

Over the past 10 years Reid™ Construction Systems have carried out research into the most accurate formula, based on embedment depth and concrete strength, for the pullout capacity of headed anchors in concrete. This research has resulted in the refinement of Reid's™ Threaded Inserts to ensure that in a minimum 30MPa concrete they are capable of breaking the reinforcing, ensure minimum slippage and have sufficient bearing area to prevent concrete crushing. The following table presents the information of Reid™ Insert Capacity based on the Haeussler formula and non cracked concrete.

Threaded Insert capacity in concrete

Minimum embedment depths for threaded inserts & footplate in 25Mpa and 30Mpa concrete

Table 31.

Product Code	Grade	L ² Depth to develop Min Yield Strength (mm)		Char Min Yield Strength (kN)	L ² Depth to develop Char Max Ult Strength (mm)		Char Max Ult Strength (kN)	Threaded Insert Length plus 8mm ³
		25Mpa	30Mpa		25Mpa	30Mpa		
RB12	500E	82	78	56.5	97	92	79	108
RBA16	500E	110	103	100.6	130	122	140.8	126
RB20	500E	137	129	157.0	162	153	219.9	156
RB25	500E	171	161	245.5	203	191	343.7	199
RB32	500E	219	206	402.0	260	244	562.9	-

Note 1: The adoption of embedment depth L² will ensure that the failure mechanism will be ductile rather than by brittle shear cone pullout. See note 3

Note 2: Embedment depth is calculated using the formulas developed by Haeussler.

The general form is given as $P = 0.972 \times L^2 \times B^{2.5}$

where: P = pullout capacity of shear cone in Newtons
L = effective embedment depth in mm
B = concrete compressive strength in MPa

(Test results have shown that pull out calculated with Haeussler will be about 15% conservative) (P.T. 2001)

Note 3: Screw in plastic nail plates recess the insert by 8mm

With modern design and construction practices, where thinner sections are used and anchorages are required in concrete tension zones that can be micro cracked, the above formula requires modification to represent the reduction in strength that will occur. While this is possible with the Haeussler approach, research in NZ has focused on an alternative formula for the prediction of cone pullout capacity which accommodates anchor centre, edge distances, material property variations and construction tolerances. Known as the ψ method, it is this design approach that is presented here to be consistent with NZ research.

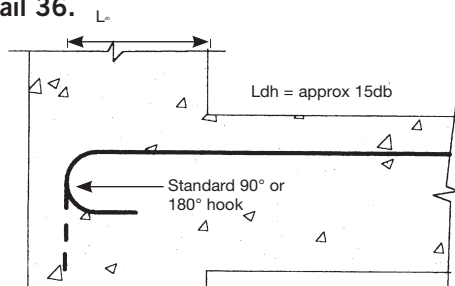
Why use a Reid™ Threaded Insert or Footplate when hooked and bent bars have always been used?

Is a common question asked by structural engineers when presented with the Reidbar™ system for the first time.

To answer this question some explanation is required:

Hooked bars and bent bars have been the standard method of providing anchorage for reinforcing steel in concrete construction where the standard bond length for a straight bar cannot be achieved. Concrete design codes account for this shorter *bond length* by specifying a minimum length, L_h from the back of the bend, or hook, to the critical surface. The minimum length equation considers the effect of concrete strength, f_c, and steel yield strength f_y.

Detail 36.



As designers and constructors become more familiar with the use of tilt-up and precast methods normal conservatism can be pushed to the limit. This is especially true with the current trend towards increasingly slimmer wall panels where the provision of an effective base anchorage for cantilever action is still required. Although bent starter bars are still widely used for this function it is not always possible to meet code requirements for minimum anchorage length in thin panels.

The Design Code NZS 3101 2006 and the previous code both draw attention to the issues related to concrete cone pullout of shallow embedment anchorage of hooked bars.

