Flange Supported Double Tees
An Historical Perspective

L G McSaveney [1]
R Fulford [2]

SUMMARY

Flange support details for precast concrete double tee flooring units were developed in several countries during the 1960's. The support method simplifies building construction and it has kept double tee flooring popular and economical in the New Zealand construction market over many years.

Fletcher Concrete and Infrastructure Ltd developed a patented method of support in the late 1960's (Figure 1) through its former subsidiary, Stresscrete. Conventional flexural theory was applied to analyze the detail and the vertical shear was carried by the inclined leg of the loop bar, combined with the anti-bursting stirrups in the ends of the legs, interacting with U-bars in the flange. Load tests to prove the capacity of the "Stresscrete Loop Bar Detail" were carried out under the supervision of Beca Carter Hollings and Ferner in 1972. Sir Ron Carter observed the tests and checked and signed the method of analysis that still conservatively predicts the ultimate capacity of the loop bar flange support. The Design Code referenced in the original analysis, was ACI 318-71, which would have been typical for an advanced design from that time.

Many additional load tests have been performed over the years. These have typically been done to validate the performance under special support conditions; to investigate the effects of construction tolerances; to advance from 1.2 metres wide to 2.4 metre units as crane capacities increased; and to prove the adequacy for specific projects when requested by consultants with no previous experience of the detail.

For commercial reasons, details of testing and other information was considered confidential and was not made widely available. This has led to uninformed speculation regarding possible failure modes. These have been theoretical issues that have never been observed in numerous tests; in the dissection of specimens following testing; or during the demolition of units at the end of their service life.

Comment has centered on compliance with current codes. NZS 3101 represents good practice and is intended to provide robust solutions for a wide variety of details and applications. Different applications impose different demands, so the degree of conservatism and the importance of each requirement will vary over a range of applications. Deviation from some details that are now considered sound practice has been found not to be an issue in the loop bar flange support, as a result of extensive testing; nor has the performance in real buildings highlighted any concern. Compliance with NZS 3101 can always be confirmed by test loading to the protocol defined in AS/NZS 1170, Appendix B1.

Recent tests at Auckland University in 2008, and by BRANZ in 2009, continue to validate the capacity, toughness and reliability of this detail. The later test demonstrated its ability to accommodate support rotations equivalent to 4.75% drift while the seating was progressively reduced to 30 mm.

Earlier tests were normally carried out to satisfy the requirements for specific applications or projects. The units tested have all met the test loading criteria of their time. The fact that they might not satisfy current research methodologies does not invalidate them, but unfortunately some of those early tests are being misinterpreted and this is leading to erroneous conclusions.

[1] *Market Development Manager, Golden Bay Cement*
[2] *Executive Director, Precast New Zealand Inc.*

Concerns raised and issues addressed by testing.

Use of plain round bar.

The loop bar detail (Fig. 3) uses Grade 300 plain round bars and previous testing has been based on this. Reinforcing bar has changed since the loop bar detail was developed, but with each change Pacific Steel's Metallurgists have been consulted and subsequent testing has confirmed the performance of the detail. Change to higher strength deformed bars does create a number of issues and compromises the performance of the detail.

Deformed bars have been tested in this application (Opus Central Laboratories, 1995) but their performance was not markedly superior. The disadvantages of risking embrittlement inside the tight bend, and the variability of bend radii with deformed bars, offset any practical benefit from their use.

Load tests have confirmed the adequacy of the bond length to develop the yield capacity of the R12 or R16 loop bars in that confined region of the double tee legs.

Bend diameter.

NZS 3101 permits bend diameters of 2d for plain round bars but requires bend diameters to be at least doubled when deformed bar is used. Increasing the bend diameter would create cover issues and compromise the durability of the detail.

Welding.

Pacific Steel has confirmed the procedure used to weld the short D20 off-cut inside the loop (as shown in Fig.3) will not impair the performance provided the loop bar is plain round, Grade 300 bar; is bent to a radius of not less than two bar diameters; and the welding complies with AS/NZS 1554.3:2008. But they do recommend that the welded loop not be used in applications where it is subject to high fatigue loads.

The purpose of the weld is to ensure the unit can support the full construction load in the non-composite condition. Without the weld, the loop bar could pull through the thin flange. The welded connection also enhances development of strut and tie action when the unit acts compositely with the topping concrete.

