RAM/STAAD Solution Center

# STAAD.pro 2007 Design of Wind Turbine Foundations

By

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# 1.0 INTRODUCTION

The interest in renewable energy production systems is growing with the increase in demand for electricity in the world along with the awareness of global warming. One such technology that is gaining a lot of attention these days is the Wind Turbine technology. Wind turbines offer electricity production for freely available wind and hence is an excellent source of energy that requires very little energy production cost. A wind turbine contains a turbine connected to a rotor which is allowed to rotate at acceptable wind speeds to generate electricity. During high wind conditions, rotors are locked and blades are positioned to minimize the wind exposed surface area. Wind turbine footings are exposed to tremendous load of the turbine and moment due to wind.

Wind turbine foundations have to be designed as per the ACI code. These types of foundations are very specialized types of footings because of their shape, design, load path provided and components. The footing is more like a "mechanical device" than a foundation.

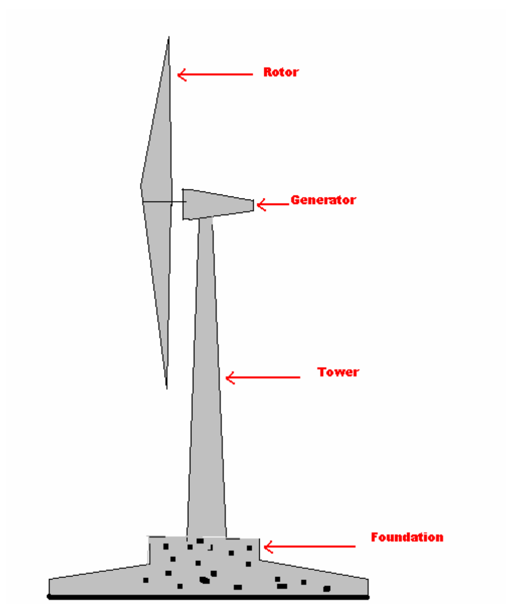


**Figure 1: Wind Turbine**

## 2.0 FOOTING GEOMETRY

Wind turbine foundations are generally octagonal in shape. The diameter of the footing may vary anywhere from 50ft to 65ft with an average depth of 4 to 6 feet. An 8ft to 9ft pedestal (includes the height of the footing) of 18ft to 20ft diameter is provided. Figure 2 shows the plan view and section of the octagonal footing.

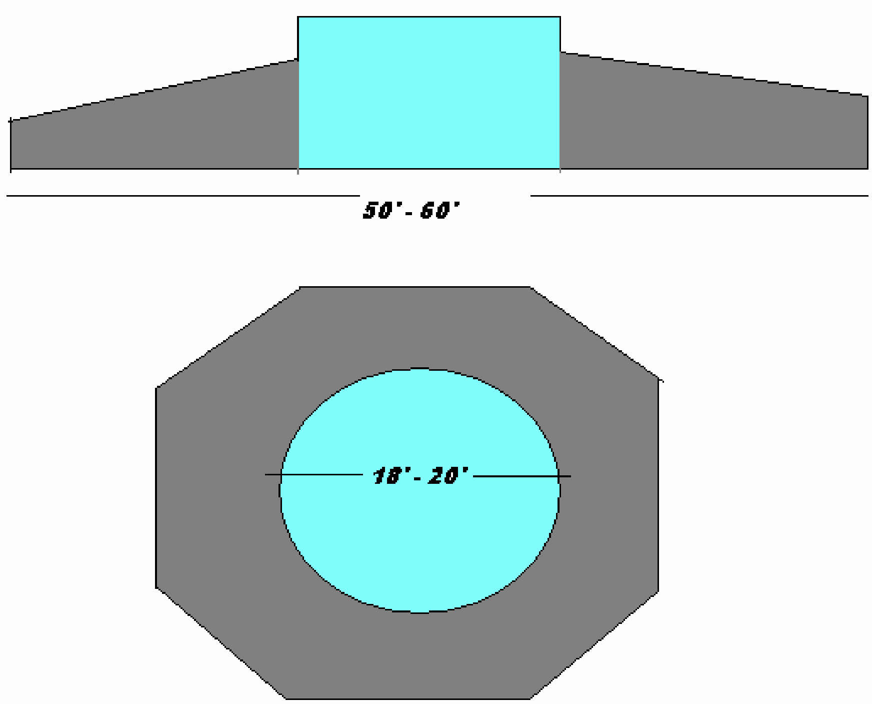


**Figure 2: Footing Geometry**

# 3.0 FOOTING DESIGN REQUIREMENTS

Wind turbine manufacturers generally specify the worst case loading that a wind turbine footing can experience. The loadings provided by the wind turbine manufacturers are factored loads.