The minimum development length of 150 mm is removed from clause 7.3.14.2 and two new clauses added

"The development length, L_d, calculated using eqn 7-11 shall apply when there is no likelihood of a failure mode of a pullout of a concrete cone from the volume of concrete in which the bar is anchored" 3 part 1 ps

"If a cone of concrete pullout is likely then a rational analysis or suitable testing shall account for the proximity of the anchored bars to other loaded elements and to edges of elements"

Essentially these amendments say that one should not use hooked bars to develop full bar capacity **unless concrete cone pullout capacity exceeds the bar strength.**

So how do I calculate concrete cone pullout ?

In 1993, NZ University of Canterbury research by *Restrepo-Posada and Park*⁴ showed that the ψ -method can be used to predict the concrete cone capacity of hooked bar and headed stud type anchorages, provided that the correct embedment depth is defined. This design approach accounts for the influence of edge distance, bar spacing and micro cracking in tension zones, by applying reduction factors to the calculated concrete cone pull out capacity of the anchorage. To reduce the probability of premature brittle failures the approach also incorporates factors in the formula to account for likely variations in material strengths and construction tolerances.

The method and corresponding formula are set out in this manual in the form of a flow diagram on page 114 and is followed by a design example that compares the design of a "L" shaped hooked anchorage to that of a comparable sized Reid™ Threaded Insert anchor for a wall panel to foundation connection. (page 115.)

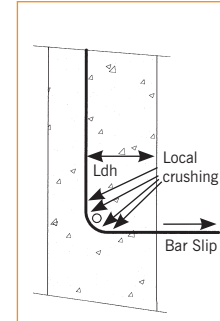
Importance of ductile failure

The importance of ductile failure should be appreciated, as it is essential to ensure that a brittle failure mechanism does not occur before a ductile failure, taking into account the possible material over strengths that can exist. In the design example it is shown that brittle failure of the anchorage will occur for both situations but in the case of the Threaded Insert it has enough capacity to ensure that the wall stem will have a ductile failure before cone pullout and thus provide a safe connection.

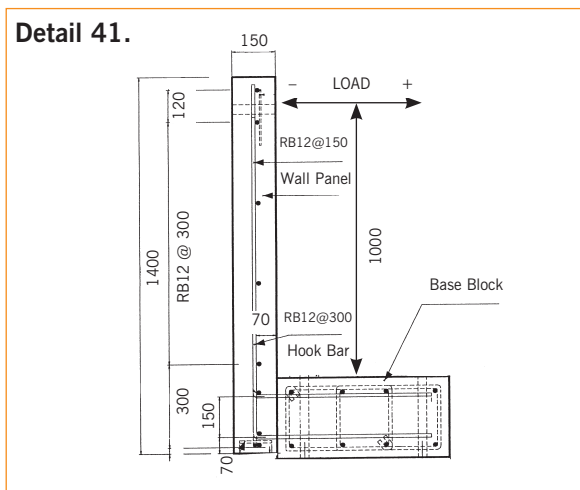
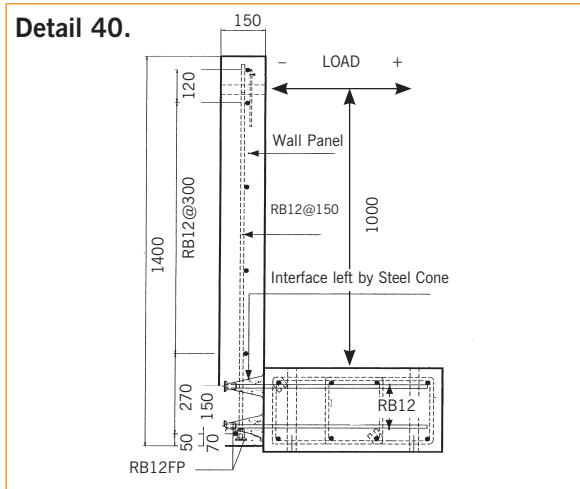
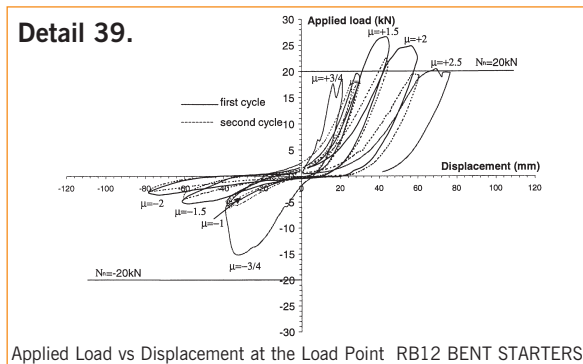
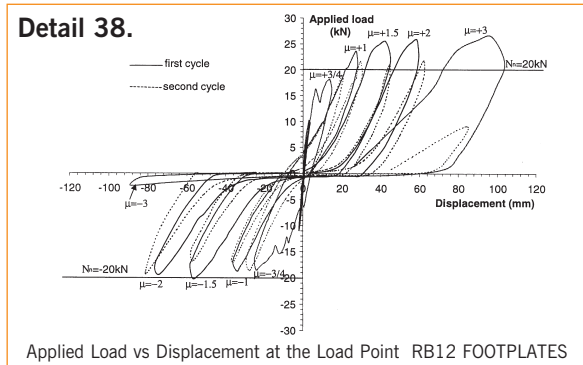
Anchorage slip

