NEW STANDARD PRECAST CONCRETE BRIDGE BEAMS
Stage 1 – Research & Identify Proposed Standard Beam Shapes and Spans

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EXECUTIVE SUMMARY

The objective of Stage 1 of this research project was to research and identify the most appropriate precast concrete bridge beam shapes that should be adopted as industry standards for the future.

This research was considered a priority as the standard bridge beam designs currently used in New Zealand were adopted as industry standards in the 1970's. These designs are almost 30 years old and out of date with respect to design codes, construction techniques and the higher strength materials now commonly used.

As well as reviewing current New Zealand practice the researchers did a literature survey of standard beam usage in Australia, North America and the United Kingdom.

Also, many precasters of bridge beams in New Zealand contributed data to a survey. From this survey information and statistics were produced to indicate the most popular beam shapes currently in use.

Extensive consultation of a wide range of industry participants was a crucial part of the research process. Workshops were held in three main centres to allow all sectors of the industry to raise and discuss issues. This included a poll of participants to select a new beam shape.

From the research above and consultation comments a range of beam selection criteria were then developed to identify the key criteria that needed to be addressed in any future designs. The most important criteria was the inclusion of the bridge superstructure in the standard bridge beam series of drawings. The research team concluded that for cost and practicality reasons that a standard bridge superstructure should be developed to limit the range of spans and cross section widths for the new bridge beams.

The beam shapes recommended for new detailed designs by the research team are the existing hollow core deck units for spans up to both 18 and 25 metres and the existing "I" beams for spans up to 32 metres. The new shape proposed is the Super-T beam for spans up to 30 metres.

ABSTRACT

The objective of Stage 1 of this research project (carried out from July 2002 to March 2003) was to research and identify the most appropriate precast concrete bridge beam shapes that should be adopted as industry standards for the future.

This research was considered a priority as the standard bridge beam designs currently used in New Zealand were adopted as industry standards in the 1970’s. These designs are almost 30 years old and out of date with respect to design codes, construction techniques and the higher strength materials now commonly used.

The researchers carried out a literature survey of standard beam usage in Australia, North America and the United Kingdom along with a survey of current New Zealand practice.

Following a survey of bridge beam precasters and three consultation workshops a range of key beam selection criteria were developed that needed to be addressed in any future designs.

The researchers recommended that full designs for two existing beam shapes (hollow core and “I” beam) and one new shape (Super-T) be carried out in the second stage of the project.

1 INTRODUCTION

In the mid 1970's the Ministry of Works (MOW) designed a range of twin hollow-core, "I" and "U" precast concrete bridge beams and small span bridges which were adopted as New Zealand industry standards. These standard designs led to cost efficiencies both in design time and also the use of standard moulds by precasters led to more competitive tenders for supply of bridge beams. Probably thousands of these standard beams were used in bridges all over New Zealand during the next 20 years.

The standard MOW bridge beam designs completed in the 1970's era are now nearly 30 years old and out of date both with respect to design codes and construction techniques now commonly used. In particular, changes to durability, width and side protection requirements have affected the current beam designs.

This report presents the findings of the research project carried out from July 2002 to March 2003 to research and identify the most appropriate precast concrete bridge beam shapes that should be adopted as industry standards for the future.

The steps involved in this research were:

- Formation of an Industry Group to comment on bridge beam options;
- Research current beam usage in NZ and compare with overseas usage (literature review);
- Survey NZ Precast Manufacturers
- Develop beam selection criteria;
- Consult with Industry representatives in 3 main centres;
- Analyse research results;
- Preliminary design of new beam shapes;
- Cost estimates and economic analysis;
- Derive conclusions and make recommendations.

The research team is made up of bridge designers, precast beam manufacturers and a representative of the precast concrete industry. The research team members are:

- Alex Gray – Team leader (Beca)
- Geoff Brown – Deputy team leader and bridge designer (Opus)
- Ross Cato – Representative of Precast New Zealand
- Paul Sweetman – Beam manufacturer (Smithbridge)
- Ian Billings – Bridge designer (Beca)
- Phil Gaby – Bridge designer (Beca)
- Don Kirkcaldie – Bridge designer (Opus)

2 REVIEW OF CURRENT SITUATION IN NEW ZEALAND

2.1 Background

The existing standard bridge beams include a range of different section types to be used for different spans of between 6 and 32 metres. Other superstructure elements including deck slabs, transverse diaphragms, edge protection details and seismic restraint details were also provided to give complete superstructure designs for the various beam types. The designs cover both single lane and two lane bridges, with and without footways, based on the bridge width standards when last updated during the mid-1990's.

2.2 Existing Standard Bridge Beams

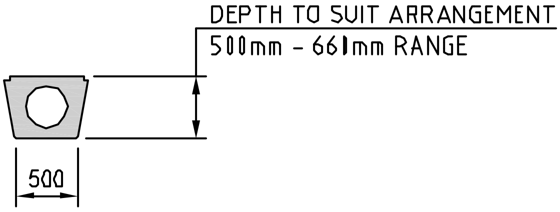
The existing standard bridge designs, which are contained in the Ministry of Works publication "Highway Bridges Standard Plans", (also known as the "red book"), cover the following beam shapes and span ranges:

- Precast pre-tensioned single circular hollow core deck units – 8 m to 14 m spans
- Precast pre-tensioned double circular hollow core deck units – 6 m to 18 m spans
- Precast pre-tensioned triple hollow core deck units – 6 m to 10 m spans
- Precast pre-tensioned "I" beams – 12 m to 20 m spans
- Precast combined pre and post-tensioned "I" beams – 18 m, 20 m, 22 m and 24 m spans
- Precast post- tensioned "I" beams – 18 m, 20 m, 24 m, 28 m and 32 m spans
- Precast pre-tensioned "U" beams- 16 m, 18 m, 20 m, 22 m, 24 m and 26 m spans

Cross sections of the existing standard beam shapes in New Zealand are shown overleaf in Figures 1 and 2.

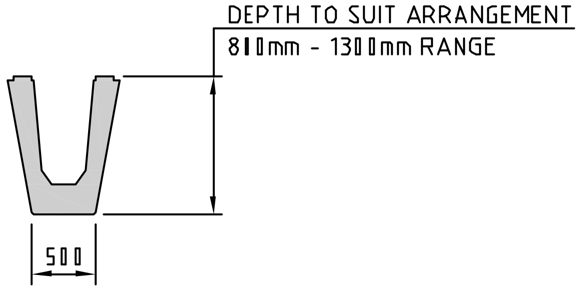
For each of these beam types full construction drawings are provided in the "red book" including beam and deck geometry, prestressing details, reinforcement details for the beams, deck slabs and transverse diaphragms, and general details covering joints between beams, seismic restraint connection to both piers and abutments, and edge protection for Bridge Guardrail and New Jersey Barrier systems. The "red book" also contains details of rural farm bridges, precast concrete piles and seismic linkages.

From the range of standard beams listed above, the single and triple hollow core deck units are now rarely used and the "U" beams are considered to be uneconomic for many situations except in some urban projects with limited headroom. Similarly, the longer "I" beam spans are not extensively used. The most popular designs are the double hollow core deck units in the span range of 12 to 18 metres and "I" beams for spans up to 24 metres. The span range for double hollow core deck units has also been extended to 22 metres for specific projects.



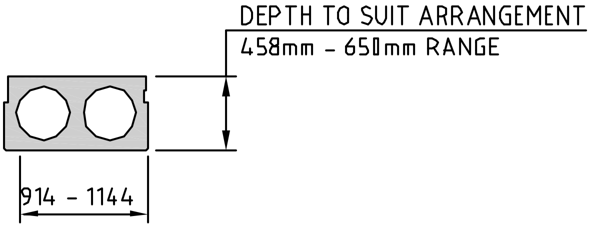
UP TO 14m SPAN

SINGLE HOLLOW CORE BEAM



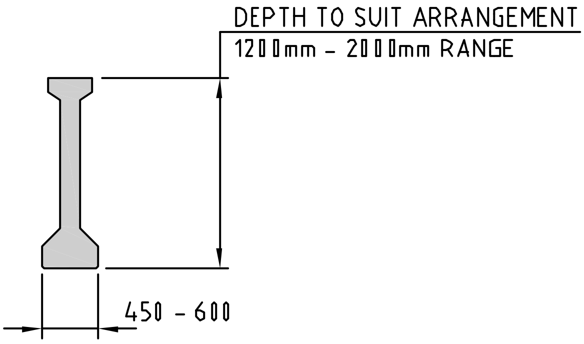
UP TO 26m SPAN

U-BEAM



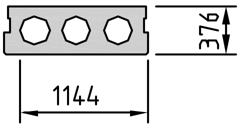
UP TO 18m SPAN

DOUBLE HOLLOW CORE BEAM



UP TO 32m SPAN

I-BEAM

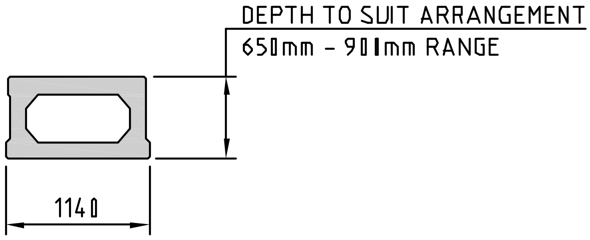


UP TO 10m SPAN

TRIPLE HOLLOW CORE BEAM

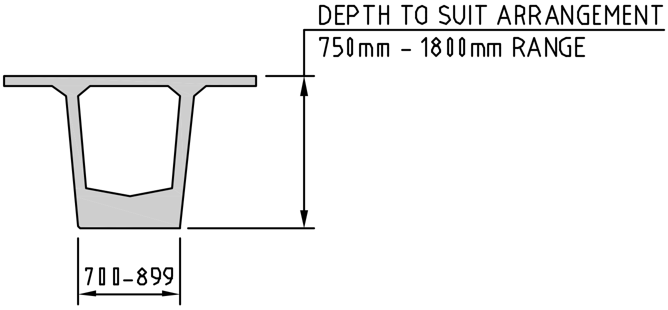
EXISTING STANDARD BEAM SHAPES IN NZ

FIGURE 1.



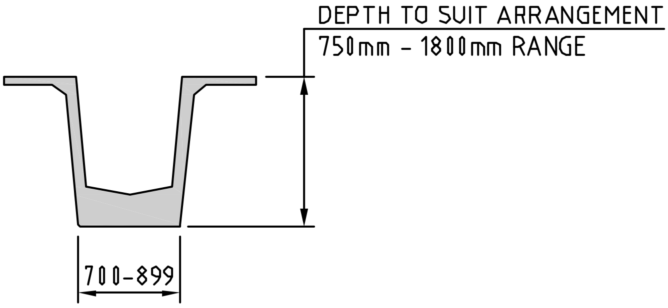
UP TO 25m SPAN

RECTANGULAR HOLLOW CORE BEAM



UP TO 35m SPAN

CLOSED FLANGE SUPER-T BEAM



UP TO 35m SPAN

OPEN FLANGE SUPER-T BEAM

OTHER SHAPES USED IN NZ.

FIGURE 2.

The “red book” replaced the earlier “blue book” following a revision of the beams in 1988. The “blue book” was published for general use by the industry whereas the “red book” was an in-house Ministry of Works publication.

2.3 Issues to be Addressed with the Existing Standard Bridge Beams

The existing designs have a number of issues relating to changes of standards for bridges that have occurred since the designs were last updated. These standards are set out in the Transit New Zealand Bridge Manual, and include:

- Increased durability requirements
- Changes to bridge width requirements
- Enhanced edge protection standards
- Possible changes to bridge design loading (currently undergoing consultation with industry)
- Changes to design criteria eg use of partial prestress now permitted.

These changes to standards have led to the current beam designs becoming out of date and requiring modification on an individual project basis.

In addition, there are a number of other issues that need to be addressed relating to the performance of the current designs, as identified through their use over recent years. These issues have been identified from feedback within the industry, and include:

- Reflective longitudinal cracking to surfacing on some bridges above longitudinal joints between double hollow core deck units, particularly in longer spans
- Problems during manufacture of voided slabs due to void flotation in wet concrete
- Possible instability of longer span “I” beams during erection due to the narrow top flanges
- Safety concerns in erecting permanent formwork between widely spaced “I” beams
- The economy of the current designs for the longer span ranges (typically >25 metres).

Completion of this research project (Stage 2 – Standard Designs) will afford the opportunity to address issues with the current standard bridge designs and, where practical, propose solutions.

2.4 Other Beam Sections Currently Used in New Zealand

In addition to the standard beam designs originating from the Ministry of Works, a number of other beam shapes are increasingly being used on a project-by-project basis in New Zealand. These are known to include the following sections:

- Precast hollow core deck units with a single rectangular void for a variety of spans up to 25 metres

- Precast Super-T beams and Tee-Roff beams (similar to those used in Australia)

We understand the Tee-Roff beam was a variant of the Super-T beam which was developed for a specific Australian project.

Individual designers and precast beam manufacturers also have their own designs that are used for specific projects.

3 LITERATURE REVIEW OF CURRENT INTERNATIONAL PRACTICE

3.1 General

For a project of this size, time and budget considerations precluded investigating a large number of countries. Instead, we carefully considered similarities between different countries and New Zealand and selected the following four countries for a detailed literature review:

- Australia – due to its proximity to NZ and similar current traffic loadings;
- United Kingdom – due to the wide range of shapes available and new shapes recently adopted;
- North America – due to several states having used standard precast bridge beam design for many years, new beam designs recently developed, and similar traffic loadings.

The literature review was conducted using standard database searches. In addition specific firms and organisations involved with precast bridge beams were also contacted for their information and views. (Refer Appendix 1).

