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Çelik Taban Plaka ile Manşonlu Ankraj Çubuğu Bağlantılarının Performans Değerlendirmesi

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Öz

Bu araştırma, çevrimsel yükleme altında çelik ankraj ile açıkta kalan taban plakası bağlantılarının performansına odaklanan bir çalışmanın sonuçlarını sunmaktadır. Çalışma, kolon-ankraj bağlantılarının sünekliğini artırmayı amaçlayan yeni bir methodu tanıtmaktadır. Taban plakası ile ankraj çubuğu rondelası arasına belirli bir geometriye sahip bir çelik pul dahil edilerek, bağlantıdaki yük yolu kesintiye uğrar ve bu da daha sünek bir davranış elde edilmesini sağlar. Araştırma, yeni yöntem metodunu tanıtmak amaçlı, farklı pul şekillerine sahip açıkta kalan taban plakası bağlantılarını incelemek için doğrulanmış ve sonuçları karşılaştırılmış bir sonlu eleman (FE) modeli kullanır. Bu çalışmada açıklanan yenilikçi yaklaşım, bağlantıların kapasitelerine ek olarak bağlantıların dönme kapasitesini önemli ölçüde geliştirme potansiyeline sahiptir.

Anahtar kelimeler: Çevrimsel yükleme, Taban plakası bağlantısı, Süneklik, Güçlendirme, Dönme kapasitesi

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Performance Assessment of Base Plate Connections with Anchor Rod Sleeves

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Abstract
This research presents findings from a study focused on evaluating the performance of exposed base plate connections featuring anchor rods under cyclic loading conditions. The study introduces an innovative sleeve system approach designed to enhance the ductility of column base connections. The inclusion of a steel sleeve with defined geometric characteristics between the base plate and the anchor rod washer modifies the load path within the connection, resulting in a more ductile response. The study utilizes a validated finite element (FE) model to analyze exposed base plate connections featuring different sleeve shapes, illustrating the concept behind this novel method. The innovative approach discussed in this research has the potential to significantly increase the rotational capacity of connections without compromising their inherent strength.

Keywords: Cyclic loading, Base plate connection, Ductility, Retrofitting, Rotational capacity

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1. Introduction

Exposed base plate connections are widely employed for transmitting axial stresses, shear, and moments from the steel structure to the foundation. The overall structural performance during earthquakes is heavily influenced by the rotational capacity and energy dissipation capabilities of these base plate connections. As a result, extensive research has been conducted on exposed base plate connections to enhance their performance characteristics [1-10].

The ductile anchor approach, as recommended by several studies [6, 8, 11, 12, 13], has been suggested to improve the rotational capacity of base connections. Various tests, including tension tests on individual anchor rods [10] and combined shear and tension tests [11], have been carried out to evaluate the impact of elongation length on deformation capacity. The force generated in the anchor rod is affected by both the bearing between the anchor and grout and exposed length, which significantly impact the overall strength of the connection. Additionally, Shaheen et al. [14] introduced a novel sleeve system applied to exposed base plate connection aimed at improving the rotational capacity, which was investigated through detailed numerical analysis. The analyses released that the proposed system noticeably increases the rotational connection capacity under monotonic loading conditions. Additionally, it is important to highlight that the research in the previous study was conducted under monotonic loading conditions [14]. This may not directly apply to connections exposed to dynamic forces, such as seismic events, without additional research.

This study introduces a novel sleeve system with the goal of enhancing deformation capacity of exposed base plate connections subjected to cyclic loading. This suggested approach not only improves the effectiveness of newly installed base plate connections but also serves as a cost-effective retrofitting device for existing connections. In the case of retrofitting phenomena, if the rod falls short in length to fit the sleeve between the washer and the base plate, it can be elongated through the use of a coupling nut or through welding for the retrofitting purpose. The focus of the research is primarily on exposed base plate connections with thick plates, where failure is predominantly influenced by the anchor rod. To carry out the parametric analysis, a finite element (FE) model is employed, which has been validated through experimental testing.

