ARCE 453 Senior Project

ARCE 453-05 Interdisciplinary Senior Project, Spring 2024
California Polytechnic State University
San Luis Obispo, CA

14 June 2024
Instructor: Kevin Dong

Richard Anatablin
Sara Engmyr
Michelle Griffith
Jora Leigh
Jesse Rainsdon

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1.0 ARCE 415

At the outset of the spring quarter, the authors of this report were enrolled in ARCE 415, the lecture version of the senior capstone project in the architectural engineering curriculum. However, this did not come to fruition as, just days before the quarter's start, an email was sent out to those enrolled in ARCE 415 alerting them to the potential cancellation of ARCE 415. Regrettably, this materialized into reality shortly after that, as the course cancellation became official once the quarter began. The absence of an available instructor and the inability to secure a suitable replacement were cited as the reasons behind the cancellation of the course.

In light of this change, we faced an urgent task of identifying a senior project under the guidance of an advisor. This marked the start of our journey to find a suitable senior project.

2.0 Poly Canyon Wall

2.1 Overview

With only a week to figure out what to do for a senior project, many students on the path to graduation in spring were panicking. While scrambling to find a senior project, an email was sent out advertising the building of a wall in Poly Canyon with an advisor of Kevin Dong.

This project involved the construction of an art wall in Poly Canyon to deter graffiti on the existing structures and instead provide a designated area for students to express themselves. The proposed project was for a freestanding wall, as depicted in Figure 1. The idea was appealing as it would be a practical and engaging experience, putting both conceptual and practical skills to the test. Thus, a senior project was determined.

Figure 1: Wall in Poly Canyon Rendering

During the first meeting, Kevin outlined the challenges in constructing the wall. These included the requirement to submit a detailed proposal to the facilities department for approval and the subsequent complexities involved in the actual construction of the wall. All of this had to be done in the 10 weeks of spring quarter.

2.2 Design

Initially, there was uncertainty about the desired and optimal size of the wall as it had to be easily constructible but stand up to the wear it would receive in Poly Canyon. After several discussions with Kevin regarding the wall's thickness, the number of layers of CMU, and its dimensions, an initial design was reached. The wall is to be 8 feet tall and 10 feet wide, providing ample space for students to express themselves while remaining feasible for construction. It would also consist of a single layer of 8-inch CMU blocks. The dimensions of the wall created a large canvas that would allow artists to remain safely on the ground when painting on the wall.

With the wall's dimensions established during the initial 2-3 weeks, the focus was turned on designing the foundation and reinforcement necessary to ensure its stability. The main goal was to create a shallow foundation for ease of constructability. Additionally, it was essential to ensure that the reinforcement spacing was compatible with the CMU blocks used.

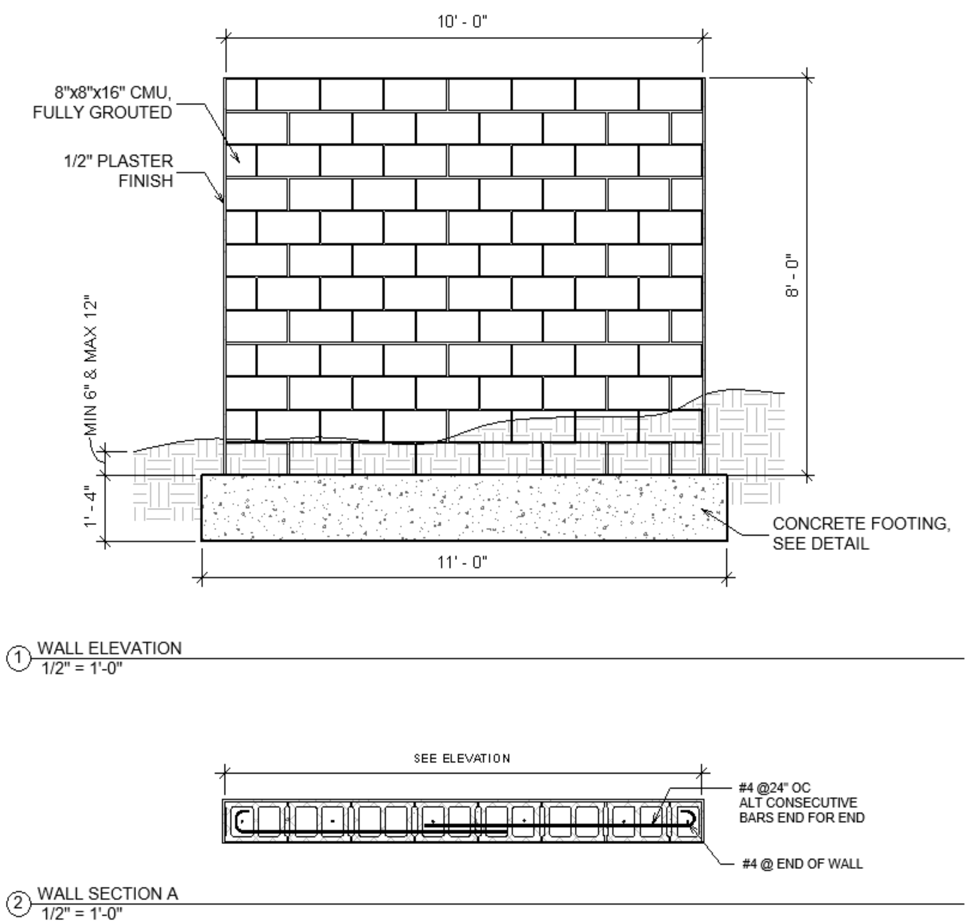

Figure 2: Wall Section & Elevation

2.3 Means and Method

Following the completion of the design phase, the next step was finding the required materials and conducting a cost analysis. These materials encompassed a range of items, including CMU, reinforcing steel, concrete, and the various tools necessary for construction. Our team also assessed the feasibility of constructing the wall by estimating how long each of the steps in the process would take for this to occur. These steps entailed the excavation of the foundation, installing the steel reinforcement, pouring the concrete, stacking the CMU, and putting the grout and mortar for the CMU.

The 10-week schedule revealed a notably tight timeframe that required no missteps to be completed (Appendix A.1). Contingency planning was essential, as any deviations from the original plan could jeopardize the project's completion.

2.4 Revisions

As outlined, several adjustments had to be made due to unforeseen factors. For instance, it became evident that employing 8-inch CMU blocks instead of 12-inch blocks would significantly enhance the likelihood of the proposal being approved. This is because it would dramatically increase the feasibility of the construction process and sourcing of the material. For CMU, 8-inch blocks weigh around ⅔ of what a 12-inch block does. This is incredibly important because over 100 blocks would be needed for the wall.

Moreover, designing a wall to withstand out-of-plane bending presented a novel challenge. There was a learning curve regarding CMU design techniques, particularly in navigating the Technical Manual for Design and Construction of Masonry Structures (TMS) to find the code sections for the needed equations. These unanticipated variables took up a lot more time than initially predicted as the group was rapidly approaching week 5.

2.5 Decision

Following a prolonged period of iterative revisions, it became apparent that progress was off track significantly from the original timeline. Notably, the project proposal had still not been submitted to facilities, which was a part of the critical path in the timeline. This variability in an unknown timeline of how long it would take for facilities to approve was becoming very apparent, especially since it could be outright denied. It became evident that getting the proposal approved and completing the wall's construction in the spring quarter was no longer feasible. Confronted with this realization, the tough decision of revising plans once again was necessary. Despite the setback, the team persevered.

Figure 3: Poly Canyon

3.0 Poly Canyon Renovations

Following an assessment of our project status with Kevin, he recommended that we proceed with submitting the proposal to enable future students to undertake the construction of the wall at a later time. Additionally, he proposed an alternative course of action instead of constructing the wall ourselves. This new idea would be for the group to restore an existing structure in Poly Canyon, thereby giving the hands-on experience we were after. To facilitate this transition, Kevin provided a couple of project options and encouraged us to visit them and make a pros and cons assessment of each. This evaluative process would help inform our selection of the most suitable project.

3.1 Truss Bridge

While assessing potential projects, we looked closely at the Truss Bridge, located towards the rear of Poly Canyon. We immediately noticed numerous critical issues. Upon inspection, we saw the bridge had evident curvature towards the right side. We then tested the truss bridge by having one of our group members go on it and shake it. This test revealed alarming levels of deflection, raising considerable safety questions.


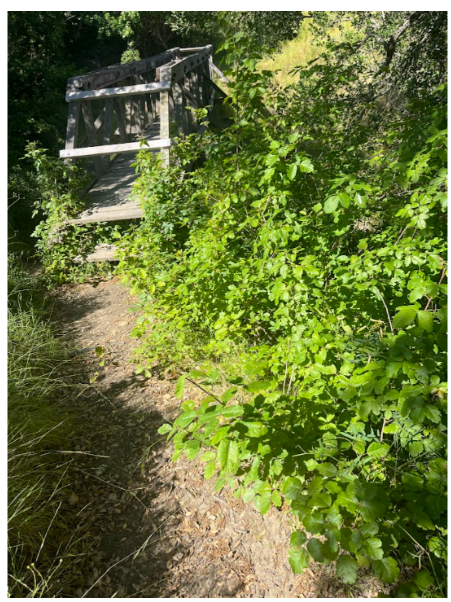

Figure 4 & 5: Truss Bridge at Poly Canyon

Moreover, as shown in Figure 5, poison ivy was extensively present, obstructing access to the bridge. This presented an additional challenge, as it would have to be cleared before any repair work could be done. The bridge deck also had widespread deterioration, characterized by many broken planks and missing nails. Additionally, horizontal and vertical members exhibited visible cracks, further showing the extent of the structural damage.

Recognizing the magnitude of the task at hand, we concluded that addressing the Truss Bridge's myriad issues would take too long compared to our time frame. This prompted us to consider an alternative project.

3.2 Techite Bridge

3.2.1 Overview

The Techite Bridge was assessed next. The Techite Bridge is located near the entrance of Poly Canyon and serves as one of the initial focal points for visitors. This historical structure was erected approximately 50 years ago. It has a distinctive architectural design that sets it apart from other projects at Poly Canyon. It comprises two support bases, each featuring four angled columns. It also has very cylindrical structures that act as a railing system.

Figure 6 & 7: Techite Bridge Damage

In contrast to the truss Bridge, the Techite Bridge was relatively unscathed structurally from the initial inspection. Upon closer examination, however, it was evident that the Techite Bridge had significant signs of neglect and pervasive graffiti on both the handrails and deck due to its location towards the entrance of Poly Canyon. Additionally, extensive chipping along the edges of the railing exposed the inner concrete layer, while the whole structure accumulated dirt and moss.

In light of these findings and considering the feasibility of the restoration, we reached a consensus to focus our efforts on the Techite Bridge. Its proximity to the entrance of Poly Canyon underscored its significance as a prominent landmark, further necessitating its restoration.

Our proposed restoration plan would entail thorough cleaning, fixing the chipped areas with appropriate filler, and refinishing to restore the bridge. Furthermore, we identified that the handrails had hooks, showing that there used to be a chain connecting the cylindrical rails, although one hook was missing. This hook would be restored, and a chain would be added to the structure. These changes would bring back the Techite Bridge to its former glory.

Figure 8: Future Hook Location

Figure 9: Graffiti Originally on Bridge

3.2.2 Means and Methods

Following a productive Zoom call with two of the original builders of the Techite Bridge, during which we gained valuable insights into the bridge's construction process and their vision for the restoration, we commenced our efforts. Our initial step involved a meticulous concrete cleaner and graffiti remover cleaning process. Given the bridge's proximity to the small river underneath, it was of utmost importance to preserve the ecosystem, thus necessitating careful execution to prevent any runoff from contaminating the water and endangering local wildlife. Conscious of the toxicity of the cleaning agents, we prioritized the environment during this phase.

Afterward, we procured the required resources and materials to repair and refinish the bridge. To address the chipped areas, we employed spray foam followed by fiberglass, resin application, and a sand coating to match the existing bridge aesthetic. We also had to be mindful of security concerns raised by the previous builders regarding the earlier instances where the chain railing was stolen; we devised a strategy to secure the new railing using grout, thereby deterring future theft attempts. We also planned to install and thoroughly bolt a new plaque to avoid theft.

The bridge then underwent cleaning. Graffiti remover and concrete cleaner were used to remove most of the graffiti. Although some of the graffiti was so strong that it wouldn't fully come out, the group decided it would be eliminated once we applied the finish.



Figures 10, 11, & 12: Cleaning

Once cleaning was completed, the group began mixing resin and hardener with some sand. A couple of batches were tested to see if the consistency was good, and eventually, a perfect consistency was achieved. The finish was then applied to the bridge. After letting the finish dry, we realized that the color of the finish was not the same as the one the Techite Bridge originally had, so some spray paint was used to match the colors, which worked perfectly.

The group then began the process of replacing the missing hook. Initially, grout was used to do this. Then, the chains were all put into their hooks, along with grout, to make sure tourists couldn't steal them. After placing the chain into the new hook, the grout failed to handle the weight of the chain. The group then tried using grout, fiberglass, and resin to hold the hook in place for the chain.

Figure 13 & 14: Grouted Hook & Fiberglass Over Filled Hole

3.2.3 Final Results

The grout and fiberglass worked when the chain was applied. The restoration of the Techite Bridge was completed. All graffiti was removed, and the bridge was refinished. A new chain was added to restore the bridge to its original shape. The plaque has been designed and will be ordered to replace the missing signage. The plaque is to be glued down with a construction adhesive and bolted down into the concrete. A top coat of resin may also need to be applied in order to ensure that the plaque remains a permanent feature of the bridge.


Figure 15 & 16: Restored Bridge & New Hook

Figure 17: Restored Cylindrical Handrails

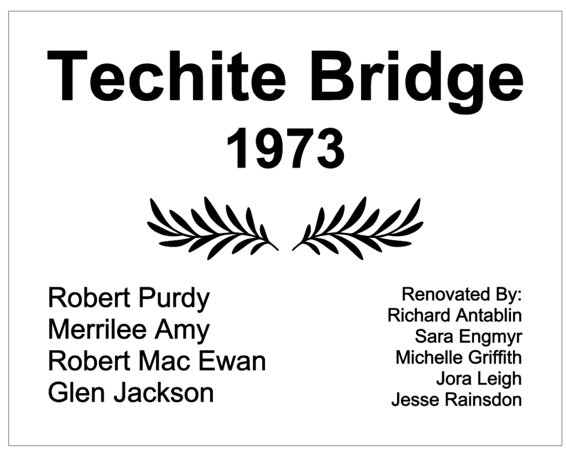

Figure 18: Proposed Plaque Design

4.0 Conclusion

Reflecting on our spring quarter endeavors, highs and lows marked our journey. Initially enrolled in ARCE 415, our plans were abruptly changed when the course was canceled. Undeterred, we promptly regrouped and joined Kevin for our senior capstone project. We then embarked on the ambitious project of constructing a public art masonry wall at Poly Canyon.

However, as challenges emerged and our progress faltered, we recognized the need for a reassessment. We then decided to pivot once more while concurrently finalizing our proposal for the Poly Canyon Wall. This pivot led us to redirect our efforts towards renovating one of the existing structures at Poly Canyon, a shift in focus that proved to be pragmatic and rewarding.

After carefully evaluating the projects in Poly Canyon that needed help, we identified the Techite Bridge as the optimal project. The Techite Bridge is positioned at the entrance of Poly Canyon, thus showing its significance. The feasibility of the required repairs for the bridge aligned perfectly with the timeframe left in the quarter. This choice allowed us to ensure that one of Poly Canyon's iconic landmarks remained structurally sound and visually appealing for all visitors.

5.0 Self Reflections

A. Richard Anatablin
B. Sara Engmyr
C. Michelle Griffith
D. Jora Leigh
E. Jesse Rainsdon

Richard Anatablin

Spring Quarter 2024 was a wild roller coaster filled with ups and downs. Through this journey I learned the importance of making the most of the situation in front of me and persevering through challenges. I gained valuable insights into real world structural engineering design scenarios. For instance building a wall may seem straightforward; just do the proposal and start construction but how the information in the proposal is presented is absolutely crucial. Additionally the process of getting feedback and going back and changing the design due to constructability concerns was a very real world experience.

The Poly Canyon Wall proposal addresses societal issues as it is a way to fix the major issue of people putting graffiti on projects that other people created. This has been a long lasting project in Poly Canyon and the Wall could help subdue it by allowing people to have a place where they can express themselves.

The restoration of the Techite Bridge is another hands-on project that provided valuable learning experiences about different materials and finishes that aren't very common. For example the resin with sand finish was very unique to make and we realized how important it is to try and keep the same consistency of resin along with hardening and sand per mixture. Using the fiberglass to refinish the chipping in the Techite bridge was something I learned how to use.

The restoration of the Techtite Bridge highlighted the societal, environmental and economical benefits of maintaining existing structures. In an era where everyone wants new things it is important to care for what already exists. Renovating and maintaining existing buildings can save significant energy and resources while greatly benefiting the environment. This project underscored the importance of sustainability in our built environment.

Sara Engmyr

Through the ups and downs of my senior project, I learned a great deal. It began with my confidence and enrollment in ARCE 415, Interdisciplinary Capstone Project, and ended with something entirely different. Coming back from abroad, I felt disconnected from the department and was relieved to have an option that had a framework and plan already in place. Learning that the course would no longer be offered was the first of many roadblocks throughout this journey. In the few days before the schedule of my last quarter at Cal Poly had to be finalized, I went on to find a group, an advisor, a focus, and some excitement to initiate this new direction. This was the start of The Wall Group. Kevin Dong offered the idea of a Poly Canyon Art Wall, designed to encourage creative expression on a specific structure, and eliminate some of the damage done to existing projects in the Experimental Structures Lab. I was attracted to the idea of creating something new and possibly leaving an impact on the Cal Poly campus, as well as seeing a project through, from start to finish. This project started strong with a schedule, mockups, and calculations. After working on The Wall for many weeks and going through countless iterations and revisions, we created a proposal to send off to Cal Poly Facilities Management. As we wrapped up this initial proposal, we realized how quickly the quarter was going by, and decided to change directions a final time. The constructability challenges and questionable timeline with submitting to Facilities Management made us reconsider our goals for the senior project. We now have a finalized proposal for The Wall and will leave our completed set of calculations and drawings for another team to pursue in the future. Our objectives remained, as we were still eager to give our attention to Poly Canyon and the Experimental Structures Lab. This time, we chose to focus on an existing structure, the Techite Bridge. The Techite Bridge attaches the entrance to the rest of Poly Canyon and is one of the first projects interacted with when entering the space. It was built in 1973 by Construction Engineering students. Most of the damage was cosmetic rather than structural as it was covered in graffiti, was extremely dirty, and had parts missing. For the remainder of the quarter our concentration was on the bridge. We cleaned, refinished, painted, restored, and revived the bridge. One of the most rewarding and meaningful experiences of the quarter was meeting with some of the original builders of the Techite Bridge, Robert Purdy and Glen Jackson. They offered insight, passion, and motivation for this project. Being over 50 years old, the bridge needed some care, and these alumni were grateful to see current students taking on the role and action to beautify this structure and the canyon.

I learned a great deal through this experience and am happy to have had some variety in my final project as an ARCE student. From working with masonry and running through many designs, I became more comfortable with a material I was rather unfamiliar with. Process, constructability, and logistics of building were also key areas I was able to dive into that weren't necessarily talked about in my lecture classes. Rather than being an extremely technical experience, the process of this project and the journey, as a whole, was the focus. This taught me how to adapt and shift the scope when needed, while also being flexible with teammates, advisors, meetings, and project work. Although the project scope was not global, when reflecting, I think it offers a worldwide proposition of renovating and then reusing existing structures. The idea of recycling also has a great economic impact. This can even be seen within our project scope, and how reasonable the cost of refurbishing the bridge was in comparison to the cost analysis of the brand-new wall. These are ideas I hope to continue to consider as I move ahead into my career.

The bridge is located over a stream and surrounded by trees and grasses. When first surveying and getting the scope of the project, we realized that the surrounding environment would have to be considered. Throughout the project we wanted to have a minimal impact despite the need to use chemicals and harsh materials for some of the work on the bridge. Through efforts of tarping and covering the surrounding areas, carefully choosing our materials, and being conscious of the setting, we were able to successfully repair the bridge without any lasting impacts on the environment.

The "Architectural Graveyard" is a common site for the Cal Poly and broader SLO community. Because of this location, we had to consider cultural and social concerns as well as the significance of our structure. The amount of foot traffic and interaction people have with the structures was immediately clear from the graffiti and damage to the bridge and other structures. Along with the vandalism, the plaque and chain railings were missing. In order to solve these problems, we had to consider not only how the bridge affects the community but how the community affects the bridge. This thought process ultimately helped us problem solve and fix the bridge in ways that could be more permanent.

New materials, a unique situation, and constructability concerns were catalysts for encouraging a "Learn by Doing" model. Many days in the canyon were filled with trial and error and hands on work, but ultimately helped us achieve a gratifying final product. Through calculations, hard work, scrubbing, and lots of sand and resin, I was rewarded with a completed project and a new connection to my home of 5 years. I am proud to soon be an ARCE alumna and to have contributed to the broader Cal Poly community. Maybe I too, in 50 years, can come back and see this bridge and be reminded of my college career and final senior project.

Michelle Griffith

In my Architectural Engineering Senior Project, we focused on two separate projects within Poly Canyon: the design plans for a masonry art wall and the repairs to the Techite Bridge.

Through the wall calculations, I learned a lot about the process that it takes to build a structure in the pre planning phases. More specifically, in the process for plan submission and facilities approval. In the wall calculations we also had to reference different code such as the IBC, ASCE, TMS, and Concrete code books so it was insightful to see how an actual project requires the use of so much use of the code books as we are often just looking at one material at a time. Both the concrete and masonry design classes and labs played a major role in this aspect of our senior project as we were designing a masonry wall to withstand all applicable loads using the knowledge we received in class along with help from our advisor. As a Construction Management minor, I found it very interesting on how the means and methods play into creating the engineering plans as when designing we kept having to go back and look at if it was feasible to make as we not only had to design the wall but actually build it.

The wall in Poly Canyon would have a cultural impact to the overall area as having a designated place for art would give an outlet for artistic expression outside of the current structures. By deterring graffiti on the current structures in the canyon, it becomes more feasible to return the canyon to its former prominence, and even potentially return caretakers to the canyon. The wall would address the current environment of the canyon by providing a designated place for art and graffiti. While its construction would break ground, it was planned to be in an area that was open and with minimal impact on the surrounding environment. Socially, having a wall in the canyon is a draw for art clubs or artistic students to go up to the canyon and paint on the wall similar to the way that the "P" at Cal Poly is periodically painted. In the constructibility, it was important to consider the weight of the project in how much we would have to transport to the canyon. Having a thicker wall may be ideal in the potential for seismic or wind events, however the constructability and sourcing of materials become a bit more difficult. Because of this, when looking at the constructibility of the wall and the fact that we as a group would be constructing it, it became clear that we should be looking at the minimum depth of foundation and using 8" CMU.

In looking at the Techite bridge, it was very interesting to talk to some of the former builders of the bridge and how they constructed it and what we could do to improve it. We learned a lot about the most common materials like the fact that they decided to use techite pipes as both an aesthetic and structural detail was insightful about how it might be out in the industry. We've learned quite a bit about concrete and its construction and seeing it in application of the techite bridge really showed how all of our curriculum contributes to actuality constructing a project. It really highlights how important it is to maintain the structures in Poly Canyon in the education impact they can have.

The structures in Poly Canyon have a global impact as Cal Poly is one of the only places in the nation that allow for this kind of freedom and exploration in how structures work and actually construct them in the canyon. Having structures up in the canyon not only provides a learning experience for those that are building them but for every one that visits the canyon while also providing inspiration to future architects and engineers. Keeping the structures in shape allows for this legacy to continue on. While there is an environmental impact of structures in the canyon, most of the construction is done in a way that preserves the local ecosystem. There are bridges built over small creeks and rivers to allow ease of access to all parts of the canyon but most of the canyon has stayed as an open environment. While there has been electrical and water access in the canyon, currently there is not either of the utilities available for visitors. There is an economic impact of structures in the canyon in building and maintaining them, but the draw of innovative structures within the canyon is a great way to advertise Cal Poly and the programs in the College of Architecture and Environmental Design. If the canyon structures are maintained there becomes more of a social draw in the canyon to visit the structures and marvel at them rather than deface them. There are a few hurdles to overcome in the constructibility within the canyon. The plans have to be approved by Cal Poly facilities and the department that is proposing them. There is also the potential for issues with access to the canyon as there is a service road but some parts of the canyon are inaccessible by vehicle. Despite the difficulties, it is still possible to build in the canyon; it just takes a bit more time.

Jora Leigh

I embarked on a transformative journey throughout this project, unearthing invaluable experiences and insights. It was a platform that unveiled the untapped strengths and weaknesses of individuals I had not previously known, propelling me to evolve into a more adaptable professional in the face of constantly changing situations. This adaptability was not just a skill but a mindset, a pivotal element in our project's success, which demanded flexibility over rigidity.

One of the key lessons learned was the importance of adaptability. Due to the dynamic nature of our project, rigid plans proved ineffective. I discovered my team member's strengths and weaknesses and learned how to leverage these traits to achieve our goals. This ability to understand and adapt to different personalities and work styles was instrumental in navigating the challenges we faced.

Our multifaceted project was a testament to our collective efforts in addressing various global, social, and environmental concerns. By restoring an existing structure, we made a significant contribution to global efforts to maintain and preserve valuable resources. This project also had profound social implications. We provided a much-needed facelift for a neglected project, earning the gratitude of the original builders. This act of restoration not only preserved a piece of history but also strengthened community ties and fostered a sense of pride among all those involved.

From an environmental perspective, our team diligently ensured that all the products and materials used did not negatively impact the diverse wildlife around the bridge. This careful consideration of environmental impact underscored our commitment to sustainability and responsible construction practices.

We encountered numerous construction challenges, particularly during the wall design phase. One hurdle was creating a wall of the right size with a shallow footing, as we had to construct it manually. Instead of obstacles, these constraints became opportunities

for innovative problem-solving and a hands-on approach, demonstrating our team's resourcefulness and capability.

During the bridge restoration, I was particularly concerned about how to fill the railing and patch it up. Bob Purdy, one of the original builders, suggested using spray foam to fill the gaps, which worked perfectly. This practical solution was complemented by using fiberglass and resin patches, materials with which I had no prior experience. Working with these materials for the first time was a valuable learning opportunity that expanded my skill set.

This project was a profound learning experience, teaching me about adaptability, teamwork, and the importance of considering global, social, and environmental impacts in construction. The challenges we faced, and the solutions we devised highlighted the necessity of flexibility and innovation in successful project execution. The skills and insights gained from this experience will be valuable in my future endeavors.

Jesse Rainsdon

As I look back on my final quarter of college, I find myself reflecting on the chaotic course of events that required us to adapt and alter our plans to succeed. Most importantly, I learned the value of perseverance as life can throw many unexpected plans your way. This was my first experience with the real-world construction process and I gained many valuable insights that I will be highlighting in this essay.

Our initial project, the Poly Canyon Wall, addressed the societal issue of graffiti defacing communal art projects. By giving graffiti artists their own space to express their art, we hoped to deter the vandalism of the existing projects. While the calculations to ensure the wall's structural integrity were challenging, I believe our real test was the proposal process. We had no prior experience regarding obtaining a permit and we ran into many complications that we did not see coming. As we did not expect so many back-and-forths with our proposal, we fell behind our anticipated schedule. In the future, we now know how we can better improve our proposal and communication to significantly cut down the days needed for preparation.

