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# Finite Element Investigation on the Performance of Anchor Rods in Square HSS Column Base Connection

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*A numerical study featuring HSS column base connection with varying plate thicknesses and eight anchor rods layout pattern is performed to observe its performance under lateral loading. For a particular thickness, ratio of tensile force resisted by middle row of anchor rods to the ones at the edges remains constant yielding a linear relationship. Another finding suggests that as the base plate gets stiffer contribution of middle row of rods in resisting tension decreases.*

**Keywords**: HSS column base connection, Lateral loading, Linear relationship

**Field of Research:** Civil and Structural Engineering

## 1. Introduction

Column base connection connects the column with the underlying foundation. Among the components of this connection base plate and anchor rods play an important role in transferring the loads coming from column and distribute it properly throughout the concrete foundation. It needs to have proper moment resisting capacity to sustain lateral loading.

Numerous analytical studies were carried out by researchers in Greece, including the development of a design procedure for the derivation of base connection moment-rotation curves (Ermopoulos & Stamatopoulos, 1996). Additional studies include (1) a closed form analytical model for the determination of the response of exposed column bases under cyclic loading (Ermopoulos & Stamatopoulos, 1996b), (2) an analytical model that describes the non-linear bearing stress distribution under the base plate (Ermopoulos & Michaltsos, 1998) and (3) a simulation of the dynamic behavior of column base connections (Michaltsos & Ermopoulos, 2001). Another analytical evaluation of the bearing stress distribution under the base plate, acted upon by axial forces and flexure, is presented by Sophianopoulos et al. (2005). In addition, Stamatopoulos & Ermopoulos (1997) developed moment-axial interaction curves for the ultimate behavior of column base connections. The proposed methodology is based on the consideration of three failure modes according the level of applied loading. In addition, the rotational stiffness of the base connection was formulated.

The poor performance of steel frame base plate connections was revealed after Northridge (1994) and Hyogo-ken Nanbu (1995) earthquakes. Midorikawa (1997) carried out the statistical analysis of the structural damage for Hyogo- keNanbu (1995) earthquake. In this earthquake, column base plate connection damage occurred more commonly than other structural elements. Many studies have been conducted to improve the seismic performance of the base plate connection (Astaneh et al. 1992, Fahmy et al. 1999, Gomez et al. 2010). However, since these elements are not replaceable, any damage or permanent deformation here can result in building

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demolition. So, there is a need to develop the base connections that sustain almost no damage during a major earthquake. Most of the work to develop a low damage steel structure is focused on the moment resisting beam to column joint (Clifton 2005, MacRae et al. 2010) and the brace (Chanchí Golondrino et al. 2012). However, even with these features, a building with damaged column bases may not be a low damage building.

Previously although many experiments have been conducted to investigate the response of W-section subjected to major axis bending attached to base plate, a very few tests have been performed using HSS sections. There also exists no design method for characterizing the base plate with more than four anchor rods. Kavinde et al (2014) investigated the seismic response of exposed hollow steel section columns to base plate connections through a series of eight experiments and proposed a new design method that explicitly incorporates the third row of rods in case of base connection with eight anchor rod layout.

As conducting experimental studies is both costly and time consuming the present study is emphasized on the numerical simulation of column base connection with square hollow structural section (HSS) column for better understanding their behavior under seismic loading. For verification purposes this model is used to simulate the experimental study done by Kavinde et al (2014).

## 2. Methodology of the Study

By using ANSYS 16.2 a numerical model of column base connection with eight anchor rods layout is developed with proper consideration for material nonlinearity. Qualitative sketch of the model is shown in Figure 1.