2. System Description

The proposed sleeve system is illustrated in Figure 1, where it is positioned between the base plate and the washer of the anchor rod in the exposed base plate connection. The sleeve system can be identified by its characteristics such as thickness, length and wall curvature, which is incorporated to prevent immediate buckling of the wall and lead to bending failure. The curvature of the sleeve wall is determined by the amplitude and waveform of the sleeve. Although several waveform configurations may define the sleeve design, the objective is to achieve optimal structural performance with minimal manufacturing costs. This study specifically focuses on a sleeve design with positive Gaussian curvature, as negative Gaussian curvatures may necessitate a non-standard washer due to the substantial forces resulting from the bearing between the sleeve and the washer.

To ensure increased ductility, it is essential for the sleeve to undergo bending deformation before any other components of the connection fail. For this reason, the capacity of the sleeve must be less than the force applied to the anchor rod at the point of failure. This ensures that the sleeve absorbs a significant portion of the forces and allows for controlled deformation, promoting a more ductile behaviour of the overall base plate connection

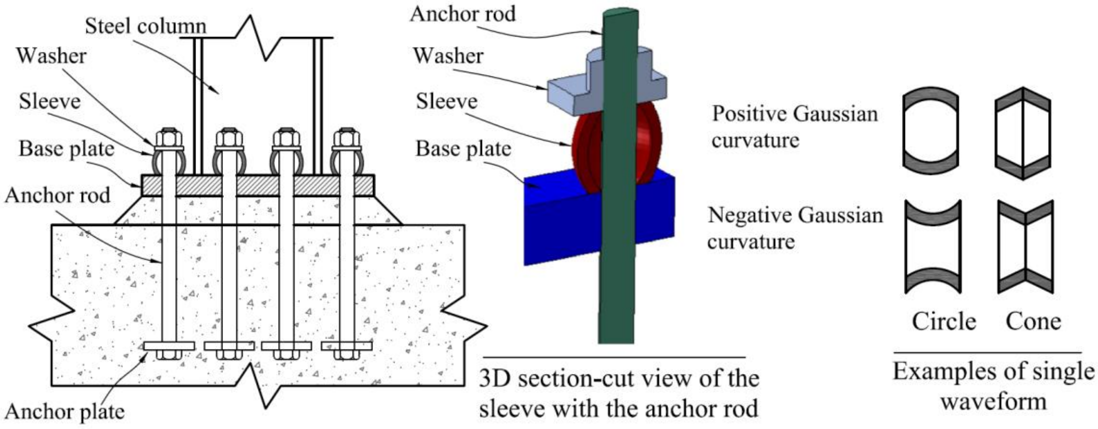


Figure 1. Base plate connection with sleeve application [13]

3. Finite Element Model Development

The column base connection depicted in Figure 2 was modelled using 3D FE implicit solver analysis in ABAQUS/CAE [15]. The accuracy of the FE model was verified by comparing it with the experimental test (#M2) conducted by Gomez et al. [16]. To simplify the modelling process, only half of the test specimen was simulated due to its symmetric geometry and boundary conditions. The symmetry axis was defined to run through the centre of the column's web as detailed in Figure 2.

The column and base plate were represented using shell elements (S4R), while the grout and the upper portion of the anchor rods were modelled using solid elements (C3D8R). To reduce computational costs, the portion of the anchor rod beneath the lower surface of the grout was modelled using beam elements (B31), and a coupling constraint was assigned between the two parts of the anchor rod. It is important to note that the concrete pedestal and foundation were not included in the model. However, lateral restraints were applied to the anchor rod using beam elements, and the bottom surface of the concrete grout was restrained in both the vertical and lateral directions to simulate the effects of the overall connection system.

