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Department of Building and Housing | Building Controls
Te Tari Kaupapa Whare

Practice Advisory 1

Bend the bar but not the rules

Bending of steel reinforcement must follow New Zealand Standard procedures

Issues of concern

Incorrect bending can severely affect the performance of steel reinforcement in service. Results can be premature fracture, which will affect the capacity of the building elements to carry design loads. Of particular concern is the practice of bending reinforcing steel to too small a diameter. Bending then straightening (rebending) the reinforcing on site is of even greater concern.

To avoid fracture or weakening, NZS 3109 requires that hooks and bends are formed in accordance with the bend requirements of Table 3.1, which is reproduced below with the permission of Standards New Zealand. The minimum diameter of bend is measured on the inside of the bar.

Grade f_y (Mpa)	**Bar type**	**Bar diameter, d_b** (mm)	**Minimum diameter of bend, d_i** (mm)	
			Plain bars	Deformed bars
300 or 500	Stirrups and ties	6–20 24	$2d_b$ $3d_b$	$4d_b$ $6d_b$
	All other bars	6–20 24–40	$5d_b$ $6d_b$	$5d_b$ $6d_b$

Note that the above table only gives part of the requirements for hooks and bends. For full details of standard hooks, bends, stirrups or ties, for mesh bend diameter requirements and for galvanised bar bend requirements, refer to Clause 3.3 of NZS 3109.

Rebending should only be carried out when unavoidable and identified at the design stage. NZS 3109 and NZS 3101 require that rebending is done in the specified manner and to the manufacturer's requirements. For guidance, refer to the Department of Building and Housing wall chart on reinforcing steel requirements.

Don't

- x **Don't** bend steel on site unless absolutely necessary and then only with equipment fit for the purpose.
- x **Don't** rebend steel on site without using a purpose-built tool and proper preparation and preheating.

Do

- ✔ **Do** obtain a copy of the hooks and bends requirements in NZS 3109.
- ✔ **Do** bend any reinforcing steel using a purpose-built tool that will achieve the correct bend diameters.
- ✔ **Do** obtain bend-o-meter discs from the Department to help quickly ensure that reinforcement is bent to the correct diameters.
- ✔ **Do** report any failures of reinforcing steel to the manufacturer and the Department. Keep a sample of the failed bar.

Figure 1 A 12 mm bar bent to correct diameter of 60 mm.
Source: CCANZ IB79

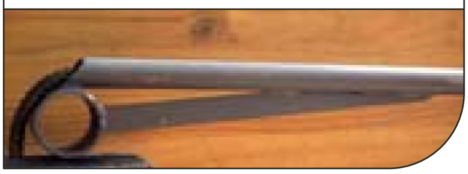

Figure 2 Cracks in Grade 500 reinforcement caused by incorrect bending and rebending

Practice Advisory 1 cont.

Background

There have been formal and informal reports of bars breaking when handled on site. In many cases this was shown to be due to incorrect bending and handling of the bars.

The Department responded by investigating the concerns and issues behind the reports. Many of the reported failures could be linked to incorrect bending and rebending practices on site. These practices are more critical with Grade 500 steel as there is less tolerance for bending this reinforcement to tight diameters.

Further information: AS/NZS 4671, NZS 3101, NZS 3109, Department wallchart, CCANZ Bulletin IB 79

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Practice Advisory 2

Pay attention to the basics!
Structural concepts and load paths

Issues of concern

Designs carried out and information supplied for building consent should show sufficient consideration of the basic structural concepts and load paths.

Inadequately defined structural concepts and poor selection of load paths can lead to the as-built structure performing below expectations.

Background

Sound structural concepts are recognised as critical to the performance of structures, particularly in earthquakes. Reports such as the Hunn Report, and the Department of Building and Housing report on the Scarry letter, indicated that some designs and drawings did not adequately demonstrate the designer's intentions in a clear and concise manner that enabled accurate checking at building consent stage.

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Don't

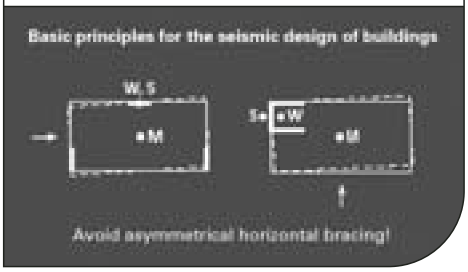
- x **Don't** assume the structural concepts are always sound and well defined, especially in unique or complicated structures.