Axial: 250 kips
Shear: 800 kips
Moment: 50,000 kip-ft

**Foundation Stiffness**

The foundation must be able to withstand these loads. The max foundation stiffness "moment required to create a 1 degree rotation" cannot exceed the foundation stiffness provided by the manufacturer.

**Avoiding Plate Uplift Condition**

The wind turbines base sits on high strength grout. The base of the wind turbines have 160 holes on the in the inside and outside edge similar to those shown in Figure 3.

**Figure 3: Wind Turbine Shaft**

Figure 4 shows the details of pedestal of the footing. Note that first the bolt cage (160 bolts with top and bottom plates is placed on site. Concrete is poured and allowed to harden. After the concrete hardens, the tower shell is placed and the bolts are pretensioned so that the tension in the bolts is 110 kips. The bolts are not bonded to the concrete.

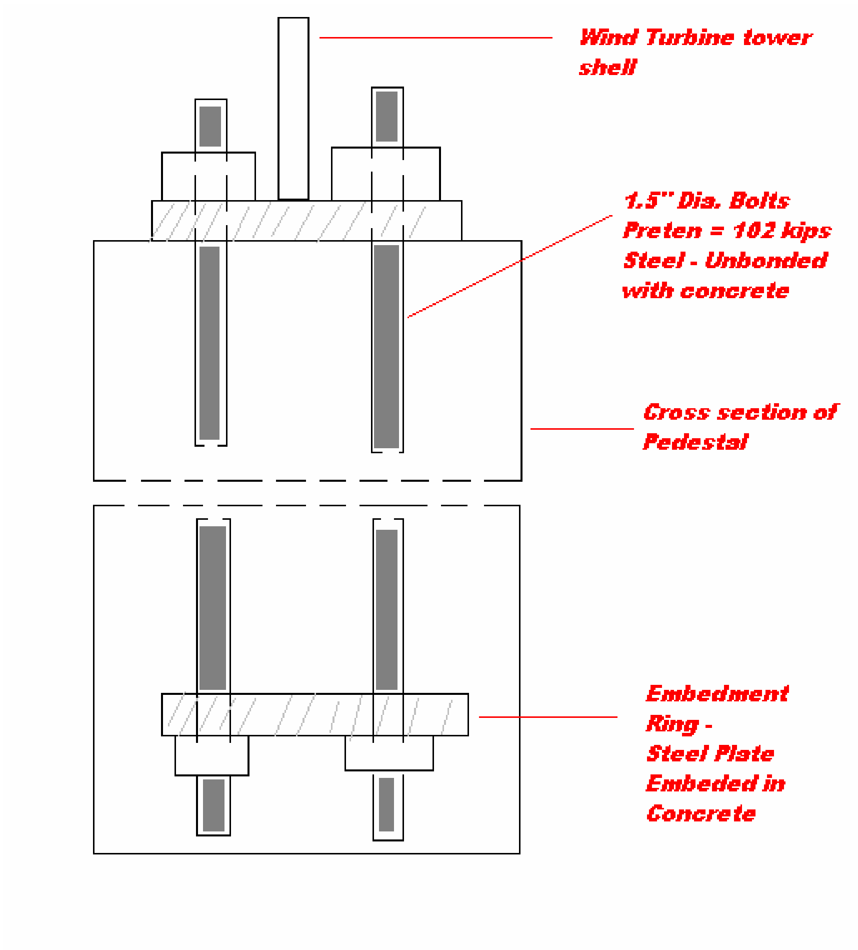


**Figure 4: Wind Turbine Foundation Details**

During extreme wind conditions, windward side of the tower can experience uplift as shown in Figure 5. The footing must be designed such that the plate must not loose contact of the pedestal.

