Evaluation of Protection Against Collapse from Buckling of Stiffened Column Based on ASME BPVC Sec. VIII Div.2 Using Finite Element Simulation

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***Abstract*— Aprotection against collapse from buckling of a stiffened column was evaluated based on ASME Boiler and Pressure Vessel Code Section VIII Division 2 using the finite element simulation. The column without the stiffener ring was also evaluated as a comparison. A finite element code ANSYS ver. 14.5 was used to perform thebuckling analysis of the columns. The linear (eigenvalue) buckling analysis was performed to obtain a critical load factor then the value was compared with the minimum design factor required based on the ASME Code. The columns was modeled using a shell element and the geometric non-linearties was not considered. The external pressure, the self-weight force and the temperature load were considered as the loading in the analysis. Among all applied loads, the external pressure was the most significant load contributing for the buckling of this column. The buckling strength of the column was greatly improved by the utilization of the stiffener ring, and the design stiffened column satisfied the requirement for protection against collapse from buckling.**

***Keywords*— Buckling; Stiffened Column; ASME Sec.VIII Div.2; Finite Element Simulation; ANSYS**

I. INTRODUCTION

A vertical pressure vessel or known as column or tower is a common equipment designed for a mass or heat transfer in petrochemical, refinery, oil and gas and food industry. The column is generally constructed by a thin-walled cylindrical shell, heads and skirt. Due to the long and high diameter to thickness ratio, the common failure modes of the shell is buckling under external pressure and/or axial compressive load.

If a long and thin-walled circular cylinder is not ring-stiffened, its buckling resistance under uniform external pressure is very poor, and this vessel may failby non-symmetric bifurcation buckling or shell instability [1]. To improve the buckling strength of such vessels,the stiffener ring is applied in their flanges. However, if the ring stiffeners are not strong enough, the general instability failure may occur, i.e. the ring-shell combination collapse due to the applied uniform external pressure [2].

The buckling stability of the circular cylindrical shells under the external load has been widely investigated. Lemak and Studnicka [3] have investigated the influence of the distance and stiffness of ring stiffeners on the buckling behaviour of a cylindrical steel shell under a wind loading. Ross et.al, [4] has investigated the plastic general instability of ring-stiffened conical shells under external pressure. Prabu et.al, [5] applied the imperfections model for analysing the buckling of thin cylindrical shell subjected to uniform external pressure using the non-linear finite element model.

The American Society of Mechanical Engineers (ASME) have developed the Boiler and Pressure Vessel Code (BPVC) to ensure the safety on the design of the vessels for their operations, including for protection against the collapse from the buckling [6]. The design of the vessels according to this code is based on the rule and the analysis requirements. For the design by the analysis requirements to protect the vessels against the collapse from the buckling, the finite element simulation is performed to the get the design factor of the vessel under the specified loads.

In the present study, the buckling of stiffened column was evaluated based on the requirement of ASME BPVC Sec. VIII Div. 2 using the finite element simulation. The column without the stiffener ring was also analysed as a comparison. A finite element code ANSYS ver. 14.5 was used to simulate the buckling of the columns. The buckling load factor obtained from the linear (eigenvalue) buckling analysis was compared to the minimum design factor required by the ASME BPVC Sec. VIII Div. 2.

II. PROTECTION AGAINST COLLAPSE FROM BUCKLING BASED ON ASME SECTION VIII - DIVISION 2

To avoid buckling of components with a compressive stress field under applied design loads based on ASME BPVCSec. VIII Div.2, a design factor for protection against collapse from buckling shall be satisfied [6]. The design factor to be considered in a structural stability assessment is based on the type of buckling analysis performed. When the buckling loads are determined using a numerical solution, the following design factors, Φ_B, shall be the minimum values for use with the shell components.

- Type 1 – If a bifurcation buckling analysis is performed using an elastic stress analysis without geometric nonlinearities in the solution to determine the pre-stress in the component, a minimum design factor of $\Phi_B = (2/\beta_{cr})$ shall be used.
- Type 2 – If a bifurcation buckling analysis is performed using an elastic-plastic stress analysis with the effects of non-linear geometry in the solution to determine the pre-

stress in the component, a minimum design factor of $\Phi_B = (1.667/\beta_{cr})$ shall be used.

