New Standard Precast Concrete Bridge Beams:

Stage 1 - Identification of New Standard Beam Shapes

Transfund New Zealand Research Report No. 252

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Contents

Executive Summary

Background

The objective of Stage 1 of this research project, carried out between July 2002 and March 2003, was to research and identify the most appropriate precast concrete bridge beam shapes that should be adopted as the industry standard in New Zealand for future bridges.

This research was considered a priority as the standard bridge beam designs currently used in New Zealand had been adopted as industry standards in the 1970s, and are therefore almost 30 years old. They are out of date with respect to design codes, construction techniques, and the higher strength materials now commonly used.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, a literature survey was made of standard beam usage in Australia, United Kingdom, the United States and Canada over recent years.

Many manufacturers of precast bridge beams in New Zealand also contributed data to the survey carried out as part of the research. From this survey, information and statistics were produced to indicate the beam shapes currently in use that are most popular.

Extensive consultation of a wide range of industry participants was a crucial part of the research process. Workshops were held in three main centres of New Zealand (Auckland, Wellington, Christchurch) 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 and consultation comments, a range of beam selection criteria were then developed to identify which of them were the key criteria that needed to be addressed in any future designs.

The most important criterion 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, a standard bridge superstructure should be developed that would limit the range of spans and cross section widths for the new bridge beams.

Conclusions

The literature review showed that precast beams are 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 precast manufacturers and our own review showed that the original Ministry of Works standard designs have been used extensively over the past 30 years with the double hollow core shape being the most popular by far. The single hollow core was popular for bridges in specific areas, and the "I" and "U" beams were used less frequently for bridges requiring longer spans.

This review of 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 poll of possible beam shapes showed a clear preference to retain the double hollow core deck unit as an existing shape, with a lower number supporting the "I" beam and single hollow core deck unit.

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

Recommendations

Detailed designs and drawings for the 11.4 m-wide 'standard' bridge are to be produced for the following precast units:

- Hollow core deck units, probably 1144 mm wide (to be confirmed during the detailed design stage) for spans up to 18 m, with either double circular voids or a single rectangular void (also to be determined during the detailed design stage).
- Hollow core deck units for spans up to 25 m, with void shape to be determined during the detailed design stage.
- Existing "I" beams for spans up to 30 m, updated for changes to design standards.
- "Super-T" beams for spans up to 30 m.

The existing single core deck units and "U" beams are not to be updated as new standard sections. The "U" beam will be replaced by the "Super-T" beam, and the single core deck unit by the updated hollow core deck unit.

Abstract

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

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

A literature survey was made of standard beam usage in Australia, United Kingdom, United States and Canada along with a survey of current New Zealand practice. Following a survey of manufacturers of precast bridge beams, and three consultation workshops, a range of key beam selection criteria were developed that would need to be addressed in any future designs.

The recommendation is that full designs for two existing beam shapes (hollow core and "I" beam) and one new shape ("Super-T") are carried out in the second stage of the project.

1. Introduction

In the mid-1970s the Ministry of Works & Development (MWD) designed a range of double 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 in the use of standard moulds by manufacturers of precast bridge beams. This also 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 following 20 years up to the present (2003).

The standard MWD bridge beam designs that were completed in the 1970s era are nearly 30 years old, and out of date both with respect to design codes and to construction techniques that are now commonly used. Also today higher strength materials are available. 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:

- Form an Industry Group to comment on bridge beam options;
- Research current beam use in New Zealand and compare with overseas use (by literature review);
- Survey New Zealand manufacturers of precast structures;
- Develop beam selection criteria;
- Consult with Industry representatives in three main centres;
- Analyse research results;
- Propose preliminary designs of new beam shapes;
- Carry out cost estimates and economic analysis;
- Formulate 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 (previously of 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 Standard Bridge Beams Used 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 (m). 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 these designs were last updated during the mid-1990s.

2.2 Existing Standard Bridge Beams

The existing standard bridge designs, which are contained in the MWD 1981 publication *Rural Bridges Standard Bridge Plans* (also known as the *'red book'*), cover the following beam sections 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.

Existing standard beam sections used now in New Zealand are shown in Figures 2.1 and 2.2.

For each of these beam types, full construction drawings are provided in the 'red book', and include 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. 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 m to 18 m, and "I" beams for spans up to 24 m. The span range for double hollow core deck units has also been extended to 22 m for specific projects.

The 'red book' replaced the earlier 'blue book' following a revision of the bridge beams in 1988. The 'blue book' was published for general use by the bridge building industry whereas the 'red book' was an in-house MWD publication.

2.3 Issues with Existing Standard Bridge Beams

There are a number of issues with the existing designs relating to changes of design standards for bridges that have occurred since the designs were last updated. These standards are set out in the Transit New Zealand Bridge Manual (2003), 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, e.g. use of partial prestress now permitted.

These changes to standards have meant that the current beam designs have become out of date and now require modification on an individual project basis.

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

- Reflective longitudinal cracking to surfacing above longitudinal joints between double hollow core deck units, particularly in longer spans of some bridges;
- Problems during manufacture of voided slabs caused by void flotation in wet concrete;
- Possible instability of longer span "I" beams during erection related 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 m).

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

2.4 Other Beam Shapes Currently Used

In addition to the standard beam designs originating from the MWD, a number of other beam shapes are increasingly being used on a project-by-project basis in New Zealand.

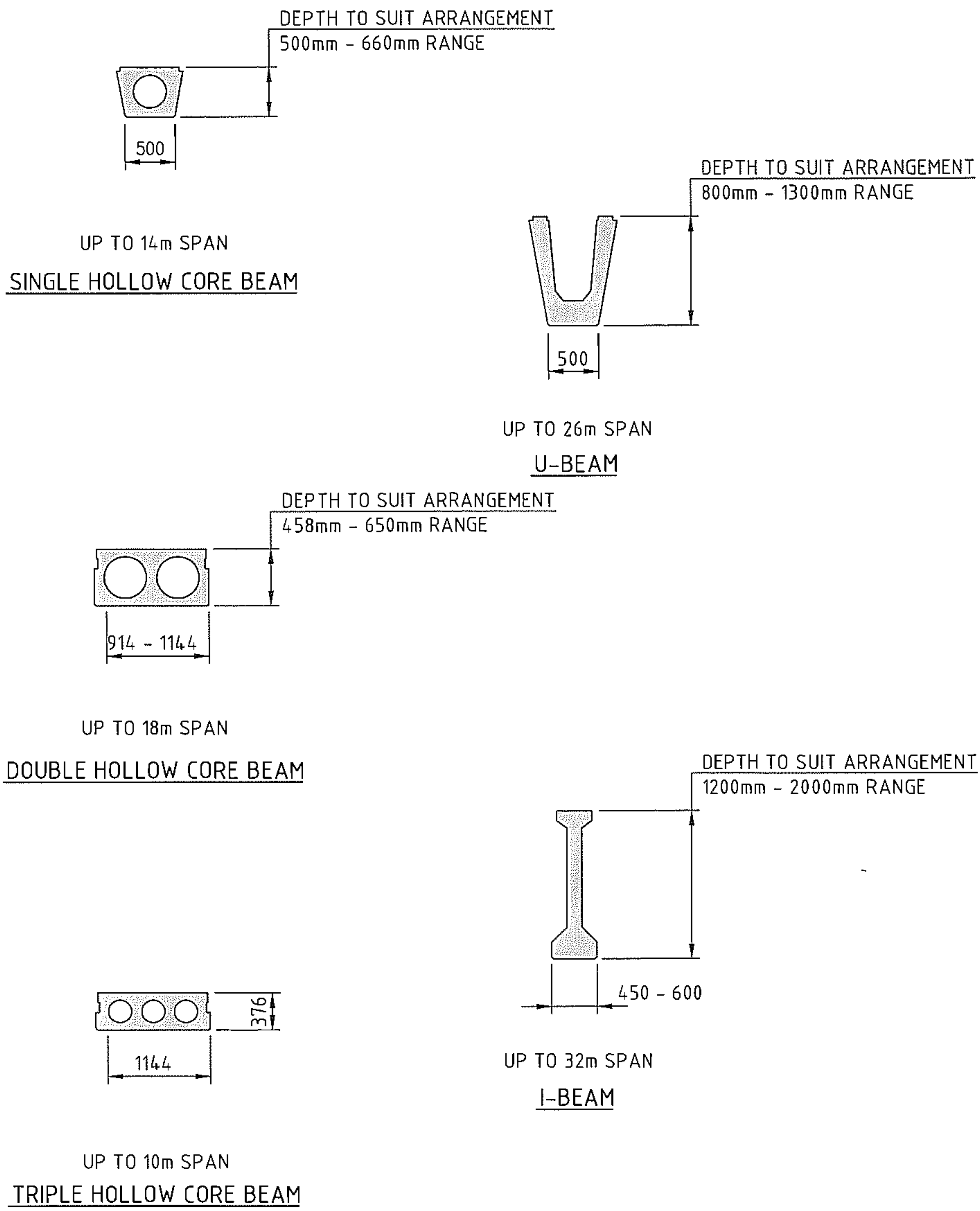


Figure 2.1 Standard beam shapes currently used in New Zealand.

