

INTISARI

Spun pile prategang merupakan salah satu jenis pondasi yang banyak digunakan karena kemampuannya dalam menahan beban aksial serta efisiensi dalam proses fabrikasi dan instalasi. Namun demikian, kajian mengenai interaksi antarparameter desain, seperti diameter penampang, rasio tulangan longitudinal, mutu beton isian, dan rasio strand prategang, terhadap respons lateral *spun pile* masih bersifat terbatas, terfragmentasi, dan kurang terintegrasi secara sistematis. Selain itu, belum adanya pendekatan holistik yang mempertimbangkan variasi desain serta kondisi pembebanan kompleks turut menciptakan celah pengetahuan yang signifikan dalam memahami perilaku nonlinier *spun pile* di bawah pengaruh beban aksial dan siklik.

Penelitian ini melakukan pemodelan numerik terhadap 60 model *spun pile* prategang menggunakan OpenSees untuk mengevaluasi respons struktur akibat variasi geometri dan pembebanan. Parameter yang divariasikan meliputi rasio strand prategang, diameter penampang, mutu isian beton, rasio tulangan isian serta rasio beban aksial sebesar 8% dan 16%. Pemodelan dilakukan secara tiga dimensi menggunakan pendekatan *fiber section* yang memperhitungkan nonlinier material dan nonlinear geometri akibat deformasi besar serta efek P-Delta. Sistem tumpuan mengikuti konfigurasi *pin-rol*, dan pembebanan siklik diinput sebagai gaya terpusat dengan *time series linear* dan *path*, berdasarkan protokol ACI 374.1-05. Distribusi plastisitas dimodelkan menggunakan elemen *force-based beam-column* dengan integrasi Gauss-Lobatto.

Hasil simulasi menunjukkan bahwa peningkatan diameter *spun pile* memberikan dampak paling signifikan terhadap performa struktur, dengan kenaikan kapasitas momen dan geser lebih dari 200%, energi disipasi lebih dari 500%, serta peningkatan daktilitas hingga 40% pada model dengan beton isian, meskipun tipe *hollow* justru mengalami penurunan daktilitas. Gabungan mutu beton isian dan rasio tulangan isian yang lebih tinggi turut meningkatkan daktilitas hingga 30% dan energi disipasi hingga 50%, meskipun pengaruh mutu beton terhadap kapasitas momen dan daktilitas relatif kecil. Peningkatan rasio strand prategang juga berdampak positif terhadap kapasitas momen (10–20%), daktilitas (5–15%), dan energi disipasi (hingga 10%), terutama pada pile berdiameter besar dan beban aksial rendah. Model numerik yang dikembangkan dengan STKO OpenSees menunjukkan akurasi baik dalam memprediksi respons *spun pile*, dengan bentuk kurva histeresis yang sebanding dengan data eksperimen, sehingga valid digunakan untuk mengevaluasi dan mengoptimalkan desain *spun pile* tahan gempa.

Kata kunci: *Spun pile*, *Fiber section*, Perilaku nonlinier, Siklik, OpenSees

ABSTRACT

Prestressed spun piles are widely used as foundation elements due to their high axial load-bearing capacity as well as efficiency in fabrication and installation. However, studies on the interaction among key design parameters, such as cross-sectional diameter, longitudinal reinforcement ratio, infill concrete strength, and prestressing strand ratio, on the lateral response of spun piles remain limited, fragmented, and insufficiently integrated. Moreover, the absence of a holistic approach that accounts for design variations and complex loading conditions has created a significant knowledge gap in understanding the nonlinear behavior of spun piles under combined axial and cyclic loading.

This study conducts numerical modeling of 60 prestressed spun pile models using OpenSees to evaluate structural responses under varying geometric and loading conditions. The investigated parameters include prestressing strand ratio, cross-sectional diameter, infill concrete strength, infill reinforcement ratio, and axial load ratios of 8% and 16%. Three-dimensional modeling is carried out using the fiber section approach, incorporating both material and geometric nonlinearities due to large deformations and P-Delta effects. The support system is configured as pinned-roller, while cyclic loading is applied as a concentrated force with linear time-series path input based on ACI 374.1-05 protocol. Plasticity distribution is represented using force-based beam-column elements with Gauss-Lobatto integration.

The simulation results indicate that increasing the pile diameter has the most significant influence on structural performance, yielding more than 200% improvement in moment and shear capacity, over 500% increase in energy dissipation, and up to 40% enhancement in ductility for infilled models, while hollow sections tend to exhibit reduced ductility. The combination of higher infill concrete strength and infill reinforcement ratio further improves ductility by up to 30% and energy dissipation by up to 50%, although the effect of concrete strength on moment capacity and ductility is relatively minor. An increase in prestressing strand ratio also contributes positively to moment capacity (10–20%), ductility (5–15%), and energy dissipation (up to 10%), particularly in larger-diameter piles subjected to lower axial loads. The numerical model developed with STKO-OpenSees demonstrates good accuracy in predicting the response of spun piles, with hysteresis curves consistent with experimental data, thus providing a reliable tool for evaluating and optimizing seismic-resistant spun pile design.

Keywords: Spun pile, Fiber section, Nonlinear behavior, Cyclic loading, OpenSees