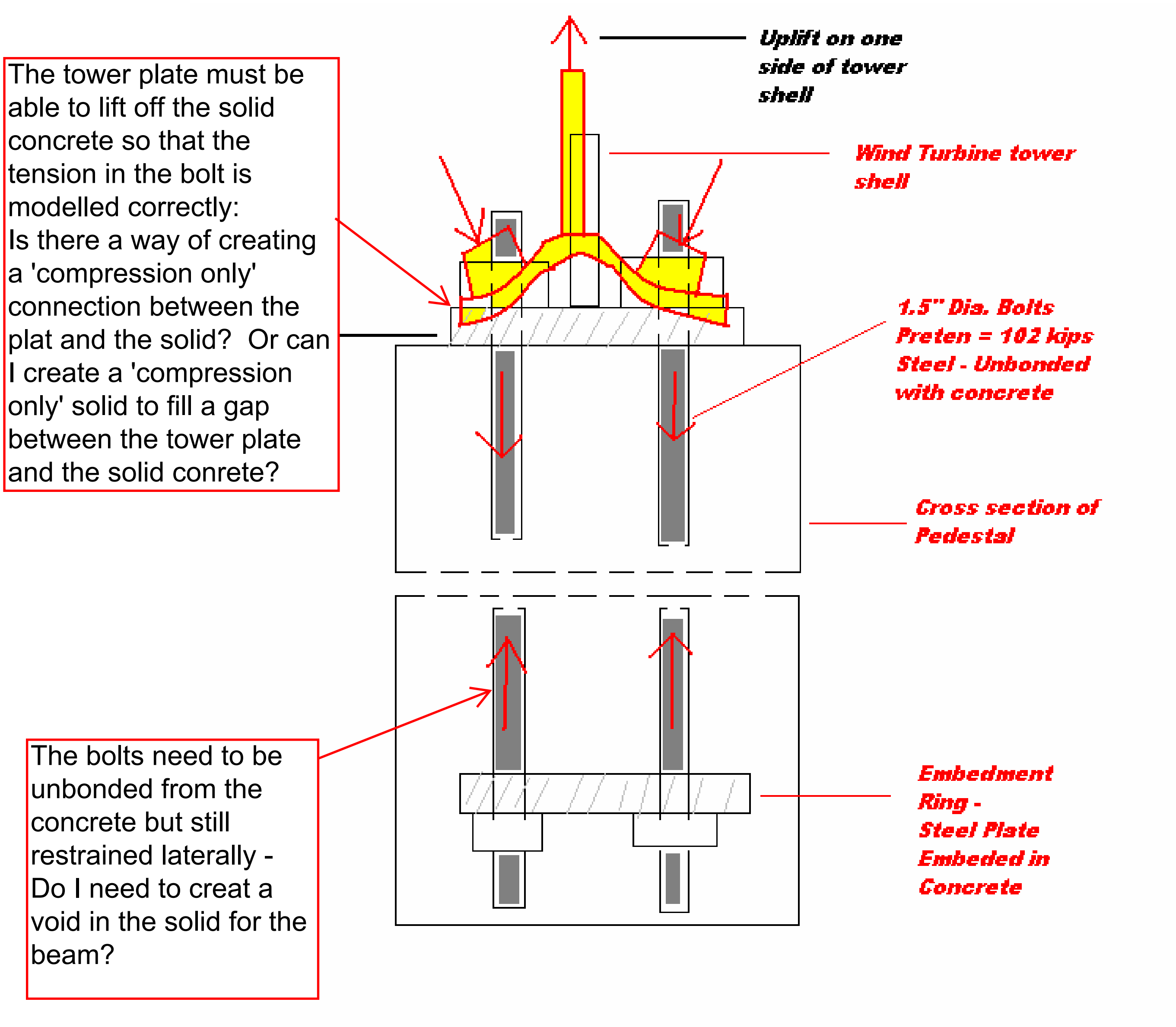


**Figure 5: Force Distribution and Plate Uplift Condition**

## Soil Pressure Under Extreme Loading

The soil pressure under extreme loading should be less than the allowable bearing pressure of the soil. Note that engineers must use unfactored loads for this analysis. For this case, it is not permitted to have more than 50% of the footing area to loose contact.

**Buoyancy Load**

In certain site conditions, it is possible to have flooding and extreme wind conditions simultaneously. The footing must be designed to withstand the extreme wind loads along with buoyant forces.

