Concrete Footings with Different Socket Shapes Subjected to the Axial Compressive Load

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Abstract. These paper concrete footings with pyramid ended sockets are discussed in comparison to the typical socket foundation constructions. Discussed connection with cut-off pyramid creates opportunity to reduce the required height of foundation in comparison to the typical solutions and leads to reduced weight as well as costs of foundation casting. Comparative analysis covered three different external shapes for both foundations (with normal and pyramid ended socket) i.e. prism, stepped and sloped. The subject of interest was if and how much the height of foundation could be reduced in comparison to the normal socket footing. Numerical analysis was performed with the utilization of SolidWorks Finite Element Method based software.

1. Introduction

Foundations are constructions which transfers different types of loading from structures and machines directly onto the ground. Today three main groups of foundations may be listed: monopile, deep and shallow foundations. Shallow foundations are utilized under rather lightweight constructions or in case of good ground conditions. In case of soils with low load bearing capacity deep foundations are utilized. This type of foundations provides stability when lower layers of the ground with appropriate bearing capacity are reached or in case of piles, the friction forces are greater than the transferred forces from construction onto the ground. The last group of foundations are monopiles. These large-diameter constructions provide stable support under chimneys and other large constructions.

Socket footings are special group of spread footings foundations where column is centred and inserted into the foundation, and then empty spaces between foundation and column are filled with the concrete. According to that, column gains additional rotation stiffness via socket base. It is worth noting that in design manuals [1-3] as well as in Eurocode [4], connection between construction column and socket foundation is realized via columns’ horizontal planar end – there is no mention about different types of possible connections. The influence of foundation shape on stress distribution is usually omitted. The influence of various soil parameters on typical foundations formed on slopes may be found in [5-7]. Researchers also utilize the numerical methods to improve the performance of foundations [8], model and optimize foundation bearing capacity [9] as well as to forecast the failure mechanism [10].

In this paper different approach of creating connection between column and socket footings is proposed. The connection between the column and the socket foundation would be realized with cut-off pyramid columns’ head. Presented solution leads to different stress distribution in the footing. It should cause a reduction of the height of analysed foundation in comparison to the socket foundation where column is ended with horizontal plane. In order to obtain Misses stress distribution in proposed types of socket foundation and for common socket foundations, SolidWorks Finite Element Method (FEM) based software was chosen.
2. Analysed Model
For the analysis purposes two groups of foundations were assumed. The first group covered typical socket footings with square (horizontal cross-section) shape of socket ended with planar plane, whereas the second group contained footings with socket ended in the shape of pyramid. Three different external shapes of foundations were taken into account i.e. prism, stepped and sloped cut-off pyramid, respectively. Moreover, it was assumed that all the foundations had square shape base with single edge dimension equal 2.50 m. Height of each foundation was preliminary assumed as 1.40 m. All foundations with their dimensions were presented in Figure 1.

![Figure 1. Schemes of analysed three types of footings with different socket shapes](image)

In order to perform comparative analysis following assumptions were made: for the prism foundation, square base was extruded vertically by 1.40 m. In the stepped footing with planar ended socket foundation base was extruded by 0.60 m, then square area with 1.00 m edge length was vertically extruded by 0.80 m, where centre point of extruded square coincided with centre point of lower step top surface. For the footing with socket ended as pyramid, foundation base was vertically extruded by 0.80 m, then square area with 1.00 m edge was extruded by 0.60 cm. Here, same as previously first and second step centre point of square area extrusion had coincided. Last foundation covered the sloped cut-off pyramid footing. In both cases square foundation base was extruded...
vertically by 0.60 m, then created top surface was extruded inwards with approximately 50.1 degrees incline angle (measuring from the horizontal plane) in order to form square surface on the top of foundation with edge dimension equal 0.90 m. For each foundation shape, square cross-section socket ended with planar surface was formed as an extruded cut of square area (0.40 × 0.40 m) with 0.90 m depth. In case of the socket ended in the shape of pyramid, socket was firstly created by 0.60 m extruded cut of square (0.40 × 0.40 m), then extruded cut was performed with inward incline angle equal 60 degrees counting from the horizontal surface. In each foundation pyramid ended socket end point was located around 0.50 m measuring from the bottom foundation surface.