Our final project, the Techite Bridge restoration, addressed the societal and environmental issues of decaying projects, and the importance of properly preserving them. As our society moves forward with new construction every day, it is crucial that we don't leave behind the older architecture that serves as a connection to the past. Additionally, restoring existing projects utilizes much less labor and resources than new construction, making it a favorable decision for our environment. In this project, I learned how to work with resin and finishes, and the importance of accurate proportions and patience during the curing process to ensure longevity.

<u>A.0 Appendix</u>

A.1 Poly Canyon Wall Proposal

A.2 Techite Bridge Materials and Cost

A.3 Original Techite Bridge Report

Poly Canyon Wall

ARCE 453: Interdisciplinary Senior Project

Spring 2024

Richard Antablin, Sara Engmyr, Michelle Griffith, Jora Leigh, and Jesse Rainsdon

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Poly Canyon Wall

Proposal

The Experimental Structures Lab in Poly Canyon at Cal Poly has upheld a "Learn by Doing" philosophy since its establishment in 1963. It offers an open space for students to explore and gain practical, hands-on building experience. However, over the years, the lab's maintenance has declined due to lack of caretakers, leading to defacement and damage to many structures. To address the current deterioration and discourage further destruction, a small art wall is proposed for community expression. This initiative marks the initial step in a broader effort to restore the lab to its former prominence.

Introducing a blank canvas to the canyon would provide students and community members with a designated outlet for artistic expression, thereby discouraging the use of existing structures as canvases. Additionally, establishing a public art space would foster community and campus engagement within the canyon, similar to the tradition of painting the "P" on campus.

The proposed wall serves as a Senior Project for Architectural Engineering students, offering them practical experience in designing with reinforced masonry and concrete, two key materials emphasized in the ARCE curriculum. Students will demonstrate their comprehension of masonry wall design and construction, including the installation of a concrete footing. Overall, the project will afford students hands-on experience in project coordination, management, and wall construction.

Scope

Site

In Poly Canyon, the best site was determined to be a area past the pole structure on the path between the tensile structure and concrete flower. This is an ideal location for the art wall as it is in a public area along the road and will likely receive greater foot traffic than if it was placed further away from the road. Being close to the road also allows for ease of construction in the pouring of the foundation and transportation of materials.

Figure 1 Satellite view of Cal Poly campus

Figure 2 Picture of site in Poly Canyon at 35.31481° N, 120.65231° W

Design

A reinforced masonry wall of dimension 8'x10'x8" constructed of 8"x8"x16" CMU blocks. See appendix for structural calculations.

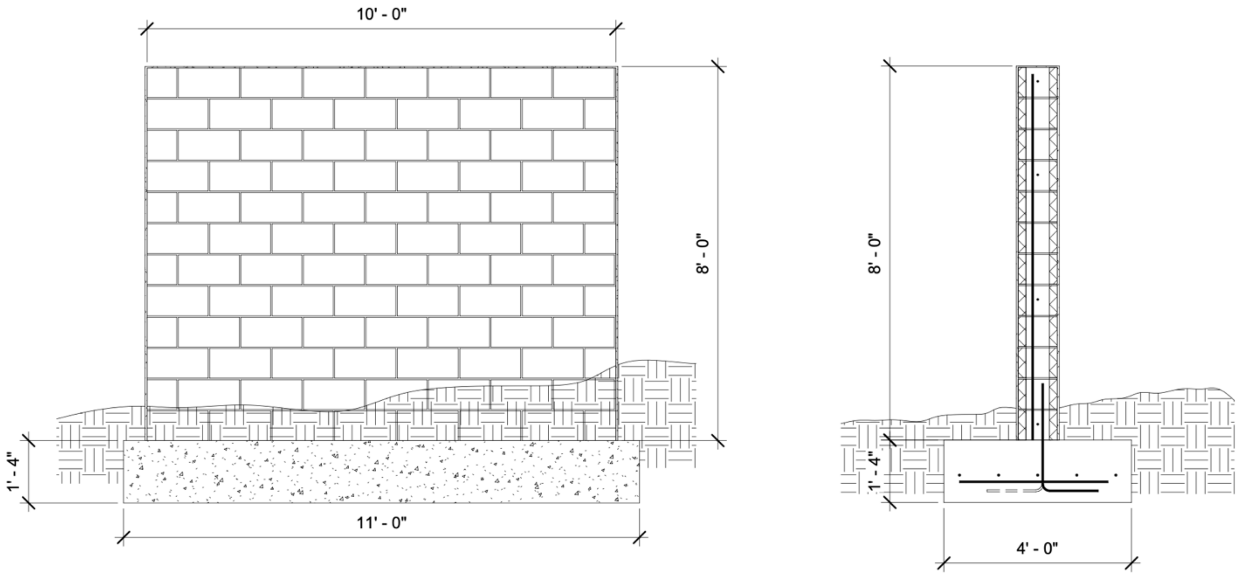


Figure 3 elevation dimensions of wall

Figure 4 mockup of wall on site

Schedule

As an Architectural Engineering senior project, the estimated time of completion is the end of Spring Quarter 2024. See Appendix for full schedule

Figure 5 Gantt Chart

Cost Estimate

Connections within the Architectural Engineering and Construction Management departments will be investigated as potential funders as well as local companies in San Luis Obispo.

Rebar	Length			
#4, Horizontal	(5) Horiz 10' + (5) Horiz 11' + (10) Horiz 4' = 145'			
#4, Vertical	(5) Vert 8' + (10) Vert 4' = 80'			
Materials	**Quantity**	**Price Per Unit**	**Total Price**	**Reference**
CMU 8"x8"x16"	120 full and 14 half		$1,181	Air-Vol Block
Mortar	11 bags	$8.02/per 80lb bag	$88	Air-Vol Block
Grout	68 bags	$4.60/per 60lb bag	$313	Air-Vol Block
Rebar	225 feet	$12.20/20' stick	$146.40	Air-Vol Block
Concrete	2.5 cubic yards		$620	Holliday Rock
Plaster	170 square feet	25$/25lb bag	$100	Home Depot
Rentals	**Quantity**	**Price Per Unit**	**Total Price**	
Concrete Pump Setup	-	$250	$250	
Supplies	**Quantity**	**Price Per Unit**	**Total Price**	
Tarp 9x20			$14	
Tarp 5x7 (4)			$12	
Pick axe	2	$30/ unit	Borrow	
Shovel	2	$30/ unit	Borrow	
Grade Stakes	6	$8/ unit	$40	
Screws	2	$7/ unit	$14	
Boots	5	$35/unit	$175	
Silt Fence	1		$55	
2x4 Screed	1		$10	
Edger	2		$50	
Plaque			$500	
Miscellaneous			$300	
		Total :	**$3,869**	
Notes:				
Holliday Concrete				
$1,200	with delivery			
120ish blocks and 14ish half blo	150 Delivery			
20' of #4 = 12.20$				
Mortar 80 pound bag = 8.02	Airvol for both			
Grout (concrete?) 60 pounds =				

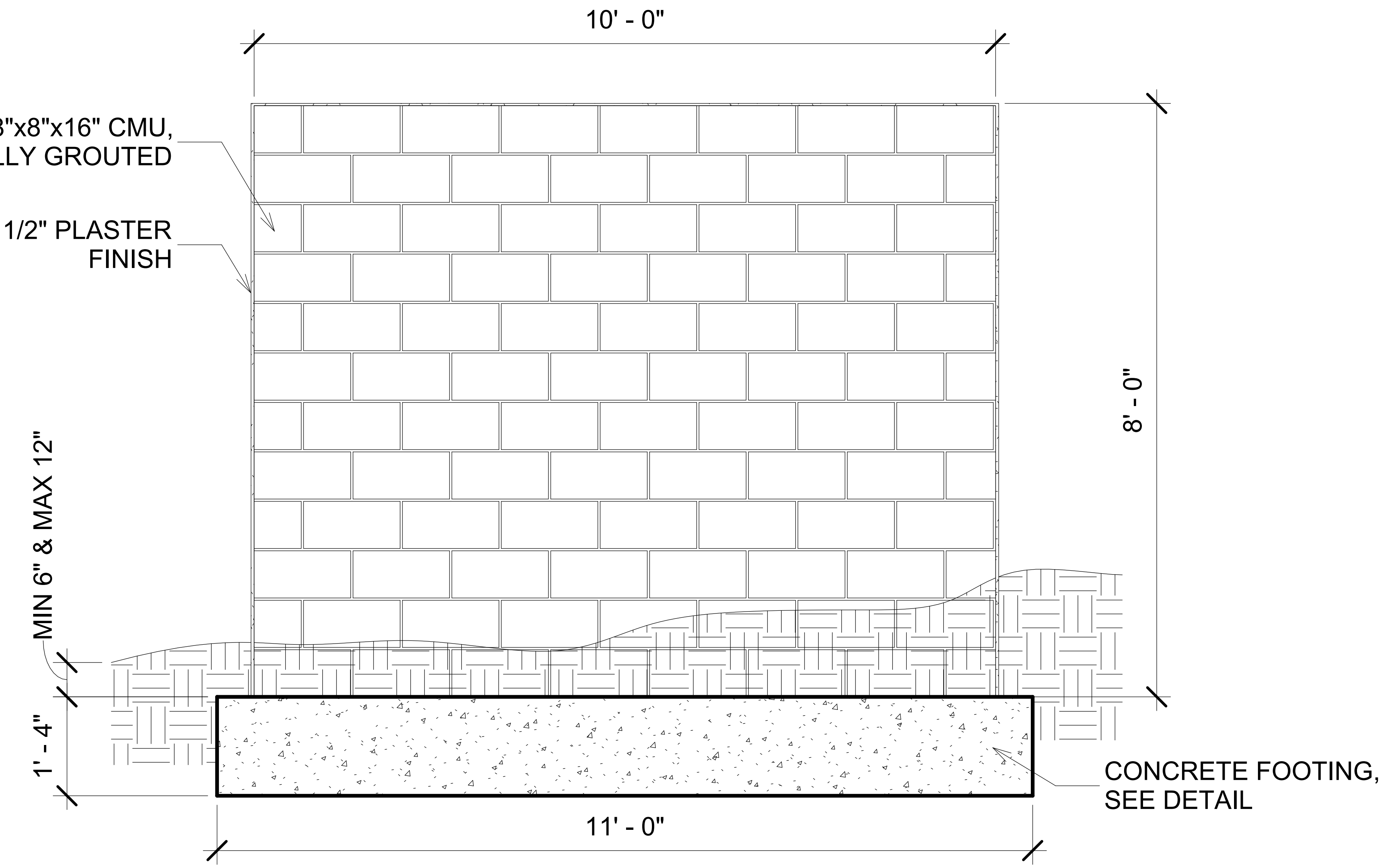
Figure 6 Cost Estimate

Appendix

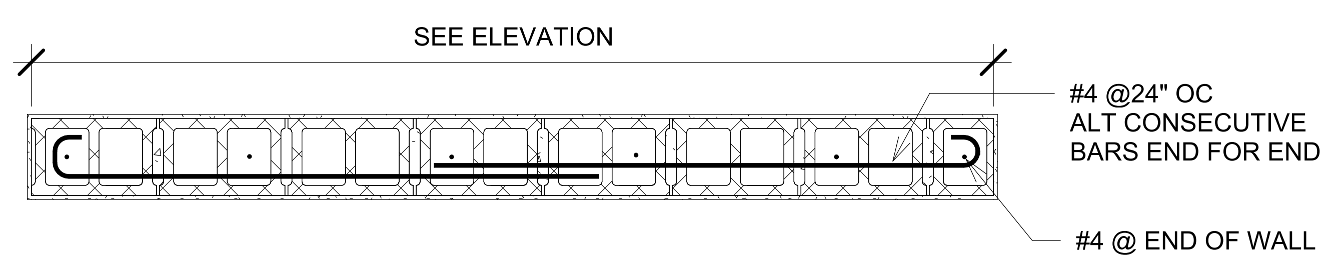
Appendix A: Structural Drawings

Appendix B: Structural Calculations

Appendix C: Gantt Chart Schedule



1 WALL ELEVATION
1/2" = 1'-0"



2 WALL SECTION A
1/2" = 1'-0"

THE CANVAS

ARCE 453,
INTERDISCIPLINARY
STUDENT SENIOR
PROJECT
W/ KEVIN DONG

STAMP:

SITE:
POLY CANYON,
SAN LUIS OBISPO,
CA 93407

DRAWN BY:
SE, JR

CHECKED BY:
KD

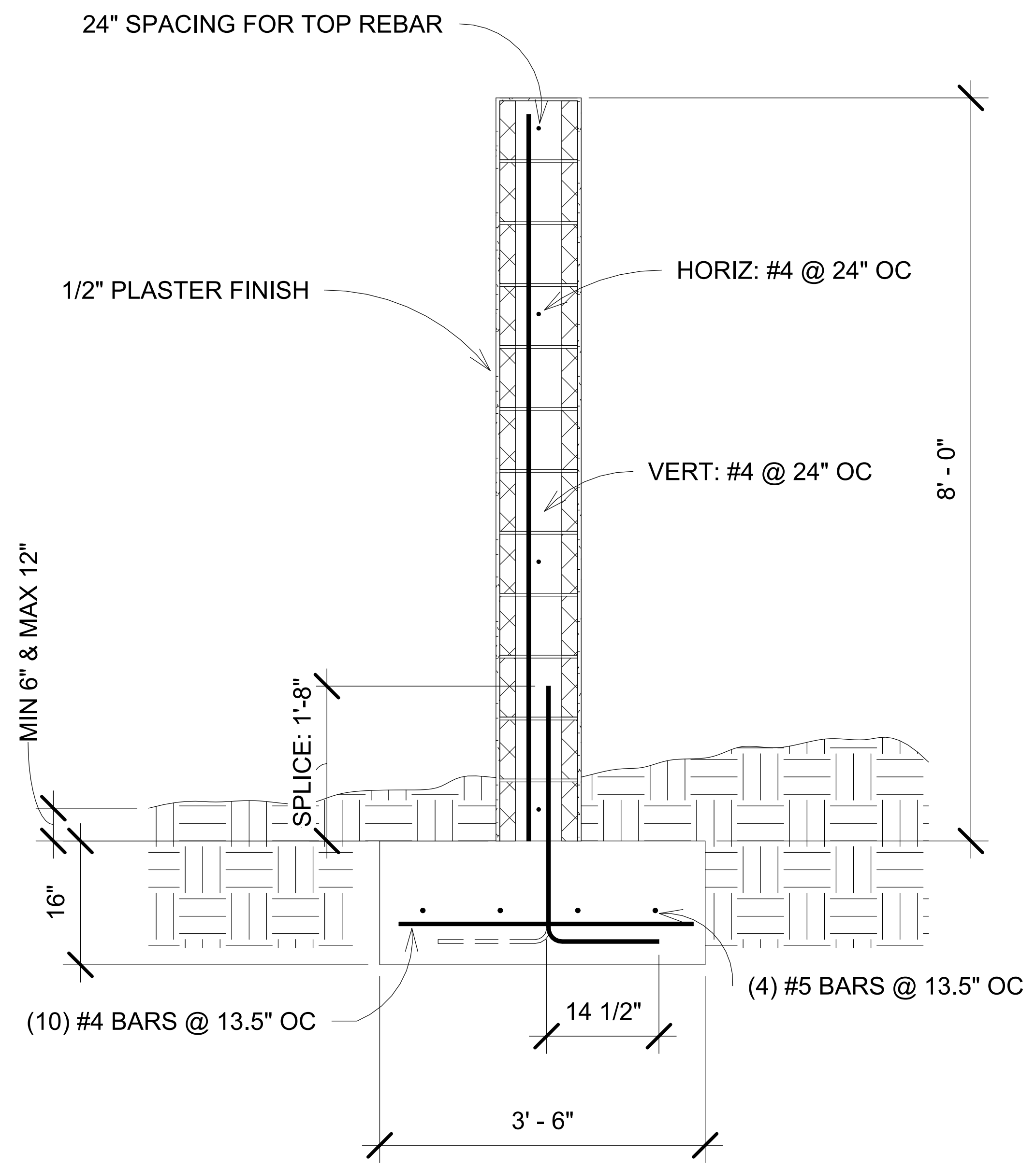
DATE:
6/19/24

SCALE:
1/2" = 1'-0"

SHEET NUMBER:

S1

STRUCTURAL
DETAILS



1 WALL ELEVATION B
1/2" = 1'-0"

THE CANVAS

ARCE 453, INTERDISCIPLINARY STUDENT SENIOR PROJECT W/ KEVIN DONG

STAMP:

SITE:
POLY CANYON, SAN LUIS OBISPO, CA 93407

DRAWN BY:
SE, JR

CHECKED BY:
KD

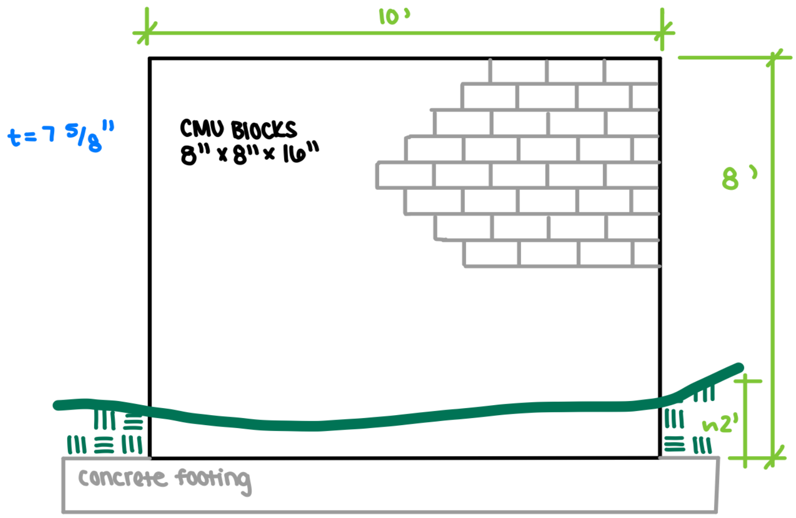
DATE:
6/19/24

SCALE:
1/2" = 1'-0"

SHEET NUMBER:
S2
STRUCTURAL DETAILS

ARCE 453, Poly Canyon Wall	Calculation: Overview	Page 1/1
Interdisciplinary Senior Project Student Group - Kevin Dong	Sheet Title: Dimensions and Weights	Date: 4/9/24 Name: Sara Engmyr

Wall Overview



CMU Blocks: 10"x8"x16" (nominal)

width =	7.625	in	weight =	95	psf (8" CMU)			
Length =	10	ft	Height =	8	ft	t =	7.625	in
				(maximum)			1	CMU Block Wide
# CMU, L:	7.5	blocks	# CMU, H:	12	blocks			

Wall Weight

W_{wall} = **7.6** **kips**

ARCE 453, Poly Canyon Wall	Calculation: Lateral	Page 1/1
Interdisciplinary Senior Project Student Group - Kevin Dong	Sheet Title: Wind Forces	Date: 4/9/24 Name: Sara Engmyr

References: ASCE 7-16
Chp. 26 Wind General Req.
Chp. 29 Wind, Other Structures
* see ASCE 7 Hazard Report for hazard vaules

V = 87 mph   Risk Cat: I   Exposure: C

Solid Freestanding Walls/Signs

Kd =	0.85	(wind directionality)
Kzt =	1	(topogrphic factor)
Ke =	1	(ground elevation factor)
G =	0.85	(gust effet)
Kh =	0.85	

$$q_h = .00256 K_h K_{zt} K_d K_e V^2$$

qh =	14.00	psf	(Eq. 26.10-1)
qh min =	16.00	psf	
therefore **qh =**	**16.00**	**psf**	

Cf = 1.425 (force coefficient) (Fig. 29.3-1)

Design Wind Force

$$F = q_h G C_f A_s$$

F =	19.38	psf
F =	**1.55**	**kips**

ARCE 453, Poly Canyon Wall	Calculation: Lateral	Page 1/1
Interdisciplinary Senior Project Student Group - Kevin Dong	Sheet Title: Seismic Forces	Date: 4/9/24 Name: Sara Engmyr

References: ASCE 7-16
Chp. 15 Seismic Design, Non Building Structures
* see ASCE 7 Hazard Report for hazard values

Seismic Design Forces (Sec. 15.4)

S_{DS} =	0.889	Soil/Site Class =	D, default	Ie =	1

Signs and Billboards (Table 15.4-2)

R =	3	Ω =	1.75	Cd =	3
$V = .3S_{DS}WI_e$		W =	7.6 kips	Cs =	0.27
$C_{s\,min} = .044S_{DS}I_e$		Cs min =	0.04	therefore Cs =	0.27
$V = C_sW$		**V =**	**2.03 kips**		

$T_a = C_t h_n^x$ (Eq. 12.8-7)

Ct =	0.02	hn =	8 ft	x =	0.75

T_a =	0.10	sec
T_L =	8	sec
S_1 =	0.408	
Fv =	1.9	

(ASCE Hazard Report)

(Eq. 11.4-2)
(Eq. 11.4-4)

$S_{M1} = F_vS_1$ SM1 = 0.78

$S_{D1} = {}^2/_3\, S_{M1}$ SD1 = 0.52

T < T_L so $C_s = \frac{S_{D1}}{T(R/I_e)}$ (need not exceed) (Eq. 12.8-3) Cs = 1.81, compare to 0.27 GOOD

Summary Seismic Design Values

V =	2.03	kip	
V =	**25.34**	**psf**	(divide by wall area, kip to psf)

ARCE 453, Poly Canyon Wall	Calculation: Lateral	Page 1/1
Interdisciplinary Senior Project Student Group - Kevin Dong	Sheet Title: Summary Design Values	Date: 4/9/24 Name: Sara Engmyr

Wind Design Values (from previous page, "Wind Forces")

Fw = 1.55 kips

Fw = 19.38 psf

Seismic Design Values (from previous page, "Seismic Forces")

F_{EQ} = 2.03 kips

F_{EQ} = 25.34 psf

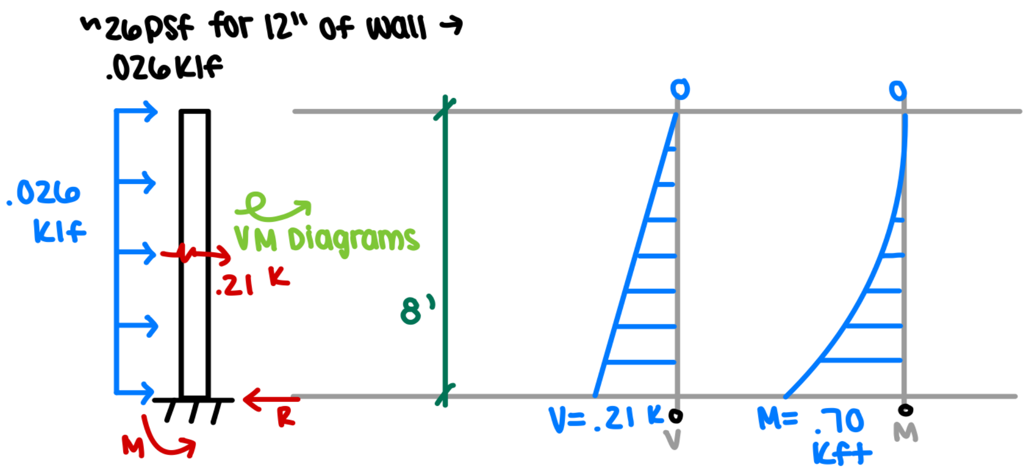
Governing Load Case: Seismic

Relevant Load Combos:

1.2D + 1.0Ev + 1.0Eh

.9D - Ev + Eh

Diagram 1.0 E (Hand Calc)



R=.026klf (8') R = .21 K

1/2(21)(8')^2 → ~.70 kft M= .70 kft

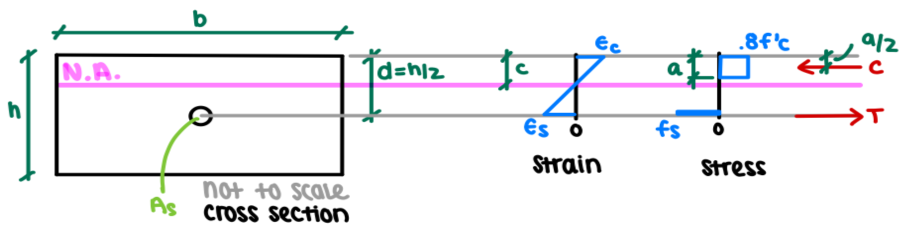
$wL^2/2$

Mu = 0.7 k*ft

per foot of wall

ARCE 453, Poly Canyon Wall	Calculation: Wall Design	Page 1/1
Interdisciplinary Senior Project Student Group - Kevin Dong	Sheet Title: Vertical Reinforcement	Date: 4/16/24 Name: Sara Engmyr

Moment Calculation



Internal Equilibrium

$\Sigma F_x = 0 \quad T = C$

$A_s f_s = .8 f'_c\, a\, b \quad \rightarrow$ solve for $a = \frac{A_s f_s}{.8 f'_c b}$

Internal Moment

$\Sigma M = 0 \quad M_n = T(d - a/2)$

$= A_s f_s \left(d - \frac{A_s f_s}{.8 f'_c b}(1/2)\right)$

$f_s = f_y, \quad M_n = A_s f_y \left(d - \frac{A_s f_y}{.8 f'_c b}(1/2)\right)$

Material Properties

f'c = 2000 psi   fy = 60000 psi

f'm

Section Properties

h = 7.625 in   b = 24 in   d = 3.81 in

(imaginary wall section, help determine spacing)

a = 0.31 in

Vertical Reinforcement

As = 0.200 in^2 --->   (for 24in)   **#4 @ 24" o.c.**

Check Reinforcement Limits   *see equations above

$A_{sv} = .0007 * s * h$ Asv = 0.128 in^2 GOOD

Mn = 43875.0 lb*in   from above equation

Mn = 3.66 k*ft

ϕMn = 3.29 k*ft

Mu = 1.4 k*ft --->   (for 24in)

DCR: 0.43   GOOD

Check Cracking Moment

$M_{cr} = S_x f_r$ Mcr = 4.49 kft

NO CRACK, GOOD

Sx = 0.04 ft^3

fr = 127.28 ft and kips

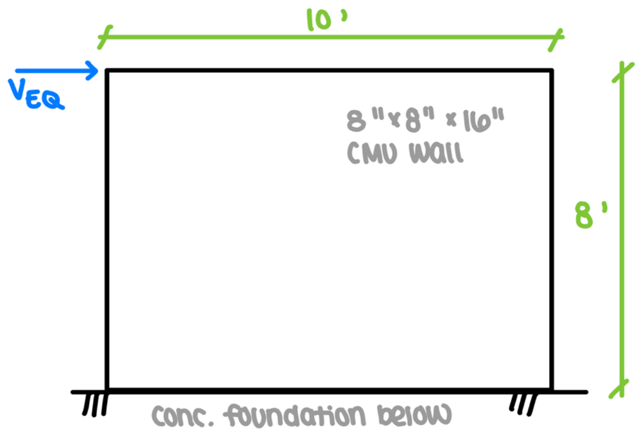
Vertical Reinforcement

#4 @ 24" o.c.