# 4.0 Modeling Turbine Footing in STAAD.Pro

It is recommended that these types of thick MAT foundations be modeled using solid elements in STAAD.Pro. The top and bottom plates should be modeled as plate elements. The bolts should be modeled as beam elements and a prestressing force will be applied to them in all load cases.

Three load cases should be analyzed. The first load case should contain the extreme loads obtained from turbine manufacturer to see the stresses in the foundation and components.

The second load case should contain 1% of the specified stiffness provided by the turbine manufacturer. This load case will be used to calculate the foundation stiffness. This load case should also contain the dead weight of the wind turbine and the footing.

The third load case should contain the unfactored extreme loads provided by the wind turbine manufacturer to produce the base pressure diagrams.

Figure 6 shows the completed octagonal footing model for the wind turbine.

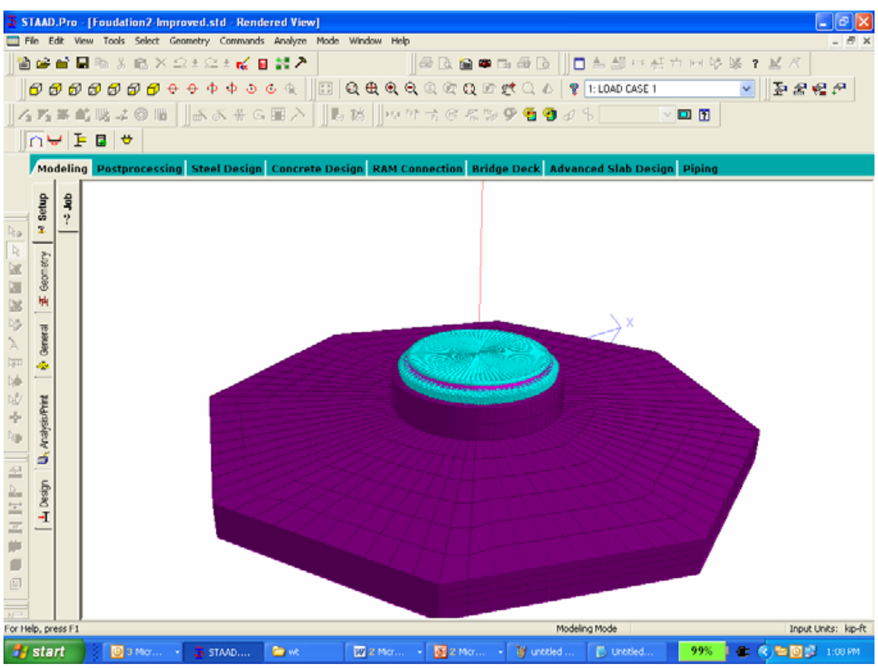


**Figure 6: STAAD.pro model of Wind Turbine octagonal footing**

One may simply construct a piece of the pedestal with the pretensioned bolts rebar and plates as shown in Figure 7. Circular repeat is done on this piece by an angle of 45 degrees 10 steps. (i.e. 45 x 8 = 360 and 10 x 8 = 80 bolts). Figure 7 shows the completed slice model of the pedestal.

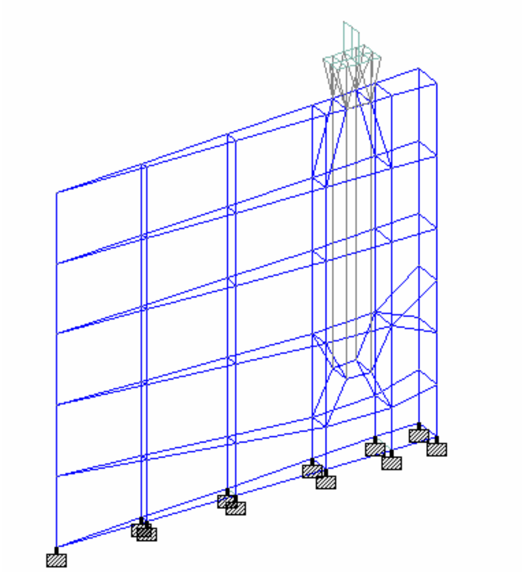

**Figure 7: STAAD.pro Footing Pedestal Slice**

An other STAAD.Pro model may contain the extension that needs to be attached to the above slice file after the circular repeat is performed.

