Technical Proceedings
33rd Annual Conference

SPI REINFORCED PLASTICS/ COMPOSITES INSTITUTE

REINFORCED PLASTICS– CONTACT '78

February 7-10, 1978
Washington. D. C.

THE SOCIETY OF THE PLASTCS INDUSTRY, INC.

PROCEEDINGS

of the

THIRTY-THIRD ANNUAL CONFERENCE

REINFORCED PLASTICS/COMPOSITES INSTITUTE

Washington, D.C.

February 7, 8, 9 and 10, 1978

(A special DESIGN ENGINEERING SEMINAR preceded the Conference on February 6, 1978)

SPI

The Society of the Plastics Industry, Inc.

355 Lexington Avenue
New York, New York 10017

The 33rd Annual Conference
of the
Reinforced Plastics/Composites Institute
is dedicated to
the late
CLARE E. BACON
a founder of the Institute and
posthumous recipient of the
Executive Award

ORDER OF PRESENTATION

33rd Annual Technical Conference, 1978
Reinforced Plastics/Composites Institute
The Society of the Plastics Industry, Inc.

THE USE OF CHEMICALLY RESISTANT FRP EQUIPMENT FOR POLLUTION CONTROL —A CASE HISTORY

by

GEORGE T. YOUNGBLOOD*

ABSTRACT

This paper traces the history of an FRP (fiberglass reinforced plastic) scrubber system for an incinerator from a realization of need through justification and design to performance in the field. Descriptions of the expected corrosive media and physical conditions, cost comparisons with alternative materials, corrosion resistance and physical testing, and related case histories are included. FRP was selected on the basis of demonstrated previous experience in related service, corrosion and physical testing, and economic considerations. Satisfactory field experience with the scrubber confirms that FRP was the proper choice.

INTRODUCTION

The use of FRP equipment in processing, transmission, and storage of corrosive chemicals is well established and adequately documented. More recently, the protection of our environment has brought new challenges and opportunities to FRP. Much larger volumes of gases, liquids, and solids must be handled; more complex mixtures, many of which contain organic substances, are encountered; and the neutralization, extraction, and recovery processes involved must be essentially quantitative. The high cost of environmental protection demands that the equipment design and material selection be optimized; the high price of failure in terms of environmental fouling, product loss, and potential legal liability demand higher and higher levels of confidence in FRP.

The use of FRP equipment in pollution prevention and control has been reviewed several times at this conference[1,2,3] and many times elsewhere. What has not been adequately covered are the decisions' development which lead to the selection or rejection of FRP; the roles and interaction of the many participants in the decision process; and an analysis of the technical, economic, and practical aspects of the alternatives. This paper, which is a history of a scrubber system, attempts to cover these effects and show how one company arrived at the decision to use FRP in a critical application.

THE PROBLEM

Huge expansions at Shell's Chemical Plant at Geismar, Louisiana and its chemical plant-refinery complexes at Norco, Louisiana and Deer Park, Texas made necessary a new approach to effluent treatment. The then existing facilities would have been totally inadequate to cope with the greatly increased production of aqueous and solid waste. Geismar acted first. Engineers of Shell and of Rust Engineering put together a unique design which called for processing the plant's total effluent, including rain water run-off, through a huge biotreater. In this system, plant wastes are reduced to a clean water stream which is returned to the Mississippi River and to a sludge which is deposited in an approved landfill on company property. Similar systems were installed at the Houston and Norco Manufacturing Complexes. At Houston, as at Geismar, the sludge is deposited in a landfill. At Norco, the unavailability of land suitable for a landfill on company property ruled out this means of solid disposal and Shell and Rust Engineering faced a tough disposal problem.

After reviewing the alternative of hauling away the sludge, they opted for incineration. Rust, who had the overall responsibility for the effluent treater at Norco, engaged the services of BSP Division of Envirotech of Belmont, California, for the incinerator project, and Envirotech, in turn, contracted Ametek of Durham, North Carolina, to handle the disposal of the off-gases of the incinerator.

The sludge, containing organic chlorides, would as a result of the incineration yield a mixture of acidic materials, the most abundant being hydrogen chloride. To handle this corrosive stream, Ametek proposed a system with a Hastelloy C precooler followed by a scrubber, also of Hastelloy C. The construction of these items was contracted to Envirofab of Detroit. Maurice Knight of Akron lined the precooler with acid brick. Hastelloy C expansion joints were supplied by V. F. Bellows of Santee, California.

At this point in the process, in-line demisters were required because the temperature fell to the condensation point, 215°F, and caustic would be injected. Highly corrosion-resistant materials were needed for these demisters. Hastelloy C could be used, but FRP could be obtained for only 20% to 25% of the cost of fabricated Hastelloy C. The estimates for FRP Construction of this type varied from $3 to $4 per fabricated pound; comparable estimates for Hastelloy C were $15 to $16. However, the Shell engineers had to be convinced of its performance. Failure in this part of the process would cripple the entire complex in just a few days. However, the cost of Hastelloy C demisters 11 feet in diameter by 33 feet in length was sufficient incentive for FRP to be considered. A search of related case histories of FRP in similar service was initiated.

CASE HISTORIES

For several years, organic chlorine wastes have been incinerated at Norco and at Houston. At Norco, the scrubbers were constructed of FRP based on a high temperature vinyl ester resin (Figure 1). The basic operation is caustic neutralization of HC1 and chlorine at 180-200°F. Depending upon the composition of the waste stream, the pH inside the scrubber varied from 10 down to 3. At the lower pH levels caused by over-chlorination, excessive attack on the FRP was experienced, presumably caused by "nascent" or atomic chlorine. The scrubber had to be relined after nine months' service. A replacement scrubber of a bisphenol A fumarate polyester was installed with similar results.

At first look, this would seem to be a failure or a misapplication of FRP. Several of the most noted fabricators using the leading high temperature, corrosion resistant resins had failed to produce a scrubber that would last a year. But what were the alternatives? Hastelloy C in a fan downstream from this scrubber failed in even less time. The only practical solution is to alternate the FRP scrubbers and to reline them as long as they are structurally sound. FRP may not be the ideal solution, but it is a practical solution. In this application at least, FRP has earned the right to be less than perfect and our engineers are learning how to use it by providing for its weaknesses and capitalizing on its unique benefits.