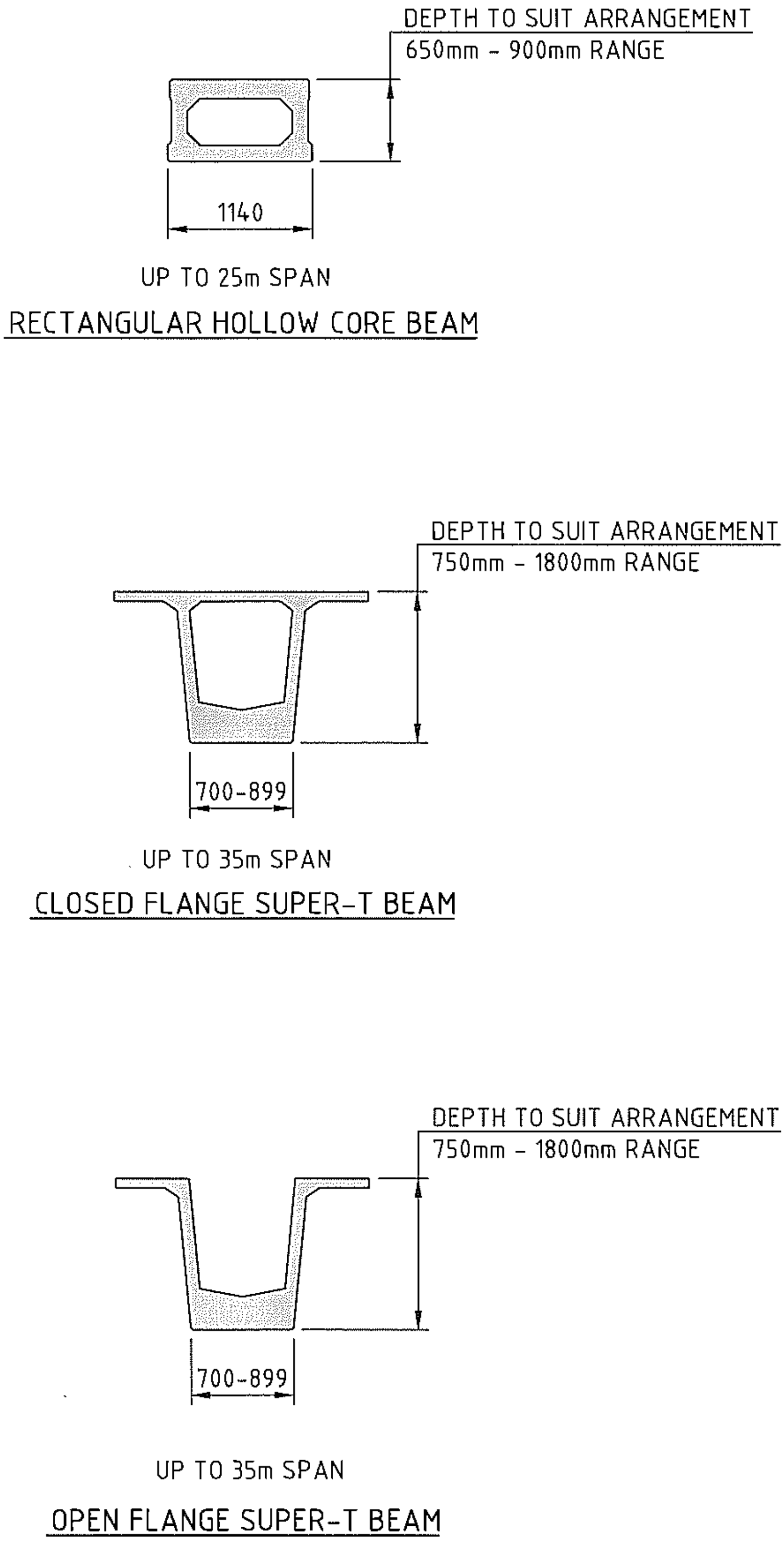


Figure 2.2 Other non-standard beam shapes currently used in New Zealand.

These are known to include the following shapes:

- Precast hollow core deck units with a single rectangular void for a variety of spans up to 25 m;
- Precast "Super-T" beams and Tee-Roff beams (similar to those used in Australia).

The Tee-Roff beam is understood to be 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 Introduction

A search of international literature was made of current overseas practice, and four countries (Australia, United Kingdom, United States and Canada) were selected. The range of beam sections that are currently used in these countries cover a very wide range and differ significantly, even between states.

Similarities between these countries and New Zealand were carefully considered, and the countries were selected for a detailed literature review because:

- Australia is close to New Zealand and has similar current traffic loadings;
- United Kingdom has a wide range of shapes available and new shapes have been adopted recently;
- United States and Canada, which show differences between several states or provinces, have both used standard precast bridge beam design for many years, new beam designs have been recently developed, and the traffic loadings are similar to those in New Zealand.

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 (Appendix 1).

3.2 Australia

3.2.1 Background

Discussions were held with specialists such as the National Precast Concrete Association of Australia, consultants and clients. The discussions showed that, up to a 17 m span, the trend in that country is to use precast voided planks. In New South Wales (NSW) these planks are typically constructed with a double-reinforced concrete overlay.

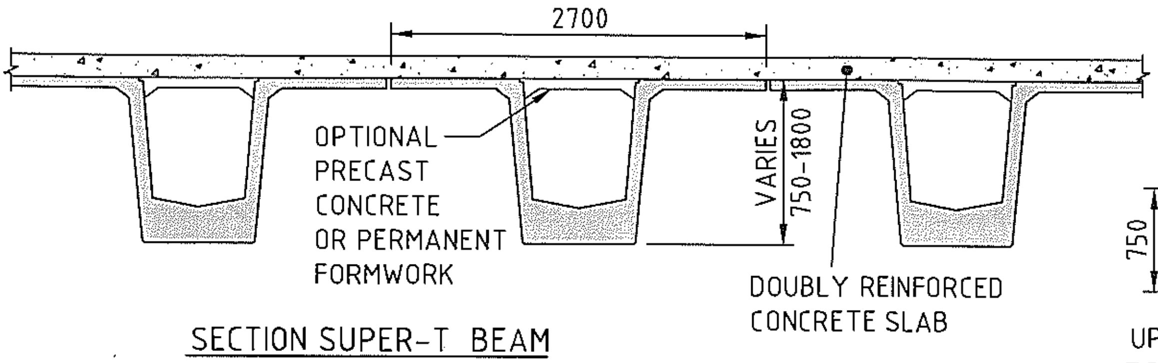
In Queensland this type of precast unit is also used in the same span range but usually without any overlay, and with a shear key detail between the abutting units and transverse prestress.

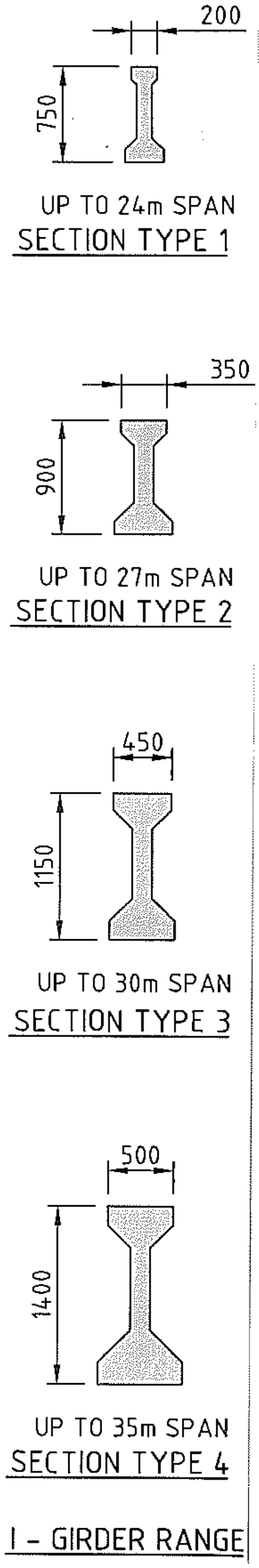
3.2.2 Beam Shapes and Current Practice

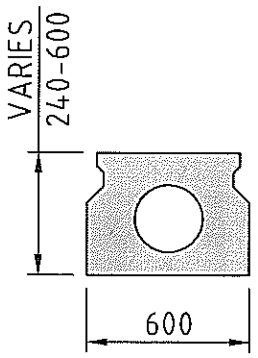
Table 3.1 and Figure 3.1 show the range of beam precast units used in Australia at the present time (2003).

The general trend is to use hollow core beams up to a 17-m span, and to use voided-box beams up to a 27-m span.