ARCE 453, Poly Canyon Wall	Calculation: Wall Design	Page 1/1
Interdisciplinary Senior Project Student Group - Kevin Dong	Sheet Title: Horizontal Reinforcement	Date: 4/16/24 Name: Sara Engmyr

In Plane Lateral Load

Shear Resistance of Concrete Masonry Shear Wall — DORMS Ex. 5.7.1



V = 2.03 kips | H = 8 ft | L = 10 ft

Load Combo: .9D - Ev + Eh

1.0 DL =	7.6	kips	**Eh =**	**2.03**	**kips**
$.2S_{DS}$ =	0.178		$M_E = V_E h$		
P = .9D - Ev =	**6.66**	**kips**	**M_E =**	**16.22**	**kft**

$$f_v = \frac{1.5V}{A_{nv}}$$

fv = 2.19 psi

*special reinforced multiplied by 1.5

$$\frac{M}{V d_v} = 0.67$$

therefore max. shear stress given by: $F_v = (F_{vm} + F_{vs})\gamma_g$

$$F_{vm} = \frac{1}{4}\left(4 - 1.75\frac{M}{V d_v}\right)\sqrt{f'_m} + .25\frac{P}{A_n}$$

Fvm = 31.68 psi

An =	1440	in^2
Anv =	1386	in^2
f'm =	2000	psi
γg =	1.00	
L = dv =	12	ft

Fvm > fv **GOOD** no need to check shear, min. reinforcing

#4 @ 24" o.c.
Horizontal Reinforcing
(max. spacing is 48")

*change to

Vertical Reinforcing	#4 @ 24" o.c.
Horizontal Reinforcing	#4 @ 24" o.c.

ARCE 453 POLY CANYON WALL INTERDISCIPLINARY SENIOR PROJECT STUDENT GROUP – KEVIN DONG ENGINEERING WEST, CAL POLY SLO	CALCULATION FOOTING	DATE 23 MAY 2024	SHEET 1/5
	SHEET TITLE EXCEL CALCULATOR	NAME JORA LEIGH	

STRIP FOOTING ANALYSIS: H = 16", B = 3.5'

MATERIAL PROPERTIES

MATERIAL PROPERTIES			REF.
CONCRETE			
f'c	2.5	ksi	
λ	1		
εcu	0.003	in/in	
β1	0.85		
wc	0.15	kcf	
STEEL			
fy	60	ksi	
fyt	60	ksi	
Es	29000	ksi	
εy	0.0021	in/in	
SOIL			
P_bear	1.5	ksf	1.
Cohesion	0.13	ksf	1.
ws	0.11	ksf	
MASONRY			
wm	0.15	ksf	

MEMBER GEOMETRY AND WEIGHTS

MEMBER GEOMETRY AND WEIGHTS		
FOOTING		
H	1.33	ft
B	3.5	ft
COVER	3	in
d	1.1	ft
Pf	0.7	k
WALL WALL		
bw	0.64	ft
lw	10	ft
hw	8	ft
Pw	0.76	k
SOIL		
tsoil	0	ft
Ps	0.0	k
Ptot	1.46	k

FORCES AND LOAD COMBINATIONS

FORCES AND LOAD COMBINATIONS			REF.
FORCES ON WALL PER FOOT			
Vtot,ULS	28.0	plf	
Vtot,ASD	19.6	plf	
Mot,ULS	1.19	k-ft	
Mot,ASD	0.84	k-ft	
OVERTURNING CHECK			
Mr	2.56	k-ft	
Mr / Mot	3.1		
CHECK Mr / Mot > 1.1	YES		4.

SOIL BEARING PRESSURE (ASD)

SOIL BEARING PRESSURE (ASD)			REF.
P	1.46	k	
Mot	0.84	k-ft	
e	0.57	ft	
CHECK B/2	STABLE		
qmax	0.84	ksf	
qmin	0.00	ksf	
qmax ok?	YES		

SOIL SLIDING

SOIL SLIDING			REF.
Vs	0.224	k	6.
Vallow	0.455	k	
CHECK Vslide	YES		
CHECK Vallow / Vs > 1	YES		

STEEL REINFORCEMENT

STEEL REINFORCEMENT			REF.
FLEXURAL TENSILE REINFORCEMENT (BOT)			
Asreq	0.21	in^2	
BAR SIZE	5		
BAR AREA	0.31	in^2	
BAR DIA	0.625	in	
# OF BARS	4		
As	1.24	in^2	
SPACING	12.0	in	
SPACING OK?	YES		
MINIMUM AREA CHECK			
Asmin (0.0018*H*B)	1.2	in^2	3.
As≥Asmin?	YES		

OTHER LONGITUDINAL REBAR

OTHER LONGITUDINAL REBAR		
Asmin (0.0009*H*1')	0.17	in
LONG WAYS (BOT)		
BAR SIZE	4	
BAR AREA	0.2	in^2
BAR DIA	0.5	in
(Asmin / BAR AREA)	0.864	
SPACING	13.5	in
SPACING OK?	YES	

FLEXURAL CALCULATIONS (BOT, ULS)

FLEXURAL CALCULATIONS (BOT, ULS)			REF.
Cc	74.4	k	
Ts	74.4	k	
Cc-Ts	0	k	
c	1.0	in	
a	0.8	in	
εs	0.0358	in/in	
εs≥εy?	YES		
Mn_kin	912.9	k-in	
Mn	76.1	k-ft	
ϕf	0.9		
ϕfMn	68.5	k-ft	

SHEAR CALCULATIONS (ONE-WAY, ULS)

SHEAR CALCULATIONS (ONE-WAY, ULS)		
Vc	9.7	k
ϕv	0.75	k
ϕvVn	7.3	k

FOOTING CAPACITY CHECKS (ULS=ASD/0.7)

FOOTING CAPACITY CHECKS (ULS=ASD/0.7)		
qmax,ULS	1.19	ksf
qmin,ULS	0.00	ksf
ONE-WAY SHEAR		
Vu	2.26	k
d/c RATIO,Vu	0.31	
CHECK Vu	YES	
FLEXURE		
j	0.95	
Mu	11.21	k-ft
d/c RATIO,Mu	0.16	
CHECK Mu	YES	

DEVELOPMENT LENGTH

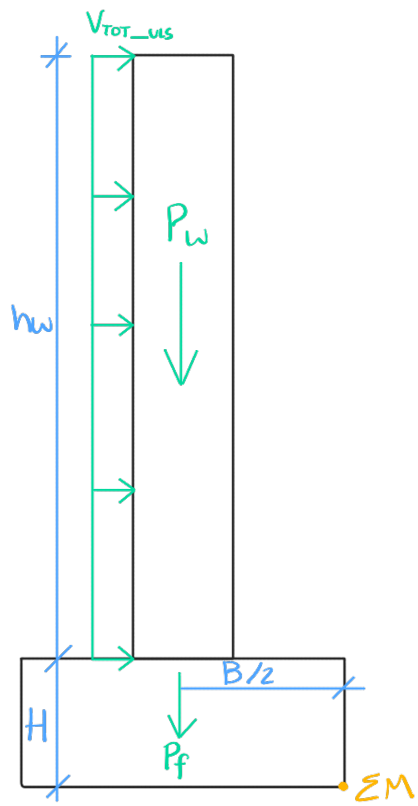
DEVELOPMENT LENGTH		
Ld	14.4	in
Ld_avail	17.2	in
CHECK Ld	YES	

SUMMARY

SUMMARY	
FLEXURE	
ALONG B=3.5'	
BOTTOM	4 #5 BARS @12IN. O.C.
LONG WAYS	
BOTTOM	#4 BARS @13.5IN. O.C.

1. **IBC 2021 Table 1806.2**
2. **IBC 2021 §1806.1**
3. **ACI 318-19 §8.6.1.1**
4. **IBC 2021 §1807.2.3**
5. **IBC 2021 §1605.2**
6. **IBC 2021 §1806.3**

ARCE 453 POLY CANYON WALL INTERDISCIPLINARY SENIOR PROJECT STUDENT GROUP – KEVIN DONG ENGINEERING WEST, CAL POLY SLO	CALCULATION FOOTING	DATE 23 MAY 2024	SHEET 2/5
	SHEET TITLE FORCES & MOMENTS	NAME JORA LEIGH	

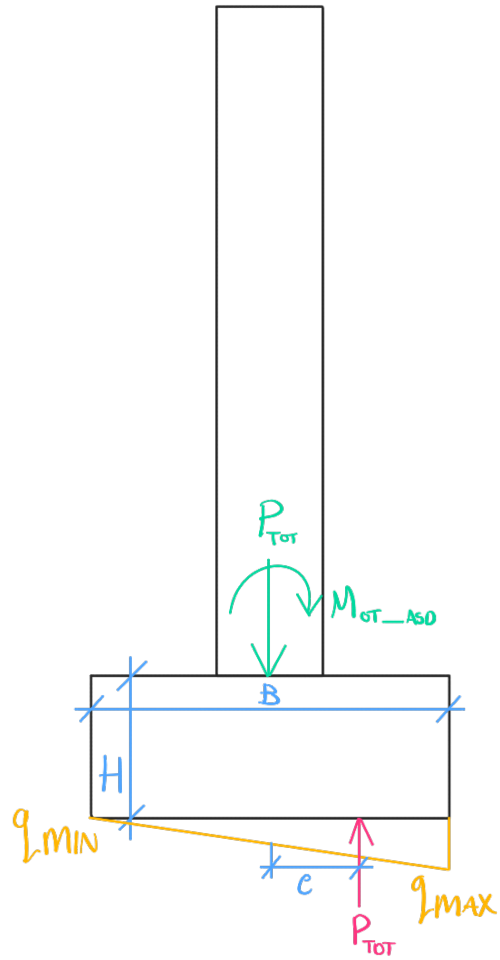


$$M_{OT} = 0.7\,V_{TOT\_US}(h_w)(h_w/2 + H)$$

$$M_r = \underbrace{(P_w + P_f)}_{P_{TOT}}(B/2)$$

$$\frac{M_r}{M_{OT}} > 1.1$$

ARCE 453 POLY CANYON WALL INTERDISCIPLINARY SENIOR PROJECT STUDENT GROUP – KEVIN DONG ENGINEERING WEST, CAL POLY SLO	CALCULATION FOOTING	DATE 23 MAY 2024	SHEET 3/5
	SHEET TITLE BEARING PRESSURE	NAME JORA LEIGH	

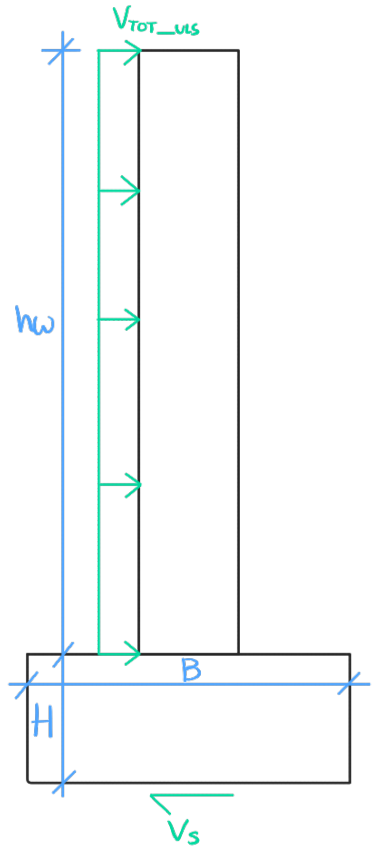


$$e = \frac{M}{P}$$

$$q_{MIN} = 0$$

$$q_{MAX} = \frac{2P}{B}$$

ARCE 453 POLY CANYON WALL INTERDISCIPLINARY SENIOR PROJECT STUDENT GROUP – KEVIN DONG ENGINEERING WEST, CAL POLY SLO	CALCULATION FOOTING	DATE 23 MAY 2024	SHEET 4/5
	SHEET TITLE SOIL SLIDING	NAME JORA LEIGH	

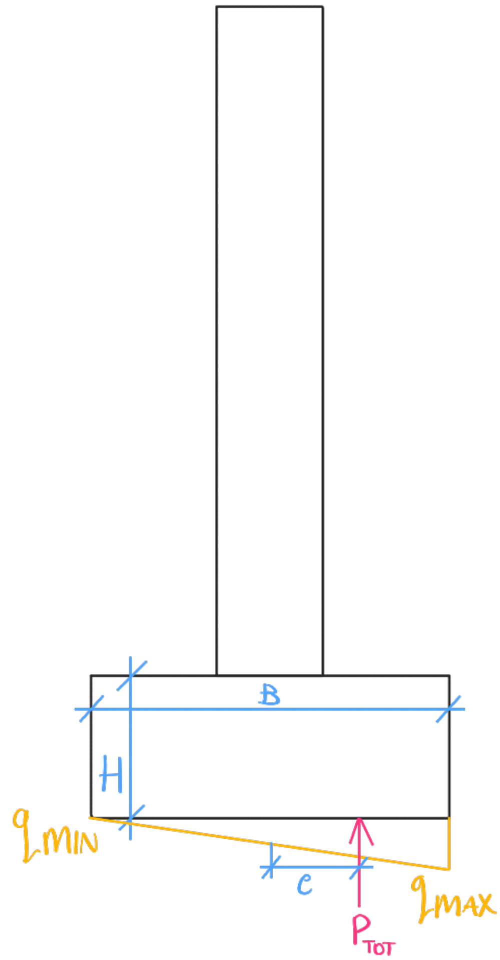


$$V_s = V_{TOT\_ULS}(hw)$$

$$V_{ALLOW} = COHESION(B)(1')$$

$$\frac{V_{ALLOW}}{V_s} > 1$$

ARCE 453 POLY CANYON WALL INTERDISCIPLINARY SENIOR PROJECT STUDENT GROUP – KEVIN DONG ENGINEERING WEST, CAL POLY SLO	CALCULATION FOOTING	DATE 23 MAY 2024	SHEET 5/5
	SHEET TITLE SHEAR & FLEXURE	NAME JORA LEIGH	



SHEAR

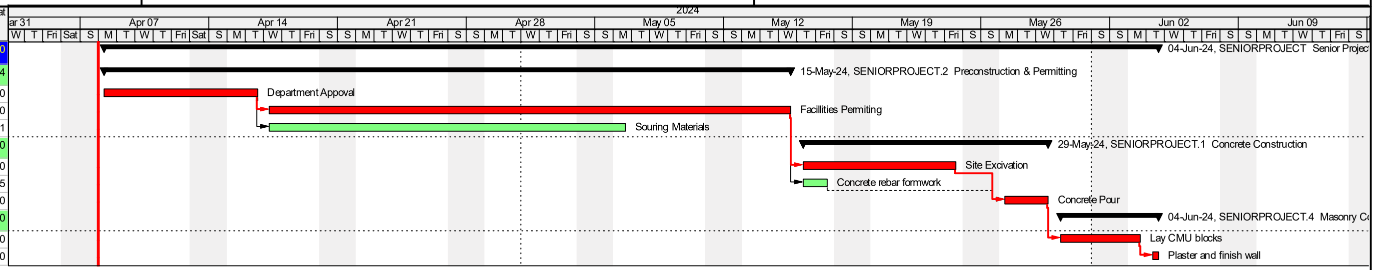
$$V_u = P_{TOT} + \frac{2}{3} q_{MAX}$$

FLEXURE

$$M_u = P_{TOT}(e + b/2) + \frac{2}{3} q_{max} b^2$$

Senior Project	Classic Schedule Layout	08-Apr-24 09:15

Activity ID	Activity Name	Original Duration	Start	Finish	Total Float
SENIORPROJECT	**Senior Proj**	42	08-Apr-24	04-Jun-24	0
SENIORPROJECT.2	**Preconst**	28	08-Apr-24	15-May-24	14
A1040	Department Appoval	7	08-Apr-24	16-Apr-24	0
A1050	Facilities Permiting	21	17-Apr-24	15-May-24	0
A1060	Souring Materials	14	17-Apr-24	06-May-24	21
SENIORPROJECT.1	**Concrete**	10	16-May-24	29-May-24	0
A1070	Site Excivation	7	16-May-24	24-May-24	0
A1080	Concrete rebar formwork	2	16-May-24	17-May-24	5
A1100	Concrete Pour	3	27-May-24	29-May-24	0
SENIORPROJECT.4	**Masonry**	4	30-May-24	04-Jun-24	0
A1000	Lay CMU blocks	3	30-May-24	03-Jun-24	0
A1090	Plaster and finish wall	1	04-Jun-24	04-Jun-24	0



Actual Level of Effort	Remaining Work	Page 1 of 1	TASK filter: All Activities
Actual Work	Critical Remainin...		© Oracle Corporation

A.2

Costs and Materials			
	Actual Cost:		
	First Home Depot Trip (Richard)		
	Scrub	Quickie Heavy D	$19.97
	Graffiti Remover		$9.47
	Concrete Cleaner		$11.47
	Scour Pad		$4.18
	Wire Brush		$4.98
	Bucket		$4.48
	Tax		$4.77
	Total		$59.32
	Second Home Depot Trip (Richard)		
	Sandpaper	2x6.98	$13.96
	10" Shear		$14.97
	Sharpie		$2.68
	Paint Stick		$1.48
	FG Nitirle Coated 5-PK		$5.00
	Grease Monkey Disp. Nitril		$21.87
	Chains	4x53.00	$212.00
	Sand		$5.47
	Fiberglass Resin		$23.98
	Grout		$13.97
	Gap Filler	2x6.48	$12.96
	Plastic Drop Cloth		$11.78
	Fiberglass Mat		$8.28
	Putty Spreader		$4.98
	Hook		$1.38
	Flat Brush		$2.94
	Duck Tape		$6.98
	Sales Tax		$32.78
	Total		$407.43
	Third Home Depot Trip (Richard)		
	Brush	2x14.47	$28.94
	Brush		$12.47
	Fiberglass Resin		$59.48
	Sales Tax		$8.83
	Total		$109.72
	Fourth Home Depot Trip (Richard)		
	Quick Link 1/4		$4.35
	Sales Tax		$0.38
	Total		$4.73
	Fifth Home Depot Trip (Richard)		
	Quick Link 3/8	2x5.40	$10.80
	Sales Tax		$0.95
	Total		$11.75
	(Richard)		
	Total		$592.95
	Sixth Home Depot (Jora)		
	Spray Paint	x5	$52.40
	Sales Tax		$4.59
	Total		$56.99

A.3

TECHITE BRIDGE

PROPOSED BRIDGE FOR POLY CANYON ENTRANCE

(Const. Engr.)

by

Robert Purdy

Merrilee Amy

Robert Mac Ewan

California Polytechnic State University

San Luis Obispo, California

1973

Date Submitted: ____

Grade: ____

Project Advisor: ____

Recorder: __

Department Head Approval: __________

TABLE OF CONTENTS

STATEMENT OF APPRECIATION

We, the students, would like to make known our appreciation for the generous assistance of our advisors. Mr. Mager and Mr. Draves, first and second quarter advisors, have shown great patience with our schedules. The confidence that they have shown us cannot be over-stressed.

Second, and equal thanks goes to the United Technology Center for their support and contribution of time and materials to this project. Mr. Oscar Weingart and Bruce Glascock provide invaluable materials that brought us up to date on fiberglass methods of design.

Lastly, the School of Architecture has provided the testing facilities to confirm the data provided by U.T.C. The experience of Mr. Bob Meyers in setting up and testing materials assured us of a minimum of error in this program.

PREFACE

From the beginning of this project, our goal has been to test Techite in a practical application. We, the students, believe that there is substantial evidence that our design would be a valuable asset to the Poly Canyon. In our study we will show the logical steps that brought us to this conclusion.

Because of our interest in and ignorance of Fiber-Reinforced Plastic (F.R.P.) we contacted the United Technology Center in Sunnyvale, California. They directed us to their Techite plant in river-side, California. We arranged for an interview and tour of the plant early in the winter quarter. Mr. Weingart, Manufacturing-Engineering Manager, and Mr. Bruce Glascock, Product Engineer, met with us for the better part of the day. We discussed the various methods of constructing F.R.P. pipe and why U.T.C. chose filament winding. This will be discussed later section one of this paper, titled What is Fiber-Reinforced Plastic?" We relied heavily on the date furnished by Bruce Glascock in our design.

THE PROBLEM

The Setting of the Problem

Fiber-Reinforced Plastic has many applications. Yet, as a structural component, F.R.P. has not been widely accepted in the building industry. Since 1956, many proposals have been written and prototypes have been built in an effort to educate the structural designers. The restraining factor seems to have been a distrust of the short and long-range characteristics (flammability, creep, and ultra-violet deterioration). There is no fire rating for F.R.P. in the Uniform Building Code.

Statement of the Problem

The purpose of this study is to explore the usefulness of Techite in a structural application. We had anticipated using Techite in more than one stress condition. The following questions are to be addressed in this paper:

1. What is Fiber-Reinforced Plastic?
2. Can it be joined easily in the field as well as in the shop?
3. Is cost a current restraining factor?
4. How do we design intelligently with this material?

The Importance of the Problem

At a time when the cost of building materials in spiraling, alternative products must be investigated. As our limited resources of wood are being sent abroad to form an artifically high cost of that material here, we fortunately have available a product that is as limitless as the sand on the beach: fiberglass.

WHAT IS FIBER-REINFORCED PLASTIC?

General Properties of Techite

Techite is a composite structure of polyester resin mortar reinforced with continuous fiberglass filaments. Techite pipe combines these materials in a properly engineered structure to produce a high-strength, light-weight pipe. The inherent tensile strength of fiberglass filaments (in excess of 200,000 psi.) in a filament-wound structure gives Techite pipe the ability to withstand high internal pressure with large factors of safety. This matrix combines resiliency with strength. As a non-brittle material, Techite can accomodate intense live loads and earth settlements without over-stressing.

The raw materials from which Techite pipe is made (fiberglass, sand, and isophthalic polyester resin) show a high degree of resistance to weathering. This resistance is not dependent upon the thickness, coatings, or additives, but is characteristic of the entire pipe structure. The high factor of safety mentioned renders a service life in excess of fifty years. (See Appendix F)

Although the Techite used in this problem was only eight inches in diameter, it can be wound larger than forty-eight inches with lengths up to eighty feet.

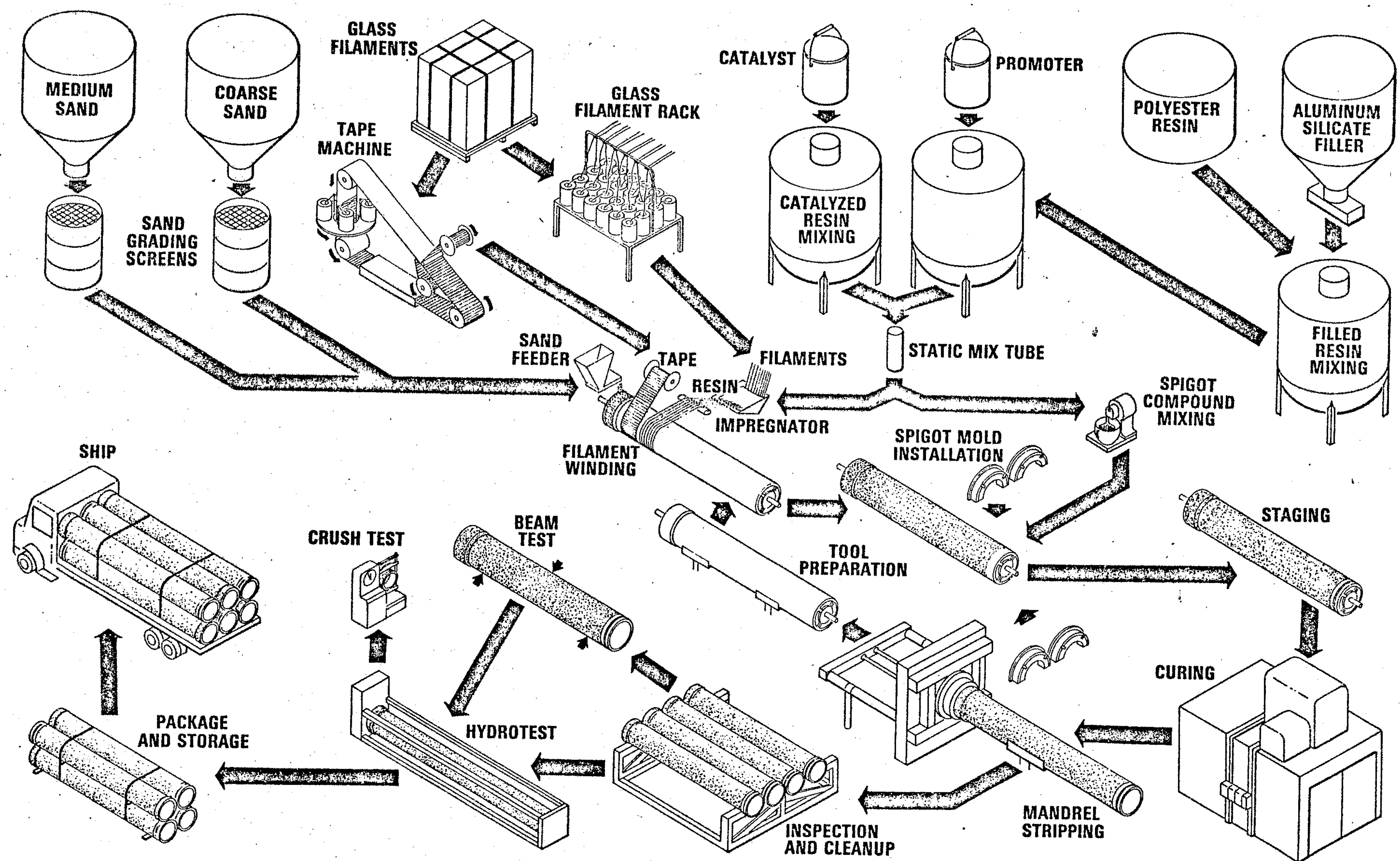
Manufacturing Techite

Filament winding is a process that has been used in the aerospace industry for many years. The glass strands are brought from their molten state through an electrically heated orifice. The rate of pull determines the diameter of the filament. The strands are either wound in coils called revings or woven in mats. Techite is wound on a steel mandrel from strands dipped in resin. This is called the wet method.

Next, an alternating mat called the tape is applied. During this operation, screened sand (.02 inches and .04 inches) is fed over the windings and mat to fill any voids and prevent air bubbles. All of this is done in one station. As mentioned before, the standard length is twenty feet. However, the only limit to length is that of the mandrel. Also, there is no limit to the thickness of the wall as the pipe will cure well despite the number of layers of glass and sand.

The pipe is now moved to an oven for a specified period of time to hasten curing. The pipe is then removed from the mandrel by the use of a hydraulic ram. Inspection is first visual. Then a random sample of one in every one-hundred pipes is tested by the normal beam test. The acceptable limits will be shown in the appendix. (See Appendix H)

TECHITE PROCESS FLOW



UTC-V-00187

United Technology Center DIVISION OF UNITED AIRCRAFT CORPORATION

CAN IT BE JOINED EASILY?

Fiberglass Joints: Field and Shop

Considering a system of joints that would be compatible with Techite became an exercise in frustration. The first thought was that the design had to be of fiberglass also. While we took our tour through the plant in riverside we saw the specialty shop that cut and pieced bends, wyes and other custom joints. We soon realized that it was a slow, tedious and exacting process. We also consulted several back issues of "Chemical Engineering." Mr. Thomas Lautenback, in the Autust 3, 1964 issue of "Chemical Engineering," points out:

> The most popular types are: plain end, bell and spigot, and integral threaded . . .The principal aim in butt-and-strap joining is to make the joints as strong as the pipe itself. Of critical importance is the width of the strapping materials which must be of sufficient dimension to withstand the shear stresses. In practice the joint is usually made much wider than is necessary. The axial and bursting stresses at the joint are satisfied by making the lam-

inate construction as thick as the pipe . . . A widely used filament-wound epozy pipe is provided with bell-and-spigot ends that can be assembled with great speed. For example, three-man crews have assembled 2,700 feet of this pipe in only one hour . . . Integral threaded pipe has the obvious advantage of requiring the least number of fabricate steps. In many cases, all that is required is manual thread assembling.