For each analysed foundation section of a column with square cross section 0.40 × 0.40 m and overall height equal 1.30 m was adopted. In order to reduce the effect of corner stresses each column edge was chamfered by 2 cm from each side. Same action was performed for the foundations sockets. In case of foundations where socket was ended with planar surface, column with planar end was taken into considerations. For pyramid ended socket foundation, column with cut-off pyramid end was adopted. Pyramid cut-off was made 0.20 m measuring from the square planar surface where inclined extrusion started. Proposed column shape should ease the centring of column in situ. It should be noted that in practice column head connected with the foundation should be made of steel in order to provide appropriate stiffness as well as to reduce the effect of concrete crushing on the contact point between column and foundation. Despite that, analysis was simplified to the column made only of concrete. Steel column head and its behaviour will be subject of interest in further authors research. Simplifications covered also the ground – it was assumed that there is no ground subsidence. Moreover, analysis covers only pure axial loading – columns were subjected to static pure axial load with value of 500 kN, where assumed concentrated force was evenly distributed onto the top surface of column.

3. Numerical Model
Having in mind that the foundations are made of concrete, for simplification and to show how the stress are concentrating, elastic-isotropic material model corresponding to the C20/25 concrete class was assumed. Simplification such as utilization of elastic-isotropic model was possible, because only stresses were the subject of interest, there were no research concerning cracking, brittle behaviour, failure etc. For the material model following parameters were adopted: Young’s modulus 30 GPa, Poisson’s ratio 0.20, maximum allowable compressive stress equal 20 MPa, yield stress equal 1.715 MPa.

In each model following boundary conditions were adopted: foundation whole base area had vertical (Z-axis) displacements fixed corresponding to the zero ground subsidence, whereas in the centre point of foundation bottom surface all translations were fixed in order to provide required model stability. Connection between column and foundation was created with the utilization of contact without penetration according to the fact that the filling layer of concrete between the column and foundation may be sheared.

Because the influence of load eccentricity was omitted in this paper, pure axial loading with value of 500 kN was assumed. Adopted load was modelled as concentrated force evenly distributed onto the top surface of the column. It is worth noting that the pressure from the ground located onto the foundation as well as material and foundation dimension imperfections were not the subject of interest.

4. Result and Discussion
In this section numerical results concerning the Misses stress distribution in the analysed foundations were presented. As the first group results concerning Misses stress distribution in the whole foundations were taken into considerations. In order to have better preview of stress distribution minimum observed stress was limited to 0.15 MPa. Shapes of Misses stress distribution under the pure axial loading for different analysed foundations were presented in Figure 2.

On the basis of presented Misses stress distribution shapes, one may notice that in foundations with column ended by cut-off pyramid (see Figure 2d-f) stress distribution near the column as well as near the foundation base was much wider than for socket foundations with column ended by planar plane counterparts (see Figure 2a-c). Observed behaviour was a result of utilized column socket shape. With
the cut-off pyramid ended column, forces transferred from the column were distributed on compressive pressure directed downwards the foundations and partially on tensile force directed perpendicularly to the foundation base. According to that, rebars in socket pyramid ended foundations would take significantly higher amount of force than its normal socket foundations counterparts. As a result, number of rebars in the foundation would increase or greater diameters would be used. The reinforcement in the foundation near the cut-off pyramid ended column would also have different construction than in the common socket foundations – there would be much more reinforcement in order to provide appropriate stiffness for the construction, reduce the effect of concrete crushing plus rods should counteract the effect of foundation rending onto two parts. Despite greater number of rebars, overall weight of foundation would only slightly increase.

