1.0 Introduction

1.1 Why checkSTRESS?

It is common practice worldwide that piping designers/layout personnel route pipes with consideration given mainly to space constraints, process and flow constraints (such as pressure drop) and other requirements arising from constructability, operability and reparability. Unfortunately, often pipe stress requirements are not sufficiently considered while routing and supporting piping systems, especially in providing adequate flexibility to absorb expansion/contraction of pipes due to thermal loads. So, when "as designed" piping systems are given to pipe stress engineers for analysis, they soon realize that the layout is "stiff" and suggest routing changes to make the layout more flexible. The piping designers, in turn, make routing changes and send the revised layout to the pipe stress engineers to check compliance again. Such "back and forth" design iterations between layout and stress departments continue until a suitable layout and support scheme is arrived at, resulting in significant increase in project execution time, which, in turn, increases project costs.

This delay in project execution is further aggravated in recent years as operating pressures and temperatures are increased in operating plants to increase plant output; increased operating pressures increase pipe wall thickness, which, in turn, increase piping stiffness further; increased operating temperatures, applied on such "stiffer" systems, increase pipe thermal stresses and support loads. So, it is all the more important to make the piping layout flexible at the time of routing by piping designers.

In order to substantially reduce the number of design iterations between the piping layout and stress departments, resulting in huge time savings during design, the "Design by Color" product "checkSTRESS" was developed and released in 2010. Since then, a number of enhancements have been added.

1.2 checkSTRESS Modules

The preliminary visual pipe stress check software checkSTRESS is an add-on product to:

- 3D Plant Design software PDMS, PDS and CADMATIC
- 3D Plant Design software that generate "PCF" files from the plant database, such as SmartPlant 3D, AutoCAD Plant 3D, CATIA, CADWORX, etc.

The checkSTRESS product performs preliminary visual pipe stress check as follows.

- Reads the following from the plant database / PCF files of 3D Plant Design software
  - Piping geometry, pipe sections and material properties
  - Temperature, pressure and weight of pipe fittings
  - Thermal anchor movements at equipment nozzles
  - Pipe support details to create the corresponding hangers, guides, etc. in checkSTRESS
  - Allowable loads at equipment nozzles
- Enables piping code compliance by displaying stress ratio contour plots for Sustained (weight + pressure), Expansion and Occasional load cases.
- Assists in locating hangers and supports by showing deflected shapes for Sustained, Operating, Expansion and Occasional load cases. Even sizes variable spring hangers.
- Generates input files for one or more of the widely accepted pipe stress software CAEPIPE, CAESAR II and PIPESTRESS (which is mostly used for nuclear piping analyses).
- Prints key results such as 10 highest stress ratios and their locations, equipment nozzle load compliance with allowable loads, spring hanger report, "active/inactive" status of resting supports during operation, Bill of Materials, Weight and Center of Gravity, and Table of Contents.

Currently, the following 3 modules of checkSTRESS are available for license.

checkSTRESS: generates stress input files only for CAEPIPE

checkSTRESS II: generates stress input files for CAEPIPE and CAESAR II

checkSTRESS Nuke: generates stress input files for CAEPIPE and PIPESTRESS

Excepting the generation of stress input files, the 3 checkSTRESS modules (available for each of the 3D Plant Design software listed above) have identical features. *Only checkSTRESS Nuke has an additional feature of displaying animated mode shapes along with natural frequencies computed.*