3.2 Australia

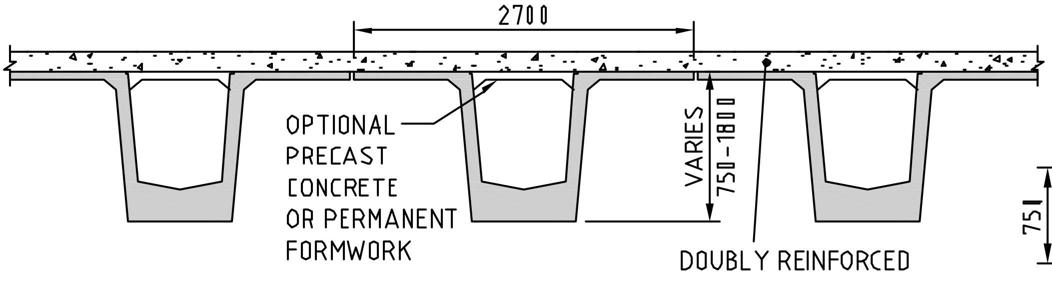
3.2.1 General

Discussions were held with specialists such as the National Precast Concrete Association of Australia, consultants and clients which showed up to a 17 metre span that the trend in this country is to use precast voided planks. In New South Wales (NSW) this is typically constructed with a double reinforced concrete overlay. In Queensland this section is also used in the same span range but usually without any overlay, but with a shear key detail between the abutting units and transverse prestress.

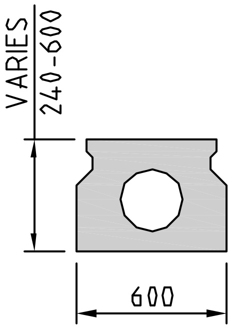
For spans from 18 to 35 metres in NSW the Road and Traffic Authority have a range of Super-T girders for which standard shapes have been developed with depths ranging from 1.0 to 1.80 metres. This new shape developed in the late 1980's and early 1990's has predominately taken over from the previously used "I" beam (which is now infrequently used).

3.2.2 Australian Beam Shapes and Practice

Table 1 and Figure 3 show the range of beam shapes used in Australia.



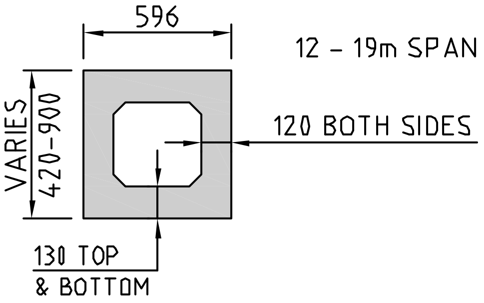
SECTION SUPER-T BEAM



BEAM SECTION PROPERTIES

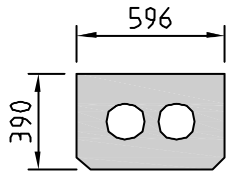
BEAM DEPTH	VOID SIZE	SPAN LENGTHS (m)
240	NO VOID	7 - 8
300	NO VOID	9 - 10
380	NO VOID	11 - 12
455	250	13
535	300	14 - 16
600	300	17 - 18

SECTION OF PRESTRESSED CONCRETE PLANKS



12 – 19m SPAN

SECTION OF PRESTRESSED DECK UNITS TYPE 1

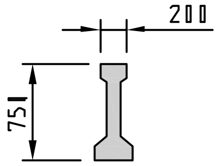


UP TO 11m SPAN

120mm WALL THICKNESS
ALL ROUND

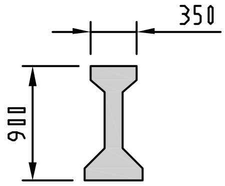
SECTION OF PRESTRESSED DECK UNITS TYPE 2

NOTE:
UNITS GENERALLY CONSTRUCTED WITH DOUBLY REINFORCED CONCRETE SLAB OVER



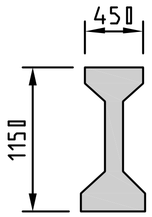
UP TO 24m SPAN

SECTION TYPE 1



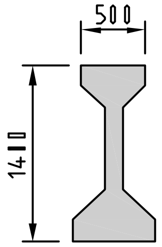
UP TO 27m SPAN

SECTION TYPE 2



UP TO 30m SPAN

SECTION TYPE 3



UP TO 35m SPAN

SECTION TYPE 4

I - GIRDER RANGE

BEAM SHAPES USED IN AUSTRALIA.

FIGURE 3.

The general trend is to use hollowcore planks up to a 17 metre span followed by voided box beams up to a 27 metre span.

The Super-T section has a theoretical range from 18 to 35 metres but is little used in the 18 to 20 metres range due to the voided box beam being more cost effective.

Longer span Super-T beams spanning up to 48 metres (and weighing up to 200 tonne) have been designed and constructed for individual projects such as the Kwinana Freeway near Perth.

The Super-T has rapidly become the preferred section for most bridge spans in the 22 to 35 metres range. Many contractors now have moulds for this shape resulting in competitive prices for specific contracts.

Table 1 Current Australian Practice

Span Range	**Precast Section**	**Comments**
Spans up to 17 m	Standard PSC voided planks (NSW predominantly)	Doubly reinforced concrete overlay or transverse prestress
Spans up to 27 m	Voided box beams (Australia wide)	Doubly reinforced concrete overlay or transverse prestress
Spans between 18 m – 35 m	Super-T & the Tee-Roff beam	Reinforced Concrete top slab. Flanges of Super-T and Tee-Roff provide formwork
Spans between 18 m – 35 m	‘I’ girder	Infrequently used. Tee-Roff and Super-T taking over

3.3 United Kingdom

3.3.1 General

Due to the size of the market in the UK, there is a much larger range of precast beam shapes in use. Also, with many motorway widening projects in progress (to widen motorways from 4 to 6 lanes) new shapes such as the “SY” beam have been developed to span up to 40 metres.

Concrete strengths in the UK are typically a 50 MPa cube strength. This equates to a cylinder strength of approximately 43 MPa.

3.3.2 United Kingdom Beam Shapes and Practice

Table 2 and Figure 4 and 5 shows the range of beam shapes in use in the United Kingdom.

Precast bridge beams have been used extensively in the UK for over 50 years. From 1990 to 1994, three new shapes were introduced. These were:

- “Y” beam for spans from 12 to 31 metres
- “SY” beam for spans from 24 to 45 metres
- “TY” beam for spans for 7.5 to 17.5 metres.

These new shapes are proving popular and cost-effective and are progressively replacing the earlier sections like the “M” and “T” beams.

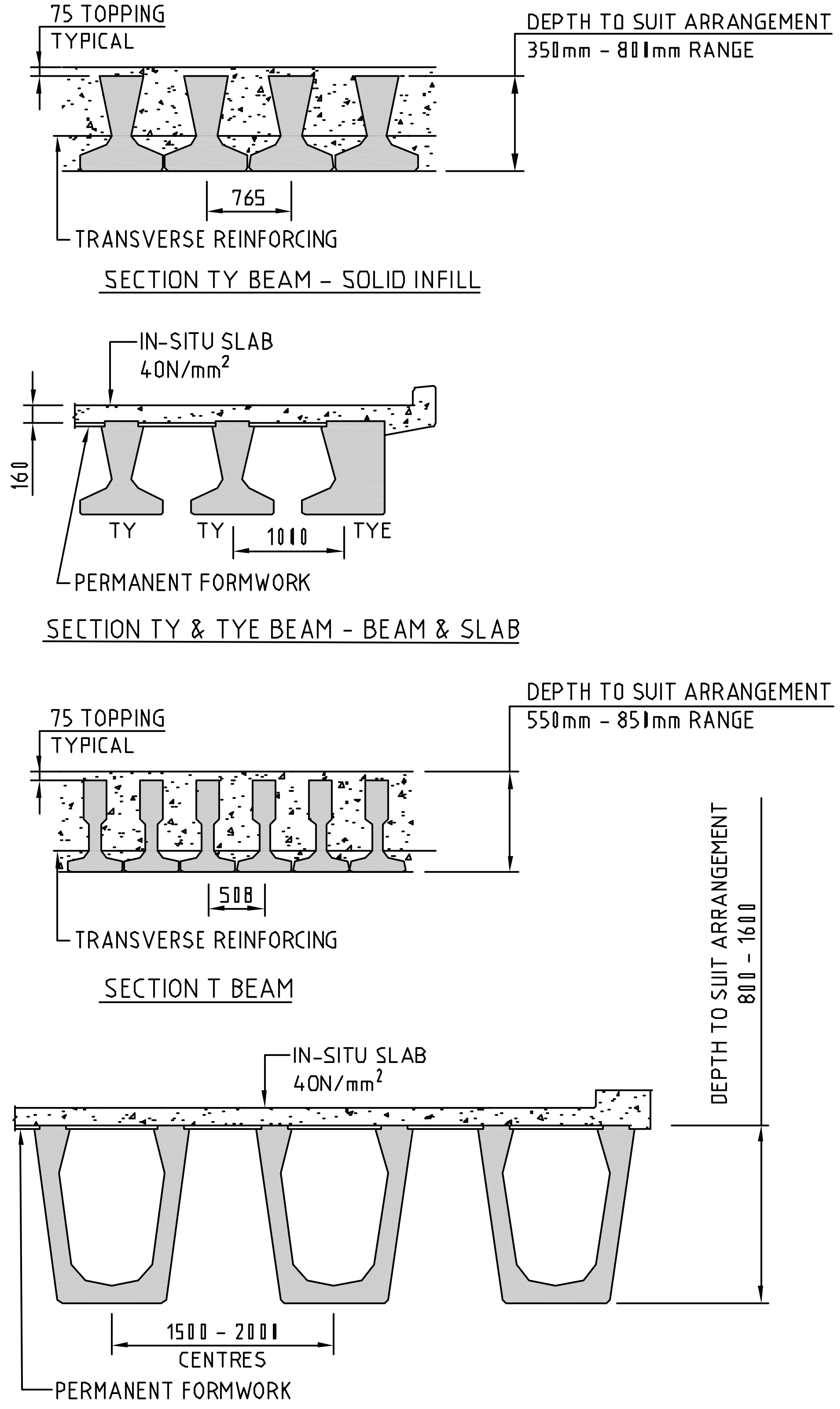
Table 2 Current UK Practice

Span Range	**Precast Section**	**Comments**
Spans up to 17 m	“TY’’ Beam	Solid infill deck. This shape was introduced in 1994 and is replacing the inverted “T” beam
Spans up to 17 m	Inverted “T” Beam	Still used but losing ground to “TY” beam
Spans between 12 m – 34 m	“U” Beam	Used for skew decks where torsional rigidity is required.
Spans between 12 m – 31 m	“Y” Beam	RC top slab. This shape was introduced in 1990 and is taking over from the “M” beam
Spans between 24 m – 40 m	“SY” Beam	Longer span adaptation of the “Y” beam introduced in 1992.
Spans between 16 m – 29.5 m	“M” Beam	Still used but losing ground to the more efficient “Y” beam.

3.4 North American Practice

3.4.1 General

There is wide variation in the beam shapes used in the various North American states with each state developing their own designs. The research focussed on a number of key states which were considered to be industry leaders in this area. These included Washington State, Florida, and Tennessee in the USA, and Alberta and British Columbia in Canada.



SECTION TY BEAM – SOLID INFILL

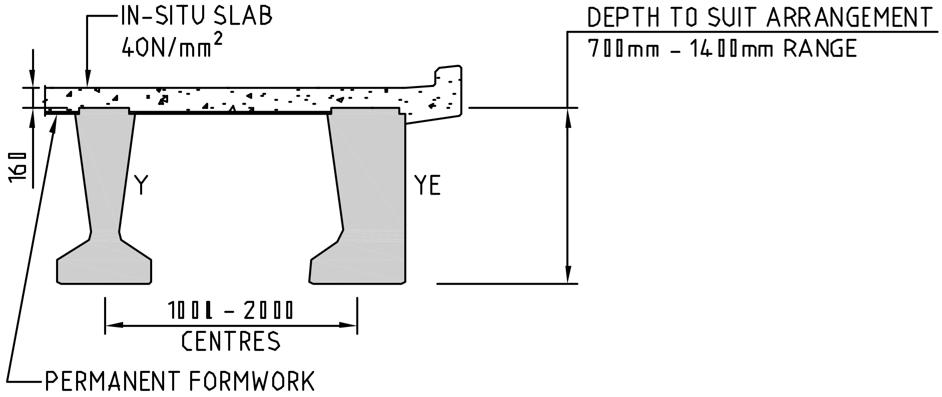
SECTION TY & TYE BEAM - BEAM & SLAB

SECTION T BEAM

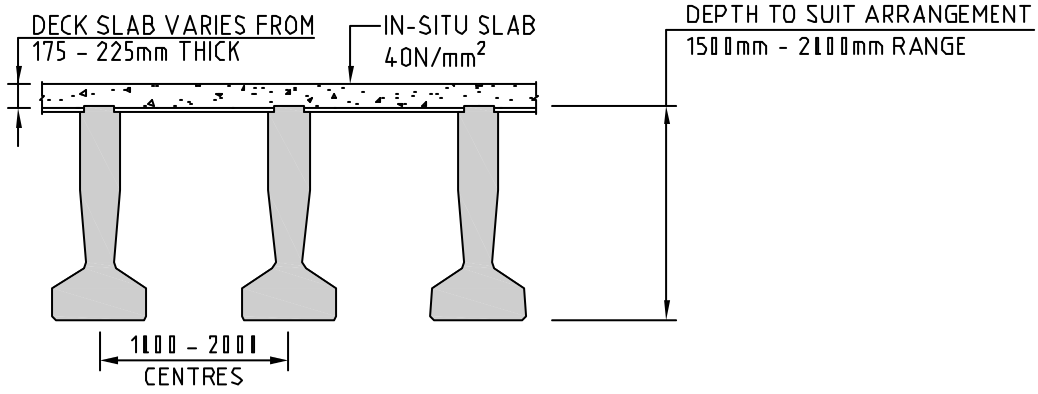
SECTION U BEAM

BEAM SHAPES USED IN THE UNITED KINGDOM.

