IOSR Journal of Mechanical & Civil Engineering (IOSRJMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X
PP 16-21
www.iosrjournals.org

COMPARISON OF SEVERAL METHODS TO ANALYSE AN EXPANSION LOOP IN A PETROLEUM REFINERY

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Abstract: *The purpose of this study is to analyze an expansion loop in a petrochemical refinery in critical pipeline. Piping is the main transportation method for fluids from one location to another within an industrial plant. Design and routing of piping is heavily influenced by the stresses generated due to thermal effects and high pressure of the operating fluid. Pressurized fluids create critical loads on the supports and elbows of the pipe which increases the overall stresses in the piping. Moreover, long pipes operating under high temperature gradients tend to expand significantly. Therefore expansion loop is provided in order to relieve the pipe from the critical stresses. However, expansion loops require extra space, supports, elbows, bends, additional steel structure that could adversely affect the operating cost. There have been analytical methods by M W Kellogg and McKetta method (adopted by Piping design handbook by Mcketta). The design approach is conducted as per the guidelines of ASME B31.3 (Process Piping) . Adequate piping system flexibility requirements through forces and moments at the equipment nozzles within allowable limits must be ensured for safety . This paper critically reviews these methods with regards to prediction of forces , moments and stresses We examine the Finite Element approach which is widely used in softwares like CAESAR II and general purpose ones like standard FEA packages like ANSYS and NASTRAN . We present a comparison of the old classics which is not present in the literature and how do these methods compare with today's CAE solutions . We are of the opinion that the simplicity of these classical methods and reduction of time and cost justifies their use in the present age and a new FEA user is likely to misinterpreted what comes as an output of FEA software if there is absence of the knowledge of physics of the problem and interpretation of results. The paper concludes that if the user is careful enough both methods give almost identical results a fact which is not so well known in the piping industry and petroleum refineries.*

Keywords: *Expansion loop, Finite element Method, Petroleum Refinery , Process Industry,CAE*

I. INTRODUCTION

Expansion loops are commonly found in Petrochemical refineries and Power plant steam piping to absorb the thermal expansion of the system and ensure adequate piping system flexibility [1,3, 4]. Expansion loop in pipe is used to reduce the effect of contraction and expansion in line due to thermal expansion. Several Methods are available in literature for analyzing the expansion loop most of them are company specific recommended practices .It is of utmost importance to see to it that the expansion of the piping induces the forces and moments within allowable nozzle limits [6] , a usual practice followed in the process industries. Nowadays the standard workhorse for design is the Finite element Method which forms an integral part of the overall design process in the world of CAE and several softwares such as NASTRAN , ANSYS and ABAQUS have become popular as they offer a speedy solution rather than experimentation which adds to time and cost. The present paper compares the M W Kellogg[1] and McKetta[2] Method for the design of expansion loop and also compares how the Finite Element Analysis results compare with these classical methods . We find that the use of the classical methods is somewhat diminished today due to CAE practices but the simplicity and cost associated with these is so less and hence the 1970 popular tag line " Piping design method beats computer " is still valid . We compare the three methods and suggest a practical use of the FEM keeping in mind the physics of the problem and a eyes wide open approach rather than a blind one .

II. PROBLEM STATEMENT

The following problem has been taken for comparison of the methods .It refers to a line carrying a hydrocarbon fluid at a high temperature in a refinery .
Material of Construction : A 53 Gr. B , Size : 8NPS Sch 40 with cold temperature is 70'F and the hot (operating) temperature is 400^0F . The distance between the two equipment (or two anchors) is 100 ft. and

the width of expansion loop is 10 ft. . The guide supports are located at a distance of 10 ft from the corner of the expansion loop .

The objective is to determine:

1. The required height of expansion loop
2. Forces and Moment by M.W.Kellogg's method
3. Forces and Moment by Mc Ketta's method
4. FEA Solution by classical beam element approach

III. SOLUTIONS

3.1 M W KELLOG METHOD :

The geometry of the expansion loop is shown in Fig. 1

Step 1 . Determining the required height of expansion loop for adequate piping system flexibility

Following the notations of the M W Kellogg method , $K_1L = 10$,i.e. $K_1.30 = 10$ OR $K_1 = 0.34$

For 8 NPS SCH 40 the outside diameter D = 8.625 in and average wall thickness t = 0.322 in.