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



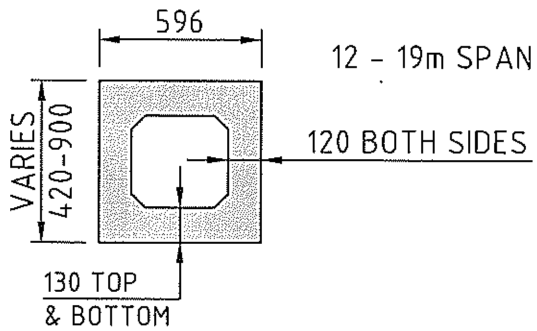




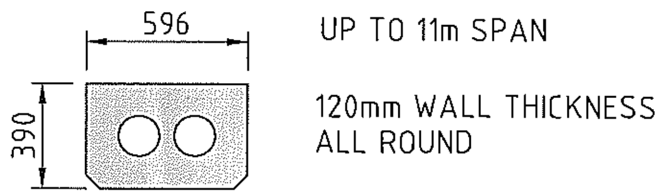
BEAM SECTION PROPERTIES

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



SECTION OF PRESTRESSED DECK UNITS TYPE 1



SECTION OF PRESTRESSED DECK UNITS TYPE 2

NOTE:
UNITS GENERALLY CONSTRUCTED WITH DOUBLY REINFORCED CONCRETE SLAB OVER

Figure 3.1 Beam shapes currently used in Australia.

Longer span "Super-T" beams extending up to 48 m (and weighing up to 200 tonnes) 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 m to 35 m range. Many contractors now have moulds for this section resulting in competitive prices for specific contracts.

Table 3.1 Current Australian practice for designing precast units for different spans.

Span Range	Precast Unit	Comments
Up to 17 m	Standard PSC-voided planks (NSW predominantly)	Doubly reinforced concrete overlay or transverse prestress.
Up to 27 m	Voided-box beams (Australia wide)	Doubly reinforced concrete overlay or transverse prestress.
Between 18 m – 35 m	"Super-T" and Tee-Roff beam	Reinforced concrete top slab. Flanges of "Super-T" and Tee-Roff provide formwork.
Between 18 m – 35 m	"I" girder	Infrequently used. Tee-Roff and "Super-T" taking over.

3.3 United Kingdom

3.3.1 Background

Practice in the UK has traditionally been to use beam with in situ infills for shorter spans, and beam and slab for longer span ranges. Design loadings and environmental conditions differ considerably from those in New Zealand, with far heavier design loads and more severe environmental conditions.

The standard bridge beams were re-designed in the early 1990s. 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 in the UK are described here.

The size of the market in the UK means that a much larger range of precast beam shapes are 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 m.

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 Beam Shapes and Current Practice

Table 3.2 and Figures 3.2 and 3.3 show the range of beam shapes in use in the UK at the present time (2003).

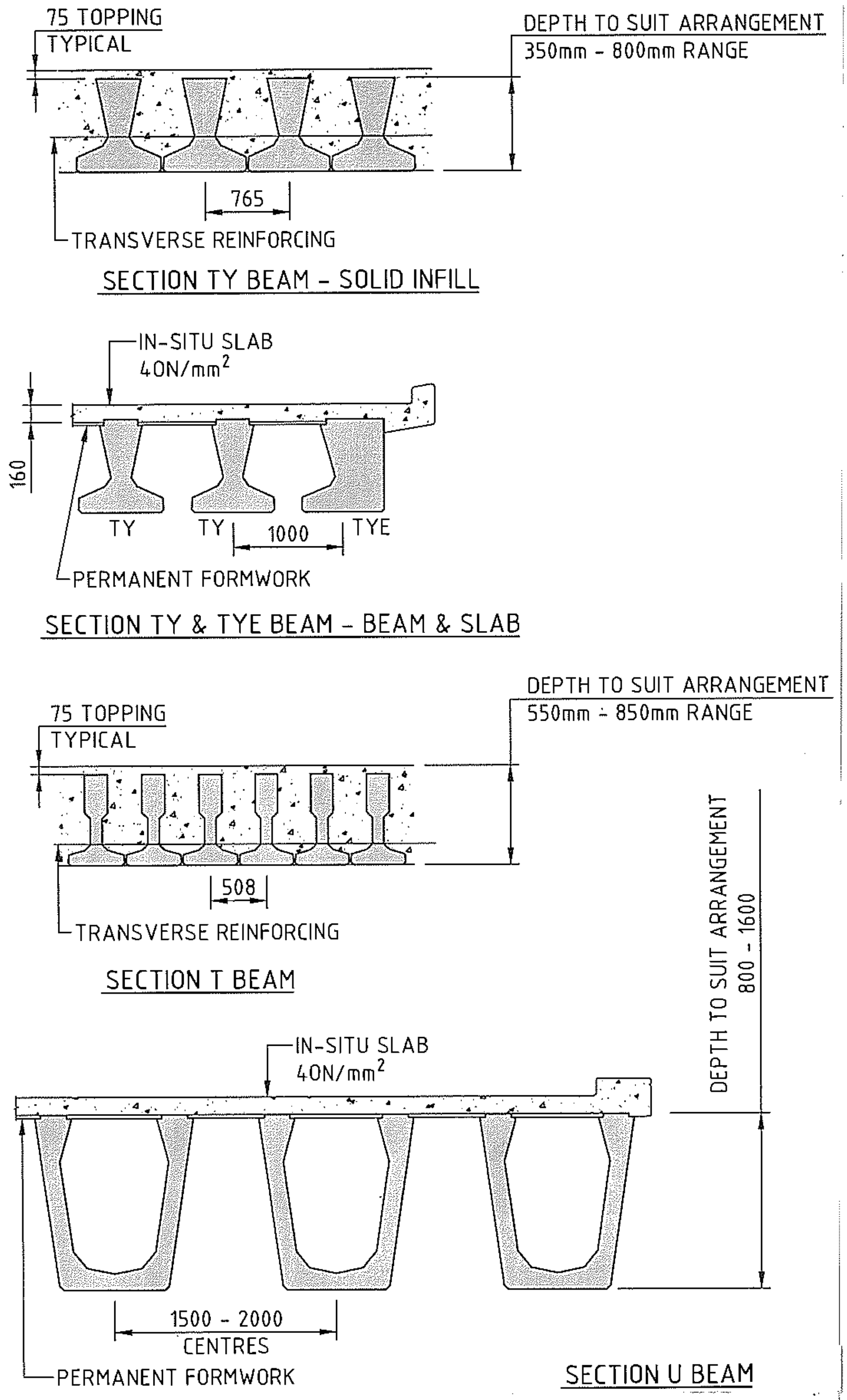


Figure 3.2 Beam shapes currently used in the United Kingdom.

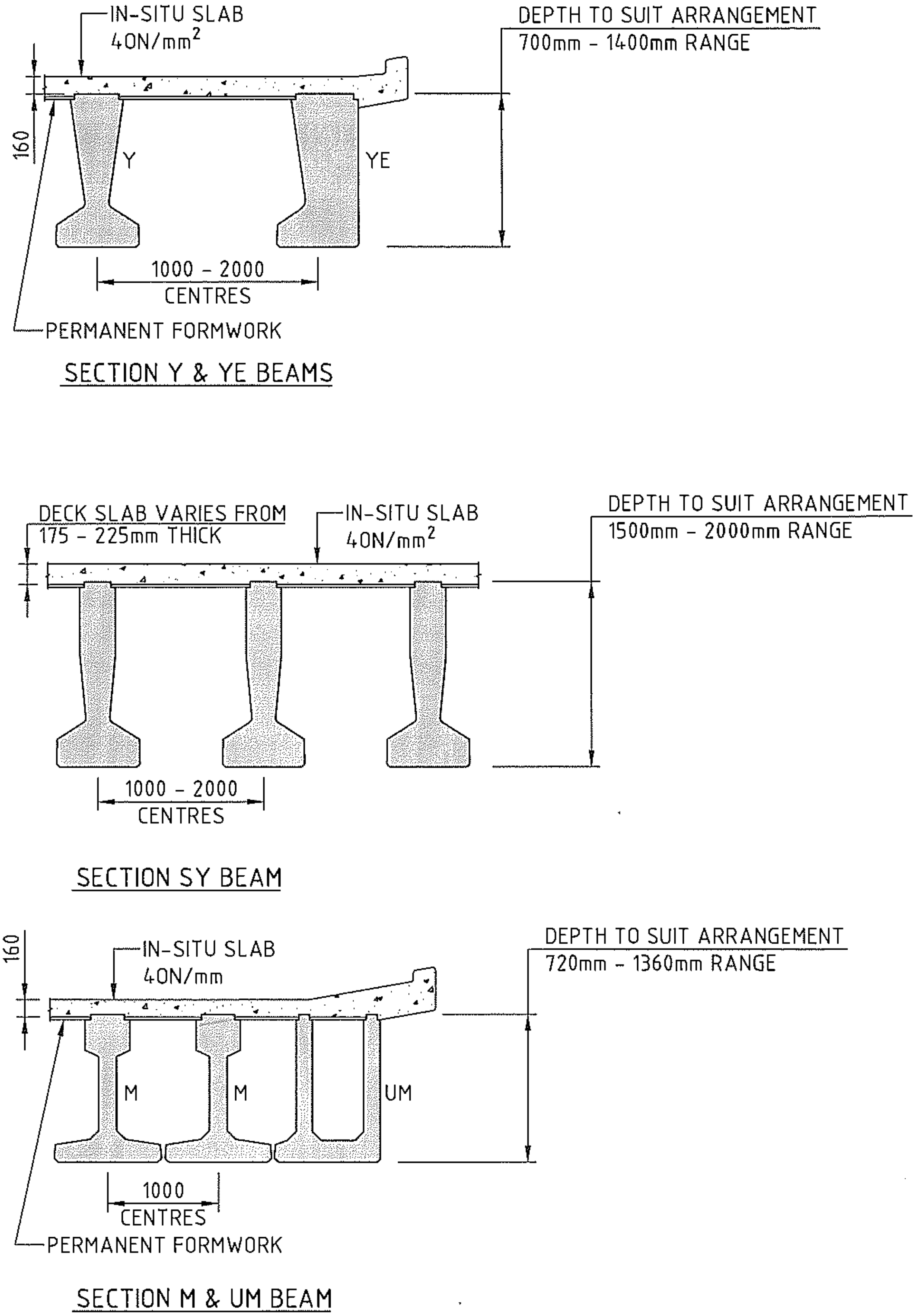


Figure 3.3 Beam shapes currently used in the United Kingdom (continued).