1.3 Benefits derived from checkSTRESS modules

1. During 3D layout stage, the Designer arrives at "flexible pipe routing with even supports including spring hanger sizes" to meet the following stress criteria:
    a. Comply with "Thermal Stress", "Sustained Stress" and "Occasional Stress" requirements of Piping Codes ASME B31.1, ASME B31.3, ASME B31.4, ASME B31.5, ASME B31.8, ASME B31.9, ASME Sec III Class 2, BS 806, Norwegian, RCC-M, Stoomwezen, CODETI, Swedish, Z183, Z184 and EN 13480.
    b. Meet the Allowable Nozzle Loads at Equipment Nozzles/Anchors
2. During 3D layout stage, the Designer identifies all possible locations for pipe supports, as the 3D plant model contains all supporting objects such as steel and concrete structures adjacent to the concerned piping system. These possible locations for pipe supports, once marked in the 3D plant model, are automatically transferred as "nodes" in the input files of pipe stress software.
3. The Designer transfers stress input files to the pipe stress engineers for mostly "code compliant" and "fairly well supported" piping systems. Pipe stress engineers can then import these input files into their pipe stress software (thereby avoiding recreation of stress models by pipe stress engineers) and perform detailed analyses and stress report preparation.
4. The Designer confirms the validity of the piping layout finalized with supports by submitting key results and relevant plots generated by checkSTRESS.

1.4 Basic Pipe Stress Concepts for Piping Designers

Piping systems experience different loadings, categorized into three basic loading types listed below.

Sustained Load:

It mainly consists of internal pressure and dead-weight. Dead-weight is from weight of pipes, fittings, components such as valves, operating fluid, test fluid, insulation, cladding, lining etc.

Internal design/operating pressure develops uniform circumferential stresses in the pipe wall, based on which pipe wall thickness is determined during the process/P&ID stage of plant design such that "failure by rupture" is avoided. In addition, internal pressure develops axial stresses in the pipe wall. *These axial pressure stresses vary only with pressure, pipe diameter and wall thickness, which are already pre-set at the P&ID stage and hence these axial pressure stresses cannot be reduced by changing the piping layout or the support scheme*.

On the other hand, dead-weight causes the pipe to bend (generally downward) between supports and nozzles, producing axial stresses in the pipe wall (also called "bending stresses"); these bending stresses linearly vary across the pipe cross-section, being tensile at either the top or bottom surface and compressive at the other surface. If the piping system is not supported in the vertical direction (i.e., in the gravity direction) excepting at equipment nozzles, bending of the pipe due to dead-weight may develop excessive stresses in the pipe and impose large loads on equipment nozzles, increasing the susceptibility to "failure by collapse".

Various international piping codes impose limits, also called “allowable stresses for sustained loads”, on these axial stresses generated by dead-weight and pressure in order to avoid “failure by collapse”.

For the calculated axial stresses to be below such allowable stresses for sustained loads, it may be necessary to support the piping system vertically. Typical vertical supports to carry dead-weight are:

a) Resting steel supports,

b) Rod hangers,

c) Variable spring hangers, and

d) Constant support hangers..

Both rod hangers and resting steel supports fully restrain downward pipe movement but permit pipe to lift up at such supports. If pipe lifts up at any of the rod hangers / resting supports during operating condition, then that support does not carry any pipe weight and hence will not serve its purpose.

Thermal Load (also referred as Expansion Load):

It refers to the “cyclic” thermal expansion/contraction of piping as the system goes from one thermal state to another thermal state (for example, from “shut-down” to “normal operations” and then back to “shut-down”). If the piping system is not restrained in the thermal growth/contraction directions (for example, in the axial direction of a straight pipe), then for such cyclic thermal load, the pipe expands/contracts freely; in this case, no internal forces, moments and resulting stresses and strains are generated in the piping.