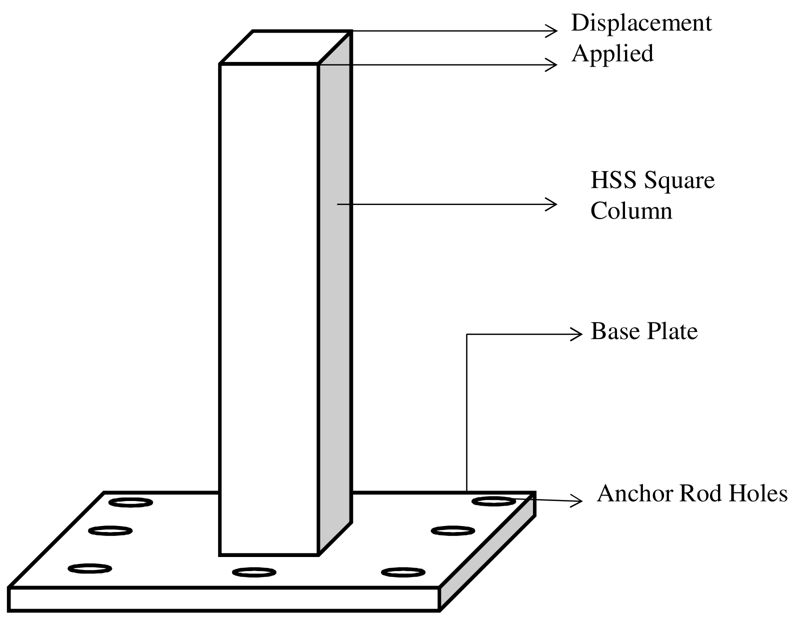


Figure 1: Schematic sketch of base connections for HSS square column

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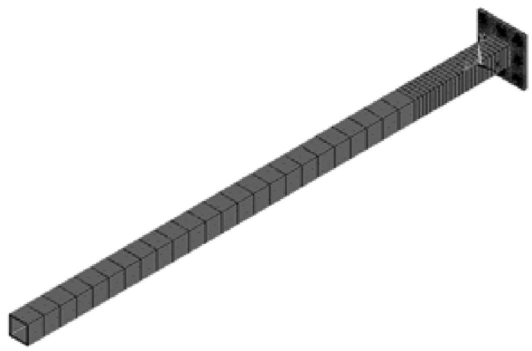
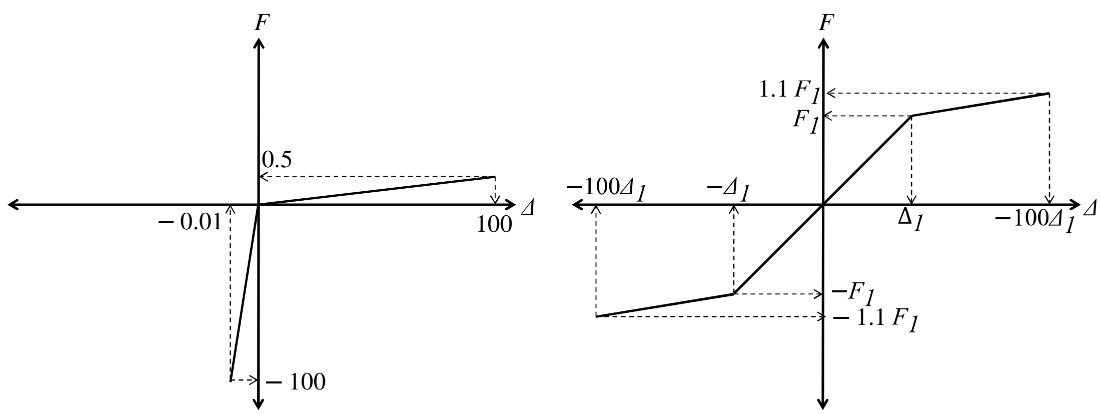


Figure 2: Finite element model of column base connection

As can be seen from Figure 2 meshing of column is done in two segments. Finer meshing is done for a more critical section near the base plate while the rest of the column meshing is kept coarser. This will effectively reduce the number of elements and thus save the computation time.Figure 3 shows the properties assigned to simulate the anchor rods and the contact between column base plate and concrete footing.




(a) (b)

