ABUAD Journal of Engineering Research and Development (AJERD) ISSN: 2645-2685
Volume 1, Issue 2, 225-231

A Simple Excel VBA Tool to Compute Stress of a Rigid Pipe Spool Conveying High Temperature and Pressure Fluid

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Date of First Submission: 21/03/2018
Date Accepted: 22/06/2018

Abstract: *This paper entails the Stress Analysis of a Pipe Spool Conveying High Temperature and Pressure Fluid, Using Excel Visual Basic Application, focused on the analysis of Dynamic stress in pipe spool for different piping materials. The stress analysis of pipe spool under the effect of sustained load, thermal load, wind load and seismic load was built with success using Excel VBA. The VBA was made to be flexible in order to accommodate other ASME Code Standard, as the existing one is able to analyse only ASME B31.3 Code. Industry best standard have been followed in the course of the analysis. The result obtained was favourable in comparison to CAESAR II stress analysis software.*

Keywords: *Analysis, Excel, Pipe, Spool, Seismic*

1. INTRODUCTION

With a specific end goal to precisely design a piping system, one must capture the two-piping system conduct under plausible loadings and also the regulatory necessity forced upon it. A System's performance can be measured through the total estimations of various physical parameters, for example, increasing speeds, velocities, displacements, internal forces and applied moments, stresses, and external responses created under applied loads [1]. Allowable ranges for every one of these parameters are set after the right failure criteria for the framework are reviewed. System reaction and failure criteria are reliant on the kind of loadings, which can be characterized by different refinements, for example, essential versus optional, maintained against infrequent and static contrasted with dynamic [2].

The ASME/ANSI B31 piping codes are the after-effect of roughly 80 years of work by the American Society of Mechanical Engineers and the American National Standards Institute (previously American Standards Association) for the sole-purpose of the codification of plan and engineering standards for piping systems [1]. The B31 pressure piping codes (and their successors, for example, the ASME Boiler and Pressure Vessel Section III atomic nuclear piping codes) recommend least outline, materials, manufacture, assembly, erection, test, and review necessities for piping systems proposed for use in power, petrochemical/refinery, fuel gas, gas transmission, and atomic applications [2,3].

Because of numerous computations required amid the investigation of piping systems, this field of designing give a characteristic application to electronic calculations particularly during the first 20 to 30 years. The proliferation of a user-friendly pipe pressure programming has had a two-fold impact: to begin with, it has removed pipe stress analysis from the hands of the highly compensated experts and made it available to the engineering specialist, also, it has made everybody, even those with lacking adequate piping foundation equipped for turning out authority looking outcomes [5].

Piping stress examination is a field which is profoundly interrelated with piping format and bolster design. The design of the piping System ought to be carried out with the necessities of piping stress and pipe supports at the top of the priority list adequate adaptability for thermal expansion; appropriate pipe routing so basic and sparing channel backings can be built; piping materials and area properties comparable with the expected service, temperatures, pressures, and foreseen loadings [5]. If need be, design schedule ought to be iterated until a reasonable result of stresses and design efficiency is accomplished. Once the piping layout is concluded, the piping support network must be resolved. Conceivable help areas and sorts must be iterated until the point when all stresses necessities are fulfilled and other piping suitable (e.g., nozzle loads, valve increasing speeds, and piping developments) are met. The piping bolsters are then composed in view of the chosen areas and types and the applied loads [3].

. A Pipe Spool is a pre-assembled component of the piping System. It incorporates the fittings, pipe and flanges which are pre-mounted in the fabrication facility and later transported to the field. They are pre-mounted in order to avoid the use of lifts, material and devices for assembling in a controlled situation [1].

Despite the fact that a number of commercial piping stress analysis software exists out there, the greater part of them are for topside pipe investigation; that cannot consolidate the impact of temperature, pressure, current and wave loads.

The VBA software estimates the stress of a vertical pipe spool, working pressure, the required pipe wall thickness for a given application in a basic, direct way. It is more adaptable since it can compute the stress level in a given pipe at a given pressure, the base pipe wall thickness, or the most extreme allowable pressure [7]. The VBA software enables the client to choose a particular material from a database of commonly utilized materials. The program examines pipes based on specifications of the ASME/ANSI B31.3 piping code.