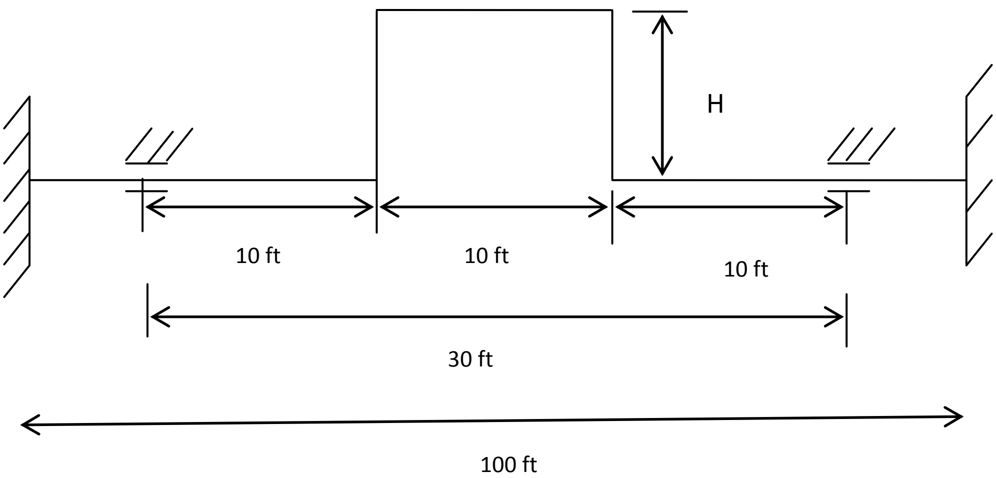

Fig.1 The Geometry of the expansion loop

The thermal expansion of the material A 53 Gr.B from ASME B 31.3 Table C is 2.7 in per 100 ft. .

Δ = Thermal expansion = 2.7 in.

For the material A53GrB, we get the following allowable stresses in the cold and hot condition .

S_h = 20,000 psi ,S_C = 20,000 psi

$S_A = 1.25 S_C + 0.25 S_h$

$= (1.25 * 2 * 10^4) + (0.25 * 2 * 10^4)$ = 30000 psi.

Let us determine the value of the parameter $\frac{L^2 S_A}{10^7 D \Delta}$ and k_1 to get the value of k_2 from the graph.

We observe that, $\frac{L^2 S_A}{10^7 D \Delta} = \frac{18^2 \times 30000}{10^7 \times 4.50 \times 2.7}$ = 0.08

With this value on the y axis and and K_1= 0.33 ,We can find out from Fig. 2 the Factor K_2 and the value we get is K_2= 0.3

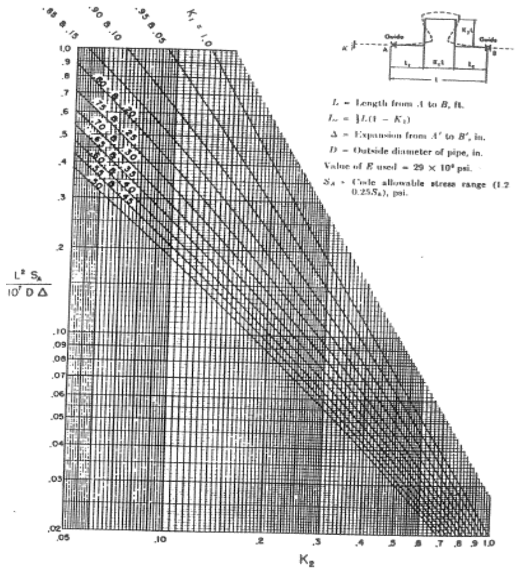

Fig. 2 . Chart for determining the height of expansion loop by M W Kellogg method.

The required height of expansion loop is thus as per the M W Kellog method is $H=K_2L$ = 0.22 X 30 =6.6 ft.

Step 2 : Determining the forces and moments

We have to use Fig.3 from which corresponding to the values of K_1 and K_2 we get the value of coefficients A_1 and A_2 to be used in the force and moment formula calculations.By using the Graph from Fig. 3 and K_1= 0.34 and K_2= 0.22 , we get A_1 = 1.4 and A_2 = 1.64. The formulas for force and moment calculations are.

