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# THE EFFECT OF GEOMETRIC ON BUCKLING STRENGTH OF RECTANGULAR HOLLOW PIPE UNDER PURE BENDING

**Hartono Yudo, Wilma Amiruddin, Sarjito Jokosisworo**
Naval Architecture Department, Diponegoro University

**ABSTRACT**

*Not only the circle hollow pipe but also the rectangular hollow pipes are used on construction. The pipe subjected various kind of load. In this research, the bending moment was given at both end of pipe. It is known that strength of buckling moment can be reduced by increasing the length of the pipe. The rectangular pipe models are varying from a/b = 0,125; 0, 25; 0,5; 1; 2; 4; a/t = 10, 15 and L/a = 10, 15, 20. The finite elements method was used to analysis of buckling strength. The buckling strength will increase with decreasing a/b. The deformation at mid span will be shown. The buckling strength will decrease with increasing of a/t and L/a.*

**Key words**: Regtangular Hollow Pipe, Buckling, Bending, Deformation.

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## 1. INTRODUCTION

The damage of material wshen buckled is difficult to be discovered, because that is suddenly occurred. The steel is one of the important material constructions. Particularly have mechanical properties which are strong enough and the ductility. Ductility is the material ability to deform, withstand the tensile and compress before failure.

The steel have random circumtances when used. If the maximum ability of construction has been discovered, thus the construction is safe. Buckle occurred due to pressure on the steel bar which has deformation in this case through an axial compressive force. Buckle can be occurred before or after maximum stress was reached. It would not a problem if the buckle occurred after the steel passed the maximum stress. However if the buckle occurred before the steel passed maximum stress, it can be a problem because the buckle will suddenly occurred.

The structure with the rectangular hollow pipe has been used on house roof construction, the bridge pillar, port construction, the offshore construction and building construction. The typical of the neither offshore construction nor coastal construction is the casing for the pile;

the offshore's leg, and the funnel. The advantage of rectangular hollow pipe is the behaviour which is buckled from two direction and particullary strong enough to withstand the twisting.

In the followings, the formulas for estimating buckling stress and moment of rectangular hollow pipe subjected to bending are briefly explained.

The maximum bending stress of a rectangular pipe under the critical (buckling) moment Mcr can be expressed by Eq. 1:

$$\sigma_{cr} = \frac{M_{cr}\mathrm{C}}{\mathrm{I}} \qquad (1)$$

where I is inertia moment and C is distance from neutral axis.

Timoshenko and Gere [1] expressed that the maximum compressive stress at the critical buckling moment is about 30 % higher than that obtained from Eq. 1.

The previous investigation by authors (Yudo and Yoshikawa [2]) for a straight pipe, whose L/D varies from 5 to 20, and D/t varies from 50 to 200, showed that the critical bending moment in linear calculation is about 10 % higher than that obtained from Eq. 1.

The initial yield moment of a pipe under bending is shown below:

$$M_Y = \sigma_Y Z \qquad (2)$$

Where $\sigma_Y$ is the yield stress and Z is section of modulus.

Hauch and Bai [3] has earned a set of equations for calculating the maximum allowable bending moment including proposed safety factors for different targeted safety levels.

The investigation by authors (Yudo and Yoshikawa [4]) obtained the calculation results, the maximum moment for a long pipe considering oval deformation is shown as follows:

$$M_{max} = 0 \qquad 52\ M_{cr} \qquad (3)$$

Essentialy the rectangular hollow pipe is not only encountered the axial load. If the truss bar loaded rapidly with axial tensile force, thus the truss bar will deform. The deformation from straight circumstance of bar to be curved circumstance that told buckling.

From the mechanic of materials known that only the very short rectangular hollow pipe can be loaded until reached the yield strength, whereas the general circumstance, the spontaneous bending due to the unstability occurred before the strength of truss bar has reached that circumstance which is told buckling.