- Type 3 – If a collapse analysis is performed using an elastic-plastic stress analysis method, and imperfections are explicitly considered in the analysis model geometry, the design factor is accounted for in the factored load combinations in Table 5.5 of ASME Sec. VIII - Div. 2.

The capacity reduction factors, β_{cr}, to be is based on the shape of the structure and the applied load.

- For unstiffened or ring stiffened cylinders and cones under axial compression
  $\beta_{cr} = 0.207$ for Do/t ≥ 1247
  $\beta_{cr} = \frac{338}{338+\frac{D_o}{t}}$ for Do/t < 1247
- For unstiffened and ring stiffened cylinders and cones under external pressure
  $\beta_{cr} = 0.80$
- For spherical shells and spherical, torispherical, elliptical heads under external pressure
  $\beta_{cr} = 0.124$

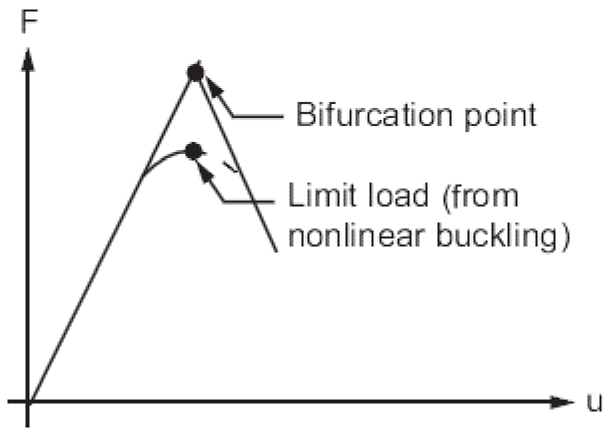
III. Buckling Analysis of Columns

A. *Buckling Analysis Technique in ANSYS*

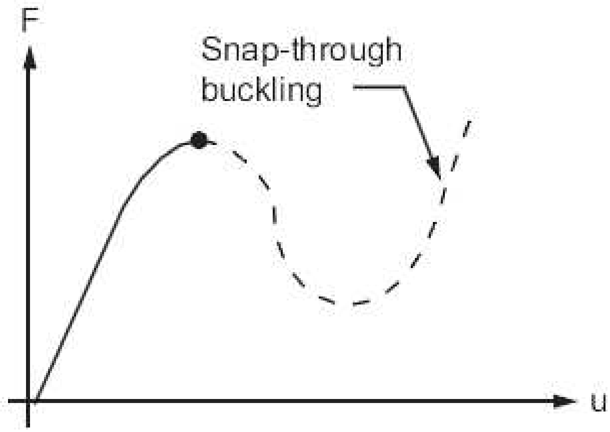
The buckling analysis in the present study was performed using the finite element commercial code ANSYS ver. 14.5. There are two techniques in the ANSYS for predicting the buckling load and buckling mode shape of a structure, that iseigenvalue (or linear) buckling analysis, and nonlinear buckling analysis [7].

- *Eigenvalue Buckling Analysis*: Eigenvalue buckling analysis predicts the theoretical buckling strength (the bifurcation point, as shown in Fig. 1 (a)) of an ideal linear elastic structure. This analysis used the linearised model of the elastic structure to predict the bifurcation point. However, imperfections and nonlinearities prevent most structures from achieving their theoretical elastic buckling strength.
- *Nonlinear Buckling Analysis:* Nonlinear buckling analysis is a more accurate approach to predict the buckling strength of the structure. This technique employs a nonlinear static analysis with gradually increasing loads to determine the load level at which the structure becomes unstable, as shown in Fig. 1 (b).This analysis gives more accurate results since the capability of analysing the actual structures with their imperfections. Thepost-buckled performance of the structure from this analysisalso can be evaluated using deflection-controlled loading.

Although a bifurcation point obtained from the linear buckling analysis over-predicts the buckling limit load obtained from the nonlinear buckling analysis, Type 1 and Type 2 of the buckling analysis based on ASME Sec. VIII Div. 2 were used this linear method.Prior performing the linear buckling analysis in ANSYS, the static analysis have to be performed first to obtain the pre-stress effects, since the buckling analysis requires the stress stiffness matrix to be calculated [7]. An expansion pass analysis is then performed to review the buckled mode shape.



(a) Linear buckling curve



(b) Nonlinear buckling curve

Fig.1 Buckling curves: (a) linear and (b) nonlinear [7].

