EXPERIMENTAL STUDY ON SHEAR CAPACITY OF STEEL ENCASED CONCRETE PILES
PART 3: CAST-IN-PLACE CONCRETE PILES

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Cast-in-place concrete Compression strut Local buckling
Shear strength Shear yield Steel encased

1. Introduction

This paper summarizes the results from cyclic shear experiments of three steel encased circular piles with cast-in-place concrete (denoted as TS piles hereafter) specimens: (a) TSS1 (axial load ratio, η=0.1); (b) TSS2 (η=-0.3); and (c) TSS3 (η=0.5). The observed shear strengths are compared with shear strength calculated using design codes. The implications of the findings in the design of TS piles are also discussed.

2. Experimental results

2.1 General behavior

The lateral load-drift responses of three TS specimens are presented in Fig. 1. The points corresponding to first yielding of the steel casing in tension, compression, and shear are also marked. In TSS1, the steel casing yielded in compression (R = 0.78%) and shear (R = 0.84%) followed by yielding in tension (R = 1.6%). The peak shear force was observed at R = 3.4%. The strength started to degrade in the subsequent loading cycles due to outward buckling of the steel casing at the ends. In the case of TSS2, the steel casing yielded in shear (R = -0.89%) followed by the yielding in tension (R = -1.02%). The tensile axial load delayed the compression yielding of steel casing to R = 3.0%. Consequently, the outward buckling of the steel tube at the ends of the specimen was observed only at R= 6%. The peak shear force was observed at R = 10.9 %. Because of the delayed buckling, the hysteretic response did not show significant strength degradation even up to R = 10%. The shear capacity of TSS1 was larger compared to TSS2 as the compressive axial load enhanced the shear resistance of the concrete. In TSS3, the steel casing yielded in compression at very small lateral drift R =-0.19% due to the high axial load. Consequently, buckling of the steel tube was evident at R=1.0% and the peak shear force was observed at this drift. This was followed by rapid drop in lateral load carrying capacity and stiffness degradation. The sudden drop in shear strength of TSS3 at relatively smaller drift indicates that the TS piles designed to carry high axial load can fail in shear even at small lateral displacement.

2.2 Extent of shear yielding

Strain rosette gauges were placed along the circumference of the steel casing to determine the extent of shear yielding in the pile specimens. The distribution of shear strain for TSS3 at the loading step corresponding to peak shear force is presented in Fig. 2. The strain gauge measurements show that shear strain in the steel surface ($\gamma_{z\theta}$) reached the yield shear strain (γ_{yield}) up to rosette gauges placed at 60° in both directions. This implies that 2/3rd of the steel cross-section is effective in resisting shear in TS piles.

2.3 Damage to the specimens

In all specimens, the steel casing buckled at the extreme compression fibers at top and bottom ends. This local buckling caused bulging of the steel tube which spread about 40 mm in length at the end of the experiment. The steel casing was removed to observe the damage to concrete after loading test. The concrete in TSS1 showed few diagonal shear cracks, but significant crushing of the concrete was observed at the end regions where

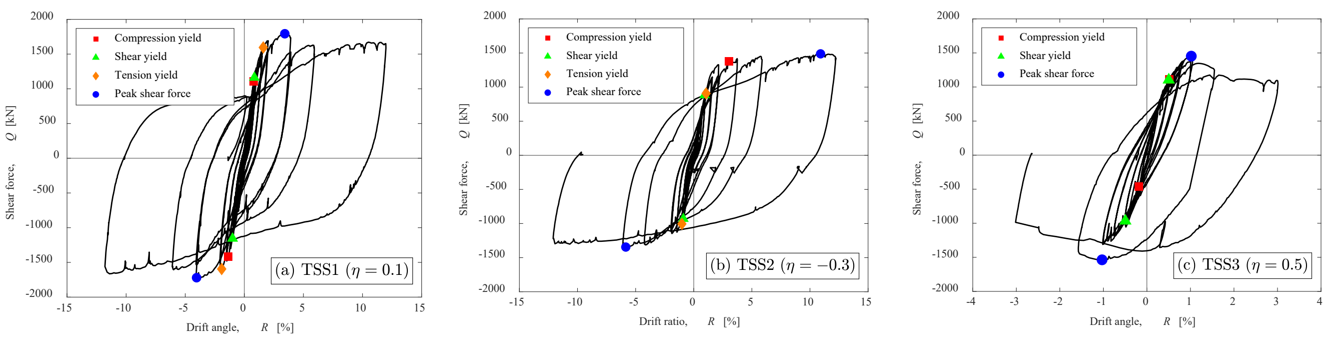

Fig.1 Shear force-drift response of the cast-in-place pile specimens.