To determine the strength of rectangular pipe, the circumstance of rectangular pipe must be gave the material

Buckling can be defined as a failure phenomenon which is occurred due to compressive load with the result that causing the deformation which have the shape of lateral deflection to another equilibrium form.

Buckling phenomenon can be divided to be two section, the global bending and local bending. An example of global bending is the entire structures have curved as one unit, whereas the local bending is the bending which is occurred at the plate elements.

To obtained critical load value, the eigenvalue should be input to this simple equation:

$$P_{cr} = P_{applied} \times \text{Eigenvalue} \qquad (4)$$

Therefore, the eigenvalue which is generated also can be interpreted as the factor of safety which is having by the structure. Decreasingly the eigenvalue which is generated, thus greater of the failure probability due to buckling. Therefore the greater eigenvalue expected on the analysis of structural strength to show the factor of safety.

The long truss bar will be collapse due to bend, in generally the failure due to compressive force occurred due to yield after fatigue of transverse plane section, this state called inelastic buckling.

There are three types of collapses, i.e. [5]

1. the collapses due to stressing which is passed the yield strength
2. the collapses due to elastic buckling, this state occurred directly,
3. the collapses due to yield of some fibre called inelastic buckling, the typical of collapse case between the $1^{st}$ and $2^{nd}$ case, when the structure was buckled, some of the fibreto be inelastic, thus the modulus of elasticity when the bending value is decreasing from the initial value.

## Elastic Buckling

The analysis of elastic buckling basically is the result of linear elastic analysis development. There is only in elastic buckling, the effect of axial force against the element stiffness is to be calculate. To understand it, imagine the guitar strings. The guitar strings is to be analogy as the element structure. If the condition of guitar strings are not be tightening, thus the strings physically seem slack. Even if the strings are strumming, there are not resistance. Whereas if in contra wise condition, if the strings are tightening, thus the strings physically condition are different. The strings will seen stiff, their can be plucked and producing a tone. The magnitudes of strings tightening are affecting the tone frequency. Increasingly the stiffness thus the tone frequency is to be high and to the contrary. The strings analogy shows that the tensile axial force will be increase the stiffness of the element.

In the elastic buckling, the magnitude of structure deformation before buckling is not affected or not to be calculated. In this case, the condition of structure geometry assumed to be equal like the linear elastic condition, where the deformation which occurred is relatively assumed to be small value, so that can be ignored.

## Plastic Buckling

The steel bar with solid profile and enough of lateral supported, when loaded gradually, thus the plane section which is have the maximum moment, the outer fibre will be yielding. If the load is continuously added, the stress magnitude is not be increased, whereas the section which is yielded is propagating to inner section of fibre. Therefore the stresses of entire plane will be plastic sooner or later.

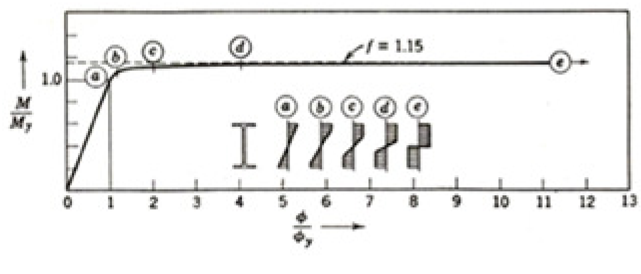



**Figure 1** The relation of moment and curvature in WF profile plane section

Comprehensive study on the buckling strength of rectangular hollow pipe under bending has not been found. In this study, the series of calculations of buckling and collapse strength of rectangular hollow pipe under bending are performed by utilizing nonlinear FE software.

# 2. PROCEDURES OF CALCULATION

## 2.1. Parameters for calculation

In the calculation of rectangular hollow pipe, the ratio between pipe length and width (L/a), the ratio between width and thickness (a/t) and the ratio between width and height (a/b) are taken as the calculation parameters. In this paper as shown L/a varies from 10 to 20, a/b varies from 0,125 to 4 in which the height is changed from 2, 5 to 80, and a/t varies from 10 to 15 where a is the width of pipe, b is the height of pipe and t is the wall thickness, and L is the pipelength.

