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Technical Note

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Subject: Designing For Expansion



During the past few years we have seen multiple failures in FRP piping systems and have been asked to investigate the cause. In every case we have found overwhelming evidence that the cause is a lack of understanding of the effects of uncontrolled expansion by the designer. FRP pipe has an expansion of at least twice that of metallic pipe and requires a close review of pipe movement. The following pictures indicate how expansion affects the pipe support and how pipe can be severely overstressed or damaged by excessive support displacement. **Uncontrolled expansion of FRP pipe is the major cause of failure in FRP piping systems.**

Discussion

Designing for Expansion- History of expansion problems in FRP pipe.

In the 1970's, as the use of FRP was becoming the material of choice for process pipe in corrosion applications in chemical and pulp and paper piping systems, a series of major failures raised serious questions regarding long term performance. FRP was fast becoming known as highly unreliable. Many plants had invested heavily in FRP piping systems because it offered a long term solution to corrosion and so a very intense investigation was begun to determine the cause of widespread failures. Many were occurring during startup in plants in various sites before the plants could be put in operation.

The result of the investigation has been presented in many technical articles and papers but in summary the findings are:

- Piping failures were found to occur at fittings and joints in almost 100% of the cases studied. Piping never failed-- only the joints or connections.
- Joint failures were found to be caused by axial tension or excessive bending.

- Uncontrolled expansion causes stresses in fittings and joints to exceed ultimate stress.
- FRP pipe must be anchored to limit or control expansion to insure a successful piping system.
- Supports for FRP pipe must consider the unique properties of FRP pipe.

As a result of these findings one major chemical company, a large user of FRP pipe, elected to adopt a method of design that mandated all systems be **fully anchored**. Anchors were placed on each side of every change in direction and the pipe running between anchors was guided to prevent lateral buckling. Loads were calculated for each anchor and steel was erected to take the loads to ground without excessive deflections. When the plant was completed all piping was hydro tested to 1-1/2 times the rated pressure (225 psi) and held for 8 hours to check for leaks. Not a single leak was found and there were no piping failures. This was the first time a plant had started up without failure or leaks.

This **fully anchored** design method was adopted plant wide and has been a model for FRP success. The piping systems in this plant are operating at the upper limits of FRP. The company has multiple sites and is one of the major users of FRP pipe.

Pros and Cons for fully **anchored** system:

PRO

- Pipe operates at minimum stress providing maximum service life.
- Stress analysis is simple, quick and proven to be successful. Minimum engineering cost.
- Support design is straight forward allowing designers with little stress experience to design the piping layout and supports.

CON

- Fully anchored system requires additional support steel to handle anchor load.
- Added expense for shear collars at each anchor.
- Designer must consider cold conditions for pipe contractions.
- Alternate supports must be guided.
- Designer must have experience in anchoring of FRP pipe.

Advantages and disadvantages must be weighed against initial cost versus the cost of pipe failures. Having a plant shut down due to pipe failure and the subsequent cost of replacement or repair is huge economic penalty and should encourage the owner to consider mandating a restrained piping system. FRP pipe does not behave like steel pipe and requires special attention by the engineer or designer.