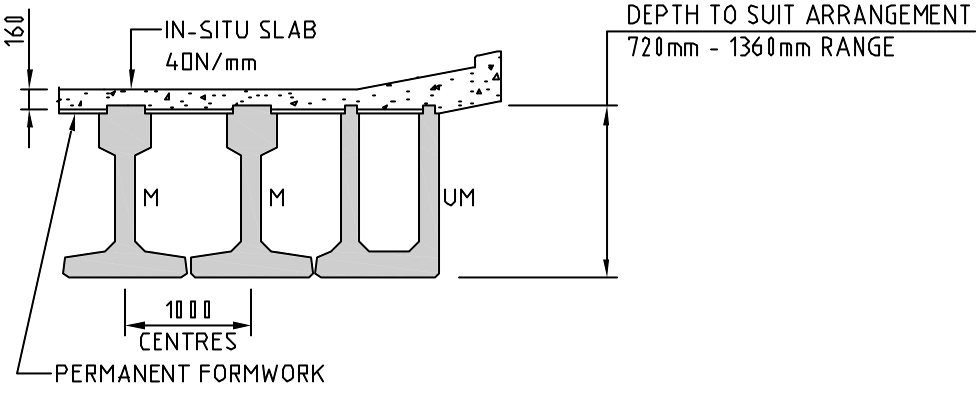
FIGURE 4.



SECTION Y & YE BEAMS



SECTION SY BEAM



SECTION M & UM BEAM

BEAM SHAPES USED IN THE UNITED KINGDOM.

FIGURE 5.

Recent development of new shapes for precast bridge beams to replace the AASHTO beams that have been in use for many years was the key finding of the research. This trend was seen in many of the state departments of transportation, and confirmed by recently published technical papers

The development of new shapes has concentrated on “I” beam and box beam shapes and in particular in providing for longer span ranges. These beams still require an insitu concrete deck slab to be provided using temporary or permanent formwork.

The new shapes have improved the efficiency of the beam in terms of material use and ease of manufacture. Generally, the new shapes have wider flanges than the earlier ASSHTO “I” beams.

Precast plank units with circular voids are still widely used for shorter span bridges as are ribbed or multiple “T” units.

Typically concrete strengths vary between 35 MPa and 45 MPa, but higher concrete strengths have been adopted by some states for new beam designs, with concrete of up to 70 MPa being specified.

3.4.2 North American Beam Shapes and Practice

Table 3 and Figures 6 and 7 shows the range of beam shapes in use in North America.

Table 3 Current North American Practice

Span Range	**Precast Section**	**Comments**
Spans up to 20 m	Solid planks, triple hollow core planks, double hollow core planks, double rectangular voided planks, double “T” planks and triple “T” planks.	Wide variety of deck slab units used for shorter spans. Preferences vary between states. Most planks are transversely post-tensioned or use overlays.
Spans between 15 m – 30 m	Bulb-Tee girders, “I” girders, inverted “U” beams, single and twin cell box beams, and “FM” girders.	Similar sections used in different states. “I” girders require insitu deck slab. Bulb-Tee girders are post-tensioned transversely with insitu joints. “FM” girders require insitu joints between webs.
Spans between 30 m – 50 m	Bulb-Tee girders, “I” girders, inverted “U” beams, single cell box beams and “FM” girders.	As above for 15 m to 30 m spans.

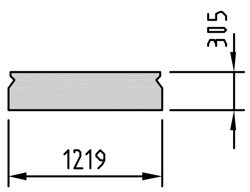
3.5 Summary of Literature Review Findings

The literature review of the four countries showed that precast beams are extensively used in these countries and that many of the beam shapes and/or spans have been updated or modified in recent years.

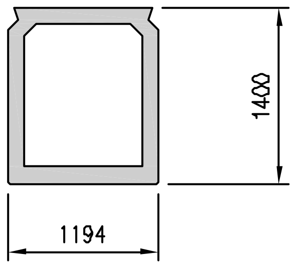
The scale and number of roading projects in North America has resulted in a wide range of bridge beam shapes some of which are far too long (and heavy) for use in New Zealand conditions. In the United Kingdom there was a lesser number of shapes, but like North America some shapes span up to 40 metres and are specifically designed for motorway widening projects and therefore unlikely to be used on a regular basis in New Zealand due to the small number of long span bridges required.

Australia was considered the most relevant country to compare beam shapes not only due to its geographical proximity but also the scale of works in the individual Australian states was similar to New Zealand.

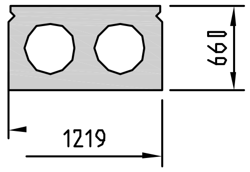
Also, some of the shapes used were very similar to those used in New Zealand and the team considered many of the factors applicable to the standard beam selection in Australia were equally relevant to New Zealand.



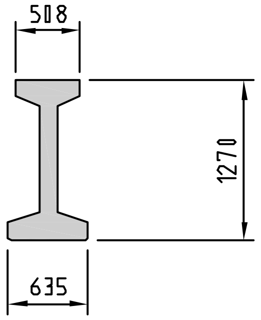
UP TO 11m SPAN
SLAB BEAM



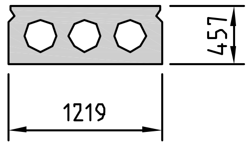
15m TO 30m SPAN
SINGLE CELL BOX BEAM



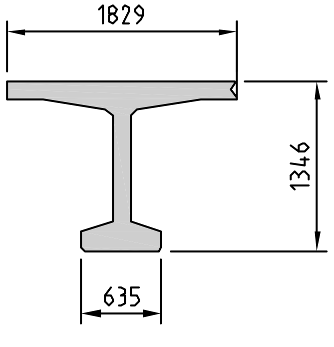
UP TO 20m SPAN
DOUBLE HOLLOW CORE BEAM



15m TO 30m SPAN
I-BEAM



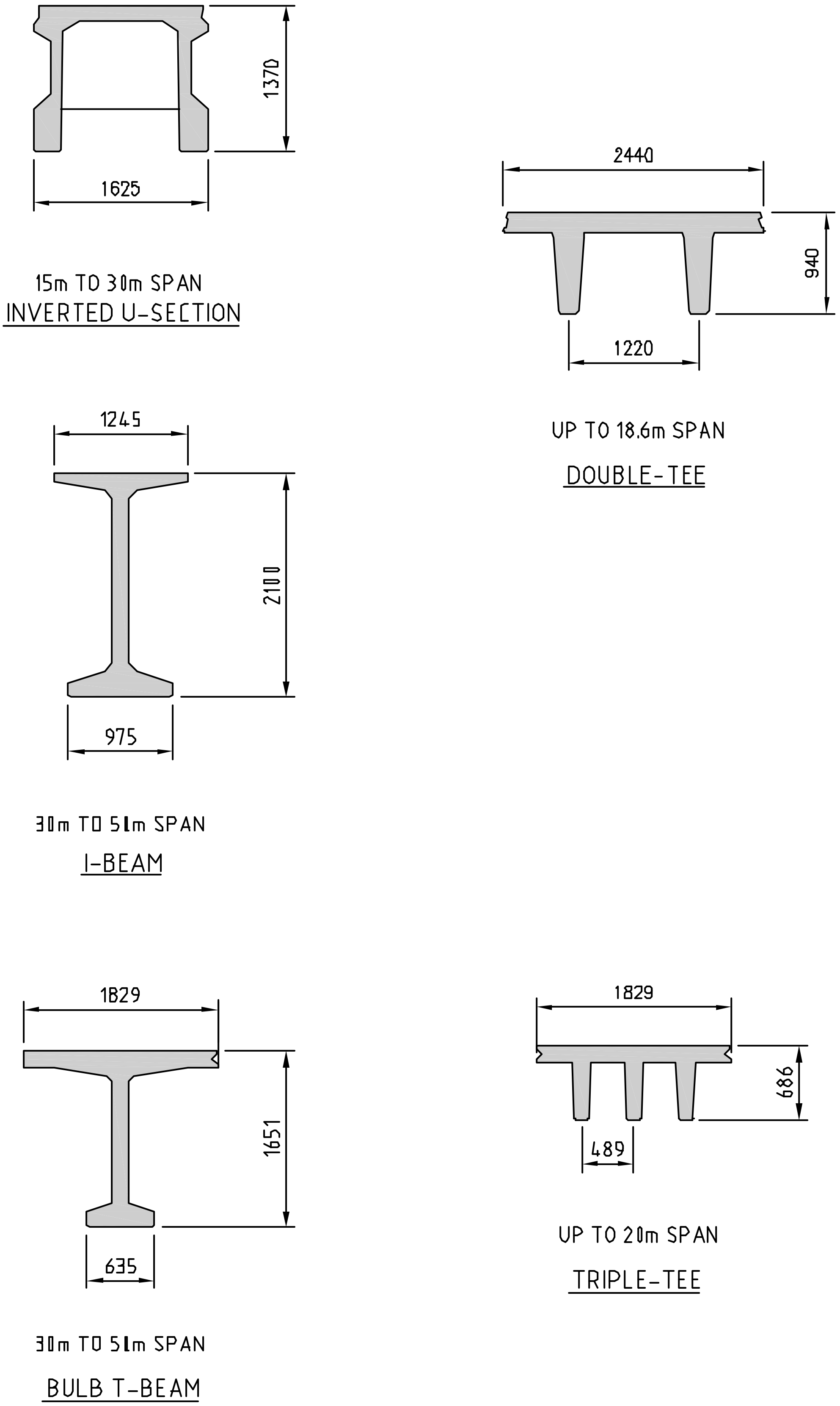
UP TO 14m SPAN
TRIPLE HOLLOW CORE BEAM



15m TO 30m SPAN
BULB T-BEAM

BEAM SHAPES USED IN NORTH AMERICA.

FIGURE 6.



15m TO 30m SPAN
INVERTED U-SECTION

UP TO 18.6m SPAN
DOUBLE-TEE

30m TO 51m SPAN
I-BEAM

30m TO 51m SPAN
BULB T-BEAM

UP TO 20m SPAN
TRIPLE-TEE

BEAM SHAPES IN NORTH AMERICA.

FIGURE 7.

4 SURVEY OF NEW ZEALAND PRECAST PRESTRESSED BRIDGE BEAM MANUFACTURERS

4.1 General

In order to understand recent trends in beam shapes and corresponding deck shapes and spans that have been manufactured over the past five years a national survey of precast manufacturers was carried out.

A survey form, (see appendix 2), was designed to capture a range of data so that definite conclusions could be reached about the deck types of recent highway bridges constructed in New Zealand. That is, bridges that were designed for the Transit HN-HO-72 highway bridge loadings. Information on non-standard designs, eg bridges designed to a standard less than HN-HO-72 were not requested.

4.2 Survey Methodology

The survey form comprised a range of possible beam types (see Table 4 below) as a guide to the respondents.

- Beam types 1, 2, 4, 5, 6 represented those standard types which were residual from the original “red” book
- Items 3 and 4 were included to determine if composite deck sections were being used.
- Item 7 refers to a more recent shape introduced into New Zealand from Australia. Essentially a variation on a spaced box shape deck section.
- Items 8 and 9 refer to a box section shape produced in the central north island region

4.3 Survey Results

Survey responses were received from a total of 10 manufacturers of which two had multiple precast sites. Six were from the North Island and four from the South Island. See appendix 2. The survey results were split into six regional zones to determine if there were regional trends or variations.

Data on 102 recently constructed bridges of six types was collected, those being the double hollow core, single hollow core, U and I section with deck slabs, gull wing and spaced box section.

The trends from the survey are shown in Figure 8.

Table 4 Existing Beam Types

Product Type N°	Beam Type Description
1	Double hollowcore deck unit (untopped)
2	Single core deck unit (untopped)
3	Double hollowcore deck unit (topped)
4	Single circular core deck unit (topped)
5	U-Beam with deck slab
6	I-Beam with deck slab
7	Gull wing section/Super T
8	Box section not spaced
9	Box section spaced

4.4 Interpretation of results

These are detailed in full in Appendix 2.

The survey results show that the original MOW standards have been used on a regular basis over the last twenty to thirty years.

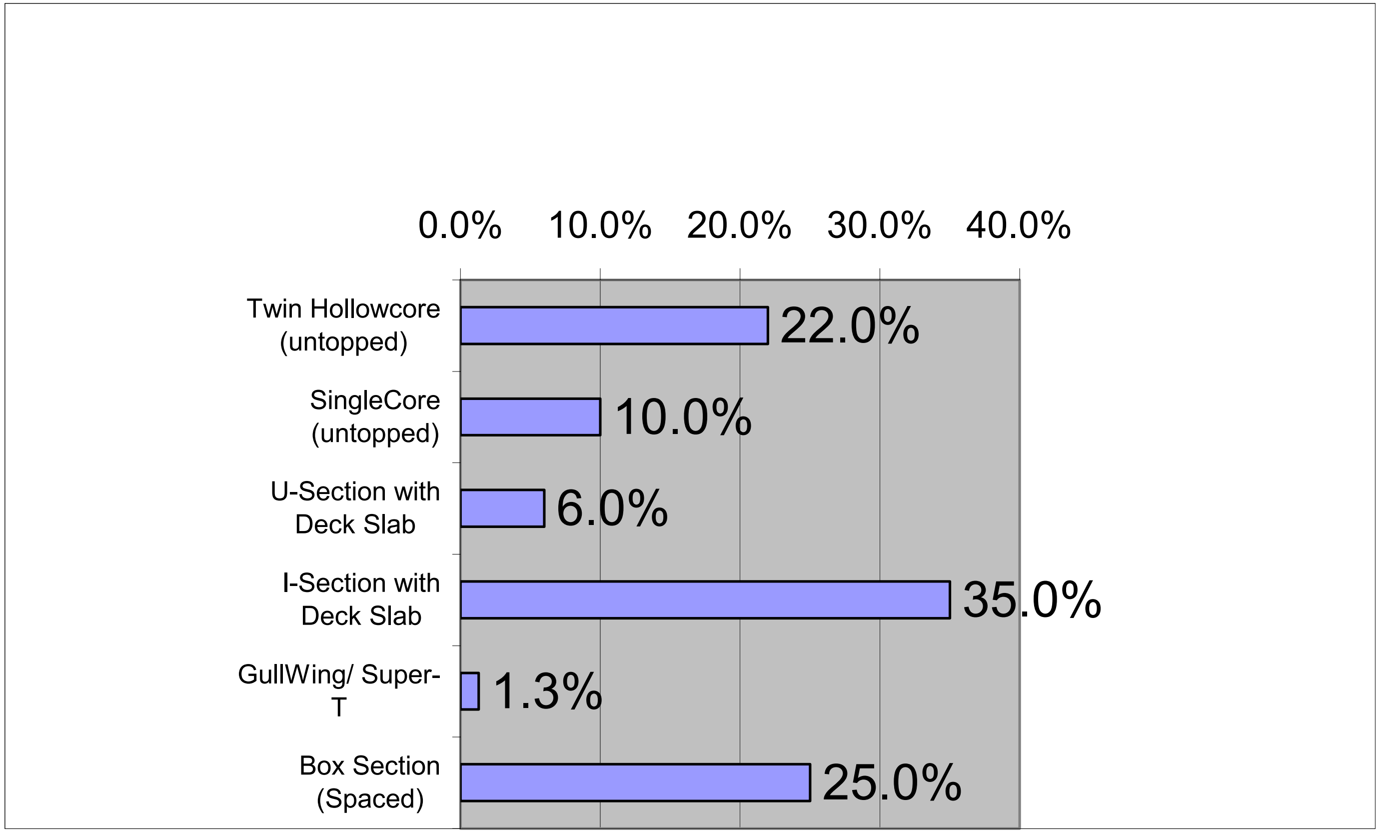
- The majority of responses indicated the popularity of double hollowcore (HC) bridge decks throughout all regions.
- Single (circular) hollowcore was popular with the north of the south island and in the central north island.
- The I and U sections were used for bridges requiring longer spans, but have been used to a lesser extent than the twin hollow core
- A variation on the popular double HC bridge decks is the large single rectangular cell box section shape which was used extensively on Route PJK in Tauranga.