He continues:

> Apex Fibre-glass Products Division of White Sewing Machine Corporation, Cleveland, Ohio, provided templates that allow joints and fittings to be fabricated directly. Templates available include tees, ells, crosses, wyes, and the like.
>
> To fabricate a fitting the template is first traced onto a section of the pipe. Cuts should initially be made with a hacksaw and then completed with a sabre saw. A one-inch-wide area next to the cut is then scuffed with a coarse sandpaper and cleaned with lacquer thinner or naptha. Special resin is then applied to glass tape (much as it is applied to butt-and-strap joint) and to the pipe. The tape is positioned over the joint and pressed firmly with a wood spatula to ensure impregnation of the resin. The resin will completely cure in a few hours at room temperature, or in a few minutes under heat lamps.

As the bridge cannot be fully prefabricated in the shop we anticipated no less than twenty-four field joints. Researching the periodicals further turned up exactly what we had been needing.

In his article entitled "Field Joining Reinforced Plastic Pipe," Mr. A. F. Fonda stresses many of the same ideas that Thomas Lautenbach did except that he gives a design equation for the minimum shear length of a butt-and-strap joing. He also makes the assertion, "While some pipe manufacturers offer installation service, the job can be done by your plant crew. . ." He later qualifies this statement; "However, it is always desirable to have a plastics engineer examine the basic design. . ." We had to come up with a simpler method.

Steel Joints: Welded and Bolted

The next alternative was a steel joint that would slip inside the pipe. We would then bolt the steel to the Techite and also to a gusset palte. As a matter of coincidence, structural steel tubing has an outside diameter that is exactly the inside diameter of Techite. Unfortunately, it also costs ten dollars per lineal foot. (For our project, this amounts to some $240 for steel tubing alone.) We tried unsuccessfully to get a donor.

We then decided to angle an iron joint welded together with two-inch, curved pieces to fit in the pipe. We anticipated that the Techite would fail near twenty thousand pounds in compression. We know that we had overdesigned our angle iron by a factor of three and felt that four high-strength bolts would do the job for testing purposes.

We were astounded and pleased when the bolts began to deform and the Techite maintained its integrity until thirty-seven thousand pounds. At that point the fiberglass began to yield in bearing at the bolts, and finally split at a planned fault line.

There was an evaluation with our advisor at which time we decided to switch to a concrete joint.

Concrete Joints

Concrete and Techite are both viscous solids with measurable amounts of creep. This plasticity can be said to work against both materials in the long run. However, they would seem to be compatible from the point of strength efficiency.

The fact that the concrete could be molded to the exact shape for a bearing connection with the Techite, while the Techite could be used for the form, was ideal. Because of this compatibility, we used a safety factor of 1.5 in our calculations for these joints. We also assumed a conservative twenty thousand pounds for the Techite. We arrived at a designed joint with six one-inch high-strength bolts.

This joint can be constructed much more easily than eigher previous possibility. The Techite will serve as the female part of the form. The high strength bolts will be tightened to their nuts through the Techite. The concrete will then be poured and the bolts loosened so that the concrete slips free for an on-site connection. The concrete strength need only be a regular two thousand psi. mix.

IS COST A CURRENT RESTRAINING FACTOR ?

COST EFFICIENCY

The cost of an erected material is more than the cost of the material itself. This may seem to be a very elementary statement at first glance. However, when the cost of a present day job is so heavily concentrated in the labor force, the chance to save a dollars labor by spending a dime more for materials seems to be a self-evident economy. Techite pipe has many reasons why it can save that dollars worth of labor.

The first good reason for economy is that it is very light. The equipment used to move around pipe can be appreciably smaller, costing less to operate, own, or rent. One such piece of pipe, twelve inches in diameter and twenty feet long weighs only two hundred pounds. This weight can be easily handled by two men, whereas other pipe made of steel or concrete this size can weigh up to ten times as much.

The cost performance index is possibly the best indicator of Techite's initial economy (see appendix G). The layup woven Roving is the most economical strength per cost item on the list. It compares very favorably with 1010 steel alloy, Techite's nearest competitor. In bending strength, it gives one third more bending strength for less money per one hundred square inches. The same is true for Techite's tensile strength. Although it does not have the stiffness that the steel pipe has, pound per dollar it is more efficient than the steel pipe.

HOW DO WE DESIGN INTELLIGENTLY WITH THIS MATERIAL ?

ENGINEERING SPECIFICATIONS

Bruce Glascock furnished our senior project team with some tests that had been conducted on Techite at the Cal Poly campus in Pomona. In these structural design property ranges, Mr. Glascock reminded us that the values of his test results reflect only process capabilities, not standard product values. We then decided that we would have to conduct some of our own tests to determine the pipe's strength in both compression and tension. The results of the compression test were discussed previously, and the following are the results of tests made on strips of pipe approximately one inch in width. These strips were cut longitudinally along the axis of the pipe.

width	cross sectional area	pounds tension	unit stress tension
1.12"	0.14 sqin	1,020 #	7,300 psi
1.10"	0.138 sqin	1,020 #	7,450 psi
0.97"	0.121 sqin	850 #	7,000 psi

The values were remarkably close together, but we did use sections taken from different samples of pipe. Therefore, there was no true random sampling of the pipe, so the values obtained from the tests cannot be classified as being independant of each other as a real random sampling would give. The purpose of the tests was satisfied though, and the figures we recieved could give us a point to start from. We had confirmed that we could use the values supplied by the manufacturer.

From this data, we found that Techite pipe is more efficient in compression than in tension. This surprized us, as fiberglass is usually thought of in terms of its good tensile properties. We were also warned that buckling might govern the design so we used the Youngs Modulus provided in Mr. Glascock's specifications to determine the maximum length we could work with. Using the eight inch diameter pipe, this length turned out to be eight to nine feet. By staying within these bounds, we were assured protection from buckling.

DESIGN PROCESS WINTER QUARTER

The structural engineer of the team, Lee Amy, conducted computer simulations during the winter quarter, a print of which is included in the appendix. This program, called ELAS, had the purpose of solving the internal stresses created by loads on a space frame. This space frame was our first speculative attempt at a workable design for our bridge. The computer output stresses showed that the Techite pipe was strong enough to take the loads we had designed for. However, the frame would require forty-one nodes of intersection for the members. The joints would be at odd angles with as many as eight members coming together at one point.

We next considered a very simple, straight forward Howe truss. This would be very easy to solve the stresses in and would make the joining angles a lot more managable. At this time we were considering the use of steel joints. Becoming disenchanted with the steel joints, we switched our line of thinking to a concrete joint system. This switch came about at the end of the winter quarter.

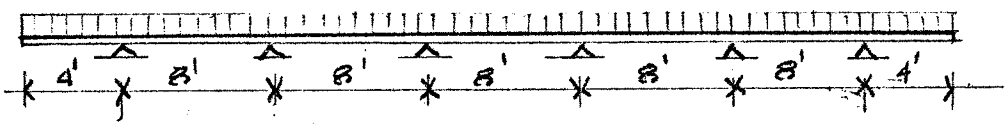
With our new concrete joints in mind, we set about designing an all new compression structure. This would also be using the Techite pipe in its most efficient state, as previously discussed. We also would be utilizing the pipe's high strength in bending. The structure's design was greatly simplified as compared to the earlier truss and space frame which made it all the more appealing.

The site of our proposed bridge was chosen to be at the entrance to Poly Canyon. It was to span the creek that runs down the canyon. This site dictated the use of only two foundation points as shown on our site survey plans and sections. From the soils profile conducted earlier this year by Hans Mager Jr. and the experience of Mr. Otto Ehrenberg, we estimated the foundations would have to go down at least six feet to bedrock.

The was a concern about the instability of a structure using only two foundation points, but our calculations revealed a very stable structure. So stable was the design that one half of the bridge could be taken away and the other half would remain standing as a full cantilever. Limiting ourselves to only two foundation points was also a move towards greater economy. The saving of material and labor that would have been involved with the making of two more foundation points was considerable. But the economics were not the only concern. The esthetic quality of the bridge was destroyed when two additional foundation points were added.

Upon determining the exact dimensions required of the bridge, we analyzed the frame as a rigid frame using the moment distribution method. From all the calculations made (see following pages), we have concluded that the frame, slab, and foundation are stable.

SLAB CALCULATIONS



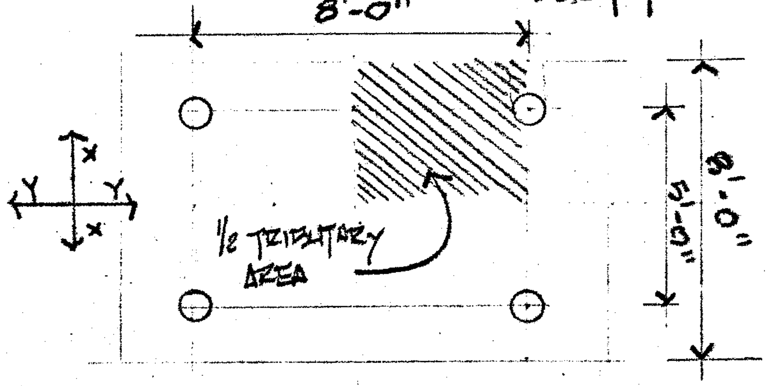
SLAB THICKNESS = 4"

PUNCHING SHEAR DOES NOT GOVERN

DL = .33[150 PSF] = 50 PLF

LL = 100 PSF = 100 PLF

150 PLF



$\frac{S}{L} = \frac{5[12]}{8[12]} = .625$

USING CASE 4 FIXED BOTH ENDS

$W_S = [.57]\ 150\ PLF = 85.5\ PLF$

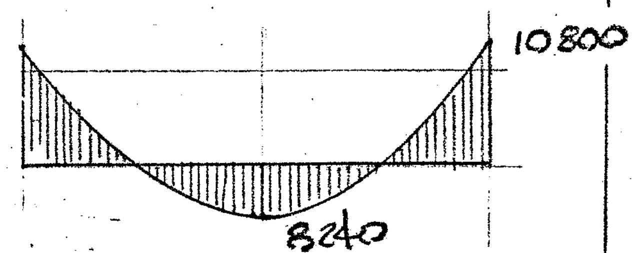
$W_L = [.43]\ 150\ PLF = 64.5\ PLF$

$MOMENT_S = \frac{WL^2}{8},\ \frac{150[5]^2[12]}{8} = 5630$

LONG DIRECTION BY MOMENT DIST.

$MOMENTS\ \frac{WL^2}{9} = \frac{150[8]^2[12]}{9} = 10800$

$\frac{WL^2}{14} = 8,240$ IN-LBS



A_S [SHORT] $= \frac{M}{7/8\, d\, f_s} = \frac{5630}{7/8[3.5][20000]}$

$A_S = 0.09\ IN^2$

A_S NEG LONG $= \frac{10800}{7/8[3.5]20000} =$

$A_S = 0.18\ IN^2$

A_S POS LONG $= \frac{8240}{7/8[3.5][20000]}$

$A_S = 0.13\ IN^2$

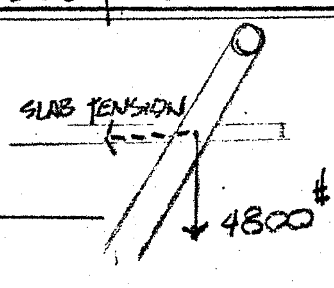
USE #4 BARS @ 12" c/c BOTH DIRECTIONS.

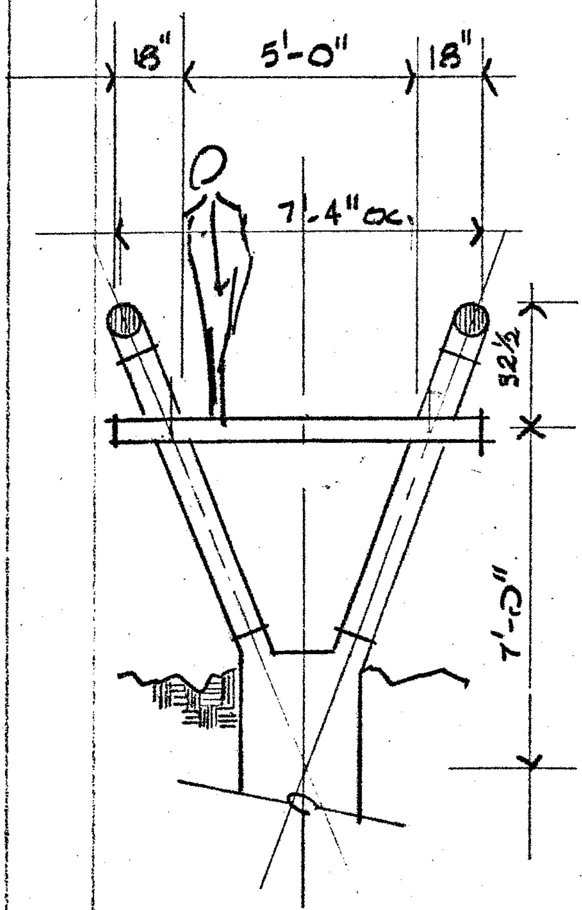
SUPPORTS

TRIBUTARY AREA = 4'-0" x 8'-0"

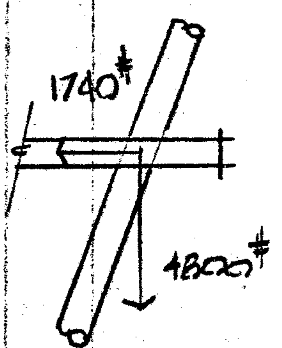
32 ☐ [150 PSF] = 4800#

CALCULATIONS X-X DIRECTION





CALCULATION X-X DIRECTION



$$\Sigma M_{@BASE} = 4800[2.5] - T[7.0']$$

$$T = \frac{4800[2.5]}{7.0}$$

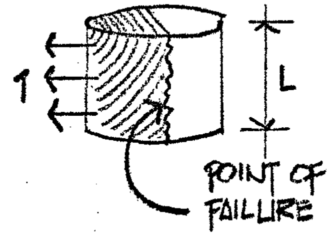
$$T = 1740^{\#}$$

$$T_{AXIAL} = 1740[\cos 68] =$$

$$1740[.926] = 1613^{\#}$$

$$T_{\perp} = 1740[.374] = 652^{\#}$$

PIPE LENGTH REQUIRED FOR RIPOUT



$$\text{AREA REQUIRED} = \frac{T_{\perp}}{F_a}$$

F_{ULT} = 15 - 45000 psi BURST PRES. [HOOP TENSILE]
USE 20,000

$$\text{AREA} = \frac{652\ P}{20,000\ psi} = 0.033\ IN^2$$

PIPE THICKNESS = 0.125"

$$\text{LENGTH} = \frac{0.033}{0.125[2\ SIDES]} =$$

LENGTH = 0.13 IN

| RIPOUT DOES NOT GOVERN |

SLAB TENSION

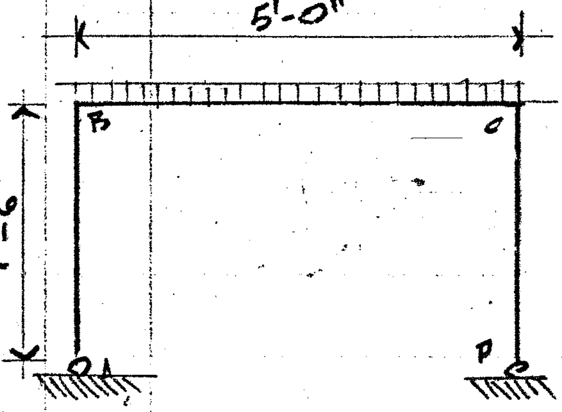
USING TENSION STEEL @ [.8]f_s

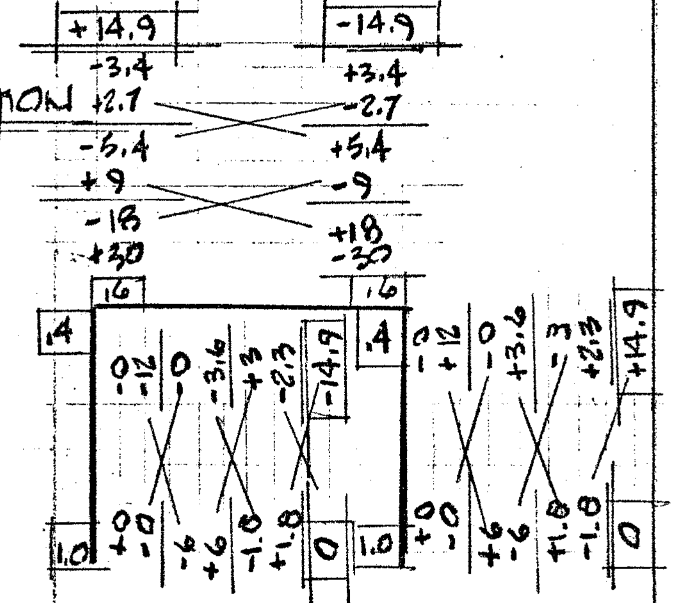
.8[20,000] = 16,000 psi

$$A_s = \frac{1740}{16000} = 0.11\ IN^2$$

| USE 1 EXTRA #4 BAR @ SUPPORT |

SLAB JOINT BY MOMENT DISTRIBUTION





K_{AB} $\frac{4EI}{L} = \frac{4}{7.5} = .53$

$K_{BC} = \frac{4EI}{L} = \frac{4}{5} = .80$

$DF_{AB} = \frac{.53}{1.33} = .40$

$DF_{BC} = \frac{.80}{1.33} = .60$

FEM's

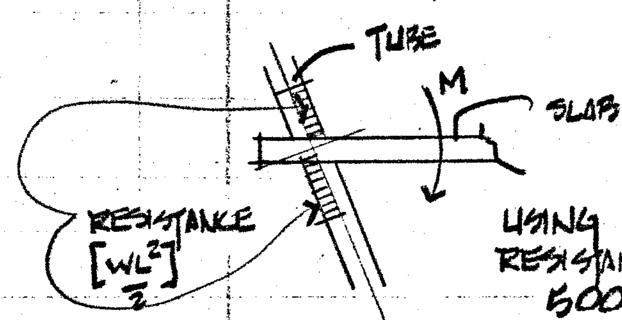
$\frac{WL^2}{12} = \frac{[150\,PSF]\,8'\,[5']^2}{12}$

$\frac{WL^2}{12} = 2500$ FT LBS [12]

M = 30000 IN-LBS

MOMENT = **14 900 IN-LBS**

TUBE RESISTANCE TO MOMENT



USING TECHITE RESISTANCE @ 5000 PLI

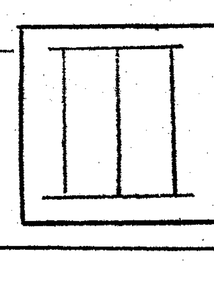
$L = \sqrt{\frac{14900\ IN^{\#}\,[2]}{5000\ \#/IN}} = \sqrt{5.97\,IN^2}$

L = 2.44 IN

$A_s = \frac{M}{7/8\ d\ F_s} = \frac{14900}{7/8\,[4.5]\,20000}$

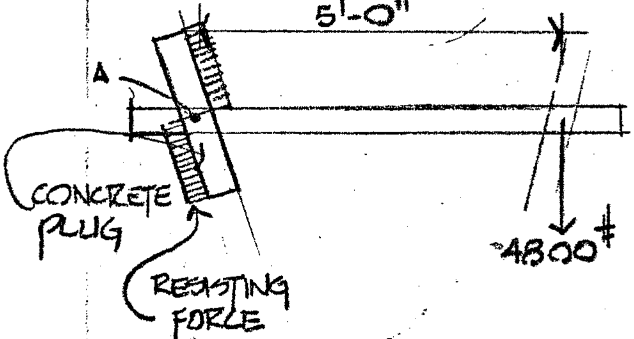
$A_s =$ **0.19 IN²**

USE 1 #4 BAR



SLAB JOINT IN ROTATION

ASSUMING COLLAPSE 1 SIDE



$\Sigma M_A : 4800^{\#}[5'\text{-}0''][12] - \frac{wL^2}{2}[2]$

USING TECHITE STRENGTH @ 20 000 PSI

RESISTANCE TO RIPOUT =

$[2]\ 20{,}000\ [.125] = 5000$ PLI

W = 5000 PLI

$L = \sqrt{\frac{24000[12]\ \text{IN}^{\#}[2]}{5000}}$

$L = \sqrt{115} = 10.72''$

USE 5.36" EACH SIDE

REINFORCING STEEL RIPOUT

$\Sigma M_A = 4800[5'\text{-}0''][12] =$

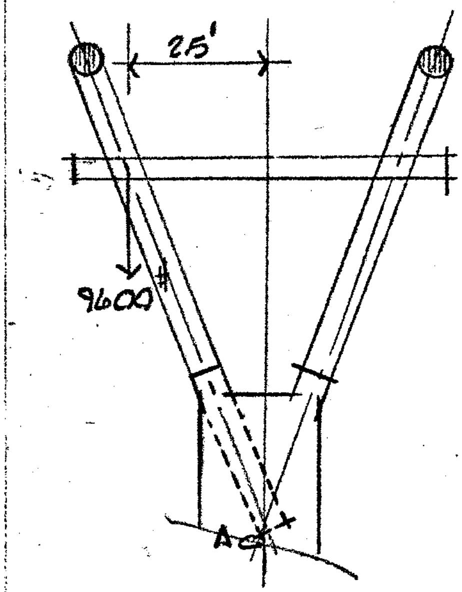
$M_A = 288000\ \text{IN}^{\#}$

$A_s = \frac{M}{7/8\ d\ F_s} = \frac{288\ \text{IN}^K}{7/8\,[4.5]\,20}$

SLAB THKNESS (4.5)

A_s = 3.66 IN² REQUIRED FOR TOTAL COLLAPSE

BASE DESIGN



$M_A = 9600[2.5'][12]$

@ TOTAL RIGHT SIDE COLLAPSE

$M_A = 288000$ IN-LBS

$A_s = \frac{M}{7/8\ d\ F_s} = \frac{288}{7/8\,[6.0]\,20}$

APPROX ℄ STEEL GROUP (6.0)

A_s 2.74 IN²

USE 3 - #9 BARS FOR TOTAL COLLAPSE

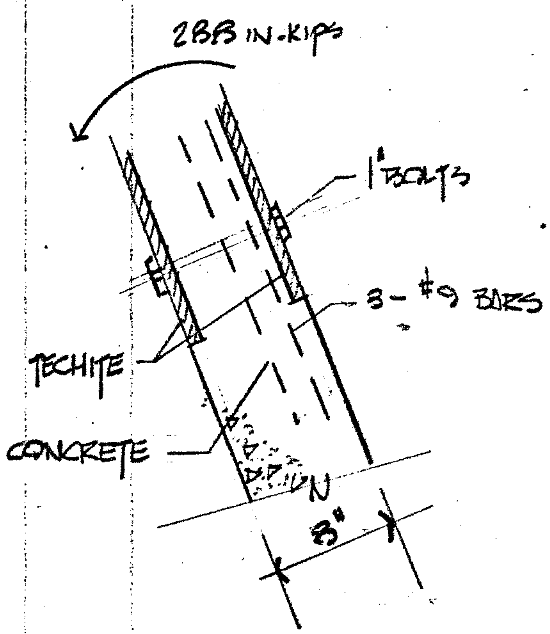
BASE CONNECTION

ULTIMATE CONNECTION STRENGTH W/ 4 BOLTS = 18000 lbs

PER BOLT

$\frac{18000}{4} = 4500$

IV



USING SAFETY FACTOR 1.5

$$\text{ULTIMATE/BOLT} = \frac{4500}{1.5} = 3000 \text{ lbs}$$

RESISTING FOR 1 BOLT =

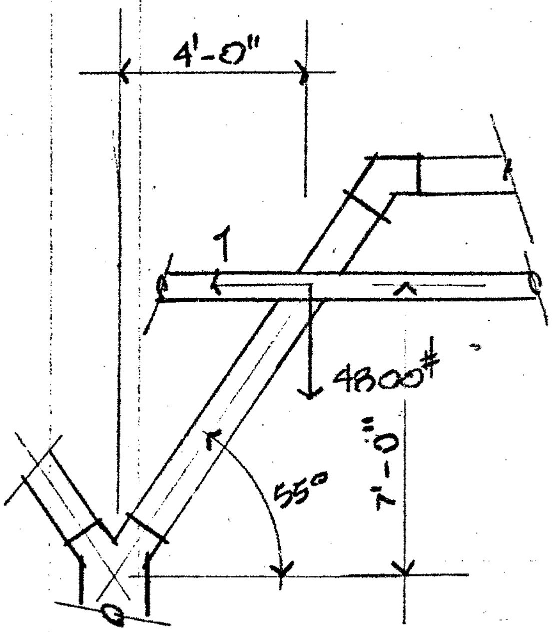
$$3000[8"] = 24000 \text{ IN.lbs}$$

$$\#\text{ BOLTS REQ'D} = \frac{288000}{24000} =$$

12 BOLTS REQ'D

USE 6-1" BOLTS EACH SIDE

FOUNDATION DESIGN



CALCULATIONS Y-Y DIRECTION

$$\Sigma M_{@BASE} = 4800[4'-0] - T[7'-0"]$$

$$T = \frac{4800[4'-0"]}{7'-0"}$$

$$T = 2743^{\#}$$

$$T_{AXIAL} = 2743[\sin 55°]$$
$$2743[.819] = 2247^{\#}$$

$$T_{\perp} = 2743[\cos 55°]$$
$$2743[.574] = 1575^{\#}$$

USE HOOP TENSILE STRENGTH @ 20000

RIPOUT AREA REQUIRED =

$$\frac{1575}{20\,000\ psi} = 0.0788\ IN^2$$

PIPE THICKNESS = 0.125 IN

$$\text{LENGTH REQ'D} = \frac{0.0788}{0.125[2]}$$

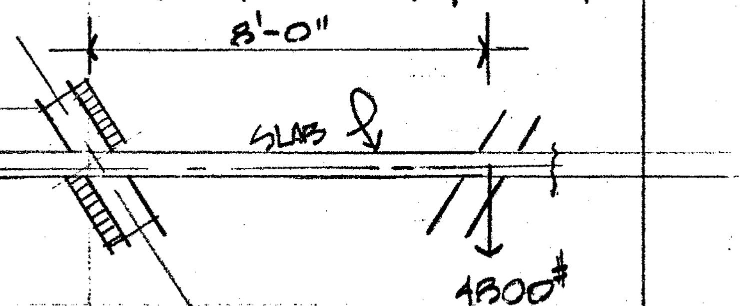
LENGTH = 0.32 IN

SLAB TENSION

$$A_s = \frac{2743}{16000} = 0.171\ IN^2$$

| USE 1 EXTRA #4 BAR |

SLAB JOINT FOR TOTAL COLLAPSE



$$\Sigma M_A = 4800[8][12] - \frac{WL^2}{2}$$

$$L = \sqrt{\frac{4800[8][12][2]}{5000}}$$

$$L = \sqrt{184} = 13.6\ IN$$

| USE 6.8 IN EACH SIDE |

REINFORCING STEEL @ JOINT

$$\Sigma M_A = 4800[8][12] = 460.8\ IN\cdot K$$

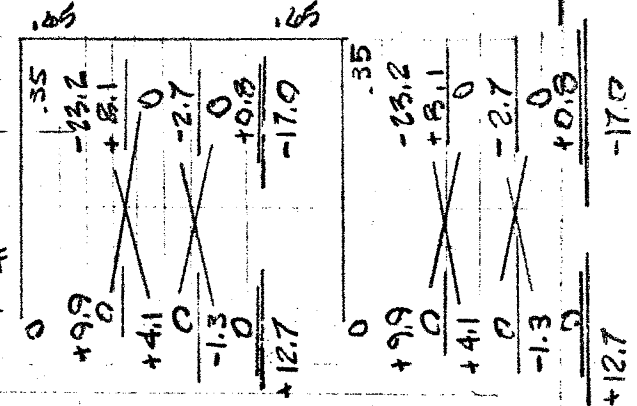
$$A_s = \frac{M}{7/8\, d\, F_s} =$$

$$A_s = \frac{460.8}{7/8[4.5][20]} = 5.85 \text{ in}^2$$

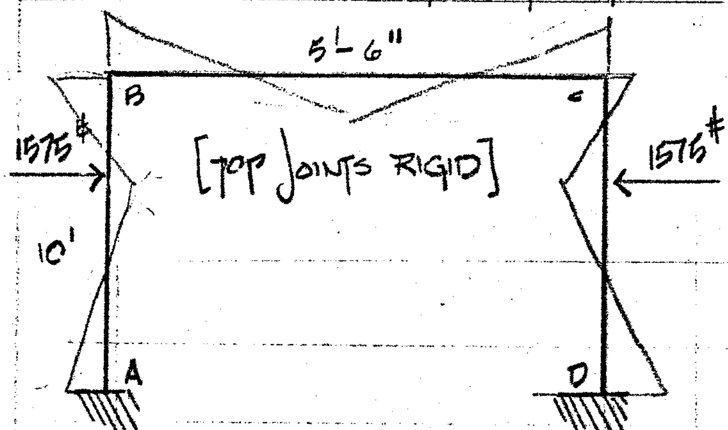
A_s = 5.85 IN² REQ'D FOR TOTAL COLLAPSE

$$M_B = \frac{Pa^2b}{L^2} = \frac{1575[7]^2[3]}{10^2} = 23152.5 \text{ FT-LBS}$$

+17.0	+17.0
+1.6	+1.6
−2.4	−2.4
−4.9	−4.9
+7.6	+7.6
+15.1	+15.1
+0	−0



SECTION BY MOMENT DISTRIBUTION

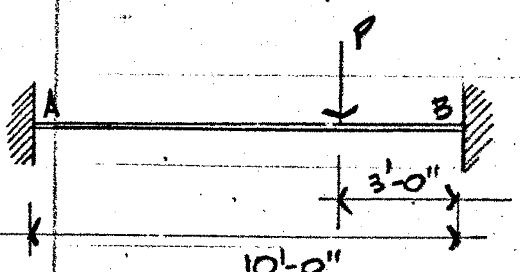


$$K_{AB} = \frac{4EI}{L} = \frac{4}{10} = .40$$

$$K_{BC} = \frac{4EI}{L} = \frac{4}{5.5} = .727$$

$DF_A = 0$ DF_{AB} .355

$DF_{BC} = .645$ $DF_{CD} = .355$



$$M_A = \frac{Pab^2}{L^2} = \frac{1575[7][3]^2}{10}$$

M_A = 9922.5 FT-LBS

POSITIVE MOMENT

$$M_{@\text{ PT OF LOAD}} = \frac{2Pa^2b^2}{L^3}$$

$$M = \frac{2[1575][7]^2[3]^2}{10^3} = 1389.2 \text{ FT LBS}$$

M = 1389[12] = **16.67 IN KIPS** @ SLAB JOINT

M @ TOP JOINT = 204 IN KIPS

M @ BOTTOM = 152.4 IN KIPS

$$A_s \text{ @ JOINT} = \frac{M}{7/8[F_s]d} = \boxed{0.22 \text{ IN}^2}$$

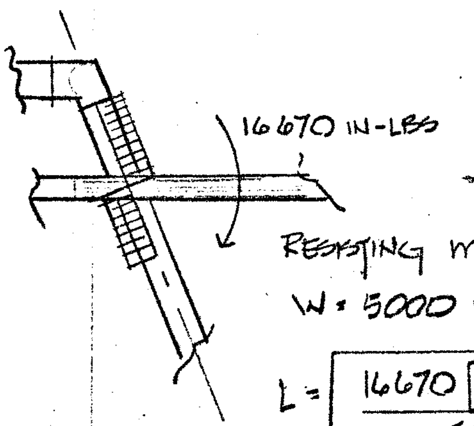
d = 4.5"

