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The Effect of Adding Stiffener on Deflection of Loading Arm by Using BEM & FEM

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Abstract

In this study we are concerned to improve the deflection of the loading arm with new suggested style , where the BEM techniques has been used to estimate a deflection at each distance (x) for the main part of loading arm pipe (3") , thereafter a simplified stiffener has been added to optimize a moment of inertia of this main part thereby the deflection will be better , for this purpose a case study has been considered according to international standard for the pipe specification that investigated to illustrate the goal of this work, adding to this ANSYS program has been used to verify the calculation.

1. Introduction

A **loading arm** permits the transfer of liquid or liquefied gas from one tank to another through an articulated pipe system consisting of rigid piping and swivel joints to obtain flexibility.
Transfer to or from a truck transported tank or rail transported tank requires a top loading arm or a bottom loading arm transfer to or from a ship or barge requires a marine loading arm, see Fig (1).In other word Loading Arm is a system consisting of rigid piping and swivel joints to obtain flexibility with several style. The OCIMF (Oil Companies International Marine Forum) and ASME have established guidelines for matters of strength calculations, working envelope and accessories [1].
Main contents:
1. Top and Bottom loading arm
2. Marine loading arm
3. External links
Generally, both types of loading arms are typically made of 3 pipes – respectively called inner arm, outer arm and drop pipe. The size can be from 2” to 6”. These 3 pipes are connected by swivel joints. Swivel joints are required to provide the flexibility needed. The loading arm unfolds to get the required working envelope to load or unload the tanker, and the reverse is to retract or get a minimal space for parking or storage. Both types of loading arms may be mounted on a column or via a plate to an existing wall. Balancing is needed due to the weight of the steel piping. Balancing of the arm is made by counterweight or by a spring balance cylinder[2].

When loading shall be ordered the fooling items should be focused

1. Pipe size
2. Style no. of joint
3. Material (aluminum , steel and stainless steel)
4. Product to be handled
5. Operating pressure.
6. End connections (threaded , flanged or beveled weld)

According to above items we will eliminate the joints and aluminum may be not used any more, where in present suggested style we will use a permanent fixed model with simple stiffener and end deflection will be diminished.[2]

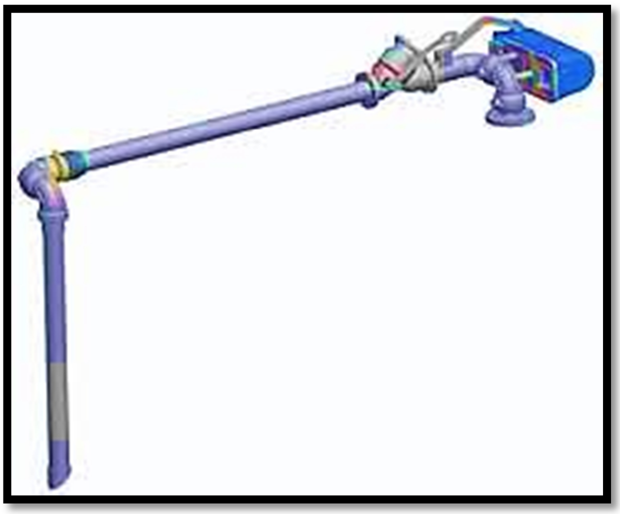

Figure (1) Modeling of loading arm

2. BEM Model & Boundary conditions

BEM method will be used to find out the governor equation by which the deflection will be estimated at each distance (x) and as indicated in the following procedure [4]**:**

For i=1 the force p=1 acts at x=0
For i=2 the force p=1 acts at x=l
For i=3 the force M=1 acts at x=0
For i=4 the force M=1 acts at x=l

As generally known:

$$Ku = p + f \quad \ldots\ldots\ldots\ldots\ldots.. \quad (1)$$

Where: k: stiffness matrix,
U: displacement,
P: applied load,

Then for beam of length 4m which is loaded by uniformly distributed load, one can gets for l=4m:

$$W(x)= x w(l)+ (1-x) w(0)+ x(1-l) w'(x)+(1/6EI)\{[-3(l-x)^2 - a(x)+3l^2(1-x)]M(l)+a(x)M(0)+[(1-x)^3+a(x)l-(1-x)l^2\}Q(l)+\int_0^x [a(x)y-(1-x)y^3]p(y)dy + \int_x^l [(y-x)^3+a(x)y-(1-x)y\hat{}3]p(y)dy] \quad \text{------------------} \quad (2)$$