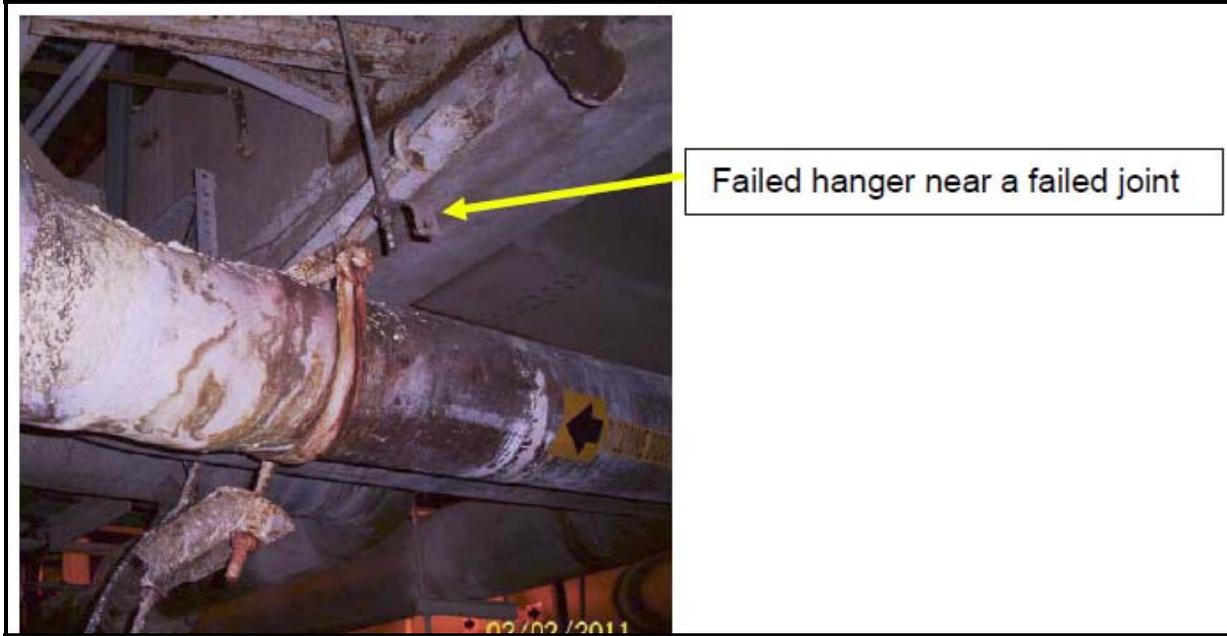
In many cases a fully anchored system is not economically practical but consideration must be given to using anchors to prevent excessive thermal expansion. A freely expanding piping system has the highest potential for failure. The following pictures are examples of free expansion.



When the support moves off of the support steel a bending stress is added to the pipe.



This process line has lost many of the clevis hangers due to excessive pipe expansion and results in severe overload of remaining hangers and high local stress on the pipe.



Failed hanger near a failed joint

This joint has been repaired several times without considering the cause.



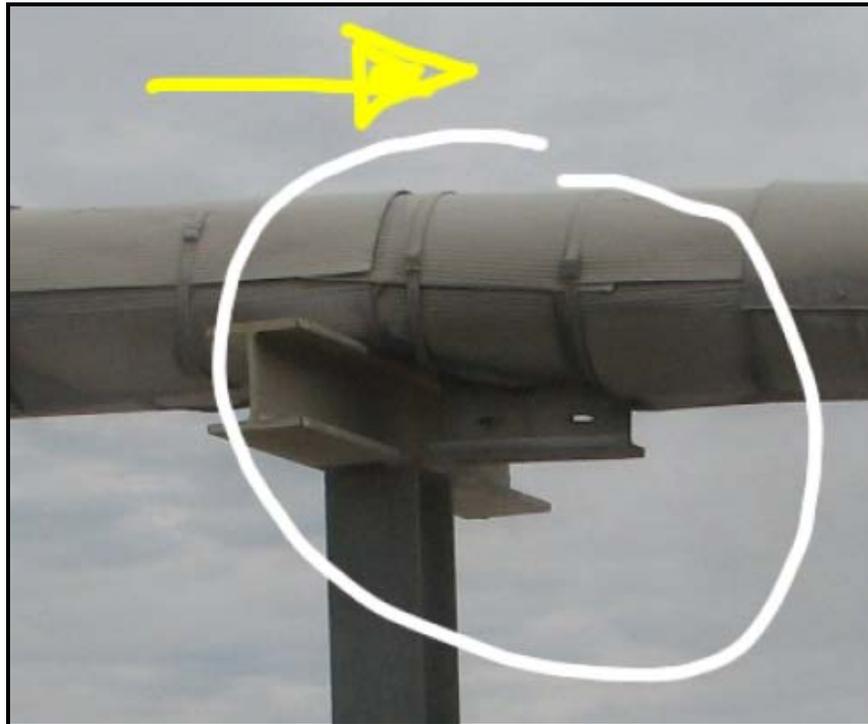
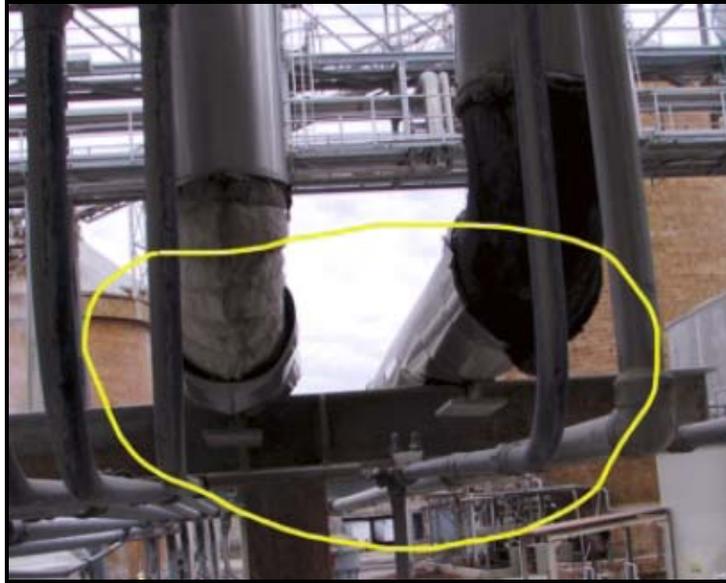
This photo depicts support failures that are caused by uncontrolled expansion and resulting over load and over stress. This entire process plant was designed without considering the effects of expansion and as a result the repair and pipe replacement have been continuous for more than 10 years since start up. The pipe is in such poor condition today only a complete replacement will solve the problem.