Do

- ✔ **Do** insist that a brief Design Features Report (DFR) (ie, a clear statement of structural concepts, load paths and loading assumptions) is included at the start of all design calculations.
- ✔ **Do** have an independent check done by an experienced designer on the basic structural concepts at concept design stage, developed design stage and on completion of construction documentation.
- ✔ **Do** submit a formal Design Features Report summarising all key design parameters and describing the structural design concept with all building consent applications.

Figure 1 Example of building with highly eccentric layout of lateral bracing elements, requiring careful design for seismic torsion response.
Source: Seismic Conceptual Design of Buildings, Bachmann H

Figure 2 Plan of buildings with eccentric horizontal bracing layout for resisting lateral loads



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Practice Advisory 3

Beware of limitations
Cold-worked wire mesh

Issues of concern

In some situations where ductility in an earthquake may be required, cold-worked wire mesh may seriously affect the performance and integrity of the structure.

As the commonly specified standard mesh has a very limited ductility, it may not be able to withstand the strains imposed as a result of the design actions (displacements, forces). This can cause the mesh to fracture and reduce the capacity of the structural element and the overall performance of the structure.

Designers must ensure they specify seismic-grade steel reinforcing bars in areas requiring ductile performance of the steel. Construction contractors must ensure the design requirements are correctly implemented on site and that care is taken when using mesh on site.

Background

Concerns have been expressed about the use of low ductility mesh in floor diaphragms that are expected to undergo large displacements requiring a high level of ductile performance from the steel.

Amendment 3 (March 2004) to the Concrete Structures Standard, NZS 3101: 1995, Clause 7.3.1.2, requires welded wire fabric to have a uniform elongation of at least 10% unless the yielding of the reinforcement will not occur at the ultimate limit state or the consequences of yielding or rupture will not affect the structural integrity of the structure.

Further information: AS/NZS 4671 Steel Reinforcing Materials, NZS 3101 Concrete Structures, NZS 3109 Concrete Construction.

Don’t

- x **Don’t** use cold-worked (ie, standard) wire mesh in seismic diaphragms or as primary flexural reinforcement in slabs where there is the potential for yielding of the reinforcement.
- x **Don’t** use standard cold-worked mesh if high ductility mesh is specified.
- x **Don’t** use Grade E (Earthquake) machine-welded wire mesh unless it has been shown that the mesh in its welded condition is suitable for use in ductile demand situations (in particular the elongation requirements).

Do

- ✔ **Do** use Grade E (Earthquake) 6, 10 or 12 mm diameter bars instead of mesh in areas of high ductility demand in floor slabs.
- ✔ **Do** obtain a copy of NZS 3109 Concrete Construction and AS/NZS 4671 Steel Reinforcing Materials.
- ✔ **Do** obtain a copy of Amendment 3 to NZS 3101 Concrete Structures.

Figure 1 Separation of floor slab putting high strains on topping reinforcement.
Source: University of Canterbury Civil Engineering Department, J Matthews

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Practice Advisory 4

Do sweat the "small" stuff
Connection design and detailing

Issues of concern

The design and detailing of structural steel connections is not always being carried out in accordance with principles of statics, material behaviour and technical guidelines.

Incorrect design and construction of connections can seriously undermine the integrity of the structure.

Background

Connection details are a time-consuming part of design, but their correct design is vital in satisfying the design concept and transmitting loads between the main structural elements.

To assist in the design process a number of standard connection details are available that have been specifically designed for a number of common situations and loads. However, these standard connections are not always applicable and can be misinterpreted if left solely to steel fabricators and erectors to carry out.

Further information: NZS 3404 Steel Structures Standard; HERA Report R4-100, Structural Guide Steelwork Connections; HERA Report R4-80, New Zealand Structural Steelwork Limit State Design Guides, Volume 1, especially Section 10; HERA Report R4-58, Manual of Standard Connection Details for Structural Steelwork; HERA Steel Design and Construction Bulletin Issue No. 78; Code of Practice for Structural Steelwork Documentation.

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Don't

- x **Don't** use minimalist drawings that rely on the fabricators to work out construction details.
- x **Don't** change or use substitute connection details without obtaining the consent of the design engineer.
- x **Don't** allow eccentricities to occur at member intersections unless they cannot be avoided.

