FEM with Analytical Approach based Wind and Seismic Design Recommendations for Vertical Tall Process Column

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Abstract

The wind and seismic design is a major requirement in equipment design in oil and gas industries. In this paper we have investigated how height column intended for being designed to withstand weighty external seismic and wind effects and few significant design steps intended for considering in order to avoid column failures. Finite element based design approach is recommended as this is not a normal industrial practice currently. Many of the fabrication industries are following analytical based approach. That may be the reason some times under designed columns fail. The disadvantage of analytical method is that we cannot see exact stresses during design, so the chances of over and under design is high in analytical methods. This is one of the major reasons for developing a firm solution through this research paper. Also there is no firm fem based design procedure available in industries to follow. The code rules like ASME SECVIII DIV-I, ASME DIV-II, ASCE, IS-875, and IS-1893 are used and the allowed stresses to determine the adequacy of this design within every required loading conditions are learnt and presented. Achieved outcomes are acceptable along with the prerequisite of international standards and codes and current industry practices. FEM was redone and found that the column is safe with is to be check various shell and skirt thickness.

Keywords: Dead Weight, Earthquake, Empty Vessel, Pressure, Static Test Pressure, Static Pressure, Test Pressure, Vessel Dead Weight, Wind

1. Introduction

In this research paper tall process column wind and seismic design calculation is discussed as per international standards and codes recommendation. Now a days wind and seismic effect is known to be one among the primary reasons for process plant failures as these are unexpected as it depends on weather conditions. The condition of wind or seismic differ place to place. Usually in gas and oil industries, on failure of any equipment because of these effects then a possibility of disaster occurrence exist which is due to hazardous and harmful process fluids that normally these industries are utilizing for their process of production\(^1\). So designing these plant equipment's must be performed with at most concern predominantly for items like tall process column as this always faces heavy wind. Also the skirt, shall with stand greater wind and seismic effects. In present industrial practice, wind and seismic study of process column is based on the building codes ASCE 93, UBC-97 and IS-875 due to non availability of any code procedures. This is one of the reasons some time failures occur.

In this paper we have recommended FEM technique along with the building code analytical approach to strengthen the procedure. The minimum check fabricator has to do in FEM is advised. The shear and bending effect of the structure is checked using FEM. The natural frequency analysis is also performed for the improved vessel thickness. The IS-875, 1893 are used with FEM for improving the existing wind and seismic procedures.

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2. Material Properties

Properties associated with strength utilized in this paper were achieved from ASME Section II Division 1, Table 1, and are appropriate for ASME Section VIII Division 12 components. Column head, shell and skirt were in assumption that it is intended for fabrication from SA 516 Grade 70 material. Table 1 illustrates the properties details. A rule of ASME Section VIII Division II is utilized for setting up the material's allowable stress limits.

3. Modeling of Tall Process Column

The assumed process column is modeled for simulation. Figures 1, 2 and 3 are the typical process column model preferred. Column's total height is 29m. In order to simplify the estimation the column was divided in to eight Table 1.

| Properties of the Material SA-516 Grade 70 |        |
|------------------------------------------|--------|
| Minimum Tensile Strength                 | 482MPa |
| Minimum Yield Strength                   | 261MPa |
| Material Density                         | 76807N/m³ |
| Product form                             | PLATE |

Table 2. Summary of material properties

![Figure 1. Top portion of tall column.](image1)

![Figure 2. Bottom portion of tall column.](image2)

![Figure 3. Full view of tall column.](image3)
dissimilar segments, every segment has 2.8m length and 1.8m internal diameter.

The segments has called as A-B, B-C, C-D, D-E, E-F, F-G, G-H, H-I, I-J, J-K, K-L for identification, the segments details are shown in Table 2. And the top and bottom dishes are 0.45m in heights. Bottom skirt height preferred as 5.6m. Column details modeling summing up is as illustrated in Table 2. For applying reality the column has modeled with nozzles, platforms, ladders and man ways but no internals considered.