$$F = -10^6 A_1 * I * \Delta / L^3$$

$$M = 10^5 A_2 * I * \Delta / L^2$$

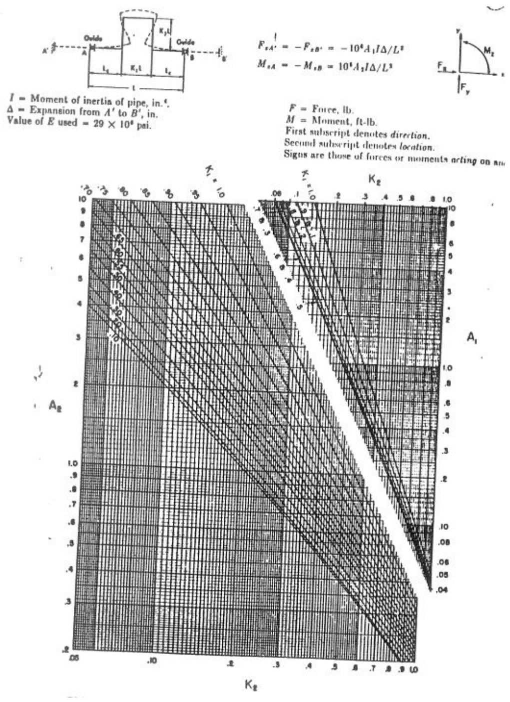

Fig 3. Graph for determining the Forces and Moments by M W Kellogg method.

Where I is the moment of inerita . From Schedule charts we find for 8 NPS Sch.40 , I= 72.5 in^4. We put the values of A_1 and A_2 with L =30 and thermal expansion Δ = 2.7 these values in the expressions of forces and moments to get the values as ,

Force = $10^6 * 1.4 * 72.5 * \frac{2.7}{27000}$ = 10,115 lb_f

Moment = $10^5 * 1.64 * 72.5 * \frac{2.7}{900}$ = 34,800 lb_f ft = 417600 lb_f in.

3.2 McKETTA METHOD

This method has been presented by McKetta in the piping design handbook[2] and widely used in the industry due to simplicity as there are very simple parameters that the user has to calculate.Value of Force corresponding to above parameters in the Force graph for U type expansion loops can be found out from the graph. This is a staircase type solution as indicated in the Fig.4. where we proceed in the sequence as β to α to δ to H to F/I value.

For the present expansion loop we get the parameters, H=16.6 ft. , β = $\frac{W}{H}$ = 10/6.6 =1.51 and α = $\frac{G}{H}$ = 10/6.6 =1.51

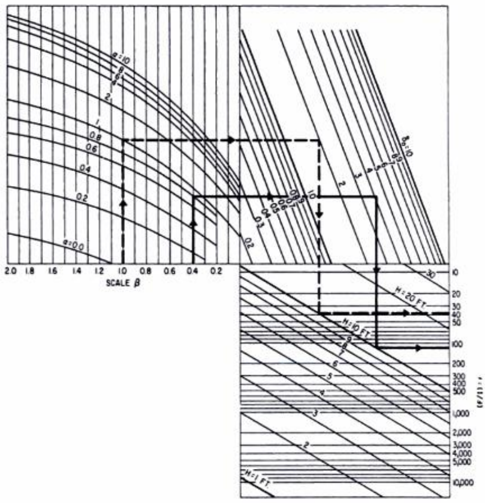

Fig.4 Force Graph for McKetta Method for Symmetric expansion loops.

Following the staircase solution we get F/I = 160 thereby F= 160x72.5= 10,150 lb_f .

The Moment graph in Fig. 5 can now be used again with a staircase type solution to get the value of

M = 400000 lbf.in = 33333.33 lb_f ft.

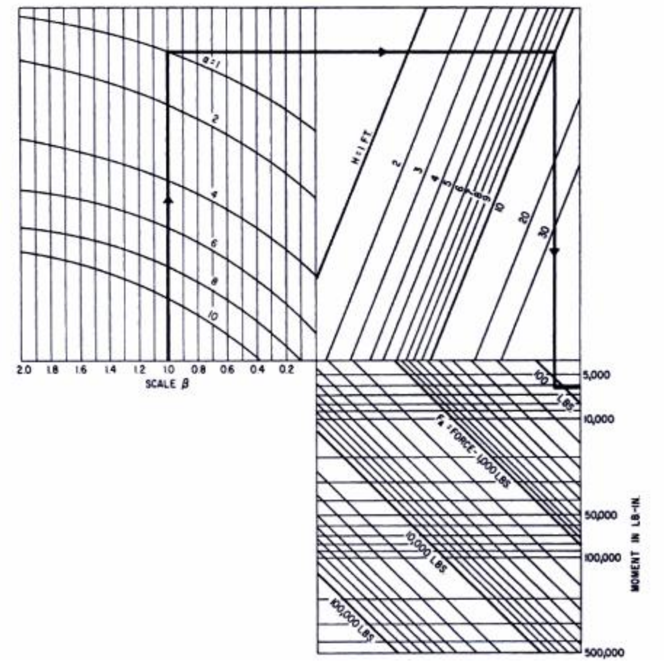

Fig.5 Moment graph for McKetta Method for determining the Moments for a symmetric expansion loop.