Welding of the anchor bar to the inside of the loop is an important detail, and to eliminate this weld would impair the performance.

The Fletcher/Stresscrete policy has been that the loop bar flange support is not to be used where it will be subject to frequently repetitive stresses, such as from heavy vehicle traffic. In those applications structural steel "Cazaly Hangers" have been used.

Hooks for anchorage to the ends of plain bars.

Use of hooks to plain bars is currently considered sound practice but it has not always been a code requirement and clearly adequate bond can be developed without the use of hooks in this type of connection. Load tests have demonstrated the ability of the existing detail to perform without hooks to the bars, and there has been no indication of bond issues as a result.

Stirrup anchorage.

Stirrups are used at the ends of double tees to confine bursting stresses in the early age concrete, as the prestress is developed. Open topped stirrups (Figure 4) would not have become the traditional default detail if they had shown any indication of deficiency in the numerous tests to date that have been used to confirm bond development and shear capacity - including more than 50 years of use around the world.

Welded wire mesh web reinforcing is now commonly used as shear reinforcement in place of traditional stirrups with anchorage provided by the welding, but traditional stirrups continue to be used in the bond transfer regions at the ends of the webs.

Although unnecessary and not as convenient to use, closed stirrups, anchored around bars embedded in the topping can be provided if specified by the building Designer.

Bearing strips.

Early detailing used a plastic (wet) cement mortar, to bed the units. In recent times this was considered inconvenient and was often omitted on site, resulting in concrete to concrete bearing, without any apparent spalling.

The 200 mm wide webs on 2.400m tees result in lower bearing stresses than other types of double tee support. Reinforcement in the flanges at the ends (Fig. 2) also provide load paths that are not normally considered in determining the safe design loads, but nevertheless provides additional capacity and robustness. The wider bearing surfaces eliminate the possibility of spalling at the support.

Although not necessary in all cases, PCNZ now recommends the use of low friction bearing strips at the supports, particularly where large movements are predicted from seismic induced support rotations.

Sun induced camber.

There have been no reported instances of failure due to sun induced camber in New Zealand, with the loop bar support. Support of units above the section centroid, as provided by loop bar flange supports, eliminates this risk as it causes compression in the critical section.

Creep and shrinkage cracks.

Observations from many thousands of square metres of units in service show cracks at right angles to span direction occur in the in-situ topping at the end of the unit, but not within the length of the unit. These cracks normally take the path of least resistance and reinforcement within the end of the flange ensures transverse shrinkage cracks do not occur within the loop bar, flange support extension.

Durability.

The very narrow gap between the end of the double tee and its support obviously reduces the exposure within that confined space. This, combined with the superior durability of heat cured precast concrete, has led to expected service life of this detail in existing buildings well in excess of that required by NZS 3101. Standard details using increased cover are now being adopted as an alternative to verification by an extensive durability study to measure chloride ion ingress in that sheltered location.

A rational method of analysis.

The most reliable method of predicting the capacity of the loop bar detail is still the inverted cantilever method, based on ACI 318-71, which is attributed to John Whittaker, and review by Sir Ron Carter. In this analysis the vertical component of the inclined bars carry the design shear. Load tests confirm that yielding first occurs in the inclined bar, well away from the loop. When the inclined legs of the loop bars start to yield, the anti-bursting stirrups in the ends of the legs start to pick up load and will also eventually yield. The Stresscrete design methodology ignores the contribution from the end stirrups, but if their capacity is included in the analysis, the actual failure load will be closer to the predicted load.

Modern load tests are currently done in accordance with Appendix B of AS/NZS 1170.0:2002 and the over-strength required from the test data (to account for statistical probability) is as set out in Table B1 of that Standard. As the capacity of the loop bar detail is governed by yielding of the reinforcing bars, it is usual to assume a coefficient of variation of 5% for the structural characteristics and, depending on the number of units tested, the over-strength required may vary from 10% to 20%. For 2.4m wide double tees, each web may have two, three, or four loop bars. There are minor variations in the design capacities of the loop bars amongst double tee manufacturers in New Zealand. The reasons for this variation relate to the number of test results available, the Tee Designer's confidence, and subtle differences in the reinforcement details.