4. Loads and Boundary Conditions

The bottom skirt is unchanging in all directions to prevent the rigid body motion. Column is Considered for mounting on cylindrical skirt that would put off differential ground settling, numerous pressure, wind and seismic. The applied forces and moments considered for this study and their direction of application is mentioned in Table 3 and Figure 4. Other assumed loads are also listed in Table 4.

5. Design of Column and Skirt Support

The thickness calculation of the column shell and dish is estimated as per ASME Section VIII Division 12. The 2:1 ellipsoidal head is considered as dishes for column’s top and bottom portion. Maximum thickness prerequisite of shell and head are 19mm for the assumed internal design

| Table 2. Summary of column sectioning |
|--------------------------------------|
| Sections     | From | To  | Y Vertical in mm |
| Skirt        | A    | B   | 5638             |
| Straight Face| B    | C   | 5791             |
| Section-1    | C    | D   | 8686             |
| Section-2    | D    | E   | 11558            |
| Section-3    | E    | F   | 14429            |
| Section-4    | F    | G   | 17300            |
| Section-5    | G    | H   | 20171            |
| Section-6    | I    | J   | 23042            |
| Section-7    | J    | K   | 25914            |
| Section-8    | K    | L   | 28800            |
| Top Dish     | L    | M   | 29250            |

| Table 3. Forces and moments applied to vessel |
|---------------------------------------------|
| From | To    | X and Z Forces in N | X,Z Moments in N.mm |
| A    | B     | 10008                | ----               |
| B    | C     | 88.96                | ----               |
| C    | D     | 10586                | 15.33E6            |
| D    | E     | 10586                | 15.20E6            |
| E    | F     | 1668                 | 2.39E6             |
| F    | G     | 1668                 | 2.39E6             |
| G    | H     | 10564                | 15.17E6            |
| H    | I     | 1668                 | 2.39E6             |
| I    | J     | 1668                 | 2.39E6             |
| J    | K     | 10564                | 15.17E6            |
| K    | L     | ----                 | ----               |

| Table 4. Wind and Seismic Data’s |
|----------------------------------|
| Considered Values | Values | Reference |
| Basic Wind Speed | 112.65 Km/hr | Assumed |
| Wind Zone Number (wind) | 1 | Ref.7 |
| Risk Factor (wind) | 1 | Ref.7 |
| Terrain Category (wind) | 1 | Ref.7 |
| Equipment Class (wind) | A | Ref.7 |
| Topological Factor (wind) | 1 | Ref.7 |
| Important Factor (Seismic) | 1 | Ref.7 |
| Zone Number (Seismic) | 1 | Ref.7 |
| Soil Factor (Seismic) | 1 | Ref.7 |

Figure 4. Boundary condition of the column.

pressure 125psig. The atmospheric pressure is considered as external design pressure. Usually design pressure is greater than the pressure at which it operates with the choice of more 10 percent. The same has assumed in this study. The MAWP and MAP were also estimated for identifying the accurate Maximum Allowable Working
Pressure (MAWP) and Maximum Allowable Pressure (MAP). The internal pressure where the column’s weakest element is loaded to the definitive permissible point, on assumption that the column to be in corroded condition, under the designated temperature effect, in usual operating position at top and under the various loading effects like Hydrostatic Pressure, External Pressure, Wind that are together with internal pressure. When MAWP calculation has not been done, the considered design pressure might be utilized as MAWP as per code rule of 3.2 of ASME VIII Division 12. The hydrostatic and MDMT are calculated analytically and found that 19mm shell thickness is suitable for SA 516 Grade 70 material. In bottom skirt design is concerned, highly general techniques to support vertical column is by mean of a conical or cylindrical shell that is rolled is referred as skirt. Skirt could be either lap, fillet, or but welded straightforwardly to the column. Supporting method is important since it minimizes the local stress at the attachment point and the direct load is consistently disseminated over the complete circumference. The skirt considered for this analysis is rolled cylinder as represented in Figure 3. It is a straight cylinder. The thickness of skirt is considered same as shell thickness 19mm.