Where: a(x) =x(1-x)(2-x)

In the present work the value of deflection must be satisfied with and without the adding of stiffener, so the loading are implemented as cantilever beam, with following boundary conditions:
w (0)=0, w' (0)=0, m(l)=0, Q(l)=0, with total uniformly distributed load of 157.69N/m consist of combination of both water weight which is equal to 4.77kg/m, and metal weight of 11.3039Kg/m.
Now, for the unknown displacement terms and then by substituting the B.Cs and solving of eq. (1) one gets:

$$w(l)=32p/EI, \quad w'(l)=10.67p/EI, \quad M(0)= -8p, \quad Q(0)= 4p$$

Then by substituting the complete set of Betti's data into influence function and so obtain the solution [4]:

$$W(x) = p/24EI\,(96x^2-16x^3+x^4)$$

3. Material Properties

In this work the material properties assumed to be with homogenous isotropic properties in both BEM and FEM, which is according to API 5L Standard specification for Seamless Line Pipe or Seamless Pipe Line[3], also similar material properties of pipe are used for stiffener[6], all the required properties illustrated in table.1

4. FEM Model

The finite element (FEM) can now be considered as the most popular theoretical technique ever known to man, and it has been applied successfully to many engineering disciplines, such as structural mechanics, computational fluid dynamics, tribology, heat transfer , electromagnetism, biomechanics,… etc.
In the present work a comparison between both BEM and FEM has been presented. Full three dimensional model has been simulated in ANSYS software version14, fig. (3) Shows full 3d model used in this study, where this model is built by using programming technique as the

programs as illustrated at the end of this work. And by applying the B.Cs mentioned above with material properties the run can be done.

