each end, comprises a 3 web, post-tensioned, cast insitu, haunched concrete box girder cantilevering 9.8m into the central span. Four 24.4m long post-tensioned precast concrete I-beams complete the 43.9m long centre span[15]. Piers are full width reinforced concrete walls supported on a group of 400mm square prestressed concrete raked piles.

Figure 9. Cobham Bridge, Whanganui

Figure 10. Cobham Bridge arial view

GOLDEN ERA FOR PRESTRESSED BRIDGES IN NEW ZEALAND (1963 - 2002)

The advancement in the technology of prestressed concrete and construction techniques, forced Kiwi bridge engineers to start refining their designs through innovation to produce some state-of-the-art prestressed concrete bridges. This was the golden era of prestressed bridges in New Zealand, when Kiwi-engineers pushed the boundaries and produced a number of elegant and ground-breaking designs.

With the establishment of the NZ Prestressed Concrete Institute, New Zealand bridge engineers embraced another innovative technique in the design and construction of bridges. Bridges constructed from each supporting column as balanced cantilevers, progressively moving out from each side, were developed.

Kiwi engineers love new ideas and embrace new technologies. From the early days, they were not afraid to take on the challenge of working with new and innovative materials. This Kiwi ingenuity has led to a number of outstanding and leading-edge bridges, which were not only unique to New Zealand, but also the world.

Among their many achievements, New Zealand bridge engineers built the Shell Gully bridges with the first application of capacity design concept, were the first to adopt the new technology of incremental launching in Australasia, and designed and constructed the world's first base isolated bridge structure. They also developed the world’s first catch frame to reduce the vulnerability of the existing bridges against major earthquakes.

During this era, Kiwi engineers also produced some elegant, aesthetically appealing and state-of-art bridges such as the South Rangitikei Viaduct, Lower Shotover Bridge, Hapuawhenua Viaduct and the Ōtira Viaduct to name a few from a long list.

The NZ Prestressed Concrete Institute

The NZ Prestressed Concrete Institute was established in 1963 and Sandy Cormack was its first president. This provided a platform for bridge engineers to share their ideas, and to learn about prestressing concrete and its application to their projects. Its founders were particularly keen to introduce to New Zealand the new wave of prestressing advances being used in Europe, particularly France. These techniques, they argued, not only provided a competitive edge over conventional steel construction, but also offered significant financial incentives. One of the institute's fundamental aims was promoting prestressing through the integration of the universities (teachers and researchers), the contractors, the suppliers of prestressing components and equipment, and consulting engineers.

Hamilton Railway Bridge

Completed in 1964, Hamilton Rail Bridge over the Waikato River, was constructed alongside its late 19th Century predecessor. It was a challenging project because of design parameters and construction restraints.

The concrete bridge is approximately 143 metres long and wide enough to carry a single track railway across the Waikato River. The substructure consists of reinforced concrete piers and abutments founded on cast insitu piles and cylinders. The superstructure consists of seven spans of prestressed concrete box girder, two of which are land spans. The remaining spans cross the river some 18m above normal water level. The bridge deck structure was constructed out from the piers by cantilevering in 2.7m blocks (cast in place) progressively stressing with Freyssinet type 100 tonne cables. This was the first use of the 100 tonne cable Freyssinet system in the country. Initially problems were encountered in the progressive stressing of the cantilevered sections, which included the positioning of the cable anchors, the clearances around and friction in the cable ducts, and quality control of the concrete.

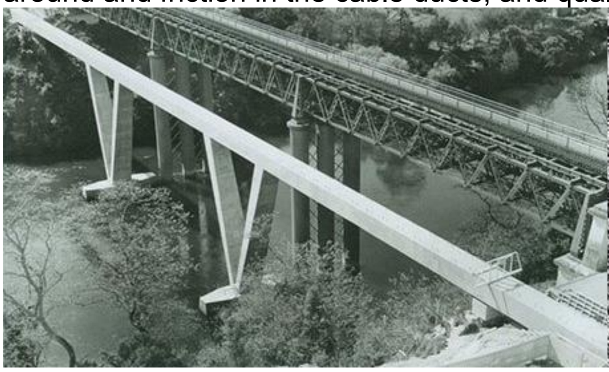

Figure 11. Hamilton Railway Bridge

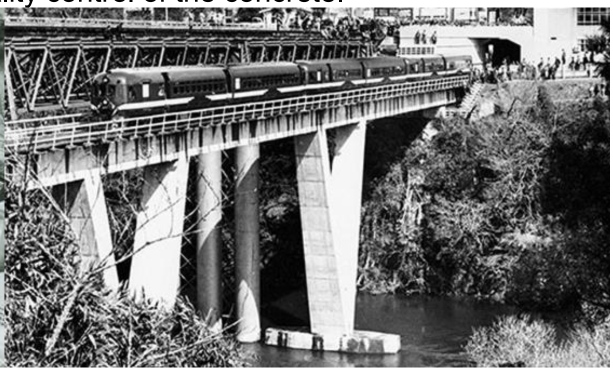

Figure 12. Hamilton Railway Bridge

Newmarket Viaduct Bridge

Newmarket Viaduct, completed in 1965, was the first road bridge designed as a balanced cantilever and the largest prestressed concrete bridge in New Zealand at the time of its construction. When it was completed in 1965 the six-lane Newmarket Viaduct with its tall, slender piers was something of an engineering wonder, the first of its kind in the Southern Hemisphere.