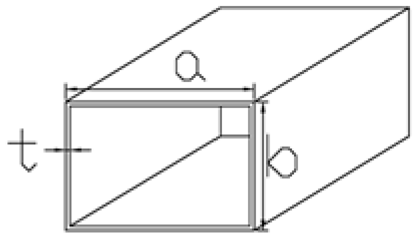



**Figure 2** Principle model

a/b = 0,125, 0,25, 0,5, 1, 2, 4

a/t = 10, 15

L/a = 10, 15, 20

and a = 100 cm

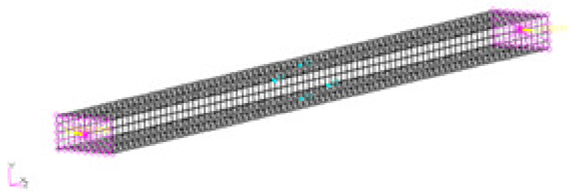


**Figure 3** The geometry of rectangular pipe

The mechanical properties which is be analysed, using the steel with the criteria i.e.

| | |
|---|---|
| *Elastic modulus* | = 2.06e+011 N/m$^2$ |
| *Poisson ratio* | = 0.3 |
| *Shear Modulus* | = 8e+010 N/m$^2$ |
| *Density* | = 7850 kg/m$^3$ |
| $\sigma_Y$ Yield Stress | = 250 MPa |

The buckling calculations of hollow pipe under pure bending were performed. The full-length models rectangular hollow pipe are used in FEA. Figure 3 shows the finite element model for rectangular hollow pipe.

General-purpose FE software Msc Marc was used for nonlinear buckling analysis in which the cross-sectional oval deformation before buckling is taken into account. The quadrilateral 4-node element (No. 75) was used

## 2.2. Boundary condition and loading condition

The following boundary conditions are given at the midspan of Rectangular pipe, except at four points in Table 1.

**Table 1** Boundary conditions

| Independent point location | translation | | |
|---|---|---|---|
| | X | Y | Z |
| Independent point at upper mid surface | Fix | - | fix |
| Independent point at side mid surface | Fix | fix | - |
| | rotasional | | |
| Independent point at upper mid surface | - | - | - |
| Independent point at side mid surface | - | - | - |

The rigid body elements (RBE) are inserted at both end sections to connect the center of a rectangular and the points on a rectangular. The bending moment is loaded at the center of rectangular at both ends. The RBE prevent the oval deformation of both end sections, and keep the section in plane under rotational deformation by a bending moment.

## The model validation

The model approved to be good validation if the percentage of the validation shoud be below 5%. The validation did with comparing the result of empiric calculation with software result.

The equation to validate the result is expressed by,

$$v_{max}=\frac{PL^3}{3EI} \quad (5)$$

The above equation is using in the one of model and the value of correction should be below 5%, that is applied for another model.

## Method to obtain bifurcation moment in nonlinear calculation

To derive the bifurcation buckling moment and its mode, the eigenvalue calculations are performed at the proper load increment, and the cross-section point of the critical moment between the buckling moment and the applied moment is defined as the bifurcation buckling moment, as exsplained in Fig. 5. In this figure, the horizontal axis shows the applied load, and the vertical axis shows the bifurcation buckling eigenvalue.

The eigenvalue is calculated at each load increment considering the pre-buckling deformation. The bifurcation buckling load is judged as follows. When the value of eigenvalue is larger than the applied load, the buckling does not happen. When the value of eigenvalue is smaller than the applied load, the buckling has already happened.