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 m;
- "SY" beam for spans from 24 to 45 m;
- "TY" beam for spans for 7.5 to 17.5 m.

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

Table 3.2 Current UK practice for precast units for different spans.

Span Range	Precast Unit	Comments
Up to 17 m	"TY" Beam	Solid infill deck. This shape was introduced in 1994 and is replacing the inverted "T" beam.
Up to 17 m	Inverted "T" Beam	Still used but losing ground to "TY" beam.
Between 12 m – 34 m	"U" Beam	Used for skew decks where torsional rigidity is required.
Between 12 m – 31 m	"Y" Beam	RC top slab. This shape was introduced in 1990 and is taking over from the "M" beam.
Between 24 m – 40 m	"SY" Beam	Longer span adaptation of the "Y" beam introduced in 1992.
Between 16 m – 29.5 m	"M" Beam	Still used but losing ground to the more efficient "Y" beam.

3.4 United States & Canada

3.4.1 Background

The beam sections used in different states of the US and provinces of Canada show wide variation because each state develops its own designs. The literature review focused on the key states that were considered to be industry leaders in this area. These included Washington State, Florida, and Tennessee states in the US, and Alberta and British Columbia provinces in Canada.

Recent development of new sections for precast bridge beams to replace the AASHTO beams that have been in use for many years was the key finding of the literature review. 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 in situ 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 AASHTO "I" beams.

Precast beam units with circular voids are still widely used for shorter span bridges, as are ribbed or multiple "T" units.

Typically concrete strengths are specified to 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 strength being specified.

3.4.2 Beam Shapes and Current Practice

Table 3.3 and Figures 3.4 and 3.5 show the range of beam shapes in use in the US and Canada.

Table 3.3 Beam precast units in current use in the US and Canada.

Span Range	Precast Unit	Comments
Spans up to 20 m	Solid planks, triple hollow core beams, double hollow core beams, double rectangular voided beams, double "T" and triple "T" beams.	Wide variety of deck slab units used for shorter spans. Preferences are different between states. Most beams 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 in situ deck slab. Bulb-Tee girders are post-tensioned transversely with in situ joints. "FM" girders require in situ 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 for 15 m to 30 m spans (above).

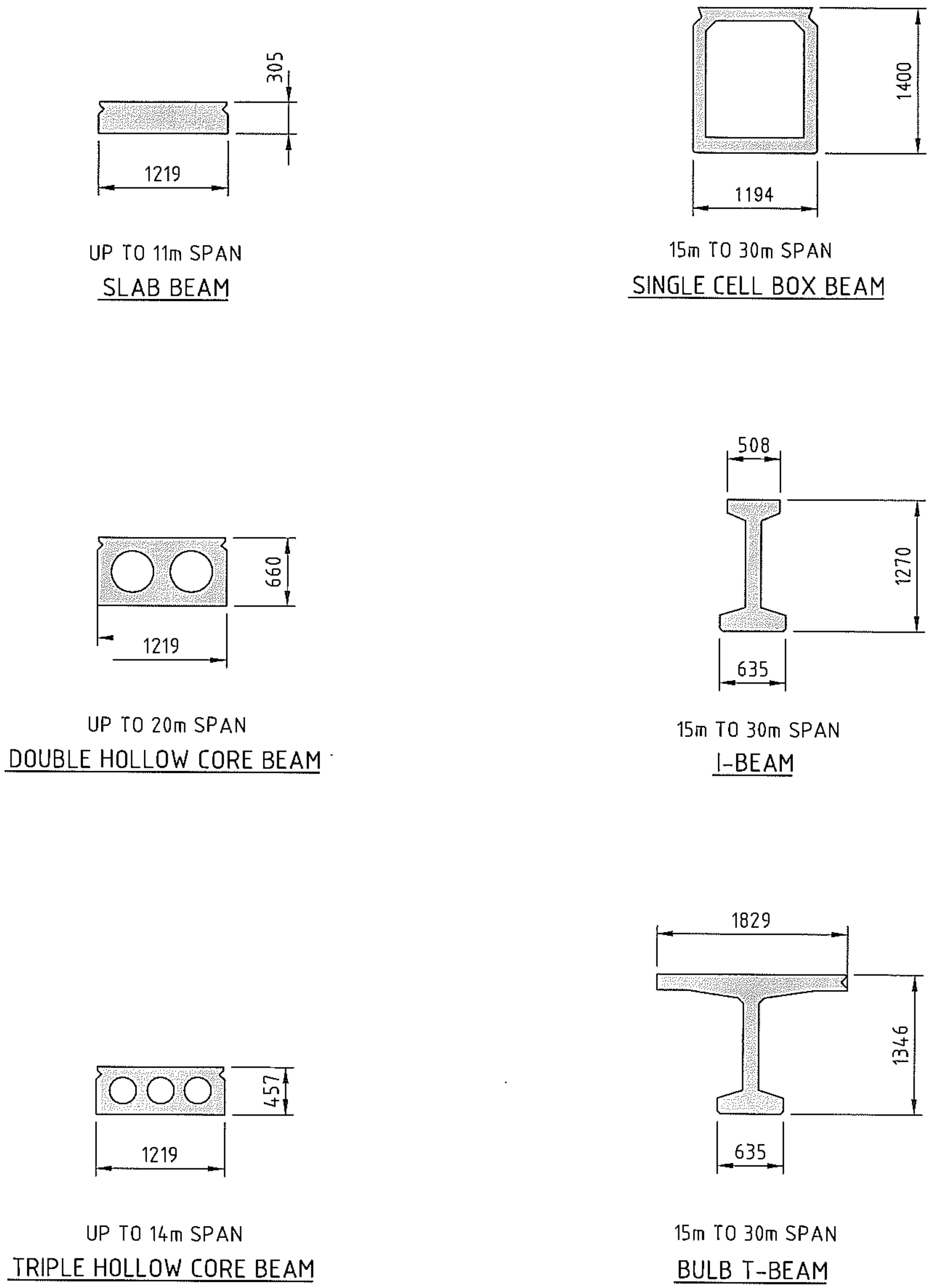


Figure 3.4 Beam shapes currently used in the United States and Canada.