Do

- ✔ **Do** use standard detail types wherever possible.
- ✔ **Do** spend the time necessary to design and draw exactly what is required in terms of connections. Look at every link in the chain.
- ✔ **Do** carry out a constructability review of the design and drawings to ensure that the correct connection details are provided and can be fabricated.
- ✔ **Do** ensure that any standard details used are appropriate for the design loads and the design concept.
- ✔ **Do** ensure that connection details are sufficient to provide the required lateral buckling and twist restraint to column and beam members.
- ✔ **Do** allow for any member eccentricity in the design of connections.

Designers should attempt to use standard New Zealand-tested connections where possible and where not applicable develop solutions from technical first principles. All connection details should be designed or called up in the engineering calculations. A chain is only as strong as its weakest link.

Figures 1 and 2 Example of poor connection design and improved details.

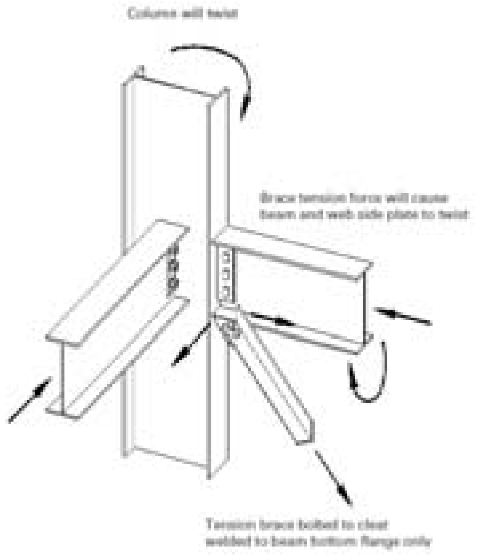

Figure 1: Poor structural design

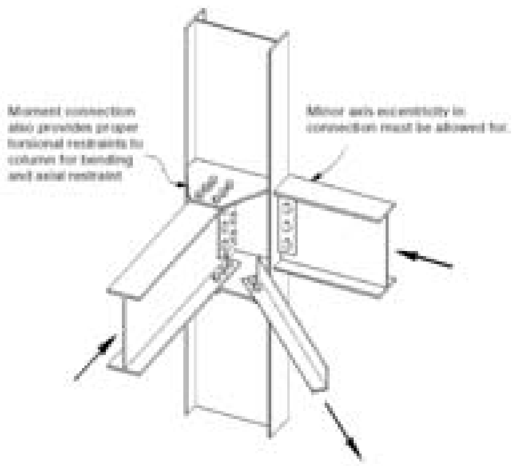

Figure 2: Improved design

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Practice Advisory 5

Allow for movement
Precast hollow-core floor assemblies

Issues of concern

Common practice to date in the design of precast hollow-core floor assemblies may not fully address the actual conditions likely to be experienced during the life of a structure, particularly in strong earthquake shaking.

Designers should consider the real actions on the design elements and the mechanisms that will be needed for the floor and its supports to maintain their integrity as the building structure deforms at or beyond the design limits. Recent research has revealed gaps in our understanding of the behaviour of these floors in such situations.

Background

Testing by Matthews et al at the University of Canterbury raised concerns about the performance of precast hollow-core floor units in a major earthquake. Key concerns were:

- beam elongation and other effects caused damage to the hollow-core seating (loss of seating or damage to the edge of the hollow-core unit)
- splitting of the hollow-core units at mid-depth occurred
- delamination of the topping concrete occurred
- in the latter stages of the test, the hollow-core units collapsed on to the floor of the laboratory.

Subsequent testing using revised details showed satisfactory performance and amendments have been made to NZS 3101: 1995. Research is ongoing to better understand the behaviour and to develop improved details.

Further information: NZS 3101 Concrete Structures Standard, University of Canterbury test results – Matthews, Lindsay.

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Don’t

- x **Don’t** ignore the effects of earthquake-induced displacements and forces on the performance of hollow-core floors.
- x **Don’t** leave detailing to chance. The designer must determine and design the appropriate connection detail between the flooring system and support structure for the type of structure.