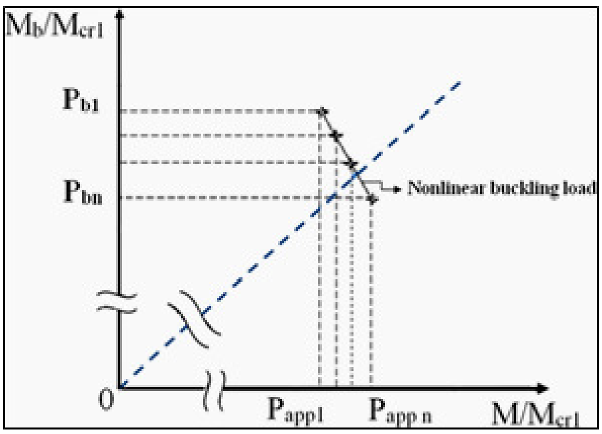



**Figure 4** Schematic diagram for estimation of bifurcation moment

## 3. CALCULATION RESULT

The typical buckling mode, which is obtained from nonlinear calculation, is shown in Fig. 6. The stress at the lower side of the cylinder is compression, and that at the upper side is tension. The oval deformation is larger in the vicinity of midspan than at the span end. Therefore, the region of buckling is limited in the bottom area close to the center.

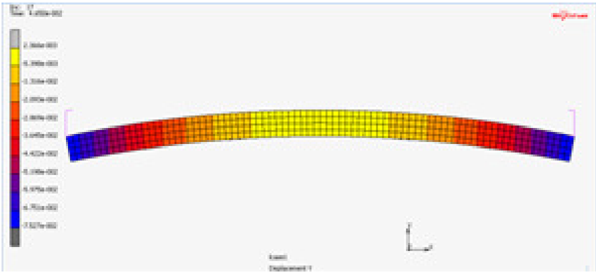


**Figure 5** Rectangular pipe deformation

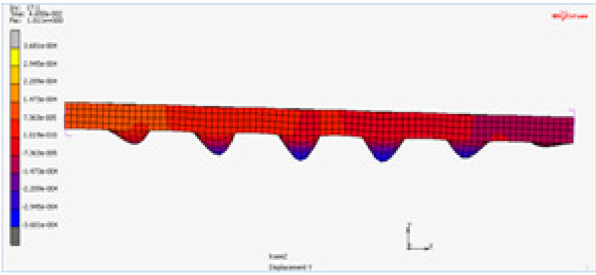


**Figure 6** Rectangulat pipe buckling

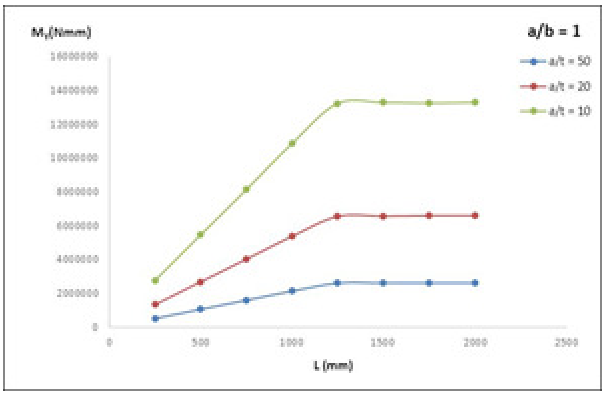



**Figure 7** Relation of Critical Moment and Iron Hollow Pipe Length (a / b = 1)

In Figure 7, it is showns that the critical moment of rectangular hollow pipe a / b = 1 will increase with increasing the thickness of pipe. The critical moment strength will be constant at the length above 1200 mm for each a/t. These calculations used the yield stress of material 250 MPa.

