

Analytical Study on Pad Footing Foundation Design using Cold-formed Steel Lipped Channel Section

Wong Kah Leong¹, Mahmood Md Tahir², Airil Yasreen Mohd Yassin³,
Shek Poi Ngian⁴, Tan Cher Siang⁵.

¹ Tutor, Fakulti Pendidikan Teknikal, Universiti Tun Hussein Onn Malaysia (UTHM),
86400 Parit Raja, Batu Pahat, Johor, Malaysia.

² Professor, ³ Lecturer, ^{4, 5} PhD Candidate, Steel Technology Centre, Fakulti Kejuruteraan
Awam, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia.

E-mail: klwong@uthm.edu.my

Abstract

This paper presents the structural performance of the proposed prefabricated pad footing foundation using BRC as reinforcement and Cold-formed Steel Lipped Channel Section as permanent formwork. Steel bars or mesh has been used traditionally in reinforced concrete. Cold-formed Steel has the advantage of higher yield strength as an effect of cold working, plus its pre-galvanised metal has high resistance to corrosion. However, the use of Cold-formed Steel Lipped Channel Section for prefabrication of pad footing structures is yet to be established. Investigation has been carried out by examining the structural performance of both the proposed and typical footings. Experimental tests of 3 typical and 3 proposed pad footings were carried out in Structural and Material Lab, UTM. Comparison on the failure mode and ultimate load was made between the two set of specimens. The results shown that the proposed pad footing performed better compared to typical footing. It is concluded that pad footing foundation designed using Cold-formed Steel Lipped Channel Sections is feasible for construction.

1. Introduction

Pad footing foundation is a simple yet important structure. Typical construction method using wooden formwork and reinforced concrete has been widely in practice for years in spite of several disadvantages such as slow construction speed, inconsistent sizes, prone to delay due to site weather problem, etc. Hence, prefabrication concept was proposed to overcome the above said drawbacks. This paper presents the study

carried out on the structural performance of the proposed pad footing which was constructed using BRC as reinforcement and Cold-formed Steel Lipped Channel Section as permanent formwork.

This paper covers the designs of the proposed footings with depth of 150 mm, breath of 1000 mm, and width of 1000 mm, 1250 mm, and 1500 mm. Comparison of structural performance for both typical and proposed footings were presented. This work was in accordance to BS 8110: Part 1: 1997 [2] and also BS 5950: Part 1: 2000 [1]. Discussion was mainly on the structural performance of the pad footing.

2. Details of Pre-fabricated Pad Footing using Cold-formed Steel Lipped Channel Sections

Conventional construction methods are still widely in practice. Prefabrication concept still not gains popularity although it has been introduced in Malaysia around 1960's. Light steel framing system utilising galvanized Cold-formed Steel sections is one of the prefabrication concepts which could be highly recommendable for construction practice, because the advantages of the cold-formed steel such as to speed up the construction time, reduce material usage, and guarantee quality of building. Framing system ensures the prefabricated components are light, easy to transport, and cement can be casted upon frames arrival at site after put into the exact location.

The proposed prefabricated pad footing implemented such framing system approach. Cold-formed Steel Lipped Channel Sections are tied together

using bracket, forming a rectangular frame, acted as permanent formwork and also contributed to the strength of the pad. Steel mesh reinforcement (BRC) is tied to the frame. The reinforcement members of the stump inclusive of steel bars and steel links are tied and sitting on top of the BRC, as in Figure 1.

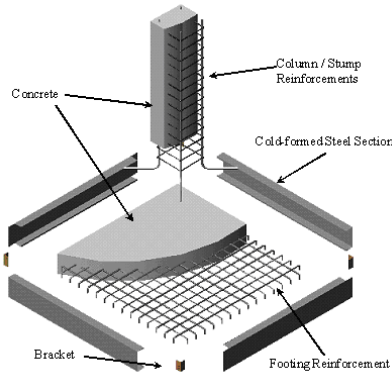


Figure 1 – The proposed pad footing.

Since the cold-formed steel members of the footing are integrated into the pad upon hardening of the concrete, intimate contact between steel and concrete restrains the plate into one-way local buckling, which reduce the tendency of the cold-formed steel to have local buckling, as in Figure 2. Thus, such reaction can potentially increase the strength of the whole structure.

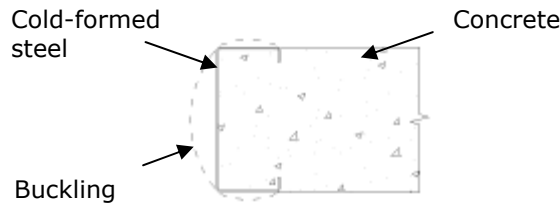


Figure 2 – One-way local buckling phenomena.

Previous study on such concept was for composite profiled beams and the profiled box section which formed the permanent formwork were found that it can substantially increase the strength of the structure and lead to an increase in the span/depth ratio in the order of 30% while reduce deflections by 40% [3].