4.4.1 Span/depth ratios

A comparison of the span/depth ratios against other authorities recommendations was carried out to see if there were patterns of structural consistency. While the “I” beam, Super-T (or Gull Wing) and box section show a reasonably good comparison the double hollow core units show a wide variation.

The survey indicated the popularity of the double hollow core unit as a standard unit which has provided highway bridge design flexibility and economic benefits during the past thirty years.

Figure 8 – Summary of Beam Types Produced



61,400 Linear Metres Total Production of All types.
Percentages are based on linear metres of each type of beam.

5 INDUSTRY CONSULTATION AND PARTICIPATION

5.1 General

A key part of Stage 1 of this research project has been regular consultation with a wide range of industry representatives. This has been achieved by the formation of an Industry Group which included representatives of clients, consultants, bridging contractors and precasters. Also consultation workshops were held in Wellington, Christchurch and Auckland.

The project was publicised widely by Transfund (in Transearch) IPENZ (in e-zine) and The Contractor magazine and this publicity encouraged those with any views on the project to contact the research team.

5.2 Industry Group

The members of the group were:

- Transit – Frank McGuire
- Opus – John Reynolds
- Holmes Consultants – Rob Park
- Bloxham, Burnett & Oliver – Graeme Jamieson
- Peters and Chong – Duncan Peters
- Meritec – Vince Scolaro

Copies of the research minutes were circulated to the group and a number of comments were received from individual members.

5.3 Industry Consultation Workshops

The objectives of the three consultation workshops held in Wellington, Christchurch and Auckland in November 2002 was to:

- Brief participants on the scope and progress of the research;
- Discuss current issues with standard beams – deck systems and rank in order of importance;
- Identify relevant criteria for selecting new or existing beam shapes and rank in order of importance;
- Vote by participants on their preferences for two new or existing beam shapes.

Nearly forty participants attended the workshops. A wide range of issues were raised and criteria for selecting new beam shapes were discussed.
The following key issues were raised at all 3 workshops:

- Preference for full superstructure designs – including deck and edge protection;

- Hollow core units – reflective cracking problems;
- Rideability for road users – the trend to continuous bridges;
- Expansion joints/bearings – minimise for rideability/maintenance;
- Curvature, skew and superelevation common in NZ bridges – flexibility needed;
- Edge protection requirements: new and existing bridges.

A large number of criteria for selection of beam shapes were identified, but the following criteria were raised at two or more of the workshops.

- Use coastal B1 rating for durability and construction specification;
- Design for minimum maintenance – less joints, bearings;
- Emphasise standardisation and use of existing moulds;
- Prefer to minimise site form work and concrete;
- Accommodate proposed design code changes;
- Ensure flexibility in standard shapes:
  - Maximum range with 1 mould (able to be modified)
  - One size/shape does not fit all
  - Need a range of spans.
- Visual appearance of handrails and edge beams important for urban bridges.

The results of the informal poll of workshop participants showed a clear preference for the Super-T/Tee-Roff as the proposed new standard shape and updating the existing hollow-core designs was the top priority for existing beam shapes. This is covered in greater detail in section 6.3.

5.4 Summary of Consultation

Overall, a large number of specialist bridge engineers and technical staff participated in the consultation process.

Extensive consultation was a crucial part of the research process and valuable comments and ideas were received from bridge clients (such as Transit), consultants, bridging contractors and precasters.

Nearly 40 industry representatives attended the three consultation workshops and this face to face contact and discussion ensured we were fully aware of the views of individual industry participants.

By consulting widely over the whole bridging industry we believe the consultation process has been robust and has crucially assisted the research team in selecting new standard beam shapes which will be widely accepted and used on a regular basis.

6 ANALYSIS OF RESEARCH RESULTS

6.1 General

Unlike a subject with easily answered yes or no questions, this project required careful discussion and debate on the views and preferences raised both from the consultation process and the various team members. The analysis of the results of the research findings is summarised below for both the preferred beam shapes and the key criteria for the selection of beam shapes.

6.2 Preferred Standard Beam Shapes

The poll of possible beam shapes provided definitive results. The workshop attendees were asked to select one existing and one new shape from the beam shapes commonly used in New Zealand, Australia, Great Britain and North America.

The results of the poll (combined from the three workshops) were as follows:

Existing Standard Beam Shapes

Double Hollow Core	25 votes
Single Hollow Core	5 votes
I-Section	6 votes
U-Section	3 votes

New Standard Beam Shapes

Super-T/Tee-Roff	22 votes
Double-T	1 vote

On the basis of the poll results, retention of the double hollow core deck units and the "I" beams were preferred from the existing beam shapes, and were marginally ahead of the single hollow core deck units. The Super-T/Tee-Roff beam from Australia was selected as the new beam shape.

6.3 Criteria for Selecting New Standard Beam Shapes

Criteria for selecting new beam shapes for use in New Zealand have been developed during this project and have been used in the selection process. The criteria where grouped into the following key areas:

- Product type and span range
- Design and aesthetics
- Beam manufacture
- Construction
- Maintenance

- Client requirements

The full criteria under each of these areas are:

Product Type and Span Range:

- Flexibility – can the same shape be used for a wide range of beam depths/spacings
- Span range – does the beam shape cater for a wide range of spans

Design and Aesthetics:

- Beam depth – are beams shallow in depth to suit limited headroom situations and to reduce approach embankment height
- Skew – can beams be used where high skews are required
- Continuity – can beams be made continuous at piers/integral with abutments
- Transverse behaviour – do beams provide good load spreading between beams
- Design codes – have beams been designed for overseas codes with different requirements to New Zealand
- Torsional capacity – are beams torsionally efficient
- Structural efficiency – are beams structurally efficient measured on cost per square meter basis including deck slab/topping
- Diaphragms – are transverse diaphragms required at beam ends and intermediate locations
- Vibration/deflection – are beams stiff enough to use in urban areas with footpaths
- Stressing – are beams pre-tensioned only or is additional post-tensioning required
- Appearance – do beams have good appearance without the need for special edge units or insitu masking
- Edge protection – can beams cater for new edge protection requirements
- Services – can services be accommodated within the beam shape without special service ducts being provided
- Curvature – can beams be used on a deck with a curved alignment.

Beam Manufacture:

- Beam weight – what are lifting requirements and are they within New Zealand crane capacity
- Cost of forms
    - Do forms already exist
    - Are forms difficult/expensive to make
    - Are forms robust
- Steel fixings
    - Is reinforcement difficult to fix
    - Is large quantity of reinforcement required
    - Are there congestion problems

- Handling – are beams robust for handling, torsionally stiff and resistant to impact damage
- Casting of beams – can concrete be placed adequately
- Strand types – are strand types readily available in New Zealand
- Concrete grades – are concrete plants capable of producing required grades of concrete in New Zealand.

Construction:

- Cost effectiveness – are beams cost effective on a cost per square metre of deck
- Slab formwork – is temporary or permanent formwork required to support the deck slab or does the precast beam act as permanent formwork
- Diaphragms – are diaphragms difficult to install
- Stability during erection – are beams stable during erection, or are temporary supports required.

Maintenance:

- Durability – are beams well detailed to provide good long term durability
- Water penetration – do beams have joints that will allow water to penetrate the deck leading to deterioration of structural elements
- Inspection – can exposed surfaces be easily inspected (adequate gaps between flanges).

Client Requirements:

- Design life – can the specified 100 year design life be achieved
- Expansion joints – can they be eliminated
- Maintenance – can a low maintenance bridge be provided.

The attendees at the consultation workshops were asked to rank a small number of the criteria which they considered important. The results were then summarised in tabular form and those issues that had been raised at more one workshop were marked accordingly.

The workshops indicated that the most important criteria in selecting new beam shapes for New Zealand were:

- Flexibility
    - Maximise span range with one mould
    - Range of spans is required up to 35 metres
    - Range of Beam Types should provide for curved bridges
- Appearance – particularly of beam edge and handrail
- Durability – include for coastal areas as well as inland
- Maintenance – minimise joints and bearings

- Cost
    - Design for minimum maintenance
    - Minimise cost per square metre of deck
- Beam weight – 40 tonnes maximum, 20 tonnes preferred
- Depth limitations – need a variety of different beam depth solutions
- Beam moulds
    - Need standardisation and use of existing moulds
    - One new shape only due to high cost of replacing moulds
- Beam web thickness – 140 mm preferred minimum.

Other key comments obtained from the industry consultation that influence the selection of beam shapes and the approach to be taken to their design include:

- The designs should provide for future design code changes
- Full standard designs are preferred over standard shapes requiring design on a project by project basis
- Adopt best practice from overseas where possible
- Minimise site formwork and concrete work where possible
- Provide for continuity over piers
- "I" beams are useful for rural areas and are versatile for curved bridges and high super elevation.

Following the consultation with industry the key design criteria to be adopted for selection of the new beam shapes were determined to be:

- Flexibility
- Cost
- Durability/maintenance
- Standardisation of shapes
- Beam weight
- Beam depth
- Appearance
- Minimisation of site work

These criteria have been adopted as the key criteria for the selection of new beam shapes. The selection of the new beam shapes is described in section 6.4 below.

6.4 Selection of New Beam Shapes

The selection of new beam shapes to replace the existing standard beams has been undertaken on the following basis:

- Review of existing beam shapes currently used in New Zealand
- Review of other beam shapes currently used in New Zealand

- Review of alternative beam shapes currently used overseas and assessment of whether these shapes would be suitable for use in New Zealand
- Selection of new beam shapes on the basis of feedback obtained from industry consultation on preferences for new beam shapes and the criteria that are most important in selecting the new beam shapes

6.4.1 Review of Existing Standard Beam Shapes

The review of the current situation in New Zealand with respect to standard bridge beams has identified the following key points:

- The existing standard bridge beams are becoming out of date
- Some of the beam types and span ranges are now rarely used as they are considered to be uneconomic due to their method of construction and cost of manufacture
- Changing design standards for bridge width, live loading (proposed), durability and edge protection, and new methods of design such as the use of a partial prestress approach need to be incorporated
- Some of the standard beams have maintenance issues

The key issues with respect to each of the current shapes are:

- Single hollow core units – rarely used except for some individual precast manufacturers as considered uneconomic compared to double hollow core units
- Double hollow core units – still widely used and considered economically competitive for spans of between 10 and 18 metres, and occasionally up to 20 metres, but have some maintenance issues, particularly when used for longer spans. Some alternative void shapes are used.
- Triple hollow core units – rarely used as considered uneconomic compared to double hollow core units
- “I” beams – still widely used for spans up to 25 metres, but maybe uneconomic for longer spans
- “U” beams – used for urban bridges where headroom is limited, but generally considered uneconomic (due to its heavy weight) compared to “I” beams and some other shapes.

In summary, the double hollow core units and “I” beams are still very popular and seem to provide both buildable and economic solutions. However, they need to be improved with respect to the changes to design standards that have occurred since they were last updated, and any maintenance issues addressed. The “U” beams are still used, but due to their lack of economy are unlikely to be worth updating. The other beam shapes are rarely used and there seems to be little point in updating them.

6.4.2 Review of Other Beam Shapes Currently Used in New Zealand

Other shapes that have been used in New Zealand in recent times are known to include:

- Hollow core units with single rectangular void 650 mm deep unit spanning up to 18 metres
- Hollow core units with single rectangular void 900 mm deep spanning up to 25 metres
- Super-T beams

The above beams have been used on an individual project basis with design undertaken for each individual bridge. The 650 mm deep hollow core units with a single rectangular void are understood to offer economic advantages related to the ease of manufacture. They use a steel internal form that is cheaper than the polystyrene voids used in the double hollow core units, and more reliable to hold in place. The 900 mm deep hollow core units have been used as an alternative to both "I" beams and "U" beams for spans up to 25 metres. They are understood to offer economic advantages due to their structurally efficient section and ease of construction, with no deck slab being required.