Figure 13. Newmarket Viaduct construction 1964

Figure 14. Old Newmarket Viaduct

Of particular interest in the engineering world, was a problem which occurred early in its life due to differential temperature within the box girders, which had a normal black bitumen wearing coarse. This caused unacceptable cracking in the continuous structure, at the joints between segments, due to differential temperature gradients that had not previously been considered in the design of bridges. The solution was to put in additional prestressed macalloys bars and place a light coloured stone chip on the road surface to reduce heat gain to the deck. Following further research, this led to bridges being designed for the effects of differential temperature gradients both in New Zealand and overseas.

Clarence River Bridge

The Clarence River Bridge is a post-tensioned box girder bridge constructed using the cast-insitu, balanced cantilever method. The depth of the superstructure varies from 3.2m at pier supports to 1.1m at mid-span. The superstructure is integral with the reinforced concrete piers and expansion joints are present at midspan of each main span. Design of the bridge was completed around 1968 by the Ministry of Works.

Piers, which are of an elongated octagonal shape, are each founded on a pair of 2.4m diameter cylinders with belled bases. The cylinders comprise hollow sections, in-filled with gravel, with in-situ concrete plugs at the top and bottom. Piers vary in height from 6m to 9m, while the cylinders are 12m in length.

Figure 15. Clarence River Bridge

Figure 16. Clarence River Bridge

Elastomeric bearings support the end spans at the abutments. Tie-down bolts were provided to the end spans, at the abutment, in accordance with standard practice at the time the bridge was designed.

Blue Book

The Ministry of Works (MoW) produced many standard designs to make beam manufacture easier. In 1970 the standard precast bridge beam designs were developed by the MoW and documented as the “Blue Book”. These standard designs played a significant role in making prestressing concrete bridges more popular than other types of bridge.

Waipuna Bridge

The Waipuna Motorway Bridge was constructed in 1971. This was the first application of precast segmental epoxy jointed box girder bridge construction in New Zealand using a self-launching overhead gantry for erecting precast segments by a balanced cantilever method. The four lane and 528m long bridge consists of 7 spans with 43m end spans and five 75m central spans. The bridge is divided into three separate structures with halving joints provided at the mid-span of spans 4 and 6. The halving joints are provided with bearings and ties to prevent vertical separation across the joints whilst allowing rotation and longitudinal movement to occur. The central spans are supported on concrete box piers. The shorter end spans are supported on rectangular concrete piers and concrete abutments at each end. The piers and abutments are founded on 1.2m diameter piles of varying length.

Figure 17. Waipuna Bridge (East view)

Figure 18. Waipuna Bridge (West view)

The bridge has suffered from sagging of the cantilever spans at the halving joints due to creep effects, and modifications to the joints and surfacing were undertaken in the 1980’s to improve the riding surface. This was a common problem among the first generation of balance cantilever box girder bridges which had joints at midspan, both in New Zealand and overseas.

Upper Harbour Bridge, Auckland

The Upper Harbour Bridge, also called the Greenhithe Bridge, was designed and constructed in the early 1970’s as a two-lane concrete balanced cantilever bridge. It is a 457m long bridge, with five 73m long main spans and two 46m long end spans. About 400m of the bridge (all but the eastern end span) is over water with depths typically of the order of 8-10m at mid-tide and with a deeper navigable channel passing under the eastern main span.

Figure 19. Original Upper Harbour Bridge

Figure 20. Inner view of box girder

Symonds Street Bridge

The Symonds Street Bridge constructed in 1972 was the first major bridge in New Zealand to use the system of off-site segmental span construction followed by epoxy jointing and prestressing to make the finished structure on-site. The bridge was built in two sections maintaining traffic flows through half the carriageway at a time. Construction of the bridge piers and foundation piling was carried out from road level prior to limited excavation been carried out. The continuous prestressed box girder was then precast in segments off-site[1]. The individual segments, each weighing some 20 tonnes, were then brought to site, placed in position, epoxy glued together, prestressed into single spans, and then further connected together into a three-span continuous structure through a second stage of prestressing. The structure was completed with handrails, etc, and carried traffic before the major excavation took place for the motorway alignment below.

Figure 21. Symonds Street Bridge (1971)

Figure 22. Symonds Street Bridge

Shell Gully Bridge, Wellington

The Shell Gully bridges on the Wellington Urban Motorway, immediately north of the Terrace Tunnel leading into the CBD, were constructed around 1973. The Shell Gully bridges were designed with provision for future duplication of the Terrace Tunnel based on separate structures being provided to carry each carriageway of the motorway, but have only been constructed to the extent necessary to feed traffic into the existing single tunnel.

The main motorway carriageway structures comprise twin continuous post-tensioned spine beams constructed integral with piers. Piers are twin column portal frames, with each column founded on a single cylinder foundation socketed into bedrock. This is one of the first bridges where capacity design was implemented in the design. The spine beams and deck slab were constructed insitu on falsework.