Other FRP structures offered more encouragement. The demisters and the stack of the chlorine incinerator at Shell's Norco plant were constructed of vinyl ester FRP. They are still in excellent condition after serving without difficulty for three years.

At the same location, a chlorine absorber made from vinyl ester has successfully operated at 150°F for five years. The related FRP

*Shell Development Company
3333 Highway 6
South Houston, TX 77077

piping and run down vessels which handle the resulting sodium hypochlorite were also made from vinyl ester.

Shell Chemical's Geismar, Louisiana, plant effluent treater contains many excellent examples of FRP for pollution control, beginning with waste accumulation in the huge concrete sump which is lined with epoxy and ending up in a 24-inch vinyl ester flow line which carries cleaned water to the Mississippi River. Almost two miles of epoxy and vinyl ester pipe ranging in sizes from 2 inches to 36 inches in diameter are used to transport streams in this system. The larger vinyl ester pipe shown in Figure 2 carries the collected waste to separation and neutralization vessels; the smaller vinyl ester pipe returns the clean water to the river. In the biotreater section, epoxy based FRP pipe handles the streams rich in organic substances. A vinyl ester tank stores phosphoric acid, an essential nutrient for the bacterial microorganisms used in the biotreater.

The HC1 absorption system at Geismar uses a furan based absorber (Figure 3), vinyl ester tanks, piping, and grating, and bisphenol A fumarate storage tanks (Figure 4).

Vinyl Ester FRP equipment is also providing excellent service in the chlorine incinerator and biotreater systems at the Deer Park Plant. The excess chlorine from several processes is incinerated, and the resulting HC1 absorbed in a vinyl ester FRP vessel. The gases from the absorber run through a series of vinyl ester demisters and piping (Figure 5) and the collected acid and organic material from the demister is sent to the "rock box" through filament wound epoxy pipe. The rock box (Figure 6) is a concrete tank lined with a vinyl ester fiber glass mat composite. The neutralized waste is sent to the collection pond where it is combined with chemical plant waste and rain run-off.

The effluent composite is first subjected to a two-stage phase separation. In the first, FRP corrugated plate interceptors (Figure 7) remove oil and particulate matter down to a level of 20 to 30 ppm. The oil is returned to the processes, the solid to a landfill, and the water phase is sent to a dissolved air flotation separator where most of the remaining oil and solids are removed. The aqueous phase is next sent to the first biotreater—the trickling filter—which consists of a bed of rocks coated with a biological material and which removes all solid particles and cleans up some of the simple organic molecules.

The solids are sent to the landfill and the liquid subjected to a second biological treatment—an aeration basin with activated sludge.

The aerators (75 HP) generate intense vibrations, which require highly resilient structures with good chemical resistance. Vinyl ester FRP bridges (Figure 8) are used because less expensive resins could not take the constant vibrations of the aerators although they may have been sufficiently resistant. An FRP tank stores the 35% phosphoric acid which is added along with ammonia as a nutrient for the micro-organisms.

Shell's Denver plant also has a chlorine incinerator and scrubber system but they differ in design and materials of construction. The scrubber is a CPVC-lined carbon steel vessel with demisters, two large vinyl ester based FRP induced draft fans, and a stack, also of vinyl ester.

There is, of course, extensive use of FRP-based equipment outside of Shell plants, but these were the most convincing, since inquiring Shell engineers could talk directly and candidly with experienced Shell engineers. The confidence which was built upon these successful case histories played a major role in the decision to use FRP demisters in the new sludge incinerator project at the Norco complex.

RESIN SELECTION

The case histories cited used many corrosion resistant polyesters and vinyl esters, e.g., EPOCRYL Resins 321, 322, and 480, DERAKANE(R)[a] Resins 411-C-45 and 470, and ATLAC(R)[b] 382-05. With the noted exception of the chlorine absorber in the Norco chlorine incineration unit, all of this equipment has performed well, with no repair since installation. Which of these excellent resins should be used for the high temperature sludge incinerator demisters? The operating temperature was expected to be 215°F and the environment was defined as HCl with small to trace amounts of organic acids and other organic materials. Published literature of the resin manufacturers and our own comparative corrosion testing indicated that the high heat resistant vinyl ester resins would be the most promising resins for testing. On the basis of direct testing in HC1 and aliphatic and aromatic halogen compounds, EPOCRYL Resin 480 was selected. The pertinent chemical resistance data of the resin in these specific tests are summarized in Table 1.

Ametek arranged for the construction by candidate fabricators of specimens using a laminate construction designed from basic engineering properties of the resin. Physical testing of these more realistic laminates at elevated temperatures was carried out and again EPOCRYL Resin 480 produced the best overall results. (See Table 2 for a summary of the heat resistance data for EPOCRYL Resin 480.)

SELECTION OF THE FABRICATOR

The successful case histories cites involved equipment made by the fabricators listed in Table 3.

Ametek received bids in the normal fashion and on the basis of normal competitive bidding, R.L. Industries were awarded the contract for the FRP demisters and related equipment.

CONSTRUCTION, SHIPPING, INSTALLATION, AND SERVICE

The FRP demisters were constructed at R.L. Industries in Miamitown, Ohio, and inspected by Shell engineers. On the basis of this inspection and a final hydrostatic test, the equipment was shipped via truck to the Norco plant and installed under the supervision of Rust Engineering and the Shell project engineers. In October of 1977, the incinerator was put into operation and the FRP demisters began to carry out their designed functions.

SUMMARY

FRP scrubber equipment based upon a high heat resistant vinyl ester resin was selected for a critical corrosion problem area on the basis of previous experience, chemical and physical testing, and economic considerations.

CONCLUSION

FRP has served well in environmental protection and pollution abatement programs in Shell plants and refineries. Several other Shell plants are now installing the total effluent treatment concept. This concept is the result of close cooperation between the user company and the construction and engineering firms. Factual technical exchange between material specialists, design engineers, equipment designers, and FRP fabricators, inspectors, and users contributes heavily to the success of this material of construction in corrosion control, not only in chemical and petrochemical plants but in protection of our environment as well.