The ψ -method does not address slippage of the anchor. With hooked bars the inside of the hook causes local crushing of the concrete as the bar tries to straighten under load. Higher slippage of the reinforcing can occur compared to a headed anchor where the bearing stress under the head can be accommodated in the design of the product to minimize crushing.

Detail 37.

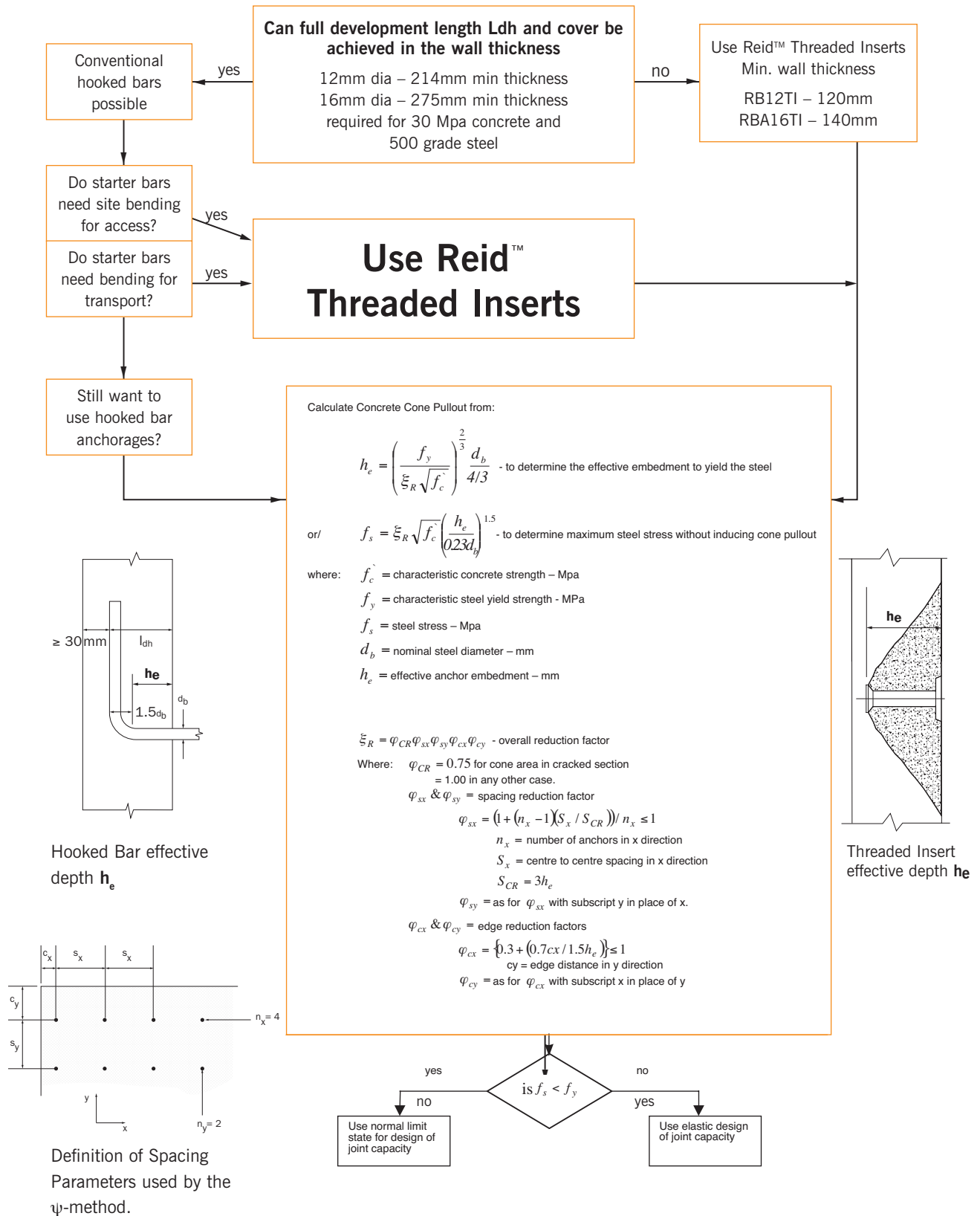


Research at NZ University of Auckland by *Maureen Ma* in 1999 into *Methods of Joining Precast Concrete components to form Structural Walls*⁶ highlighted the performance of Reid™ Threaded Inserts compared to that of conventional hooked bar construction. The diagram below shows the test comparison between the two forms of anchorage in a wall panel to footing connection when subject to cyclic loading. It can be seen that the threaded inserts performed significantly better.



REIDBAR & FITTINGS

Design Process for Cone Pullout



Example calculation of typical base fixing for Threaded Insert Connection and Hooked Bar Connection

Material Properties

$$\text{MPa} := 10^6 \text{Pa} \quad \text{kN} := 10^3 \text{N} \quad \text{kNm} := \text{kN} \cdot \text{m} \quad \text{GPa} := 10^9 \cdot \text{Pa}$$

