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The Effect of D/t ratio on Buckling Strength Analysis of Fixed Offshore Platform

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ABSTRACT

A jacket, or template, structures are still the most common offshore structures used for drilling and production. Fixed jacket structures consist of tubular members interconnected to form a three-dimensional space frame. Hence, the jacket structure can be categorized into a column structure. The D/t ratio of a typical member on the jacket structure has significant influence to buckling strength. Although only the axial load acts on the jacket legs, the local and global deformation of the structural member due to this load must be taken into account. This paper discusses the effect of D/t ratio on fixed jacket platform in the buckling strength analysis. A kind of fixed jacket offshore structure namely tripod is taken as the object of the analysis. Only the axial load is considered and it is applied to all jacket legs. The material and dimension of the structure are taken based on the structural member. Crack and corrosion are not considered in the analysis. To assess the buckling strength of the structure due to the effect of D/t ratio, the Finite Element Method (FEM) is performed. As a fundamental case, the buckling strength analysis is conducted on the structure by taking two dimensional planes (2D) into consideration to obtain the critical buckling load due to the effect of D/t ratio for two dimensional plane. The result obtained by FEA is compared with the analytical solution.

Keywords: Buckling strength, fixed jacket structure, D/t ratio, Finite Element Method

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INTRODUCTION

Fixed offshore platform is one kind of the offshore structure which is generally used in Indonesia. The structure commonly categorized as a column structure where the axial compressive load is applied to the jacket legs. The jacket legs play an important role because axial compressive loads are distributed vertically to these legs and the structure can deformed in horizontal direction, so this phenomenon is called buckling as shown in Figure 1. The jacket, or template, structures are still the most common offshore structures used for drilling and production. Some structures contain enlarged legs, which are suitable for self-buoyancy during its installation at the site. Fixed jacket structures consist of tubular members interconnected to form a three-dimensional space frame. Hence, the jacket structure can be categorized into a column structure. These structures usually have four to eight legs battered to achieve stability against not only toppling in waves but also axial compressive loads. Main piles which are tubular are usually carried with the jackets and driven through the jacket legs into the seafloor.

The piles bear the axial compressive loads due to the component of the main deck and these loads are distributed to all the jacket legs. The effect of D/t ratio of a typical member on the jacket structure has significant influence to the buckling strength. Horizontal and diagonal braces play an important role to resist the axial compressive load on the jacket legs. Although only the axial load acts on the jacket legs, the local and global deformation of the structural member due to this load must be taken into account.

Figure 1. Buckling phenomenon

This paper discusses the effect of D/t ratio in buckling strength analysis on the fixed jacket offshore platform. A fixed jacket offshore structure namely tripod is taken as the object of the analysis. Only the axial load is considered and it is applied to all of jacket legs. The material and dimensions of the structure are taken based on the structural member. Crack and corrosion are not considered in the analysis. To assess the buckling strength of the structure due to the effect of D/t ratio, the Finite Element Method (FEM) is used. As a fundamental case, the buckling strength analysis is performed on the structure by taking two dimensional planes (2D) into consideration to obtain the critical buckling load for two dimensional plane. The result obtained by FEA is compared with the analytical solution.

2. METHOD

The stability phenomenon of a structure is defined by its state of equilibrium. The equilibrium of a designed structure is stable if small imperfections or defects will cause correspondingly small deviations from the idealized operating condition. Buckling or structural instability is considered one of the main modes of failure of ship structure members subjected to compressive forces as shown in Figure 2. The design of an idealized column differs from the actual structure of the column. This difference is due to the presence of numerous small imperfections, defects or deviations. The buckling mode of a column corresponds to the lowest buckling load, which is referred to as the critical buckling load. Structural stability should be provided for the structure as a whole and also for each of its structural members. Because of the inevitable presence of geometric imperfections in fabricated structures, actual instabilities may be expected to occur at a load rather less than the load of an ideal column.