Figure 23. Shell Gully Bridge construction

Figure 24. Shell Gully Bridge (underside)

A similar design was adopted for Newton N°1 Bridge in Auckland, which carries SH1 northbound through Spaghetti Junction, as an alternate design to the conforming design of an insitu box girder, in 1975. The superstructure of the alternative design had 10% more material than the confirming design, but it was 30% below the nearest conforming tender. This reflected a major trend in which insitu box girder construction had become too expensive because of labour cost increases associated particularly with the internal formwork and the complexity of box girders. A similar concept was adapted for Sunset Road Bridge over SH1 in Auckland built in 1990's.

Thorndon Overbridge

Thorndon Overbridge, constructed in late 1960's-early 1970's, is the largest concrete bridge project involving a prestressed concrete ever built in New Zealand[1]. The bridge utilised over 300 post-tensioned 'I' beams utilising some 800 tonnes of prestressing. The design was again carried out by the MoW. The Thorndon Overbridge off ramp onto Aotea Quay was constructed using insitu box girders[1].

Figure 25. Thorndon Overbridge

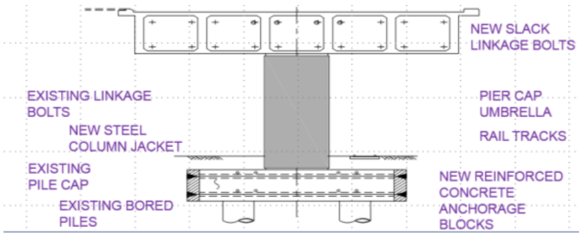

Figure 26. Pile cape strengthen by prestressing

Each pier comprises of a single circular column, supported from a pile cap, on which a post-tensioned cellular 'umbrella' crosshead structure is located. Half joints support the precast I-beams from the spans on each side. In the mid 1990's, a seismic assessment was completed for Thorndon Overbridge and vulnerabilities to earthquake loads were identified. Geotechnical assessment of liquefaction risks was undertaken and investigations carried out to locate the Wellington Fault which passes under the bridge. Linkage deficiencies were considered and a linkage bolt retrofit scheme developed. The foundations were strengthened by introducing prestressing in the foundations. The world's first 'catch frames' were developed to mitigate against the loss of spans in the event of a predicted 5m local fault movement below the bridge.

Lower Shotover Bridge

Described at its 1975 opening as “mathematical precision combined with beautiful form”, the bridge has a two-lane carriageway. Measuring 320m long, it is made up of 169 precast, pretensioned concrete box girder sections. Governed by aesthetics, the design is a slender, curving structure that blends easily with the landscape. Opting for a precast, box girder bridge was appealing because construction crews wouldn’t have to truck aggregate from a considerable distance to a tricky site.

The shape of the piers is functional as well as aesthetic, in that the height had to be adaptable from 5m to 7.5m, and wide enough at the top to collect the reactions from bearing under the outer webs. The load from the middle web was transferred at the pier to the outer webs by means of transversely prestresses diaphragms.

Figure 27. Lower Shotover Bridge

Figure 28. Lower Shotover Bridge top view

Red Book

Two major projects, Victoria Park Viaduct and Thorndon Overbridge Viaduct, constructed in the 1960’s and 1970’s using the standard design precast prestressed bridge beams, are still the largest projects in New Zealand involving prestressed concrete. After completion of these projects in 1980, the MoW updated the 1970’s “Blue Book” of Standard Bridge beam and released it as the “Red Book”. These standard designs continued to play a significant role in making concrete bridges more popular than other types of bridge.

South Rangitikei Viaduct

South Rangitikei viaduct constructed in 1981, is the fourth highest and second longest railway viaduct in New Zealand[21]. It is a 78m high, 315m long viaduct spanning the Rangitikei River. It is an impressive all-concrete structure with twin-shafted vertical piers carrying a continuous prestressed hollow box superstructure of six spans. It incorporates an earthquake resistant feature that is unique in New Zealand and rare in the world. In an earthquake the pier bases could lift up to 13cm to allow energy and load to shift from one pier leg to another. The rocking action is controlled by large "energy dissipaters" installed in the pier bases.

Figure 29. South Rangitikei Viaduct

Figure 30. South Rangitikei Viaduct superstructure

The construction method used a self-launching steel false-work system and involved only minor earthworks so there would be minimal disturbance to the surrounding landscape. The bridge is located in a seismically active area and was designed as the world's first base isolated structure with the tall piers stepping or rocking from side to side in the event of a major earthquake shaking. Special steel torsion energy dissipating devices were installed at the base of each leg to ensure satisfactory performance under large earthquakes.

North Rangitikei and Kawhatau Railway Bridges

Two valleys in the Mangaweka and Utiku rail deviation are similar in size and nature allowing the same design to be used for the North Rangitikei and Kawhatau Viaducts in 1981. The bridges are unique three-span balanced cantilever bridges constructed over very deep river gorges. The design is a prestressed concrete box girder spanning 110m across the gorge, the longest span of any rail bridge in New Zealand. The bridges have shorter end spans giving a total length of 182m. The unusually short side spans are tied down at the ends with rock anchors. Construction was by the cantilever method using a mobile formwork system and cast in place concrete. The structural depth varies from 3m at mid-span to 7.75m at the main piers.