High local stress due to support displacement.



High local load and torsional moment (local stress) caused by tipped support.



Excessive movement has locked the support and support steel. When the system is shut down the support becomes a restraint and pipe is under high stress.



Excessive expansion has moved supports off of support steel and allows the pipe to be overstressed and damaged. Pipe has dropped 6"-7", insulation has been destroyed, and pipe rests on steel beam.



This is a typical condition throughout the process plant and the result has been a 15 to 20 year reduction in the service life of the FRP pipe. Maintenance has been constant since the plant was started more than 10 years ago.



Excessive pipe movement allowed support to fall from bridge. Cause of the black areas on slides is unknown.



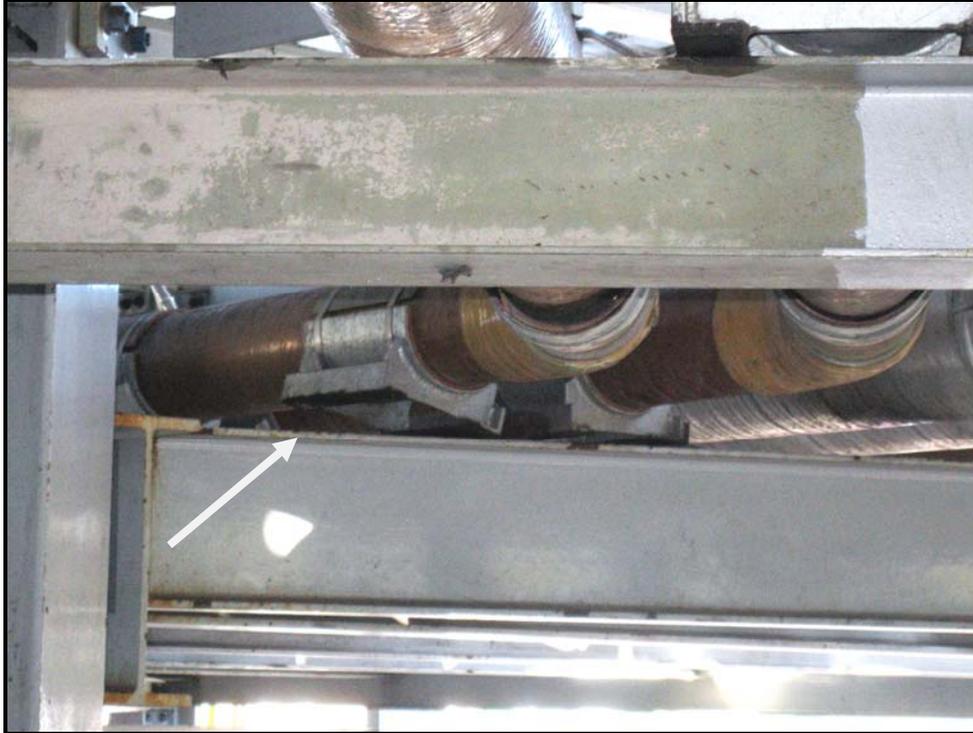
Uncontrolled pipe expansion - Supports moving off of support steel.