6. Wind and Seismic Design

After calculating all basic calculations, the wind and seismic calculation are performed as per IS-875 and IS-1893. ASME Section VIII Division I2 does not give any specific procedure for wind and seismic on the other hand paragraph UG-22 loadings does list wind to be one among the loading which has to be preferred during design. Three main nationally recognized standards exists which are very often utilized for wind and seismic design is ASCE-93, UBC and IS-875,1893. These codes outlines the wind design is utilized for determining the forces and moments at every elevation for checking whether the estimated shell thickness are adequate\(^6\). Overturning moment at the base is utilized for determining every details regarding anchorage and support. The given information incorporates anchor bolts number and size, skirts and base plates\(^7\) thickness. On variation with loading wind from seismic which is almost constant, while seismic seems to be comparatively less in duration? Additionally the winds pressure various with the vessel height. A vessel has to be designed for worst case of the wind or seismic but does not demand design both for simultaneously\(^8,9\) while normally the worst case for seismic design is having full vessel, wind’s worst case is involving empty vessel\(^10\). This would generate the maximum uplift because of the least restraining weight. Wind forces are achieved by multiplying every element’s projected area, under each height zone by the essential wind pressure for that height zone for the shape factor of each element. Entire forces of the vessel are the forces addition of every elements. Forces of the elements are functional centroid of the projected area. The weights and natural frequencies are also found out. The estimated natural frequencies are 1.4455 Hz (Empty) and 1.4450 Hz (Operating). The input values are listed in Table 4 based on the recommendation of IS-875 and IS-1893. The IS-875 provides basic wind speed map of India as appropriate to 10m height higher than the mean ground level for country’s dissimilar zones. The taken wind speed depends on peak gust velocity average over the short time interval of around 3 seconds and associates to mean heights over the level of ground in a terrain that is open. Similarly, the risk factor, terrain category, equipment class, topological factor, important factor, zone number, and soil factor considered for this calculation is listed in Table 4. Based on these inputs, the shear and bending effects are calculated [Tables 5 and 6]. The segmental wise wind and seismic load is also calculated and the maximum wind and seismic loads are appeared in the bottom portion of the column A-B and the values are 9637N, 1174N. With respect to this, the bending and shear effect is found out [Tables 7 and 8]. Simultaneously the bending is also calculated [Tables 8

| From | To | Distance to Support in mm | Wind Height in mm | Element Wind Loads in N |
|------|----|---------------------------|-------------------|------------------------|
| A    | B  | 5638                      | 5638              | 9637                   |
| B    | C  | 5791                      | 5791              | 0244                   |
| C    | D  | 8686                      | 8686              | 6121                   |
| D    | E  | 11558                     | 11558             | 6441                   |
| E    | F  | 14429                     | 14429             | 6869                   |
| F    | G  | 17300                     | 17300             | 4935                   |
| G    | H  | 20171                     | 20171             | 7151                   |
| H    | I  | 23042                     | 23042             | 5186                   |
| I    | J  | 25914                     | 25914             | 7345                   |
| J    | K  | 28800                     | 28800             | 7565                   |
| K    | L  | 29250                     | 29250             | 0891                   |
Table 6. Analytical result of seismic load calculation [IS-875, 1893]

| From | To  | Distance to Support in mm | Seismic Weight | Seismic Loads in N |
|------|-----|----------------------------|----------------|-------------------|
| A    | B   | 5638                       | 117477        | 1174              |
| B    | C   | 5791                       | 107464        | 0075              |
| C    | D   | 8686                       | 056389        | 0335              |
| D    | E   | 11558                      | 049697        | 0293              |
| E    | F   | 14429                      | 041853        | 0229              |
| F    | G   | 17300                      | 044191        | 0221              |
| G    | H   | 20171                      | 045172        | 0254              |
| H    | I   | 23042                      | 036486        | 0176              |
| I    | J   | 25914                      | 044131        | 0252              |
| J    | K   | 28800                      | 046987        | 0269              |
| K    | L   | 29250                      | 004922        | 0040              |