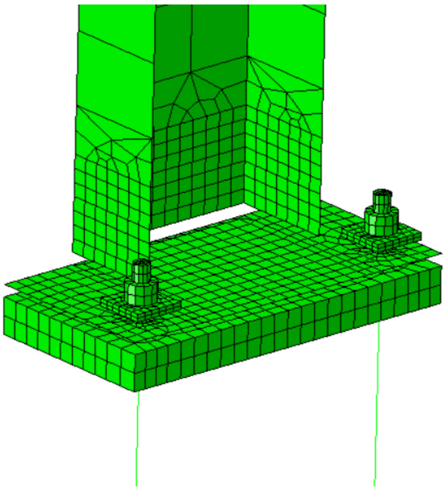


Figure 2. Exposed base plate FE modelling presentation

In the FE model of the connection part, surface-to-surface interactions were incorporated between various components. All the surface interactions (anchor rod - base plate, bottom surface of the base plate - top surface of the concrete grout, washer - base plate) included a coefficient of friction of 0.2

[14]. For certain components, such as anchor rod-nut, and nut-washer, monolithic surface interactions were employed. This means that separation between these components was not allowed during the analysis, assuming a rigid connection. Similarly, since the welds did not experience any crack deformations during the test, a monolithic surface was considered for the surface interacted between the base plate and column.

A bilinear von Mises yield criterion with isotropic hardening was utilized to model the material behaviour in the FE model of connection. The material properties were determined based on the findings of Gomez et al. [3]. For the anchor rod, the yield stress (f_y) was set to 785 MPa, and the ultimate stress (f_u) was set to 1010 MPa. Regarding the base plate, the yield stress (f_y) was defined as 278 MPa, while the ultimate stress (f_u) was set to 473 MPa. The constitutive model employed for the concrete material was assumed to be elastic-perfectly-plastic, since a compressive strength of 25 MPa was entered to the concrete material.

4. FE Model Validation

In this subsection, the experimental performance of an exposed base plate connection was validated through a 3D FE modelling simulation analysis. The model was subjected to lateral loading using displacement control with cyclic drift, following the methodology described in reference [3]. The moment-rotation results obtained from the FE analysis were compared to the experimental test results, and a strong agreement between the two was observed, as shown in Figure 3. This agreement indicates that the FE model accurately presents the elastic and plastic behaviour of the reference model connection. Furthermore, it is noteworthy that the tested connection had a capacity of 120 kN.m, while the FE model predicted a capacity of 118 kN.m. The alignment between the experimental and FE model capacities illustrates a high level of accuracy in predicting the performance of the connection.