1.1 Justification of the Research

There are few pressure investigation programming that can evaluate the combined impact of temperature, pressure current and wave loads on pipes. The few ones accessible are exceedingly costly which make them to be less utilized amid the reasonable period of the plan. For the outline of the Floating Production Storage and Offloading (FPSO) spool associating the Steel Catenary Riser (SCR) to the topside piping, it will be of a gigantic favourable position to have a straightforward and viable instrument to survey its power under extraordinary states of temperature, pressure current and wave, amid the theoretical plan. Consequently, there is a requirement for a straightforward, adaptable, and powerful device for this reason.

To realize this, a VBA programming language will be used in Microsoft Excel environment. This was chosen because of the adaptability of the programming language, accessibility of Microsoft Excel and the colossal numerical crunching capacity of Excel.

1.2 Aim and Objectives of the Study

The aim of this research is to develop a simple excel VBA tool to compute stress of a rigid pipe spool conveying high temperature and pressure fluid. The objectives to be met by this research are:

a) To analyse the stress of a pipe spool;
b) To develop a Microsoft Excel VBA source code to compute the stress of the pipe spool exposed to high temperature and pressure throughout their service life.

2. BACKGROUND STUDY

2.1 Theory and Development of Pipe Stress Requirements

1) Basic Stress Concepts:

Normal Stresses: Normal stresses are direct stresses acting in a direction perpendicular to the face of the crystal structure of the material. It can be tensile or compressive in nature. In fact, normal stresses in piping tend more to tension due to predominant nature of internal pressure as a loads case. Normal stresses may be applied in more than one direction; and may develop from a number of different types of loads for a piping system, as shown in Figure 1.

Longitudinal Stress: Longitudinal, or axial stress is the stress acting parallel to the longitudinal axis of the pipe. This may be caused by an internal forces acting axially within the pipe, as shown in Figure 1.

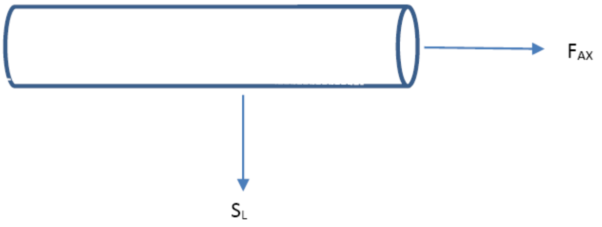

Figure 1: Longitudinal Stress in a Pipe

$$S_L = \frac{F_{AX}}{A} \qquad (1)$$

Where:
S_L = Longitudinal stress, Nm^{-2}
F_{AX} = Internal axial force acting on cross-section, N
A = Metal cross-sectional area of pipe, m^2
$= \frac{\pi(d_o^2 - d_i^2)}{4}$

d_o= outer diameter, m
d_i= internal diameter, m

A particular occasion of longitudinal stress is that cause by internal pressure, as shown in Figure 2

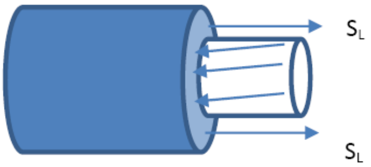

Figure 2: Internal Pressure

$$S_L = P(\frac{A_i}{A_m}) \qquad (2)$$

Where:
P= design pressure, Nm^{-2}
A_i= internal area of pipe, m^2

2) Failure Theories, Stress Categories, Stress Limits, and Fatigue Failure Theories:

The most commonly used theories of failures in describing the strength of piping Systems are the *maximum principal stress theory* and the *maximum shear stress theory* (also known as the *Tresca criterion*).

The maximum principal stress theory forms the basis for piping Systems governed by ASME B31 and Subsections NC and ND (Classes 2 and 3) of Section III of the ASME Boiler and Pressure Vessel Codes. According to this theory, yielding in a piping component occurs when the magnitude of any of the three mutually perpendicular principal stresses is greater than the yield strength of the material [3].

The maximum shear stress theory however is more accurate than the maximum principal stress theory for predicting both yielding and fatigue failure in ductile metals. This maximum shear stress theory forms the basis for piping of Subsection NB (Class 1) of ASME Section III.

The maximum shear stress at a point τ_{max} is defined as the algebraic difference between the largest and the smallest of the three principal stresses σ_1, σ_2, and σ_3. If $\sigma_1 > \sigma_2 > \sigma_3$ divided by two.

Then, $$\tau_{max} = \frac{\sigma 1 - \sigma 2}{2} = \frac{S_y}{2} \qquad (3)$$

The maximum shear stress theory postulates that failure of a piping component will occur only when the maximum shear stress is larger than the shear stress at the yield point in a tensile test. In the tensile test, at yield, $\sigma_1 = S_y$, $\sigma_2 = \sigma_3 = 0$.