Figure 2. Misses stress distribution for different shapes of analysed foundations: a-c) footings connected with column ended by horizontal plane, d-f) footings with column ended by cut-off pyramid. Minimum Misses stress limited to 0.15 MPa

Comparing Misses stress shapes from the Figure 2 it was clearly visible, that the prism foundation was not properly used for the transferring pure axial compressive force – much of the foundation volume was not used to distribute forces. In case of stepped and sloped type of foundation, for both types of sockets much greater volume was utilized, however it is worth noting that in the stepped type of foundation for both socket types there were observed corner stresses on the connection between steps. Moreover, the first step of discussed foundation looking from the top, narrowed down free distribution of forces in all directions.

The wider area of stress distribution in the foundations with pyramid ended socket in comparison to other socket footings (see Figure 2) may suggest that the stress under the bottom base may be lower than under normal socket foundations. Maximum Misses stress under the bottom surface for analysed foundations was presented in Figure 3.
Figure 3. Maximum Misses stress [MPa] under the base for different foundations shapes and different socket shapes.

As shown in the Figure 3 one may notice that the stresses under the bottom base for planar ended socket were comparable. The lowest Misses stress was obtained for the sloped shape of foundation with the pyramid ended socket. In prism shape footing stresses were the highest due to the foundation stiffness in perpendicular direction to the applied load. In case of stepped footing with pyramid ended socket, foundation base had greater height in comparison to the normal socket, which increased the perpendicular footing stiffness. Hence the result for the pyramid ended socket was greater than for the sloped one foundation.

With the utilization of column with cut-off pyramid end Misses stress were around two, three times lower in comparison to planar end sockets, which was the result of forces distribution by columns’ end. According to that in case of comparison with the same soil (same soil load bearing capacity) it is possible to reduce the foundation height, in consequence reducing foundation weight and costs.

5. Conclusion

Due to lack of research concerning different shapes of foundation sockets, footings with pyramid ended sockets and well-known external shapes were proposed. Presented solutions were supposed to change some amount of the axial force transferred from the columns onto the tensile force, which in consequence would be transferred onto the steel rebars. It is worth noting that presented solutions would require a bit more complicated steel reinforcement, however in the overall view, weight of proposed foundations would be increased insignificantly. The main aspect for which the authors have emphasized was the possibility of foundation height reduction in comparison to normal socket foundations and as a result reduction of foundation weight and costs.

Through the numerical analysis preliminary assumption of changing some amount of transferred axial force from the column into the tensile force distributed in the foundation was proved. It was observed that for the proposed solutions depending on the external foundation shape, Misses stress under the foundation base was two, three times lower than for its counterparts with normal sockets. It is worth noting that the maximum Misses stress obtained on the connection surface between columns and foundations (pyramid ended sockets) were in all cases nearly the same and stood at level of 5.10 MPa. Such compressive stress was far beyond the maximum allowable stress, assumed as 20MPa for C20/25 concrete class.

It should be noted that presented in this paper analyses of proposed socket footings with pyramid ended socket had many simplifications – only pure axial loading transferred from construction, no material and object imperfections, lack of modelled reinforcement rods and socket footing subsidence.
equal zero. Considerations of above mentioned simplifications will be the subject of interest of present authors in further numerical analyses.

Finite Element Method (FEM) software in hands of skilled engineer can be a very powerful tool. FEM analyses may cover almost all areas of life and are frequently used in civil engineering [11], mechanical engineering [12], medicine etc. Not everybody knows that even some everyday objects were analysed and/or even optimized with FEM software to maximize product advantages. As an example in footwear industry, sport shoes are analysed for specific conditions [13] – for some football players are performed special FEM analyses to minimize the overload and maximize the comfort. Moreover, FEM software is also utilized to perform analyses of concept designs. As an example authors of this paper performed some analyses to propose innovative concrete-rubber composite blocks [14, 15], which allow passively reduce the vibrations derived from external environment, machines, traffic moves etc.

6. References
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