A_s @ BASE = **1.34 IN²**

d = 6.5"

VII

TUBE RIPOUT



RESISTING MOMENT = $\frac{WL^2}{12}$

W = 5000 PLI

$L = \sqrt{\frac{16670\,[2\text{ SIDES}]}{5000}}$

$L = \sqrt{6.67} = 2.58$ IN

USE 1.29 IN EACH SIDE.

FOR CONCRETE SLAB, ASSUME 2'-0" WIDE STRIP RESISTS MOMENTS

$\therefore E = 3.66 \times 10^6$ PSI

$I = \frac{bd^3}{12} = \frac{24[5]^3}{12} = 250$ IN^4

$K_{AB} = \frac{4EI}{L} = \frac{4[2.2 \times 10^6]40.7}{7.5}$

$K_{AB} = 48$

$K_{BC} = \frac{4EI}{L} = \frac{4[3.66 \times 10^6]250}{8.0}$

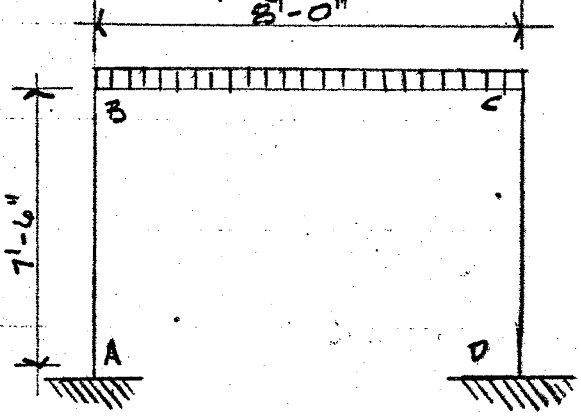
$K_{BC} = 460$

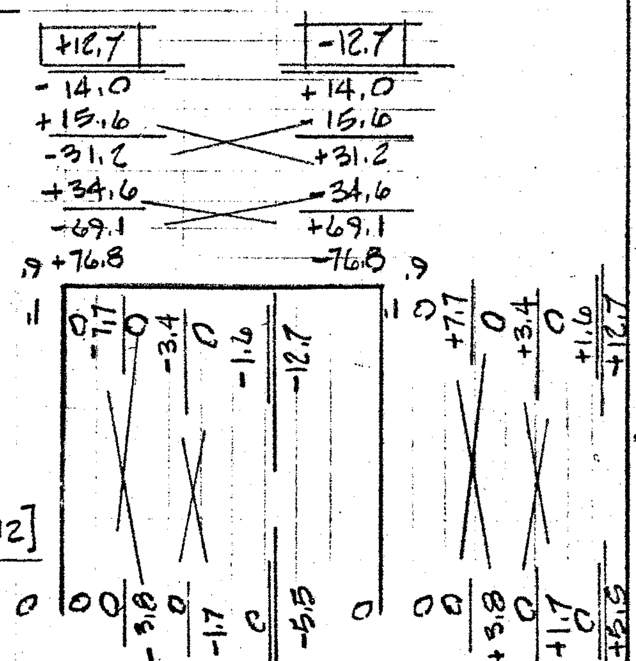
$DF_B = \frac{48}{518} = .09$ USE .10

$DF_C = \frac{460}{518} = .89$ USE .90

JOINT BY MOMENT DISTRIBUTION

[TOP JOINT PINNED]





FEM'S = $\frac{WL^2}{12} = \frac{150\text{PSF}[8'][8']^2[12]}{12}$

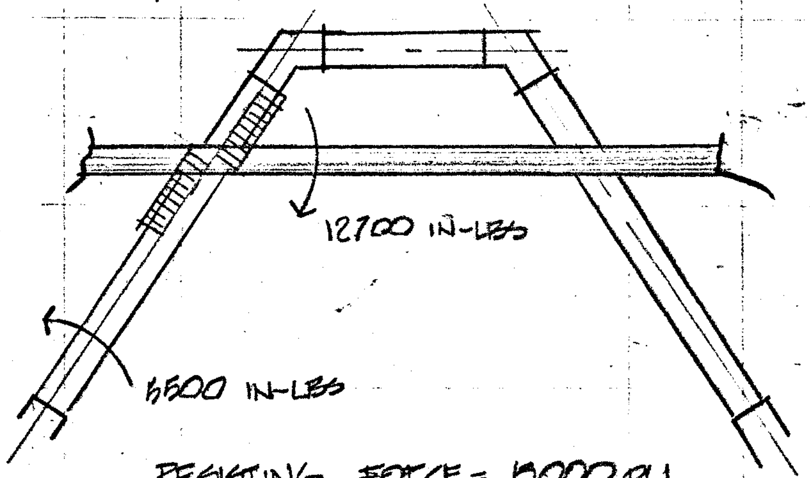
$\frac{WL^2}{12} = 76\,800$ IN-LBS

E OF TECHITE = 2.2×10^6

$I = \frac{\pi[[8.34]^4 - 8.0^4]}{64} = .049087[4830 - 4100]$

$I = 40.7$ IN^4

JOINT DETAIL



RESISTING FORCE = 5000 pli

$$L = \sqrt{\frac{12700\,[2]}{5000}} = \sqrt{5.08}$$

L = 2.25" REQ'D TUBE LENGTH AGAINST RIPOUT

USE 1.125" EACH SIDE

STEEL REQ'D @ JOINT

$$A_s = \frac{M}{7/8\,[4.5]\,20000} = 0.16\ IN^2$$

USE 1 #4 BAR

CONCLUSIONS !!!!

IT AIN'T GOING TO FALL DOWN

IX

CONCLUSIONS

We have answered, to our satisfaction, the four questions that dealt with this study. We have analyzed the use of Techite on the basis of both qualitative and quantitative methods. From this study, we have become more informed about the characteristics of Fiber-Reinforced Plastics. Our research into joining this material has led us to a practical solution for a bridge design. The answer to the question of cost revealed that the area that Fiberglass is most efficient per unit cost in tension and bending. From the test results and information provided us by U.T.C. we have arrived at a design that is pleasing, economical,and durable, that should be fairly easy to construct.

APPENDIX

APPENDIX A

WORKING DRAWINGS

APPENDIX B

GLOSSARY OF TERMS FOR

FILAMENT WINDING

GLOSSARY OF TERMS FOR FILAMENT WINDING

BUSHING

A bushing is an electrically heated alloy container encased in insulating material. It is used for melting, feeding, and controlling the glass temperature in the formation of the many individual fibers or filaments which make up a strand.

COMPATIBILITY

The ability of two or more substances combined with each other to form a homogeneous composition of useful plastic properties.

CONTINUOUS FILAMENT

A term used to describe a fiberglass product containing strands composed of many fine fibers of great or indefinite length.

FIBER

An individual rod of glass of sufficiently small diameter to be flexible, having a known or approximate limit to its legth.

FIBER DIAMETER

The measurement of the diameter of an individual filament usually expressed in hundred-thousandths of an inch.

FILAMENTS

Individual glass fibers of indefinite or great length as pulled from a stream of molten glass flowing through an orifice of the bushing. In the operation, a number of filaments are gathered together to make a strand or end of fiberglass roving or yarn.

GLASS TYPES

Electrical grade (E), High strength (S), and Low dielectric (D).

MODULUS OF ELASTICITY

The ratio of the unit stress to the unit strain within the proportional or elastic range of the material.

NON-HYGROSCOPIC

Lacking the property of absorbing and retaining any appreciable quantity of moisture from the air.

ORIFICE

The hole in the bushing tip from which the stream flows that is drawn out into glass fiber or filament.

ROVING

A number of ends or strands of glass gathered together into a ribbon without twist, then wound onto a cardboard table.

STRANDS

A primary assembly of continuous filaments combined in a single compact unit without twist.

STRESS

The external force per unit area which tends to cause change in the size or shape of the body.

GIRTH STRESS

The unit area composed of glass and resin in the girth direction.

HELECAL GLASS STRESS

The unit area composed of glass only of the helical windings.

90 DEGREE STRESS

The unit stress area composed of glass only in the 90 degree windings

S-994

A low alkali, magnesia alumina silicate, high tensile strength glass fiber. The fiber or strand is coated with an appropriate sizing to increase adhesion to epoxy and silicone resin systems.

WET WINDINGS

A term used to describe the process of winding glass on a mandrel where the strand or strands are impregnated with resin, just prior to contact with mandrel.

APPENDIX C

GLOSSARY OF TERMS RELATING TO PLASTICS

GLOSSARY OF TERMS RELATING TO PLASTICS

CREEP

The dimensional shange with time of a plastic under load, following the instantaneous elastic or rapid deformation.

CURE

To change the properties of a plastic or resin by chemical reaction, which for example may be condensation, polymerization, or addition; usually accomplished by the action of either heat, catalyst, or both.

DETERIORATION

A permanent change in the physical properties of a plastic evidenced by impairment of these properties.

FILLER

A relatively inert material added to a plastic to modify its strength, permanence, working properties, or other qualities to lower costs.

LAMINATE

A product made by bonding together two or more layers of material or materials.

APPENDIX D

COMPUTER PRINTOUT

```
//SPACED   JOB    '5131 19   050  05','MERRILEE AMY        ' MSGLEVEL=1
 **** CAL POLY OS/19.6 **** MERRILEE AMY *************     11       99999999   ***** DATE 73.044 **** TIME 01.01.51 ***
 **** CAL POLY OS/19.6 **** MERRILEE AMY *************    111      9999999999  ***** DATE 73.044 **** TIME 01.01.51 ***
 **** CAL POLY OS/19.6 **** MERRILEE AMY *************     11      99      99  ***** DATE 73.044 **** TIME 01.01.51 ***
 **** CAL POLY OS/19.6 **** MERRILEE AMY *************     11      99      99  ***** DATE 73.044 **** TIME 01.01.51 ***
 **** CAL POLY OS/19.6 **** MERRILEE AMY *************     11      9999999999  ***** DATE 73.044 **** TIME 01.01.51 ***
 **** CAL POLY OS/19.6 **** MERRILEE AMY *************     11       999999999  ***** DATE 73.044 **** TIME 01.01.51 ***
 **** CAL POLY OS/19.6 **** MERRILEE AMY *************     11              99  ***** DATE 73.044 **** TIME 01.01.51 ***
 **** CAL POLY OS/19.6 **** MERRILEE AMY *************     11      99      99  ***** DATE 73.044 **** TIME 01.01.51 ***
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 **** CAL POLY OS/19.6 **** MERRILEE AMY *************   111111     99999999   ***** DATE 73.044 **** TIME 01.01.51 ***
```

```
***ELAS PROGRAM/VERSION 30.07.71/***

PRELIMINARY ANALYSIS OF SPACE FRAME SUBJECT TO UNIFORM LOAD OF ONE.

PROBLEM TYPE:     EQUILIBRIUM

TOTAL NUMBER OF NODES            41   IBUN  DBC INPUT INDICATOR          0
TOTAL NUMBER OF ELEMENTS        128   ICOR  COORDINATE INPUT INDICATOR 0
DEGREES OF FREEDOM PER NODE       3   IGEM  GEOMETRY INDICATOR           1
NUMBER OF VERTICES PER ELEMENT    2   IMES  MESH INPUT INDICATOR         0
WORDS PER ELEMENT DESCRIPTION     5   INP   PRINTOUT LEVEL INDICATOR     1
NUMBER OF DBC INPUT UNITS         8   INX   NUMBER OF LAST LINK XOTED    4
NUMBER OF C.LOAD INPUT UNITS     25   IPIR  SHELL COORDINATE INDICATOR 0
NUMBER OF MATERIAL TYPES          1   ISHUF RELABELING INDICATOR         1
NUMBER OF PRESSURE TYPES          0   ISTR  PLANE STRAIN INDICATOR       0
NUMBER OF THICKNESS TYPES         0   ITYPE MATERIAL TYPE INDICATOR      0
NUMBER OF TEMP.CHANGE TYPES       0
NUMBER OF TEMP.Y-GRAD.TYPES       0   IO    INPUT UNIT NUMBER            5
NUMBER OF TEMP.Z-GRAD.TYPES       0   MO    OUTPUT UNIT NUMBER           6
NUMBER OF AREA TYPES              1   ITAS  SCRATCH UNIT NUMBER          8
NUMBER OF TORSION CONS.TYPES      0   ITAP  PROBLEM TYPE INDICATOR       0
NUMBER OF AREA Y-MOMENT TYPES     0
NUMBER OF AREA Z-MOMENT TYPES     0   ACCELERATION*UNITMASS   0.0
NUMBER OF ANGLE FI TYPES          0   ACCL.DIR.COSINES 0.0    0.0    0.0
ELAS JOB IDENTIFIER            PREL
```

MATERIAL PROPERTIES

TP	E	G	ALPHA	TP	E	G	ALPHA
1	0.2900E 07	0.6000E 06	0.0				

CROSS-SECTIONAL AREA TYPES

1	0.1000E 01

NODAL COORDINATES

NODE	X	Y	Z
1	-0.10000E 01	0.10000E 01	0.0
2	-0.30000E 01	0.10000E 01	0.0
3	-0.50000E 01	0.10000E 01	0.0
4	-0.70000E 01	0.10000E 01	0.0
5	-0.70000E 01	0.30000E 01	0.0
6	-0.50000E 01	0.30000E 01	0.0
7	-0.30000E 01	0.30000E 01	0.0
8	-0.10000E 01	0.30000E 01	0.0
9	-0.10000E 01	0.50000E 01	0.0
10	-0.30000E 01	0.50000E 01	0.0
11	-0.50000E 01	0.50000E 01	0.0
12	-0.70000E 01	0.50000E 01	0.0
13	-0.70000E 01	0.70000E 01	0.0
14	-0.50000E 01	0.70000E 01	0.0
15	-0.30000E 01	0.70000E 01	0.0
16	-0.10000E 01	0.70000E 01	0.0
17	0.0	0.0	0.10000E 01
18	-0.20000E 01	0.0	0.10000E 01
19	-0.40000E 01	0.0	0.10000E 01
20	-0.60000E 01	0.0	0.10000E 01
21	-0.80000E 01	0.0	0.10000E 01
22	0.0	0.20000E 01	0.10000E 01
23	-0.20000E 01	0.20000E 01	0.10000E 01
24	-0.40000E 01	0.20000E 01	0.10000E 01
25	-0.60000E 01	0.20000E 01	0.10000E 01
26	-0.80000E 01	0.20000E 01	0.10000E 01
27	0.0	0.40000E 01	0.10000E 01
28	-0.20000E 01	0.40000E 01	0.10000E 01
29	-0.40000E 01	0.40000E 01	0.10000E 01
30	-0.60000E 01	0.40000E 01	0.10000E 01
31	-0.80000E 01	0.40000E 01	0.10000E 01
32	0.0	0.60000E 01	0.10000E 01
33	-0.20000E 01	0.60000E 01	0.10000E 01
34	-0.40000E 01	0.60000E 01	0.10000E 01
35	-0.60000E 01	0.60000E 01	0.10000E 01
36	-0.80000E 01	0.60000E 01	0.10000E 01
37	0.0	0.80000E 01	0.10000E 01
38	-0.20000E 01	0.80000E 01	0.10000E 01
39	-0.40000E 01	0.80000E 01	0.10000E 01
40	-0.60000E 01	0.80000E 01	0.10000E 01
41	-0.80000E 01	0.80000E 01	0.10000E 01

SORTED DEFLECTION BOUNDARY CONDITIONS

NO	1ST PAIR	2ND PAIR	CONSTANT	NO	1ST PAIR	2ND PAIR	CONSTANT
1	1 2	1 2	0.0	2	1 3	1 3	0.0
3	4 3	4 3	0.0	4	13 1	13 1	0.0
5	13 3	13 3	0.0	6	16 1	16 1	0.0
7	16 2	16 2	0.0	8	16 3	16 3	0.0

ELEMENT PROPERTIES

NO	N1	N2	N3	N4	N5	N6	N7	N8	TY	MA	PR	TO	,Y	TZ	HT	AR	MX	MY	MZ	FI
1	17	18	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
2	18	19	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
3	19	20	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
4	20	21	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
5	26	25	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
6	25	24	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
7	24	23	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
8	23	22	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
9	27	28	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
10	28	29	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
11	29	30	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
12	30	31	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
13	36	35	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
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18	38	39	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
19	39	40	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
20	40	41	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
21	41	36	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
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23	31	26	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
24	26	21	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
25	20	25	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
26	25	30	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
27	30	35	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
28	35	40	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
29	39	34	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
30	34	29	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
31	29	24	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
32	24	19	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
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34	23	28	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
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36	33	38	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
37	37	32	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
38	32	27	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
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43	3	4	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
44	5	6	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
45	6	7	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
46	7	8	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
47	9	10	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
48	10	11	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
49	11	12	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
50	13	14	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
51	14	15	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
52	15	16	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
53	13	12	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
54	12	5	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
55	5	4	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
56	3	6	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
57	6	11	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
58	11	14	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
59	15	10	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
60	10	7	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
61	7	2	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0

63	8	9	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
64	9	16	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
65	17	1	0	0	0	0	0	0	1	1	0	[illegible]	[illegible]	0	0	1	0	0	0	0
66	1	18	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
67	18	2	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
68	2	19	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
69	19	3	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
70	3	20	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
71	20	4	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
72	4	21	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
73	26	4	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
74	4	25	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
75	25	3	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
76	3	24	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
77	24	2	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
78	2	23	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
79	23	1	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
80	1	22	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
81	22	8	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
82	8	23	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
83	23	7	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
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85	24	6	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
86	6	25	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
87	25	5	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
88	5	26	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
89	31	5	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
90	5	30	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
91	30	6	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
92	6	29	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
93	29	7	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
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95	28	8	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
96	8	27	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
97	27	9	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
98	9	28	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
99	28	10	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
100	10	29	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
101	29	11	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
102	11	30	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
103	30	12	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
104	12	31	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
105	36	12	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
106	12	35	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
107	35	11	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
108	11	34	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
109	34	10	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
110	10	33	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
111	33	9	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
112	9	32	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
113	32	16	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
114	16	33	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
115	33	15	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
116	15	34	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
117	34	14	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
118	14	35	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
119	35	13	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
120	13	36	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
121	41	13	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
122	13	40	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
123	40	14	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
124	14	39	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
125	39	15	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
126	15	38	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
127	38	16	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0