In the case of composite profiled beams, the buckling of the profiled sheet is unlike the standard forms of buckling of thin-plate elements because the steel plate elements in composite profiled beams are restricted to form outwards from the concrete [4], and

increased the strength of the structure. Such situation also applied for the authors proposed pad footing.

3. Details of the Proposed Design

The proposed pad footing was designed in consideration to four aspects referred to BS 8110-1:1997 [1]. Design calculation is shown as following example:

Provided a pad footing with depth 150 mm, both of width and length 1000 mm, and stump size of 225 mm by 225 mm, concrete strength 35 N/mm² and BRC A10 (mesh with bar size of 10 mm at 200 mm distance and yield strength of 460 N/mm²), cover at 40 mm, thus:

- i. Maximum Punching Shear (occurred around stump perimeter), from Section 3.7.7.2 and 3.4.5.8

$$v_{max} = \frac{V}{u_o d} \quad (1)$$

$$v_{max} < 0.8 \sqrt{f_{cu}} \quad (2)$$

$$u_o = 4 \times 225 = 900, \text{ and}$$

$$d = 150 - 40 - 10 - 10/2 = 95,$$

$$V < 0.8 u_o d \sqrt{f_{cu}}, \text{ so, } V < 404.4 \text{ kN.}$$

Knowing that $P = N/A$, and $V = P \times \text{Area}$ subjected to shear, so the maximum force allowable could be derived as,

$$N = (404.4 \times 1^2) / (1^2 - 0.225^2) = 426 \text{ kN.}$$

- ii. Punching Shear (occurred around 1.5 d from stump face), from Section 3.11.3.4(b) and Table 3.8

$$v_c = 0.79 \left\{ \frac{100 A_s}{b_v d} \right\}^{\frac{1}{3}} \left(\frac{400}{d} \right)^{\frac{1}{4}} \left(\frac{f_{cu}}{25} \right)^{\frac{1}{3}} / \gamma_m \quad (3)$$

$$\left\{ \frac{100 A_s}{b_v d} \right\}^{\frac{1}{3}} = 0.74 \quad \left(\frac{400}{d} \right)^{\frac{1}{4}} = 1.43$$

$$\left(\frac{f_{cu}}{25} \right)^{\frac{1}{3}} = 1.12$$

$$v_c = 0.79 \times 0.74 \times 1.43 \times 1.12 / 1.25 = 0.75 \text{ N/mm}^2$$

Substitute values into equation (1) yield $V = 145 \text{ kN}$, thus $N = 196 \text{ kN}$.

iii. Punching Shear (occurred around d from column face).

Going through equation (3) then (1), the calculated maximum force allowable is $N = 237$ kN.

iv. Moment Resistance (strength contributed from steel reinforcement), from Section 3.4.4.4

$$K = M / bd^2 f_{cu} \quad (4)$$

$$z = d \left\{ 0.5 + \sqrt{\left(0.25 - \frac{K}{0.9} \right)} \right\} \quad (5)$$

$$A_s = M / 0.95 f_y z \quad (6)$$

It is expected that cold-formed steel functioning as the permanent formwork also contribute to the moment resistance. The used C Section has area of 480 mm^2 , roughly assumed half of it in tension and half of it in compression, so two sections bounding the pad contribute another 480 mm^2 to the steel area resisting moment. Thus, solving equation (4) to (6) yields:

$M = 11.42$ kNm before adding C Section and
 $M = 25.88$ kNm after adding C Section.

Knowing that $M = wL^2/2$, so the maximum force allowable is calculated as:

$$w = 2 \times 11.42 / [(1 - 0.225)/2]^2 = 152 \text{ kN}$$

* without C Section, or

$$w = 2 \times 25.88 / [(1 - 0.225)/2]^2 = 345 \text{ kN}$$

* with C Section added in.

Summarising all into a single table and the weakest value indicate the failure occurrence possibility, as in the following Table 1.

Consideration	Calculated Value, kN	
	Typical	Proposed
Max. Punch Shear	426	426
1.5 d Punch Shear	196	196 *
1.0 d Punch Shear	237	237
Moment Resistance	152 *	345

* denote failure occurrence possibility.

Table 1 – Summary of calculation.

4. Details of the Experimental Tests

In order to properly investigate the accuracy of the proposed calculation, proper experimental tests were to be carried out. Typical and proposed pad footings were prepared accordingly, and tested upon desired strength were achieved. Experiments were set-up as in Figure 4 to examine the strength and also if the failure were caused by punch, shear, moment, and/or any combination of them. DARTEC machine which gave the outputs of deflection and load applied to the specimens in plain text data files were then analysed later, and processed data can be generated into graph as in Figure 5.



Figure 4 – Setting of specimen on test rig to test for shear/moment (above) and test for punch (lower).