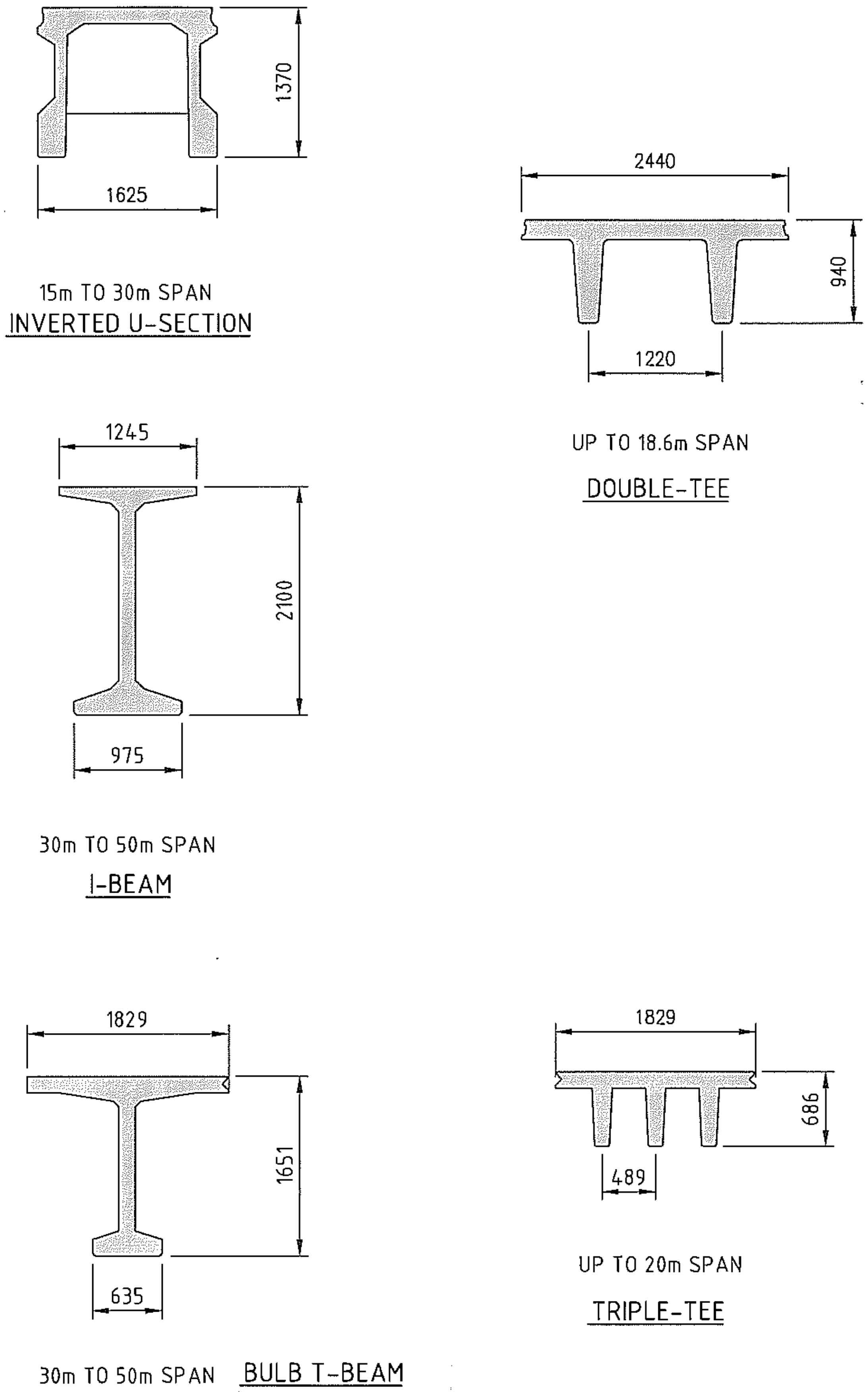


Figure 3.5 Beam shapes currently used in the United States and Canada (continued).

3.5 Summary of International Practice

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

The large scale and number of roading projects carried out in the US and Canada has resulted in a wide range of bridge beam sections, some of which are far too long (and too heavy) for use in New Zealand conditions.

In the UK the range of precast units used was smaller, but some span up to 40 m. As these spans have been specifically designed for motorway widening projects, they are unlikely to be used on a regular basis in New Zealand where the number of long-span bridges required is smaller.

Australia was considered the most relevant country with which to compare beam sections, not only because it is close geographically but also the scale of works was similar to that in New Zealand. 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.

4. Survey of Precast Prestressed Bridge Beams Made in New Zealand

4.1 Introduction

Preferences for producing and for employing the different precast prestressed bridge beams used in New Zealand were determined by means of a survey of the manufacturers of the bridge beams themselves. As well consultations were undertaken with industry representatives as a special group, and with practitioners, contractors and manufacturers at workshops.

To understand recent trends in beam sections and corresponding deck shapes and spans that have been manufactured over the past five years (1998-2003) in New Zealand, a national survey of the beams made by precast manufacturers and their products was carried out.

A survey form (Appendix 2) was designed to capture a range of data on which definite conclusions could be made about the deck types used in recent highway bridges constructed in New Zealand. The bridges selected were those designed using the Transit New Zealand HN-HO-72 highway bridge loadings (as in the Bridge Manual). Information on non-standard designs, e.g. bridges designed to a standard less than HN-HO-72, was not requested.

4.2 Survey Methodology

The survey form comprised a range of nine possible beam types (Table 4.1) as a guide to the respondents:

- Beam types 1, 2, 4, 5, 6 (in column *Product Type No.*) represented those standard types listed in the original 'red book' which are still in use.
- Beam types 3 and 4 were included to determine if composite deck sections were being used.
- Beam type 7 ("Super-T") refers to a more recent shape introduced into New Zealand from Australia. Essentially it is a variation on a spaced box shape deck section.
- Beam types 8 and 9 refer to a box section shape produced in the central North Island region.

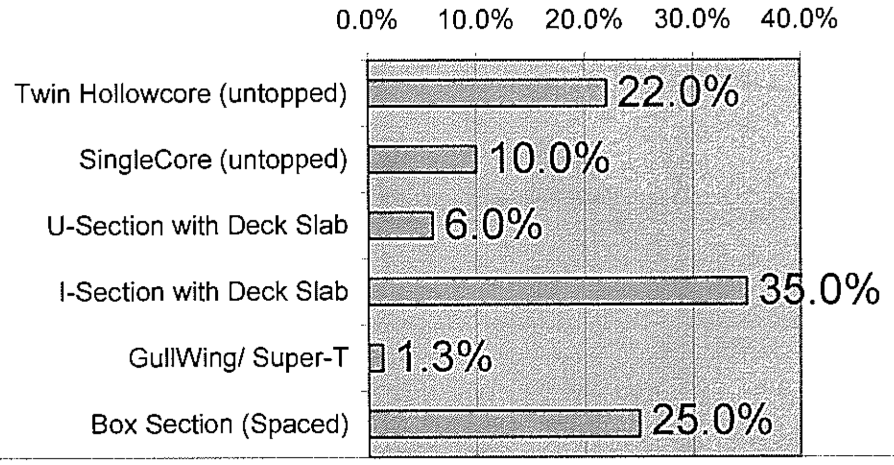
4.3 Survey Results

Survey responses were received from ten manufacturers, of which two had multiple precast sites. Six were from the North Island and four from the South Island (Appendix 2). The survey results were split into six regional zones to determine any regional trends or variations. The trends in production (in linear metres) of bridge beams indicated from the survey are shown in Figure 4.1.

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

Table 4.1 Existing beam types available for use in highway bridges in New Zealand.

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



Total production of all types is 61,400 linear metres
Production of each beam type is expressed as % of the total production

Figure 4.1 Summary of beam types produced by New Zealand manufacturers.

5. Industry Consultation and Participation

5.1 Introduction

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, industry consultation workshops with industry representatives and other interested parties were held in Wellington, Christchurch and Auckland.

The project was publicised widely by Transfund (using their regular publication *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 this 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

Nearly 40 industry representatives attended the three consultation workshops held in Wellington, Christchurch and Auckland in November 2002. The objectives of the workshops were to:

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

A wide range of issues was raised and criteria for selecting new beam shapes were discussed, of which the following are key issues:

- 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 New Zealand 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 least two of the workshops:

- Use NZS 3101:1995 coastal B1 rating (SNZ 1995) for durability and construction specification;
- Design for minimum maintenance – less joints, bearings;
- Emphasise standardisation and use of existing moulds;
- Prefer to minimise site formwork 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;
- Consider visual appearance of handrails and edge beams for urban bridges.

5.4 Workshop Polling

A poll of possible beam shapes taken during the workshops 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, UK, US and Canada.

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

5.5 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. The face-to-face contact and discussion at the three consultation workshops ensured that the researchers 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. It has crucially assisted the research team in selecting new standard beam shapes that will be widely accepted and therefore more likely to be used on a regular basis.

6. Analysis of Research Survey

6.1 Introduction

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 survey and consultation is summarised below.

6.2 Industry Consultation Workshop Polling

The results of the informal poll of workshop participants (Section 5.4 of this report) 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.

6.3 Review of Existing Standard Beam Shapes Used in New Zealand

The review of the current situation in New Zealand with respect to standard bridge beams (Section 2.2) 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 because of their method of construction and cost of manufacture;
- Changing design standards for bridge width, live loading, 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 m to 18 m, and occasionally up to 20 m, 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 m, but maybe uneconomic for longer spans.
- "U" beams – used for urban bridges where headroom is limited, but generally considered uneconomic (with 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 in accordance with changes to design standards that have occurred since they were last updated, and also any maintenance issues need to be addressed. The "U" beams are still used, but because they are not economic 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 Review of Other Beam Shapes 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 m;
- Hollow core units with single rectangular void, 900 mm-deep unit, spanning up to 25 m;
- "Super-T" beams.

These beams have been used on an individual project basis with design undertaken for each individual bridge. The 650 mm-deep hollow core units with 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 is 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 m. They are understood to offer economic advantages because of their structurally efficient section and ease of construction, as no deck slab is 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 m. They offer advantages of structural efficiency and ease of construction with the outstand wings providing a permanent form for the in situ 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 have demonstrated some advantages over the existing beam shapes, in that they have been selected and are currently being used in New Zealand for a number of projects. These beam shapes should be investigated further as possible new standard bridge beams to be used in New Zealand.

6.5 Review of Beam Shapes Used Overseas

From the international literature search of current overseas practice, covering Australia, UK, US and Canada, the range of beam shapes currently used is very wide and differs significantly between countries, and even between states within Australia, US and Canada.

The main beam shapes used overseas that are likely to be considered for use in New Zealand are discussed as follows:

Australia
Australian practice differs between states, but generally the beam shapes described in Section 3.2 of this report are used over the entire country with some local variations. Beams are designed for similar loading and environmental conditions to those in 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 .