Equation 3 has an unnecessary operation of dividing both sides by 2 before comparing them. For the sake of simplicity, a stress defined as $2\tau_{max}$ and equal to $\sigma_{max} - \sigma_{min}$ of the three principal stresses has been used for Class 1 piping. This stress is called the *combined equivalent intensity of stresses,* or simply *stresses intensity*. Thus the stress intensity S is directly comparable to the tabulated yield stress values S_y from tensile tests with some factor of safety [5].

3) Stress Categories:

The failure modes which could affect a piping system vary. The piping engineer can make available protection against some of these failure modes by performing stress analysis based on the piping codes. Protection against other failure modes is given by strategies other than stress analysis. For instance, assurance against brittle fracture is given by material selection. The piping codes address the accompanying failure modes: excessive plastic deformation, plastic instability or incremental collapse, and high strain– low-cycle fatigue. Every one of these methods of failure is caused by an alternate form of stress and loading. It is important to put these stresses into various classifications and assign limits to them.

The major stress categories *are primary, secondary, and peak.* The limits of these stresses are related to the various failure modes as follows:

1. The primary stress limits are aimed at preventing plastic deformation and bursting.
2. The primary plus secondary stress limits are intended to prevent excessive plastic deformation leading to incremental collapse.
3. The peak stress limit is aimed at preventing fatigue failure resulting from alternating loadings.

Primary stresses which are developed by the imposed loading are necessary to satisfy the equilibrium between external and internal forces and moments of the piping System. Primary stresses are not self-limiting. Therefore, if a primary stress exceeds the yield strength of the material through the entire cross section of the piping, then failure can be prevented only by strain hardening in the material. Thermal stresses are never classified as primary stresses. They are placed in both the secondary and peak stress categories.

Secondary stresses are developed by the constraint of displacements of a structure. These displacements can be caused either by thermal expansion or by outwardly imposed restraint and anchor point movements. Under this loading condition, the piping System must satisfy an imposed strain pattern rather than be in equilibrium with imposed forces. Local yielding and minor distortions of the piping System tend to relieve these stresses. Therefore, secondary stresses are self-limiting. Unlike the loading condition of secondary stresses which cause distortion, peak stresses cause no significant distortion. Peak stresses are the highest stresses in the region under consideration and are responsible for causing fatigue failure. Common types of peak stresses are stress concentrations at a discontinuity and thermal gradients through a pipe wall.

Primary stresses may be further divided into general primary membrane stress, local primary membrane stress, and primary bending stress. The reason for this division is that, as will be discussed in the following paragraph, the limit of a primary bending stress can be higher than the limit of a primary membrane stress.

4) Basic Stress Intensity Limits:

The basic stress intensity limits for the stress categories just described are determined by the application of limit design theory together with suitable safety factors.

The piping is assumed to be elastic and perfectly plastic with no strain hardening. When this pipe is in tension, an applied load producing a general primary membrane stress equal to the yield stress of the material S_y results in piping failure. Failure of piping under bending requires that the entire cross section be at this yield stress. This will not occur until the load is increased above the yield moment of the pipe multiplied by a factor known as the *shape factor* of the cross section. The shape factor for a simple rectangular section in bending is 1.5.

When a pipe is under a combination of bending and axial tension, the limit load depends on the ratio between bending and tension. In Figure 3, the limit stress at the outer fibre of a rectangular bar under combined bending and tension is plotted against the average tensile stress across the section. When the average tensile stress P_m is zero, the failure bending stress is 1.5 S_y. When P_m alone is applied (no bending stress P_b), failure stress is yield stress S_y.