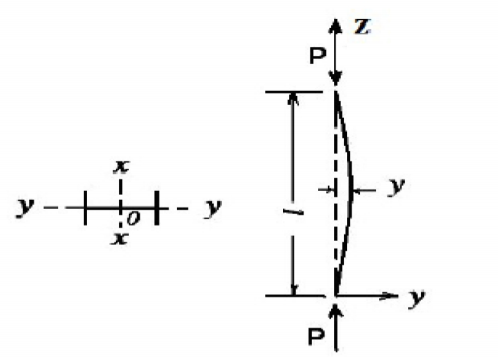


Figure 2. Buckling failure subjected to a compressive load

A slender member may lose its load-carrying capacity, i.e., the ability to withstand external forces, not as a result of failure of the material, but due to the loss of stability (buckling). The problem of stability of steel structural members is of great significance as its disregarding may lead to disastrous results. If a straight rod is compressed by an axially applied force P, then the bar will initially remain straight, and this is the state of stable equilibrium. The stable state of equilibrium of an elastic bar is characterized by the rod returning to its original position after removal of the external cause. Upon a further increase in the compressive force until it reaches such a value that its work will be equal to the work of deformation in bending induced by any small disturbing factor. In this instance the compressive force reaches its critical value [1].

A perfect straight bar when loaded with a force up to the critical state has a linear shape in the stable state of equilibrium. When the force reaches its critical value, the linear shape of equilibrium stops being stable, the bar may buckle in the plane of least stiffness and it will now have a new curvilinear shape of stable equilibrium. The magnitude of the force which causes the original stable equilibrium of the bar to become unstable is known as the critical force. If there is a slight initial curvature of the bar (or a slight eccentricity of the point of application of the compressive force) then upon an increase in the load the bar will immediately deflect from a straight position. Structural stability should be provided for the structure as a whole and also for each of its structural members. Because of the inevitable presence of geometric imperfections in fabricated structures, actual instabilities may be expected to occur at a load rather less than the load of an ideal column [1] and [2]. Therefore, the critical buckling load for an ideal column can be approaced by using Euler's equation.

The critical buckling load firstly introduced by Euler as,

$$P_E/\,P_{cr} = \frac{\pi^2 EI}{Le^2} \qquad (1)$$

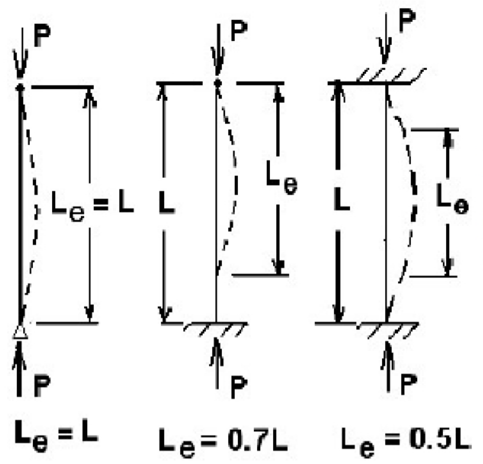
$$L_e = kL \qquad (2)$$

P_E/P_{cr} is the critical buckling load corresponding with young's modulus (E), moment of inertia (I), effective length of column (L_e), true length of column (L) and factor depending on the support end condition (k). The effective length is that length at which the length with hinged ends is equivalent in stability to the column with the given end conditions as shown in Figure 3. The effect of D/t ratio can be trecered by interconnection of the critical buckling load and the critical buckling stress. A is the cross sectional area and λ is the slenderrness ratio. The critical buckling stress can be calculated by using the expression:

$$\sigma_E/\,\sigma_{cr} = \frac{P_E/P_{cr}}{A} \qquad (3)$$

The expression of the critical buckling stress or Euler buckling stress is induced by the cross sectional area and slenderness ratio. Therefore, the slenderness ratio need to be modified in associated with the typical column, z is taken depending on the geometry of the column shape.