B. *Model of Columns and Condition of Buckling Analysis*

The buckling of columns with and without stiffener ring were analysed in this study. The geometry and dimension for the unstiffened and stiffened columns are shown in Fig. 2. The dimension of the unstiffened column was similar with that the stiffened column to evaluate the effect of the stiffener ring on the buckling strength of the column.

The condition used for the buckling analysis of the columns is shown in Table 1. The external pressure of 0.101 MPa was applied to the shell of the columns. The temperature was applied as a type of a body force obtained from the thermal analysis result. The acceleration of gravity was applied for considering the force from the weight of the columns. The cylindrical coordinate system was used for applying boundary conditions to the bottom of the skirt, where the displacement in the vertical and azimuthal direction were fixed, whereas in the radial direction was free. The geometric non-linearities of the columns was not considered in the static analysis solution.

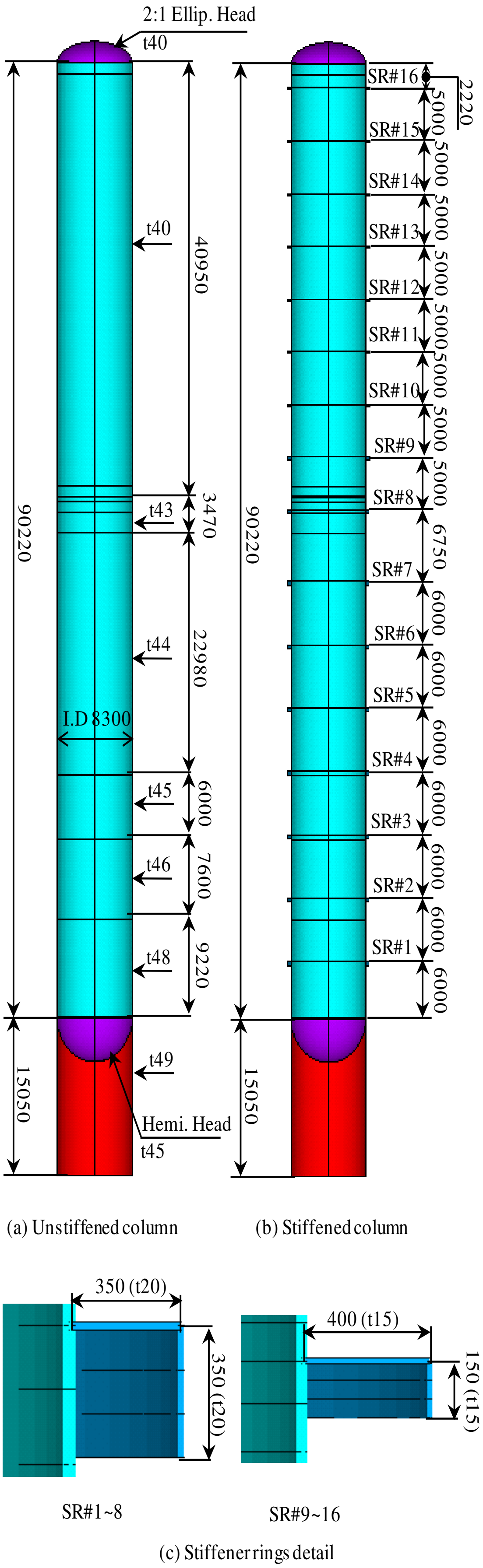


Fig. 2 Geometry and dimension for (a)unstiffened column, (b) stiffened column and (c) stiffener ring (unit in millimetre).

TABLE I
CONDITIONS USED FOR BUCKLING ANALYSIS OF COLUMNS

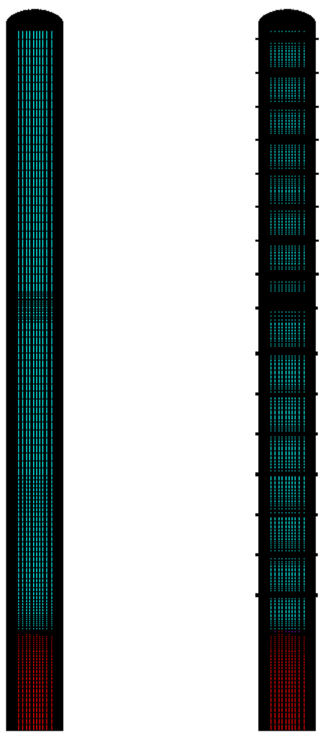
Design pressure	0.101 MPa
Design temperature	300 ºC
Ambient temperature	20 ºC
Corrosion allowance	3.2 mm
Operating weight (stiffened)	2,632,800 kg
Stiffener ring weight	48,802 kg

The carbon steel SA516-70N was used for the material of the columns. The material properties for SA516-70N is shown in Table 2. The density and the poisson's ratio for the steel used in the analysis was 7,800 kg/m^3 and 0.3, respectively.