ACKNOWLEDGEMENTS

The author expresses appreciation to Mr. M.B. Launikitis of Shell Chemical Company, Mr. W.B. Breitigam and Mr. R.C. Allen of Shell

---

[a]Trademark, Dow Chemical Company
[b]Trademark, ICI, United States

Development Company for their assistance with the technical background of the paper; to Mr. J.L. Baker and Mr. C.L. Wollenweber of Shell Oil Co., Engineering Department for their contributions of end use case histories; to Mr. R.L. Linneman of R.L. Industries for fabrication information; Mr. Jack Gallagher of Ametek for engineering background; Mr. Mark Helm and Mr. Don Barker of BSP Division of Envirotech for information on the incinerator project and to Mr. Elmer Matthews of Rust Engineering for providing the overview of the Effluent Treater System described.

REFERENCES

1. The Important Role of Reinforced Polyester in Pollution Control, R.H. Varland and D.M. Longenecker, 27th Annual Conference of the Reinforced Plastics/Composites Division of the SPI (7-E), Washington, D.C. 1972.

2. Reinforced Plastics—The Bridge to Low Cost Pollution Control, R.F. Stavinoka, T.F. Anderson, and David L. Russel, 29th Annual Conference of the Reinforced Plastics/Composites Division of the SPI (2-E), Washington, D.C. 1974.

3. End-Use Performance Standards in Water/Waste-Water Market: A Marketing Key to Productive Growth, Douglas S. Barno, 32nd Annual Conference of the Reinforced Plastics/Composites Division of the SPI (5-B), Washington, D.C. 1976

GEORGE T. YOUNGBLOOD

George Youngblood is a native of South Carolina. He attended Clemson University graduating with a BS degree in chemistry in 1953. This was followed by Graduate School at Duke University from which he received the AM degree in 1956 and the PhD degree in 1957.

In late 1956, George joined Shell Chemical Company in their Houston Research Laboratory and worked on insecticides, resins and plastics. In 1963, he was assigned to Shell's corporate offices where he was responsible for product development and then market development of new resins. In these capacities he worked with epoxy resins, foams and vinyl ester resins. Since late 1976 he has been assigned to Shell Development Company where he is responsible for Shell's resin literature.

Table 1

Chemical Resistance of EPOCRYL Resin 480
One-Year Exposure Data with ASTM C-581 Test Laminates

Environment	15% HCl	15% HCl	Chlorobenzene	Perchloroethylene
Temperature, °F	150	210	77	77
Weight change, %	0.8	1.0	0.5	0.2
Barcol hardness, % retention	83	65	79	88
Flexural strength, % retention	100	85	100	100
Flexural modulus, % retention	100	82	96	100

Table 2

Elevated Temperature Properties of EPOCRYL Resin 480

Laminate thickness, inch, nominal	0.5
Laminate construction[a]	V/M/M/M/WR/M/WR/M/WR/M/WR/M/M
Glass content, %w	41.1
Strength properties, psi	
Flexural @ 77°F	28,000
Flexural @ 215°F	20,400
Flexural @ 250°F	12,200
Flexural @ 300°F	3,660
Moduli, psi	
Flexural @ 77°F	1.2×10^6
Flexural @ 215°F	0.86×10^6
Flexural @ 250°F	0.63×10^6
Flexural @ 300°F	0.25×10^6
Tensile @ 215°F	1.18×10^6

[a]V = 10 mil C-glass veil

M = 1.5 oz. chopped strand mat

WR = 24 oz. woven roving

Table 3

Fabricators of Cited Equipment Used By Shell In Pollution Control

1. Ameron (epoxy pipe)
2. Barthel (vinyl ester pipe)
3. Beetle-Justin (vinyl ester and bisphenol A fumarate tanks and scrubbers)
4. Ceilcote (vinyl ester tanks and tank linings)
5. Composites Technology (vinyl ester bridge)
6. Dart Industries - Heil Division (vinyl ester vents, corrugated plate interceptors)
7. Ershigs (vinyl ester scrubbers)
8. Fibercast (vinyl ester pipe and tanks)
9. Fibergrate (vinyl ester grating)
10. I. W. Industries (vinyl ester tank linings)
11. Mesa Fiberglass (vinyl ester stack)
12. Owens-Corning (vinyl ester and bisphenol A tanks)
13. R. L. Industries (vinyl ester tanks)
14. Wallace Murray (vinyl ester scrubbers and tanks)

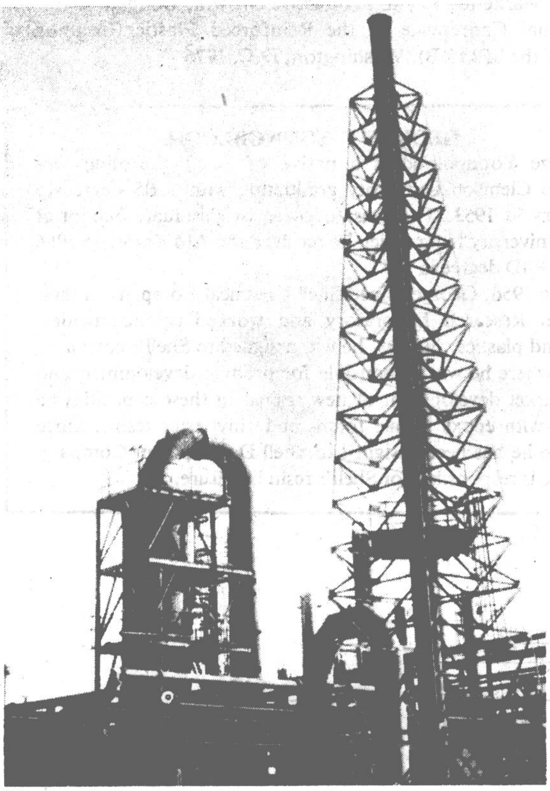


Fig. 1. Vinyl ester scrubber system

Fig. 2. Vinyl ester filament wound pipe 24" and 36" diameters

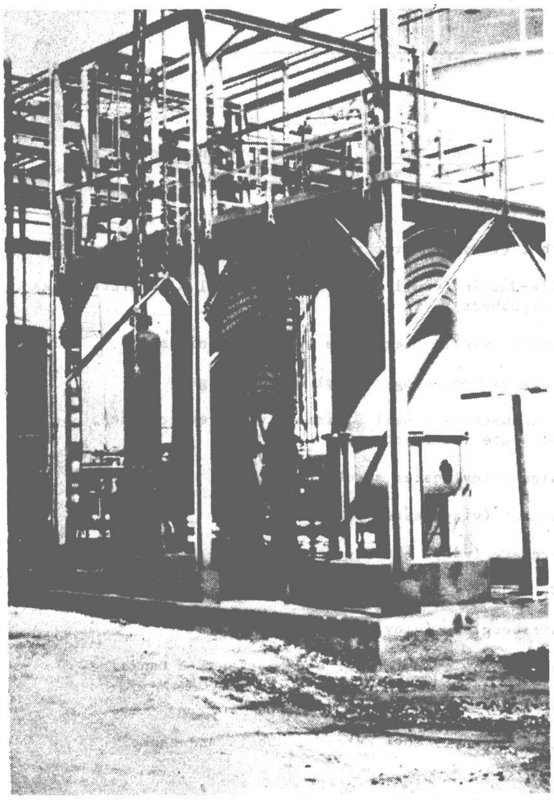


Fig. 3. HCl absorber system, furan based absorber and vinyl ester tank, pipe, and grating