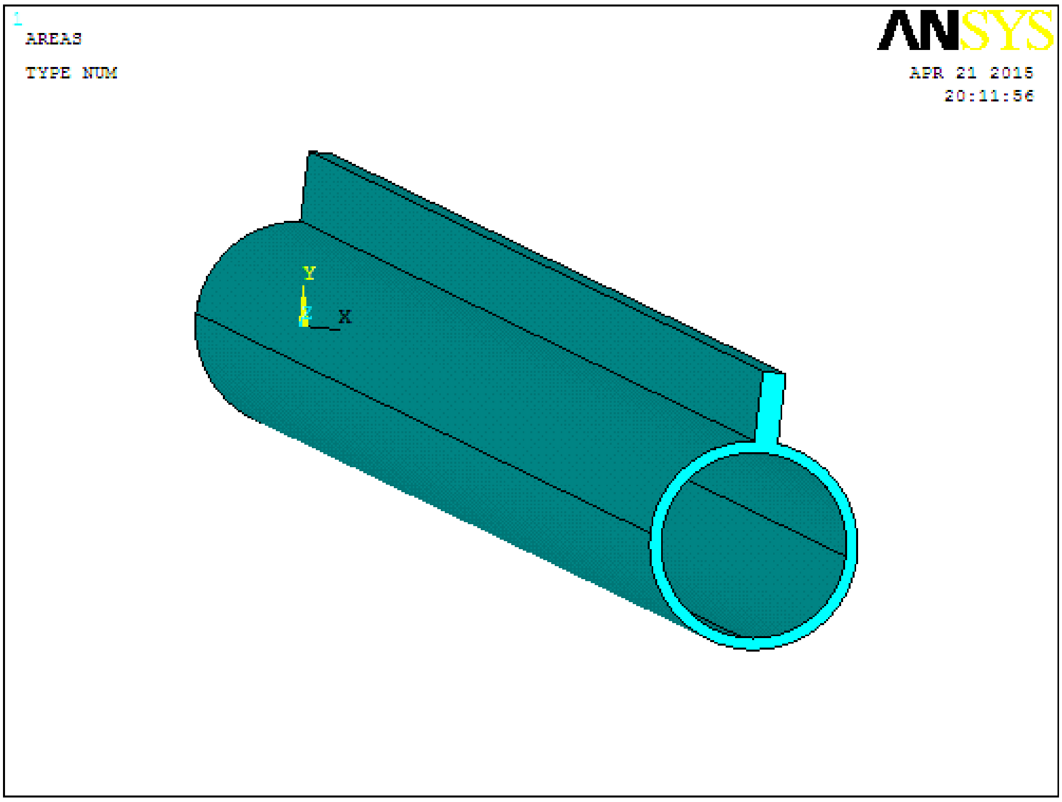

Figure (2) 3D model

The model which was used should be discretized to small elements for finite element analysis; the element type that used in this discrediting was SOLID 45, 10-node tetrahedral. SOLID 45 has a quadratic displacement behavior and is well suited to modeling irregular meshes; the element is defined by 10 nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions as shown in Fig. 3 , the element has plasticity, , creep, stress stiffening, large deflection, where this is a three- dimensional, eight-node , higher order quadrilateral element that can be located on the surfaces of three- dimensional solid or shell element with mid side nodes[5]. It can be degenerated to 3-7 node quadrilateral triangular shapes, and also element target where it is a three- dimensional element and shape is described by a sequence of triangles, quadrilaterals, straight lines, parabolas, cylinders, and cones. Where by changing the coarser of this element in order to investigate the right element number. The result of the convergence test show that the best element number that can 2531elements.

