5 CASE STUDY

5.1 Introduction

Proposed tower is a 350m tall tower located in Colombo Sri Lanka.The tower mast at the top is reinforced concrete at lower half and steel at the its' upper half. The steel mast is 64.1m tall and it is made out of tubular sections (figure 5.1). The section shape and size change in 3 stages.

There are openings at all these stages. Out of these the openning at the bottom which is subjected to highest stress level and largest in size is valnerable to fatigue failure under cyclic loading.

Since the structure is at 300m height the wind induced vibrations are significant. There is a probability that the wind induced vibrations can cause fatigue. In order to check its vulnerability to fatigue and to compare the sensitivity to thickness, shape of the openning different finite element models are checked for fatigue.

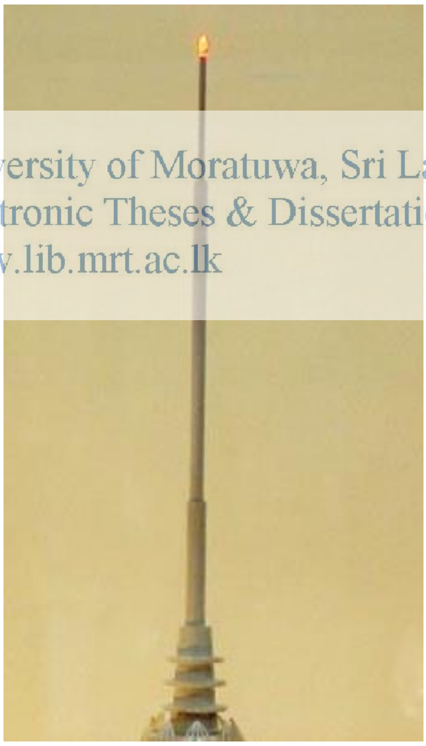

Figure 5.1: Proposed shape of the Steel tower

5.2 Dimensions and properties

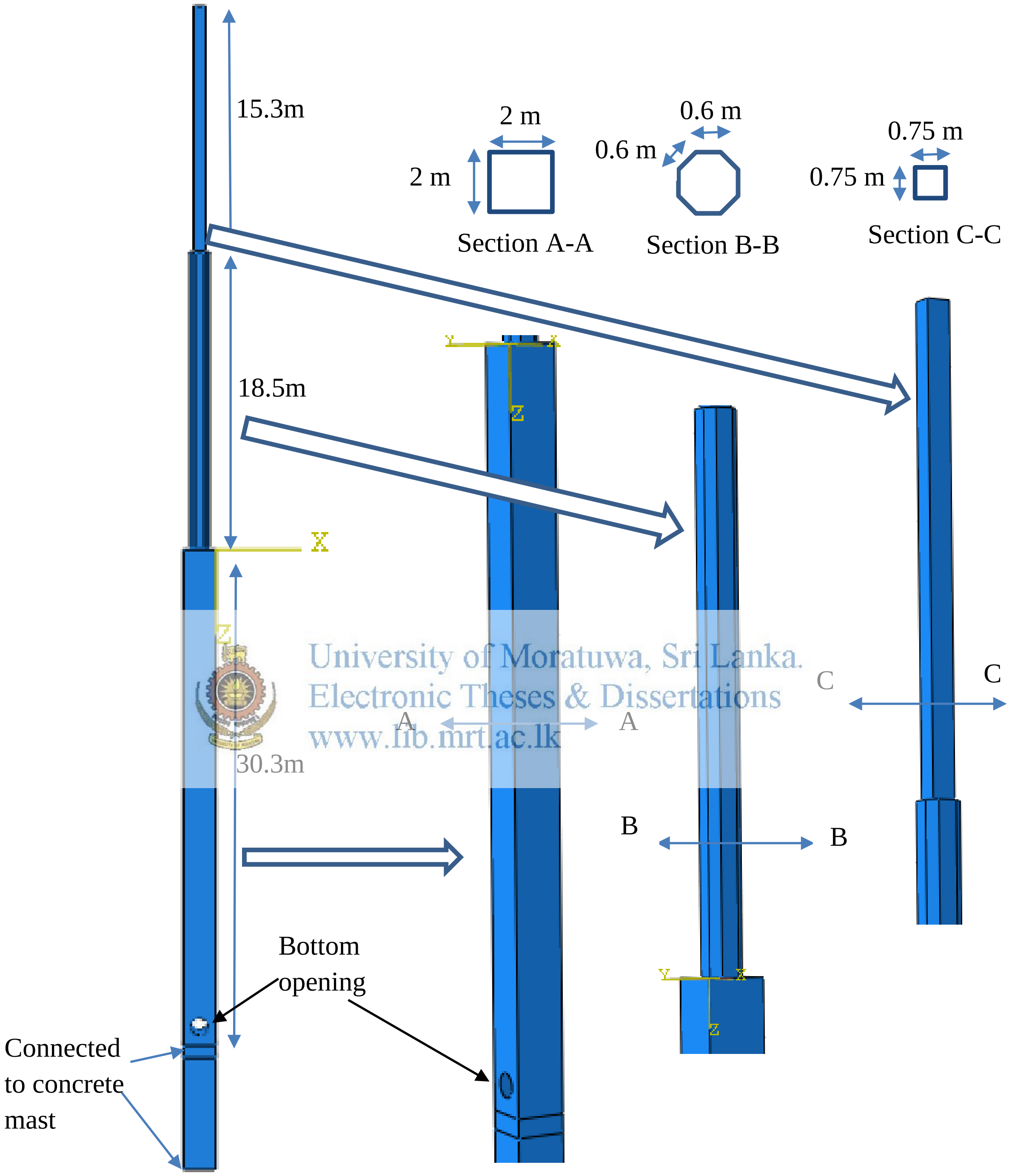

Figure 5.2: Dimensions and the shape of the steel mast

Table 5.1: Material properties

density	
Cyclic elastic properties ((Hachim, et al., sep 2012)	
Young's modulus	200Gpa
Poisson's ratio	0.3
Yield strength	372Nm^{-2}
BS 5950-1:2000:Table 9 335Nm^{-2} (40mm<thickness<63mm)	
Fatigue properties ((Fe-safe, 2014)	
B	-0.122
C	-0.598
ε_f'	0.182
σf'	1081

The maximum stresses are lower than 300Nm^{-2} in all the simulations. Hence elastic analysis can be performed.

5.3 Finite element modelling