Do

- ✔ **Do** ensure that account is taken of three-dimensional effects when considering floor support details and floor system behaviour.
- ✔ **Do** follow recommended practices in NZS 3101 Amendment 3 and the details shown in this Advisory to show exactly the correct connection details.
- ✔ **Do** design floor systems to have robust and displacement-tolerant support connections.
- ✔ **Do** insist that the contractor provides adequate shop drawings.
- ✔ **Do** ensure that the designer and contractor’s engineer review shop drawings and sign them off.

Designers and building officials should inform themselves of the latest recommendations from research in the area of hollow-core flooring and the updated design guidelines. These can be obtained through the Cement and Concrete Association, New Zealand Society of Earthquake Engineering and Standards New Zealand among other sources.

Figure 1 Example of failure in hollow-core flooring test after severe lateral displacement.
Source: University of Canterbury, Department of Civil Engineering

Figure 2 Improved hollow-core flooring details adapted from NZS 3101 Amendment 3.

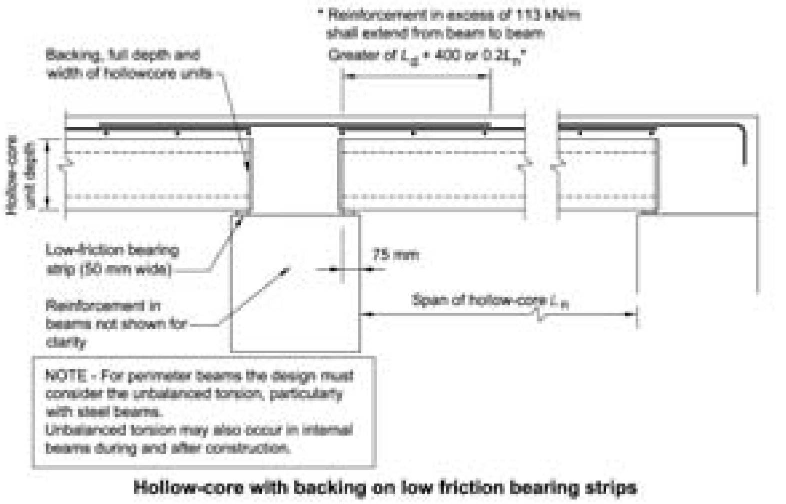
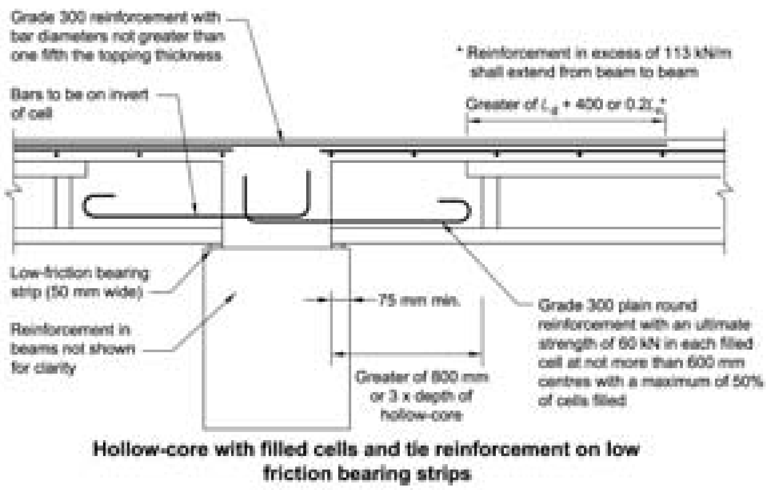


Figure 3 Improved hollow-core flooring details adapted from NZS 3101 Amendment 3.



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Practice Advisory 6

Achieve best practice – every step of the way
General design and construction practice

The following advisories should be read in conjunction with the cover note for the 'Practice Advisories 1 to 6 – Maintain professional standards'. This is available on the Department's website.