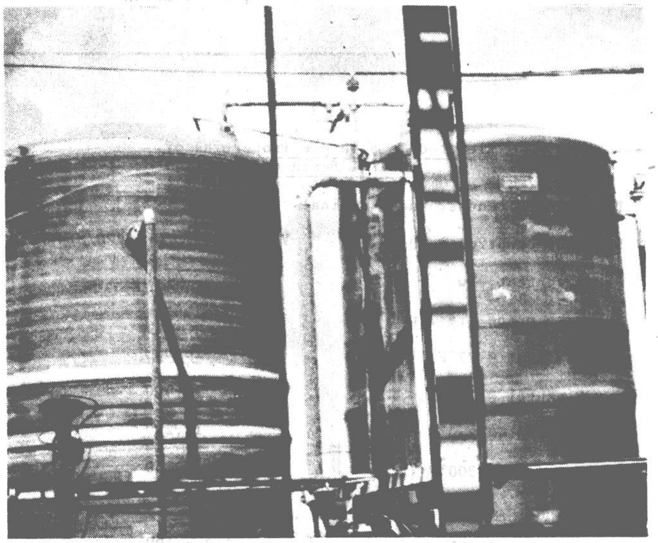


Fig. 4. Vinyl ester and bisphenol—A fumarate storage tank for 30% HCl at ambient conditions