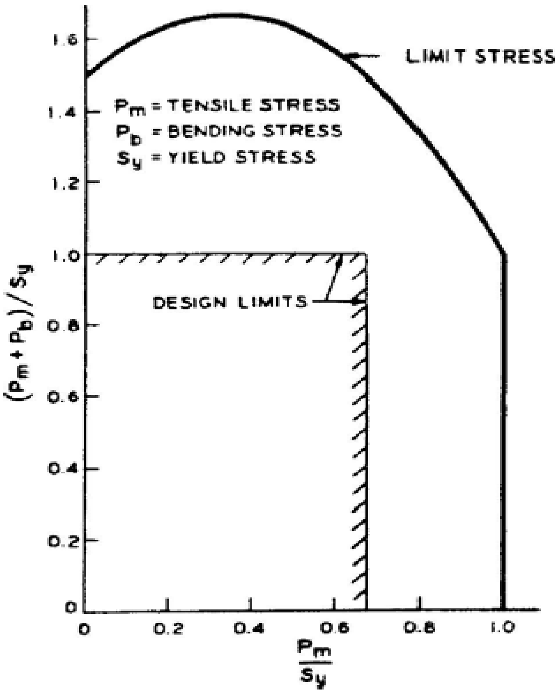

Figure 3: Limit stress for combined tension and bending (rectangular section). (*ASME, "Criteria", Courtesy of ASME*)

It also can be seen in Figure 3 that a design limit of 2/3 S_y for general primary membrane stress P_m and a design limit of S_y for primary membrane-plus-bending stress $P_m + P_b$ provide adequate safety to prevent yielding failure.

2.2 Classification of Loads, Service Limits, and Code Requirements

1) Classification of Loads:

Primary loads can be divided into two categories based on the duration of loading. The first category is *sustained loads.* These loads are expected to be present throughout normal plant operation. Typical sustained loads are pressure and weight loads during normal operating conditions. The second category is *occasional loads.* These loads are present at infrequent intervals during plant operation. Examples of occasional loads are earthquake, wind, and fluid transients such as water hammer and relief valve discharge.

In addition to primary loads, there are *expansion loads.* Expansion loads are those loads due to displacements of piping. Examples are thermal expansion, seismic anchor movements, thermal anchor movements, and building settlement.

2) Service Limits and Code Requirements:

Service levels and their limits are defined for nuclear power plant safety-related piping by the ASME Boiler and Pressure Vessel Code, Section III. They are described in the following list:

1. *Level A service limits.* The piping components or supports must satisfy these sets of limits in the performance of their specified service function. Examples of level A loadings are operating pressure and weight loadings.
2. *Level B service limits.* The piping component or support must withstand these loadings without damage requiring repair. Examples of level B loadings are fluid transients such as water hammer and relief valve discharge, and *operating-basis earthquake (OBE),* defined as the maximum likely earthquake postulated to occur during plant design life or one-half of the safe shutdown earthquake (see definition below), whichever is higher.
3. *Level C service limits.* The occurrence of stress up to these limits may necessitate the removal of the piping component from service for inspection or repair of damage. An example of level C loading is the combination of fluid transient loads occurring simultaneously with the operating-basis earthquake.
4. *Level D service limits.* These sets of limits permit gross general deformations with some consequent loss of dimensional stability and damage requiring repair, which may require removal of the piping component from service. An example of level D loading is the loading associated with a loss-of-coolant accident or a *safe-shutdown earthquake (SSE),* which is defined as the maximum possible earthquake postulated to occur at the site of the plant at any time.

There are various ASME and ANSI codes which govern the stress analysis of different kinds of pressure piping. These codes contain basic reference data, formulas, and equations necessary for piping design and stress analysis.
Each power Plant is committed to a particular edition of a code for different types of piping. For example, the nuclear Class 1, 2, and 3 piping of a power plant may be committed to comply with the ASME Boiler and Pressure Vessel Code, Section III, 1974 edition, while the nonnuclear piping may be committed to ANSI B31.1 *Power Piping Code*, 1973 edition. The following sections provide summaries of the ASME and ANSI codes.

3) Explanation of Terms Related to Pipe Supports:

Anchor: A rigid restraint providing sustainability full fixity for three translation and rotations bout the three reference axes.

Brace: A device primarily intended to resist displacement of the piping due to the action of any forces other than those due to thermal expansion or to gravity. Constant-Effort Support: A support capable of applying a relatively constant force at any displacement within its useful operating range (e.g. counterweight or compensating spring device)

Damping Device: A dashpot or other frictional device that increases the damping of a system.
Offering high resistance against rapid displacement caused by dynamic loads while permitting essentially free movement under very gradually applied displacements (e.g. snubber)

Hanger: A support by which piping is suspended from a structure, and so on, and which functions by carrying the piping load in tension.
Limit Stop: A device that restricts translator movement to a limited amount in one direction along any single axis. Paralleling the various stops. There may also be double-acting limit stops, two axis limit stops, and so on.
Resilient Support: A support that includes one or more largely elastic member
Resting or Sliding Support: A device providing support from beneath the piping but offering no resistance other than frictional to horizontal motion.
Restraint: Any device that prevents resists or limits the free movement of the piping.
Rigid (Solid) Support: A support providing stiffness in at least one direction, which is comparable to that of the pipe.
Stop: A device that permits rotation but prevents translator movement in at least one direction along any desired axis. If translation is prevented in both directions along the same axis, the term double-acting stop is preferably applied. Stop is also known as "Bumper."
Support: A device used specifically to sustain a portion of weight of the piping system plus any superimposed vertical loadings.
Two–Axis Stop: A device which prevents translator movement in one direction along each of two axes.