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128  16  37   0   0   0   0   0   0  1  1  0  0  0  0  0  1  0  0  0  0
AT -35.23 SEC. OF RELABELING   336 INTERCHANGES DONE
UPPER OFF-BAND ELEMENT COUNT OF CONNECTIVITY MATRIX      567.
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STIFFNESS MATRIX REQUIRES  2372  WORDS OF STORAGE
TOTAL COMMON REQUEST   7000   WORDS
COMMON REQUEST  5180  WORDS MORE THAN REQUIRED FOR LINK  1
COMMON REQUEST  2938  WORDS MORE THAN REQUIRED FOR LINK  2
COMMON REQUEST  2822  WORDS MORE THAN REQUIRED FOR LINK  3
COMMON REQUEST  3844  WORDS MORE THAN REQUIRED FOR LINK  4
COMMON REQUEST  7000  WORDS MORE THAN REQUIRED FOR LINK  5
```

LIST OF CONCENTRATED LOADS (OR CONCENTRATED MASSES)

INDEX	VALUE	INDEX	VALUE	INDEX	VALUE
17 3	-0.2500E 00	18 3	-0.5000E 00	19 3	-0.5000E 00
20 3	-0.5000E 00	21 3	-0.2500F 00		
22 3	-0.5000E 00	23 3	-0.1000E 01	24 3	-0.1000E 01
25 3	-0.1000E 01	26 3	-0.5000E 00		
27 3	-0.5000E 00	28 3	-0.1000E 01	29 3	-0.1000E 01
30 3	-0.1000E 01	31 3	-0.5000E 00		
32 3	-0.5000E 00	33 3	-0.1000E 01	34 3	-0.1000E 01
35 3	-0.1000E 01	36 3	-0.5000E 00		
37 3	-0.2500E 00	38 3	-0.5000E 00	39 3	-0.5000E 00
40 3	-0.5000E 00	41 3	-0.2300E 00		

INPUT LINK TOOK 227.87 SECONDS.
GENERATION LINK TOOK 199.97 SECONDS.

NODAL DEFLECTIONS

NODE	X-DISPLMT	Y-DISPLMT	Z-DISPLMT	X-ROTATN.	Y-ROTATN.	Z-ROTATN.
1	0.1804E-05	0.0	0.0	0.0	0.0	0.0
2	0.9367E-06	-0.6836E-06	-0.7682E-05	0.0	0.0	0.0
3	-0.9527E-06	-0.1050E-05	-0.7697E-05	0.0	0.0	0.0
4	-0.1829E-05	-0.1802E-05	0.0	0.0	0.0	0.0
5	-0.1068E-05	-0.9218E-06	-0.7715E-05	0.0	0.0	0.0
6	-0.4920E-06	-0.4727E-06	-0.1033E-04	0.0	0.0	0.0
7	0.4740E-06	-0.3323E-06	-0.9581E-05	0.0	0.0	0.0
8	0.1061E-05	-0.3407E-06	-0.5334E-05	0.0	0.0	0.0
9	0.6935E-06	0.3524E-06	-0.5318E-05	0.0	0.0	0.0
10	0.3328E-06	0.3408E-06	-0.8836E-05	0.0	0.0	0.0
11	-0.3392E-06	0.4958E-06	-0.9591E-05	0.0	0.0	0.0
12	-0.6896E-06	0.9748E-06	-0.7705E-05	0.0	0.0	0.0
13	0.0	0.1855E-05	0.0	0.0	0.0	0.0
14	-0.3360E-06	0.1084E-05	-0.5345E-05	0.0	0.0	0.0
15	0.3573E-06	0.7020E-06	-0.5324E-05	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0
17	-0.5059E-06	0.1136E-05	0.2998E-05	0.0	0.0	0.0
18	-0.6784E-06	0.2589E-06	-0.4122E-05	0.0	0.0	0.0
19	0.2656E-06	-0.5018E-06	-0.8717E-05	0.0	0.0	0.0
20	0.1285E-05	0.2968E-06	-0.3012E-05	0.0	0.0	0.0
21	0.1113E-05	0.1152E-05	0.5448E-05	0.0	0.0	0.0
22	-0.8988E-06	0.1308E-05	-0.6133E-06	0.0	0.0	0.0
23	-0.1244E-05	0.6037E-06	-0.6463E-05	0.0	0.0	0.0
24	-0.2910E-06	-0.1569E-06	-0.1022E-04	0.0	0.0	0.0
25	0.6092E-06	0.6417E-06	-0.7612E-05	0.0	0.0	0.0
26	0.2644E-06	0.1324E-05	-0.3032E-05	0.0	0.0	0.0
27	-0.4967E-06	0.2795E-06	-0.4747E-05	0.0	0.0	0.0
28	-0.8415E-06	-0.2760E-06	-0.8294E-05	0.0	0.0	0.0
29	-0.4866E-06	-0.4673E-06	-0.1085E-04	0.0	0.0	0.0
30	-0.1776E-06	-0.2597E-06	-0.1023E-04	0.0	0.0	0.0
31	-0.5224E-06	0.3020E-06	-0.8750E-05	0.0	0.0	0.0
32	-0.8687E-06	-0.6738E-06	-0.1715E-05	0.0	0.0	0.0
33	-0.1214E-05	-0.1209E-05	-0.5321E-05	0.0	0.0	0.0
34	-0.2812E-06	-0.8232E-06	-0.8301E-05	0.0	0.0	0.0
35	0.5984E-06	-0.1213E-05	-0.6479E-05	0.0	0.0	0.0
36	0.2535E-06	-0.6499E-06	-0.4142E-05	0.0	0.0	0.0
37	-0.4908E-06	-0.5014E-06	0.5442E-06	0.0	0.0	0.0
38	-0.6632E-06	-0.8637E-06	-0.1717E-05	0.0	0.0	0.0
39	0.2955E-06	-0.4783E-06	-0.4758E-05	0.0	0.0	0.0
40	0.1334E-05	-0.8685E-06	-0.6146E-06	0.0	0.0	0.0
41	0.1176E-05	-0.4913E-06	0.3110E-05	0.0	0.0	0.0

FORCES ACTING AT THE NODES

NODE	X-FORCE	Y-FORCE	Z-FORCE	X-MOMENT	Y-MOMENT	Z-MOMENT
1	-0.9537E-06	0.1875E 01	0.3999E 01	0.0	0.0	0.0
2	-0.9537E-06	0.1192E-05	-0.1907E-05	0.0	0.0	0.0
3	0.2003E-04	-0.1907E-05	0.2766E-04	0.0	0.0	0.0
4	-0.2861E-05	0.1335E-04	0.4004E 01	0.0	0.0	0.0
5	0.1252E-05	0.1812E-04	0.7629E-05	0.0	0.0	0.0
6	0.7331E-05	0.1776E-04	-0.9537E-05	0.0	0.0	0.0
7	0.9477E-05	0.1591E-04	0.6676E-05	0.0	0.0	0.0
8	0.5960E-07	0.3815E-05	0.0	0.0	0.0	0.0
9	0.1639E-04	0.1007E-04	-0.1186E-04	0.0	0.0	0.0
10	-0.1609E-05	0.2414E-04	-0.1907E-05	0.0	0.0	0.0
11	-0.7212E-05	0.1454E-04	0.1907E-05	0.0	0.0	0.0
12	-0.1276E-04	0.1335E-04	-0.2861E-05	0.0	0.0	0.0
13	0.1890E 01	0.1621E-04	0.3973E 01	0.0	0.0	0.0
14	-0.9537E-06	-0.1192E-05	-0.4768E-05	0.0	0.0	0.0
15	0.9954E-05	0.9716E-05	-0.1103E-04	0.0	0.0	0.0
16	-0.1890E 01	-0.1875E 01	0.4004E 01	0.0	0.0	0.0
17	0.5960E-06	-0.1907E-05	-0.2500E 00	0.0	0.0	0.0
18	0.2861E-05	0.2146E-05	-0.5000E 00	0.0	0.0	0.0
19	0.2861E-05	0.1258E-04	-0.5000E 00	0.0	0.0	0.0
20	-0.2861E-05	0.3815E-05	-0.5000E 00	0.0	0.0	0.0
21	0.2861E-05	-0.2861E-05	-0.2500E 00	0.0	0.0	0.0
22	0.0	-0.3815E-05	-0.5000E 00	0.0	0.0	0.0
23	0.3815E-05	-0.1049E-04	-0.1000E 01	0.0	0.0	0.0
24	-0.1240E-04	-0.6795E-05	-0.1000E 01	0.0	0.0	0.0
25	0.1335E-04	-0.1907E-04	-0.1000E 01	0.0	0.0	0.0
26	0.1907E-05	-0.1049E-04	-0.5000E 00	0.0	0.0	0.0
27	-0.7749E-05	0.9537E-06	-0.5000E 00	0.0	0.0	0.0
28	-0.5722E-05	-0.2003E-04	-0.1000E 01	0.0	0.0	0.0
29	0.1490E-05	-0.1687E-04	-0.1000E 01	0.0	0.0	0.0
30	-0.1478E-04	-0.9537E-05	-0.1000E 01	0.0	0.0	0.0
31	0.2503E-04	0.3815E-05	-0.5000E 00	0.0	0.0	0.0
32	-0.4768E-05	0.1907E-05	-0.5000E 00	0.0	0.0	0.0
33	-0.5722E-05	-0.1049E-04	-0.1000E 01	0.0	0.0	0.0
34	-0.8583E-05	-0.2480E-04	-0.1000E 01	0.0	0.0	0.0
35	-0.3815E-05	-0.1049E-04	-0.1000E 01	0.0	0.0	0.0
36	0.9537E-05	0.1907E-05	-0.5000E 00	0.0	0.0	0.0
37	-0.1192E-06	0.3994E-05	-0.2500E 00	0.0	0.0	0.0
38	0.9537E-06	-0.6676E-05	-0.5000E 00	0.0	0.0	0.0
39	-0.3815E-05	0.2384E-06	-0.5000E 00	0.0	0.0	0.0
40	-0.4768E-05	0.4768E-05	-0.5000E 00	0.0	0.0	0.0
41	0.0	-0.4172E-06	-0.2300E 00	0.0	0.0	0.0

DEFLECTION LINK TOOK 159.59 SECONDS. 180.90

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STRESS AND MOMENT RESULTANTS AT THE NODES OF ONE DIMENSIONAL ELEMENTS.
QUANTITIES ARE IN LOCAL COORDINATE SYSTEMS AT T[illegible] ENDS OF ELEMENTS
ELT NOD TP          N-X          Q-Y          Q-Z          -X          M-Y          M-Z
  1DIR COS XI-1.000 0.0   0.0  ET 0.0  -1.000 0.0  ZT 0.0   0.0   1.000
  1  17  1  0.250E 00 0.0       0.0        0.0        0.0       0.0
  1  18  1  0.250E 00 0.0       0.0        0.0        0.0       0.0
  2DIR COS XI-1.000 0.0   0.0  ET 0.0  -1.000 0.0  ZT 0.0   0.0   1.000
  2  18  1 -0.137E 01 0.0       0.0        0.0        0.0       0.0
  2  19  1 -0.137E 01 0.0       0.0        0.0        0.0       0.0
  3DIR COS XI-1.000 0.0   0.0  ET 0.0  -1.000 0.0  ZT 0.0   0.0   1.000
  3  19  1 -0.148E 01 0.0       0.0        0.0        0.0       0.0
  3  20  1 -0.148E 01 0.0       0.0        0.0        0.0       0.0
  4DIR COS XI-1.000 0.0   0.0  ET 0.0  -1.000 0.0  ZT 0.0   0.0   1.000
  4  20  1  0.250E 00 0.0       0.0        0.0        0.0       0.0
  4  21  1  0.250E 00 0.0       0.0        0.0        0.0       0.0
  5DIR COS XI 1.000 0.0   0.0  ET 0.0   1.000 0.0  ZT 0.0   0.0   1.000
  5  26  1  0.500E 00 0.0       0.0        0.0        0.0       0.0
  5  25  1  0.500E 00 0.0       0.0        0.0        0.0       0.0
  6DIR COS XI 1.000 0.0   0.0  ET 0.0   1.000 0.0  ZT 0.0   0.0   1.000
  6  25  1 -0.131E 01 0.0       0.0        0.0        0.0       0.0
  6  24  1 -0.131E 01 0.0       0.0        0.0        0.0       0.0
  7DIR COS XI 1.000 0.0   0.0  ET 0.0   1.000 0.0  ZT 0.0   0.0   1.000
  7  24  1 -0.138E 01 0.0       0.0        0.0        0.0       0.0
  7  23  1 -0.138E 01 0.0       0.0        0.0        0.0       0.0
  8DIR COS XI 1.000 0.0   0.0  ET 0.0   1.000 0.0  ZT 0.0   0.0   1.000
  8  23  1  0.500E 00 0.0       0.0        0.0        0.0       0.0
  8  22  1  0.500E 00 0.0       0.0        0.0        0.0       0.0
  9DIR COS XI-1.000 0.0   0.0  ET 0.0  -1.000 0.0  ZT 0.0   0.0   1.000
  9  27  1  0.500E 00 0.0       0.0        0.0        0.0       0.0
  9  28  1  0.500E 00 0.0       0.0        0.0        0.0       0.0
 10DIR COS XI-1.000 0.0   0.0  ET 0.0  -1.000 0.0  ZT 0.0   0.0   1.000
 10  28  1 -0.515E 00 0.0       0.0        0.0        0.0       0.0
 10  29  1 -0.515E 00 0.0       0.0        0.0        0.0       0.0
 11DIR COS XI-1.000 0.0   0.0  ET 0.0  -1.000 0.0  ZT 0.0   0.0   1.000
 11  29  1 -0.448E 00 0.0       0.0        0.0        0.0       0.0
 11  30  1 -0.448E 00 0.0       0.0        0.0        0.0       0.0
 12DIR COS XI-1.000 0.0   0.0  ET 0.0  -1.000 0.0  ZT 0.0   0.0   1.000
 12  30  1  0.500E 00 0.0       0.0        0.0        0.0       0.0
 12  31  1  0.500E 00 0.0       0.0        0.0        0.0       0.0
 13DIR COS XI 1.000 0.0   0.0  ET 0.0   1.000 0.0  ZT 0.0   0.0   1.000
 13  36  1  0.500E 00 0.0       0.0        0.0        0.0       0.0
 13  35  1  0.500E 00 0.0       0.0        0.0        0.0       0.0
 14DIR COS XI 1.000 0.0   0.0  ET 0.0   1.000 0.0  ZT 0.0   0.0   1.000
 14  35  1 -0.128E 01 0.0       0.0        0.0        0.0       0.0
 14  34  1 -0.128E 01 0.0       0.0        0.0        0.0       0.0
 15DIR COS XI 1.000 0.0   0.0  ET 0.0   1.000 0.0  ZT 0.0   0.0   1.000
 15  34  1 -0.135E 01 0.0       0.0        0.0        0.0       0.0
 15  33  1 -0.135E 01 0.0       0.0        0.0        0.0       0.0
 16DIR COS XI 1.000 0.0   0.0  ET 0.0   1.000 0.0  ZT 0.0   0.0   1.000
 16  33  1  0.500E 00 0.0       0.0        0.0        0.0       0.0
 16  32  1  0.500E 00 0.0       0.0        0.0        0.0       0.0
 17DIR COS XI-1.000 0.0   0.0  ET 0.0  -1.000 0.0  ZT 0.0   0.0   1.000
 17  37  1  0.250E 00 0.0       0.0        0.0        0.0       0.0
 17  38  1  0.250E 00 0.0       0.0        0.0        0.0       0.0
 18DIR COS XI-1.000 0.0   0.0  ET 0.0  -1.000 0.0  ZT 0.0   0.0   1.000
 18  38  1 -0.139E 01 0.0       0.0        0.0        0.0       0.0
 18  39  1 -0.139E 01 0.0       0.0        0.0        0.0       0.0
 19DIR COS XI-1.000 0.0   0.0  ET 0.0  -1.000 0.0  ZT 0.0   0.0   1.000
 19  39  1 -0.151E 01 0.0       0.0        0.0        0.0       0.0
 19  40  1 -0.151E 01 0.0       0.0        0.0        0.0       0.0
 20DIR COS XI-1.000 0.0   0.0  ET 0.0  -1.000 0.0  ZT 0.0   0.0   1.000
 20  40  1  0.230E 00 0.0       0.0        0.0        0.0       0.0
 20  41  1  0.230E 00 0.0       0.0        0.0        0.0       0.0
 21DIR COS XI 0.0  -1.000 0.0  ET 1.000 0.0   0.0  ZT 0.0   0.0   1.000
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21  36  1  0.230E 00 0.0       0.0         0.0         0.0         0.0
22DIR COS XI 0.0  -1.000 0.0  ET 1.000 0.0    0.0  ZT 0.0    0.0    1.000
22  36  1 -0.138E 01 0.0       0.0         0.0         0.0         0.0
22  31  1 -0.138E 01 0.0       0.0         0.0         0.0         0.0
23DIR COS XI 0.0  -1.000 0.0  ET 1.000 0.0    0.0  ZT 0.0    0.0    1.000
23  31  1 -0.148E 01 0.0       0.0         0.0         0.0         0.0
23  26  1 -0.148E 01 0.0       0.0         0.0         0.0         0.0
24DIR COS XI 0.0  -1.000 0.0  ET 1.000 0.0    0.0  ZT 0.0    0.0    1.000
24  26  1  0.250E 00 0.0       0.0         0.0         0.0         0.0
24  21  1  0.250E 00 0.0       0.0         0.0         0.0         0.0
25DIR COS XI 0.0   1.000 0.0  ET-1.000 0.0    0.0  ZT 0.0    0.0    1.000
25  20  1  0.500E 00 0.0       0.0         0.0         0.0         0.0
25  25  1  0.500E 00 0.0       0.0         0.0         0.0         0.0
26DIR COS XI 0.0   1.000 0.0  ET-1.000 0.0    0.0  ZT 0.0    0.0    1.000
26  25  1 -0.131E 01 0.0       0.0         0.0         0.0         0.0
26  30  1 -0.131E 01 0.0       0.0         0.0         0.0         0.0
27DIR COS XI 0.0   1.000 0.0  ET-1.000 0.0    0.0  ZT 0.0    0.0    1.000
27  30  1 -0.138E 01 0.0       0.0         0.0         0.0         0.0
27  35  1 -0.138E 01 0.0       0.0         0.0         0.0         0.0
28DIR COS XI 0.0   1.000 0.0  ET-1.000 0.0    0.0  ZT 0.0    0.0    1.000
28  35  1  0.500E 00 0.0       0.0         0.0         0.0         0.0
28  40  1  0.500E 00 0.0       0.0         0.0         0.0         0.0
29DIR COS XI 0.0  -1.000 0.0  ET 1.000 0.0    0.0  ZT 0.0    0.0    1.000
29  39  1  0.500E 00 0.0       0.0         0.0         0.0         0.0
29  34  1  0.500E 00 0.0       0.0         0.0         0.0         0.0
30DIR COS XI 0.0  -1.000 0.0  ET 1.000 0.0    0.0  ZT 0.0    0.0    1.000
30  34  1 -0.516E 00 0.0       0.0         0.0         0.0         0.0
30  29  1 -0.516E 00 0.0       0.0         0.0         0.0         0.0
31DIR COS XI 0.0  -1.000 0.0  ET 1.000 0.0    0.0  ZT 0.0    0.0    1.000
31  29  1 -0.450E 00 0.0       0.0         0.0         0.0         0.0
31  24  1 -0.450E 00 0.0       0.0         0.0         0.0         0.0
32DIR COS XI 0.0  -1.000 0.0  ET 1.000 0.0    0.0  ZT 0.0    0.0    1.000
32  24  1  0.500E 00 0.0       0.0         0.0         0.0         0.0
32  19  1  0.500E 00 0.0       0.0         0.0         0.0         0.0
33DIR COS XI 0.0   1.000 0.0  ET-1.000 0.0    0.0  ZT 0.0    0.0    1.000
33  18  1  0.500E 00 0.0       0.0         0.0         0.0         0.0
33  23  1  0.500E 00 0.0       0.0         0.0         0.0         0.0
34DIR COS XI 0.0   1.000 0.0  ET-1.000 0.0    0.0  ZT 0.0    0.0    1.000
34  23  1 -0.128E 01 0.0       0.0         0.0         0.0         0.0
34  28  1 -0.128E 01 0.0       0.0         0.0         0.0         0.0
35DIR COS XI 0.0   1.000 0.0  ET-1.000 0.0    0.0  ZT 0.0    0.0    1.000
35  28  1 -0.135E 01 0.0       0.0         0.0         0.0         0.0
35  33  1 -0.135E 01 0.0       0.0         0.0         0.0         0.0
36DIR COS XI 0.0   1.000 0.0  ET-1.000 0.0    0.0  ZT 0.0    0.0    1.000
36  33  1  0.500E 00 0.0       0.0         0.0         0.0         0.0
36  38  1  0.500E 00 0.0       0.0         0.0         0.0         0.0
37DIR COS XI 0.0  -1.000 0.0  ET 1.000 0.0    0.0  ZT 0.0    0.0    1.000
37  37  1  0.250E 00 0.0       0.0         0.0         0.0         0.0
37  32  1  0.250E 00 0.0       0.0         0.0         0.0         0.0
38DIR COS XI 0.0  -1.000 0.0  ET 1.000 0.0    0.0  ZT 0.0    0.0    1.000
38  32  1 -0.138E 01 0.0       0.0         0.0         0.0         0.0
38  27  1 -0.138E 01 0.0       0.0         0.0         0.0         0.0
39DIR COS XI 0.0  -1.000 0.0  ET 1.000 0.0    0.0  ZT 0.0    0.0    1.000
39  27  1 -0.149E 01 0.0       0.0         0.0         0.0         0.0
39  22  1 -0.149E 01 0.0       0.0         0.0         0.0         0.0
40DIR COS XI 0.0  -1.000 0.0  ET 1.000 0.0    0.0  ZT 0.0    0.0    1.000
40  22  1  0.250E 00 0.0       0.0         0.0         0.0         0.0
40  17  1  0.250E 00 0.0       0.0         0.0         0.0         0.0
41DIR COS XI-1.000 0.0    0.0  ET 0.0  -1.000 0.0  ZT 0.0    0.0    1.000
41   1  1  0.126E 01 0.0       0.0         0.0         0.0         0.0
41   2  1  0.126E 01 0.0       0.0         0.0         0.0         0.0
42DIR COS XI-1.000 0.0    0.0  ET 0.0  -1.000 0.0  ZT 0.0    0.0    1.000
42   2  1  0.274E 01 0.0       0.0         0.0         0.0         0.0
42   3  1  0.274E 01 0.0       0.0         0.0         0.0         0.0
43DIR COS XI-1.000 0.0    0.0  ET 0.0  -1.000 0.0  ZT 0.0    0.0    1.000
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 43   4  1  0.127E 01 0.0          0.0          0.0          0.0          0.0
 44DIR COS XI 1.000 0.0    0.0  ET 0.0     1.000 0.0   ZT 0.0     0.0   1.000
 44   5  1  0.835E 00 0.0          0.0          0.0          0.0          0.0
 44   6  1  0.835E 00 0.0          0.0          0.0          0.0          0.0
 45DIR COS XI 1.000 0.0    0.0  ET 0.0     1.000 0.0   ZT 0.0     0.0   1.000
 45   6  1  0.140E 01 0.0          0.0          0.0          0.0          0.0
 45   7  1  0.140E 01 0.0          0.0          0.0          0.0          0.0
 46DIR COS XI 1.000 0.0    0.0  ET 0.0     1.000 0.0   ZT 0.0     0.0   1.000
 46   7  1  0.851E 00 0.0          0.0          0.0          0.0          0.0
 46   8  1  0.851E 00 0.0          0.0          0.0          0.0          0.0
 47DIR COS XI-1.000 0.0    0.0  ET 0.0    -1.000 0.0   ZT 0.0     0.0   1.000
 47   9  1  0.523E 00 0.0          0.0          0.0          0.0          0.0
 47  10  1  0.523E 00 0.0          0.0          0.0          0.0          0.0
 48DIR COS XI-1.000 0.0    0.0  ET 0.0    -1.000 0.0   ZT 0.0     0.0   1.000
 48  10  1  0.974E 00 0.0          0.0          0.0          0.0          0.0
 48  11  1  0.974E 00 0.0          0.0          0.0          0.0          0.0
 49DIR COS XI-1.000 0.0    0.0  ET 0.0    -1.000 0.0   ZT 0.0     0.0   1.000
 49  11  1  0.508E 00 0.0          0.0          0.0          0.0          0.0
 49  12  1  0.508E 00 0.0          0.0          0.0          0.0          0.0
 50DIR COS XI 1.000 0.0    0.0  ET 0.0     1.000 0.0   ZT 0.0     0.0   1.000
 50  13  1 -0.487E 00 0.0          0.0          0.0          0.0          0.0
 50  14  1 -0.487E 00 0.0          0.0          0.0          0.0          0.0
 51DIR COS XI 1.000 0.0    0.0  ET 0.0     1.000 0.0   ZT 0.0     0.0   1.000
 51  14  1  0.101E 01 0.0          0.0          0.0          0.0          0.0
 51  15  1  0.101E 01 0.0          0.0          0.0          0.0          0.0
 52DIR COS XI 1.000 0.0    0.0  ET 0.0     1.000 0.0   ZT 0.0     0.0   1.000
 52  15  1 -0.518E 00 0.0          0.0          0.0          0.0          0.0
 52  16  1 -0.518E 00 0.0          0.0          0.0          0.0          0.0
 53DIR COS XI 0.0  -1.000 0.0  ET 1.000 0.0    0.0   ZT 0.0     0.0   1.000
 53  13  1  0.128E 01 0.0          0.0          0.0          0.0          0.0
 53  12  1  0.128E 01 0.0          0.0          0.0          0.0          0.0
 54DIR COS XI 0.0  -1.000 0.0  ET 1.000 0.0    0.0   ZT 0.0     0.0   1.000
 54  12  1  0.275E 01 0.0          0.0          0.0          0.0          0.0
 54   5  1  0.275E 01 0.0          0.0          0.0          0.0          0.0
 55DIR COS XI 0.0  -1.000 0.0  ET 1.000 0.0    0.0   ZT 0.0     0.0   1.000
 55   5  1  0.128E 01 0.0          0.0          0.0          0.0          0.0
 55   4  1  0.128E 01 0.0          0.0          0.0          0.0          0.0
 56DIR COS XI 0.0   1.000 0.0  ET-1.000 0.0    0.0   ZT 0.0     0.0   1.000
 56   3  1  0.837E 00 0.0          0.0          0.0          0.0          0.0
 56   6  1  0.837E 00 0.0          0.0          0.0          0.0          0.0
 57DIR COS XI 0.0   1.000 0.0  ET-1.000 0.0    0.0   ZT 0.0     0.0   1.000
 57   6  1  0.140E 01 0.0          0.0          0.0          0.0          0.0
 57  11  1  0.140E 01 0.0          0.0          0.0          0.0          0.0
 58DIR COS XI 0.0   1.000 0.0  ET-1.000 0.0    0.0   ZT 0.0     0.0   1.000
 58  11  1  0.853E 00 0.0          0.0          0.0          0.0          0.0
 58  14  1  0.853E 00 0.0          0.0          0.0          0.0          0.0
 59DIR COS XI 0.0  -1.000 0.0  ET 1.000 0.0    0.0   ZT 0.0     0.0   1.000
 59  15  1  0.524E 00 0.0          0.0          0.0          0.0          0.0
 59  10  1  0.524E 00 0.0          0.0          0.0          0.0          0.0
 60DIR COS XI 0.0  -1.000 0.0  ET 1.000 0.0    0.0   ZT 0.0     0.0   1.000
 60  10  1  0.976E 00 0.0          0.0          0.0          0.0          0.0
 60   7  1  0.976E 00 0.0          0.0          0.0          0.0          0.0
 61DIR COS XI 0.0  -1.000 0.0  ET 1.000 0.0    0.0   ZT 0.0     0.0   1.000
 61   7  1  0.509E 00 0.0          0.0          0.0          0.0          0.0
 61   2  1  0.509E 00 0.0          0.0          0.0          0.0          0.0
 62DIR COS XI 0.0   1.000 0.0  ET-1.000 0.0    0.0   ZT 0.0     0.0   1.000
 62   1  1 -0.494E 00 0.0          0.0          0.0          0.0          0.0
 62   8  1 -0.494E 00 0.0          0.0          0.0          0.0          0.0
 63DIR COS XI 0.0   1.000 0.0  ET-1.000 0.0    0.0   ZT 0.0     0.0   1.000
 63   8  1  0.100E 01 0.0          0.0          0.0          0.0          0.0
 63   9  1  0.100E 01 0.0          0.0          0.0          0.0          0.0
 64DIR COS XI 0.0   1.000 0.0  ET-1.000 0.0    0.0   ZT 0.0     0.0   1.000
 64   9  1 -0.511E 00 0.0          0.0          0.0          0.0          0.0
 64  16  1 -0.511E 00 0.0          0.0          0.0          0.0          0.0
 65DIR COS XI-0.577 0.577-0.577ET-0.707-0.707 0.0   ZT-0.408 0.408 0.816
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65   1  1 -0.433E 00 0.0         0.0         0.0          0.0          0.0
66DIR COS XI-0.577-0.577 0.577ET 0.707-0.707 0.0  ZT 0.408 0.408 0.816
66   1  1 -0.183E 01 0.0       -0.596E-07 0.0          0.0          0.0
66  18  1 -0.183E 01 0.0       -0.596E-07 0.0          0.0          0.0
67DIR COS XI-0.577 0.577-0.577ET-0.707-0.707 0.0  ZT-0.408 0.408 0.816
67  18  1  0.969E 00 0.0       -0.596E-07 0.0          0.0          0.0
67   2  1  0.969E 00 0.0       -0.596E-07 0.0          0.0          0.0
68DIR COS XI-0.577-0.577 0.577ET 0.707-0.707 0.0  ZT 0.408 0.408 0.816
68   2  1 -0.528E 00 0.0       -0.596E-07 0.0          0.0          0.0
68  19  1 -0.528E 00 0.0       -0.596E-07 0.0          0.0          0.0
69DIR COS XI-0.577 0.577-0.577ET-0.707-0.707 0.0  ZT-0.408 0.408 0.816
69  19  1 -0.338E 00 0.0         0.0         0.0          0.0          0.0
69   3  1 -0.338E 00 0.0         0.0         0.0          0.0          0.0
70DIR COS XI-0.577-0.577 0.577ET 0.707-0.707 0.0  ZT 0.408 0.408 0.816
70   3  1  0.106E 01 0.0        0.596E-07 0.0          0.0          0.0
7C  20  1  0.106E 01 0.0        0.596E-07 0.0          0.0          0.0
71DIR COS XI-0.577 0.577-0.577ET-0.707-0.707 0.0  ZT-0.408 0.408 0.816
71  20  1 -0.193E 01 0.0         0.0         0.0          0.0          0.0
71   4  1 -0.193E 01 0.0         0.0         0.0          0.0          0.0
72DIR COS XI-0.577-0.577 0.577ET 0.707-0.707 0.0  ZT 0.408 0.408 0.816
72   4  1 -0.433E 00 0.0         0.0         0.0          0.0          0.0
72  21  1 -0.433E 00 0.0         0.0         0.0          0.0          0.0
73DIR COS XI 0.577-0.577-0.577ET 0.707 0.707 0.0  ZT 0.408-0.408 0.816
73  26  1 -0.193E 01 0.0         0.0         0.0          0.0          0.0
73   4  1 -0.193E 01 0.0         0.0         0.0          0.0          0.0
74DIR COS XI 0.577 0.577 0.577ET-0.707 0.707 0.0  ZT-0.408-0.408 0.816
74   4  1 -0.264E 01 0.0         0.0         0.0          0.0          0.0
74  25  1 -0.264E 01 0.0         0.0         0.0          0.0          0.0
75DIR COS XI 0.577-0.577-0.577ET 0.707 0.707 0.0  ZT 0.408-0.408 0.816