Proof by Load Test, is a powerful design tool for easily tested elements such as flange support details, power poles, the fatigue performance of railway sleepers, and culverts. The method has been widely used around the world to achieve maximum reliability, with real economy. Witnessing testing to failure gives a degree of understanding and a level of confidence not readily achieved otherwise.

Where designers can be led astray is in trying to fit a flexural theory to a population of test results that represent different failure modes. For example; if production double tees are taken at random from a stockpile and the flange support is tested, the most common result will be a flexural failure out in the span – well away from the flange support reinforcement. That result will be reported as the end point of the test, but the loop bar detail will show no distress. The failed unit will usually have surpassed its design load capacity by a comfortable margin and the Designer and the Precaster will be reassured by the result, but to someone who is later trying to fit that test result to a loop bar theoretical capacity calculation, it may appear as a low test result.

The different end points for the testing gives the false appearance of high variability and results in a low level of confidence if back analysis is used inappropriately.

How many load tests are required?

Over the years a manufacturer will build up a library of load tests to suit the different conditions encountered in double tee construction. In the past, Fletcher/Stresscrete kept tests confidential, sharing them only with the Designers responsible for the contract that they were bidding to supply units to. Lately there has been more of a tendency to share information to reduce the cost of testing.

Many tests have been carried out in the past, including those by manufacturers other than Stresscrete.

From the historic tests in the Fletcher Concrete & Infrastructure Ltd archives, records exits for:

The original development work on four foot wide double tees.
Design of these units was based on ACI 318-71. They were eighteen inches deep and enough units were tested to confirm that the analytical method was reliable, the detail was robust and the failure mode was ductile. An outcome of those tests was the need to weld a short piece of #6 (20mm) bar inside the loop bars to improve the reliability under construction over-load conditions.

Long-span units.
An extensive series of tests were done in 1973 to test 530mm deep, 1220mm wide units for the Shore City shopping centre parking building in Takapuna. These units spanned more than 16 metres and the Takapuna City Council required test data to confirm their design.

2.4 m wide units.
In 1979, 2.4 metre wide, flange-supported double tees were developed for a fish processing facility on the reclamation in the Port of Nelson. These units required 4 – R12 loop bars per leg and failed in a similar ductile manner to the narrower units. Crack patterns at the ULS load confirmed that the inclined legs of the loop bars yielded first and that 400mm of the flange adjacent to each web was contributing to the load-carrying mechanism.

Extended loop bar tests:
An extended loop bar has been developed to reduce the torsional load on structural steel support beams. This detail has been used in the Acute Services Building at Auckland Hospital in 2001, and was subject to further testing at Auckland University in 2008 at the request of Beca Consultants following use in the Whangarei Police Station by Stresscrete (Northern). The modified detail performed very well in both series of tests and if failure can be induced in the flange support by increasing the flexural and shear capacity of the main span, the extended loop bar always failed in a predictable and ductile manner. Those results are to be reported at this Conference by Rogers.

Resisting axial tension and beam rotation.
This test, commissioned by Precast NZ and performed by BRANZ earlier in 2009, examined the effect of axial tension pulling the double tee off its support. The test also rotated the unit on its support to observe the effect of relative rotation between the double tee and its supporting beam - as could occur in a ductile frame building undergoing high inter-storey drift in a major earthquake. The unit tested, coped easily with the tensile force which yielded only the topping reinforcement. It also coped comfortably with progressive reduction of the seating length to 30 mm or less, and the relative rotation at the support. The unit was seated on a McDowel Bearing Strip and minor edge spalling only occurred at a displacement beyond 4% drift. An additional test in this series may be reported at this Conference.

Non-standard Loading.

Flange supported double tees are typically designed for uniform loads. Where units are designed to support point loads, or other load configurations, the flooring designer must check for flexure, shear and bond - as would normally be done.

Where to from here?

The loop bar flange support has provided an economical and effective support solution that has been in use for 35 years without any reported instances of distress or failure. The detail may have been subject to more testing than any other flooring detail in New Zealand. Test specimens have been dissected for examination in close detail and demolition of existing stock has been checked for evidence of problems: none have been found.

PCNZ is of course concerned with safety and will address any issues that are demonstrated to be valid. Theoretical concerns have been expressed, but to date no deficiencies have been demonstrated or observed.