If, on the other hand, the pipe is “restrained” in the directions it wants to thermally deform (such as at equipment nozzles and pipe supports), such constraint on free thermal deformation generates cyclic thermal stresses and strains throughout the system as the system goes from one thermal state to another. When such calculated thermal stress ranges exceed the “allowable thermal stress range” specified by various international piping codes, then the system is susceptible to “failure by fatigue”. So, in order to avoid “fatigue failure” due to cyclic thermal loads, the piping system should be made flexible (and not stiff). This is normally accomplished as follows:

a) Introduce bends/elbows in the layout, as bends/ elbows “ovalize” when bent by end-moments, which increases piping flexibility.

b) Introduce as much “offsets” as possible between equipment nozzles (which are normally modeled as anchors in pipe stress analysis). For example, if two equipment nozzles (which are to be connected by a pipeline) are in line, then the straight pipe connecting these nozzles is “very stiff”. If, on the other hand, the two equipment are located with an “offset”, then their nozzles will have to be connected by an “L-shaped” pipeline which includes a bend/elbow; such “L-shaped” pipeline is much more flexible than the straight pipeline mentioned above.

c) Introduce expansion loops (with each loop consisting of four bends/elbows) to absorb thermal growth/contraction.

d) Lastly, introduce expansion joints such as bellows, slip joints etc., if warranted.

In addition to generating thermal stress ranges in the piping system, cyclic thermal loads impose loads on static and rotating equipment nozzles. By following one or more of the steps from (a) to (d) above and steps (e) and (f) listed below, such nozzle loads can be reduced.

e) Introduce “axial restraints” (which restrain pipe in its axial direction) at appropriate locations such that thermal growth/contraction is directed away from equipment nozzles, especially critical ones.

f) Introduce “intermediate anchors” (which restrain pipe movement in the three translational and three rotational directions) at appropriate locations such that thermal deformation is absorbed by regions (such as expansion loops) away from equipment nozzles.

Occasional Loads:

These are the third type of loads, which are imposed on piping by occasional events such as earthquake, wind etc. To protect piping from wind (which normally blows in horizontal plane), it is normal practice to attach “lateral supports” to piping systems. During an earthquake, the earth may also move vertically. To protect piping against both horizontal and vertical movement during earthquake, some of the resting supports may be made as “integral 2-way vertical and lateral restraints”.

checkSTRESS presently performs preliminary visual stress checks only for sustained (mainly dead weight, pressure and other sustained mechanical loads), thermal loads, static seismic ‘g’ loads and response spectrum loads (uniformly applied at anchors and nozzles).

Fortunately, to carry sustained loads, normally vertical supports (as those listed under the Section titled “Sustained Load” above) are required. To withstand static seismic ‘g’ loads and/or response spectrum loads, “integral 2-way vertical and lateral restraints” are required. Generally, some of the vertical weight supports can be modified as “integral 2-way vertical and lateral restraints”. On the other hand, for thermal loads, zero supports give zero stresses. So, thermal stresses and equipment nozzle loads will normally decrease as the number of supports goes down. Axial restraints and intermediate anchors are recommended only to direct thermal growth away from equipment nozzles.

1.5 Recommended Procedure for checkSTRESS

The steps given below may normally be followed using checkSTRESS to perform preliminary visual stress checks of piping systems designed using 3D plant design systems.

Step1: Generating checkSTRESS model

Apply checkSTRESS on the piping system under consideration in the 3D plant model, as outlined in the checkSTRESSPDMS / checkSTRESSPDS / checkSTRESSCADMATIC / checkSTRESSPCF Manual.

In case some of the important inputs (such as Thermal Anchor Movements at equipment nozzles and Allowable Nozzle Loads) are not available in the 3D plant database/PCF file, they can be manually entered using the “Edit Layout” button provided in checkSTRESS.

Step2: Studying Thermal Stress results for the Initial Layout

Review first stress contour plot for thermal stresses. The plot is color-coded such that “blue” region denotes areas with the least stress ratios (where stress ratio equals to actual computed stress divided by allowable thermal stress), “green” region with higher stress ratios, “yellow” region with even higher stress ratios, and “red” region with the highest stress ratios. Intermediate areas between these distinct colors will be of “bluish-green”, “greenish-yellow” and “orange” colors.