3.3 FINITE ELEMENT ANALYSIS SOLUTION

The finite element model of the expansion loop can be constructed with a three degree of freedom (d.o.f) approach the d.o.f being axial displacement, vertical displacement and the slope .This a plane frame element which is a combination of rod and beam element sometimes in the literature also called as generalized beam element. The reader is referred to any standard book on Finite Element Method [5]. Further due to the symmetry of the expansion loop we can also analyze only half model as shown in the Fig. 6. The plane frame element d.o.f are shown in Fig. 7

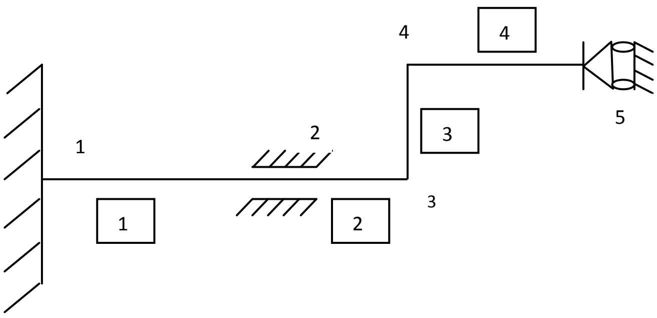

Fig.6: Finite Element Model of the Expansion loop showing the constraints.

Fig. 7: Degree of Freedom of a plane frame element

The boundary conditions (Constraints) of the model can be now written down as :

1. At the fixed support all degree of freedom (translation in x, y and rotation about z) = 0.0
2. At the guide support, the vertical translation i.e displacement in y direction = 0.0 and
3. At the plane of symmetry we put the translation along the x direction = 0.0 which is shown by putting a roller support.

The stiffness matrix can now be formed by using the standard Young's modulus of steel E= $30x10^{6}$ psi and other properties such as the element length and moment of inertia. The final size of the stiffness matrix gets reduced from 15 x 15 to 9 x 9 after application of the constraints and we can solve the system for displacements and reaction forces .

From the programme given in the format of an excel sheet in Chandrupatla [7] , we get the values of the forces and moments experienced by the loop as:

F= 10680.2lb_f and M =34187.45 lb_f ft

Thus now we see that these values are also in close agreement with the classical methods and thus the FEA results compare well .

III. COMPARISON OF THE SOLUTIONS

The results of various methods for Forces and Moments are given in Table no.1

We observe that although the methods have a totally different procedure for computations ultimately the results obtained are closer to each other.

Table no.1 Comparison of various methods.

SR NO.	METHOD	RESULT
1	MW KELLOG	F= 10115 lb_f M = 34800 lb_f ft.
2	Mc KETTA	F = 10150 lb_f M = 33333.33 lb_f ft.
3	FEA	F = 10680. lb_f M = 34187.45 lb_f ft.

IV. CONCLUSION

We have presented here a critical assessment of the M W Kellogg , McKetta and FEA . We observe that the methods compare with each other extremely well and also with finite element method . It is expected that amidst the use of somewhat blind use of FEA and CAE technology , the classical methods save a lot of valuable time and cost in the overall design process . Knowledge of FEA software is a necessary condition but the practical user also has to keep in mind the physics of the problem and the vast domain knowledge available through the literature . The practical piping design engineers working in power plants, and process industry and petroleum refineries will benefit from this approach.

VI. REFERENCES

[1] M .W.Kellogg, *The Design of Piping Systems* (Martino Fine books, 2007).

[2] J.J.McKetta (ed), *Piping Design Handbook* (CRC Press, 1992)

[3] M.L.Nayyar, *Piping Handbook,(*McGrawHill , 7th edition,1999)

[4] G.K.Sahu, *Handbook of Piping Design* (New Age International Publishes, 2014).

[5] D.A.Logan, *A first course in Finite Element Method,* (Cengage Learning, 2015)

[6] S. S. Deshpande, *Notes on Piping stress analysis for industrial training programme for various companies like ESSAR steels, Thermax , Larsen and toubro etc.*(Asian Academy of Professional Training , Pune , 2012)

[7] Chandrupatla and Belegundu, *Introduction to Finite Elements in Engineering* (Pearson 2015)