Different support types at same location



Support/ pipe movement exceeds design.



Extreme pipe expansion beyond design. Extreme stress on elbow and pipe due to torsion and loss of support.

Design Approach to Control Expansion

The method of design preferred by many engineering firms is an *anchor-to-anchor design*. This design method can be economical and offers many advantages. The *anchor-to-anchor* system is more rigid and less susceptible to damage due to uncontrolled thermal and pressure expansion as well as dynamic loading. This system provides a means for controlling expansion (thermal and pressure), thereby reducing the length of offsets and eliminating the need for expansion joints. Anchors are placed on either side of every change in pipe direction and as near to the fitting as possible. The amount of structural steel required to absorb the loads imposed on the anchors can be minimized by keeping the pipe elevation (BOP) close to the steel and by utilizing tension members between anchors. It is important to recognize that the pipe must be guided between anchors to prevent buckling. In cases where there are long straight runs, anchors should be placed no more than 150 to 200 feet apart.

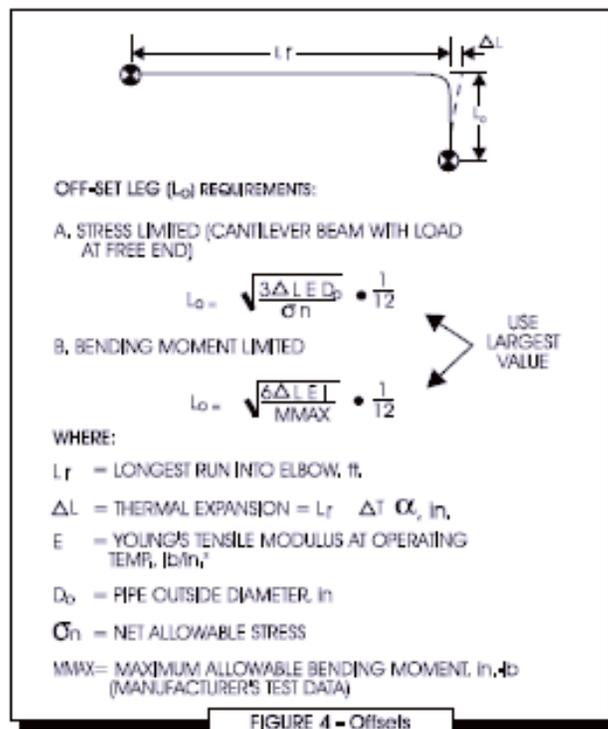
A less conservative approach involves a design where anchors are only used to control excessive expansion and is referred to as the ***semi-anchored design***. This design has been successful but requires careful attention to the design of off sets or turns, branches and fittings. Any piping components such as valves, flow meters or flow control components need to be checked for load limits. Any reducers in a piping system also need to be analyzed for load capability.

In piping segments where anchoring is feasible the anchored system is preferred but a combination of the two methods offers a more economical and can be successfully combined.

Why Use an Anchored approach?