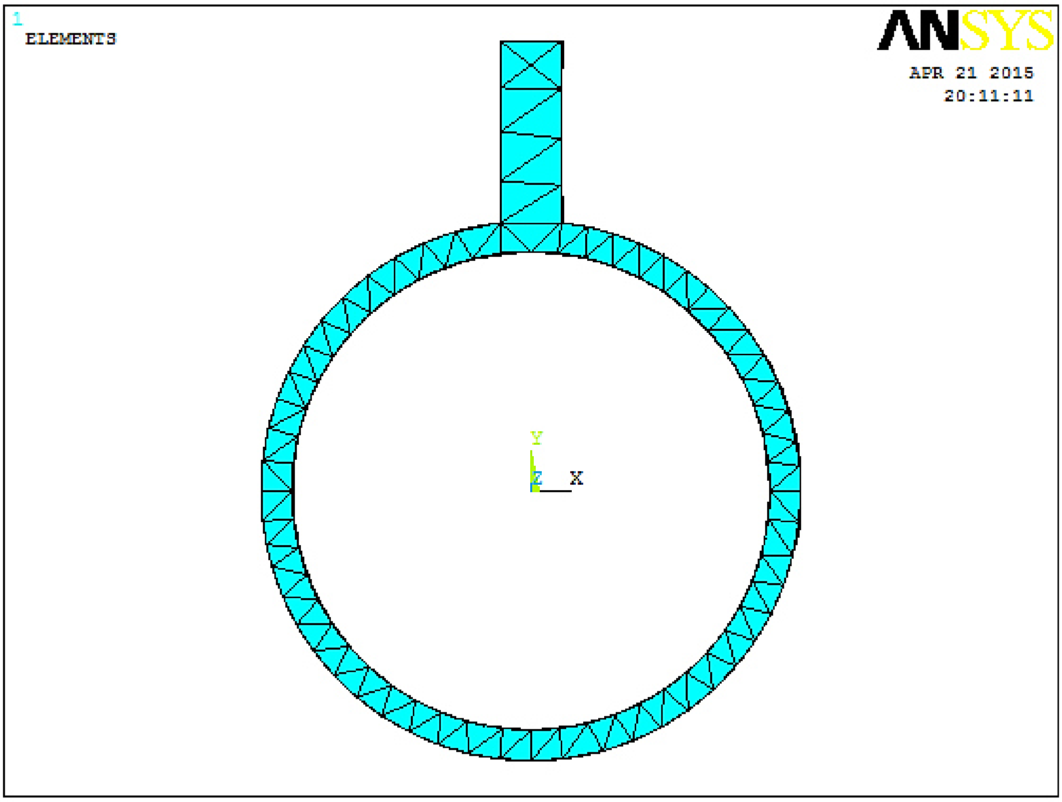

Figure (3) Meshed model used in this study

5. BEM/FEM Results Comparison

After completed the hand calculations for BEM for the mention model used in this study the authors found high degree of agreement in deflection values of both BEM and FEM when a comparison has been made between these two techniques, this comparison has made for deflection values at x=4 (free edge of loading arm), with two stiffener dimensions where first one of 30mm in height and the another was 84mm with both constant width of 10mm.
An important point is that the BEM is nearer to exact results with very small difference from FEM, so this support the opinion that high degree of accuracy had performed by BEM. Values of deflections and von misses stresses has illustrated in Table 2.
From this comparison and according to known benefit of using the stiffener the authors noticed the adding of stiffener helps the piped to overcome the heavily loaded case with lower deflection and stresses values. Also get the system more stability during moving of liquid inside and increasing the natural frequency values where the adding of stiffener with increased the overall system's stiffness.
Figure (4) shows the maximum effective stress for first model used in this study, and figure (5) presents the deflection values of first model of 30mm stiffener's height that used in this study. Figure (6) shows cross sectional stress (von misses).

Another comparison has been done between FEM and BEM for loading arm without stiffener and also the results mentioned in table.3, finally figures 7, 8 shows graphical representation for stiffened unstiffened loading arm respectively.

