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Technical Memorandum

Subject: Stress Analysis of FRP Pipe

Background

The use of formal stress analysis programs to analyze and design FRP piping systems has been employed by piping engineers for a number of years but success has not always been achieved. In many cases when failures occur the blame has been placed on the pipe fabricator for lack of pipe quality or on the contractor for poor installation practices. These may be the cause in some cases but in the analysis of failures we see that 95% of the failures occur in fittings and joints and this indicates that it could be the design of the piping system that is a major cause.

This brief technical note addresses some of the issues we have found when evaluating the use of formal programs when applied to FRP Pipe. While the formal programs are very valuable tools for analyzing and designing high temperature steel pipe they can lead the engineer to believe a design is safe when he finds later that the system has failed. By understanding the limits of formal programs the engineer can avoid some of the pitfalls of the formal analysis.

<u>Formal Pipe Stress Analysis.</u>

A great deal of work has been done to develop various stress programs for analysis of steel pipe used in high temperature piping systems but all of these programs are for isotropic materials. FRP pipe can be analyzed using these formal programs but since FRP pipe and all FRP piping components are anisotropic these programs will not yield accurate results. Understanding the limits of the formal programs is very important because the algorithms used in the analysis do not accommodate antistrophic materials. Some of the different issues are:

1. Steel pipe analysis tends to facilitate free expansion and flexibility. Since FRP has an expansion coefficient that is twice that of steel care must be taken to check movements.
2. Filament wound pipe has different tensile and compressive properties.
3. Each type of pipe, FW, Cast, or Contact Molded, has a wide range of properties that are very different.
4. Fittings such as elbows, tees and branch connections are stress intensified and there are no proven analytical methods other than FEA to evaluate intensification of FRP fittings. Values have never been determined experimentally.
5. Steel joints are not considered in formal steel analysis. FRP joints are the weakest link in an FRP piping system and are also not analyzed by formal programs.

6. FRP fittings are made by various processes and differences in mechanical properties are not considered in formal programs. Each type has a different stiffness which affects flexibility and expansion.
7. FRP pipe subjected to torsion must be analyzed for torsional shear. The torsional properties of FRP pipe have not been investigated.
8. Axial and lateral movements of FRP pipe must be carefully evaluated to insure that the pipe supports do not move past the structural support steel. Since formal programs tend to facilitate free expansion the engineer is cautioned to check movements at each support point.
9. Formal programs will evaluate wind loads and may require guides to limit lateral movements. These guides may cause overstress in fittings that would go undetected unless an additional check to insure maximum bending moments are not exceeded.

There is a major problem with the evaluation of stress concentrations in nonlinear shapes such as fittings and tees. Over many years of testing these stress factors have been determined experimentally for steel pipe but it is a serious mistake to assume that these values are compatible with FRP fittings. Experimental evaluation of FRP fittings would be a monumental task that would be very expensive and would take many years to complete. One FRP pipe fabricator realized the importance of stress intensification at fittings and began a series of tests to determine ultimate and allowable bending stresses on fittings and components. Other companies joined in the effort and began to publish allowable bending moments for various sizes and types of fittings. The stress analysts began to consider these bending moment limits in the design with considerable success.

Formal programs have been a huge benefit for high temperature metal piping but applying these programs to FRP pipe has not been highly successful for reasons stated above. That is not to say that the programs are not useful for analysis but the engineer who may be experienced in steel pipe analysis must be cautioned to understand the limits of formal analysis.

Other Stress Analysis Methods

Hand calculations using structural equations that have been modified for FRP pipe have been successfully used for many years. The following equations apply to any piping system when mechanical properties of the pipe are known. A more detailed discussion and explanation is presented in a technical paper that was presented in 1997 and is attached to this TN.