The finite element model of the tower is constructed as shown in the figure 5.2 by merging 3 uniform parts. Different shapes of openings and different thicknesses are introduced to check the sensitivity. Abaqus standard was used with General static analysis neglecting the geometric nonlinearity.

5.3.1 Loading and boundary conditions

The gust factor was found to be 1.77 and design wind pressure is 2.6kNm-2. (See Appendix 2) Hence application of 4.6kNm-2 uniform pressure will generate equivalent stresses on the elements.

The pressure is applied on windward side as a uniform pressure load. Boundary condition at the connection to the concrete mast is idealized as a connection restraining all 3 translational degrees of freedom. The loading and boundary conditions applied on the FE model is shown in the figure 5.3.

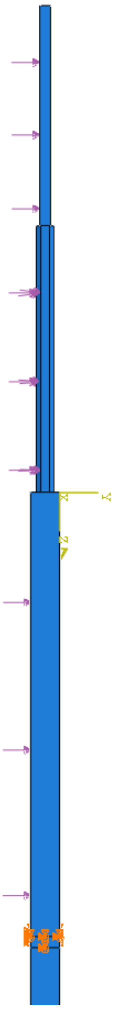

Figure 5.3: Loading on the mast FE model

5.3.2 Mesh

S8R: Eight-node doubly curved thick shell elements with varying mesh densities are used in order to model the steel mast. A finer mesh was used to model the area near the opening to obtain a detail stress distribution as shown in the figure 5.4 below.

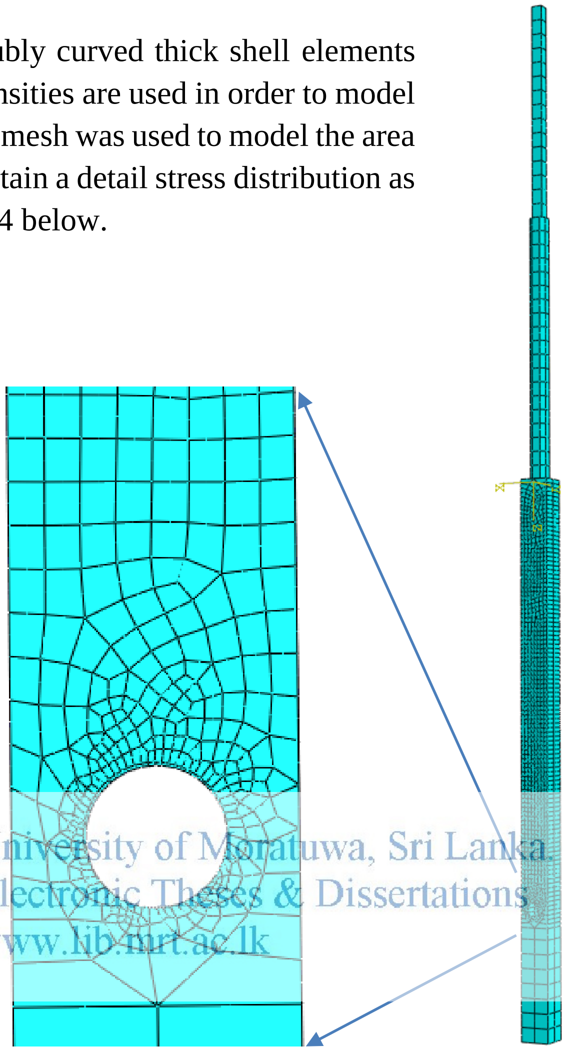

Figure 5.4: Finite element mesh of the mast

5.4 Fatigue analysis

Elastic fatigue analysis can be performed because all stresses are within elastic range. Therefore loading can be changed as desired in the fe-safe software itself unlike in elasto-plastic analysis.