TABLE II
MATERIAL PROPERTIES FOR SA516-70N

Temp	Elastic Modulus (MPa)	YieldStress (MPa)	Thermal expansion (mm/mm/ºC)	Thermal conductivity (W/mm.ºC)
20	202,350	262	11.5E^{-6}	60.4E^{-3}
100	198,000	239	12.1E^{-6}	58.0E^{-3}
200	192,000	225	12.7E^{-6}	53.6E^{-3}
300	185,000	204	13.3E^{-6}	49.2E^{-3}

The finite element model of the columns was constructed using a shell element.A four-node structural element with six degrees of freedom at each node SHELL181 was used for structural analysis, whereas SHELL57 that has four-nodes and single degree of freedom (temperature) was used for thermal analysis. The finite element model of the unstiffened and stiffened columns are shown in Fig. 3.



(a) Unstiffened column (b) Stiffened column

Fig. 3 Finite element model of (a)unstiffened and (b) stiffened columns

IV. Results of Buckling Analysis of Columns

The linear (eigenvalue) buckling analysis was performed to predicts the buckling load factorof the columns then compared with the minimum design factor required by ASME BPVC Sec. VII Div. 2. Since the geometry non-linearities of the columns was not consider in the analysis solution, thus the minimum required design factor for thesecolumns based on the ASME Code is Type 1, $\Phi_B = (2/\beta_{cr})$.

Since the columns was subjected with the external pressure, thus the capacity reduction factors, β_{cr}, for this analysis is 0.80. Thus the design factor to be satisfied for the buckling analysis of these columns is:

$$\Phi_B = \frac{2}{\beta_{cr}} = \frac{2}{0.8} = 2.5 \quad (1)$$

In this linear buckling analysis, the subspace method was used as the eigenvalue extraction method, since the used of the Black Lancoz method for solving larger model requires a significant amount of computer memory and requires longer time for solving the model than the subspace. The first three eigenvalue was requested to obtained the lowest load buckling factor of the columns.

A. Buckling Analysis of Unstiffened Column

The plot of the first mode shape for the buckling analysis of the unstiffened column is shown in Fig. 4. The first and the lowest buckling mode for the column has a load factor of 0.6812. Since the load factor is lower than the minimum design factor of 2.5, thus the unstiffened column doesn't meet the requirements for the protection against collapse from buckling.

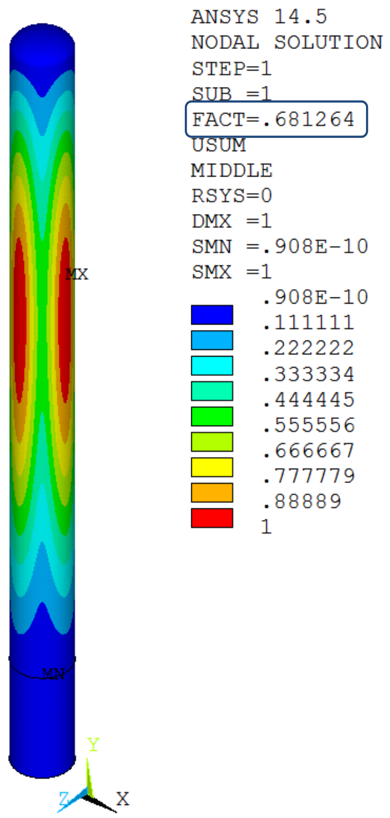


Fig. 4 Plot of first mode shape for buckling analysis of unstiffened column.

B. Buckling Analysis of Stiffened Column

The plot of the first mode shape for the buckling analysis of stiffened column is shown in Fig. 5.The first and the lowest buckling mode for the column has a load factor of 6.281 and is greater than the minimum design factor of 2.5. Thus the design of the stiffened column satisfies the requirements for the protection against collapse from buckling. It was found that the used of the stiffener ring significantly increase the buckling strength of the column.