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
Practice in the UK has traditionally been to use beams with in situ infills for shorter spans, and beam and slab for longer span ranges. Design loadings and environmental conditions differ considerably from those in New Zealand, because they are designed for much heavier design loads and more severe environmental conditions.

The standard bridge beams were re-designed in the early 1990s. 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 in the UK are described in Section 3.3 of this report.

UK practice is for beam shapes and strand positions to be standardised, but for each bridge to be individually designed. Their new range of shapes offers beams that are structurally efficient and have 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 larger in the UK than in New Zealand because de-icing salts are used and freeze-thaw conditions occur.

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 because their philosophy is to use beam and slab or beam and in situ infill construction for all spans, and their design criteria are different.

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. Both the industry and the country are unlikely to support such an approach, or want to pay for the required investment in new moulds.

United States and Canada
North American (US and Canadian) practice differs widely between states and provinces. The traditional use of AASHTO "I" girders has gradually been replaced by a new generation of "I" and Bulb-Tee girders. These have been re-engineered to improve their economy, extend their span range and, in some states, to use higher strength materials. Current practice is summarised in Section 3.4 of this report.

Generally, standard beams are fully designed and detailed in the US 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 m) 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 differ, but in some states are similar to New Zealand.

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. This is because the beams used for the shorter spans are similar to those already available in New Zealand, and a major investment in changes to the moulds would be required to change the shape of the "I" beams. 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.

6.6 Review of Survey of Precast Prestressed Bridge Beams made in New Zealand

The results of the survey are summarised in Section 4.3 of this report, and 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 thirty years, and:

- Most responses indicated the popularity of double hollow core bridge decks throughout all regions;
- Single (circular) hollow core was popular in northern 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 double hollow core;
- A variation on the popular double hollow core bridge decks is the large single rectangular cell box section shape, which was used extensively on Route PJK in Tauranga.

A comparison of the span:depth ratios of bridge beams used in New Zealand against recommendations of other authorities was carried out to determine any 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 that the double hollow core unit as a standard unit was popular, and that it has provided highway bridge design flexibility and economic benefits over the past thirty years.

7. Selection of New Standard Beam Shapes

7.1 Introduction

The selection of new beam shapes to replace the existing standard beams was undertaken based on the work described in Chapters 2, 3 and 4 of this report.

- Review of existing beam shapes currently used in New Zealand (Chapter 6.3).
- Review of other beam shapes currently used in New Zealand (Chapter 6.4).
- Review of beam shapes currently used overseas, and assessment of whether these shapes would be suitable for use in New Zealand (Chapter 6.5).
- Review of results of a survey of precast prestressed bridge beams made in New Zealand (Chapter 6.6).
- Review of selection criteria (Chapter 7.2).
- Selection of new beam shapes on the basis of feedback obtained from industry consultation on their preferences for new beam shapes, and the criteria that they consider are most important in selecting the new beam shapes (Chapter 7.3).

7.2 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 were grouped into the following key areas:

- Product type and span range
- Design and aesthetics
- Beam manufacture
- Construction
- Durability/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 in situ 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.

Durability/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 noted.

A summary of the results from the workshops indicated that the most important criteria in selecting new beam shapes for New Zealand would be:

- Flexibility
  - Maximise span range with one mould
  - Range of spans is required up to 35 m
  - 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
- Complete 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
- Minimised 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 7.3.

7.3 Options for New Standard Beam Shapes

Options have been identified for new standard beam shapes to be used in New Zealand, from the review of the current standard bridge beams, of the alternative beam shapes currently being used in New Zealand, of current international practice, and from the preferences expressed by attendees at the industry workshops. The options identified and listed in Table 7.1 are:

- Option 1 – Retain the single hollow core deck units 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 range of unit depths to cater for different spans up to 18 m

- Option 6 – Introduce a deeper hollow core unit than currently used to extend the span range up to 25 m, 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 range of beam depths to cater for various spans up to 30 m

A span range of 12 to 30 m is being considered for the further study.

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 7.1.

We consider it practical to develop and maintain only a limited number of standard beam shapes in operation in New Zealand (say three or four, rather than the existing five, beam types), because the number of new bridges that are constructed is relatively small. This low number limits the demand for any particular beam shape which, in turn, limits the number of different mould shapes than can be available because of 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.

On the basis of the preferences for beam shapes expressed by the industry at the workshops, and the analysis of the shapes against the key criteria for new beam shapes selected by the participants, we consider 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.

7.4 Proposed New Standard Beam Shapes

The new beam shapes proposed, covering the span range from 12 m to 30 m, are therefore:

- Hollow core deck units 1144 mm wide for spans up to 18 m, with the use of 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 m, with void shape to be determined during the detailed design stage.
- Existing "I" beams for spans up to 32 m, updated for changes to design standards.
- "Super-T" beams for spans up to 30 m.

Our proposal is that the existing single core deck units and "U" beams are not updated as new standard shapes.

Table 7.1 Comparison of options for new beam 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 for 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.
Durability/ Maintenance	Possible concern at longitudinal joints.	Possible concern at longitudinal joints.	Good, although some covers may need to be increased.	Good.	As for Option 2.	As for 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.
Minimised site work	Precast planks minimise site work.	Precast planks minimise site work.	Significant site work for in situ slab requiring formwork.	Significant site work for in situ slab requiring formwork.	Precast planks minimise site work.	Precast planks minimise site work.	In situ slab required but precast outstands act as formwork.

8. Preliminary Design of New Standard Beam Shapes

8.1 Introduction

Once the selection and proposals for new beam shapes had been made, preliminary design was undertaken to determine basic parameters for the new beams. These parameters 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 addressed the changes required for design standards and 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.

8.2 Criteria for New Standard Bridge Superstructure

To achieve a practical output from this project we proposed to limit the range of spans and cross section widths for the new bridge beams. Agreement was also reached on the criteria for a standard bridge superstructure to be carried forward to Stage 2.

The proposed design criteria for the preliminary design of the new standard bridge superstructure 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 11.4 m (2 x 3.5-m lanes plus 1.2-m wide shoulders and 1.0-m wide barrier edge width). (The proposed standard bridge superstructure cross-section is shown in Figure 8.1.)
- 100 km/h design speed.
- HN-HO-72 design live loading (as modified by the proposed revision to the serviceability loading currently being considered).
- Test Level 4 (TL4) edge protection (typical requirement for rural bridge with low traffic volumes) assuming flexible barrier requiring 1.0-m edge distance.
- Durability in NZS 3101:1995 Class B1 exposure zone for coastal perimeter, but excluding Class B2 coastal frontage zone.
- 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 detailed design to be carried out in Stage 2 of this project, to give greater economy).
- Design meets the requirements of Transit New Zealand Bridge Manual.
- Span range from 12 m to 30 m.

These criteria have been used for the preliminary design of the proposed new bridge beams.

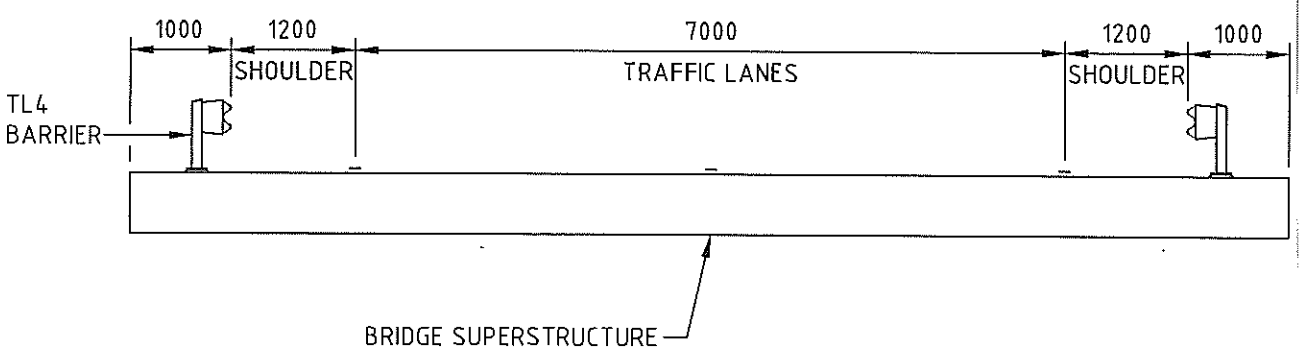


Figure 8.1 Cross section of proposed standard bridge beam superstructure.

8.3 Criteria for Hollow Core Deck Units

The following design issues have been considered in the preliminary design of the hollow core deck units and described in Section 8.3.1 – 8.3.7:

- 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

8.3.1 Span Range and Unit Depths

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

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

The maximum span:depth ratio ranges between 26.2 : 1 for the 458-mm deep unit and 27.7 : 1 for the 576-mm and 650-mm deep units.

Since spans below 12 m length are rarely used, the proposal is that the following hollow core units should be provided:

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

The new 900 mm-deep unit will have a span:depth ratio of 27.7 : 1, consistent with the existing designs.

8.3.2 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 that 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 m, 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.

However the existing unit width will probably be retained because of 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.

8.3.3 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 8.1) for a typical 18-m span unit:

Table 8.1 Comparison of units having circular or rectangular voids.