$$\sigma_E/\sigma_{cr} = \frac{\pi^2 EI}{ALe^2} = \frac{\pi^2 E}{\lambda^2} \quad (4)$$



k = 1 for hinged support
k = 0.7 for fixed end support
k = 0.5 for hinged-fixed

Figure 3. Effective length of column for different end conditions

A fixed offshore platform namely tripod is used as the object to be analyzed for the assessment of the critical buckling load and critical buckling stress or Euler buckling stress as shown in Figure 4.

$$\lambda = \pi \sqrt{\frac{A2\, Ld^3}{z\, Ad\, Li\, a^2}} \quad (5)$$

Where;
A_2 : Cross sectional area of the horizontal brace
A_d : Cross sectional area of the diagonal brace
L_d : Length of diagonal brace
L_i : Length of column
a : Length of horizontal brace
z : Coeffcient of column shape (z=2

The boundary conditions are assumed to be fixed at the bottom level and the material and dimensions are taken based on the structural component. To investigate the buckling strength including its behavior, the structure is setup in two plane-section and symmetric at any plane. In this case, only x-z and/or y-z plane is selected. As a fundamental case, buckling strength analysis is carried out in the x-z plane. The axial compressive load is applied to the jacket legs as shown in Figure 4. The column length of the tripod is 351.9 in. The moment of inertia for tripod is 7383.479 in^4. In the FEM analysis, the property modification factor for area is set to be 100000 and the property modification factor for shear area is set to be 0. These properties modification factor are imposed for all structural members.

To calculate the critical buckling load and critical buckling stress on the column structure, the FEM is carried out and the result will be compared with the analytical solution. The effect of D/t ratio for tripod structure is taken as D/t = 12, D/t = 18, D/t = 24, D/t = 36, D/t = 48, and D/t = 60. Only the lower shape of the column structure is considered to be analyzed. The young's modulus, length of horizontal brace, length of column and coefficient of coulmn shape respectively are setup to be constant.

3. Results and Discussion

The buckling strength analysis is conducted by applying the Finite Element Method to assess the critical buckling load and critical buckling stress or Euler buckling stress for tripod column structure. The result obtained by FEA is therefore compared with the analytical solution.