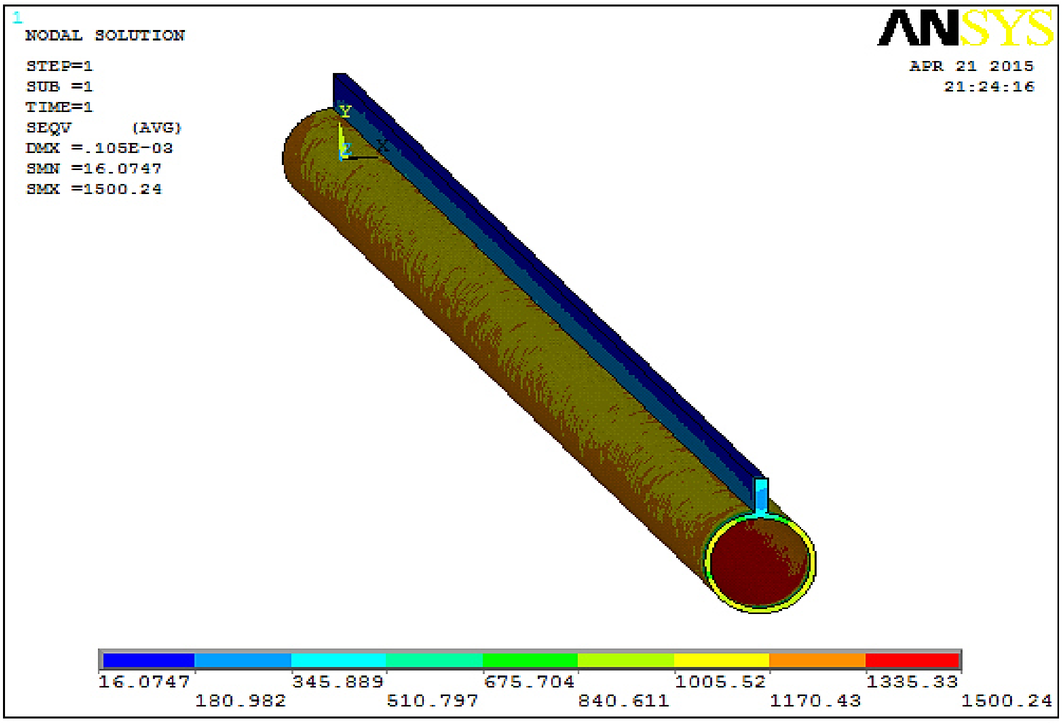

Figure (4) Maximum effective stress of loading arm with 30mm stiffener's height

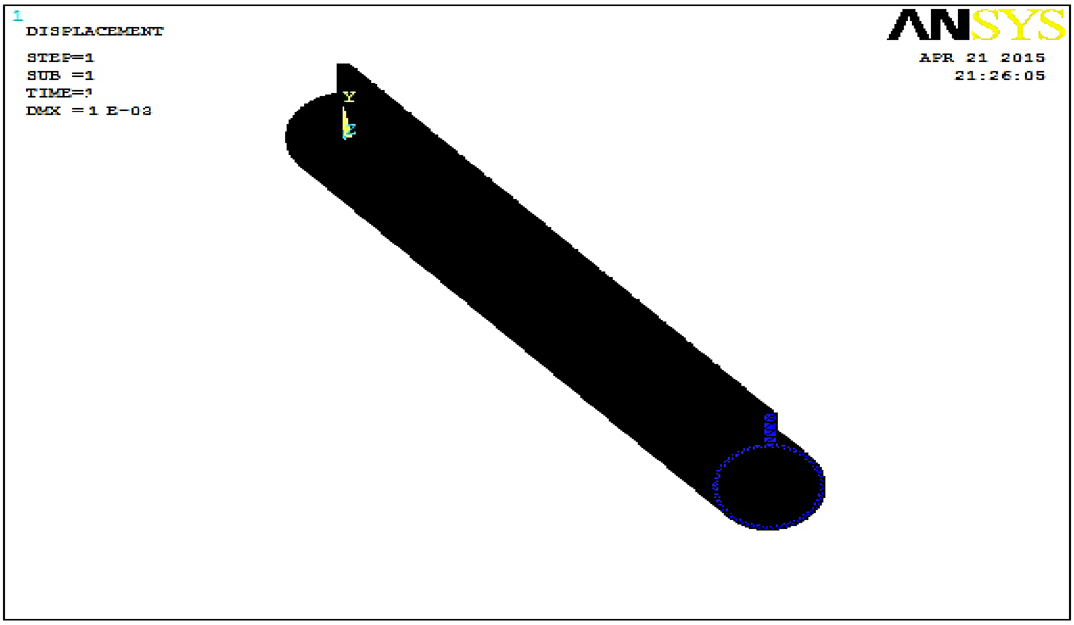

Figure (5) Total deflection of 84mm stiffener loading arm displacement

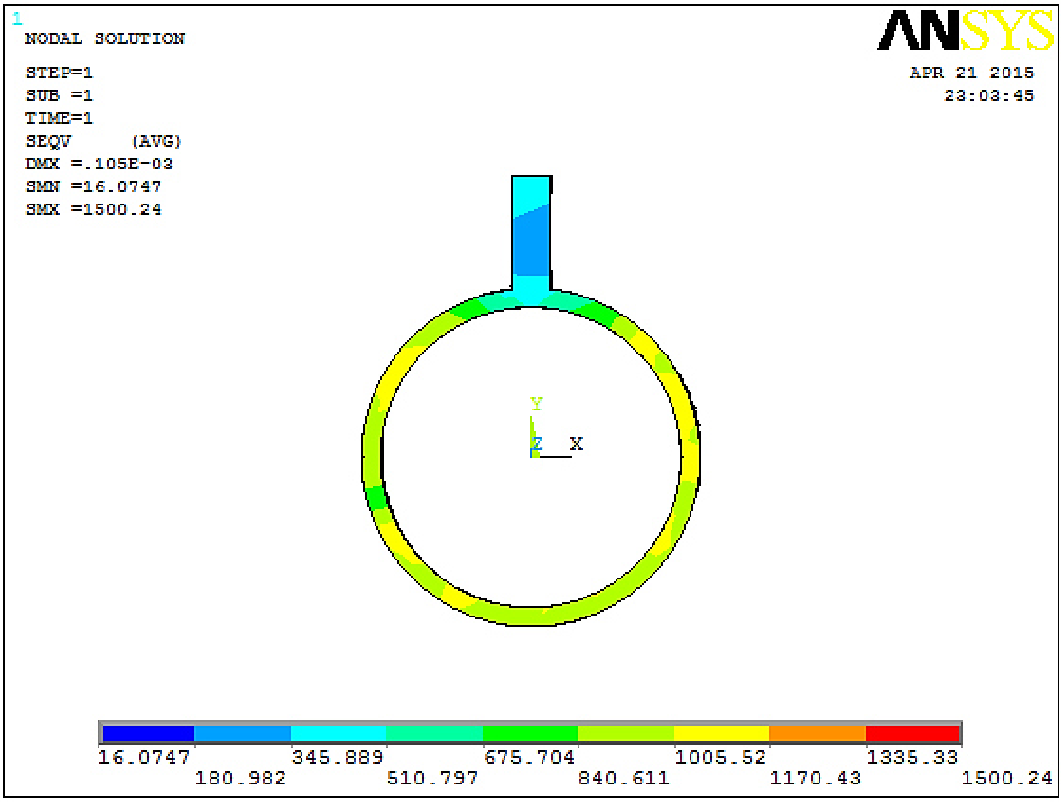

Figure (6) Stress contour through the cross sectional area of loading arm displacement