The surface finish of the steel plates are assumed as fine machined (4< Ra< 16) with no residual stresses. BS 4360 G50A inbuilt material which is equivalent to S355 material has been chosen as material properties for analysis.

The fatigue analysis is done using brown miller equation with morrow’s mean stress correlation.

5.5 Results and Discussion

In order to evaluate the sensitivity for opening shape, two shapes of openings (circular and square) of same area are compared. The diameter of the circular opening is 1m whereas the side length of the square opening is 0.89m.

In order to evaluate the sensitivity for thickness around the opening, two thicknesses 30mm and 40 mm were compared.

The design wind induced stress distributions are shown below.

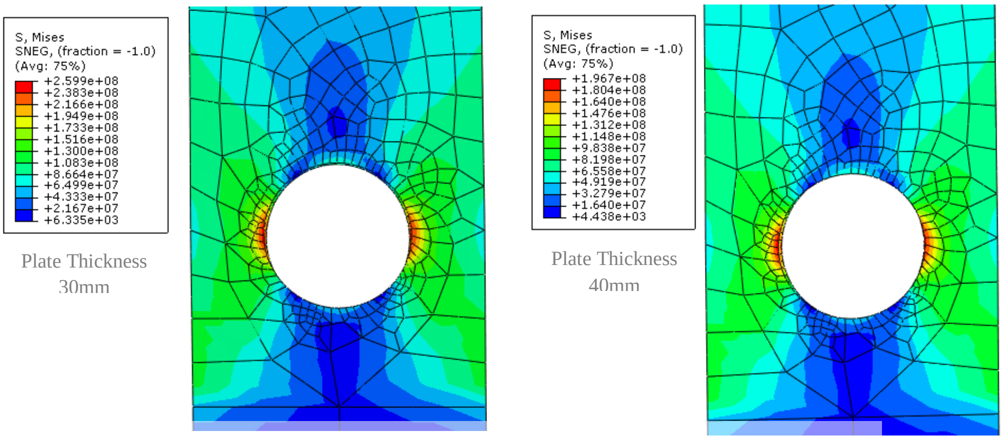

Figure 5.5: Stress distribution around the circular opening

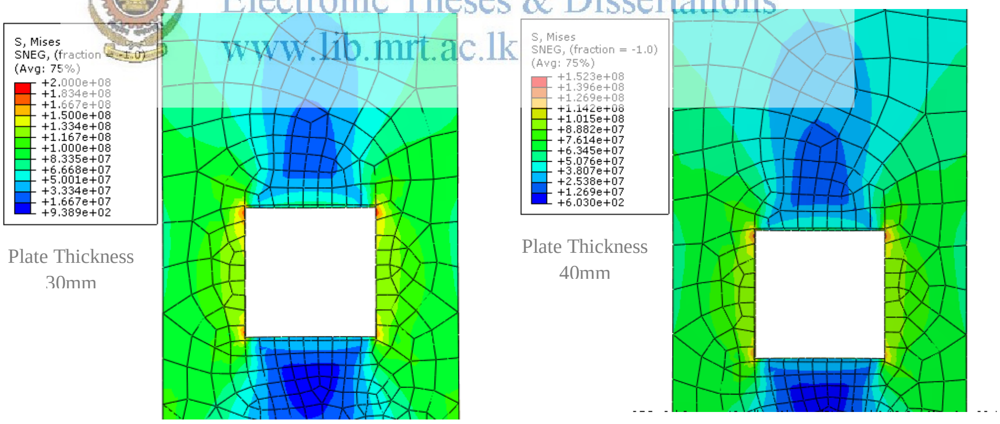

Figure 5.6: Stress distribution around the square opening

The results indicate that there are higher stresses around the circular opening (figure 5.5) than in the square opening (figure 5.6) of same area with same plate thickness. Although corners of square openings create higher stress concentrations, the bending stress increase due to larger opening dimension in the centre level of circular opening has predominated.

Around the circular opening, lowest stresses are noticed at the top and the bottom edges while highest stress concentrations are at the side edges.