(a) 3D view (b) 2D view

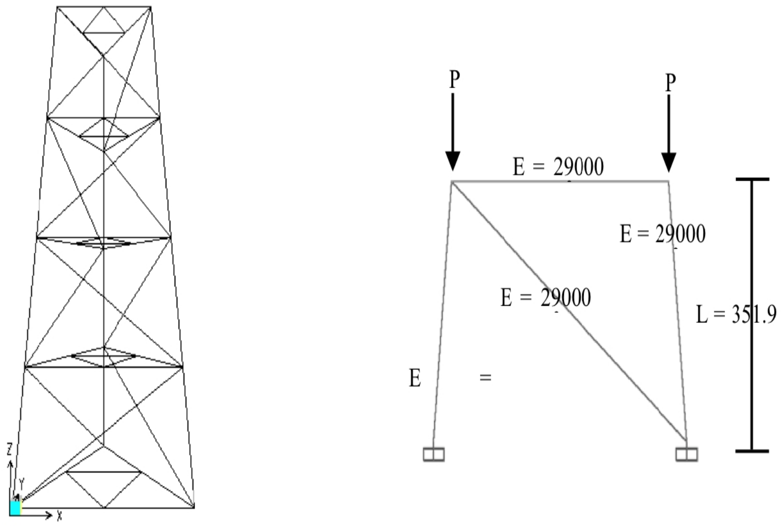


Figure 4. A tripod, material and column length of the structures

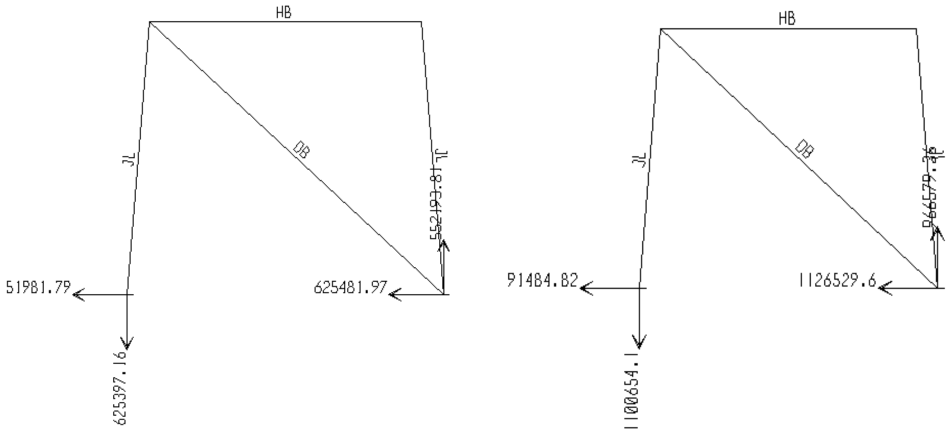


Figure 5. P_{cr} obtained by FEM for D/t = 12 and P_{cr} obtained by FEM for D/t = 18

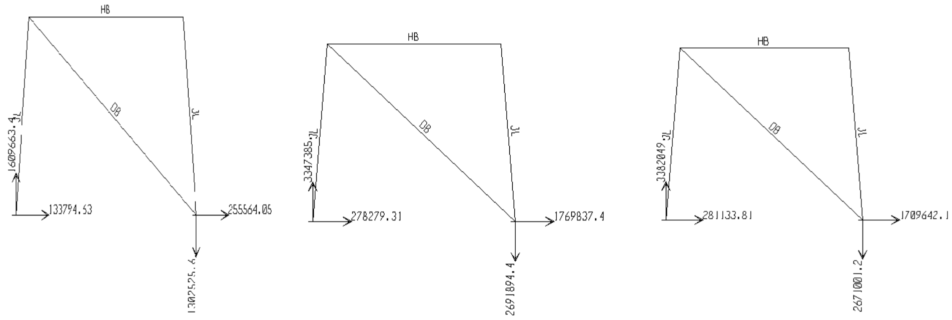


Figure 6. P_{cr} obtained by FEM for D/t = 48 and P_{cr} obtained by FEM for D/t = 60

As the fundamental case, the result obatined by FEA and analytical solution is taken for the effect of D/t = 12, D/t = 18, D/t = 24, D/t = 36, D/t = 48 and D/t = 60. The critical buckling load (P_{cr}) for D/t = 12 to D/t = 60 obtained by FEM is shown by the following figures 5 to 10.

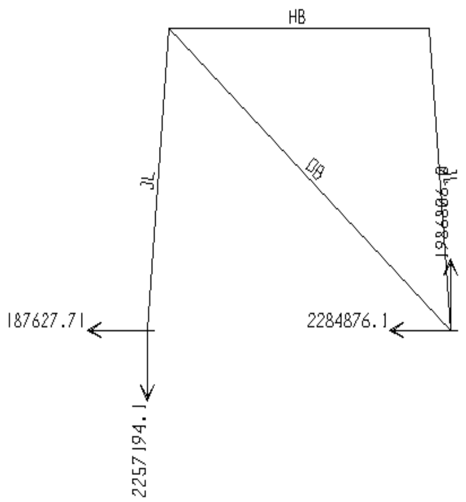


Figure 7. P_{cr} obtained by FEM for D/t = 24 and P_{cr} obtained by FEM for D/t = 36

According to those figures, the critical buckling load obtained by FEA is compared to the analytical solution. The table 1 and 2 can be drawn.