Table1 Comparison of shear strength predictions to the experimental value (Q is in kN).

	Q_{exp}	Q_{AIJ}	Q_{COPITA}	$Q_{u, Case1}$	$Q_{u, Case2}$	$Q_{flex, Case3}$
TSS1 (η= 0.1)	1793	689 (2.60)	740 (2.42)	1213 (1.48)	1259 (1.42)	2019 (0.89)
TSS2 (η= -0.3)	1488	702 (2.12)	751 (1.98)	1030 (1.44)	851 (1.75)	1432 (1.04)
TSS3 (η= 0.5)	1536	702 (2.19)	755 (2.03)	1059 (1.45)	1466 (1.05)	1951 (0.79)

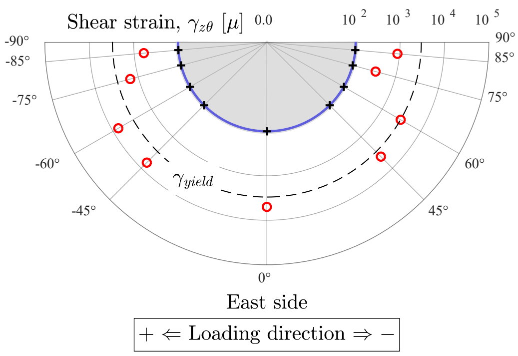

Fig.2 Shear strain distribution along the outer surface of steel casing for TSS3 at peak shear force.

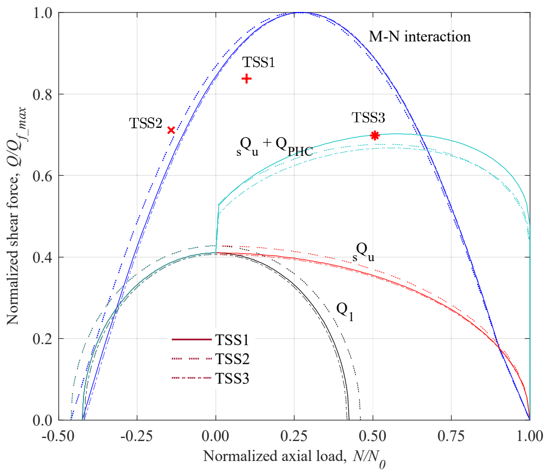

Fig.3 Comparison of shear strength predictions to the experimental values.

the steel casing bulged. In TSS2, shear cracks oriented at 45° were observed (in both directions) in the concrete indicating the development of diagonal compression struts. In addition, limited concrete crushing was also seen at the ends where local buckling of steel occurred. Specimen TSS3 showed clear evidences of shear failure. The steel casing showed excessive diagonal deformations, and the concrete failed along the diagonal compression struts.

2.4 Comparison with shear strength predictions

The experimentally obtained shear strengths are compared with the shear capacity predictions using the provisions of different design codes (discussed in Part 2) in Table 1 and Fig. 3. The predictions from AIJ[1)] and COPITA[2)] methods are overly conservative for all three TS specimens. Shear strength $Q_{u,\ Case2}$ (which used PHC equation for concrete contribution) resulted in shear strength very close to the experimental value for TSS3. Among the available expressions, shear strength $Q_{u,Case1}$ is reasonably conservative (average experimental to predicted shear capacity:1.46) for the design of TS piles. It should be noted that this method assumes yielding of the $2/\pi^{th}$ part of the total cross-section of the steel tube (i.e., A_{eff} = $0.64A_s$) in shear, with reductions to account for the axial load carried by the steel. This in agreement with the strain gauge measurements, which show that $2/3^{rd}$ of steel cross-section is effective in resisting shear in TS piles.

3. Conclusions

The main conclusions drawn from this study can be summarized as follows:

a) Under tensile axial load (η=-0.3) and small axial compressive load (η=0.1), TS pile showed ductile response and failed with bulging of steel tube at ends. However, under very high axial compression (η=0.5) the shear capacity decreased due to early onset of steel buckling and the failure was brittle.

b) Based on the extent of shear yielding of steel casing ($\gamma_{z\theta} \geq \gamma_{yield}$), the area of steel effective in resisting shear can be taken as $2/3^{rd}$ of the total cross-sectional area.

c) The $Q_{u,Case1}$ method gives reasonably safe estimate of shear capacity of TS piles and is recommended for the design.

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