Further testing will be carried out, and some aspects of the detail will no doubt be modified where it can be demonstrated that the changes will not compromise the performance of the loop bar detail. As it is currently designed, the detail has a very low carbon footprint, 100% New Zealand content and low cost: all this with the ability to easily cope with normal construction tolerances. It also copes better than most other prestressed floor systems with the effects of creep, shrinkage and sun-camber. In the current economic climate it is the most practical type of double tee support for normal building construction.

Recommendations,

When one company had exclusive use of the detail, applications could be easily monitored, but if the loop bar is to be used by any producer the following limitations should apply:

- Only Grade 300, plain round bar, should be used for the loop bars.
- The detail should incorporate the 20mm diameter bar off-cut welded inside the loop, to resist construction loads.
- Welding must comply with AS/NZS 1554.3:2008.
- The detail should not be subjected to high fatigue loads as could occur with frequent bus or truck traffic.
- Design, testing and production should be monitored by Precast NZ.
- Precast NZ should be the repository of loop bar design and test information.

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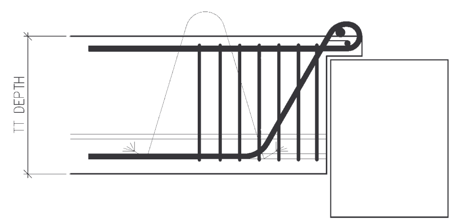

Figure 1 – Loop bar

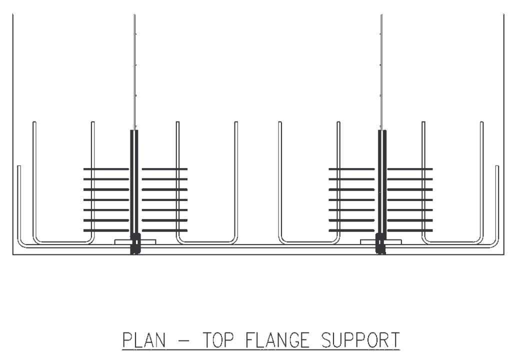

Figure 2 – Flange Support Reinforcement

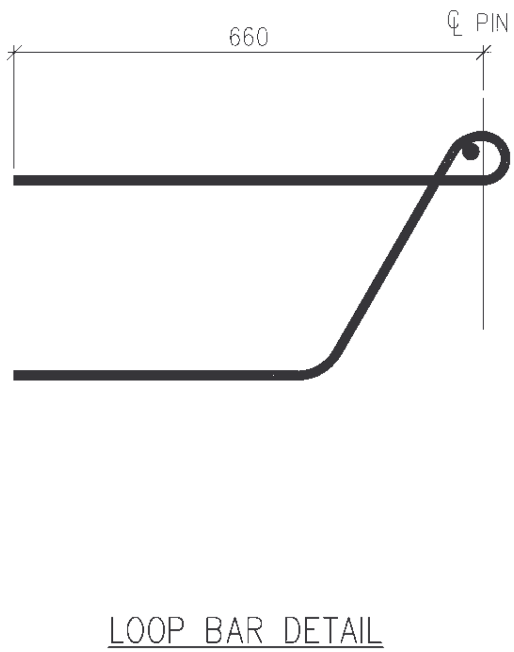

Figure 3

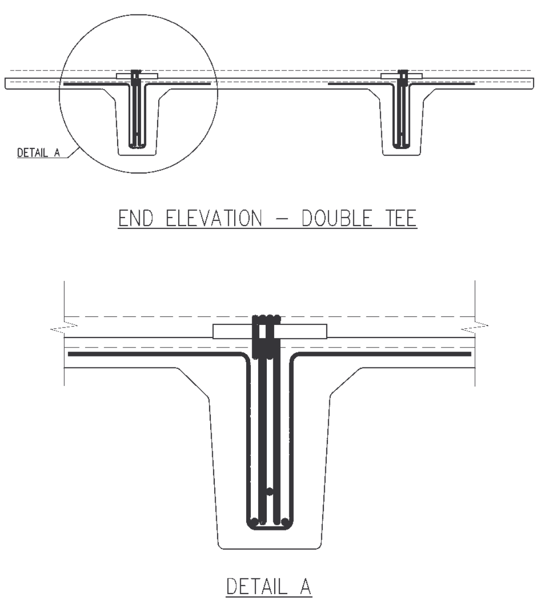

Figure 4 – Preferred Stirrup Type