75  25  1  0.208E 00 0.0         0.0         0.0          0.0          0.0
75   3  1  0.208E 00 0.0         0.0         0.0          0.0          0.0
76DIR COS XI 0.577 0.577 0.577ET-0.707 0.707 0.0  ZT-0.408-0.408 0.816
76   3  1 -0.933E 00 0.0       -0.596E-07 0.0          0.0          0.0
76  24  1 -0.933E 00 0.0       -0.596E-07 0.0          0.0          0.0
77DIR COS XI 0.577-0.577-0.577ET 0.707 0.707 0.0  ZT 0.408-0.408 0.816
77  24  1 -0.755E 00 0.0         0.0         0.0          0.0          0.0
77   2  1 -0.755E 00 0.0         0.0         0.0          0.0          0.0
78DIR COS XI 0.577 0.577 0.577ET-0.707 0.707 0.0  ZT-0.408-0.408 0.816
78   2  1  0.314E 00 0.0         0.0         0.0          0.0          0.0
78  23  1  0.314E 00 0.0         0.0         0.0          0.0          0.0
79DIR COS XI 0.577-0.577-0.577ET 0.707 0.707 0.0  ZT 0.408-0.408 0.816
79  23  1 -0.272E 01 0.0         0.0         0.0          0.0          0.0
79   1  1 -0.272E 01 0.0         0.0         0.0          0.0          0.0
80DIR COS XI 0.577 0.577 0.577ET-0.707 0.707 0.0  ZT-0.408-0.408 0.816
80   1  1 -0.194E 01 0.0       -0.596E-07 0.0          0.0          0.0
80  22  1 -0.194E 01 0.0       -0.596E-07 0.0          0.0          0.0
81DIR COS XI-0.577 0.577-0.577ET-0.707-0.707 0.0  ZT-0.408 0.408 0.816
81  22  1  0.108E 01 0.0       -0.596E-07 0.0          0.0          0.0
81   8  1  0.108E 01 0.0       -0.596E-07 0.0          0.0          0.0
82DIR COS XI-0.577-0.577 0.577ET 0.707-0.707 0.0  ZT 0.408 0.408 0.816
82   8  1  0.223E 00 0.0         0.0         0.0          0.0          0.0
82  23  1  0.223E 00 0.0         0.0         0.0          0.0          0.0
83DIR COS XI-0.577 0.577-0.577ET-0.707-0.707 0.0  ZT-0.408 0.408 0.816
83  23  1  0.449E 00 0.0       -0.596E-07 0.0          0.0          0.0
83   7  1  0.449E 00 0.0       -0.596E-07 0.0          0.0          0.0
84DIR COS XI-0.577-0.577 0.577ET 0.707-0.707 0.0  ZT 0.408 0.408 0.816
84   7  1 -0.448E-01 0.0       -0.373E-08 0.0          0.0          0.0
84  24  1 -0.448E-01 0.0       -0.373E-08 0.0          0.0          0.0
85DIR COS XI-0.577 0.577-0.577ET-0.707-0.707 0.0  ZT-0.408 0.408 0.816
85  24  1  0.154E-02 0.0         0.0         0.0          0.0          0.0
85   6  1  0.154E-02 0.0         0.0         0.0          0.0          0.0
86DIR COS XI-0.577-0.577 0.577ET 0.707-0.707 0.0  ZT 0.408 0.408 0.816
86   6  1  0.489E 00 0.0         0.0         0.0          0.0          0.0
86  25  1  0.489E 00 0.0         0.0         0.0          0.0          0.0
87DIR COS XI-0.577 0.577-0.577ET-0.707-0.707 0.0  ZT-0.408 0.408 0.816
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87   5  1  0.209E 00 0.0         0.0         0.0         0.0         0.0
88DIR COS XI-0.577-0.577 0.577ET 0.707-0.707 0.0  ZT 0.408 0.408 0.816
88   5  1  0.107E 01 0.0         0.596E-07 0.0         0.0         0.0
88  26  1  0.107E 01 0.0         0.596E-07 0.0         0.0         0.0
89DIR COS XI 0.577-0.577-0.577ET 0.707 0.707 0.0  ZT 0.408-0.408 0.816
89  31  1 -0.344E 00 0.0         0.596E-07 0.0         0.0         0.0
89   5  1 -0.344E 00 0.0         0.596E-07 0.0         0.0         0.0
90DIR COS XI 0.577 0.577 0.577ET-0.707 0.707 0.0  ZT-0.408-0.408 0.816
90   5  1 -0.932E 00 0.0         0.0         0.0         0.0         0.0
90  30  1 -0.932E 00 0.0         0.0         0.0         0.0         0.0
91DIR COS XI 0.577-0.577-0.577ET 0.707 0.707 0.0  ZT 0.408-0.408 0.816
91  30  1  0.682E-03 0.0         0.0         0.0         0.0         0.0
91   6  1  0.682E-03 0.0         0.0         0.0         0.0         0.0
92DIR COS XI 0.577 0.577 0.577ET-0.707 0.707 0.0  ZT-0.408-0.408 0.816
92   6  1 -0.492E 00 0.0        -0.596E-07 0.0         0.0         0.0
92  29  1 -0.492E 00 0.0        -0.596E-07 0.0         0.0         0.0
93DIR COS XI 0.577-0.577-0.577ET 0.707 0.707 0.0  ZT 0.408-0.408 0.816
93  29  1 -0.431E 00 0.0         0.596E-07 0.0         0.0         0.0
93   7  1 -0.431E 00 0.0         0.596E-07 0.0         0.0         0.0
94DIR COS XI 0.577 0.577 0.577ET-0.707 0.707 0.0  ZT-0.408-0.408 0.816
94   7  1  0.274E-01 0.0         0.0         0.0         0.0         0.0
94  28  1  0.274E-01 0.0         0.0         0.0         0.0         0.0
95DIR COS XI 0.577-0.577-0.577ET 0.707 0.707 0.0  ZT 0.408-0.408 0.816
95  28  1 -0.960E 00 0.0         0.0         0.0         0.0         0.0
95   8  1 -0.960E 00 0.0         0.0         0.0         0.0         0.0
96DIR COS XI 0.577 0.577 0.577ET-0.707 0.707 0.0  ZT-0.408-0.408 0.816
96   8  1 -0.338E 00 0.0         0.0         0.0         0.0         0.0
96  27  1 -0.338E 00 0.0         0.0         0.0         0.0         0.0
97DIR COS XI-0.577 0.577-0.577ET-0.707-0.707 0.0  ZT-0.408 0.408 0.816
97  27  1 -0.528E 00 0.0         0.596E-07 0.0         0.0         0.0
97   9  1 -0.528E 00 0.0         0.596E-07 0.0         0.0         0.0
98DIR COS XI-0.577-0.577 0.577ET 0.707-0.707 0.0  ZT 0.408 0.408 0.816
98   9  1 -0.785E 00 0.0         0.0         0.0         0.0         0.0
98  28  1 -0.785E 00 0.0         0.0         0.0         0.0         0.0
99DIR COS XI-0.577 0.577-0.577ET-0.707-0.707 0.0  ZT-0.408 0.408 0.816
99  28  1 -0.147E-01 0.0         0.0         0.0         0.0         0.0
99  10  1 -0.147E-01 0.0         0.0         0.0         0.0         0.0
100DIR COS XI-0.577-0.577 0.577ET 0.707-0.707 0.0  ZT 0.408 0.408 0.816
100  10  1 -0.377E 00 0.0       -0.596E-07 0.0         0.0         0.0
100  29  1 -0.377E 00 0.0       -0.596E-07 0.0         0.0         0.0
101DIR COS XI-0.577 0.577-0.577ET-0.707-0.707 0.0  ZT-0.408 0.408 0.816
101  29  1 -0.432E 00 0.0        0.596E-07 0.0         0.0         0.0
101  11  1 -0.432E 00 0.0        0.596E-07 0.0         0.0         0.0
102DIR COS XI-0.577-0.577 0.577ET 0.707-0.707 0.0  ZT 0.408 0.408 0.816
102  11  1 -0.457E-01 0.0       -0.373E-08 0.0         0.0         0.0
102  30  1 -0.457E-01 0.0       -0.373E-08 0.0         0.0         0.0
103DIR COS XI-0.577 0.577-0.577ET-0.707-0.707 0.0  ZT-0.408 0.408 0.816
103  30  1 -0.755E 00 0.0        0.596E-07 0.0         0.0         0.0
103  12  1 -0.755E 00 0.0        0.596E-07 0.0         0.0         0.0
104DIR COS XI-0.577-0.577 0.577ET 0.707-0.707 0.0  ZT 0.408 0.408 0.816
104  12  1 -0.522E 00 0.0       -0.596E-07 0.0         0.0         0.0
104  31  1 -0.522E 00 0.0       -0.596E-07 0.0         0.0         0.0
105DIR COS XI 0.577-0.577-0.577ET 0.707 0.707 0.0  ZT 0.408-0.408 0.816
105  36  1  0.962E 00 0.0       -0.596E-07 0.0         0.0         0.0
105  12  1  0.962E 00 0.0       -0.596E-07 0.0         0.0         0.0
106DIR COS XI 0.577 0.577 0.577ET-0.707 0.707 0.0  ZT-0.408-0.408 0.816
106  12  1  0.315E 00 0.0        0.0         0.0         0.0         0.0
106  35  1  0.315E 00 0.0        0.0         0.0         0.0         0.0
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107  11  1  0.450E 00 0.0        0.0         0.0         0.0         0.0
108DIR COS XI 0.577 0.577 0.577ET-0.707 0.707 0.0  ZT-0.408-0.408 0.816
108  11  1  0.280E-01 0.0        0.373E-08 0.0         0.0         0.0
108  34  1  0.280E-01 0.0        0.373E-08 0.0         0.0         0.0
109DIR COS XI 0.577-0.577-0.577ET 0.707 0.707 0.0  ZT 0.408-0.408 0.816
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```
109  34  1 -0.142E-01 0.0        0.0        0.0        0.0        0.0
109  10  1 -0.142E-01 0.0        0.0        0.0        0.0        0.0
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110  10  1  0.406E 00 0.0        0.596E-07 0.0      0.0        0.0
110  33  1  0.406E 00 0.0        0.596E-07 0.0      0.0        0.0
111DIR COS XI 0.577-0.577-0.577ET 0.707 0.707 0.0  ZT 0.408-0.408 0.816
111  33  1  0.332E 00 0.0        0.0        0.0        0.0        0.0
111   9  1  0.332E 00 0.0        0.0        0.0        0.0        0.0
112DIR COS XI 0.577 0.577 0.577ET-0.707 0.707 0.0  ZT-0.408-0.408 0.816
112   9  1  0.981E 00 0.0        0.0        0.0        0.0        0.0
112  32  1  0.981E 00 0.0        0.0        0.0        0.0        0.0
113DIR COS XI-0.577 0.577-0.577ET-0.707-0.707 0.0  ZT-0.408 0.408 0.816
113  32  1 -0.185E 01 0.0        0.596E-07 0.0      0.0        0.0
113  16  1 -0.185E 01 0.0        0.596E-07 0.0      0.0        0.0
114DIR COS XI-0.577-0.577 0.577ET 0.707-0.707 0.0  ZT 0.408 0.408 0.816
114  16  1 -0.280E 01 0.0        0.0        0.0        0.0        0.0
114  33  1 -0.280E 01 0.0        0.0        0.0        0.0        0.0
115DIR COS XI-0.577 0.577-0.577ET-0.707-0.707 0.0  ZT-0.408 0.408 0.816
115  33  1  0.332E 00 0.0       -0.596E-07 0.0      0.0        0.0
115  15  1  0.332E 00 0.0       -0.596E-07 0.0      0.0        0.0
116DIR COS XI-0.577-0.577 0.577ET 0.707-0.707 0.0  ZT 0.408 0.408 0.816
116  15  1 -0.786E 00 0.0       -0.596E-07 0.0      0.0        0.0
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117DIR COS XI-0.577 0.577-0.577ET-0.707-0.707 0.0  ZT-0.408 0.408 0.816
117  34  1 -0.960E 00 0.0        0.0        0.0        0.0        0.0
117  14  1 -0.960E 00 0.0        0.0        0.0        0.0        0.0
118DIR COS XI-0.577-0.577 0.577ET 0.707-0.707 0.0  ZT 0.408 0.408 0.816
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119DIR COS XI-0.577 0.577-0.577ET-0.707-0.707 0.0  ZT-0.408 0.408 0.816
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122DIR COS XI 0.577 0.577 0.577ET-0.707 0.707 0.0  ZT-0.408-0.408 0.816
122  13  1 -0.194E 01 0.0       -0.596E-07 0.0      0.0        0.0
122  40  1 -0.194E 01 0.0       -0.596E-07 0.0      0.0        0.0
123DIR COS XI 0.577-0.577-0.577ET 0.707 0.707 0.0  ZT 0.408-0.408 0.816
123  40  1  0.107E 01 0.0        0.0        0.0        0.0        0.0
123  14  1  0.107E 01 0.0        0.0        0.0        0.0        0.0
124DIR COS XI 0.577 0.577 0.577ET-0.707 0.707 0.0  ZT-0.408-0.408 0.816
124  14  1 -0.332E 00 0.0        0.0        0.0        0.0        0.0
124  39  1 -0.332E 00 0.0        0.0        0.0        0.0        0.0
125DIR COS XI 0.577-0.577-0.577ET 0.707 0.707 0.0  ZT 0.408-0.408 0.816
125  39  1 -0.534E 00 0.0        0.0        0.0        0.0        0.0
125  15  1 -0.534E 00 0.0        0.0        0.0        0.0        0.0
126DIR COS XI 0.577 0.577 0.577ET-0.707 0.707 0.0  ZT-0.408-0.408 0.816
126  15  1  0.987E 00 0.0        0.0        0.0        0.0        0.0
126  38  1  0.987E 00 0.0        0.0        0.0        0.0        0.0
127DIR COS XI 0.577-0.577-0.577ET 0.707 0.707 0.0  ZT 0.408-0.408 0.816
127  38  1 -0.185E 01 0.0        0.596E-07 0.0      0.0        0.0
127  16  1 -0.185E 01 0.0        0.596E-07 0.0      0.0        0.0
128DIR COS XI 0.577 0.577 0.577ET-0.707 0.707 0.0  ZT-0.408-0.408 0.816
128  16  1 -0.433E 00 0.0       -0.596E-07 0.0      0.0        0.0
128  37  1 -0.433E 00 0.0       -0.596E-07 0.0      0.0        0.0
STRESS LINK TOOK 131.69  SECONDS.
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APPENDIX E

QUANTITY ESTIMATE

QUANTITY ESTIMATE

DESCRIPTION	DIMENSIONS	NO.	QUANTITIES
Techite pipe	8"dia. x 8'0"	8	64 lin.ft.
	8"dia. x 3'6"	10	35 lin.ft.
		Total :	99 lin.ft.
Concrete			
slab	48' x 8' x 4"	1	7.26 cu.yds.
foundations	6' x 3' x 3'	2	4.00 cu.yds.
joints	1'4"x 1'0"x 8"	12	5.52 cu.yds.
		Total :	16.78 cu.yds.
Reinforcing steel			
#4 bar	4'0"	42	168 lin.ft.
	2'0"	60	120 lin.ft.
	10'6"	42	441 lin.ft.
	8'0"	42	336 lin.ft.
	11'0"	16	176 lin.ft.
		Total :	1241 lin.ft.
		Total :	820 lbs.

APPENDIX F

REFERENCE MATERIALS

Reprinted from CHEMICAL ENGINEERING PROGRESS, April 1965

Reinforced polyester piping systems

Corrosion resistance, light weight, excellent flow characteristics, low initial investment, ease of fabrication and handling, long service history, good insulating characteristics, and low maintenance are features of reinforced polyester piping.

W. A. SZYMANSKI, *Durez Plastics Division, Hooker Chemical Corp., North Tonawanda, N. Y.*
and
R. C. TALBOT, *Hooker Chemical Corp., Niagara Falls, N. Y.*

MORE THAN TWO MILES of fiberglass-reinforced polyester pressure piping was installed in sizes varying from 2 to 14 in. in diameter in a new caustic-chlorine process at the Niagara Falls, N. Y., plant of the Hooker Chemical Corp., a little more than three years ago. The pipe, made with a corrosion resistant, inherently fire-retardant, chlorinated polyester resin, Hetron 72 (Durez Plastics Div., Hooker Chemical Corp. trademark) has been performing quite suitably ever since. The piping carries neutral or alkaline (pH's to 11) saturated sodium and potassium chloride brines, at temperatures to 175°F, to mercury cells where it is converted to caustic and chlorine. The depleted brines, at slightly lower concentrations, containing some chlorine are returned to resaturators and treaters in similar piping. Pressures are as high as 80 lb./sq. in. and velocities as high as 10 ft./sec. This article reviews this installation and other piping applications. Figures 1 and 2 show different views of the brine installation.

Fabrication

The pipe was fabricated by the contact, hand lay-up, wet technique to fabricator's specifications. Details were critically reviewed and approved by the corporate corrosion, engineering, and purchasing groups as well as the fabricator.

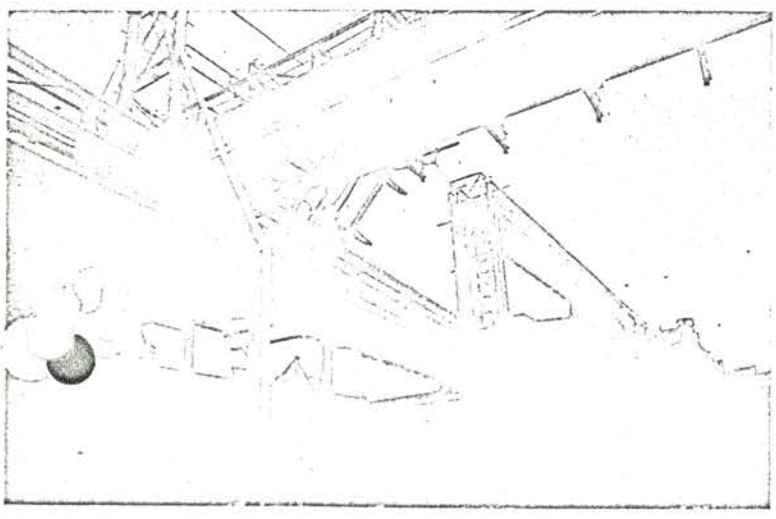
The pipe was made in 20-ft. lengths with a smooth resin-rich interior surface reinforced with a 10-mil surfacing veil of Type C (chemical grade) glass mat to prevent cracking or crazing. This was followed by two layers of 1½-oz. Type E (electrical grade) chopped-strand random glass mat. These layers, which are closest to the corrosive environs, form the corrosion resistant portion of the fabrication. Glass content averaged approximately 25%. Hoop and axial strength was provided by spirally winding glass cloth over this core. At least one layer of mat was placed between the layers of cloth. The exterior of the pipe was finished with resin containing ultraviolet screeners to protect the surface from sunlight degradation. Room temperature cures were used for all fabrications.

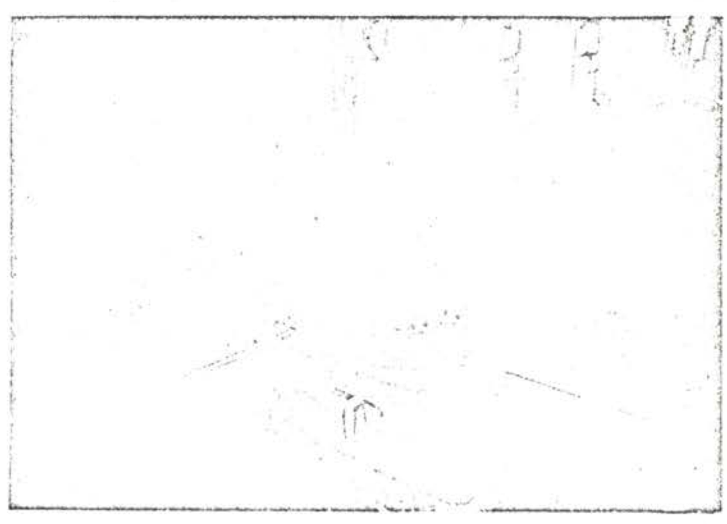
Since the fabricator was known for quality workmanship on previous jobs and had an excellent reputation throughout the industry, and because of the large scope of the job, it was agreed that final inspection would be made at the plant site. To facilitate visual inspection and to ensure highest quality, specifications called for an unfilled, unpigmented resin. Although appearance is by no means necessarily indicative of serviceability, additives, fillers, or anything that can mask certain defects, such as voids, resin-poor areas, pitting, air entrapment, etc., can result and have been known to result in early failures.

Several sections from each shipment of pipe were critically inspected for these and other defects. In addition, the pipe was checked to ensure that the inner surface was smooth and frictionless, that the diameter was true and not out of round, and that wall thicknesses were no less than 1/32 to 1/16 in. below design requirements. Quality was such that only a very small proportion of material was rejected.

Fittings and flanged stub ends

Figures 1 and 2. Different views of brine installation in a caustic-chlorine process at the Niagara Falls, N. Y., plant of Hooker Chemical Corp.





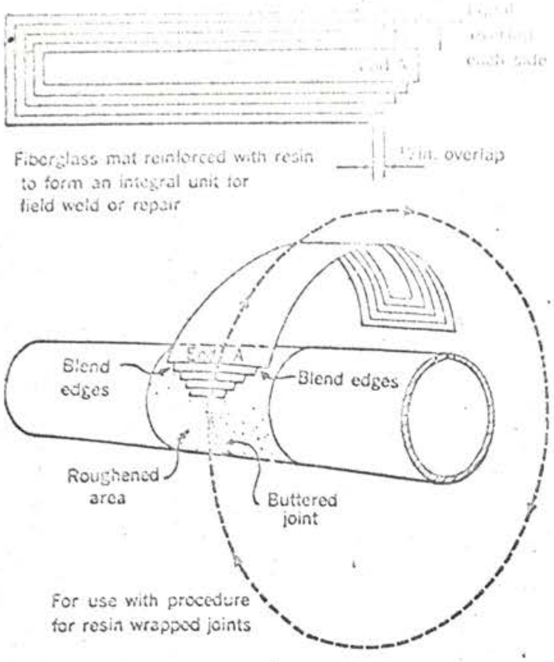


Figure 3. Butt and strap technique for joining reinforced-polyester piping.

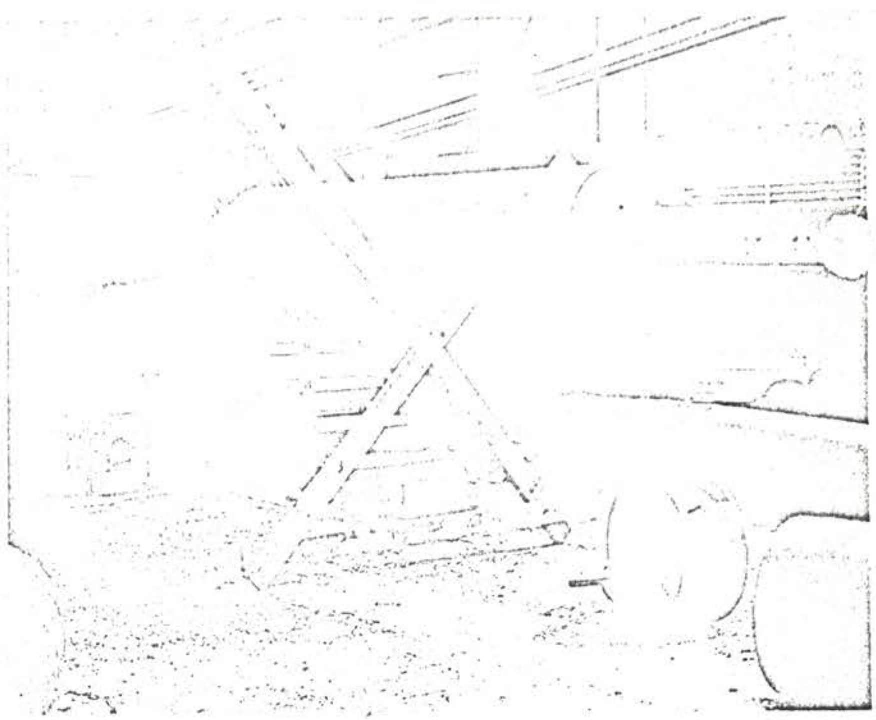


Figure 4. Usually a simple support arrangement suffices during fabrication.

were fabricated similarly by the hand lay-up technique, and also inspected on the site.

Design

The pipe and fittings were designed using the following minimum physical properties:

Tensile strength	12,000 lb./sq. in.
Flexural strength	18,000 lb./sq. in.
Flexural modules	8.5×10^5 lb./sq. in.

Wall thicknesses were established for an operating pressure of 100 lb./sq. in. gauge with a safety factor of 8-10 to 1 (based on the tensile strength of the laminate) using the basic Barlow formula,

$$t = pR/S$$

where, t is the wall thickness, in., p is the design pressure, lb./sq. in. gauge, R is the inside radius, in., and S is the design or allowable stress, lb./sq. in.

Sections of various fabrications were proof tested to determine if minimum physical requirements were met. In addition, several pipe sections with attached flanged stub ends were pressure proof tested with brine to check the strength of the pipe and to determine how the construction worked under applied hoop stress. Although facilities were only available for pressures to about 300 lb./sq. in. gauge, tests, in some instances, were run for several days, and pressure surges were applied many times during the tests. The fabricator also tested pipe and fitting sections at or close to theoretical bursting pressures.

System installation

The system was installed by contract pipefitters who had never handled reinforced plastics or resins before.

Flanged joints were kept to a minimum because of the relatively high cost of flanges, the butt and strap joint being used extensively. This technique is most economical and, if made properly, the joint can be stronger than the pipe itself. Figure 3 shows this joint, which is made by butting two prepared pieces of pipe together, buttering the joint with Cab-O-Sil filled resin, and overwrapping with resin-saturated multiple layers of reinforcing. Joint construction, as specified by the fabricator, was quite similar to that of the pipe itself. Fonda (*1*) and Lautenback (*2*) give excellent detailed descriptions of this joining technique. This design problem is also covered rather well by Perry (*3*). The secondary bonds at these joints, incidentally, are about 80% as strong as similar primary bonds, and this fact was taken into account during joint design.

Realizing how extremely important this phase of the installation would be in regard to service, the fabricator furnished a production foreman to train the contractor's supervisory personnel and pipefitters in the proper techniques. Several days were spent with the men, and, in addition, the fabricator periodically visited the plant site to check the joints, techniques, and the installation in general.

As many of the joints as possible were made on a production line basis in field shops, which were moved close to the final assembly and installation points.

Pipe support

To simplify support requirements, the pipe was supported horizontally approximately every 10 ft. on a 180° shoe or clamp-type support to minimize stresses. Loose U-

Figure 5. A flanging operation being performed on large-diameter pipe.

bolts were used to hold vertical pipe in place against a 180° shoe.

Because of the complex nature of the installation, which required a number of bends and elbows, no special methods were required, other than the natural flexibility of the layout, to compensate for expansion and contraction. At some selected points the lines were anchored, with essentially a 180° shoe and U-bolt assembly, and allowed to move freely in each direction from this point, making use of the natural flexibility inherent in the layout. Some of the long pipe runs were cold sprung during installation.

After start-up, expansion and contraction were checked to determine if the linear coefficient of thermal expansion, about 15×10^{-6} in./in./°F, as found by laboratory tests for this construction, was valid. Agreement was quite good.

Figures 4 and 5 show typical phases of the fabrication and installation, pointing out the simple support requirements and a flanging operation.

Service experience

Reinforced Hetron 72 polyester was chosen for this application for economic reasons, being less costly than rubber-lined construction, the next most suitable material. Since even trace amounts of heavy metal contamination can affect cell operation, metallic pipe, other than perhaps high cost super corrosion resistant alloys, would not be satisfactory. Selection was also based on service experience of similar piping, some of which had been in similar service for about four years (to date about seven years) with no corrosion difficulty. The presence of a combustible pipe which would contribute to fire hazard also could not be tolerated in this chemical complex. The decision was also based on the realization that the new plant was to be integrated with existing facilities and spread over a wide area, and that it would be difficult to anticipate all requirements or take into account all contingencies. An important advantage, therefore, was the fact that the plastic construction could be cut and joined easily in the field to facilitate changes and/or additions. With rubber-lined construction, on the other hand, greater engineering costs could be anticipated to design for the prefabrication requirements of this type pipe.

Once installation was under way, this advantage proved to be even more important than originally anticipated. It became quite apparent also that significant savings in installation costs were being realized because of the light weight and ease of handling of the plastic pipe. More than half of the pipe was installed on elevated pipe bridges and in some rather difficult, hard-to-reach locations. The pipe bridges, of course, could be constructed more economically of lighter gauge steel. Additional significant savings were realized since no painting was

Figure 7. Two inch pipe system handling 85 to 95°F benzene wet with hydrochloric acid and chlorine.

Figure 6. Polyester pipe is supported at 10- to 20-ft. intervals.

required. Less pump horsepower requirements and no scaling problems because of the smooth interior surface and excellent flow characteristics also add to the savings picture.

Start-up problems