The result obtained by the linear buckling analysis was the buckling load factor that scale the loads applied in the static structural analysis. Since the loads applied in these columns were consisted of a variable load (pressure) and constant loads (weight load and temperature load), thus the load factor was scaling both the constant and variable loads. To obtain the more accurate result of the buckling load factor, the variable load (pressure) should be multiplied by a certain factor until the buckling load factor of the structure becomes nearly to 1.0.

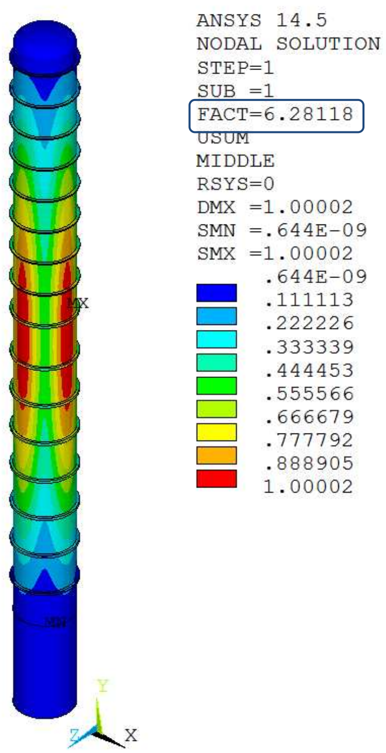


Fig. 5 Plot of first mode shape for buckling analysis of stiffened column

For the stiffened column, the load factor from the linear buckling analysis becomes nearly to 1.0 when the pressure load was multiplied by 6.273. The plot of the first mode shape for the buckling analysis of stiffened column with the pressure load of 0.6335 MPa is shown in Fig. 6.

From the prior analysis where the load factor multiplied all the applied loads, the critical buckling load factor is 6.281. When the weight and temperature load is multiplied by one, the critical buckling load is occurred when the pressure loadmultiplied by 6.273. The pressure load multiplier value almost have similar value with that the the load factor for all applied loads. It was found that the pressure load was the most significant load for contributing the buckling in this column.

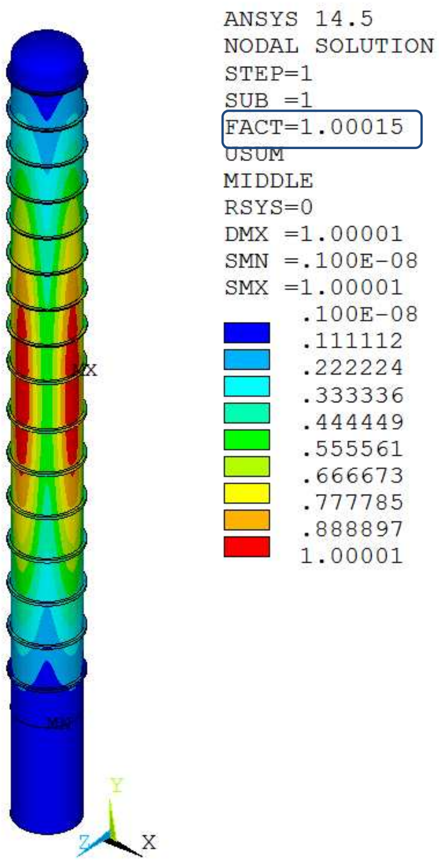


Fig. 6 Plot of first mode shape for buckling analysis of stiffened column with pressure load of 0.6335 MPa.

V. Conclusions

A protection against collapse from buckling of a stiffened column was evaluated based on ASME Boiler and Pressure Vessel Code Section VIII Division 2 using the finite element code of ANSYS ver. 14.5. The column without the stiffener ring was also evaluated as a comparison. The linear (eigenvalue) buckling analysis was performed to obtain the critical load factor then the value was compared with the minimum design factor required based on the ASME Code.Among the external pressure, self-weight and temperature loads applied on this column, the external pressure was the most significant load contributing for the buckling of this column. It was found that the utilization of the stiffener ring significantly increase the buckling strength of the column and the design of the stiffened column satisfied the requirements for the protection against collapse from buckling based on the ASME code.

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