Metallic Pipe. - Designers and stress analysts trained in the design of metallic pipe understand that anytime anchors are placed in a piping system to control expansion there is an increase in stress somewhere in the system. It is normal practice to add anchors only when it is necessary to restrict deflections due to expansion, or when controlling expansion to insure proper operation of expansion joints or expansion loops. Sometimes anchors are necessary to attenuate fluid shock or fluid dynamics but these must be carefully selected and placed.

FRP Pipe - FRP pipe requires a different approach because thermal expansion is twice as large as in metallic pipe. ***This increase in expansion causes higher stresses in the fittings and pipe when there is a change in direction*** and since it has been well documented that almost all failures occur at connections or joints it is important that expansion toward any turns be minimized. This can be accomplished by anchoring the pipe prior to the turn. Figure 4 illustrates the approach to the design of FRP off sets.



FRP pipe connections are most often the point of failure in piping systems simply because there is a stress concentration at the connection. The joint is designed to carry the axial thrust load caused by pressure and is capable of carrying the circumferential load (hoop) due to pressure but these connections are susceptible to very high bending loads at support points and at off sets and are usually the points of failure. In long

straight runs of pipe the connections must be capable of carrying the pressure load and bending loads and at turns where connections may see increased loading due to bending and torsion. These are very seldom a problem with metallic pipe but are critical issues with FRP pipe.

It has been shown that 95% of all FRP pipe failures occur at connections and when thermal expansion is controlled by anchoring the failures are all but completely eliminated. To illustrate, if we apply the anchored approach to long runs of pipe by anchoring at each end we see that the pipe located between the anchors are subjected to a compressive stress thereby relieving the joints of axial pressure stress. The total stress in the pipe is minimized and the joints are subjected to hoop stress only. The resulting compressive stress on the pipe and joints is less than 10% of ultimate whereas an unanchored pipe system may be operating at stresses at or near ultimate.

In more than 2000 FRP pipe projects where the anchored approach is used, the service life has been increased to the point where FRP reaches its full potential for corrosive environments. Thirty to forty years of continuous service without failure is the norm.

Fluid Shock and Dynamics. - Piping systems can be destroyed or damaged by high dynamic stress. A visit to a paper mill where intermittent blow down digesters are in operation will illustrate the worst in steel pipe dynamics and only careful placement of anchors and guides will prevent blow out of the systems. Extra heavy wall pipe reduces the effect but the pipe must be restrained to safely operate the system.

Dynamics are much more critical an issue when designing FRP systems. The weaker joints must be realized to be a critical problem but the forces placed on an FRP system create very large momentary stresses when the pipe is displaced by dynamic forces. FRP pipe weighs less than 25% of metallic pipe and so the fluid mass tends to lift and displace the light pipe mass. FRP pipe offers little resistance to these forces. By anchoring the pipe these dynamic forces can be absorbed at anchor points before the pipe can be damaged. When the anchored approach is used dynamic forces do not damage the pipe and joints are protected.

Summary

1. History has shown that a FRP piping system that has been designed using steel pipe methods of analysis is likely to fail because thermal expansion is not a primary concern. In FRP design expansion is a critical concern and when uncontrolled will result in failure. Piping and duct systems require the same degree of concern and without thermal expansion control the system service life is measurably reduced.
2. Control of expansion is not an option when designing FRP piping systems because failure is not an option. Engineers must learn to employ anchors if a successful design is a goal. Formal stress programs which are designed to analyze high temperature metallic piping systems will not insure a successful FRP piping design. FRP requires a much different approach.

3. Pipe supports, anchors and guides for FRP pipe must be designed to allow the pipe to operate without adding large local stresses to the pipe. Elastomeric liners are a must but do not permit steel pipe support standards to be substituted for FRP pipe support standards.
4. Design of auxiliary steel plays a more critical part in the design of FRP pipe and must be designed in concert with the piping layout and support requirements.

This technical note is the result of a request to analyze the cause of a piping failure that occurred in a plant that seemed to be similar to several other plant piping failures. Some historical data was added that corroborates the conclusions that uncontrolled expansion is a serious matter and has been the primary cause of many failures.

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