$$f_c := 30 \text{MPa} \quad f_y := 500 \text{MPa} \quad \phi := 0.85$$

Concrete modulus of Elasticity $E_c := (3320 \cdot \sqrt{\text{MPa}} \cdot \sqrt{f_c} + 6900) \text{MPa}$ Steel Modulus of Elasticity $E_s := 200 \text{GPa}$

Wall Panel Properties

Wall thickness $\text{wall}_t := 120 \text{mm}$ Unit width of $B := 1000 \text{mm}$

Wall panel flexural strength

Reinforcing - bar diameter $d_r := 12 \text{mm}$ centres $c_r := 300 \text{mm}$ top cover

Area of reinforcing per unit length

$$A_s := \frac{\pi \cdot d_r^2}{4} \cdot \frac{B}{c_r} \quad A_s = 377 \text{mm}^2$$

$$a := \frac{A_s \cdot f_y}{0.85 \cdot f_c \cdot B} \quad a = 7.392 \text{mm} \quad \phi M_n := \phi \cdot A_s \cdot f_y \cdot \left(\frac{\text{wall}_t}{2} - \frac{a}{2} \right)$$

$$\phi M_n = 9 \text{kNm}$$

Nominal tensile capacity of section $M_t := 0.6 \cdot \sqrt{f_c} \cdot \frac{B \cdot \text{wall}_t^2}{6} \cdot \text{MPa}^{0.5}$

$$M_t = 7.9 \text{kNm}$$

Over strength - cl. 2.6.5.5 (b) iii)

$$a_{\text{com}} := \frac{A_s \cdot 1.35 \cdot f_y}{0.85 \cdot (f_c + 15 \text{MPa}) \cdot B} \quad a_{\text{com}} = 6.65 \text{mm}$$

$$\phi M_{\text{over}_{\text{ncom}}} := (A_s \cdot 1.35 f_y) \cdot \left(\frac{\text{wall}_t}{2} - \frac{a_{\text{com}}}{2} \right)$$