2.3 Microsoft Excel

Excel is a spreadsheet application developed by Microsoft for Microsoft Windows and Mac OS [6]. It features calculation, graphing tools, pivot tables, and a macro programming language called Visual Basic for Applications. It has been a very widely applied spreadsheet for these platforms, especially since version 5 in 1993, and it has replaced Lotus 1-2-3 as the industry standard for spreadsheets. Excel forms part of Microsoft Office [7].

1) VBA Programming:

The Windows version of Excel supports programming through Microsoft's Visual Basic for Applications (VBA), which is a dialect of Visual Basic [7]. Programming with VBA allows spreadsheet manipulation that is awkward or impossible with standard spreadsheet techniques.
Programmers may write code directly using the Visual Basic Editor (VBE), which includes a window for writing code, debugging code, and code module organization environment [7]. The user can implement numerical methods as well as automating tasks such as formatting or data organization in VBA and guide the calculation using any desired intermediate results reported back to the spreadsheet [8].

3. METHODOLOGY

3.1 ASME Boiler and Pressure Vessel Code, Section III, Subsections NC and ND.

These two subsections give the code requirements of nuclear piping designated as Class 2 and Class 3, respectively. The loadings required to be considered for Subsections NC and ND are the effects of pressure, weight, other sustained loads, thermal expansion and contraction, and occasional loads. The stress limits to be met are as follows:

1) Stresses due to sustained loads:

The calculated stresses due to pressure, weight, and other sustained mechanical loads must meet the allowable $1.5S_h$, that is

$$\frac{B_1 P D_O}{2t} + \frac{B_2 M_A}{Z} \le 1.5S_h \quad (4)$$

Where;
P = internal design pressure, kNm^{-2}
D_o = outside diameter of pipe, m
t = nominal wall thickness, m
Z = section modulus of pipe, m^3
M_A = resultant moment loading on cross section due to weight and other sustained loads, kNm
S_h = basic material allowable stress at design temperature, kNm^{-2}

2) Stresses due to occasional loads:

The calculated stress due to pressure, weight, other sustained loads, and occasional loads must meet the allowables as follows:

$$\frac{B_1 P_{max} D_O}{2t} + \frac{B_2(M_A+M_B)}{Z} \le kS_h \quad (5)$$

Where;
M_B = resultant moment loading on cross section due to occasional loads, such as thrusts from relief and safety valves, loads from pressure and flow transients, and earthquake, if required.
$P_{\max}$ = peak pressure, kNm^{-2}
kS_h $=1.8S_h$ for service level B (upset condition) but not greater than $1.5S_y$; $2.25S_h$ for service level C (emergency condition) but not greater than $1.8S_y$; and $3.0S_h$ for service level D (faulted condition) but not greater than $2.0S_y$
S_h = material allowable stress at temperature consistent with loading under consideration, psi
S_y = material yield strength at temperature consistent with loading under consideration, psi

3) Stresses due to thermal expansion:

Thermal expansion stress range must meet the allowable S_A [3], that is,

$$\frac{iM_C}{Z} \le S_A \quad (6)$$

Where;
S_A = allowable stress range for expansion stresses = $f(1.25S_c + 0.25S_h)$, kNm^{-2}
f = stress range reduction factor,
M_C = range of resultant moment due to thermal expansion, kNm; also include moment effects of anchor displacements due to earthquake if anchor displacement effects were omitted from occasional loadings

S_C = basic material allowable stress at minimum (cold) temperature, kNm^{-2}
S_h = basic material allowable stress at maximum (hot) temperature, kNm^{-2}
i = stress intensification factor

3.2 Piping Design for Loading Types

1) Minimum Wall Thickness Requirements:

Piping codes necessitate that the minimum thickness (t_m) together with the allowance for mechanical strength, shall not be less than the thickness calculated in equation 7, [3]:

$$t_m = \frac{PD_o}{2(SE_q + PY)} + A = t + A \qquad (7)$$

$$Y = \frac{d}{d + D_o} \quad \text{if } t \geq \frac{d}{6} \qquad (8)$$

where
t_m = minimum required wall thickness, (m)
T = Pressure design thickness
D_o = Outside diameter of pipe, (m)
S = Allowable stress at design temperature - known as hot stress (kNm^{-2})
A = Allowable, additional thickness to provide for material removed in threading, corrosion, or erosion allowance
Y = coefficient that takes materials properties and design temperature into account.