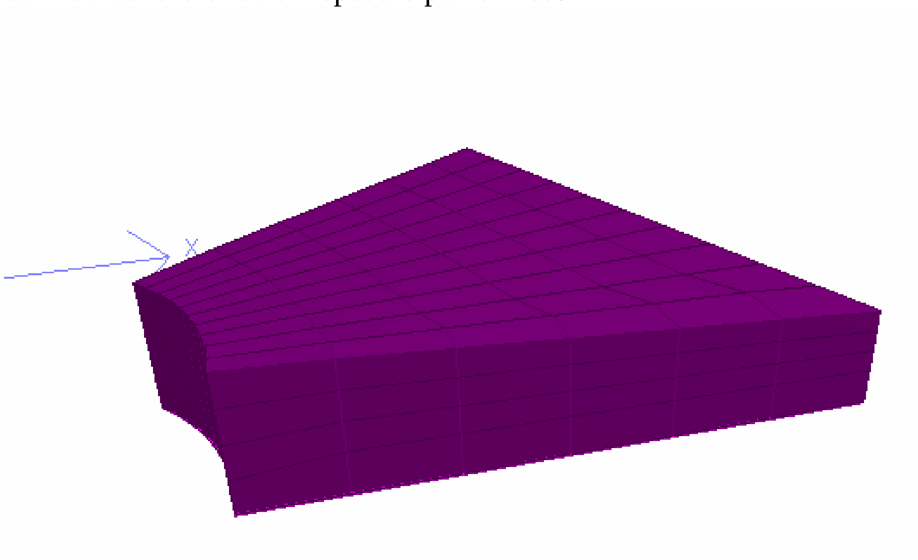

**Figure 8: STAAD.pro Footing Extension Piece**

For most of these projects, the pedestal dimensions remain same but the extension can change. The geometry generation process can be automated using OpenSTAAD.

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## 5.0 Analysis Option

The octagonal footing is supported by plate elements. The intent of these plates is to help STAAD.Pro generate compression only foundation supports using the subgrade modulus. As a result of this support specification, high uplift moment and rigidity of the foundation, the analysis is expected to run through several iterations. Part of the foundation will loose contact of the soil and hence the stiffness matrix has to be recreated for each iteration. It is recommended that the advanced analysis engine be used to solve this problem.

# 6.0 Analysis Results

As expected the footing will behave rigidly as shown in Figure 9.

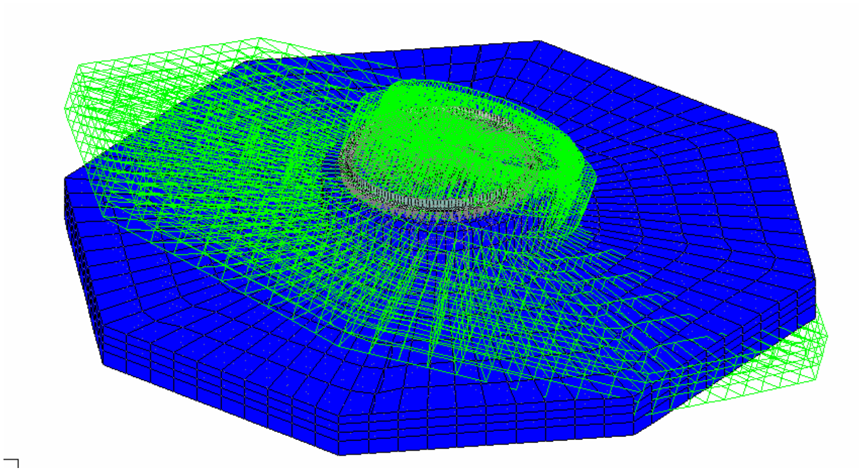

**Figure 9: Footing Deflection Diagram**

In this case it is noted that more than 50% of the foundation has lost contact of the soil. The soil bearing capacity has been exceeded at the corner of the footing as seen in Figure 10.