$$\phi M_{\text{over}_{\text{ncom}}} = 14.4 \text{kNm}$$

Overstrength factor

$$\frac{\phi M_{\text{over}_{\text{ncom}}}}{\phi M_n} = 1.6$$

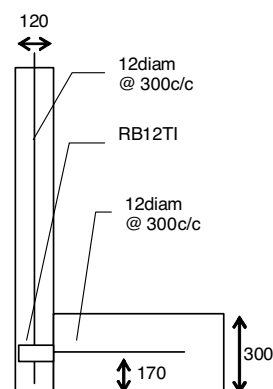
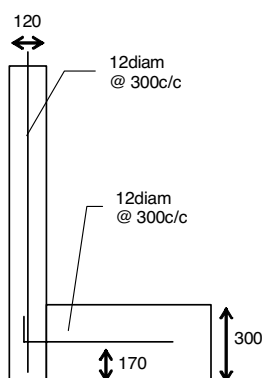
Foundation to wall panel connection:

Foundation depth $D := 300 \text{mm}$

Starter bars/ inserts of diameter $d_b := 12 \text{mm}$ at spacing of

Hooked bar pullout cone capacity $s := 300 \text{mm}$

Threaded Insert pullout cone capacity



Effective embedment depth of hooked bar with cover to starter = 30mm

Bar height $ht_{bar} := 170\text{mm}$

$$h_{e_bar} := wall_t - \frac{3 \cdot d_b}{2} - 30\text{mm} \quad h_{e_bar} = 72\text{mm}$$

Reduction factor for cracked section

$$\psi_{cr_bar} := 0.75$$

Critical Spacing for embedment depth

$$s_{cr_bar} := 3 \cdot h_{e_bar} \quad s_{cr_bar} = 216\text{mm}$$

Spacing reduction factors therefore are

$$\psi_{sx_bar} := 1 \quad \psi_{sy_bar} := 1$$

Edge reduction factors are

$$\psi_{cy_bar} := 0.3 + 0.7 \cdot \frac{ht_{bar}}{1.5 \cdot h_{e_bar}}$$

$$\psi_{cy_bar} = 1.402 \quad \psi_{cx_bar} := 1$$

SO $\psi_{cy_bar} := 1$

Total reduction factors to apply

$$\xi_{R_bar} := \psi_{cr_bar} \cdot \psi_{sx_bar} \cdot \psi_{sy_bar} \cdot \psi_{cy_bar} \cdot \psi_{cx_bar}$$

$$\xi_{R_bar} = 0.75$$

$$d'_b := \frac{d_b}{\text{mm}} \quad h'_e := \frac{h_{e_bar}}{\text{mm}} \quad f'_c := \frac{f'_c}{\text{MPa}}$$

$$f_{s_bar} := \left(\frac{h'_e}{0.23 \cdot d'_b} \right)^{1.5} \cdot \sqrt{f'_c} \cdot \xi_{R_bar}$$

$$f_{s_bar} := f_{s_bar} \cdot \text{MPa} \quad f_{s_bar} = 158\text{MPa}$$

Yielding of the reinforcement cannot be achieved before pullout failure will occur.

Using elastic analysis for an opening moment on the connection:

Modular ratio

$$m' := \frac{E_s}{E_c} \quad m' = 7.973$$

$$d'_1 := ht_{bar} \quad A'_{st} := \pi \cdot \frac{d_b^2}{4} \cdot \frac{B}{s} \quad A'_{st} = 377\text{mm}^2$$

$$na' := 100\text{mm}$$

Effective embedment depth of threaded insert with cover to insert = 12mm (galvanised)