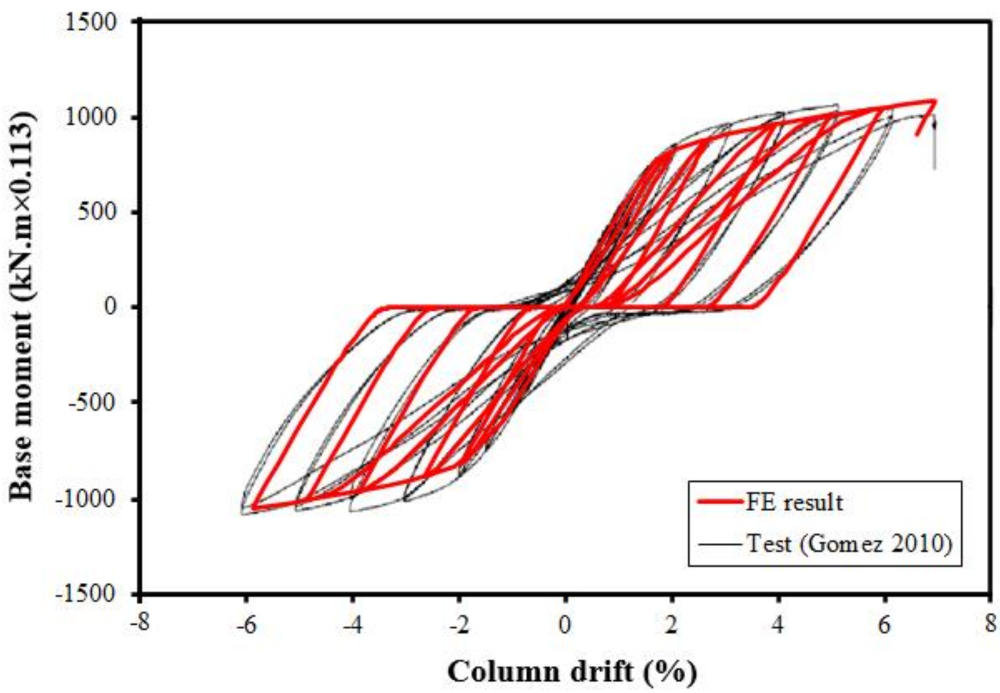


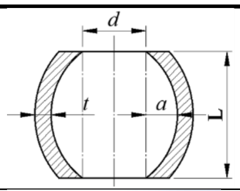
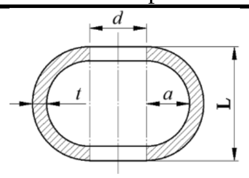
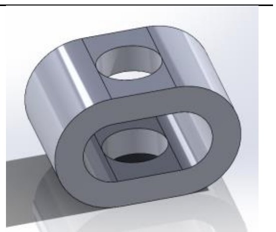
Figure 3. Experimental and numerical results comparison

5. Parametric Study

The behaviour of the proposed connection model under cyclic loading was investigated by conducting a numerical analysis on the validated FE model. The focus was on two types of sleeves: circular waveform (CW) and U-shape (US), both made of steel grade S355, as outlined in Table 1 and Figure 4.

For the CW and US sleeve types, the plastic amplitude (PA) was determined by incrementally increasing the amplitude value by 1.0 mm until the sleeve reaches its maximum capacity, resulting in crushing phenomena occurring before failure of other components. The analysis of the results was based on the geometric characteristics of each sleeve, including variations in length (L), amplitude (a), and thickness (t). By contrasting the obtained results for the connection with and without sleeves, the study aimed to determine the impact of the sleeve device on the structural performance.

Table 1. Sleeve waveform configurations and geometric parameters

	Circular	U-shaped
Geometric parameters		
3D view		

US / CW: The wave form of the sleeve.
L: The sleeve length.
t: The sleeve thickness in mm.
a: The amplitude value in mm.

Figure 4. Specimen identifi**cation**

5.1. Cyclic behaviour and failure modes of Circular waveform (CW) sleeves in exposed base plate connections

The distribution of plastic strain and connection performance for CW sleeve connections are shown in Figure 5. With a 7 mm amplitude, the sleeve reached its load-bearing capacity at 7% drift before the bolt reached its limit, causing a severe plastic deformation that was followed by total crushing of the sleeve at 10% drift (see Figure 5). A significant force created in the anchor rods once the sleeve got jammed in between the end plate and the washer. It should be noted that the connection eventually failed because of to the anchor rod, showing that the sleeve did not change the failure mode, even though it postponed it to a higher drift.