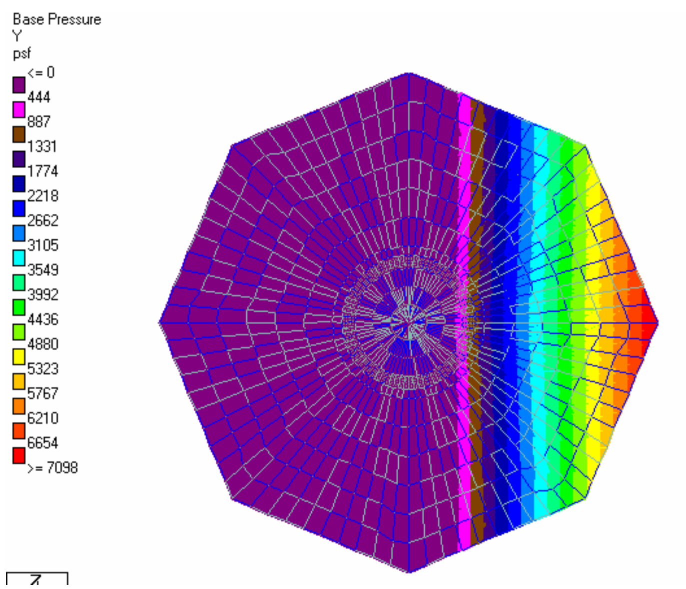


**Figure 10: Footing Base Pressure Diagram**

Figures 11 to 13 show stresses in other components.