4. RESULT AND DISCUSSION

A test result was obtained by inputting sample pipe and fluid data to the system called VBAPipePro. The results obtained were compared to that of Intergraph Caesar II result. The results obtained are presented in Tables 1-5 as displayed on the VBAPipePro and Caesar II interface.

4.1 Pipe and Fluid Parameters

The following data were fed in to VBAPipePro and the Caesar II software:
Pipe Length: From 10 to 20 m
Initial Translation: Dx = 10 m, Dy = 10 m, Dz = 10 m
Pipe Code: B31.3
Schedule: 20000 kN/m^2
Temperature 1: 31.56 ^{o}C
Pressure 1: 150 kN/m^2
Material: A106B
Elastic Modulus: 29,500,000 kN/m^2
Pipe Density: 0.2830000 kN/m^3
Fluid Density: 0.306944 kN/m^3
Bend: Radius = 6 in, Bend Angle = 90 degrees, Angle /Node = 45

4.2 Excel VBA Results

1) Bend Report:

Table 1: VBA Bend Report

BEND	TYPE	SIFo	SIFi	Ki	Ko
20	0 Flanges	1.623	1.949	5.270	5.270

2) Allowable Report:

Table 2: Allowable Report

FROM	10
TO	20
SC	17900
SH1	20000
SH2	20000
SH3	20000
SH4	20000
SH5	20000
SH6	20000
SH7	20000
SH8	20000
SH8	20000

3) Sustained Load Case Report:

Stress due to Sustained load = 8708.18641724968
kS_h = 17300
Since 8708.18641724968 <= 17300, then the stress due to sustained load test is passed.

4.3 Caesar II Test Results

1) Caesar II Bend Report:

Table 3: Caesar Bend Report

BEND	TYPE	SIFo	SIFi	Ki	Ko
20	0 Flanges	1.613 to 1.627	1.935 to 1.952	5.230 to 5.272	5.230 to 5.272

2) Caesar II Allowable Report:

Table 4: Caesar II Allowable Report

FROM	10
TO	20
SC	17900
SH1	20000
SH2	20000
SH3	20000
SH4	20000
SH5	20000
SH6	20000
SH7	20000
SH8	20000
SH8	20000

4.4 Results Variation

1) Bend Report:

Table 5: Bend Report Comparison

	EXCEL VBA	CAESAR	% Difference
BEND	20	20	
TYPE	0 Flanges	0 Flanges	
SIFo	1.623	1.627	0.246460
SIFi	1.949	1.952	0.153925
Ki	5.270	5.272	0.38000
Ko	5.270	5.272	0.38000

2) *Allowable Report:*

Table 6: Allowable Report Comparison

	EXCEL VBA	CAESAR	% Difference
FROM	20	20	
TO	0 Flanges	0 Flanges	
SC	17900	17900	0.000
SH1	20000	20000	0.000
SH2	20000	20000	0.000
SH3	20000	20000	0.000
SH4	20000	20000	0.000
SH5	20000	20000	0.000
SH6	20000	20000	0.000
SH7	20000	20000	0.000
SH8	20000	20000	0.000
SH9	20000	20000	0.000

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The stress examination of a pipe spool under the impact of sustained load, thermal load, wind load and seismic load have been effectively worked with Excel VBA. The VBA was made to be adaptable to suit other ASME Code Standard, as it can dissect just ASME B31.3 Code. Industry best standard have been followed over the process of the investigation. The developed tool demonstrates great comparison with existing commercial programs in view of the scope of tests performed.

5.2 Recommendation

Going ahead the UI of the VBA could be enhanced to incorporate the designs of the pipe beginning interpretation; shading coding could as well be fused to indicate territories most influenced by the loads and how the pipe distorts. Speculation ought to be made to grow the extent of the VBA to incorporate other ASME Code Standard.

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