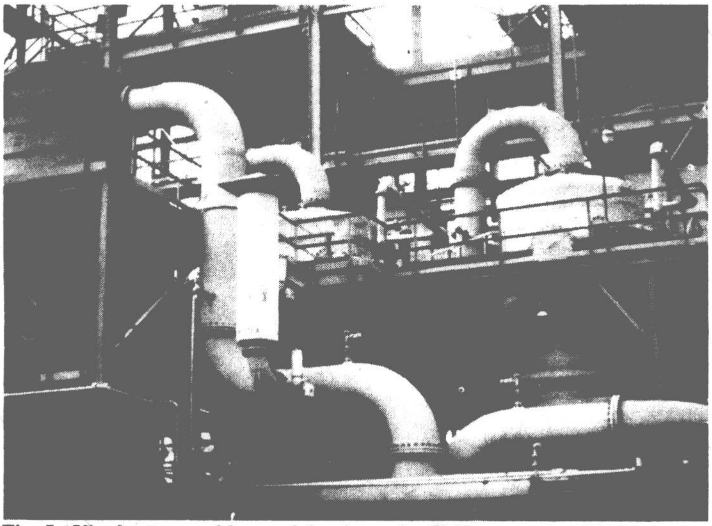


Fig. 5. Vinyl ester scrubber and demisters for HCl removal at 165°F

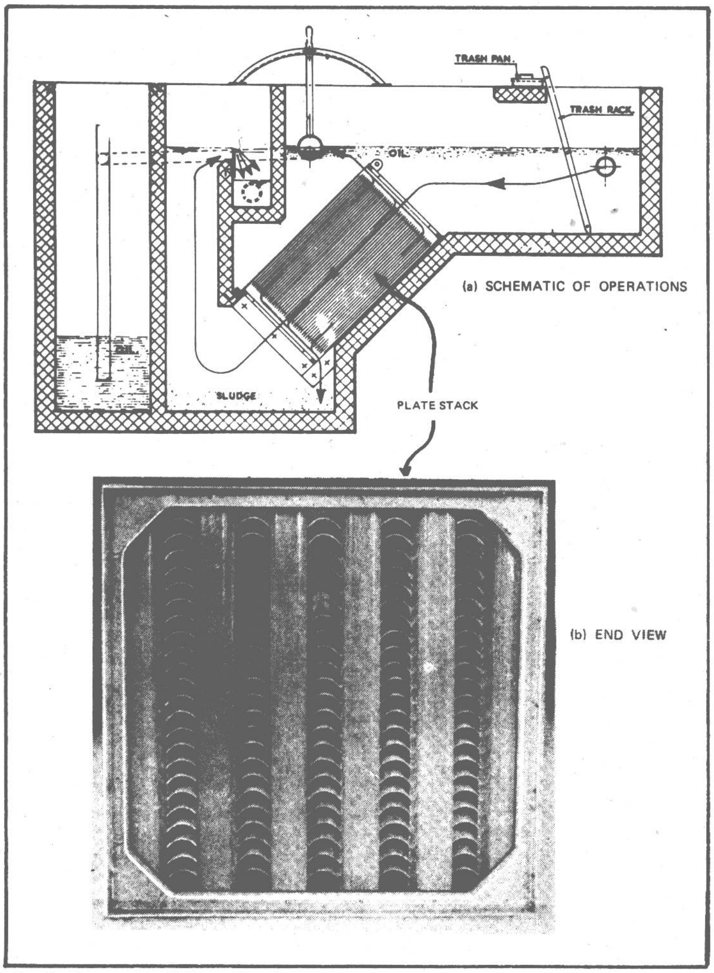


Fig. 7. Corrugated Plate Interceptor

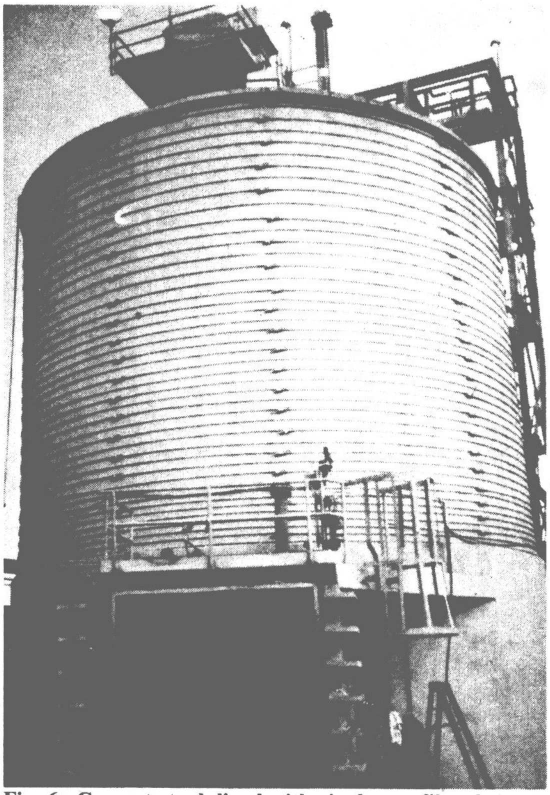


Fig. 6. Concrete tank lined with vinyl ester fiberglass mat lining for plant effluent neutralization

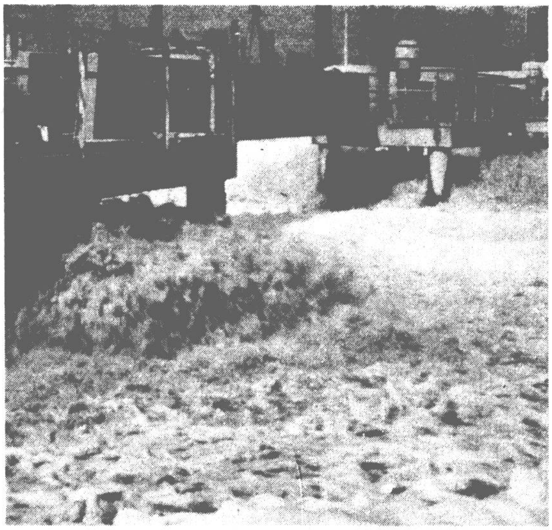


Fig. 8. Vinyl ester FRP bridges in aeration pond

33rd Annual Technical Conference, 1978
Reinforced Plastics/Composites Institute
The Society of the Plastics Industry, Inc.

DESIGN FOR RELIABILITY IN LARGE FIBER REINFORCED PLASTIC STRUCTURES

by

WINSTON J. RENOUD, OTTO H. FENNER and RICHARD J. LEWANDOWSKI*

ABSTRACT

The use of Fiber Reinforced Plastics (FRP) in increasingly complex industrial applications, demands design techniques which produce highly reliable equipment. There are many areas of variation between FRP and other materials of construction, and they must be carefully considered in equipment design. This paper will briefly consider such variations and ways of using them as valuable tools in design. Also, there will be discussion of how advanced design tools, which accurately account for these variations, allow the design of large FRP industrial equipment.

INTRODUCTION

Fiber Reinforced Plastics offer great advantages when used in custom industrial equipment. Considering its light weight, flexibility in construction, and high corrosion resistance FRP is a premium material from which to build cost effective and complex corrosion resistant equipment. FRP offers the process engineer and plant designer the potential for new, highly profitable, low maintenance processes and plants not previously possible.

The latent potential possible by the marriage of the unusual attributes of FRP and new, highly efficient chemical processes has only slightly been tapped. The key to future creative applications is better understanding of FRP and its attributes by process and plant designers.

This paper will briefly discuss the basic new areas of consideration and variation between FRP and other non-composite materials of construction. Next, the application of this material to tall slender structures will illustrate how more advanced design techniques allow more advanced and reliable equipment applications. This discussion should offer a first step in understanding the basic engineering and design nature of FRP and its proper application to advanced industrial equipment.

BASIC NEW AREAS OF DESIGN EMPHASIS FOR FRP COMPARED TO OTHER MATERIALS

There are eight basic areas of special consideration and variation between FRP and other materials of construction. These are very complex and significantly effect equipment design, but the limitations of this paper allow them to be discussed only briefly. Also, to keep the scope of this paper from being too broad, we will focus only on primarily variations between FRP and metals. Some of the characteristics of FRP will appear as liabilities, when, in fact, with the use of new design approaches, they are profound assets. Design with the use of composites will allow new freedoms for fighting corrosion with new, highly efficient FRP equipment.

*Fiberglass Structural Engineering
486 W. Lake Samish Dr.,
Bellingham, Washington 98225

The first area of consideration between FRP and metals is that with industrially produced FRP material, the thicknesses and physical properties will vary significantly throughout a piece of FRP equipment as a result of variation in materials and production. With metals a designer can be assured that there will be only a few percent variation at most in physical properties between the mil spec and the actual metal from which a vessel will be produced. Thickness in metals will normally vary less than one percent from nominal. With FRP thicknesses may be up to 20%, but not greater than 1/8" over or under the specified thickness (PS 15-69). The actual physical properties for the same type of construction in the same vessel may vary 10-20% from spot to spot throughout the vessel.

These variations are caused by two basic sources. The first is that the FRP material is actually produced as the equipment is being formed. Because of the many variables a plastician must control during fabircation, skill in wall thickness control and in consistently producing high quality laminates demands a high degree of experience. Where metals rely upon machines for the major portion of their materials consistency, FRP must rely upon man. Because of this human element, care should be taken to assure only experienced plasticians in key production areas and good quality control of materials and laminating procedures.

Because the skill and consistency of the plastician is so very important in the production of good quality FRP equipment, it has been suggested that such workers' skills be verified by a certification program. This certification program is currently being considered by the Material's Technology Institute as part of their program of objectively determining the qualifications of the different fabricators of the nation. Also, the purchaser is committed to having qualified inspectors evaluate equipment during fabrication and installation. It should be remembered that inspection must be based on a complete detailed design description of the proposed equipment. The detail fabrication drawings and specifications supplied to the fabricator by the purchaser or his representative should be compared during inspection with the work being done. The inspector should verify that the purchaser's detail design intentions have been adequately met.

A second fundamental source of physical property variation is the effect of glass orientation and the total percentage amount of glass reinforcing in the wall laminate. Within one vessel there may be both contact molded and filament wound walls. The ratio of the tensile strength of these two forms of construction may be 6 to 15 times. Also, in the filament wound portion of the vessel the tensile strength may vary in the hoop and axial directions from nothing to 50 times.