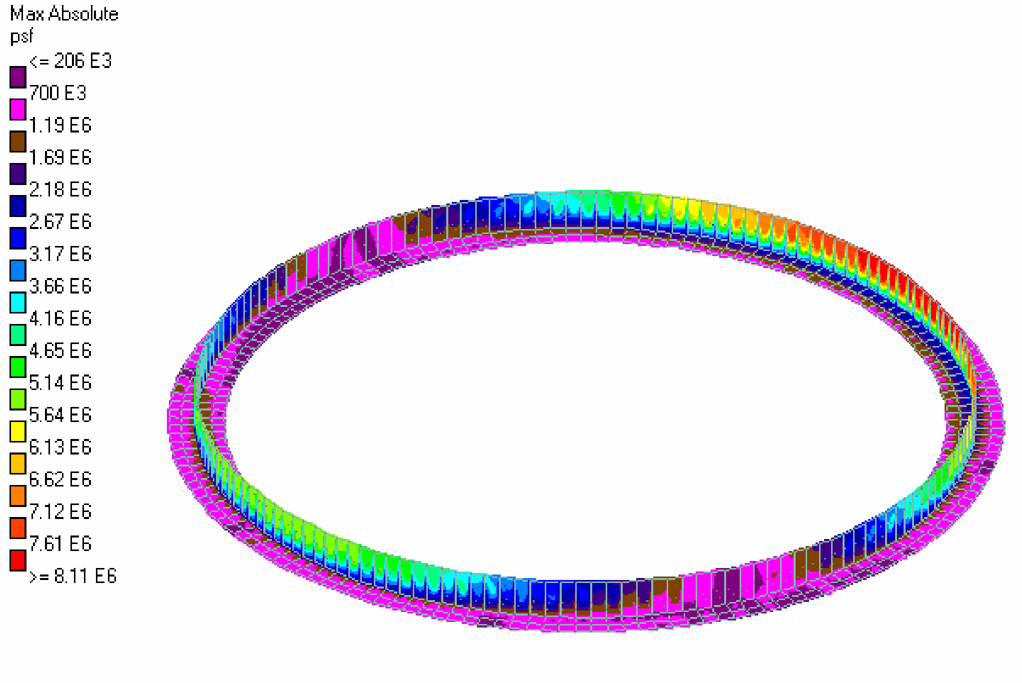


**Figure 11: Stresses in Top Steel Plate**

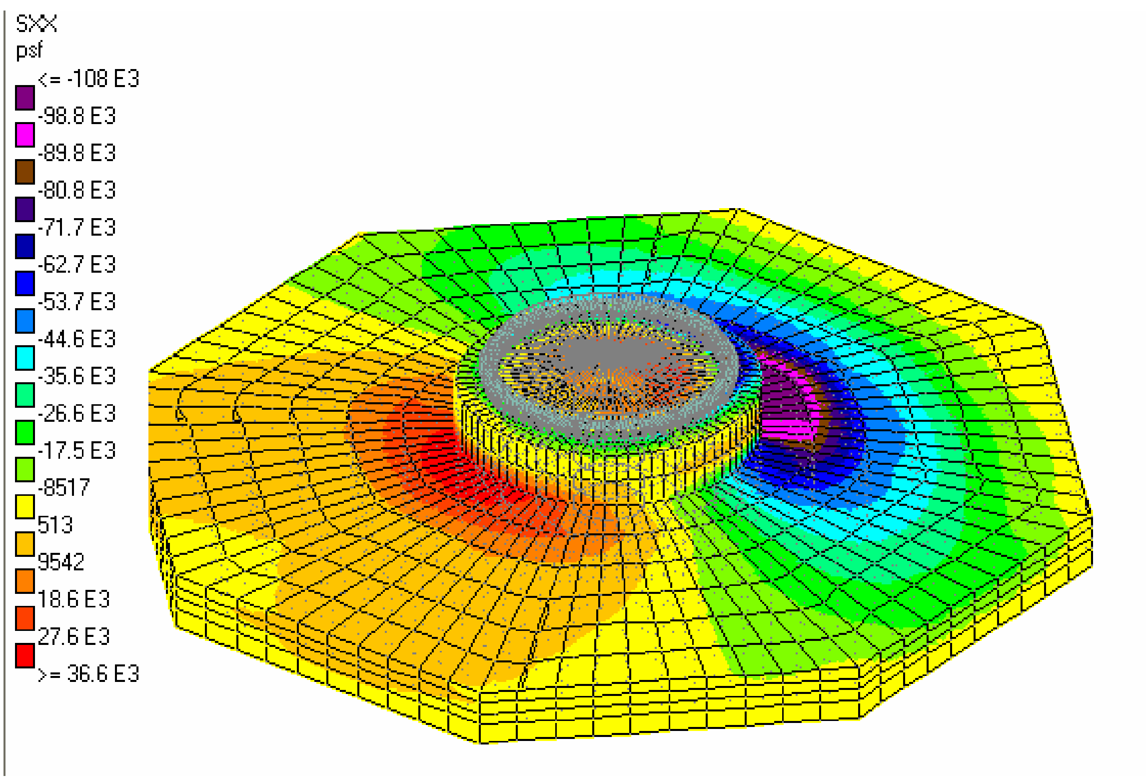


**Figure 12: Stresses in Concrete**

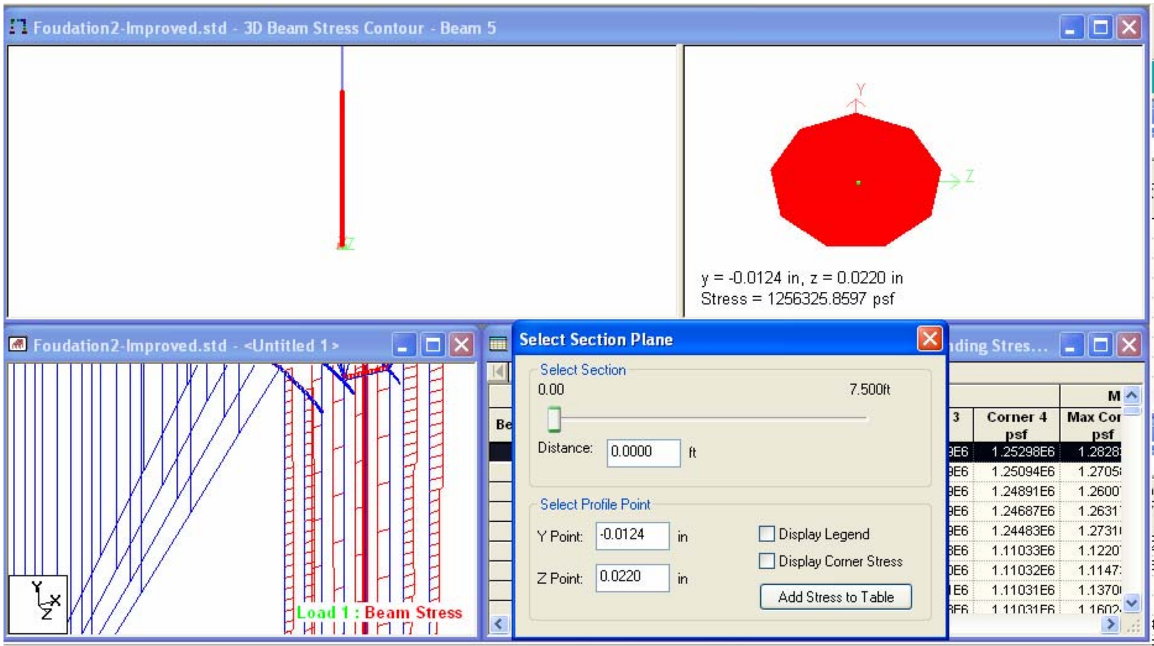


**Figure 13: Stresses in Bolts and Steel Concrete Interface**