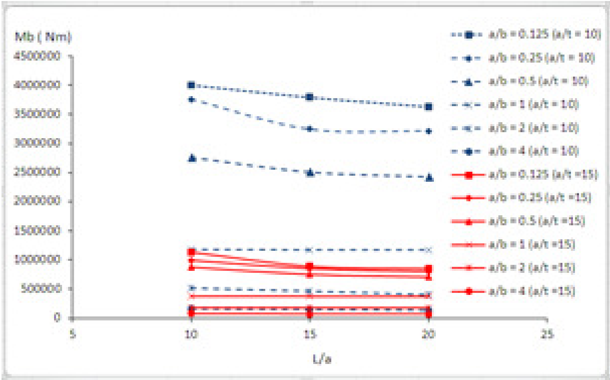



**Figure 8** Relationship of buckling moment Holow iron pipe and L / a

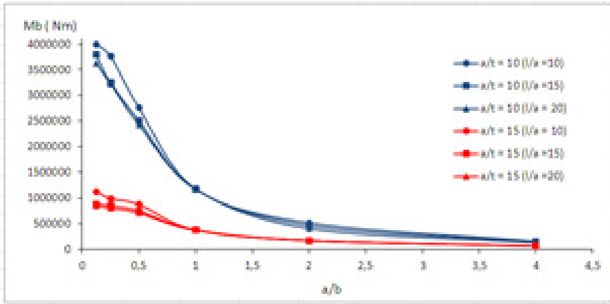



**Figure 9** Relationship of buckling moments Iron Holow pipes and a / b

Figure 8 shows that the strength of the buckling moment in the elastic state will decrease with increasing of a/t and a/b. In Figure 9 shown for a/b = 1, the strength of buckling moment will tend to be equal at L/a = 10-20.

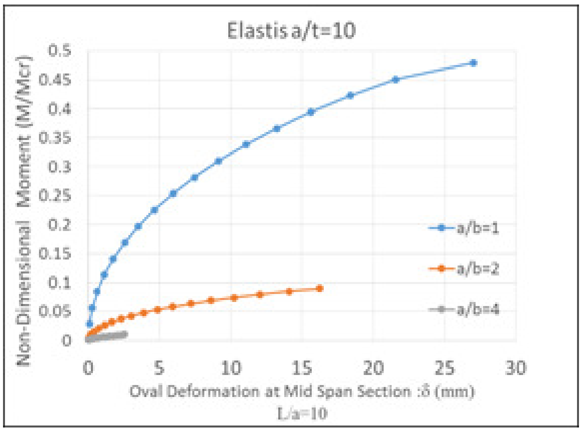
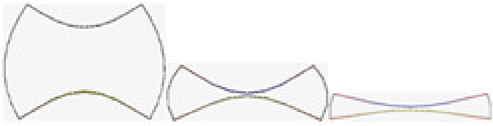



**Figure 10** The deformation on middle of rectangular pipe (elastic)

On the rectangular pipe which is have larger rectangle area (a/b), have the larger deformation. Vice versa on the rectangular pipe which is have smaller rectangle area (a/b), as though on a/b = 2 model and a/b = 4 model which is have smaller deformation. Therefore, the conclude that is the larger one of rectangle area (a/b) on rectangular pipe then the deformation is large too. It was shown in figure 10. Figure 11 shows the difference of deformation on mid-span for each rectangular pipe.



a/b = 1  a/b = 2  a/b = 4

**Figure 11** The deformation on mid-span of rectangular pipe (elastic)

# 4. CONCLUSIONS

In this study, the series calculations of buckling and collapse strength of rectangular hollow pipe under bending are performed by utilizing nonlinear FE software. The typical buckling modes for rectangular hollow pipes are obtained by numerical calculations. The followings are clarified by the numerical calculations.

1. The region of buckling is limited at the compressive side in the vicinity of midspan.
2. The critical moment of rectangular hollow pipe a / b = 1 will increase with increasing the thickness of pipe. The critical moment strength will be constant at the length above 1200 mm for each a/t. These calculations used the yield stress of material 250 MPa.
3. The strength of the buckling moment in the elastic state will decrease with increasing of a/t and a/b. In Figure 10 shown for a/b = 1, the strength of buckling moment will tend to be equal at L/a = 10-20.
4. The rectangular pipe which is have larger rectangle area (a/b), have the larger deformation.

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