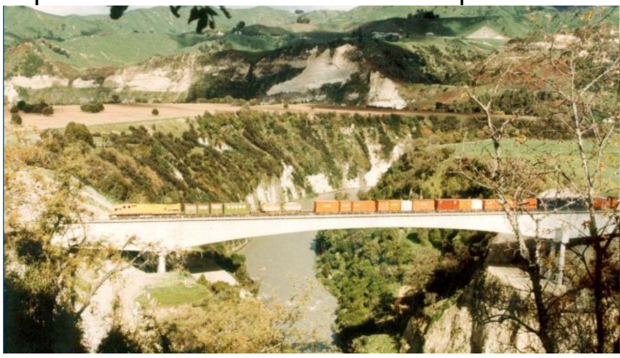

Figure 31. North Rangitikei Bridge

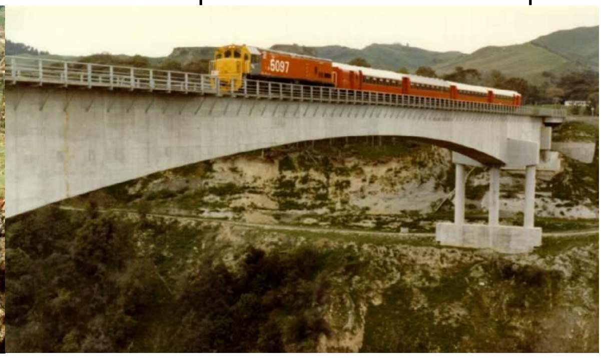

Figure 32. Kawhatau Viaduct

North Rangitikei Bridge is the second highest railway viaduct in New Zealand[21] and is 81m high spanning the Rangitikei River. Kawhatau viaduct is the sixth highest railway viaduct in New Zealand[21] and is 73m high spanning the Kawhatau River.

Māngere Bridge

Figure 33. Māngere Bridge construction 1980

Figure 34. Manukau Harbour Crossing

In 1983 a new Motorway Bridge, known as the New Māngere Bridge was constructed over the Manukau Harbour using cast-in-situ post-tensioned and balanced cantilever techniques. It is a 646m long, 21.5m wide motorway bridge. It is located alongside the existing crossing of the

Manukau Harbour on SH20. The bridge design employed twin (linked) cast-in-situ box girders with 100m main spans, the superstructure being continuous from abutment to abutment, and supported on flexible piers which allowed the elimination of bearings at piers. Particular attention was given to the design and during construction to achieving the desired whole-of-life performance and durability for the completed structure [12].

Ngauranga Interchange Bridges

Close to the end of 1982, another landmark structure was being constructed in Wellington, the Ngauranga interchange bridges. Designed by the Ministry of Works and built by Mainzeal Construction Ltd, these twin-curved bridges were the first use of the incremental launching method in Australasia[19]. At the opening, the Prime Minister Sir Robert Muldoon, referred to the bridge as a magnificent piece of engineering. In the language of its country of origin, West Germany, the bridge was called a Taktschiebeverfahren, a 20-letter word. Sir Robert dryly went on to add that an engineer had translated this to ‘incrementally launched bridge’ and yet another more down-to-earth engineer who worked on the job, further reduced it to a four letter description; a ‘push bridge.’ Subsequent to this project, four other bridges have been constructed in New Zealand using the same technique.

Figure 35. Ngauranga Flyover Bridge

Figure 36. Night view of Ngauranga Flyover

Hapuawhenua Viaduct

Figure 37. Hapuawhenua Viaduct

Figure 38. Hapuawhenua Viaduct

The Hapuawhenua viaduct epitomises the three aims of engineering: function, economy and (above all) grace. Completed in 1987, it is the longest high railway viaduct in New Zealand[21] being 51m high and 414m long. The viaduct is a major structure constructed from a combination of reinforced and prestressed concrete[1]. The viaduct consists of 21 prestressed concrete spans on 22 reinforced concrete piers. This slender structure is a 'state-of-the-art' design, which takes advantage of the development of engineering knowledge of the behaviour of structures under extreme conditions, and especially those of a major earthquake. As a result of improved knowledge the amount of material used in construction has been minimised while the safety of trains has been enhanced.

Tauranga's First Harbour Bridge

The bridge, opened in 1988, is significant because it was New Zealand's first incrementally-launched harbour crossing. After preliminary assessments of various structures, designer Murray North selected an incrementally-launched prestressed concrete box girder. It was considered the most cost-competitive form of construction for the bridge which, at that stage, was to be straight in plan, but with a vertical curve. The joints between the concrete segments were sealed with epoxy resin.

The 480m bridge was constructed onshore and then pushed into place. Its superstructure consists of a single-cell, concrete box girder, continuous over all supports with expansion joints at both abutments.