Insert height $ht_{insert} := 170\text{mm}$

$$h_{e_insert} := 108\text{mm} \quad h_{e_insert} = 108\text{mm}$$

Reduction factor for cracked section

$$\psi_{cr_insert} := 0.75$$

Critical Spacing for embedment depth

$$s_{cr_insert} := 3 \cdot h_{e_insert} \quad s_{cr_insert} = 324\text{mm}$$

Spacing reduction factors therefore are

$$\psi_{sx_insert} := \frac{s}{s_{cr_insert}} \quad \psi_{sy_insert} := 1$$

Edge reduction factors are

$$\psi_{cy_insert} := 0.3 + 0.7 \cdot \frac{ht_{insert}}{1.5 \cdot h_{e_insert}}$$

$$\psi_{cy_insert} = 1.035 \quad \psi_{cx_insert} := 1$$

SO

$$\psi_{cy_insert} := 1$$

Total reduction factors to apply

$$\xi_{R_insert} := \psi_{cr_insert} \cdot \psi_{sx_insert} \cdot \psi_{sy_insert} \cdot \psi_{cy_insert} \cdot \psi_{cx_insert}$$

$$\xi_{R_insert} = 0.69$$

$$d'_b := \frac{d_b}{\text{mm}} \quad h_e := \frac{h_{e_insert}}{\text{mm}} \quad f'_c := \frac{f'_c}{\text{MPa}}$$

$$f_{s_insert} := \left(\frac{h_e}{0.23 \cdot d'_b} \right)^{1.5} \cdot \sqrt{f'_c} \cdot \xi_{R_insert}$$

$$f_{s_insert} := f_{s_insert} \cdot \text{MPa} \quad f_{s_insert} = 268.8\text{MPa}$$

Yielding of the reinforcement cannot be achieved before pullout failure will occur.

Using elastic analysis for an opening moment on the connection:

Modular ratio

$$m := \frac{E_s}{E_c} \quad m = 7.973$$

$$d_1 := ht_{insert} \quad A_{st} := \pi \cdot \frac{d_b^2}{4} \cdot \frac{B}{s} \quad A_{st} = 377\text{mm}^2$$

Given

$$\left[na'^2 - \frac{m' \cdot A'_{st} \cdot 2}{B} \cdot (d'_1 - na') \right] = 0$$

$$d'_{na} := \text{Find}(na')$$

$$d'_{na} = 29.1 \text{ mm}$$

$$na := 100 \text{ mm}$$

Given

$$\left[na^2 - \frac{m \cdot A_{st} \cdot 2}{B} \cdot (d_1 - na) \right] = 0$$

$$d_{na} := \text{Find}(na)$$

$$d_{na} = 29.1 \text{ mm}$$

stress in the steel is $f_{s_bar} = 158 \text{ MPa}$

stress in the steel is $f_{s_insert} = 268.8 \text{ MPa}$

Total force in reinforcing bars is $F_{s_bar} := f_{s_bar} \cdot A'_{st}$

Total force in reinforcing bars is

$$F_{s_insert} := f_{s_insert} \cdot A_{st}$$

moment will be $M_{e_bar} := F_{s_bar} \cdot \left(d'_1 - \frac{d'_{na}}{3} \right)$

moment will be $M_{e_insert} := F_{s_insert} \cdot \left(d_1 - \frac{d_{na}}{3} \right)$

Hooked bar opening moment capacity:

$$M_{e_bar} = 9.5 \text{ kNm}$$

Reid Threaded Insert opening moment capacity:

$$M_{e_insert} = 16.2 \text{ kNm}$$

Conclusions:

The **hooked bar** base connection is an unsafe design with brittle failure of the connection likely to occur before the yielding of the wall panel. $M_{e_bar} = 9.5 \text{ kNm}$ compared to possible wall strength of $\phi M_{over_{ncom}} = 14.4 \text{ kNm}$

On the otherhand the **Reid threaded Insert** connection is safe because yielding in the wall panel is likely to occur before cone failure in the foundation connection.

$M_{e_insert} = 16.2 \text{ kNm}$ compared to possible wall strength of $\phi M_{over_{ncom}} = 14.4 \text{ kNm}$

NOTE: Software for wall/base calculation is available on Reids Resource Disc or direct from Reids Engineering Manager Ph 09 920 4346

REFERENCES

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- 2) NZS:3101:Part 2:1995 Commentary on The Design of Concrete Structures
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- 4) Tensile Capacity of Steel Connectors with Short Embedment Lengths in Concrete - Restrepo- Prosada and Park August 1993
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