Description of concern	Possible implications for the performance of the structure	Recommended action
6.1 Diaphragm load paths Inadequate or impractical load paths are provided through diaphragms and transfer diaphragms.	Damage to floor diaphragms in a major earthquake may be significant and may result in failure of the floor to transfer earthquake and gravity loads.	Be clear on the viability and robustness of load paths from concept to final design. *Review NZS 3101: 1995 Section 13 – Design of Diaphragms.* *Refer general structural concept texts such as: White R et al, Structural Engineering, SESOC Journal, Puzzle Series 2003.*
6.2 Diaphragm detailing Inadequate consideration of detailing requirements of local effects due to steps in diaphragms, penetrations, or re-entrant corners in diaphragms. Inadequate consideration to confirm primary structural load paths for transfer diaphragms.	Significant localised damage to the diaphragm in a major earthquake and possible loss of integrity of the structure.	Ensure all links are robust and capable of performing when deformed by earthquake actions. Beware of lightly reinforced toppings and penetrations for stairs/lifts etc. Confirm that a clear structural load path is provided for all transfer diaphragms. Give consideration to the effects of variations in relative stiffness of the diaphragm and primary load resisting elements. *Review NZS 3101 Section 13, note Clause 13.3.3.* *Ensure structural analysis allows for accurate determination of the design actions in local discontinuities such as re-entrant corners.* *Refer SAFE slab design software as one means of analysing steps or re-entrant corner in slabs.*
6.3 New methods and forms of construction New methods and unusual forms of construction can introduce significant uncertainties to structural performance.	The use of unusual forms of construction and products not proven as being fit for purpose can result in a serious reduction in structural performance and safety.	Ensure all new products and systems have been appropriately tested and formally approved by a recognised authority before using them in building construction. A risk-based approach, taking into consideration the likelihood and consequences of an incorrect design, could be used to set the level of specialist expertise, scale modelling, peer review, proof testing and other steps needed to ensure the completed structure will satisfy the design intention.
6.4 Detailing requirements for reinforcement Inadequate consideration of the detailing requirements for curtailment of reinforcement in tension zones and bond stress in areas of high shear.	Significant damage in a major earthquake but unlikely to lead directly to collapse of the structure.	Detail reinforcement rigorously with appropriate input from a CPEng structural engineer. *Review NZS 3101 Concrete Structures Standard Sections 7 and 9, Clauses 7.3.22.4 and 9.4.4.2.* *Refer Park R, Paulay T, Reinforced Concrete Structures, Chapter 13 The Art of Detailing.*

Practice Advisory 6 cont.

Description of concern	Possible implications for the performance of the structure	Recommended action
6.5 Anchoring of spiral reinforcement in columns Spiral and hoop reinforcing in columns and piles is not being correctly anchored into core concrete in some circumstances.	Serious implications for performance in major seismic events. The columns and piles can fail in a brittle manner if the confining effect of spirals and hoops is lost.	Anchor both ends of every section of spiral reinforcement with a 135 degree hook. If welded splices are necessary they should be carried out in accordance with AS/NZS 1554. Welding must not affect the main reinforcing bars. *Refer NZS 3101 Section 8.*
6.6 Rebending of reinforcement Rebending reinforcing on site can seriously affect the strength and ductility of the bar.	Serious reduction in load carrying capacity may occur with possible collapse for some parts of structures.	Rebending is discouraged. Give consideration to design details that avoid the requirement for rebending. If it is unavoidable, then it must be done in accordance with manufacturers' recommendations. *Covered in NZS 3101 Section 3, Clauses 3.8.4.2 and C3.8.4.2.* *Also NZS 3109 Concrete Construction, Section 3 Clause 3.3.5.* *Refer Department report on Grade 500E steel reinforcement.*
6.7 Reinforcing for lateral bursting Poor consideration of the lateral bursting forces associated with cranked reinforcing bars.	Can lead to damage and some loss of strength.	Place special reinforcement to provide restraint against the lateral bursting forces. *Refer NZS 3101 Section 7, Clause 7.3.16.7 which generally requires transverse steel to resist 1.5 times the transverse thrust from the cranked bar.*
6.8 Grade 8.8 bolts Welding of high strength (Grade 8.8 and above) bolts will seriously affect their ductility.	Depending on the importance of the member to which the bolts are fastened, welding can cause serious failure as the bolts can fail in a brittle manner.	No welding of high strength bolts should be carried out. This includes tack welding. Bolts can be fixed in position through the use of temporary frames or adhesive. See details in HERA Report R4-58.
6.9 Shear design of beams Shear design of: – beams supporting precast flooring – shell beams may be carried out using unconservative values for the contributory width.	Likely to be of concern, especially where the structure is subjected to major earthquake actions. Localised serious damage in a major earthquake could result, such as brittle failure of beams and floor supports.	Always adopt a conservative approach in assessing shear capability to avoid brittle failures. *Review NZS 3101 Part 1 and 2 Section 10, Clauses 10.3.6 and C10.3.6.2.* *Note that the width to be used in determining shear capacity will vary as a function of the location along the beam (plastic hinge zone vs. non-hinge zone).* *Refer Bull DK,1984. Park R Behaviour of structural concrete frames with precast concrete shell beams subjected to seismic loading.*

Practice Advisory 6 cont.