Around the square opening, lowest stresses are noticed along top and the bottom edges while highest stress concentrations are along the side edges near the corners.

When the plate thickness is reduced by 25% the maximum stress levels around the opening is also reduced by nearly same value (24%) in both shapes. Adding a stiffener with higher thickness around the opening will create same effect. It will reduce the stress level by the same percentage as the thickness increase given that the stresses are within the elastic range.

The results of the fatigue analysis are shown here.

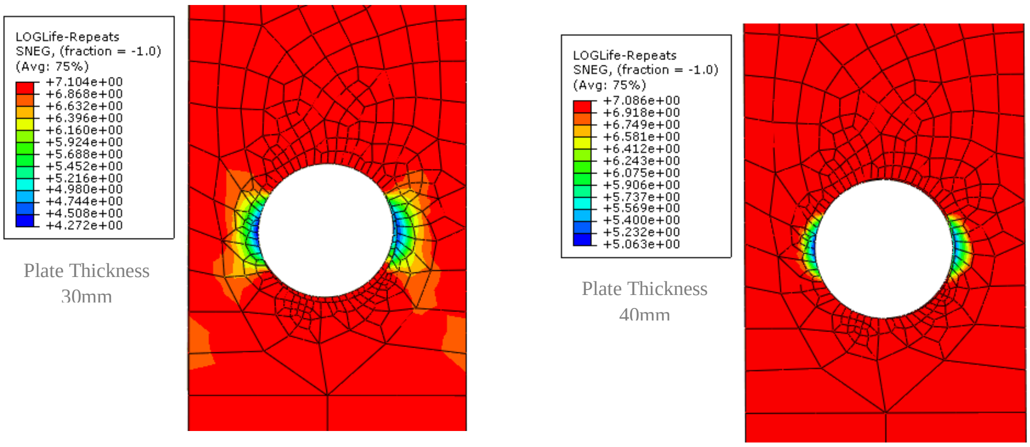

Figure 5.7: Distribution of number of reversals to failure around the circular opening

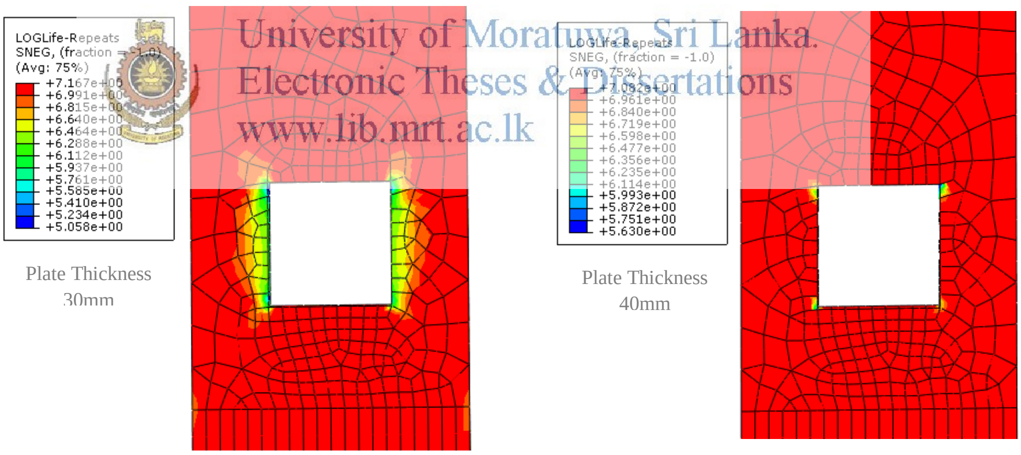

Figure 5.8: Distribution of number of reversals to failure around the square opening

Table 5.2: Minimum number of reversals to failure for combinations considered

No of reversals to failure($2N_f$)	Thickness 30mm	Thickness 40mm
Circular opening	18,367	113,161
Rectangular opening	60,051	426,693

The fatigue analysis results indicate highest stress concentrated areas (figure 5.5 & figure 5.7) having lowest endurance (figure 5.7 & figure 5.8). This is clear by the fact that the plate used is of same properties everywhere around the opening.

Although the maximum stress around the opening is reduced by the same percentage (33%) as the plate thickness increased, the endurance has increased by around 500-600% in both of the opening shapes (table 5.2). This indicates the importance of adopting stiffeners in the areas with stress concentrations such as openings corners etc.

The endurance in the square opening is almost 230-270% higher than in the circular opening for both thicknesses (table 5.2). This indicate the importance of choosing a proper shape for openings of steel structures which are subjected to dynamic vibrations. If the corners of the rectangular opening are smoothed more endurance can be expected.

By considering all above aspects we can assume that the fatigue life of the opening can be improved by adopting a rectangular opening with minimum dimension across horizontal direction with smooth corners and stiffeners along the edges.