Since thermal stresses generated are directly dependent on how “flexible” the layout is, it may be necessary to make the layout as “flexible” as possible (by including bends, offsets, loops etc.) to reduce thermal stresses. So, the Designer’s goal is to arrive at a “flexible” layout for which thermal stress ratios remain within “blue” to “yellow” range and not get into “orange” and “red” zones. For a more “flexible” layout, even “yellow” zone may be avoided. That would leave even more thermal margin for stress engineers to meet other pipe stress criteria not considered under checkSTRESS.

Step 3: Finalizing Layout to meet Thermal Stress criteria

In case thermal stress ratios exceed “yellow” zone (i.e., “orange” and “red” zones appear in one or more areas of the piping system), it is important to study the deformed shape for “thermal” load case in order to understand how the piping deforms for “pure thermal” load (where only temperature change is considered). By studying such deformed shape, it is possible to arrive at a layout with appropriate bends, offsets and loops and/or with appropriately located axial restraints/intermediate anchors such that thermal stress ratios do not exceed “yellow” zone. This process may require the Designer to perform several iterations on layout and/or locations for axial restraints/intermediate anchors.

Step 4: Studying Results for Sustained Load

After finalizing piping layout under Steps 2 and 3 for thermal loading, the next task is to support the system vertically to carry its own deadweight under operating condition. In this connection, first review stress contour plot shown in color codes from “blue” to “red” (as in Step 2 above) for sustained stress ratios generated by deadweight and pressure for the system without any vertical supports (excepting those provided by equipment nozzles and intermediate anchors introduced in Step 3 above).

The Designer’s goal is to arrive at a vertical support scheme consisting of (a) resting steel supports, (b) rod hangers, (c) variable spring hangers and (d) constant support hangers, at appropriate locations (where such pipe supports can be attached to adjacent concrete/steel structures, platforms etc.) so that stress contour plot for sustained stress ratios avoids “orange” and “red” zones and remains within “blue to yellow” range.

Step 5: Finalizing Vertical Supports to carry Sustained Load

In case sustained stresses exceed “yellow” zone in one or more areas of the piping system, study the deformed shape provided by checkSTRESS for sustained load case in order to understand how the piping responds to its own deadweight. Next, identify pipe locations in the 3D model where the pipe can be vertically supported by the support types listed under Step 4 above. Based on this input, vertically support the piping such that sustained stresses do not exceed “yellow” zone. This step may require the Designer to execute checkSTRESS on the system with several different locations for weight supports.

checkSTRESS automatically sizes variable spring hangers wherever such hangers were located in the 3D model.

In case resting steel supports are selected to provide vertical support for piping under sustained load, it is to be made sure that piping continues to rest on such steel supports even during operating condition (= weight + pressure + thermal) and does not lift off from these supports. If pipe lifts up at any of these resting supports during operating condition, then that support does not carry any pipe weight and hence will not serve its purpose. Similarly, at rod hanger locations, the tendency of piping should be to deform downward for operating load case, so that the rod hangers carry the pipe weight under tension. On the other hand, if pipe lifts up at any of the rod hangers, then that rod hanger goes into compression thereby not carrying the weight of the piping during operating condition. Whether the pipe weight is being carried during operation by resting steel supports and/or rod hangers (both types are mathematically modeled as one-way vertical Limit Stops in checkSTRESS) or whether the pipe lifts up at those support locations is shown in the report titled “Status of Limit Stops – Operating Load”. The goal is to make sure the status is shown as “Reached” at all vertical Limit Stops for Operating Load case.

Step 6: Studying Results for Occasional Load(s)

After arriving at a final layout with an acceptable pipe support scheme under Steps 2 to 5 for thermal and sustained loads, the next task is to protect piping against large horizontal and vertical movements that could occur due to static seismic “g” load and/or response spectrum load. This can be accomplished by replacing some of the weight supports with “integral 2-way vertical and lateral restraints”.

In this regard, review stress contour plot for occasional stresses generated by deadweight, pressure, static seismic “g” load and/or response spectrum load shown in color codes from “blue” to “red” (as in Step 2 above).