Figure 39. Tauranga's first Harbour Bridge

Figure 40. Tauranga Harbour Bridge view

Sylvia Park Viaduct Bridge

Sylvia Park Viaduct, which carries South-Eastern Highway over Sylvia Park, is a 475m long bridge with span lengths of 21m and 25m, and was built in 1995. During the design stage the designer carried out a comparative evaluation of the structural efficiency of commonly available standard precast beams in New Zealand at that time. The closed top Super-T beam, developed by VicRoads, for a span range of 21m to 26m, was selected as the most economical type to use for the project. The Super-T beam was found to be the most efficient and it also had the advantage of providing a complete working surface for casting the in-situ deck slab on. This was an added advantage for the viaduct spans over a busy road and railway line.

Based on the investigation results, Super T beams were adopted for the viaduct. The Super T beams were the original closed top type with an expanded polystyrene void former. The constructor developed a high slump 60 MPa mix for the beams and saw cut sections through a trial beam to prove that the concrete was fully compacted around the void. About 240 Super T beams were cast for Sylvia Park Viaduct. This was the first use of Super T beams in New Zealand.

Figure 41. Sylvia Park Viaduct arial view

Figure 42. Sylvia Park Super T beams

After successful use of Super T beams for Sylvia Park Viaduct, Super T beams were used for the highly skew Southern Motorway Underpass, Mungavin Avenue Bridge in Porirua and Puhinui Interchange Bridge built on SH16 near Auckland airport in 2001. In 2005 Super T beams were also used for the 413m long, 15 span Hewletts Flyover in Tauranga. Here the Super T beams design was based on the Partial Prestress approach.

Pukete Bridge

Pukete Bridge is a prestressed concrete box girder bridge in Hamilton, spanning the Waikato River. This balanced cantilever bridge links Hamilton's eastern residential areas with the commercial and industrial facilities in the West. The bridge is 158m long and has a main span of 75m, with landspans of 36m. The construction of the bridge was completed in October 1996.

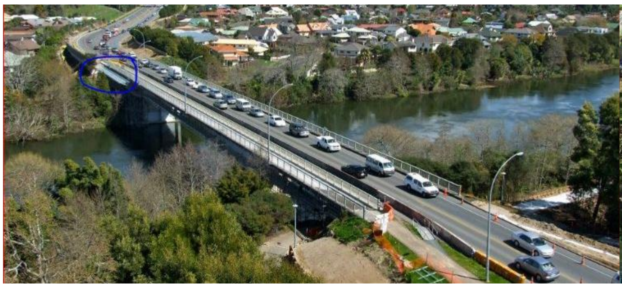

Figure 43. Pukete Bridge

Figure 44. Pukete Bridge

Ōtira Viaduct

The Ōtira Viaduct, constructed in 2000 in the Ōtira Gorge at Arthur's Pass, is the longest span concrete bridge in New Zealand. The topography of the area required the construction of a 442m long, four-span viaduct, with end spans of 87m and central spans of 134m.

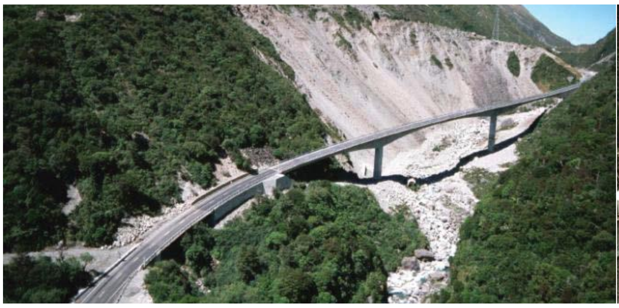

Figure 45. Ōtira Viaduct

Figure 46. Ōtira Viaduct construction

The superstructure consists of a haunched single cell box girder with maximum depth of 7.75m at piers. The bridge is supported on single concrete box piers up to 45m high, constructed on 4m diameter foundation cylinders.

REFINEMENT ERA FOR PRESTRESSED BRIDGES IN NEW ZEALAND (2003 - TODAY)

This era is considered as a refinement era for prestressed concrete in New Zealand. In this era engineers focused on better understanding prestressed concrete behaviour. The designers refined the design process to address secondary effects with the help of detailed and complex analyses. Engineers adopted partial prestressing design, which needs more computational and design effort to optimise the design, but reduces the amount of prestress required.

Durability and urban design of bridges became other key design considerations in this era. Safety-in-Design, precasting and prefabrication became key aspects for safe and quality construction. As a result of these considerations, almost all prestressed bridge beams today are made using the pretensioning process. Pretensioning requires the construction of large “casting beds” to hold the strands in a highly tensioned state while the concrete is poured around them in moulds, and allows factory production.

With pretensioning, during this period fabricators created much larger beams and slabs. The casting beds were constructed in factory-like precasting yards, allowing year-round production under controlled conditions. The length of the pretensioned beams was limited by transportation restrictions between the plant and the bridge site, and by the availability of cranes capable of lifting the beams into place. Despite of all these new considerations, Kiwi engineers still managed to produce some outstanding prestressed bridges. A few examples are listed below.

Central Motorway Junction, Auckland - Stage 1

Central Motorway Junction Stage 1 improvements were built in 2003 and required widening, live load capacity strengthening and seismic retrofit of three existing major bridges; Grafton Bridge Nº 2, Grafton Bridge Nº 3A and Khyber Pass Viaduct. All three bridges are major multi-span, post tensioned concrete box girder structures constructed in the 1970’s with lengths respectively of 110m, 110m and 200m.