Table 7. Result of wind and seismic shear [IS-875, 1893]

| From | To  | Distance to Support in mm | Wind Shear in N | Seismic Shear in N |
|------|-----|----------------------------|-----------------|-------------------|
| A    | B   | 5638                       | 62391           | 5047              |
| B    | C   | 5791                       | 52754           | 3872              |
| C    | D   | 8686                       | 52509           | 3698              |
| D    | E   | 11558                      | 46388           | 3134              |
| E    | F   | 14429                      | 39947           | 2637              |
| F    | G   | 17300                      | 33077           | 2218              |
| G    | H   | 20171                      | 28140           | 1777              |
| H    | I   | 23042                      | 20989           | 1325              |
| I    | J   | 25914                      | 15802           | 0960              |
| J    | K   | 28800                      | 08456           | 0519              |
| K    | L   | 29250                      | 00891           | 0049              |

Table 8. Result of wind and seismic bending [IS-875, 1893]

| From | To  | Distance to Support in mm | Wind Bending in Nmm | Seismic Bending in Nmm |
|------|-----|----------------------------|---------------------|------------------------|
| A    | B   | 5638                       | 964E6               | 67.34 E6               |
| B    | C   | 5791                       | 640E6               | 42.18 E6               |
| C    | D   | 8686                       | 632E6               | 41.60 E6               |
| D    | E   | 11558                      | 488E6               | 31.70 E6               |
| E    | F   | 14429                      | 364E6               | 23.41 E6               |
| F    | G   | 17300                      | 259E6               | 16.44 E6               |
| G    | H   | 20171                      | 172E6               | 10.70 E6               |
| H    | I   | 23042                      | 101E6               | 06.24 E6               |
| I    | J   | 25914                      | 048E6               | 02.96 E6               |
| J    | K   | 28800                      | 013E6               | 835466                 |
| K    | L   | 29250                      | 222682              | 012300                 |

Table 9. Wind deflection for operating cases [IS-875, 1893]

| From | To  | Wind Shear in N. | Deflection in mm |
|------|-----|------------------|------------------|
| A    | B   | 62391            | 0.378            |
| B    | C   | 52754            | 1.45             |
| C    | D   | 52509            | 2.26             |
| D    | E   | 46388            | 4.19             |
| E    | F   | 39947            | 6.61             |
| F    | G   | 33077            | 9.48             |
| G    | H   | 28140            | 12.67            |
| H    | I   | 20989            | 16.07            |
| I    | J   | 15802            | 19.57            |
| J    | K   | 08456            | 23.14            |
| K    | L   | 00891            | 24.98            |
Figure 6. Displacement due to critical wind load.

Figure 10. Shear stress XZ due to critical seismic load.

Figure 7. Von Misses due to critical seismic load.

Figure 11. Shear stress YZ due to critical seismic load.

Figure 8. Deflection due to critical seismic load.

Figure 12. Von Misses due to combined wind and seismic.

Figure 9. Shear stress XY due to critical seismic load.

Figure 13. Shear XY due to combined wind and seismic.
Figure 14. Shear XZ due to combined wind and seismic.

Figure 15. Shear YZ due to combined wind and seismic.

Figure 16. Deflection due to combined wind and seismic.

Figure 17. Von Misses for improved thickness 22mm (Wind + Seismic).

Figure 18. Stress intensity for thickness 22mm (Wind + Seismic).

Figure 19. Shear stress XY for improved thickness 22mm.

Figure 20. Shear stress XZ for thickness 22mm (Wind + Seismic).