For the comparison and validation purposes, buckling analysis was studied by adopting the model calculated by Timoshenko [3]. A rigid steel frame structure had been analyzed and investigated including its deformation behavior under axial compressive load. Firstly, the geometry dimensions and material properties were set up to be identic. Then, the axial compressive load was applied only on the vertical bar assuming that the end support was completely fixed condition. Finally, the critical buckling load was calculated and deformation of the structure was discussed. What Timoshenko did, the Computer and Structure (CSi) [4] also conducted by considering the same model. The model was also analyzed to obtain the critical buckling load.

To calculate the critical buckling load, the CSi used Finite Element Method (FEM) for the comparison and validation purposes. It was found that the critical buckling load obtained by Finite Element Method was in good agreement with the analytical solution performed by Timoshenko.

Although, there was still a little different due to 3D FEM model and some constraints in the application which is not taken into consideration when the analytical solution was used, but deviation of result of the critical buckling load between two methods were not significant influences, because deviation result was very small, less than 5% at least. This indicates that the software verification result performed by CSi was able and suitable to be used for the comparison and validation of the structure.

From this view point, it can be concluded that the diagonal braces has significant effect toward the critical buckling load including its behavior which was not considered by the previous model.

Because the model calculated by Timoshenko and CSi did not have diagonal brace.

It should be noted that the frame structure calculated by Timoshenko is a typical of a frame structure where the vertical brace is perpendicular. Unlike the tripod, the structure has a batter so that the jacket legs is sloped, i.e. the jacket has an angle toward the vertical direction. It is shown that the critical buckling load obtained by FE Analysis is smaller than analytical solution. However, that the critical buckling load obtained by FE Analysis is in good aggrement with the analytical solution based on the Table 1.

Table 1. Comparison of the critical buckling load

D/t ratio	Critical buckling load (Kip)	
	FEM	Analytical Solution
12	625327.08	625397.16
18	966406.48	966579.36
24	1302525.6	1307491.12
36	1986806	1989653.17
48	2671001.2	2671822.45
60	3347385	3353991.73

The reduction of the critical buckling load not exceed more than 5%. The effect of diagonal brace in the column structure gives different supporting end reaction. This is because the axial compressive load is therefore forwarded by not only for vertical brace but also for diagonal brace. This again shaws that the applicability of the Finite Element Method can be further assessed for the buckling strength of a column structure influenced by D/t ratio. The critical buckling stress for variation of D/t ratio is summerized in Table 2.

According to the table, it is shown that the critical buckling stress for variation of D/t ratio becomes smaller from the D/t=12 to D/t=60. This is because the slenderness ratio which is induced by cross sectional area of vertical brace. This is also indicated that horizontal and diagonal braces gives significant contribution toward critical buckling stress where each braces has different dimension.

Table 2. The critical buckling stress

D/t ratio	Critical buckling stress (Kip/in^2)
12	725
18	483.333
24	362.5
36	241.667
48	181.25
60	145

The buckling phenomenon also had been investigated by Timoshenko and Gere [3], the frame structure was taken into account by considering the axial compressive load and the critical buckling load was calculated. The frame structure made by him was validated by Computer and Structure [4]. The CSi validate the model by investigating the critical buckling load in two dimensional (2D). The software verification result for the critical buckling load obtained by CSI was compared to Timoshenko's result based on the model that had been made before. It was found that the result between two method was identic for critical buckling load. Therefore, this become a good basis for the assessment of the buckling strength for frame structure especially for fixed offshore platform.

4. Conclusions

The buckling strength analysis has been performed using the Finite Element Method for the assessment of the critical buckling load of the fixed offshore platform. The following conclusions can be drawn:

1. The effect of D/t ratio of the structural member has significant influence toward critical buckling load.
2. The diagonal brace gives different supporting end reaction for a typical column structure.
3. The critical buckling load obtained by FE Analysis is in good aggrement with the analytical solution.

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