This type of variation due to different wall construction, is both one of FRP's greatest strengths and greatest weaknesses. The weakness is that the designer may be attracted by a very high available design stress in a particular direction and overlook a very low property in another direction. Design of equipment where the highest strength laminates are to be used, must be done with the highest degree of engineering skill. The strength of the variability of laminate physical properties can be demonstrated in filament winding where the properties may vary significantly in different directions depending on the winding helix angle. With hand layup, unidirectional roving and various cloths and mats can be used to produce laminates with a wide variety of physical properties in various directions. When a laminate must resist flexure, various coring material such as end grain balsa wood or honeycomb can be used to produce laminates which consist of only a thin skin of FRP on each side of the thick core material. The composite acts as though it were a thick sheet of FRP. Control and use of laminate variations is the basis of the design of FRP equipment.

To summarize, the physical nature of the FRP equipment wall is far more variable than in metals. As a result, production skill, quality control, and proper complete equipment design are critical for the production of reliable and cost effective FRP equipment. This equipment must be inspected to assure that the detail design intentions have adequately been accomplished during construction.

The second basic area of discussion is the difficulty of accurately determining what are the nominal physical properties of a particular composite for a basis of equipment design or for inspection purposes. The primary sources of test difficulty result from both the sample randomness discussed above, and the relative fragileness of FRP compared to metals. The fragileness of FRP makes its actual tensile properties hard to approach during test. With metals one can measure within a few percent of the actual metal physical properties. Especially with filament winding, only a fraction (40-80%) of the actual physical property can normally be measured in test. In addition, the test procedure is a major contributor of random error to the test results. This, combined with the inherent variable nature of the samples being tested produces random results. This randomness makes determining a particular property's statistical description with adequate confidence quite costly.

The sampling procedure used to make the results representative to field or shop produced equipment, must be planned and done very carefully. The tests cannot be based on flat lab prepared samples only. Any change in materials or fabrication technique will produce an entirely new laminate and the need of a new testing program. Because of the almost infinite combination of laminates, there is the need of accurate mathematical models to design and predict laminate physical properties consistently. Also, tests must be carefully designed and run to accurately define the statistical nature of FRP for both the basis of design and the final equipment inspection.

The third basic area of difference between FRP and other materials of construction is that the tensile properties of FRP vary with exposure and time. The key physical properties are elongation to fracture of the corrosion resistant liner and tensile strength of the structural wall. These physical properties will decrease (Figure 1) in time with exposure to any of the conditions which will be present in actual service, such as static strain, cyclical strain, exposure to corrosive liquids or gases, elevated temperatures, or sunlight, among others. The physical strength may eventually reach a level which is so low that it will not support the loads it is exposed to, and failure occurs. The time for the tensile properties to reach a safe minimum value is called the service life based upon tensile failure. The equipment design stress must be low enough so that there will be an adequate reserve strength to produce the desired service life. Traditionally a blanket safety factor of 10:1 has been used on short term fractures. Also, there must be adequate protection from sunlight and corrosive media to minimize attack rate and physical property decrease rate. This protection is dependent upon the materials and construction of outer and inner corrosion barriers.

The fourth area of discussion is the critical nature and fragileness of the inner corrosion resistant liner which is normally nominally 1/8″ thick. This inner liner as discussed above, is the primary protection of the structural portion of the wall from the effects of the corrosive environment around the FRP equipment. The rate of strength property decrease is very dependent upon corrosion protection provided by this inner liner. The liner's integrity over a period of time is dependent upon its construction, materials, reinforcing, thickness, actual strain history, and exposure. Because of the extreme complexity of the corrosion resistant liner and its relationship with the structural wall, further discussion will be deferred to a later paper. The design of the corrosion resistant inner layer must be carefully done for each application.

The fifth area of variation between FRP and other materials is the relatively low modulus of elasticity (MOE) of FRP. The ratio of steel MOE to that of FRP is from 6 to 50 times. The modulus of FRP in various directions can significantly be effected by laminate design as mentioned earlier. In any case, FRP's modulus is very low and equipment design demands a focus upon the areas of strain effects upon the liner integrity and elastic stability. Elastic stability predictions of non-isotropic FRP must be done with care. Complications are produced in that first, temperature greatly affects MOE in plastics, and second, that MOE in the same direction in the same material is different in compression and tension. Very little information is known about the compressive MOE of reinforced plastics, and this is the basis of design of structures in compression. Many things can be done to resist elastic instability. Cored laminates can be used to give increased effective thickness to increase the permissable design strain. Ribs can be used to reduce strain, to increase the permissable design strain, and to provide overall redundant support to resist equipment collapse in the event of local skin buckling.

The sixth area of discussion is the creep rate of "plastic" materials. Because the matrix material in FRP is a plastic, it tends to be "plastic"—dimensions change in the direction of loading permanently as a function of time under load. If other conditions such as temperature or exposure are changes, the creep rate will be changed also. This discussion of creep may seem academic, but it is not. As mentioned above, because of the low MOE nature of reinforced plastics, elastic stability becomes predominant in design of the compression areas of structures. Elastic stability is dependent upon the total critical strain (stretch) to instability. A structure's total strain may be contributed to initially by the elastic nature of the material under load, according to "Hook's Law" (Figure 2, A to B). This strain times the safety factor would normally be the collapse strain (A to D). A safety factor of five is normally considered adequate for long term loading. The remaining four-fifths of the strain between this design level and the critical collapse strain (B to D) is continuously diminished during service by this activity of creep. When collapse strain is reached (D) the structure fails elastically, and its ability to support loads decreases rapidly. The time for the total strain to reach a safe minimum is called the equipment service life based upon elastic stability.

The seventh area of variation of FRP from traditional materials is the non-isotropic nature of FRP. Almost the total world of stress analysis, which is the cornerstone of equipment design, is based upon the assumption of isotropic (not a function of direction) physical properties. As we have mentioned above, in FRP the physical properties are extremely non-isotropic. This basically means in many cases the original general mathematical models which are the tools of structural design need to be completely rederived from first principles for FRP and verified with test data, or, a system of correction factors need to be developed for each specific case. Today consistent and accurate design of composite equipment is possible with the availability of new computer systems to process these new generalized math models, and to statistically interpret test results for the purposes of composite equipment design. The real deficiency is that these design tools are currently only available to a few offices across the United States.