The Designer’s goal is to replace some of the weight supports (for example, resting supports) located in the “yellow” to “red” zones with “integral 2-way vertical and lateral supports”, so that stress contour plot for occasional stresses avoids “orange” and “red” zones and remains within “blue to yellow” range.

Step 7: Finalizing 2-way Vertical and Lateral Restraints to withstand Occasional Load(s)

In case occasional stresses exceed “yellow” zone in one or more areas of the piping system, study the deformed shape provided by checkSTRESS for occasional load case(s) in order to understand how the piping responds to static seismic “g” load and/or response spectrum load. Next, identify those weight support locations (for example, resting supports) in the “yellow” to “red” zones where the pipe can also be laterally supported and replace those weight supports with “integral 2-way vertical and lateral restraints”, such that occasional stresses do not exceed “yellow” zone. This step may require the Designer to execute checkSTRESS on the system with several different locations for “integral 2-way vertical and lateral restraints”.

Step 8: Meeting Allowable Loads at Nozzles / Anchors

After locating relevant supports (a) to minimize thermal stresses, (b) to carry weight of the piping during operation, and (c) to withstand static seismic “g” load and/or response spectrum load, the Designer should check the calculated loads at nozzles/anchors in the Support Load Summary. If the calculated loads at nozzles/anchors exceed the corresponding Allowable Loads, by studying the deformed shapes provided by checkSTRESS for different load cases, it is possible to further modify the layout and/or support scheme such that the calculated loads at nozzles/anchors do not exceed the Allowable Loads.

As a minimum, the above said Nozzle Load compliance should be carried out for <u>Operating Load case</u>.

Any such changes made to the layout and/or support scheme at this stage (i.e., at Step 8) should not adversely affect the stresses for thermal, sustained and occasional load cases (i.e. all the 3 stress contour plots should continue to avoid “orange” and “red” zones and remain within “blue to yellow” range). This process may require the Designer to perform several iterations on layout and/or support scheme.

Step 9: Key Results to confirm Validity of Layout with finalized Support Scheme

Designers are to perform Step 1 to Step 8 for all relevant piping systems of the project.

Once the layout and support scheme are finalized for a system, the Designer confirms the validity of that design by submitting key results generated by checkSTRESS as listed below.

a) Ten (10) highest stress ratios and their locations,

b) Equipment nozzle load compliance with allowable loads,

c) Report listing spring sizes, hot loads, cold loads and travel for variable spring hangers sized by checkSTRESS,

d) Status of Piping at resting supports during operation (i.e., is the pipe resting on or lifting off a resting support?),

e) Bill of Materials,

f) Weight and Center of Gravity,

g) Table of Contents, and

h) Relevant stress contour plots and deflected shapes.

Step 10: Export checkSTRESS models to Pipe Stress Software input files

Piping systems, for which the layout and support schemes are finalized, can then be translated into stress input files of the pipe stress software currently covered under the checkSTRESS modules (see Subsection 1.2 above). Pipe stress engineers can then import these stress input files into their pipe stress software and perform detailed analyses and stress report preparation. This eliminates (a) generation of “stress isometric drawings” and (b) re-inputting the data into the pipe stress software.

Pipe stress engineers should check the stress models so sent by Designers and add (wherever required) additional input data into the models such as insulation thickness and density, corrosion allowance and mill tolerance of pipe sections, thermal anchor movements, seismic anchor movements, support conditions such as friction and gap, other occasional loads such as wind and water/steam/fluid hammer, multiple thermal and pressure cases, etc. and perform detailed analyses.

It is most likely that the layout with the support scheme finalized by Designers using checkSTRESS should be able to meet all other pipe stress criteria (for examples, stress compliance for other thermal ranges and occasional loads, leakage checks at flanges, qualification of lug attachments welded to pipes etc.), thereby substantially reducing the number of iterations between stress and layout departments.