Description of concern	Possible implications for the performance of the structure	Recommended action
6.10 Uneven loading Insufficient consideration of uneven loading arrangements or imposed lateral displacements, especially when checking punching shear on cast in-situ slabs/column heads.	When not considered in design the situation could lead to unsatisfactory performance, possibly partial collapse of a floor and even the overall collapse of the structure.	Consider non-uniform loading, or effect of displacement when determining critical member actions. *Refer NZS 3101 Section 9, Clauses 9.3.15 and 9.3.16.* *Refer NZS 3101 Commentary Clauses C9.3.15 and C9.3.16.* *Also refer NZS 3404 Clause 4.3.3.1 and Fig C4.3.1.*
6.11 Precast concrete Precast concrete is not covered adequately in NZS 3101. A view that precast concrete hollow-core floors performed poorly in recent earthquakes in California.	Specific implications are dealt with in other items in this table. The performance of precast concrete hollow-core floors in California is not directly comparable to New Zealand situations due to different methods of design and construction.	The revised NZS 3101, in preparation, includes a chapter specifically devoted to precast concrete. *Refer CAE Guidelines for the Use of Structural Precast Concrete in Buildings, University of Canterbury, Christchurch, New Zealand. 2nd Edition December 1999.*
6.12 Saw cuts in diaphragms Uncontrolled saw cuts in diaphragm slabs reduce transfer capacity through reducing concrete depth and potentially cutting reinforcement.	Can seriously affect diaphragm performance as noted in Item 1.	**Designers:** Indicate position and maximum depth of saw cuts clearly. Warn of dangers of cutting too deep or in a different location. *Specify a concrete mix that minimises shrinkage by minimising water content, maximising aggregate size.* **Contractors:** Do not carry out saw cuts in diaphragms (including slab on grade) without obtaining the approval from the designer. *Use good curing practices, refer NZMP 3100: 1999 The Guide to Concrete Construction.*
6.13 Buckling restraint In reinforced concrete construction tie-bars between the column and floor system in one-way frames must be sufficient to provide restraint against column buckling.	In steel construction the degree of lateral restraint provided must be correctly assessed to ensure sufficient restraint against column buckling. Lack of proper column restraint can lead to premature failure of the columns and overall structure.	**Reinforced Concrete:** Design, detail and provide reinforcement in accordance with NZS 3101 Section 4, Clause 4.3.6.7. *Floor system must be able to provide sufficient restraint to prevent column buckling and separation of the columns and diaphragm. Generally require larger of 5% of maximum axial load in column or 20% column shear from lateral forces.* **Structural Steel:** Provide detailing that will ensure the member is restrained to the degree assumed in the design calculations. *Refer NZS 3404, Section 1.3 and 4, Clause 4.8, Section 5, Clause 5.4, Section 6, Clause 6.7.* *Refer HERA Report R4-92, Restraint Classifications for Beam Member Moment Capacity Determination to NZS 3404: 1997.* *Refer Nethercot L, Lateral stability of steel beams and columns: common cases of restraint, SCI 1992.*

Description of concern	Possible implications for the performance of the structure	Recommended action
6.14 Composite steel beams Over-estimation of theoretical shear stud capacity in precast floor systems on composite steel beams.	Could lead to under-design of composite members and significant damage under service or ultimate loads.	Note reduction in shear stud capacities. *Refer HERA Report R4-113. Notes from a seminar on composite construction, especially sessions 2.2 and 4.2. Consider the effects of accumulated creep and shrinkage and moment continuity effects on stud capacity.*
6.15 Serviceability Performance of composite floor systems. Serviceability considerations (deflection, vibration) may control the size and spacing of support members and slab thicknesses in composite floor systems (insitu-slab on steel deck supported on composite steel beams).	The floor system may undergo excessive deflections, especially in local areas, or undergo excessive vibration under in-service conditions.	These are well covered in design guidance. *Refer HERA Report R4-107 and HERA Report R4-112.*

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