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# 7.0 Flexural Steel Design

STAAD.founation should be used to design the flexural reinforcement as shown in Figure 14.

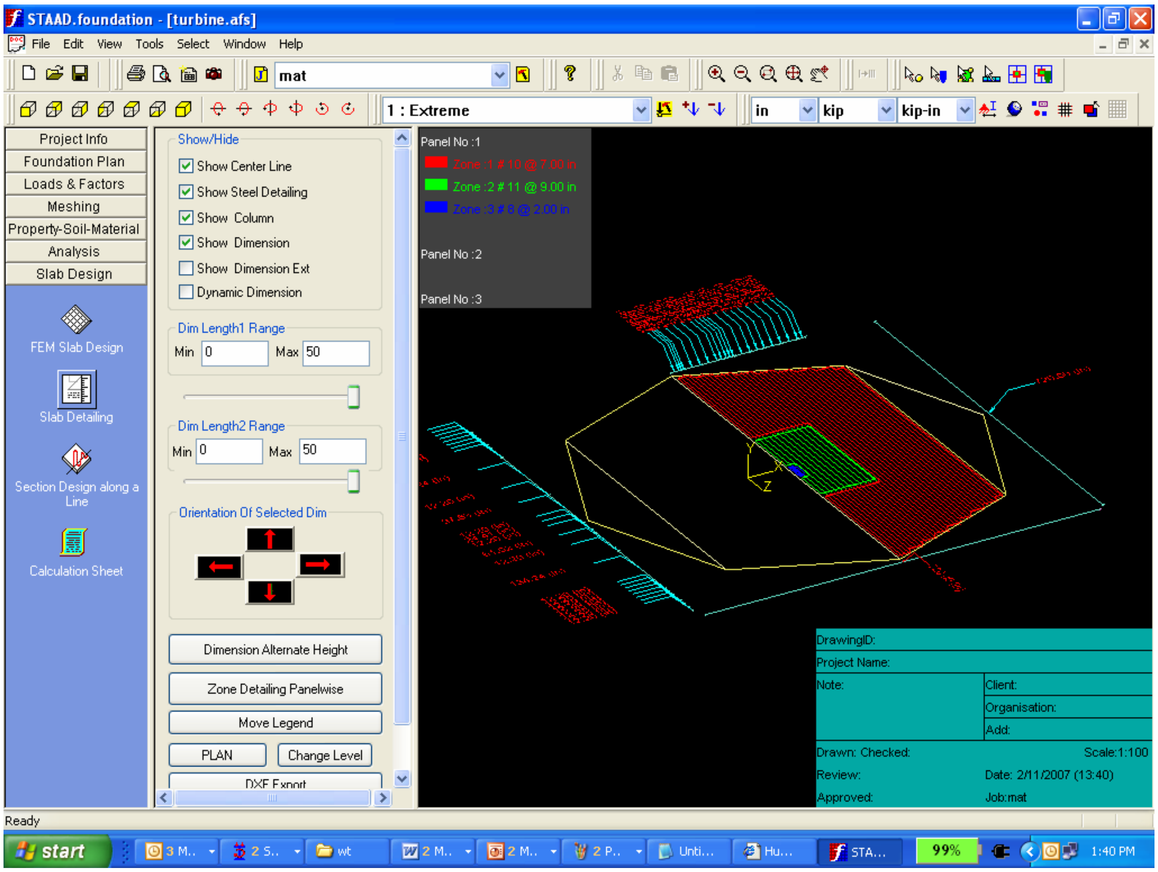


**Figure 14: Flexural reinforcement in STAAD.foundation**