Figure 3: Real constant for (a) contact spring (b) anchor rod

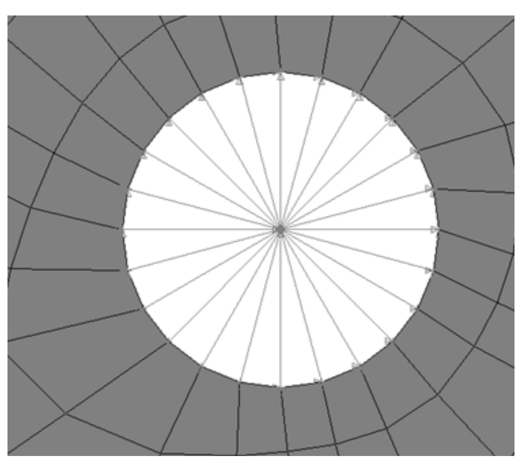


Figure 4: Coupled center nod

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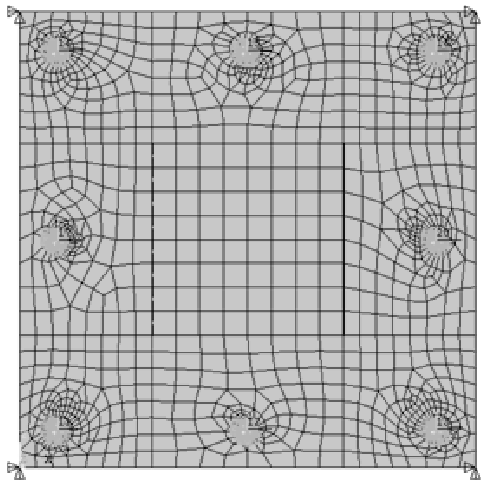

Figure 5: Lateral restraints at base corners

As shown in Figure 4 the peripheral nodes of the circular holes are coupled with the center node. This is done so that the summation of the peripheral nodes can be found directly from the central node. The ends of contact elements are kept fixed. The four corner points of the base plate is laterally restrained in both X and Y direction to prevent lateral movements. It is shown in Figure 5.Displacement is applied at the top of the column and the resulting deformation can be shown in Figure 6. The verification of the model is presented is Figure 7.

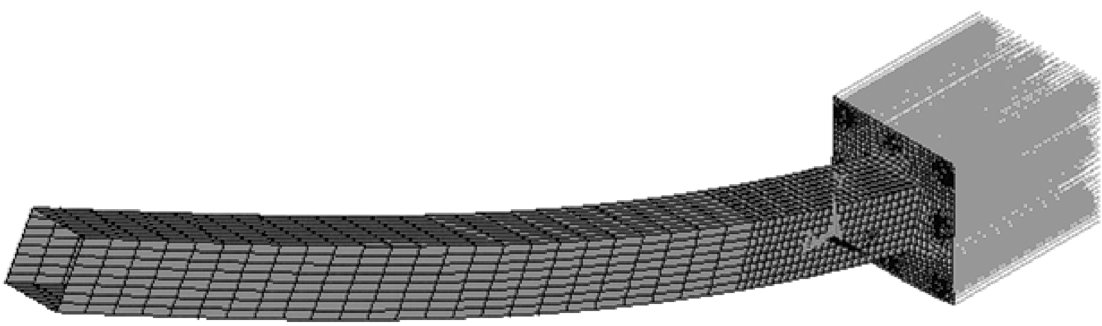

Figure 6: Isometric view of deformed shape of square hollow steel section

## 3. Result and Discussion

This study mainly focuses on the contribution of anchor rods in resisting tension caused by the bending moment at the base plate. No axial load is applied in this aspect. The ratio of tension resisted by inner row of rods and that of outer row of is determined for a particular column section designated by HSS 203×203×9.5 with varying baseplate thicknesses. This ratio is defined as '*k*'. Figure 5 along with Eqn. 1present a more pronounced definition of this ratio.

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$$T_{inner}^{new} = k \times T_{outer}^{new} \quad (1)$$