Figure 21. Shear stress YZ for thickness 22mm (Wind + Seismic).
Table 11. Finite element analysis results

| Sl. No. | Stresses for Worst Load | Values      | Report |
|---------|-------------------------|-------------|--------|
| 1.      | Von Misses for Critical Wind Load [Figure - 5] | 319MPa | FAIL  |
| 2.      | Deflection for Critical Wind Load [Figure - 6] | 14mm | ---    |
| 3.      | Von Misses for Critical Seismic [Figure - 7] | 323MPa | FAIL  |
| 4.      | Deflection for Critical Seismic [Figure - 8] | 14mm | ---    |
| 5.      | Shear XY for Critical Seismic [Figure - 9] | 36MPa | ---    |
| 6.      | Shear XZ for Critical Seismic [Figure - 10] | 31MPa | ---    |
| 7.      | Shear YZ for Critical Seismic [Figure - 11] | 21MPa | ---    |
| 8.      | Von Misses (Wind + Seismic) [Figure - 12] | 2234MPa | FAIL  |
| 9.      | Shear XY (Wind + Seismic) [Figure - 13] | 251MPa | ---    |
| 10.     | Shear XZ (Wind + Seismic) [Figure - 14] | 216MPa | ---    |
| 11.     | Shear YZ (Wind + Seismic) [Figure - 15] | 146MPa | ---    |
| 12.     | Deflection (Wind + Seismic) [Figure - 16] | 100mm | ---    |
| 13.     | Von Misses -22mm Thickness (W+S) [Figure-17] | 226MPa | PASS  |
| 14.     | Stress Intensity -22mm (W+S) [Figure-18] | 241MPa | PASS  |
| 15.     | Shear XY(W+S) [Figure - 19] | 25MPa | ---    |
| 16.     | Shear XY (W+S) [Figure - 20] | 21MPa | ---    |
| 17.     | Shear YZ (W+S) [Figure - 21] | 14MPa | ---    |
| 18.     | Displacement [Figure - 22] | 10mm | ---    |

NOTE: Serial number 1 to 12 is the simulation result of 19mm thickness plate and the serial number 13 to 18 is the result of 22mm thickness plate simulation outputs.

Table 10. Wind deflection for operating cases

| Mode Shapes | Frequency in Rad/Sec | Frequency in Hz | Period in Sec |
|-------------|----------------------|-----------------|--------------|
| MODE-1      | 9.08                 | 1.4450          | 0.492        |
| MODE-2      | 9.45                 | 1.5046          | 0.492        |
| MODE-3      | 10.10                | 1.6089          | 0.081        |
| MODE-4      | 10.70                | 1.7045          | 0.080        |
| MODE-5      | 11.93                | 1.9000          | 0.037        |

7. Recommendation and Conclusions

With regard to this research, it has been found that wind and seismic design based only on analytical approach does not give exact solution all the time and it is not suitable for all types of column geometry. The FEM is required with analytical approach (Table 7, Table 8, and Table 9) to ensure the design is safe. We found in this study, the passed analytical design is failing during FEM analysis (Figure 7) and the column requires more thickness to withstand the external forces based on FEM. Accordingly the thickness has been improved as 22mm and the FEM was redone and found that the column is safe with 22mm shell and skirt thickness. (Figures 17 to 23).

- The fabricator shall least fulfill mentioned prerequisite's for designing and fabricating column's process.
- The fabricator might consider conical skirt instead of straight skirt as conical has more load absorbing capabilities.
• The fabricator might utilize internal or external stiffening rings everywhere requisite to save the column from surplus internal and external conditions of loading.
• The fabricators could often counsel usage of materials that are upgraded for designing column and skirt.
• The fabricator is advised in maintaining good factor of safety limit to column's shear and bending effect.
• Prerequisite on anchor bolts and foundation could be verified properly depending on the code recommendation prior to column's erection.

8. References

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