The eighth topic of discussion is the sensitivity of FRP equipment to variations in process conditions. All process equipment has problems when used outside the designed operating envelope. FRP equipment for several reasons is more sensitive. The low MOE of reinforced plastics causes a lower reserve of safety factor to resist an unexpected vacuum condition than steels, for example, with MOE 30 times greater. Also, due to the high MOE temperature sensation of FRP compared to inorganics, an over-temperature condition can much more rapidly reduce available safety factor in an FRP vessel. Another reason for sensitivity in FRP equipment is that the corrosive environment of many FRP applications is extremely complex and severe. Nothing in the price range other than FRP can survive the service. In these extreme conditions, changes in temperature, composition, or concentration can radically increase corrosion rate and for no apparent reason the FRP equipment will fail prematurely.

Highly reliable, cost effective FRP equipment can in fact be designed, produced, and used in service. The remainder of this paper will emphasize in an overall qualitative way what is necessary for successful FRP equipment application. The key to successful FRP industrial equipment is to approach its design from a new direction completely different than that used with isotropic materials. This approach will take advantage of the above mentioned flexibility of composites. With traditional materials a designer is limited to the basic capabilities of that family of materials in which a product is being produced. The physical properties are fixed and the designer does the best possible design of the equipment around these specific material capabilities. Because of the composite nature of FRP, a wide range of material properties and characteristics can be easily produced in various areas of equipment, as required. What this means is that desired material characteristics can be determined for an optimal equipment design. Next, a composite material can be designed to have particular desired properties in different areas of the equipment, to satisfy the equipment design requirements. The value of this freedom at first glance may not be understood. Actually this has profound strength in providing design opportunities not previously available to allow designers to generate new and highly efficient equipment. The major problem is that design emphasis for FRP is opposite that of isotropic materials. Now the emphasis must be on using not only the freedom of equipment design, but also to integrate that with the freedom of material properties design over a broad range of physical properties. Though this radically increases the complexity of design, it opens the door to the opportunity of new, cost effective, highly reliable corrosion resistant industrial equipment.

With adequate chemical resistance and structural design for the proposed equipment service life, using the many strengths of FRP to provide an optimal design, there must be production, installation, and maintenance inspections of FRP equipment. Because current equipment production techniques produce such random results, inspectors knowledgeable in fabrication and the specific equipment design, must verify that in fact the proposed design is realized in the actual equipment. During its service life, the equipment must be properly used and maintained. All the areas in an FRP project are extremely interdependent and must be integrated and cared for properly by experienced people if success is to be the consistent fruit of the labor.

FRP chimney liners will be discussed next as an illustration of the size and complexity of FRP equipment that can be designed for highly reliable and cost effective service, when the above design challenges are successfully resolved.

STACK LINERS — THE LARGEST FRP STRUCTURES IN THE WORLD

Until about five years ago steel reinforced concrete chimneys were lined with either brick or metal liners. The outer concrete column provided protection and support for the base supported steel or brick liner. The liner consisted of a corrosion resistant structure up the center of the chimney which contained the corrosive hot gases passing up the chimney. The liner protected the outer concrete column from corrosion by these gases. Recently with the advent of wet scrubbing systems, the brick, metal, or coated metal liners have proven unacceptable due to short service life and difficulty of repair. There was need of a new, reliable lining system for these chimneys. FRP chimney liners have proven to be cost effective, long lived, and reliable. These structures are highly corrosion resistant and have a high strength to weight ratio.

The basic configuration for one of the first FRP liners was as shown in Figure 3. This structure is base supported. The maximum stress occurs at the liner base in the form of compression. For very tall liners, this compression causes the resulting liner walls to be very thick due to elastic stability. For these liners the safety factor on ultimate tensile stress is extremely high, while only having a small compressive safety factor. The optimal liner would have to take advantage of the high tensile properties of FRP and the support available from the outer concrete column. As very tall structures are produced, however, the tensile stresses also start to generate excessively thick liner walls. Normally, if independently supported modules can be produced in very large structures the efficiency of the structure can be radically increased.

Figure 4 shows a module of a highly efficient chimney liner which is hung in tension. The liner is supported at the top by the chimney column, but the bottom is free to move vertically (thermal expansion). This configuration allows the FRP tension liner to efficiently conduct the highly corrosive gases up the chimney while allowing the strong outer column to carry the liner weight to the foundation. Figure 5 shows a diagram of an actual liner consisting of a stack of these modules which is 24′Ø x 1,215′ tall. The modules are nominally 300′ long. For this application the use of these tension liner modules allows the liner wall thickness to be one-sixth what it would be if the liner were base supported as one piece.

Figure 6 is of one 33′ long x 24′Ø piece of a module. Figure 7 is of the bottom gored 90° elbow of the liner. Figure 8 shows the entire length of the installed 1,200′ liner. Figure 9 shows the rain cover being set in place at 1,200′ up.

CONCLUSION

This paper was designed to introduce the reader to the basic variations between the design of isotropic equipment and that of composite equipment. This is general information which can apply to any type of composite material. The attempt was to show the power as well as the weaknesses of composites. Finally, there was basic discussion of the design of FRP stacks and chimney liners to demonstrate the power of advanced design and analysis techniques used in a practical fashion to produce reliable, cost effective, corrosion resistant structures made of FRP.

OTTO H. FENNER

Otto H. Fenner has been active in the Chemical Industry for 43 years with the Monsanto Company in Research, Production and Corporate Engineering. He has served as a Consultant Materials-Corrosion Engineering Specialist for the past 25 years, with particular emphasis in the field of Fiberglass Reinforced Plastics.

Mr. Fenner received his AB Degree in Organic Chemistry, College of Liberal Arts and Sciences, Washington University, St. Louis, Mo., 1942. Professional affiliations include: American Chemical Society (1941), National Association of Corrosion Engineers (1947), Society of Plastics Engineers (Senior Member 1961), Society of Plastics Industry, American Society for Testing and Materials, and Alpha Chi Sigma — National Professional Chemical Fraternity.

Mr. Fenner has served as lecturer at numerous universities and has published over 100 papers on various aspects of corrosion engineering and plastics applications in major technical journals. He is a past National Director of N.A.C.E. and received the Citation of National Recognition for Outstanding Contribution to N.A.C.E. in 1976. Mr. Fenner is a Certified Corrosion Engineer — N.A.C.E. #739. He is a working member of the S.P.I. Reinforced Plastics/Composites Institute and the A.S.T.M. D20.23 Committee on Reinforced Plastic Piping Systems and Chemical Equipment.