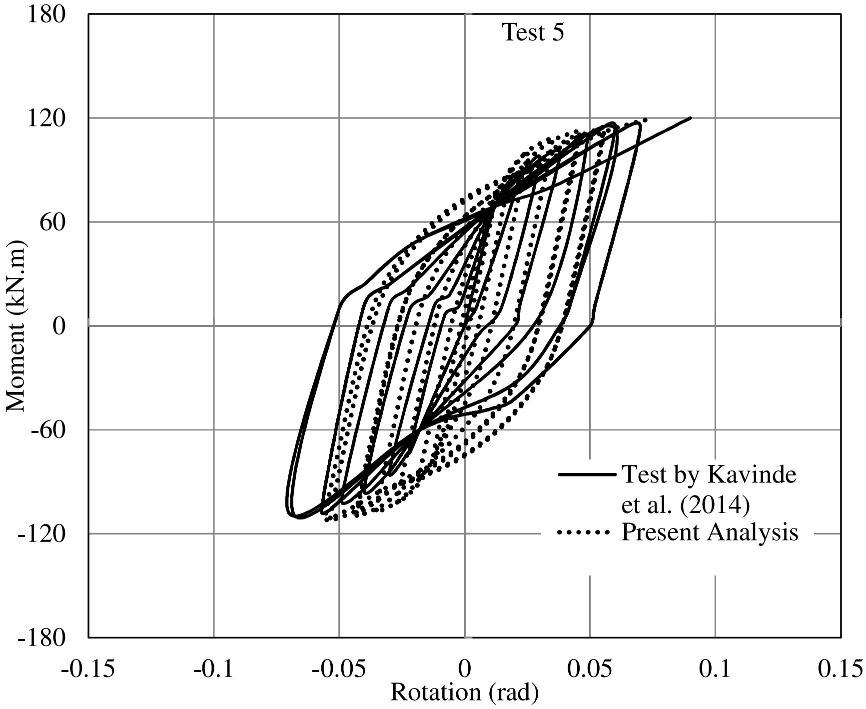


Figure 7: Verification of numerical model by experimental study done by Kavinde et al (2014)

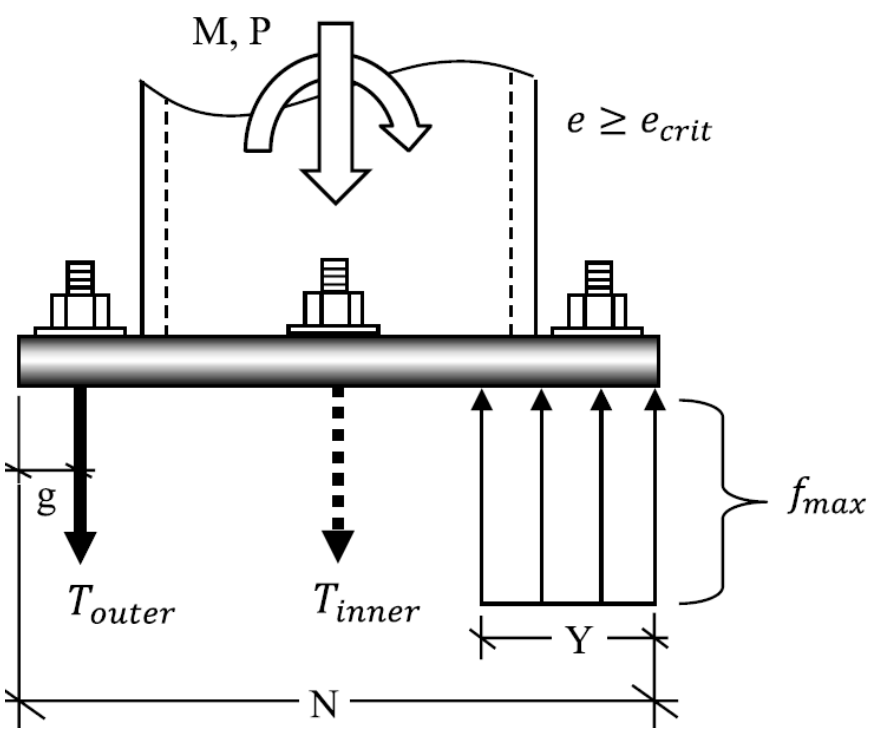


Figure 8: Stress distributions for base connection (Kavinde et al (2014))

In the following Figure 9 and 10 variation of *k* with base plate thickness is shown.From these graphical representations it can be concluded that higher thickness of the base

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plate yields a linear relationship between the inner and outer row of rods in terms of resisting tension