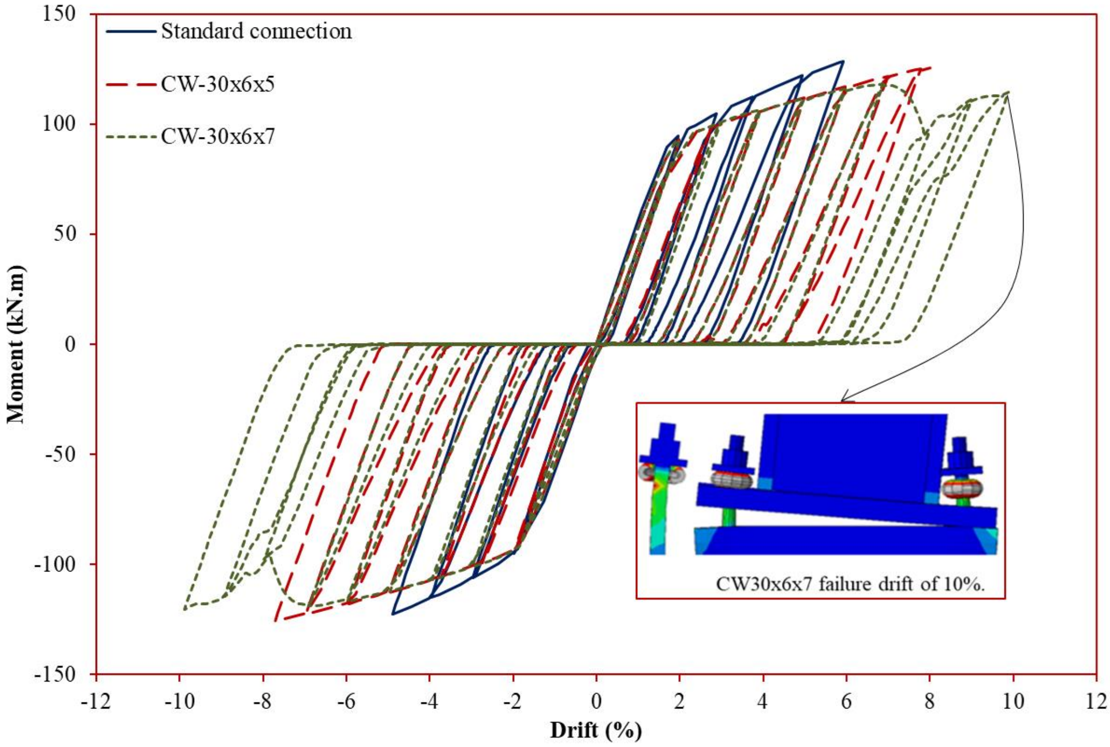


Figure 5. Moment-drift response and deformed shape for the base plate connection with the CW sleeves of length 30 mm

The initial stiffness of the proposed sleeve system is nearly identical to that of the standard configuration for all amplitude values. However, the drift capacity varies depending on the amplitude value, resulting in different levels of drift. When an amplitude value of 5 mm was adopted, the drift ratio enhanced by approximately 50% compared to the standard connection. Examination of the deformed configuration of the connections at their maximum capacity indicated that sleeves with a 5 mm amplitude exhibited greater capacity than the bolts, leading to bolt failure occurring before complete sleeve failure (see Figure 5). The improvement in drift can be attributed to the limited deformation observed in the sleeve before the failure of the anchor rod.

The plastic amplitude (PA) at which the sleeve's capacity is marginally lower than that of the bolt, resulting in complete crushing of the sleeve before bolt failure, was established at 7 mm. When the PA was adopted, the drift ratio for the sleeved connection was approximately 73% higher compared to the connection without the use of a sleeve. The moment for PA initially decreases once the sleeve reaches its full capacity at around a 7% drift (see Figure 5 for model CW-30x6x7). Following the complete crushing of the sleeve, which jammed between the base plate and the washer, the moment increases as the drift continues until bolt failure is observed.

5.2. Cyclic behaviour and failure modes of U-shape waveform (US) in exposed base plate connection

The U-shape sleeves designed with a length of 40 mm and varying thicknesses are influenced by the amplitude values in terms of their performance. Figure 6 presents an analysis of sleeves with a U-shape regarding the distribution of plastic strain and the moment-drift behaviour. In the case of model US-40x9x11, the sleeve was crushed prior to the failure of the bolt due to the lower capacity of the sleeve compared to the bolt. It is worth noting that increment in the thickness of the sleeve leads to a higher capacity than that of the bolt. Consequently, the bolt fails prior to the sleeve which should experience a high level of plastic deformation to observe more ductile behaviour. Moreover, sleeve types with larger wall thicknesses, such as US-40x11x9, did not exhibit substantial plastic deformation before the bolt failure.