RICHARD J. LEWANDOWSKI

Richard J. Lewandowski is a graduate of Loyola College in Baltimore, Md. He was employed for six years at Cities Service, Princeton, N.J., where he gained basic background in rubber and plastic polymer chemistry through his R&D studies. In 1966, he joined Atlas Chemical (ICI-United States) as a Technical Service Representative for their Atlac resins.

Mr. Lewandowski has gained an in-depth knowledge of the corrosion resistant FRP industry through his eleven years with ICI-United States. Among his contributions were the development and commercial introduction of their flexible, fire retardant and vinyl ester resins and the secondary bonding primer agent.

Mr. Lewandowski has been active in many N.A.C.E., A.S.T.M. and S.P.I. activities. He served as an industry representative to the N.F.P.A., coordinated the writing of the FRP duct section of the N.F.P.A.—91 Standard, and has been consulted on many industry fire problems. He served on the S.P.I. Laminate Quality subcommittee, and authored several papers on this subject and on the interpretation of FRP corrosion test results.

WINSTON J. RENOUD

Winston J. Renoud is a registered professional engineer, who graduated from Oregon State University in Mechanical Engineering. Mr. Renoud's years of work experience have been in engineering design, research and development, and project management with the Boeing Company, Seattle, Wa. (Supersonic Transport and B-1 Bomber projects); and with Western Washington State College and Ershig's, Inc., Bellingham, Wa.

While the Design Engineer at Ershig's, Inc., Mr. Renoud used his engineering experience in research and development for applying traditional engineering to the design and production of a generation of very large, complex, and highly reliable corrosion resistant FRP industrial equipment. As one of the principal engineers of Fiberglass Structural Engineering he has been responsible for engineering analysis and design in both general engineering and in FRP equipment development for major national mining, pulp and paper, and chemical companies.

Mr. Renoud has been active in presenting papers at conferences such as the Northeast District N.A.C.E., and the S.P.I. in Washington, D.C. He is also an active member in the National Association of Corrosion Engineers, the Society of Plastics Engineers, and the American Society for Testing and Materials.

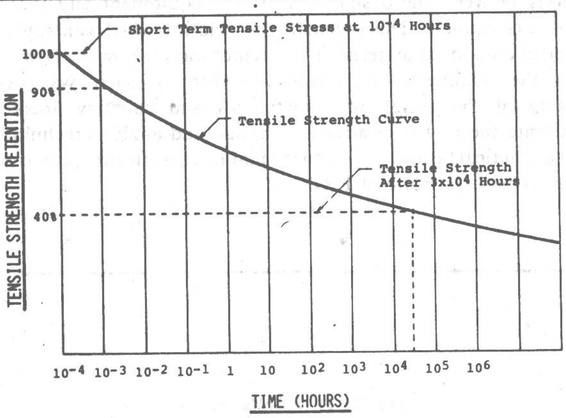
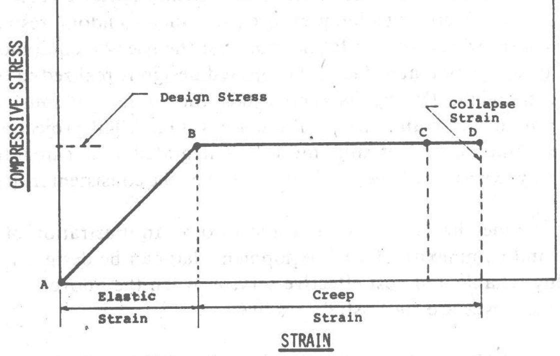


Figure 1 - Tensile Strength Retention Versus Time.

Figure 2 - Creep Effect on Elastic Stability.



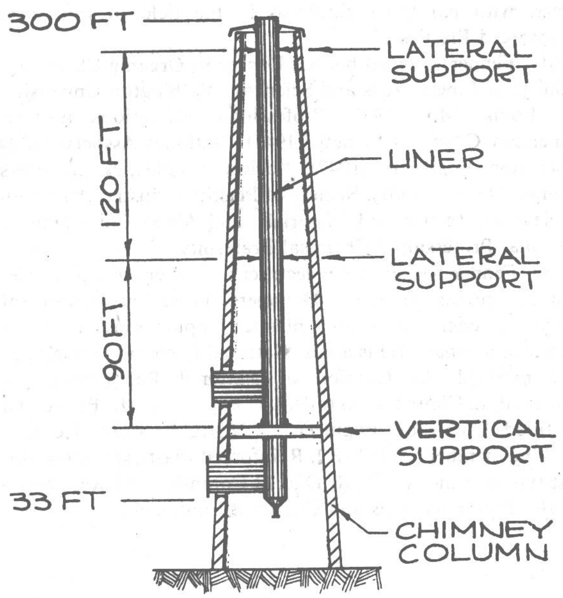


Figure 3 - Base Supported FRP Chimney Liner.

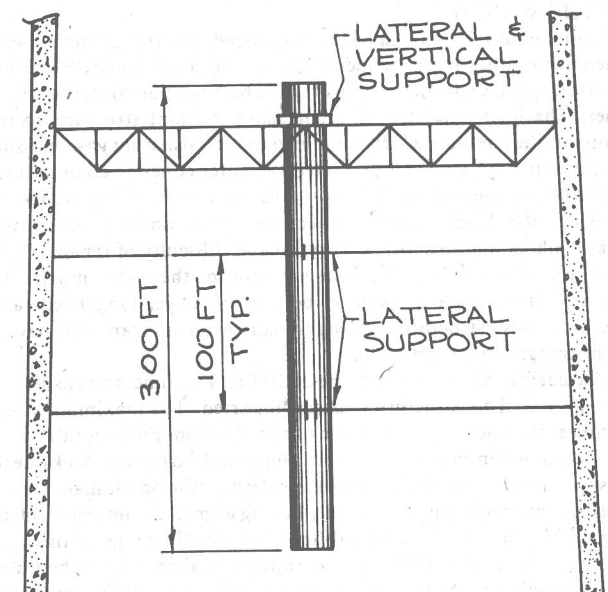


Figure 4 - 300' Long Tension Chimney Liner Module.