The Super-T (and Tee-Roff) beams have been used as an alternative to both "I" beams and "U" beams for spans in the range of 20 to 25 metres. They offer advantages of structural efficiency and ease of construction with the outstand wings providing a permanent form for the insitu concrete deck slab. They also provide an attractive box shape that can be used in a variety of situations and are comparable in this respect to the standard "U" beams. The disadvantages of this shape relate to their ability to cater for curved bridges and bridges with significant warping, in which the units need to be stepped at their longitudinal joints between beams. Again, these have been designed on an individual bridge basis.

Clearly the alternative beam shapes that are currently being used in New Zealand have demonstrated some advantages over the existing beam shapes as they have been selected instead of the existing shapes for a number of projects. These beam shapes should be investigated further as possible new standard bridge beams to be used in New Zealand.

6.4.3 Review of Beam Shapes Currently Used Overseas

From the international literature search of current overseas practice, covering Australia, UK and North America, the range of beam shapes that are currently used is very wide and differs significantly between countries. Within Australia and North America there are significant differences in the shapes used between different states.

The main beam shapes used overseas are considered for use in New Zealand as follows:

Australia

Australian practice varies between states, but generally the beam shapes described in section 3.2 are used over the entire country with some local variations. Beams are designed for similar loading and environmental conditions to New Zealand and practice is generally to provide standard designs with full details.

In summary, practice for short span bridges is similar to that in New Zealand with precast plank units commonly used, except that structural overlays are used as an alternative to transverse prestress in some states. For longer spans, the Super-T beams are now the beams of choice and seem to offer real advantages of economy and buildability, as well as having good appearance .

It is considered that the use of structural overlays for hollow core deck units as an alternative to transverse prestress, and the use of Super-T beams for longer spans, should be considered for use in New Zealand.

United Kingdom

United Kingdom practice has traditionally been to use beam with insitu infills for shorter spans and beam and slab for longer span ranges. Design loadings and environmental conditions very considerably from those in New Zealand, with far heavier design loads and more severe environmental conditions.

The standard bridge beams were re-engineered in the early 1990's. This led to beams that are easier to manufacture and with a greater span range than the earlier designs. The current shapes that are used are described in section 3.3.

UK practice is for beam shapes and strand positions to be standardised, but for each bridge to be individually designed. The new range of shapes offer beams that are structurally efficient and that offer advantages in beam manufacture and construction. The beams generally appear to be of heavy proportions, reflecting concerns about concrete placing that existed with the previous standard beam designs, and the heavy design loading. Concrete covers are also generally greater in the UK than New Zealand due to the use of de-icing salts and freeze-thaw conditions.

It is considered that while the UK beam shapes are well engineered and are likely to offer economic and buildable solutions, they are probably not appropriate for New Zealand due to the philosophy of using beam and slab/insitu infill construction for all spans, and the differences in design criteria. Adoption of the UK beams would require a radically different approach to that historically taken in New Zealand and a complete new start with respect to beam manufacture and construction practice. It is considered unlikely that the industry would support such an approach, or that the country would want to pay for the required investment in new moulds.

North America

North American practice varies widely between states. The traditional use of ASSHTO "I" girders has gradually been replaced by a new generation of "I" and Bulb-Tee girders that have been re-engineered to improve their economy, extend their span range and in some states utilise higher strength materials. Current practice is summarised in section 3.4.

Generally, standard beams are fully designed and detailed in North America with most states being responsible for the development of new designs. The focus in recent years appears to have been on engineering longer span (>30 metres span) beams and in improving the efficiency of the beams. The shorter span beams using precast planks and I girders are very similar to those currently used in New Zealand. Loadings and environmental conditions in North America vary, but in some states are similar to New Zealand.

In view of the similarities of beams used for the shorter spans to those already available in New Zealand, and the major investment that would be required to change the shape of the "I" beams, it is considered unlikely that any of the beams currently available in North America would offer substantial advantages for use in New Zealand over the existing shapes. The longer span beams that are used in North America are not routinely needed in New Zealand and lifting and transporting such heavy beams is likely to be beyond readily available craneage capacity.

It is therefore considered that none of the North American beam shapes offer solutions for New Zealand standard beams, in the light of the similarities of the available beam shapes with those already used in New Zealand, and the high cost of modifying the beam moulds to suit the new shapes.

6.4.4 Selection of Beam Shapes

Options have been identified for new beam shapes to be used in New Zealand from the review of the current standard bridge beams, the alternative beam shapes currently being used in New Zealand, and current international practice, and from the preferences expressed by attendees at the industry workshops. The options identified are:

- Option 1 – Retain the single hollow core deck unit currently used in New Zealand and modify the design to cater for changes in design standards
- Option 2 - Retain the double hollow core deck units currently used in New Zealand and modify the design to cater for changes in design standards
- Option 3 - Retain the "I" beams currently used in New Zealand and modify the design to cater for changes in design standards
- Option 4 – Retain the "U" beams currently used in New Zealand and modify the design to cater for changes in design standards
- Option 5- Introduce a hollow core deck unit with a different void shape to simplify manufacture and improve cost effectiveness using a variety of unit depths to cater for different spans up to 18 metres

- Option 6 – Introduce a deeper hollow core unit than currently used to extend the span range up to 25 metres to provide an alternative to the current "I" beams and "U" beams
- Option 7- Introduce the Super-T or Tee-Roff beam unit that is currently widely used in Australia, and that has been used in New Zealand on some projects, with a variety of beam depths to cater for various spans up to 30 metres.

All of the above options are based on the range of selected shapes covering a span range from 12 to 30 metres.

These options reflect the results of the poll undertaken at the industry workshops in which the retention of the double hollow core units was the preferred option for the existing beam shapes by a significant margin, followed by retention of the "I" beams and single hollow core units. Of the new shapes from overseas, the Tee-Roff beam from Australia was preferred by a significant margin over any other beam shape.

These options have been analysed against the key criteria identified from the industry workshop. The results are given in Table 5.

We only consider it practical to develop and maintain a limited number of standard beam shapes in New Zealand, because of the relatively small number of new bridges that are constructed, which limits the demand for any particular beam shape. In turn, this limits the number of different mould shapes than can be available due to the high cost of establishing new moulds and maintaining existing ones. There are also limits on the amount of money that can be invested in the design of new beams and maintenance of existing designs.

We therefore consider it practical to have only three or four beam shapes in operation, compared to the existing five beam types. We consider that, on the basis of the preferences for beam shapes expressed by industry at the workshops, and the analysis of the shapes against the key criteria for new beam shapes selected by the participants, that options 2, 3, 5, 6 and 7 should be chosen for further study. Options 2 and 5 are alternatives that require further assessment before a final decision on void shape is made.

6.4.5 New Standard Beam Shapes Proposed

The new beams shapes proposed covering the span range from 12 to 30 metres are therefore:

- Hollow core deck units 1144 mm wide for spans up to 18 metres with either double circular voids or single rectangular void to be determined during the detailed design stage (with further industry consultation required)
- Hollow core deck unit for spans up to 25 metres, with void shape to be determined during the detailed design stage
- Existing "I" beams for spans up to 32 metres, updated for changes to design standards
- Super-T beams for spans up to 30 metres.

We propose that the existing single core deck units and “U” beams are not updated as new standard shapes.

Table 1 Comparison of Options for New Beams Shapes

Criteria	Option 1 – Existing Single Hollow Core Units	Option 2 – Existing Double Hollow Core Units	Option 3 – Existing “I” Beams	Option 4 – Existing “U” Beams	Option 5 – New Hollow Core Unit With New Void Shape	Option 6 – New Deeper Hollow Core Unit for Longer Spans	Option 7 – New “Super-T” Beams
Flexibility	Good for spans up to 14m. Not so flexible for curved or warped bridges.	Good for spans up to 18m (some used up to 20m). Not so flexible for curved, warped or highly skewed bridges.	Very flexible for spans up to 32m. Good for curved and warped bridges.	Very flexible for spans up to 26m. Limited flexibility for curved and warped bridges.	As option 2.	Good for spans up to 25m. Not so flexible for curved, warped or highly skewed bridges.	Good for spans up to 35m. limited flexibility for curved or warped bridges.
Cost	Preferred by some small contractors with small cranes, but generally not economic.	Economic solution, but may be more expensive than option 5.	Economic solution, but may be more expensive than option 7.	Considered to be expensive option compared to I beams and Super-T beams.	Could be more cost effective than option 2, but needs to be demonstrated.	Could be more cost effective than “I” beams for spans up to 25m, but needs to be demonstrated.	Appears to be cost effective on the basis of a few NZ projects to date.
Maintenance	Possible concern at longitudinal joints.	Possible concern at longitudinal joints.	Good, although some covers may need to be increased.	Good.	As option 2.	As option 2.	Good.
Standardisation of shapes	Existing moulds can be used.	Existing moulds can be used.	Existing moulds can be used, but may not be commonly available for deeper beams.	Existing moulds can be used.	Existing DHC moulds can be used.	New moulds required, although some exist in NZ.	New moulds required, although some exist in NZ.
Beam weight	Narrow units are well within available crane capacity.	Units are well within available crane capacity.	Beams are within existing crane capacity up to 25m long. Longer spans are heavy.	Beams are within existing crane capacity.	Units are well within available crane capacity.	Units are expected to be within available crane capacity as similar to “I” beams for same span.	Beams are expected to be within available crane capacity.
Appearance	Satisfactory although vertical edge is plain.	Satisfactory although vertical edge is plain.	Okay for rural areas, but less acceptable for urban bridges.	Good with sloping webs and overhung slab.	Satisfactory although vertical edge is plain.	Satisfactory although vertical edge is plain.	Good with sloping webs and overhung slab.
Minimise site work	Precast planks minimise site work.	Precast planks minimise site work.	Significant site work for insitu slab requiring formwork.	Significant site work for insitu slab requiring formwork.	Precast planks minimise site work.	Precast planks minimise site work.	Insitu slab required but precast outstands act as formwork.

7 PRELIMINARY DESIGN OF NEW BEAM SHAPES

7.1 General

Preliminary design has been undertaken for the proposed new beam shapes to determine the basic parameters for the new beams. These include the span range, beam depth, beam cross section, deck slab thickness, maintenance issues and material strengths. For the existing beams that are to be retained and updated, the preliminary design also addresses the changes to design standards and the any other issues that need to be considered.

The preliminary design considers the full superstructure for a particular beam, including the deck slab, diaphragms, joint details and seismic connection to the piers and abutments.

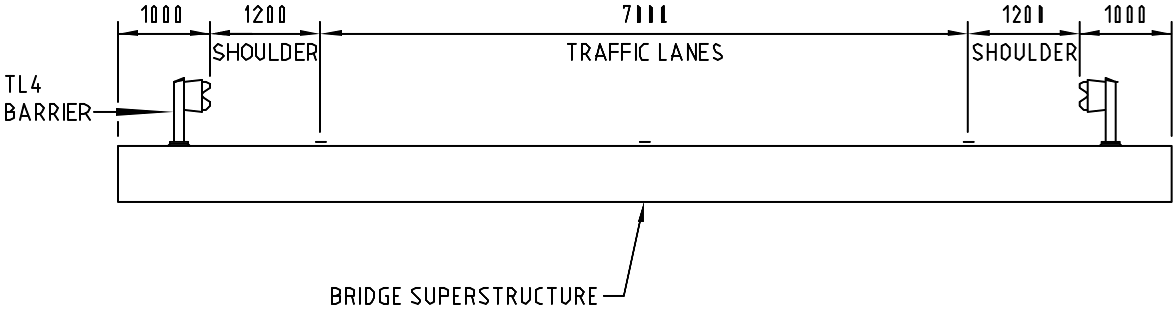
7.2 Criteria for a Standard Bridge Superstructure

The existing standard bridge beams cater for a wide range of spans of between 8 and 32 metres and for a variety of bridge widths from a single lane bridge to a two lane bridge with footways. To achieve a practical output from this project, we considered it was necessary to limit the range of spans and cross section widths for the new bridge beams, and to agree criteria for other design standards to be adopted.

The proposed design criteria for the standard bridge beams are:

- Two lane rural highway bridge without footways (extra beams can be added to provide footways with little additional design effort) giving overall bridge deck width of 11.4metres (2 x 3.5 metre lanes plus 1.2 metre wide shoulders and 1.0 metre wide barrier edge width)
- 100 km/hr design speed
- HN-HO-72 design live loading (as modified by the proposed revision to the serviceability loading currently being considered)
- Test Level 4 edge protection (typical requirement for rural bridge with low traffic volumes) assuming flexible barrier requiring 1.0 metre edge distance
- Class B1 durability to NZS 3101 for coastal perimeter, but excluding coastal frontage (class B2)
- Square span which will cater for skew up to about 15 degrees without special analysis
- Zero tension design (partial prestress approach will reduce the amount of prestress and will be used in the Stage 2 detailed design to give greater economy)
- Design meets the requirements of Transit New Zealand Bridge Manual
- Span range from 12 to 30 metres.

These criteria have been used for the preliminary design of the proposed new bridge beams. The proposed standard bridge cross-section is shown in Figure 9.



PROPOSED STANDARD BRIDGE CROSS SECTION.

FIGURE 9

7.3 Hollow Core Beams

7.3.1 General

The preliminary design of the hollow core deck units has considered the following design issues:

- Span range and unit depths
- Width of hollow core units to suit standard bridge width
- Void shape – circular or rectangular
- Concrete strength
- Transverse design – transverse prestress or structural overlay slab
- Longitudinal joints between units
- Maintenance issues

The findings of the preliminary design are described below.

7.3.2 Span Range and Unit Depths

The existing double hollow core designs cover a wide range of spans between 8 m and 18 m and use three different unit depths as follows:

- 458 mm deep unit, 914 mm wide – spans 6 m to 12 m
- 576 mm deep unit, 1144 mm wide – spans 12 m to 16 m
- 650 mm deep unit, 1144 mm wide – spans 16 m to 18 m

The maximum span/depth ratio varies between 26.2 for the 458 mm deep unit and 27.7 for the 576 mm and 650 mm deep units.

Since spans below 12 metre are only rarely used, it is proposed that the following hollow core units should be provided:

- 576 mm deep unit - spans 12 m to 16 m
- 650 mm deep unit - spans 16 m to 18 m
- 900 mm deep unit - spans 18 m to 25 m

The 900 mm deep unit will have a span/depth ratio of 27.7, consistent with the existing designs.