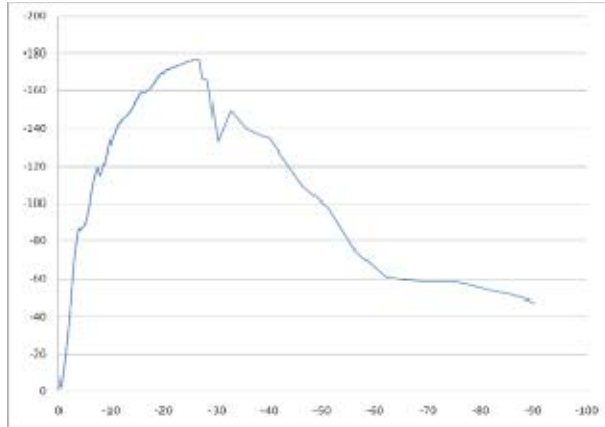


Figure 5 – Example graph of Load (kN) vs Displacement (mm).

5. Comparison and Discussion

The calculated pad strength data derived from the method described in Section 3 of this paper and tested pad strength data acquired from experiments are summarised in the following Table 2.

Pad width	Typical pad, kN		Proposed pad, kN	
	Calculated	Tested	Calculated	Tested
1000	122	120	168	177
1250	81	88	156	147
1500	61	58	149	130

Table 2 – Comparison of calculated vs tested pad strength.

Calculation done for the above Table 2 were already considering the actual steel area of BRC, concrete strength, steel strength, moment lever arm, and etc, which based on the data from tensile test and compression test carried out for the material used.

The predicted failure modes gotten from design approach and actual failure modes observed from experiments were summarised in the following Table 3.

Pad width	Typical pad		Proposed pad	
	Predicted	Actual	Predicted	Actual
1000	Moment	Moment	Punch 1.5d	radial
1250	Moment	Moment	Punch 1.5d	symmetry
1500	Moment	Moment	Punch 1.5d	yield lines

Table 3 – Comparison of predicted vs actual failure mode.

From Table 2 it is shown that 48% to 124% increment of actual pad strength could be achieved using cold-formed steel lipped channel section as permanent formwork of pad footing. Failure mode also changed to radial symmetry yield lines similar to the failure mode of two-way slab, as in Figure 6

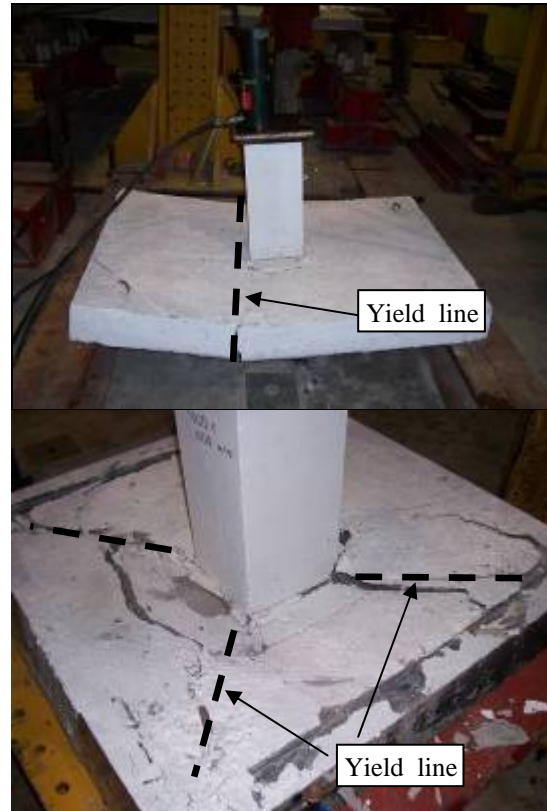


Figure 6 – Failure modes observed in experimental test, moment (above) and radial symmetry (lower).

In reference to thin walled composite filled beams [5], the beams could yield before buckling or buckling before yield. While the proposed pad only yield before buckling, post yielding failure mode for the cold-formed steel was observed, where the end expansion similar to the thin walled composite section, and the bracket torn away from the cold-formed steel, as in Figure 7.



Figure 7 – Failure observed in experimental test, bracket torn off (left) and edge expansion (right).

6. Conclusion

The results shown the approach used in this paper was very near to actual situation where data of actual strength of the pad were 97.7% of the calculation derived value. It can be concluded that it is feasible to implement such calculation procedure for the design of the proposed pad footing and pad footing foundation designed using Cold-formed Steel Lipped Channel Sections is feasible for construction.

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8. Appendix

Notations used in this paper:

- A_s = Area of tension reinforcement
- b = breath of section of the pad
- b_v = breath of section of the pad
- d = effective depth of the pad
- f_{cu} = characteristic strength of concrete
- f_y = characteristic strength of reinforcement
- K = factor based on simplified stress block
- L = length of moment lever arm
- M = factor design ultimate moment
- N = Load
- P = Pressure
- u_o = stump perimeter

- v_c = design concrete shear stress
- v_{max} = maximum design shear stress
- V = design shear force due to ultimate loads
- w = Load
- z = lever arm
- γ_m = partial safety factor

9. References

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