Work on Grafton Bridges Nº 2 and Nº 3A included widening by 6.5m, strengthening of existing girder webs and seismic retrofit of pier foundations. Grafton Bridge Nº 2 was widened on two sides and Grafton Bridge Nº 3A on one side only.

Work on the Khyber Pass Viaduct included widening and strengthening the deck cantilevers with steel brackets, adding external longitudinal post-tensioning to existing box girders, locking the northbound and southbound bridges together, infilling the deck between and seismic retrofit of all pier foundations. The team had to add new internal diaphragms inside the Khyber Pass Viaduct box girders and add additional width to the existing internal diaphragms. To get the concrete into these tight spaces and to get it to fill right up to the underside of the deck the team needed a flowable concrete, hence they used self-compacting concrete. It is believed to be the first application of self-compacting concrete in bridges in New Zealand. The supplier developed the concrete mix design and the team undertook a lot of testing to convince themselves it would work.

Figure 47. Khyber Pass Viaduct – Cantilever deck strengthening with steel brackets

Figure 48. Khyber Pass Viaduct – New external longitudinal post tensioning

Upper Harbour Bridge, Auckland

Figure 49. Upper Harbour Bridge duplication construction

Figure 50. Upper Harbour Bridge duplication

In 2005 a new bridge was built immediately adjacent to the existing Upper Harbour Bridge in Auckland. The new bridge with a 17.8m wide deck now carries the east-bound carriageway of the new motorway along with a footpath/cycleway. The old bridge carries the west-bound carriageway. The new bridge was designed to match the existing 457m long, 7-span balanced cantilever bridge aesthetically with similar continuous box girder sections over its full length. A key difference between the original and duplicate Upper Harbour Bridge is the elimination of joints and bearings within the bridge length, except at abutments. Micro-silica concrete was used in the substructures and part of the superstructure to improve the durability[14]. The documents also showed that self-compacting concrete was used[20] in columns with congested reinforcement. This is one of the early uses of self-compacting concrete in the New Zealand bridge industry.

Central Motorway Junction, Auckland Stage 1

Central Motorway Junction Stage 2, was built in 2006 and required the construction of five new bridges and the retrofit/widening of four existing bridges. The new bridges range from 35m to 200m long and typically comprise continuous spans of 1500 deep concrete Super T beams supported on single columns and bored piles. Nelson Street off ramp, Beresford Street Viaduct and Newton Nº 2 bridges on this project are the first application of integral Super T bridge beams in New Zealand.

Figure 51. CMJ2 - first integral Super T deck

Figure 52. CMJ2 - first deck construction

Newmarket Viaduct Replacement


Figure 53. Newmarket Viaduct replacement construction 2007

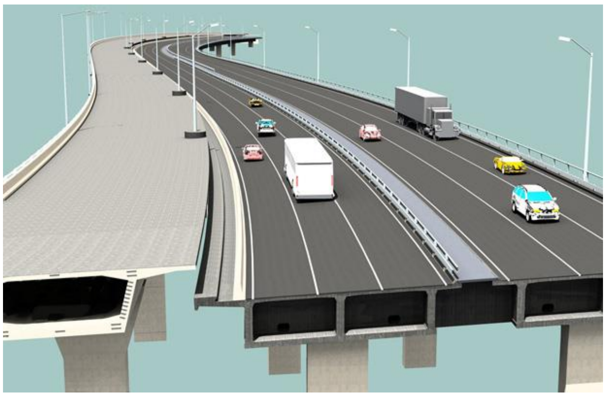
Figure 54. Replacement concept

By 2007, the 1966 viaduct carried an average of 163,500 vehicles per day making it one of the busiest sections of Auckland's motorway system, and more lanes were needed. Rather than upgrade the original viaduct the decision was made to replace it. The replacement viaduct was designed to withstand an earthquake that might occur only once in 2500 years, and was constructed in four stages. The first stage, completed in 2010, saw four new southbound lanes constructed on the northern side of the original viaduct. Following this, stage two involved dismantling of the original southbound bridge. Stage three was to build three new northbound lanes in place of the old viaduct's southbound bridge, and the final stage was the demolition of the original northbound section of the viaduct. Figure 62 illustrates the construction stages.

Demolition of the existing post-tensioned box girder viaduct was complex and required the bridge to be de-constructed in a reverse process to its original balanced cantilever construction.

NZTA Research Report 364

In the early 2000's New Zealand Transport Agency (NZTA), took the initiative to update the standard precast prestressed bridge beam designs. NZTA Research Report 364 "Standard Precast Concrete Bridge Beams" was released in December 2008 with updated designs of bridge beams including Super T, single and double hollow core beams and I beams. The new design reflected current practice and design requirements and replaced the previous MoW designs.