7.3.3 Width of Units

The existing deck units are 1144 mm wide and were developed at a time when the standard bridge width was less than required for the present bridge width standards. The 1144 mm wide unit gives a modular width of 1150 mm between centres of joints.

For the standard bridge width of 11.4 metres, the 1144 mm unit width would require 9.9 units. Reducing the unit width to 1140 mm would rationalise the number of units required to exactly 10 units.

We consider that the existing unit width will probably be retained due to the cost of modifying the beam moulds, and as the difference between the required width for the standard bridge and the width provided by the existing units is only 100 mm. This will be further considered and finalised at the detailed design stage.

7.3.4 Void Shape

The existing double circular void shape has been compared with an alternative rectangular void shape that has been used for some recent bridges to assess whether changing the void shape would give design or cost advantages. Preliminary comparisons indicate the following properties (Table 6) for a typical 18 metre span unit:

Table 2 Comparison of Units with Circular and Rectangular Voids

Criteria	**Hollow Core Unit with Circular Voids**	**Hollow Core Unit with Rectangular Void**
Unit depth	650 mm	650 mm
Unit width	1144 mm	1140 mm
Cross sectional area	450,211 mm^2	418,600 mm^2
Moment of inertia	22,580 x 106 mm^4	22,790 x 106 mm^4
Section modulus	71.2 x 106 mm^3	70.1 x 106 mm^3
Unit weight	21.92 tonnes	18.1 tonnes
Concrete volume	8.43 m^3	7.87 m^3
Prestress required	30 strand	30 strand
Reinforcement required	193 kg	567 kg
Shear area	148,200 mm^2	162,500 mm^2
Durability	30 mm cover (B1)	45 mm cover (B1)
Continuity	Joint provided	Has been made continuous
Robustness	Well proven design	Thinner flanges are not fully proven
Manufacturing problems	Floating void formers	Uses internal steel form
Transverse behaviour	Potential for reflective cracking at joints	Potential for reflective cracking at joints
Construction issues	Units are 7% heavier	Units are 7% lighter
Edge protection	Leave void out for fixings	Modify internal form
Overall structural efficiency indicator*	0.475	0.514

* The Guyon ratio (see below): the higher the number the greater the structural efficiency.

Overall, the unit with circular voids has a slightly greater cross sectional area than the rectangular voided unit but because of the void shape the moment of inertia and section modulus are similar. The rectangular voided section is more structurally efficient using the Guyon ratio, which is calculated as:

$P = r^2/yt.yb$ where r = radius of gyration.

The prestress required is similar in both sections whilst the rectangular voided section requires less concrete but a greater quantity of reinforcement.

The rectangular voided section is also understood to be easier to manufacture due to the use of a steel void former that is withdrawn laterally, rather than polystyrene void forms which are known to be difficult to place and need to be heavily restrained to avoid flotation problems.

We considered that the rectangular voided unit may offer some manufacturing and cost advantages over the circular voided section, but that further detailed analysis will be necessary before a final choice can be made. In particular, analysis of the rectangular voided section for distortion effects in the box cross section will be required to ensure that there are no long term structural concerns with this shape. This will be undertaken during the detailed design stage.

7.3.5 Concrete Strength

The existing hollow core deck units use concrete with a 28 day strength of 40 MPa. Transfer of prestress is allowed at 30 MPa. Some alternative designs use higher grade concrete to allow earlier transfer of prestress.

A concrete strength of 40 MPa is adequate structurally for the units and allows adequate durability to be achieved for a B1 exposure.

We therefore propose that 40 MPa concrete is retained for the design of the units unless the industry advise that earlier strength gain is a significant advantage to the manufacture of the units.

7.3.6 Transverse Design

The original design of the hollow core bridge decks was based on the premise that the deck units would share load transversely by shear transfer across the longitudinal joints. The joints were detailed to behave as “pinned” joints with grout only provided over part of their depth. The analysis of the time assumed pinned connections between units to determine the distribution of loading between the deck units. Inherent in this assumption is the expectation that the joints between the deck units will crack under transverse bending effects. It is considered unlikely that this approach would be justified to current concrete code requirements, which limit permitted crack widths.

From consultation with the industry we understand that there have been some instances where reflective cracking has occurred in the road surfacing above the longitudinal joints, and that this has given rise to maintenance concerns. This has been addressed on an individual project basis by providing additional transverse prestress, providing continuous prestress ducts to protect the tendons and by increasing the depth of the grouted joints so that the joint behaves more as a monolithic connection. This concern is believed to have mainly occurred with longer span units.

An alternative method of transverse connection between the deck units is to provide a cast insitu overlay slab on top of the units instead of transverse prestressing. Overlays are commonly used in Australia where the insitu slab is made composite with the precast deck units. Provision of an overlay slab is likely to reduce the structural efficiency of the precast deck units and increase the cost of the bridge deck compared to a fully precast solution.

The three options to improve the design of the hollow core deck units with respect to their transverse design are therefore:

- Increase the transverse prestress, provide continuous ducts and increase the depth of the grouted joints between deck units
- Provide a structural overlay slab composite with the deck units.

Preliminary design indicates that increasing the transverse prestress, providing continuous ducts and increasing the depth of the grouted joints between units is likely to provide the most cost effective solution for the hollow core deck units, since the provision of an overlay slab will increase the cost of construction due to a reduction in structural efficiency for the deck units and an increase in site construction work.

We recommend that the transverse prestress option should be selected for the detailed design.

7.3.7 Longitudinal Joints Between Units

The existing detail for the joint between hollow core deck units provides a grouted joint with a profiled shear key formed in the sides of the abutting deck units. The joint is typically less than half the depth of the unit.

The maintenance concerns that have been described above in which reflective cracking has been found to occur on some longer span bridges, have been in part attributed to the detailing of the joints between units. Modifications have been made on an individual project basis to improve the performance of the joint by increasing its depth so that 75% or more of the unit depth is grouted. The dimensions of the shear keys have also been increased, and in some cases non-shrink grout has been used. The performance of the longitudinal joint is also improved by the additional transverse prestress described in 7.3.6 above.

We recommend that the longitudinal joints between deck units be modified for the new standard beam shapes for hollow core deck units to increase the depth of the grouted joints, and that the specification for the grout should be reviewed. The transverse prestress should also be increased as described in 7.3.6.

7.3.8 Maintenance Issues

Maintenance issues that have been identified in relation to the existing hollow core designs include:

- Concrete cover and provision of adequate durability to meet current standards
- Reflective cracking above longitudinal joints
- The durability of the sealed joints at the end of the deck units

The existing cover provided is 30 mm to exposed surfaces. This is adequate to provide a 100 year design life to meet the Bridge Manual requirements for class B1 exposure, as required for the standard bridge. No changes are therefore proposed to the concrete cover for the existing standard designs.

The issue of reflective cracking has already been addressed in section 7.3.6 above.

The durability of the sealed joints at the end of the hollow core units where they connect to either abutments or pier cap beams will be addressed in the detailed design stage.

7.3.9 Summary of Findings

The preliminary design of the hollow core deck units for the new beam shapes has concluded the following:

- Hollow core units should be provided for spans of between 12 and 25 metres using hollow core units of 576 mm, 650 mm and 900 mm depth
- The precast industry would like the existing 1144 mm unit width to be retained. This would appear to fit the current Transit Bridge Manual range of width requirements based on the standard bridge criteria developed as part of this project. This will be confirmed during the detailed design stage.
- Twin or single voids should be provided, the final void shape to be confirmed during detailed design
- Concrete strengths of 40 MPa should be used unless the precast industry advises that there are manufacturing advantages to using higher concrete strengths for early stripping
- The transverse design should be improved by increasing the amount of transverse prestress, providing continuous ducts and increasing the depth of the grouted joints between units
- Concrete covers are adequate for long term durability

- Joint details at the ends of the deck units should be reviewed during detailed design

7.4 “I” Beams

7.4.1 General

The preliminary design of the “I” beams has considered the following design issues:

- Beam spacing in relation to increased deck widths
- Beam shape
- Concrete strength
- Edge protection requirements
- Durability.

The findings of the preliminary design are described below.

7.4.2 Beam Spacing

The existing standard bridge beam designs indicate that the spacing of the “I” beams is 2.3 metres. The original design of the beams was based on the beam spacing to increase to 2.5 metres when wider bridge decks were required.

For the standard 11.4 metre wide bridge, preliminary design indicates that five beams will be required (compared to four beams at present) at a spacing of 2.3 metres, with outer cantilevers of 1.1 metres. This will allow the existing deck slab thickness to be maintained.

The existing “I” beam designs will therefore be modified for the wider bridge deck. The bridge deck slab will require re-design to cater for the additional beam and increased barrier loads.

7.4.3 Beam Shape

The research of current international practice and in particular North America, has indicated that development of new “I” beam shapes has taken place in recent years. Comparison of these new “I” beam shapes with the existing New Zealand “I” beams has shown that the new shapes are similar in shape but tend to have wider top flanges and are shallower in depth for a particular span. Bottom flanges shapes and web dimensions are similar to the existing New Zealand shapes.

The main difference with the new beam shapes is that the new beams have a greater span range and go well beyond what is currently used in New Zealand. Prestress and reinforcement details have not been studied in depth, but may show that the new beams are more economical than the existing beam shapes through refinement of the design method.

We propose that as the existing “I” beams in New Zealand are very similar to the new shapes available in North America for the span ranges currently available (up to 32 metres), there is little point in adopting the new beam shapes as this would require significant investment in new beam moulds and in re-design of the beams. This is reinforced by the views expressed in the industry consultation findings that the existing “I” beams should be retained, but that a new shape in the form of the Tee-Roff beam should be introduced for spans up to 30 metres.

We therefore propose that the existing “I” beam shapes should be retained and updated for changes to design standards that have occurred where the existing designs would be inadequate.

7.4.4 Concrete Strength

The existing “I” beams use concrete with a 28 day strength of 40 MPa. Transfer of prestress is allowed at 30 MPa for pre-tensioned beams and 35 MPa for post-tensioned. The insitu deck slabs use 25 MPa concrete.

A concrete strength of 40 MPa is adequate structurally for the “I” beams and it is understood that adequate formwork stripping times are also achieved. The 25 MPa deck concrete is also adequate for the deck slab design.

It is therefore considered that 40 MPa concrete is retained for the design of the “I” beams, and that the deck slab concrete be kept as 25 MPa at 28 days, on the basis of structural considerations.

7.4.5 Edge Protection Requirements

The Test Level 4 (TL4) edge barrier proposed for the standard bridge can be supported by the existing 180 mm thick deck slab provided for the “I” beam standard design. It is therefore not necessary to increase the deck slab unless a higher level of side protection is to be provided for a particular bridge, above TL4.

7.4.6 Durability

A concrete strength of 40 MPa for the “I” beams allows adequate durability to be achieved for class B1 exposure with the existing 30 mm cover to reinforcement. For the deck slab the existing cover of 40 mm is below the 50 mm cover necessary for class B1 exposure with 25 MPa concrete. Changing the deck slab concrete to 30 MPa at 28 days would meet the class B1 durability requirements. It is not considered practical to increase the cover to reinforcement without increasing the deck slab thickness, which is undesirable.

It is therefore considered that 40 MPa concrete is retained for the design of the “I” beams, and that the deck slab concrete be increased to 30 MPa at 28 days to meet durability requirements.

7.4.7 Summary of Findings

The preliminary design of the “I” beams for the new beam shapes has concluded the following:

- The standard bridge will need to be re-designed to cater for the additional beam required to suit the increased bridge width and for the increased edge barrier loads
- The existing “I” beam shapes should be retained and not replaced by the new “I” beam shapes that have been developed overseas
- Concrete strengths for “I” beams and deck slab are adequate structurally
- The existing 180 mm thick deck slabs are of adequate thickness to cater for the proposed Test Level 4 edge protection on the standard bridge
- The concrete strength for the deck slab should be increased to 30 MPa to ensure that the slab has adequate durability for class B1 conditions. The “I” beams have adequate durability with the specified 40 MPa concrete.

7.5 Super-T Beams

7.5.1 General

The preliminary design of the Super-T beams has considered the following issues:

- Span range for the various depths of unit
- Flange width & beam spacing
- Top slab depth
- Concrete Strength
- Prestressing
- Edge protection
- Durability
- Maintenance

The findings of the preliminary design are described below.

7.5.2 Span Range for the various depths of unit

The preliminary design has assumed that the typical beam depths for the various span lengths used in Australia are appropriate for New Zealand. This assumption is considered reasonable because AUSTROADS loadings generally produce similar effects to the loadings in the Transit NZ Bridge Manual. The assumption is also backed up by recent design experience on Super T bridges in New Zealand.

Typical span ranges for the various units are as follows:

Depth	Span
750 mm	15 to 20 m
1000 mm	20 to 25 m
1200 mm	25 to 30 m
1500 mm	30 to 35 m

7.5.3 Flange Width and Beam Spacing

The width of the flanges on the Super-T beams can be varied to give an over-all width of section ranging from a minimum of 1200 mm to a maximum of 2500 mm. For the 11.4 metre wide standard bridge this would equate to five beams of 2.28 metres width.

7.5.4 Top slab Depth

Typical depth thicknesses range from 160 mm to 200 mm. For the preliminary design, a 160 mm thick top slab has been assumed. This will need to be confirmed in the detailed design. Initial calculations indicate that the critical load case for the design of the slab is likely to be the TL4 barrier loading.

7.5.5 Concrete Strength

(a) Prestressed Beam

It is proposed to base the detailed design on a 28-day concrete strength of 40 MPa and strength at transfer of 30 MPa. Recent design work using the Super T shape indicates that the above strengths are likely to be adequate. The concrete grade also allows adequate durability for B1 exposure.

Higher strengths will be considered if further economies become apparent in the design phase.

(b) Top slab

A top slab strength of 30 MPa will be considered in the standard design.