Criteria	**Hollow Core Unit with Circular Voids**	**Hollow Core Unit with Rectangular Voids**
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

* Guyon ratio (see below): in which the higher the number the greater is 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 (P), which is calculated as:

$$P = r^2/yt.yb$$

where:

r = radius of gyration;

yt and yb = depths from the neutral axis and top (t) and bottom (b) flanges.

The prestress required is similar in both sections, while the rectangular voided section requires less concrete but more reinforcement.

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

The rectangular voided unit may offer some manufacturing and cost advantages over the circular voided section, but 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 this shape raises no long-term structural concerns. This will also be undertaken during the detailed design stage.

8.3.4 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 bridge with B1 exposure.

The proposal is to retain 40 MPa concrete for the design of the units unless the industry advises that earlier strength gain is a significant advantage to the manufacture of the units.

8.3.5 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 provided only over part of their depth. The assumption made in the analysis at that 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. This approach is unlikely to meet current concrete code requirements as permitted crack widths are likely to be exceeded.

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. These problems have 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.

An alternative method of transverse connection between the deck units is to provide a cast in-situ overlay slab, on top of the units, instead of transverse prestressing. Overlays are commonly used in Australia where the in situ 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 to increase the cost of the bridge deck, compared to a fully precast solution.

The four 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;
- 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 are likely to provide the most cost-effective solution for the hollow core deck units. On the other hand the provision of an overlay slab will increase the cost of construction because of a reduction in structural efficiency for the deck units and an increase in site construction work.

The transverse prestress option is recommended for selection for the detailed design in Stage 2.

8.3.6 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 Section 8.3.5 above.

The recommendations are that longitudinal joints between deck units are to 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 Section 8.3.5.

8.3.7 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 Transit Bridge Manual requirements for class B1 exposure (SNZ 1995). No changes are therefore proposed to the concrete cover in the existing standard designs.

The issue of reflective cracking has already been addressed in Section 8.3.5, Transverse Design.

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

8.3.8 Summary of Design Criteria for Hollow Core Deck Units

From the preliminary design of the hollow core deck units for the new beam sections the following conclusions are made:

- Hollow core units should be provided for spans of between 12 and 25 m using hollow core units of 576 mm, 650 mm and 900 mm depths.
- 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.
- Double 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 manufacturing advantages are gained by using higher concrete strengths for early stripping of formwork.
- 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.

8.4 Criteria for "I" Beam Units

The following design issues have been considered in the preliminary design of the hollow core deck units, and are described in Sections 8.4.1 – 8.4.5:

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

8.4.1 Beam Spacing

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

For the standard 11.4 m-wide bridge, preliminary design indicates that five beams will be required (compared to four beams at present) at a spacing of 2.3 m, with outer cantilevers of 1.1 m. 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.

8.4.2 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 flange 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 capacity than are 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.

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 m), adopting these new beam sections is not proposed, as these sections 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 m.

Therefore the proposal is that the existing "I" beam shapes should be retained, and updated to incorporate changes to design standards.

8.4.3 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 in situ 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.

Therefore the recommendation is that 40 MPa concrete should be retained for the design of the "I" beams, and the deck slab concrete should be kept as 25 MPa at 28 days, on the basis of structural considerations.

8.4.4 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. Therefore increasing the deck slab is not necessary unless a higher level of side protection than is provided by the TL4 barrier is required.

8.4.5 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 less than the 50 mm cover necessary for class B1 exposure (SNZ 1995) with 25 MPa concrete. Changing the deck slab concrete to 30 MPa at 28 days would meet the class B1 durability requirements. Increasing the cover to the reinforcement is not considered practical because it would increase the deck slab thickness, and this is undesirable.

Therefore 40 MPa concrete should be retained for the design of the "I" beams, and the deck slab concrete should be increased to 30 MPa at 28 days to meet durability requirements.

8.4.6 Summary of Design Criteria for "I" Beam Units

The following criteria have been concluded from the preliminary design of the "I" beams for the new beam shapes:

- 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 slabs 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.

8.5 Criteria for "Super-T" Beam Units

The following issues have been considered in the preliminary design of the "Super-T" beams, and they are described in Sections 8.5.1 – 8.5.8:

- Span range for different unit depths
- Flange-width and beam spacing
- Deck slab depth
- Concrete strength
- Prestressing
- Edge protection
- Durability
- Maintenance

8.5.1 Span Range for Different Unit Depths

The preliminary design of "Super-T" beams is based on the assumption that the typical beam depths for the different span lengths used in Australia are appropriate for New Zealand. This assumption is considered reasonable because AUSTROADS (1992) loadings generally produce similar effects to the loadings required in the Transit New Zealand Bridge Manual. This 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:

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

8.5.2 Flange Width and Beam Spacing

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

8.5.3 Deck Slab Depth

Typical deck slab depth thicknesses range from 160 mm to 200 mm. For the preliminary design, a 160 mm-thick deck 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.

8.5.4 Concrete Strength

(a) Prestressed Beam

The proposal is 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 bridges in the B1 exposure zone.

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

(b) Deck slab
A deck slab strength of 30 MPa will be considered in the standard design.

8.5.5 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.

8.5.6 Edge Protection

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

8.5.7 Durability

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

8.5.8 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.

8.6 Summary of Preliminary Design Proposals

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

The preliminary design undertaken to date has shown that the proposed precast units have the capacity to meet the Bridge Manual 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 TL4 edge barrier protection.

9. Cost Estimates and Economic Analysis

9.1 Introduction

Costs incurred by adopting the proposed new beam shapes have been assessed to confirm if the change to a new shape that is in use overseas would have a sound economic basis.

The precast units to be assessed on an economic basis are:

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

9.2 Cost Estimates for New Precast Units

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

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

The estimated costs for the various bridge beams are presented in Table 9.1. These costs (in NZ$) are current at March 2003, and exclude preliminary and general items, professional fees and GST.

Table 9.1 Costs of proposed bridge precast units.

Precast Unit	Span Range	Whole Cost NZ$/m^2 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 *
"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 *

* Only limited data available

9.3 Economic Assessment of New Precast Units

The costs listed in Table 9.1 for the new precast units indicate that the hollow core deck units for spans up to 18 m have the lowest cost of construction of the options under consideration.

The parameter cost for the deeper hollow core deck units for spans up to 25 m is lower than those for the alternative "I" beams, "U" beams or "Super-T" beams for the same range of spans.

The "Super-T" beams are of similar cost to the "I" beams, and generally are cheaper than the "U" beams of equivalent spans.

9.4 Summary of Costs

The proposal to retain the hollow core deck units for spans up to 18 m, and "I" beams for spans up to 32 m, has a robust cost basis as these units are competitive when compared to alternative options.

Equally, the proposal to adopt deeper hollow core deck units for spans up to 25 m 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 unit is also supported on the basis of cost, as these beams have, on the basis of the limited cost information available in New Zealand, a 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 new standard beam shapes to be used in future is also supported on the basis of cost, as these beams (up to a 26 m span) are the most expensive sections of all 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 shallower beam depth is required.

10. Conclusions & Recommendations

10.1 Conclusions

The literature review of Australian, United Kingdom, United States and Canadian practice showed that precast beams are 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 the most popular by far. The single hollow core was popular for bridges in specific areas, and the "I" and "U" beams were used less frequently for bridges requiring longer spans.

This review of 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.

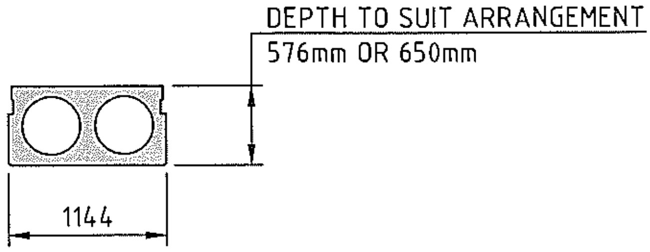
The consultation process was a crucial part of the research to ensure that all sectors of bridge industry had the opportunity to raise and discuss issues.

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 a lower number supporting the "I" beam and single hollow core deck unit.

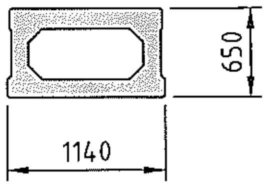
The "Super-T" beam was the clear choice as the preferred new beam shape.