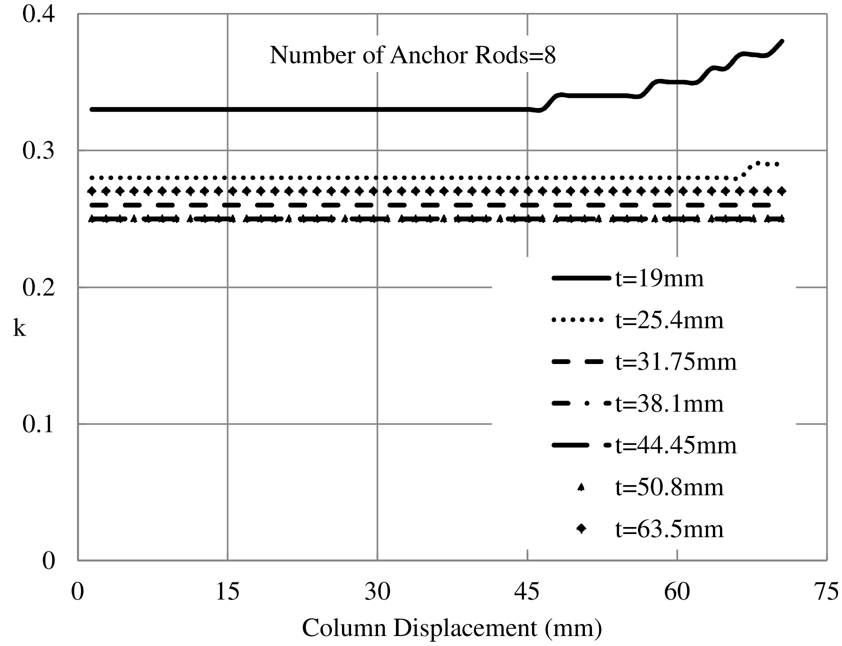


Figure 9: Variation of *k* with base plate thickness *t*.

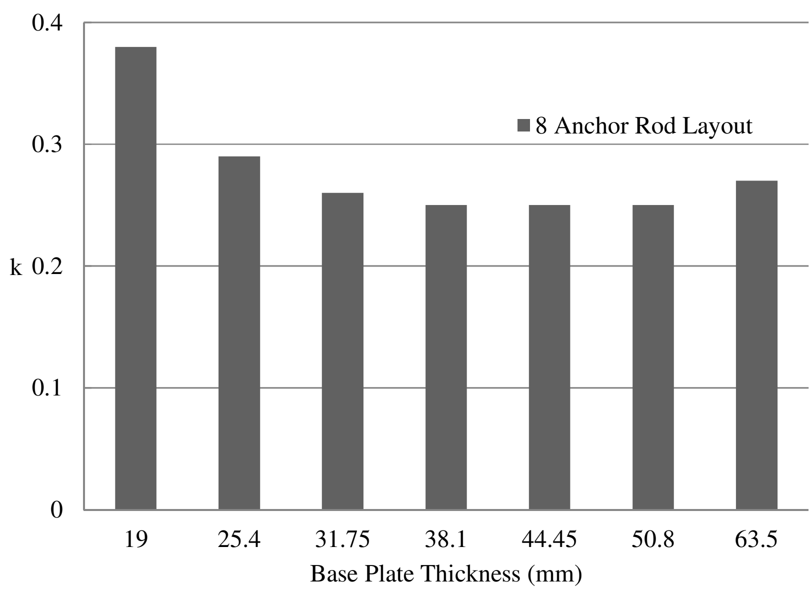


Figure 10: Comparison of *k* value for different plate thickness

For the particular problem as shown in Figure 8 there are three unknowns ($T_{outer}$, $T_{inner}$, $Y$) with two equilibrium equations namely force equilibrium and moment equilibrium equation. By introducing the linear relationship as described earlier this indeterminate problem can be madedeterminate and analysis for the connection becomes simple. Another factor which can be seen from Figure 6 is that with increasing base plate thickness the contribution of middle row of anchor rods in resisting tension decreases. As the base plate thickness increases and it becomes stiffer bending is resisted

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effectively by the plate itself. So even if tension develops in the outer row of anchor rods, tension developed in the middle row of anchor rods is considerably lower as deflection of the base plate in that portion is lower.

## 4. Limitations

There are some limitations in this study. This study is done for lateral load only whereas in practical scenario axial load exists along with lateral bending. Here the concrete footing is not modeled and only the contact between the footing and the base plate is simulated. Another particular limitation is that in this study the variation of $k$ with base plate thickness is not addressed. Although from the developed finite element model $k$ can be found for any base plate thickness, whether any mathematical relationship exists between $k$ and base plate thickness is not addressed in this study. Further research is required in this aspect.

## 5. Conclusion

The aim of this study is to observe the behavior of column base connection with eight anchor rods layout under lateral loading. From the results it can be concluded that as the base plate becomes stiff the relation between inner and outer row of anchor rods become linear in terms of tensile resisting capacity. Although there are some limitations in this study, with further research these limitations can be overcome and a more accurate and practical result can be obtained.

## 6. Notations

$P$= Axial load
$M$= bending moment
$e$ = Load eccentricity
$e_{crit}$= Critical eccentricity
$T_{outer}$ = Tension forces in outer row of rods
$T_{inner}$ = Tension forces in inner row of rods
$Y$= Bearing width
$f_{max}$= Maximum Bearing Stress

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