7.5.6 Prestressing

Standard practice in Australia is to use 12.7 mm strand for 750 mm and 1000 mm deep units and 15.2 mm strand in the 1200 mm and 1500 mm deep beams. Recent design work in New Zealand indicates that 15.2 mm strand for the deeper beams may be required.

The preliminary design will however look at both options for strand. A decision as to the type of strand to be used in the standard designs is likely to be a function of structural capacity requirements along with industry preference and overall economy.

7.5.7 Edge Protection

An overall slab thickness of around 200 mm is generally required to support a TL4 barrier as proposed in the standard bridge. The 160 mm poured insitu slab assumed in the preliminary design will therefore be required to act compositely with the precast concrete flanges to provide the required capacity.

7.5.8 Durability

The 40 MPa concrete grade proposed for the standard bridge prestressed beams allows adequate durability for B1 exposure with 30 mm cover to reinforcement. A cover of 40mm is requirement in the 30 MPa slab to achieve the same level of protection.

7.5.9 Maintenance

Options for reducing long-term maintenance costs will be considered and adopted in the standard bridge design. However the extent of work required to eliminate expansion joints etc (to cover the range of bridge lengths) may be outside the budget of Stage 2 of the project.

7.6 Overall Summary

The two key decisions made for the preliminary design of the new beam shapes were the inclusion of the deck slab (as part of the standard designs) and to develop criteria for a standard bridge.

The preliminary design undertaken to date has shown that the proposed sections have the capacity to meet the design live loading of HN-H0-72. Further work is still to be completed (in stage 2 of the project) on a number of design details including the transverse design of the hollow-core deck units and design requirements for Test Level 4 edge protection.

8 COST ESTIMATES AND ECONOMIC ANALYSIS

8.1 General

The proposed new beams shapes have been assessed on the basis of cost to confirm that there is a sound economic basis for changing the existing standard beam shapes and adopting a new shape from overseas. The beam shapes that need to be assessed on an economic basis are:

- Hollow core deck units for spans of between 12 and 25 metres
- "I" beams for spans up to 32 metres
- Super-T/ beams for spans up to 30 metres

8.2 Cost Estimates for New Beam Shapes

The cost of the various beam shapes have been assessed on the basis of the whole superstructure cost per square metre to allow different structural systems to be compared on an equal basis. They exclude sub-structure costs.

The costs have been assembled from historic records for hollow core beams up to an 18 metre span, "I" beams up to a 25 metre span, and "U" beams up to a 26 metre span. The costs for the longer hollow core beams, with up to a 25 metre span, and for the Super-T beams are based on recent projects, and due to their limited use in New Zealand do not have the same confidence levels as the other beam shapes.

The estimated costs for the various bridge beams are presented in Table 7. These costs are current at March 2003 exclude preliminary and general items, professional fees and GST.

Table 3 Beam Costs

Beam Shape	Span range	Whole Cost $/m2 of bridge deck
Hollow core deck units	Up to 18 m	\$500-\$600/m^2
Hollow core deck units	18 m to 25 m	\$600-\$700/m$^{2\text{(limited data)}}$
"I" beams	Up to 32 m	\$400-\$900/m^2
"U" beams	Up to 26 m	\$700-\$900/m^2
Super-T beams	Up to 30 m	\$750-\$850/m$^{2\text{ (limited data)}}$

8.3 Economic Assessment of New Beam Shapes

The above costs for the various new beams shapes indicate that the hollow core deck units for spans up to 18 metres are the lowest cost form of construction out of the options under consideration.

The parameter cost for the deeper hollow core deck units for spans up to 25 metres can be seen to be lower than the alternative “I” beams, “U” beams or Super-T beams for the same span range.

The Super-T beams can be seen to be of similar cost to the “I” beams and generally cheaper than the “U” beams of equivalent spans.

8.3.1 Summary of Findings

We have concluded that the proposal to retain the hollow core deck units for spans up to 18 metres, and “I” beams for spans up to 32 metres has a robust cost basis as these units are competitive when compared to alternative beam sections.

Equally, the proposal to adopt deeper hollow core deck units for spans up to 25 metres is supported on the basis of cost as these units have lower parameter costs than the alternative “I” beams or “U” beams.

The proposed introduction of the Super-T beam section is also supported on the basis of cost, as these beams are, on the basis of the limited cost information available in New Zealand, of lower cost than the alternative “U” beams. Also, the consultation workshops overwhelmingly supported the adoption of this section.

The proposal to exclude the “U” beam from the proposed standard beams shapes to be used in future is also supported on the basis of cost, as these beams (up to a 26 metre span) are the most expensive shapes from the shapes being considered. The adoption of the Super-T beams will also provide an alternative beam solution to the “U” beam for situations where a lower beam depth is required.

9 CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

The literature review of Australia, United Kingdom and North America practice showed that precast beams were extensively used in these countries and that many of the beam shapes and/or spans had been updated or modified in recent years.

The survey of New Zealand precast manufacturers and our own review showed that the original MOW standard designs have been used extensively over the past 30 years with the double hollow core shape easily the most popular. The single hollow core was popular in specific areas and the “I” and “U” beams were used less frequently for bridges requiring longer spans.

Our review of the current standard bridge beams indicated that a number of design and construction issues needed to be addressed in any future designs. These included enhanced edge protection standards, increased durability requirements, maintenance issues and the economy of current designs.

The consultation process was a crucial part of the research to ensure that all sectors of bridge industry had the opportunity to raise and discuss issues.

A large number of issues and ideas were raised both for current and new shapes and distilled into key criteria for selecting new beam shapes.

The poll of possible beam shapes showed a clear preference to retain the double hollow core deck unit as an existing shape with lesser numbers supporting the I-beam and single hollow core deck unit.

The Super-T beam was the clear choice as the preferred new beam shape.

From the consultation process the research team have refined a number of specific options for new beam shapes and concluded that two existing beam shapes should be updated (Hollow Core and I beam) and one new shape (Super-T) be put forward for funding for standard beam designs.

9.2 Recommendations

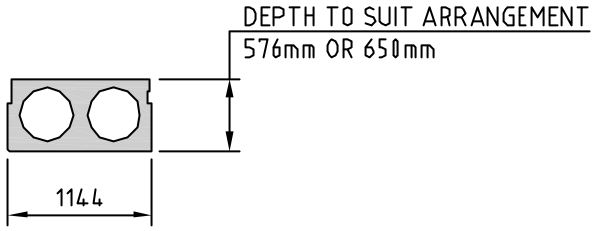
We recommend that detailed designs and drawings be produced for the 11.4 metre wide “standard” bridge (see section 7.2) for the following beam shapes:

- Hollow core deck units probably 1144 mm wide (to be confirmed during the detailed design stage) for spans up to 18 metres with either double circular voids or a single rectangular void (Also to be determined during the detailed design stage).

- Hollow core deck unit for spans up to 25 metres, with void shape to be determined during the detailed design stage
- Existing “I” beams for spans up to 32 metres, updated for changes to design standards
- Super-T beam for spans up to 30 metres.

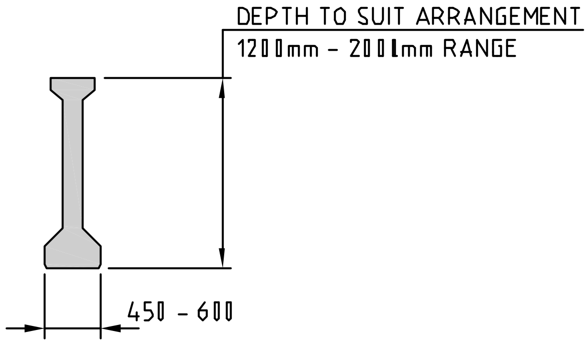
We also recommend that the existing single core deck units and “U” beams are not updated as new standard shapes. The “U” beam will be replaced by the new Super-T beam, and the single core deck unit by the new hollow core deck unit.

These shapes are shown in Figure 10.



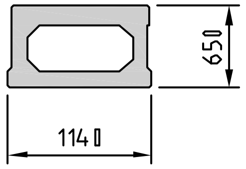
UP TO 18m SPAN

DOUBLE HOLLOW CORE BEAM



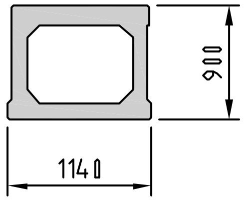
UP TO 31m SPAN

I-BEAM



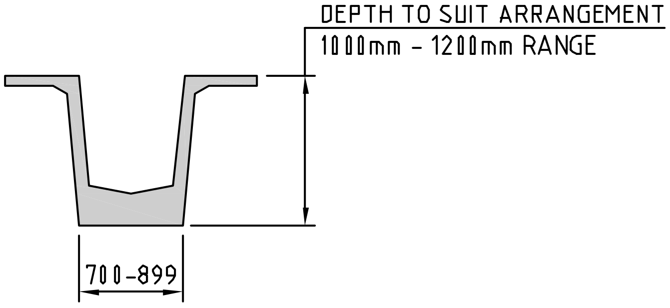
UP TO 18m SPAN

RECTANGULAR HOLLOW CORE BEAM



UP TO 25m SPAN

RECTANGULAR HOLLOW CORE BEAM



UP TO 31m SPAN

OPEN FLANGE SUPER-T BEAM

PROPOSED BEAM SHAPES.

FIGURE 10.

Appendix 1: International Literature Review

Two internal reports were prepared by the research team.

1 Standard Bridge Beams

- Review of North American Practice
by Donald Kircaldie of Opus International Consultants Wellington

2 Standard Bridge Beams

- Review of United Kingdom and Australian Practice
by Phil Gaby of Beca Consultants Wellington

The review was conducted by internet search, review of relevant technical papers and personal communications.

Four papers were found to be of particular relevance in summarising current practices and trends in the United States:

- Meir JV, Ciciarelli MR, Ramirez JA and Lee RH, "Alternatives to the Current AASHTO Standard Bridge Sections", PCI Journal, January-February 1997, pp56-66.

  This paper presents an investigation by the Indiana DOT as the basis for developing new standard precast I beams, and summarises beams in use throughout the USA. In the evaluation of sections, consideration was given to structural efficiency and cost effectiveness and a number of prescribed constraints (minimum web thickness, minimum span/depth ratios, and no end blocks).

  For spans from 9.1 to 21.3 m the AASHTO types I to III girders were found to be most appropriate, from 21.3 to 27.4 m the ASSHTO type IV and Illinois 54" deep girders, and from 27.4 to 39.6 m the Kentucky BT 66" and 78" deep girders.

  Excluded from this study was the University of Nebraska developed girders discussed in the next paper.

- Geren KL, Abdel-Karim AM, and Tadros MK, "Precast/Prestressed Concrete Bridge I-Girders: The Next Generation", Concrete International, June 1992, pp25-28.

  This paper describes the initiation of the study that has led to the recent development of the NU girder, which is understood to be gaining in acceptance. This development focused on girders that could initially be erected and carry the weight of the deck as simply supported spans, but then be made continuous for other loads through the addition of post-tensioning.

- Waheed A, Delaurentiis N, and Hancock L, "Use of Long Span Concrete Girders (NU) in Alberta", Proceedings of the Sixth International Conference on Short and Medium Span Bridges, Vancouver, Canada, 2002.

  This paper provides a description of the NU girders, including two case studies of their use, and description of their design and fabrication features.

- Seguirant S, "New Deep WSDOT Standard Sections Extend Spans of Prestressed Concrete Girders", PCI Journal, July/August 1998, pp92-119.

  This paper describes the development of new, deep, precast, prestressed concrete girder sections for the Washington State DOT. The girders can be used at wider spacings with fewer girder lines, in place of the previous standard beams used. The sections are available in both single-piece, pretensioned, and multiple-piece post-tensioned segmental versions. These sections represent a further development from the University of Nebraska's NU girder series.

Appendix 2: Survey of New Zealand Precast Prestressed Bridge Beam Manufacturers

a. General

In order to understand recent trends in beam shapes and corresponding deck shapes and spans that have been manufactured over the past five years a survey of national precast manufacturers was carried out.

A survey form, appended, was designed to capture a range of data so that definite conclusions could be reached about the deck types of recent highway bridges constructed in New Zealand. That is, bridges that were designed for the Transit HN-HO-72 highway bridge loadings. Information on non standard designs, that is, special designs which were outside the scope of the original MWD Standard Bridge manual were not requested.

b. Survey Methodology

The survey form (Figure A and Figure B) comprised a range of possible beam types (see appendix) as a guide to the respondents.

- Beam types 1, 2, 4, 5, 6 represented those standard types which were residual from the original MWD blue book days
- Items 3 and 4 were included to determine if composite deck sections were being used.
- Item 7 refers to a more recent shape introduced into New Zealand from Australia. Essentially a variation on a spaced box shape deck section.
- Items 8 and 9 refer to a box section shape produced in the central north island region

From this data we were able to extract the following information.

c. Survey Results (Figure C and D)

Survey responses were received from a total of 10 manufacturers. Six from the North Island and the remainder from the South Island. See appendix. The survey results were split into six regional zones to determine if there were regional trends or variations.

Data on 102 bridges of 6 types was collected, being double hollow core, single hollow core, U and I section with deck slabs, gull wing and spaced box section.

d. Interpretation of results (Figure E)

The original MWD standards have lasted well over the last twenty to thirty years with many of the sections still used on a regular basis for particular applications..

- The majority of responses indicated the popularity of Double HC bridge decks throughout all regions.
- Single hollowcore was popular with the north of the south island and in the central north island.
- The I and U sections were used for bridges requiring longer spans, but have been used to a lesser extent than the twin hollow core
- A variation on the popular Double HC bridge decks is the single cell box section shape, which was used extensively on Route PJK in Tauranga.

Span/depth ratios:

A comparison of the span/depth ratios against other authorities recommendations was carried out to see if there were patterns of structural consistency. While the I, Gull wing and box section show a reasonably good comparison the Double Hollow core units show a wide variation.

The survey indicates the popularity of the Double Hollow Core unit as a standard stock unit which has provided highway bridge design flexibility and economic benefits during the past thirty years.