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[Type text]

ANCHOR LOAD

$$F_A = \underbrace{A_t E_T \Delta T \alpha}_{\text{THERMAL LOAD}} + \underbrace{P A_f}_{\text{PRESSURE LOAD}}$$

WHERE:

α = THERMAL COEFICIENT OF EXPANSION

A_t = CROSS-SECTIONAL AREA, TOTAL WALL, in.²

E_T = CROSS-SECTIONAL AREA, TOTAL WALL, in.²

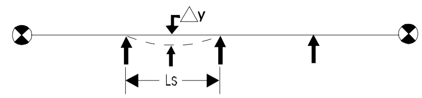
$\Delta T = T_{OP} - T_{INS}$, °F

P = MAXIMUM OPERATING PRESSURE, lb/in.²

A_f = FLOW AREA, = $\frac{\pi D_f^2}{4}$

NOTE: ANCHOR LOAD IS INDEPENDENT OF PIPE LENGTH

FIGURE 2 - Anchor loads



SUPPORT SPAN REQUIREMENTS:

A. DEFLECTION LIMITED, Δy = 1/2 INCH

$$L_s = \sqrt[4]{\frac{460.8\,E\,I}{W}} \bullet \frac{1}{12}$$

B. STRESS LIMITED $\sigma_n = \frac{\sigma_{tu}}{5} - \sigma_p$

$$L_s = \sqrt{\frac{.67\,\sigma_n\,S}{W}}$$

USE SMALLEST VALUE

WHERE:

E = YOUNG'S TENSILE MODULUS AT OPERATING TEMP., lb/in.²

I = MOMENT OF INERTIA, STRUCTURAL WALL, in.⁴

W = WEIGHT/FOOT.PIPE + FLUID, lb/ft.

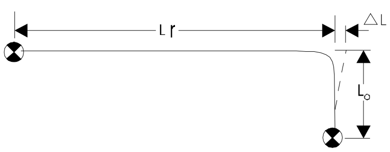
σ_n = NET ALLOWABLE STRESS, lb/in²

σ_{tu} = ULTIMATE TENSILE STRESS, lb/in²

σ_p = PRESSURE STRESS, $\frac{P A_f}{A_t}$

S = SECTION MODULUS, STRUCTURAL WALL, in³

FIGURE 3 - Support Spans.



OFF-SET LEG (L_O) REQUIREMENTS:

A. STRESS LIMITED (CANTILEVER BEAM WITH LOAD AT FREE END)

$$L_O = \sqrt{\frac{3\Delta L\,E\,D_O}{\sigma_n}} \bullet \frac{1}{12}$$

B. BENDING MOMENT LIMITED

$$L_O = \sqrt{\frac{6\Delta L\,E\,I}{M_{MAX}}} \bullet \frac{1}{12}$$

USE LARGEST VALUE

WHERE:

L_r = LONGEST RUN INTO ELBOW. ft.

ΔL = THERMAL EXPANSION = $L_r\ \Delta T\ \alpha$, in.

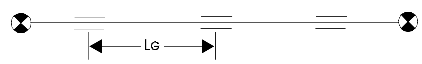
E = YOUNG'S TENSILE MODULUS AT OPERATING TEMP., lb/in.²

D_O = PIPE OUTSIDE DIAMETER, in

σ_n = NET ALLOWABLE STRESS

M_{MAX}= MAXIMUM ALLOWABLE BENDING MOMENT, in.-lb (MANUFACTURER'S TEST DATA)

FIGURE 4 - Offsets



GUIDE SPACING REQUIREMENTS:

$$L_G = \sqrt{\frac{\Pi^2}{A_t\,\alpha\,\Delta T\ (2)}} \bullet \frac{1}{12}$$

EULER EQUATION FOR PIN ENDED COLUMNS

WHERE:

L_G = GUIDE SPACING ft.

I = MOMENT OF INERTIA, STRUCTURAL WALL, in.⁴

A_t = CROSS-SECTIONAL AREA, TOTAL WALL, in.²

W = COEFFICIENT OF EXPANSION, in./in.- F °

$\Delta T = T_{OP} - T_{INS}$, °F

(2) = FACTOR FOR ECCENTRICITY OF LOADING OR DEVIATION FROM PIN COLUMN

FIGURE 5 - Guide Spacing