Tauranga Harbour Link Nº 2

Chapel Street Viaduct is the largest of the bridges on the Tauranga Harbour Link (THL) Project constructed in 2009. It is about 560m long and 40m wide at its widest point. Chapel Street Viaduct crosses over two major roads, one minor road and a railway. To overcome these obstructions and numerous site constraints, the optimum pier spacing was determined as approximately 35.5m. This is a little beyond the normally accepted limit for 1500mm deep Super T beams with conventional pre-tensioned strand. Therefore the solution was to design the beams with a mixture of pre-tensioned strands and post-tensioned tendons. This combination optimised the beam design while still allowing daily casting cycles in the precast yard[11]. Self-compacting concrete was used for the manufacture of all the Super T beams on Chapel Street Viaduct. Although the material cost was a little more than normal bridge beam concrete, savings came from the speed of concrete placement and the elimination of labour requirements for concrete vibration which offset this additional cost. This was the first time post-tensioned Super T beams had been used in New Zealand and it is also a major application of self-compacting concrete for bridge beams.

Figure 57. Chapel Street Viaduct

Figure 58. Post-tensioning Super T beam

<u>Northern Gateway Toll Road</u>

The project on SH1 North of Auckland was completed in 2009 and key bridges in this project are Otanerua Viaduct, Nukumea Viaduct, Hillcrest Bridge and Waiwera Viaduct.

Otanerua Viaduct is a 256m long bridge that crosses the Otanerua Valley and provides an ecological corridor between two areas of regionally significant bush that the new motorway would otherwise bisect. The Viaduct superstructure comprises 8 x 32m spans each with ten 1500mm deep Super T beams which are designed as partially prestressed.

Nukumea Viaduct is 180m long and comprises 6 spans of 30m. The cross section of the bridge comprises eight 1500mm deep Super T beams with an insitu concrete deck. The deck was designed to carry 100 tonne earthworks vehicles during construction and as a consequence is more heavily reinforced than needed for legal traffic loads[10]. The design and construction of this viaduct was very similar to Otanerua Viaduct. The only difference being, Nukumea has deck joints at both ends of the bridge while Otanerua has one deck joint at mid-length.
Waiwera Viaduct is a balanced cantilever bridge constructed in 2009. The project involved the application of a self-launching overhead gantry for erecting precast segments by balanced cantilever to form the 537m long twin viaducts. This method was chosen since it allowed the superstructure to be constructed without access from ground level as it was off-limits to protect wildlife habitats. The piers were constructed from reinforced concrete, incorporating a microsilica additive for protection from the marine environment[10]. The Viaduct was constructed as two independent structures, which have a separation varying from 2.5m to 11m. The variable separation was necessary to split the northbound and southbound lanes before entering tunnels, which are situated immediately North of the viaduct.

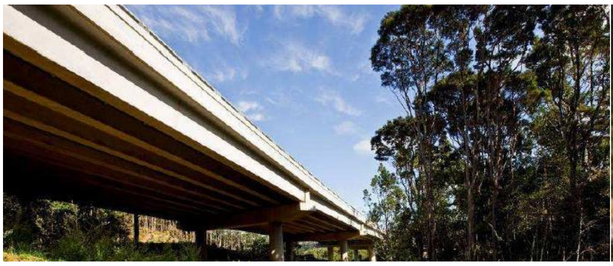

Figure 59. Otanerua Viaduct

Figure 60. Waiwera Viaduct

<u>Ashley River Bridge</u>

Ashley River Bridge is 300m long with 10 spans of 30m, and opened to traffic in 2015. The superstructure consists of 1200mm deep hollowcore units, which were made continuous over piers (except the central pier) to extend the span to 30m for Single Hollow Core (SHC) type beams. The Beams are simply supported at abutments and the central pier. The SHC bridge beams of this bridge superstructure are the deepest SHC bridge beams in New Zealand.

Figure 61. NZ's deepest SHC beam

Figure 62. Ashley River Bridge

Haywards Interchange SH02/SH58 Project

The Haywards Interchange is part of the wider Hutt Corridor with the aim to improve safety, reliability and efficiency outcomes for SH2 and SH58 users. The interchange design is based on twin bridge structures carrying the elevated roundabout over the SH2 carriageway. Both bridges are similar in design, and have a span of 33.6m.

Figure 63. Haywards Interchange

Figure 64. Haywards Pedestrian Bridge

The Interchange bridge structures are single span bridges with a superstructure comprising precast, prestressed Super T beams spanning approximately 33.6 metres each. The bridge structures are founded on reinforced concrete pad foundations integral with the 1525mm deep Super T beams which are seated on top of the reinforced earth retaining wall. The abutment retaining walls are reinforced earth walls with steel strip reinforcement and precast concrete panels parallel with the state highway. The bankseat abutment eliminates the requirement to pile through the reinforced earth retaining wall. This arrangement has become a popular solution for short and medium span bridges in recent years.

The project also has a pedestrian and cyclist link bridge, built using a single precast prestressed Super T beam 1525mm deep, with a 180mm thick insitu concrete topping. The girders are made integral with the piers by casting insitu diaphragms together with the concrete topping. This integral connection provides a robust structural form during the event of an earthquake by developing frame action in the longitudinal direction and will distribute loads into the substructure through slab diaphragm action in the transverse direction.

M2PP Project - Waikanae River Bridge

The Waikanae River Bridge is the longest bridge of the 17 bridges along the alignment of the Mackays to Peka Peka (M2PP) Expressway Project. M2PP expressway is an 18km, four lane highway that takes SH1 along the Kāpiti Coast.