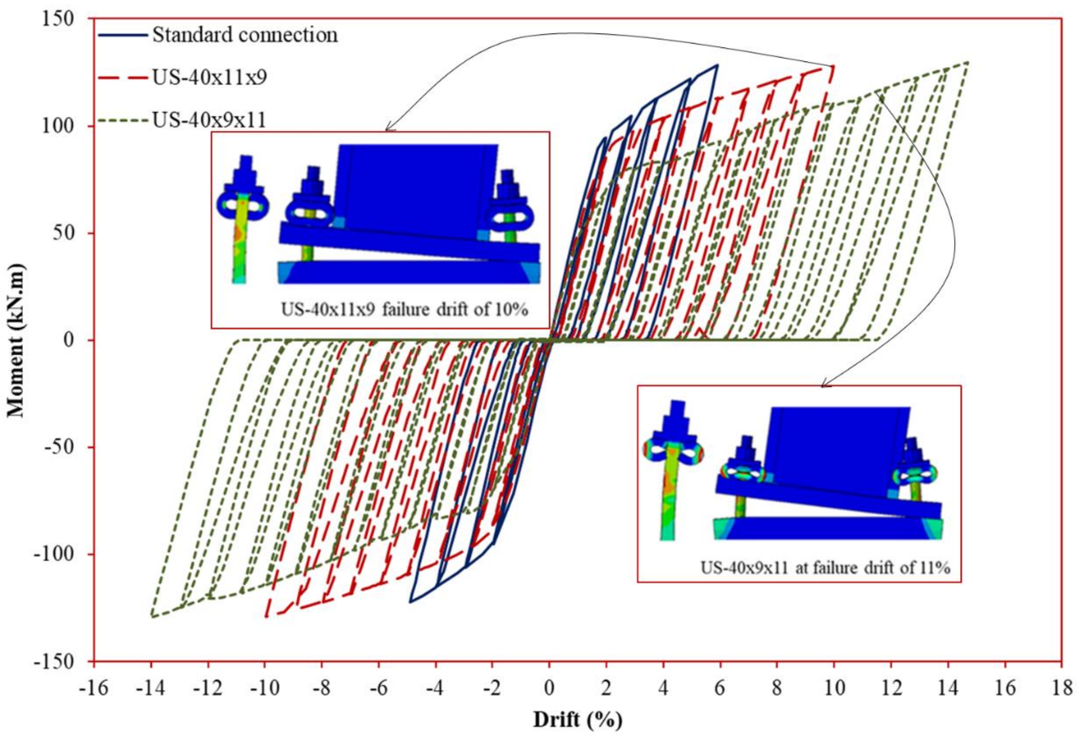


Figure 6. Moment-drift response and deformed shape for the base plate connection with the U-shape sleeves of length 40 mm

Although the proposed sleeve system exhibits a similar initial stiffness as the standard configuration for all amplitude values, it has been observed that the column drift is higher in connections utilizing the sleeves compared to the standard connection.

The drift capacity is dependent on the chosen amplitude value, with different amplitudes yielding different levels of drift. Specifically, when amplitude values of 11 mm were employed, there was a significant increase in the drift ratio, approximately 183% higher than that of the standard connection. Upon examining the connection model at their maximum capacity, it was discovered that the US-40x9x11 sleeve type had a lower capacity than the bolt, resulting in the complete crushing of the sleeve before the bolt failure as depicted in Figure 6. It is worth noting that the full crushing of the US-40x11x9 sleeve model was not observed, as the capacity of the proposed sleeve system exceeded the bolt capacity.

6. Conclusion

The main focus of this paper is to assess a recently developed sleeve system designed for column-base connections subjected to cyclic loading. The study involves modelling and validation of a finite element model through reference model (experimental tests). The study expanded with parametric study to examine different types of sleeve with distinct geometries: circular (CW) and U-shaped (US) waveforms. The objective is to compare the performance of the proposed system with that of a standard connection in terms of ductility and rotational capacity.

The results of the study indicate that the proposed sleeve system exhibits higher resistance and improved rotational capacity compared to the standard connection. This suggests that the performance of steel column base connections can be enhanced through the implementation of the sleeve system. Both the

CW and US geometries of the sleeve system demonstrate effectiveness in improving connection performance.

7. Author Contribution Statement

In the study, Author 1 contributed to forming the idea, making the design and literature review, modelling and validation, reviewing and examination of the results; Author 2 contributed to conceptualization, reviewing and checking the spelling and checking the article in terms of content.

8. Ethics Committee Approval and Statement of Conflict of Interest

"There is no need for an ethics committee approval in the prepared article"
"There is no conflict of interest with any person/institution in the prepared article"

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