DATA CAPTURE SURVEY FORM – PRECAST BRIDGES MANUFACTURED in NZ

For the period 1997 to 2002

COMPANY NAME: ________________________LOCATION:____________________

Figure A

1	2	3	4	5	6A	6B	7	8	9	10	11
Item	**Contract Name and Bridge location**	**Date produced (mth., yr)**	**Number of Spans**	**Deck Spans m**	**Number of Lanes**	or **Deck width m**	**Product Type No.**	**Prod. Type depth x width mm x mm**	**Specified 28 day strength MPa**	**Units per Span**	**Insitu Deck Thickness mm**

DATA CAPTURE SURVEY FORM – PRECAST BRIDGES in NZ

For the period 1997 to 2002

Figure B

NOTE:
The data is not recording the presence of footpaths or cycle ways

Column No.	Description
1	Record sequential number of contracts entered
2	Identify the contract name and geographical location of the bridge
3	Month and year that deck units were manufactured
4	The bridge may comprise 1, 2, 3 or many spans.
5	Against each span please record the span length in metres
6A	Provide either – the number of lanes **OR**
6B	The total deck width
7	Please enter a product type number according to the legend shown in the table below
8	Give the depth x width which corresponds to each span of the bridge
9	Enter the specified 28 day concrete strength in MPa
10	For each bridge span provide the number of precast units. From which the total number of units for the contract can be established.
11	Insitu deck thickness refers to the deck provided for I or U type sections.

Product Type No.	Product Type Description Please record other product types in line 10 to 13
1	Twin hollowcore deck unit (untopped)
2	Single core deck unit (untopped)
3	Twin hollowcore deck unit (topped)
4	Single core deck unit (topped)
5	U – Section with deck slab
6	I – Section with deck slab
7	Gull wing section / T-roff
8	Box section not spaced
9	Box section spaced
10	
11	
12	
13	

Manufacturers List

Precast Prestressed Bridge deck elements

Figure C

Survey Respondents

	First Name	Surname	Company	Box Number	Suburb	Town
1	Russell	Bennetto	Busck Prestressed Concrete Ltd	P O Box 310		Whangarei
2	Robert	Gibbes	Stresscrete	Private Bag 99904	Newmarket	Auckland
3	Kevin	Badcock	Concrete Structures (NZ) Ltd	P O Box 849		Rotorua
4	Paul	Sweetman	Smithbridge Precast	21 Aerodrome Rd.,	Mt. Maunganui	Auckland
5	Harry	Romanes	Unicast Concrete Ltd	P O Box 2061		Hastings
6	Peter	Watson	Precast Components (Wgtn) Ltd	P O Box 20		Otaki Railway
			MAINLAND			
7	Errol	Thelin	Thelin Construction	14 McPherson St.		Nelson
8	Colin	Chisolm	Fulton-Hogan Civil Division	P.O. Box 65,	Belfast	Christchurch
9	Ray	Hughes	Pipeco Certified Concrete	767 Main South Road	Paroa	West Coast
10	Kevin	Dowling	Fulton Hogan Concrete Division	P O Box 242	Balclutha	Balclutha

Unable to respond

1	Grant	Wilson	Wilson Precast Construction Ltd	P O Box 962	Drury	Auckland
2	Malcolm	Kenah	Precast & Craneage	Ford Road		Napier
3	Hugh	Lattey	Lattey Civil Engineers Ltd	Omahu Road		Hastings
4	Richard	Emmett	Emmett Bros Ltd	400 Heads Road		Wanganui
5	Daniel	Smith	Daniel Smith Industries	315 Flaxton Rd.		Rangiora

Figure D

Zone	Description	Bridges by Zone	BEAM TYPES									
			1 DHC	2 SHC	3 DHC topped	4 SHC topped	5 U-Sectn + deck slab	6 I-Sectn + deck slab	7 Gull wing	8 Box sectn. not spaced	9 Box sectn. spaced	
1	Otago-Southland	7	6				1					7
2	Nth. Sth. Island	26	18	6				2				26
3	Wgtn.+Manawatu	6	4					1	1			6
4	Central Nth. Island	48	35	6			2	2			3	48
5	Auckland	2					1	1				2
6	Nth. Auckland	13	10	2			1					13
		102	73	14	0	0	5	6	1	0	3	102
		Span/Depth Ratios:	13 to 42	25 to 31	0	0.00	20 to 26	14 to 23	22	0	14 to 16	
		Comparison recommendations for span/depth taken from T.Y. Lin	24 to 26					22 to 24			24 to 26	

Figure E

Item	PRODUCT			Span/		Topping	Deck	Units	No.	Total		Conc
	Type No.	Span m	Depth mm	Depth Ratio	Width mm	Thickness mm	Width m	per Span	of Spans	Units No.	Region	f'c MPa
1	1	8.20	458	18	914	0	4.57	5	1	5	Wgtn	40
2	5	22.00	1100	20	874	150	8.74	10	5	50	Auck	40
3	1	12.20	458	27	914	0	12.80	14	1	14	Central N. I.	40
4	1	12.20	575	21	1144	0	9.15	8	1	8	Central N. I.	40
5	1	14.20	575	25	1144	0	10.30	9	2	18	Central N. I.	40
6	1	11.75	458	26	914	0	9.14	10	2	20	Central N. I.	40
7	1	10.20	458	22	914	0	8.23	9	1	9	Central N. I.	40
8	6	20.40	1500	14	450	150	10.00	4	3	12	Wgtn	40
9	1	12.20	575	21	1144	0	6.86	6	3	18	Central N. I.	40
10	1	18.20	575	32	1144	0	9.15	8	3	24	Central N. I.	40
11	1	16.20	575	28	1144	0	10.30	9	1	9	Central N. I.	40
12	1	18.20	650	28	1144	0	9.15	8	1	8	Central N. I.	40
13	1	18.00	650	28	1144	0	9.15	8	5	40	Wgtn	40
14	1	16.50	575	29	1144	0	5.72	5	1	5	Wgtn	40
15	1	12.00	458	26	914	0	10.97	12	2	24	Central N. I.	40
16	1	14.00	575	24	1144	0	11.44	10	2	20	Central N. I.	40
17	1	16.00	575	28	1144	0	11.44	10	2	20	Central N. I.	40
18	1	12.00	576	21	1144	0	0	5	16	80	Nth.Cn.Sth.I	40
19	6	23.00	1200	19	-	0	0	4	4	16	Nth.Cn.Sth.I	40
20	1	12.00	576	21	1144	0	0	5	3	15	Nth.Cn.Sth.I	40
21	1	15.00	576	26	1144	0	0	5	6	30	Nth.Cn.Sth.I	40
22	1	16.00	576	28	1144	0	0	4	1	4	Nth.Cn.Sth.I	40
23	1	18.00	576	31	1144	0	0	4	1	4	Nth.Cn.Sth.I	40
24	6	24.00	1600	15	-	200	0	5	3	15	North Shore	50
25	6	20.40	1500	14	-	200	0	4	4	16	Nth.Cn.Sth.I	40
26	1	6.20	458	14	914	0	0	6	4	24	Nth.Cn.Sth.I	40
		11.20	576	19	1144	0	0	9	4	36		40
		11.60	576	20	1144	0	0	6	4	24		40
27	1	8.00	458	17	914	0	0	2	11	22	Nth.Cn.Sth.I	40
		6.00	458	13		0	0	6	3	18		40
28	1	9.60	458	21	914	0	0	6	5	30	Nth.Cn.Sth.I	40
29	1	17.50	650	27	1144	0	0.00	10	4	40	Otago/Sth	40
30	1	14.20	576	25	1144	0	0.00	20	1	20	Otago/Sth	40
31	1	16.20	576	28	1144	0	0.00	20	1	20	Otago/Sth	40
32	5	20.40	1000	20	500	190	0.00	19	1	19	Otago/Sth	40
33	1	18.20	650	28	1144	0	0.00	3	1	3	Otago/Sth	40
34	1	10.20	458	22	914	0	0.00	10	1	10	Otago/Sth	40
35	1	16.12	576	28	1144	0	8.00	7	1	7	Nth.Auck	55
36	1	16.37	576	28	1144	0	4.57	4	1	4	Central N. I.	40
37	1	18.30	650	28	1144	0	4.57	4	1	4	Central N. I.	45
38	1	12.60	458	28	915	0	10.98	12	1	12	Nth.Auck	40
39	1	18.20	650	28	1144	0	4.50	4	1	4	Nth.Auck	40
40	1	8.00	458	17	915	0	4.57	5	1	5	Nth.Auck	40
41	1	12.20	458	27	915	0	9.15	10	1	10	Nth.Auck	40
42	1	16.00	576	28	1144	0	24.00	21	2	42	Nth.Auck	40

43	1	16.00	576	28	1144	0	24.00	42	2	84	Nth.Auck	40
44	2	24.80	900	28	632	0	7.65	12	1	12	Nth.Auck	40
45	2	26.20	900	29	632	0	11.38	18	1	18	Nth.Auck	40
46	10	10.60	320	33	1200	0	7.30	6	1	6	Wgtn	40
47	1	18.20	650	28	1144	0	-	8	1	8	Central N. I.	40
48	1	7.80	576	14	1144	0	-	4	2	8	Central N. I.	45
49	1	16.70	576	29	1144	0	-	9	1	9	Central N. I.	40
50	1	13.30	458	29	1144	0	-	10	1	10	Central N. I.	40
51	1	12.70	576	22	1144	0	-	26	2	52	Nth.Auck	45
52	1	20.00	576	35	1144	0	-	9	1	9	Central N. I.	45
53	1	18.65	650	29	1144	0	-	12	3	36	Central N. I.	60
54	1	11.70	575	20	914	0	-	5	1	5	Central N. I.	40
55	1	6.90	458	15	914	0	-	10	1	10	Central N. I.	40
56	1	6.00	458	13	1144	0	-	-	-	4	Nth.Cn.Sth.I	40
57	1	9.00	458	20	1144	0	-	-	-	4	Nth.Cn.Sth.I	40
58	1	10.80	458	24	1144	0	-	-	-	20	Nth.Cn.Sth.I	40
59	1	15.60	576	27	1144	0	-	-	-	40	Nth.Cn.Sth.I	40
60	1	16.00	576	28	1144	0	-	-	-	16	Nth.Cn.Sth.I	40
61	1	16.00	576	28	1144	0	-	-	-	24	Nth.Cn.Sth.I	40
62	2	27.00	930	29	1140	0	-	24	1	24	Central N. I.	50
63	6	27.00	1200	23	610	150	-	26	9	234	Central N. I.	45
64	6	21.00	1200	18	610	180	-	26	13	338	Central N. I.	50
65	1	14.50	576	25	1144	0	23.00	10	1	10	Nth.Auck	50
66	5	30.80	1200	26	1863	160	11.50	21	3	63	Nth.Auck	50
67	2	16.00	650	25	1100	0	11.00	10	4	40	Central N. I.	50
68	9	31.00	2200	14	9500	0	20.00	24	4	96	Central N. I.	50
69	9	35.00	2200	16	10400	0	21.00	26	12	312	Central N. I.	50
70	2	20.00	650	31	1120	0	32.00	26	1	26	Central N. I.	50
71	2	15.50	650	24	1120	0	13.00	10	3	30	Central N. I.	50
72	2	20.40	750	27	1120	0	24.20	21	4	84	Central N. I.	50
73	2	15.00	650	23	1120	0	13.00	10	2	20	Central N. I.	50
74	9	30.00	2200	14	10400	0	21.00	26	2	52	Central N. I.	50
75	1	22.00	900	24	1144	0	21.00	18	3	54	Nth.Auck	50
76	1	11.90	450	26	1144	0	4.16	4	1	4	Central N. I.	42
77	1	15.10	575	26	1144	0	4.16	4	1	4	Nth.Cn.Sth.I	42
78	1	24.00	900	27	1144	0	4.16	4	3	12	Nth.Cn.Sth.I	42
79	1	12.80	458	28	914	0	-	10	2	20	Central N. I.	42
80	1	12.80	458	28	914	0	-	12	1	12	Central N. I.	42
81	7	22.40	1000	22	1863	100	-	5	7	35	Wgtn	42
82	1	24.00	575	42	1144	0	4.60	4	1	4	Central N. I.	42
83	1	18.00	650	28	1144	0	-	4	2	8	Central N. I.	42
84	1	15.70	450	35	1144	0	-	5	1	5	Central N. I.	42
85	1	9.80	400	25	1144	0	-	4	1	4	Central N. I.	42
86	1	6.44	450	14	1144	0	-	4	1	4	Central N. I.	42
87	1	15.00	576	26	1144	0	-	11	3	33	Central N. I.	42
87	5	23.00	1100	21	874	130	-	8	3	24	Central N. I.	42
88	1	10.64	500	21	1144	0	-	6	1	6	Nth.Cn.Sth.I	42
89	1	16.34	576	28	1144	0	-	4	1	4	Central N. I.	42
90	1	8.80	350	25	1144	0	-	4	1	4	Central N. I.	42
91	1	16.00	575	28	1144	0	-	8	1	8	Otago/Sth	42
92	1	16.20	650	25	1144	0	-	5	1	5	Wgtn	42

93	1	16.10	576	28	1144	0	-	10	2	20	Central N. I.	42
94	1	18.00	650	28	1144	0	-	8	9	72	Central N. I.	42
95	2	18.20	650	28	650	0	-	4	6	24	Nth.Cn.Sth.I	40
96	2	18.00	650	28	650	0	-	12	2	24	Nth.Cn.Sth.I	40
97	2	22.00	800	28	750	0	-	12	1	12	Nth.Cn.Sth.I	40
98	2	22.00	800	28	750	0	-	12	1	12	Nth.Cn.Sth.I	40
99	1	14.00	585	24	1144	0	-	14	1	14	Nth.Cn.Sth.I	40
100	2	16.50	650	25	650	0	-	6	2	12	Nth.Cn.Sth.I	40
101	2	16.50	650	25	650	0	-	7	1	7	Nth.Cn.Sth.I	40