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



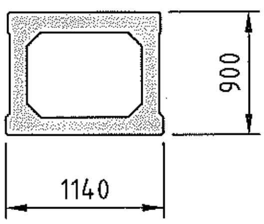
UP TO 18m SPAN

a. DOUBLE HOLLOW CORE BEAM



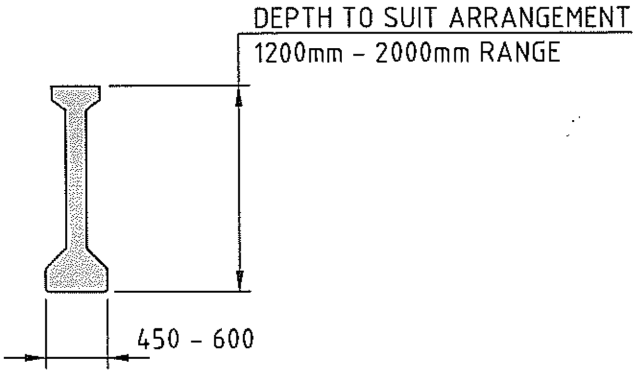
UP TO 18m SPAN

b. RECTANGULAR HOLLOW CORE BEAM



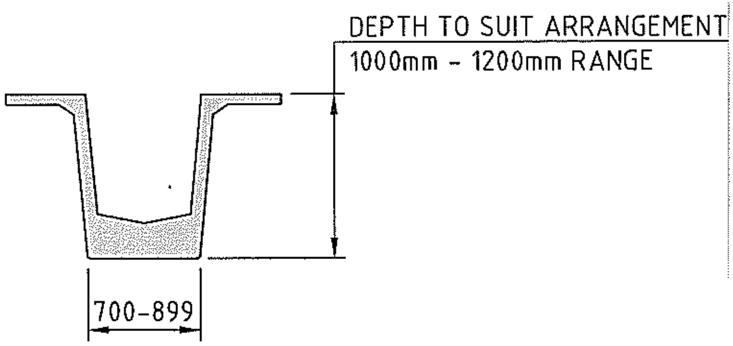
UP TO 25m SPAN

c. RECTANGULAR HOLLOW CORE BEAM



UP TO 30m SPAN

d. "I" BEAM



UP TO 30m SPAN

e. OPEN FLANGE "SUPER-T" BEAM

Figure 10.1 Bridge beam shapes for which detailed designs and drawings are to be produced in Stage 2 of this project.

10.2 Recommendations

Detailed designs and drawings for the 11.4 m-wide 'standard' bridge (Section 8.2) are to be produced for the following precast units (shown in Figure 10.1):

- Hollow core deck units, probably 1144 mm wide (to be confirmed during the detailed design stage) for spans up to 18 m, with either double circular voids (Figure 10.1a) or a single rectangular void (Figure 10.1b) (also to be determined during the detailed design stage).
- Hollow core deck units for spans up to 25 m (Figure 10.1c), with void shape to be determined during the detailed design stage.
- Existing "I" beams for spans up to 30 m (Figure 10.1d), updated for changes to design standards.
- "Super-T" beams for spans up to 30 m (Figure 10.1e).

The existing single core deck units and "U" beams are not to be 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 updated hollow core deck unit.

11. References

AUSTROADS. 1992. *Austroads Bridge Design Code.* AUSTROADS, Sydney, Australia.

Geren, K.L., Abdel-Karim, A.M., Tadros, M.K. 1992. Precast/prestressed concrete bridge I-girders: the next generation. *Concrete International (June)*: 25-28.

Lin, T.Y., Burns, N.H. 1981. *Design of prestressed concrete structures.* 3rd edition. John Wiley & Sons, New York. 646pp.

Meir, J.V., Ciciarelli, M.R., Ramirez, J.A., Lee, R.H. 1997. Alternatives to the current AASHTO standard bridge sections. *PCI Journal (January/February)*: 56-66.

Ministry of Works & Development. 1981. *Rural bridges.* Part 1: Standard bridge plans. Part 2: Specification. *Civil Engineering Division CDP 903/A:1981.* (The "red book")

Seguirant, S. 1998. New deep WSDOT standard sections extend spans of prestressed concrete girders. *PCI Journal (July-August):* 92-119.

Standards New Zealand (SNZ). 1995. Concrete structures standard. *NZS3101:1995,* Parts 1 and 2. Standards New Zealand, Wellington.

Transit New Zealand. 2003. *Bridge Manual.* SP/M/022, 2nd edition. Transit New Zealand, Wellington, New Zealand.

Waheed, A., Delaurentiis, N., Hancock, L. 2002. Use of long span concrete girders (NU) in Alberta. *Proceedings of the Sixth International Conference on Short and Medium Span Bridges.* Vancouver, Canada.

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 Kirkcaldie of Opus International Consultants, Wellington

2. Standard Bridge Beams: Review of UK and Australian Practice
by Phil Gaby of Beca Consultants, Wellington

These two reviews were 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:

Abstracts of Relevant Papers

- Meir, J.V., Ciciarelli, M.R., Ramirez, J.A., Lee, R.H. 1997. Alternatives to the current AASHTO standard bridge sections. *PCI Journal (January/February)*: 56-66.

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 US. 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 AASHTO 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 were girders developed at the University of Nebraska discussed in the next paper (Geren et al. 1992).

- Geren, K.L., Abdel-Karim, A.M., Tadros, M.K. 1992. Precast/prestressed concrete bridge I-girders: the next generation. *Concrete International (June)*: 25-28.

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 initially could 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., Hancock, L. 2002. Use of long span concrete girders (NU) in Alberta. *Proceedings of the Sixth International Conference on Short and Medium Span Bridges.* Vancouver, Canada.

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. 1998. New deep WSDOT standard sections extend spans of prestressed concrete girders. *PCI Journal (July-August):* 92-119.

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 Manufacturers of Precast Prestressed Bridge Beams

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. These are bridges that were designed for the Transit HN-HO-72 highway bridge loadings (Transit Bridge Manual 2003). Information on non-standard designs, i.e. special designs which were outside the scope of the original MWD Standard Bridge Manual, were not requested.

1. Survey Methodology

The survey form sent out to the manufacturers is supplied as Figure A. The column headings are explained in Figure B.

Figure B is in two parts. The first table lists information required from manufacturers to describe the bridges and their components.

The second table in Figure B includes a list for product types with a range of possible beam types as a guide to the respondents. They are:

- Beam types 1, 2, 4, 5, 6 represent 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 it is 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.
- Items 10-13 were included for other product types which may have been used by the manufacturer.

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

2. Survey Results

Survey responses were received from a total of 10 manufacturers: six from the North Island and four from the South Island (Figure C). The survey results were split into six regional zones (Figure D) to determine if there were regional trends or variations.

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

3. Interpretation of Results

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.

- Most responses indicated the popularity of double hollow core bridge decks throughout all regions.
- Single hollow core was popular in the northern 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 double hollow core.
- A variation on the popular double hollow core bridge decks is the single cell box section shape, which was used extensively on Route PJK over the Harbour in Tauranga.

4. Span:Depth Ratios

A comparison of the span:depth ratios against recommendations of other authorities 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 that has provided highway bridge design flexibility and economic benefits over 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)

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 lines 10 to 13
1	Twin hollow core deck unit (untopped)
2	Single core deck unit (untopped)
3	Twin hollow core 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

Figure C **Precast Prestressed Bridge deck elements**

Survey Respondents

	Company	Box Number	Suburb	Town
1	Busck Prestressed Concrete Ltd	PO Box 310		Whangarei
2	Stresscrete	Private Bag 99904	Newmarket	Auckland
3	Concrete Structures (NZ) Ltd	PO Box 849		Rotorua
4	Smithbridge Precast	21 Aerodrome Road	Mt Maunganui	Auckland
5	Unicast Concrete Ltd	PO Box 2061		Hastings
6	Precast Components (Wgtn) Ltd	PO Box 20		Otaki Railway
7	Thelin Construction	14 McPherson Street		Nelson
8	Fulton-Hogan Civil Division	PO Box 65,	Belfast	Christchurch
9	Pipeco Certified Concrete	767 Main South Road	Paroa	West Coast
10	Fulton Hogan Concrete Division	PO Box 242	Balclutha	Balclutha

Unable to respond

1	Wilson Precast Construction Ltd	PO Box 962	Drury	Auckland
2	Precast & Craneage	Ford Road		Napier
3	Lattey Civil Engineers Ltd	Omahu Road		Hastings
4	Emmett Bros Ltd	400 Heads Road		Wanganui
5	Daniel Smith Industries	315 Flaxton Road		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	Total
1	Otago-Southland	7	6				1					7
2	Nth S. Island	26	18	6				2				26
3	Wgtn.+Manawatu	6	4					1	1			6
4	Central N. Island	48	35	6			2	2			3	48
5	Auckland	2					1	1				2
6	N. 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	20 to 26	14 to 23	22	0	14 to 16	
		Comparison recommendations for span/depth taken from Lin & Burns (1981)	24 to 26					22 to 24			24 to 26	

DHC Double hollow core
SHC Single hollow core

Figure E

Item	PRODUCT Type No.	Span m	Depth mm	Span: Depth Ratio	Width mm	Topping Thickness mm	Deck Width m	Units per Span	No. of Spans	Total Units No.	Region	Conc 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	CNI	40
4	1	12.20	575	21	1144	0	9.15	8	1	8	CNI	40
5	1	14.20	575	25	1144	0	10.30	9	2	18	CNI	40
6	1	11.75	458	26	914	0	9.14	10	2	20	CNI	40
7	1	10.20	458	22	914	0	8.23	9	1	9	CNI	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	Nth.Cn.Sth.I	40
	?	11.60	576	20	1144	0	0	6	4	24	Nth.Cn.Sth.I	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	Nth.Cn.Sth.I	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

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
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