Figure 65. Waikanae River Bridge

Figure 66. New Zealand's first 1825 Super T beam

The 35m clear waterway channel under the Waikanae River Bridge required a span length of about 39m. However, a 39m span was beyond the span limits of all available precast concrete bridge beams in New Zealand. The design team and constructors carried out a preliminary study and evaluated options using composite steel or concrete beams. The study showed that the 1825 Super T beam option would provide a cost efficient, safe-to-construct, durable and aesthetically appealing solution, which would fit well within the urban environment. This led to the design and construction of New Zealand's first 1825 Super T beams to span 39m on the Waikanae River Bridge – the longest precast bridge beam in New Zealand.

Waterview Project

The New Zealand Transport Agency's $1.4 billion Waterview Connection in Auckland is the largest roading project ever undertaken in New Zealand. One of the dominant features of the project, which opened in 2017, is the Great North Road motorway to motorway (SH20 to SH16) interchange (GNRI). The interchange ramps incorporate four separate curved viaducts varying in height (up to 20m above SH16) and ranging in length from 225m to 500m. The substructures typically consist of reinforced concrete hammerhead type cross-heads supported on single pier columns and single piles. However, a number of variations were necessitated by restrictions on pier positions, including some portal type piers and 'tabletop' piers. The viaduct superstructures utilise precast Super-T girders made fully integral with all substructures, apart from abutments and a portal pier at the mid-length of one viaduct. Delayed stitch pours at some piers were utilised to reduce creep and shrinkage demands on end piers to acceptable levels. The superstructures were constructed using a self-launching gantry, over one of the busiest motorways in Auckland.

Figure 67. Waterview SH20/SH16 Interchange bridges

Figure 68. Great North Road motorway ramp bridges

CONCLUSION

This paper provides a brief historical outline of the use of prestressed concrete in bridges and also provides a journey through the developments of prestressed concrete bridge construction in New Zealand. It recognises and celebrates some of the notable achievements of our pioneer bridge engineers and constructors. Concrete is the most used construction material for bridges in New Zealand. Prestressing has played an important role in extending the span capability of concrete bridges.

This journey shows that prestressed concrete is one of the most cost effective, durable and aesthetic construction materials for bridges and can provide many advantages over other materials. It further indicates that the history of New Zealand's prestressed concrete bridges can broadly grouped into three eras:

- Adoption Era, 1953-1962, engineers incorporated prestressing technology in bridges.
- Golden Era, 1963-2002, engineers pushed for innovations and elegancy in bridge designs.
- Refinement Era, 2003- Today, engineers focused on better understanding the behaviour of prestressed concrete.

Prestressed concrete was virtually unknown in New Zealand before 1952. Kiwis began using prestressed concrete in bridge construction from about 1953, and soon it became a preferred material for bridge construction. In 1956 New Zealand bridge engineers had built Waitaki River bridge, the longest bridge the world (at that time), using precast, pre-tensioned I-Beam.

By 1960, prestressed concrete became one of the foremost bridge-building materials for medium span bridges. Prestressing techniques were mainly used in precasting components (largely beams) in factories. In 1962 Kiwi bridge engineers were able to construct the first cast-in-situ prestressed concrete box girder structure in New Zealand.

During the golden era of prestressed bridges in New Zealand, Kiwi-engineers pushed the boundaries and produced a number of elegant and ground-breaking designs. With the establishment of the NZ Prestressed Concrete Institute, New Zealand bridge engineers embraced another innovative technique in the design and construction of bridges. Bridges constructed from each supporting column as balanced cantilevers, progressively moving out from each side, were developed.

Kiwi engineers love new ideas and embrace new technologies. From the early days, they were not afraid to take on the challenge of working with new and innovative materials. The construction of segmental concrete bridges began in New Zealand in the start of the golden era and by end of the golden era prestressed box-girder spans reached a record 110m.

This Kiwi ingenuity has led to a number of outstanding and leading-edge bridges, which were not only unique to New Zealand, but also the world. Among their many achievements, New Zealand bridge engineers built South Rangitikei viaduct, the world's first base isolated and rocking bridge structure, and were the first to adopt the new technology of incremental launching in Australasia.

During the golden era, Kiwi engineers also produced some elegant, aesthetically appealing and state-of-art bridges such as the South Rangitikei Viaduct, Lower Shotover Bridge, Hapuawhenua Viaduct and the Ōtira Viaduct to name a few from a long list.

In the refinement era for prestressed concrete in New Zealand, the engineers focused on better understanding prestressed concrete behaviour. The designers refined the design process to address secondary effects with the help of detailed and complex analyses. Engineers adopted partial prestressing design, which needs more computational and design effort to optimise the design, but reduces the amount of prestress required.

Durability and urban design of bridges became other key design considerations in this era. Safety-in-Design, precasting and prefabrication became key aspects for safe and quality construction. As a result of these considerations, almost all prestressed bridge beams today are made using the pretensioning process.

With pretensioning, during this period fabricators created much larger bridge beams. The length of the pretensioned beams was limited by transportation restrictions between the plant and the bridge site, and by the availability of cranes capable of lifting the beams into place. Despite of all these new considerations, Kiwi engineers still managed to produce some outstanding prestressed bridges.

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