6. Conclusion

1- Generally adding of stiffener leads to decrease deflection of loading arm in comparison with one without stiffener.
2- Addition of stiffener gives the loading arm more stability during movement of oil or any liquid inside pipe.
3-Suggested stiffener leads to increase cost and slightly increasing in weight of loading arm but it gives the pipe more ability to withstand high stress values.
4- Any value above 30mm stiffener's height will not be useful and not economic, because it will not reduce the maximum stress and deflection resulted in the loading arm, where by obtaining of optimum height of stiffener useful to get light weight and low cost of plate-stiffener system, where the deflection of free end with using stiffener with 30mm in height is bout 1.2mm which is fair enough to use in comparison with merely loading arm.
5-A little consideration will show that the deflection in unstiffened loading arm pipe at x=0.67m was equal to 0.98mm (i.e. identical to the deflection of stiffened arm (84mm height) at x=4m.
Also the deflection in unstiffened arm at x=0.75m was equal to 1.2mm (i.e. identical to the deflection of stiffened arm (30mm height) at x=4m.

Table.1 Material properties [3], [6]

Material	Density(g/cm^3)	Young's modulus	Poisson's ratio
API 5L seamless line pipe	7.85	206.85e9	0.33

Table.2 Comparison between BEM & FEM results of stiffened loading arm [Deflection]

Technique	Deflection with 30mm stiffener's height[mm] at fee end	Deflection with 84mm stiffener's height [mm] at free end
BEM	1.2	0.98
FEM	1.098	1

Table.3 Comparison between BEM & FEM results of unstiffened loading arm [Deflection]

Technique	Free end deflection of unstiffened loading arm[mm]	ANSYS V.14
BEM	20	
FEM	18.905	

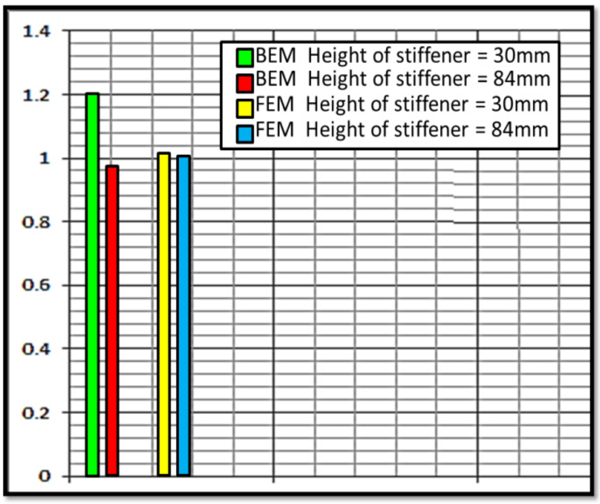

Figure.7 Graphical representation of deflections for stiffened loading arm

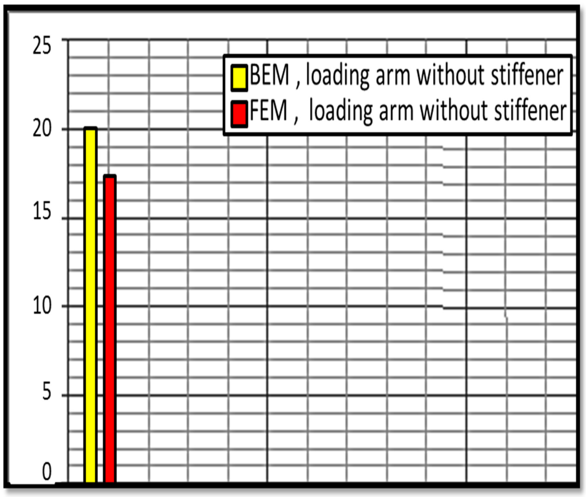

Figure.8 Graphical representation of deflections for unstiffened loading arm

ANSYS program V.14 /

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! /COM,ANSYS RELEASE 14.0
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MPDATA,EX,1,,206e9
MPDATA,PRXY,1,,0.33
CYL4, , ,44.45, ,39.45
RECTNG,-5,5,0,30,
RECTNG,-5,5,0,30,
FLST,3,1,5,ORDE,1
FITEM,3,3
! move the upper area above the pipe
AADD,all
VSEL,all
vmesh,all
SFA,P51X,1,PRES,157
SOLVE
FINISH
```

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