During preliminary plant start-up, a few problems arose. Because of restricted movement, a sample valve and a small branch line broke off due to expansion of the main line. Higher operating pressures and temperatures than originally planned for and pressure surges caused several leaks at flanges and at butt-and-strap joints which were not properly made. A few sections of pipe and a few fittings with defects, as mentioned previously, which were not found before installation also leaked. Vibration of a vertical section of line resulted in a leak in a joint. Replacements and or repairs, however, were made quickly and easily. In some instances, repairs could be made with no plant shutdown.

All in all, taking into consideration the inexperienced pipefitters, the extensiveness of the installation, and the initial operating problems, etc., these difficulties were insignificant.

Since this break-in period, the operation has been performing quite satisfactorily with no major problems. Leaks did occur after about a year at a couple of joints. It was obvious, however, that this was due to improper joining to begin with. Upon examination, it was found that only about one inch of strap was bonded to the pipe on each side of, and about three inches away from, the butt joint. It was amazing that the joint held up as long as it did.

Vacuum failure

The biggest failure occurred when a length of vertical pipe collapsed due to either full or close to full vacuum when one valve was opened while the upper valve remained closed. Wall thickness was actually sufficient for service under full vacuum; however, the geometry of the pipe or some defect or flaw in construction may have caused failure.

The insulating characteristics of the plastic became a disadvantage in this system when a modification in the process was made. The brine did not cool sufficiently in the circulation loop and a cooler had to be installed. Of course, in other installations this characteristic could be and has been highly advantageous.

The biggest problem in the entire system was due to flanged joints. Because of the nature of the fabrication, some warpage and unevenness of the normally smooth faced flange resulted at times in a small gasket seating area and, consequently, leakage and, in one or two instances, a blown gasket. Application of higher and more uniform torque force on flange bolts helped considerably but was not the solution. Several different designs, *e.g.*, serrated, raised face, and variations of these, and steel back-up rings, which were installed during a plant shutdown, also helped considerably. This problem is in no way serious enough to detract from the other advantages offered by the use of reinforced polyester pipe, nor should it act as a deterrent to use. The new molded flange and flanged stub end designs which several fabricators are currently offering should eliminate this problem completely.

Other piping systems

Other piping systems are in excellent condition handling wet chlorine at temperatures of 205 to 210°F after about 10 years and at 210°F after about 5 years. Hundreds of feet of pipe in sizes to 18 in. in diameter handling wet chlorine gas off electrolytic cells, brine dechlorinators, and blow gas at temperatures to 180°F have been in service for more than 3 years with little evidence of attack. The Hetron provides much greater resistance to thermal and mechanical shock, which in itself is justification for its use at some points in the system. Installed costs are significantly lower than for stoneware, the former standard material, because of ease of handling, simpler joints, and ease of support. Where stoneware requires support at 2 to 3 ft. intervals, the polyester is supported at 10 to 20 ft. intervals. Figure 6 shows an installation in this service.

Where extra heavy steel failed in two months, reinforced Hetron piping has been in service for about 1½ years. This 2-in. pipe system, shown in Figure 7, handles 85 to 95°F benzene wet with hydrochloric acid and chlorine. The insulating characteristics of the plastic in this instance were beneficial, significantly reducing freeze-ups. With extreme cold weather, steam tracing was applied to this line. Previously, steam pressure was used to blow out freeze-ups with no detrimental effects.

Pipe has also successfully handled dilute and concentrated hydrochloric acid at temperatures to 150°F for about 9½ years; city water at 40 to 65°C, 0 to 5 ft./sec., and 10 to 65 lb./sq. in. gauge for about 9 years with no sweating problems; alcohol, sulfides, chlorides, and water at 105°F for about two years where extra heavy steel failed in two months; various organics, water, 1% HCl, Cl_2, and $FeCl_3$ at 90°F for over three years; chlorine water at ambient room temperature to 205°F for 6½ years; and chlorinated brine solutions at 200°F for approximately one year.

The above serves to indicate that reinforced polyester piping, due to a unique combination of properties, has found acceptance as a corrosion resistant material of construction. Corrosion resistance, light weight, excellent flow characteristics, low initial investment, ease of fabrication, installation, modification, and handling, long service history, good insulating characteristics, and low maintenance are among the properties and features which indicate that such piping can be used quite effectively for corrosion prevention and control.

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3. Perry, H. A., "Adhesive Bonding of Reinforced Plastics," p. 253, McGraw-Hill, New York (1959).

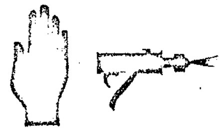
Szymanski

Talbot

W. A. Szymanski is a graduate of the University of Buffalo and has been active in corrosion work since 1948. Except for two years in the Army, he has been concerned with corrosion mitigation problems and corrosion research of all types.

R. C. Talbot is senior technician in the Corporate Corrosion Laboratory, Corporate Engineering Div., Hooker Chemical Corp. He has an associate degree in metallurgy from the Erie County Technical Institute.

RESINS AND OTHER MATERIALS FOR FIBERGLAS REINFORCED PLASTICS



hand lay-up or spray-up

POLYESTER RESINS

Polyesters offer the advantage of a balance of good mechanical, chemical and electrical properties, dimensional stability, low cost, and ease of handling. The table below will guide you in selecting, from the many types of polyesters available, the particular type best suited for your end use.

Much of the versatility of polyester resins results from a wide selection of raw materials and basic processing available to meet product characteristics that may be required.

When resin, monomer, and catalyst are mixed together, a cross-linking reaction starts. In this reaction, the polyester resin connects with the monomer to form a thermoset polyester resin. When fully cured, thermoset resins have higher temperature resistance than most thermoplastics.

Completion of this reaction is dependent both on the formulation and on the time and temperature balance selected in the design of the formulation. Pressure is not necessarily required for curing, but does effect other factors such as surface smoothness, density, and other process considerations.

The cure itself proceeds in two distinct stages. The first is the formation of a soft gel. Immediately after gelation, the cure proceeds rapidly with considerable evolution of heat which must be properly controlled. This evolution of heat is called an exothermic reaction. Complete cure is obtained without liberation of volatile materials when reaction is properly controlled. This last consideration coupled with low pressures accounts in large measure for the simplicity of the Fiberglas-reinforced plastic molding operation.

	POLYESTER RESINS	
Polyester	**Characteristic**	**Typical Uses**
General Purpose	Rigid moldings	Trays, boats, tanks, boxes, luggage, seating.
Flexible resins and semi-rigid resins	Tough, good impact resistance, high flexural strength, low flexural modulus	Vibration damping: machine covers and guards, safety helmets, electronic part encapsulation, gel coats, patching compounds, auto bodies, boats.
Light stable and weather resistant	Resistant to weather and ultra-violet degradation	Structural panels, sky-lighting, glazing.
Chemical resistant	Highest chemical resistance of polyester group, excellent acid resistance, fair in alkalies.	Corrosion resistant applications such as pipe, tanks, ducts, fume stacks.
Flame resistant	Self-extinguishing, rigid.	Building Panels (interior), electrical components, fuel tanks.
High heat distortion	Service up to 500°F, rigid.	Aircraft parts.
Hot strength	Fast rate of cure (hot), moldings easily removed from die.	Containers, trays, housings.
Low Exotherm	Void-free thick laminates, low heat generated during cure.	Encapsulating electronic components, electrical premix parts — switchgear.
Extended pot life	Void-free and uniform, long flow time in mold before gel.	Large complex moldings.
Air dry	Cures tack-free at room temperature.	Pools, boats, tanks.
Thixotropic	Resists flow or drainage when applied to vertical surfaces.	Boats, pools, tank linings.

EPOXIES

Epoxy Resins have excellent mechanical properties, dimensional stability and chemical resistance and are generally used to provide one of these characteristics in the finished part. They are more expensive and generally more difficult to handle than polyesters.

OTHER MATERIALS

The resin mix consists of materials other than the glass reinforcement. These ingredients include fillers, monomer, catalyst, activators, inhibitors, pigments, and mold release.

FILLERS

Inorganic fillers such as clay, talc, calcium carbonate, and calcium silicate are used for economic and performance reasons in Fiberglas-reinforced plastics. Economics, surface appearance, strength, resistance to environment, and moldability can be improved by proper selection and use. They are generally not used in hand lay-up or spray-up because they make the resin opaque, making it difficult to detect areas of air entrapment.

MONOMER

The resin as supplied by the resin manufacturer contains monomer. Additional monomers, such as styrene or vinyl toluene may be added to the resin in the molder's plant as directed by the resin manufacturer to vary the viscosity and lower the cost of the resultant resin mix. The addition of excessive amounts of styrene monomer lowers the weathering performance of the molding.

CATALYSTS

Organic peroxides are widely used (to catalyze polyester resins) due to convenience, cost, speed and control of action. Polymerization of polyester resins can also be achieved by exposure to radiation, ultra-violet light and heat.

Some factors regulating the catalyst choice are:

1. Desired temperature, allowable time and/or operation.
2. Type of monomer or mixture of monomers employed.
3. Desired pot life.
4. Desired gel and cure times.
5. Influence of sunlight and weathering on product performance.
6. Any other specifically required properties of the finished end product influenced by the catalyst choice.

The most commonly used organic peroxides are benzoyl peroxide, methyl ethyl ketone peroxide, and lauroyl peroxide.

ACTIVATORS AND INHIBITORS

Activators or accelerators — promote the action of the polyester catalyst to reduce the required processing time. Inhibitors are added to the resin to give control over the cure cycle and to impart adequate shelf life to the material. Both of these materials are normally added or specified by the resin supplier.

PIGMENTS

Reinforced-plastic resins can be colored to nearly any desired shade. This flexibility is one reason for the growth of the reinforced-plastics industry. Choice of pigments affects the difference in reflected and transmitted color, clarity of the resin mix, reactions between colorants and other additives such as catalysts, and performance of the end product in terms of color fastness and resistance to heat.

MOLD RELEASE

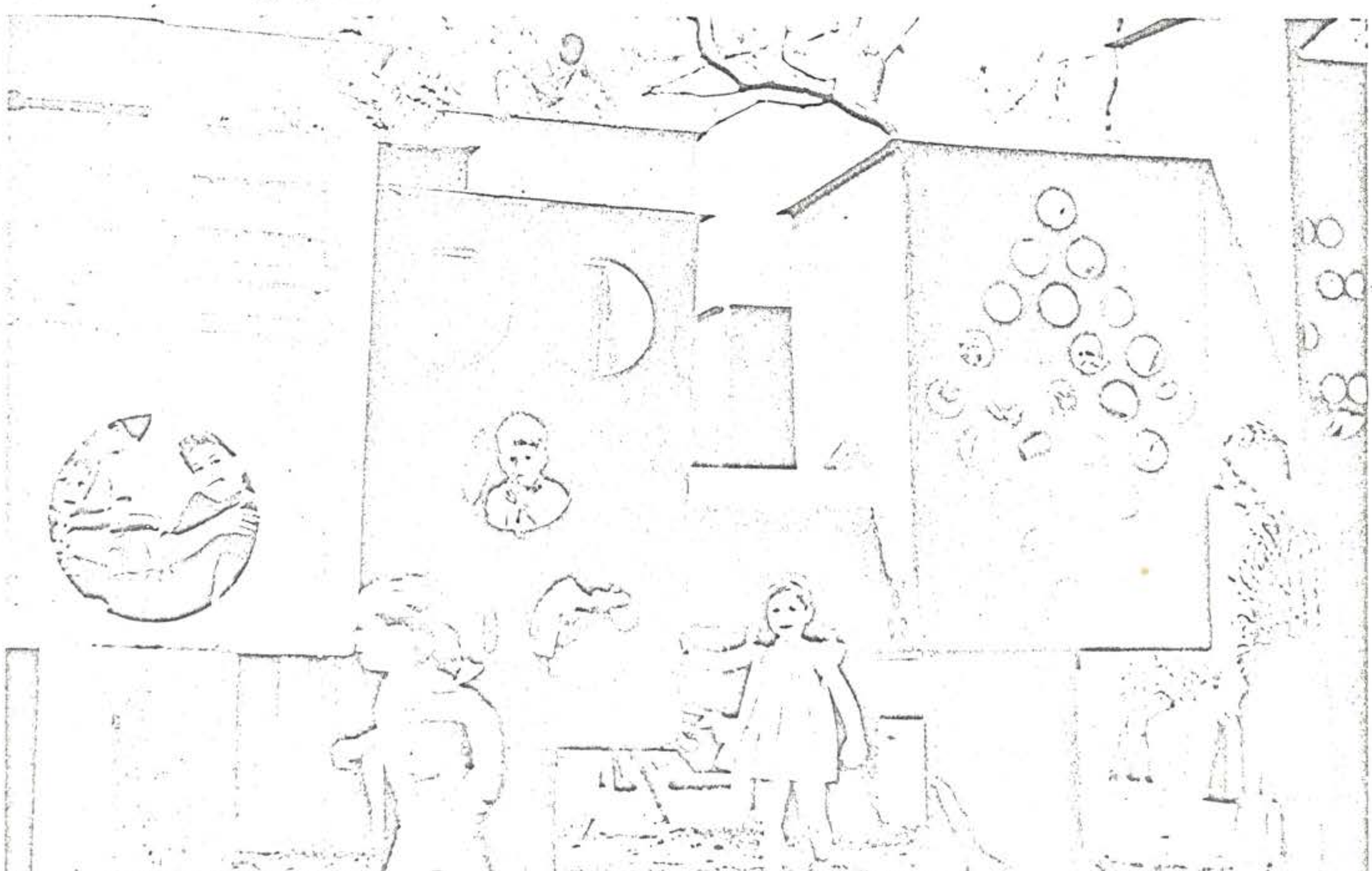
Easy release of the part from the mold after completion of the curing cycle is normally effected by treating the mold with waxes or silicones to lubricate the surface. At other times such substances as zinc stearate are added to the resin mix in order to facilitate the removal of parts. This is common practice on parts where the draft is low or where removal is difficult.

OTHER ADDITIVES

Other substances are added to the resin mix either by the resin supplier or the molder to impart special performance qualities. Typical of these substances are ultra-violet absorbers. They are added to resin mixes subject to exposure to ultra-violet rays in natural sunlight or fluorescent light.

Flame-proofing substances, such as antimony oxide or chlorinated waxes, are added to give a fire retardant effect. In this case, the adverse effect of these additives on outdoor weathering performance must be carefully considered.

Hand lay-up and spray-up of FRP is finding increased use in playground structures. The "Tree-Houses" shown here have proven extremely popular in this New York City playground.



PART CURING

hand lay-up or spray-up

The part cure will vary with the type of resin and catalyst used and may be governed by two conditions. (1) Air cure for parts that are not to be used immediately. (2) Oven and post cure for parts to be used soon after molding.

1. If the part can be stored (preferably at 70 to 80°F) and if the proper catalyst to promote air cure has been used, the part will reach a useable cured condition in storage.

   The resin and catalyst system and ambient curing environment will determine the time required for cure before part removal is possible.

   In any event, the part must be sufficiently rigid to retain the original shape and not distort after removal from the mold. This occurs if part is pulled while incompletely cured or, in the case where oven cures are employed, while it is too hot.

As a guide to apparent cure three changes may be noted.

a. Tack of the surface resin—should be very little tack.
b. Color change of the laminate from the wet state.
c. Loss of exotherm heat.

To further expedite part removal, the laminate may be placed in an oven at 120 to 150°F for 15 to 20 minutes before air dry.

If dimensions and contours must be held to close tolerance, the part should be placed in a cooling jig after it has been taken from the mold, or be permitted to reach room temperature while still in the mold.

OVEN-CURE

Convection type hot air ovens or infra-red heat lamp banks are suggested for the curing heat.

The box part can be cured at 125 to 150°F in 15 to 60 minutes (depending on the resin-catalyst system).

A Barcol hardness test of the surface is suggested after the part has been taken from the mold and cooled to 70°F.

If the reading indicates a hardness of 40 or over it can be assumed that part is close to final cure.

REMOVING PART FROM MOLD

Removing a part from a mold should be done carefully. Parts and even the mold can be disfigured or completely destroyed by clumsy handling.

One common method is to construct a "grapple" point in the part so that when a hoist is engaged to lift upward, the weight of the mold will cause it to drop off. Another method is to mold flanges on the edge of the part where tap-out wedges may be inserted.

For laminates which are thin in relation to length and width, air ports which are built into one or more points of the mold can be used to inject high pressure under the part, lifting it without damage. Water pressure is also used. Several or those methods are sometimes used at once for difficult parts.

Any cured laminate hanging over the edge should be checked to see that it does not mechanically stop ejection, causing fractures or tears. If minor bonds occur, vibration and moderate pressure will sometimes work the part loose; but it is usually better to sacrifice the part than the mold if major bonding occurs because of lack of mold preparation or care.

TRIMMING

One time-saving "trick of the trade" is to use a sharp paper-board knife to cut on or near the trim line while the resin is at a point of heavy gel before final cure. This is done while the part is still in the mold. Sample cuts can be made at short intervals to help determine the best time to do this. After ejection, a quick sanding will produce desired dimension.

Cutting off excess laminate can be done in a variety of ways; the best method depends on the size, shape and thickness of the part to be trimmed. Flat, straight-sided moldings can be run through a table saw equipped with an abrasive wheel. When the part is too large or complex for this, hand tools (preferably air powered) are available.

If very little flash is involved, a high speed grinder with 40-60 grit sanding disc can very quickly cut down and smooth the edge. Cutting of large, heavy laminates is done with saber saws, abrasive wheels, hand routers and sometimes diamond blades. The use of air or water is helpful in keeping blades cool.

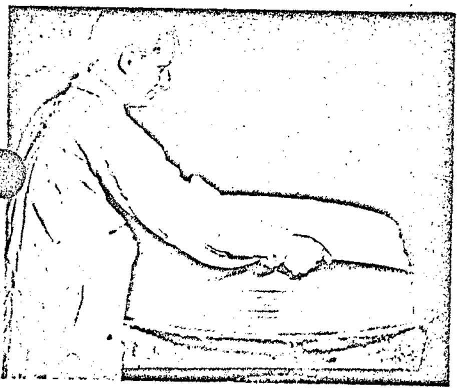
REPAIRS

Repair of voids, scratches, cracks, chips or spalls can be easily done with a little practice and care. Dirt, wax, mold release, oil, etc., should be sanded out of the area to be patched so that an absolute bond can be achieved. Using the same resin and pigment as the original laminate, fill the imperfection a little more than level full. After cure, sand the surface down level, finishing with very fine sandpaper. (600 grit) A wool buffing pad on a high speed hand tool will usually bring the gloss up to match the surrounding surface. The back side of a laminate can be reinforced or patched by adding layer after layer of fiber and resin across the flaw, making each layer succeedingly larger so that the patch tapers out on all sides.

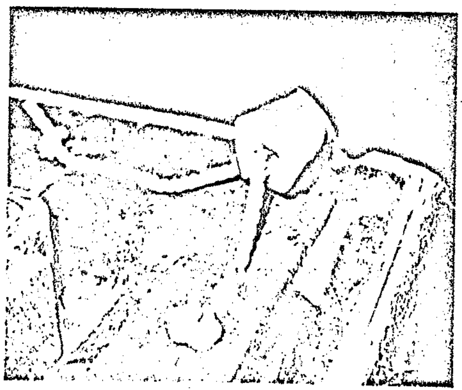
REINFORCEMENTS

Bonding later lay-ups (bulkheads, stiffeners, etc.) to a cured laminate where higher strength is required calls for the use of a "bonding resin" with high bonding strength and resilience.

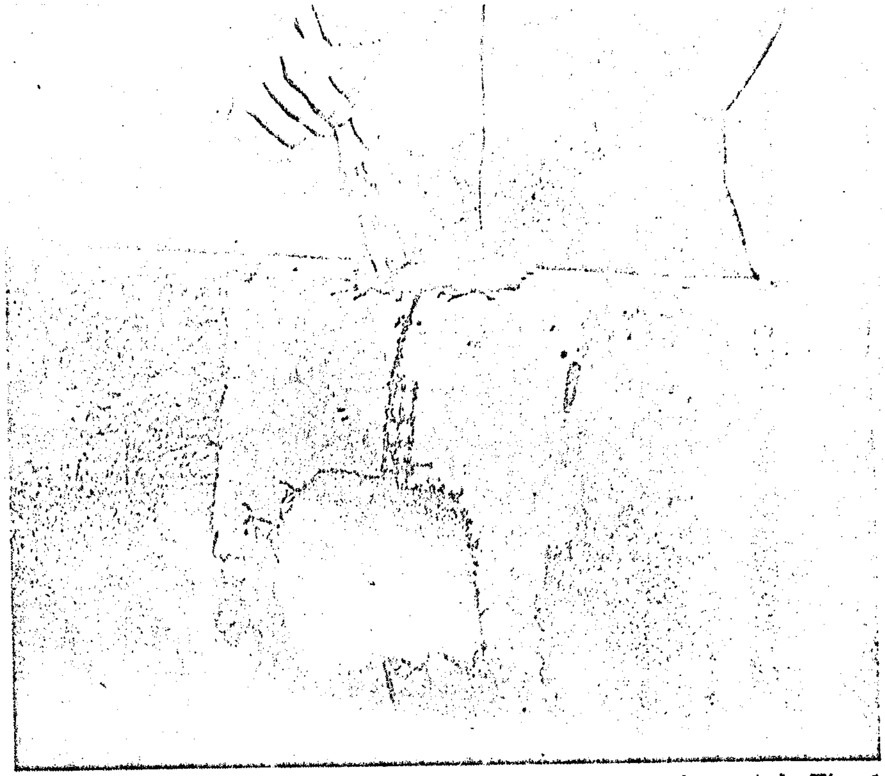
1. After curing remove part from mold.



2. Molded-in grapple facilitates removal of part from mold.



3. A sabre saw trims away flashing quickly.



Pipe ends are cleaned, sanded, butted together and resin coated—Fig. 1

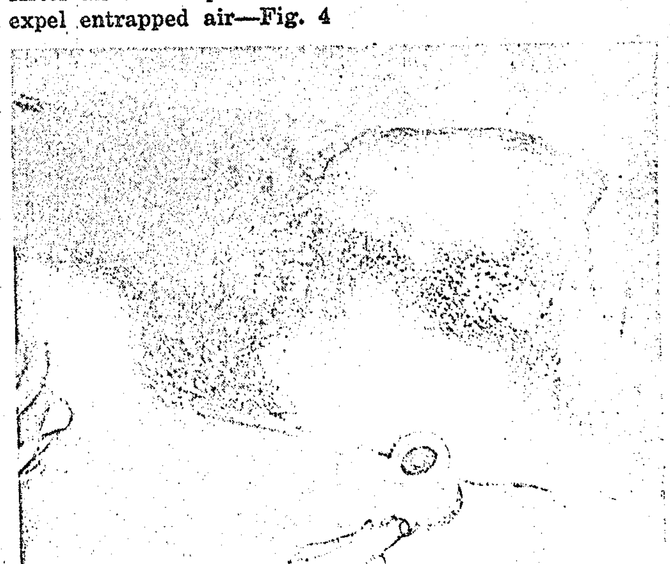
Butt-and-Strap Joining Method

Glass-fiber mat of varying widths is cut to length and saturated with resin —Fig. 2

Resin-saturated mat strips are applied to the joint, with the narrowest at the bottom—Fig. 3

Joining Glass-Fiber Reinforced Pipe

After all the strips have been applied, joint is rolled to expel entrapped air—Fig. 4



THOMAS LAUTENBACH
Owens-Corning Fiberglas Corp.

Sound joints in glass-fiber, reinforced-plastic piping systems can be the difference between years of trouble-free service and failure of an entire process.

There are two basic types of glass-fiber, reinforced-plastic pipe: machine-made (centrifugally-cast or filament-wound) and hand layup. Both types are available in sizes and configurations required for most industrial needs. Hand layup pipe can, of course, be made virtually any size for special applications; the size of machine-made pipe is limited by available equipment. The primary difference, however, lies in the resin used—machine-made pipe is predominantly epoxy based; pipe produced by hand layup is made with polyester resins (usually to customer specifications). Each type of resin has its own advantages that make it most suitable for a particular end-use.

Methods used to install and join pipe vary, depending upon the service requirements and the type of end provided. The most popular types are: plain end, bell and spigot, and integral threaded.

Joining Plain-End, Hand Layup Pipe

Plain-end sections of glass-fiber reinforced-plastic pipe, can be joined by the butt-and-strap method. Joints are made by butting two pieces of pipe together and then overwrapping the connections with successive layers of glass-fiber mats saturated with resin. This system is used for both epoxy- and polyester-based pipe and fittings.

The principal aim in butt-and-strap joining is to make the joints as strong as the pipe itself. Of critical importance is the width of the strapping materials, which must be of sufficient dimension to withstand the shear stresses. In practice, the joint is usually made considerably wider than is called for. The axial and bursting stresses at the joint are satisfied by making the laminate construction as thick as the pipe.

To assemble pipe by this method, the ends are first cleaned and sanded, and then aligned for strapping. Tabs are often used to ensure continuous alignment during the strapping operation. To obtain a smooth overlap of successive layers of the glass-fiber mat, each butt joint is made with several different widths of strap, with the widest placed on top. Each layer is partially saturated with resin before the succeeding layer is applied, to ensure complete saturation of the bottom layer. To eliminate air entrapment, a paint roller is applied at the center and moved in both outward directions. This procedure is repeated around the periphery of the strap joint. In addition to expelling entrapped air, the roller action also causes fibers to interlock, creating a strong, dense laminate.

Optimum curing temperatures for butt-and-strap joining are between 65 and 85 F.

Joining Bell-and-Spigot Pipe

A widely used filament-wound epoxy pipe is provided with bell-and-spigot ends that can be assembled with great speed. For example, three-man crews have assembled 2,700 ft. of this pipe in only one hour.

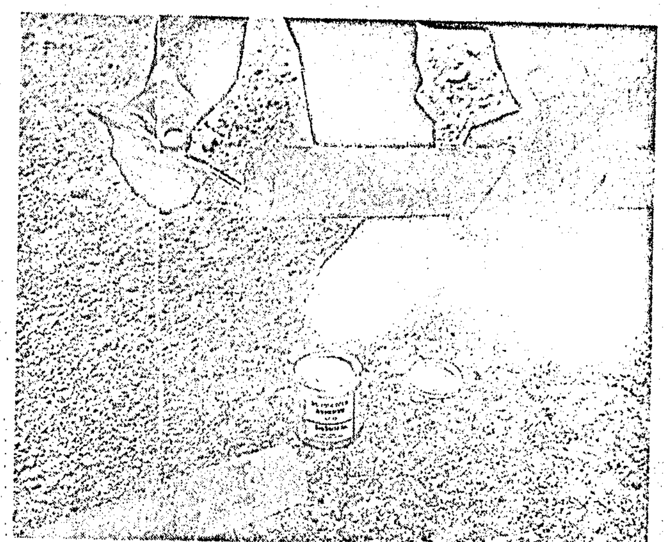
Installation consists of cleaning the ends of the pipe to be joined, applying a special epoxy adhesive inside the bell and on the spigot, and then joining the two ends with a slight manual turning motion. A pressure-tight joint is obtained when the adhesive hardens.

When a standard length of pipe has to be cut to smaller size, a portable tapering tool is used to make a spigot before joining the pipe with an integral bell or fitting.

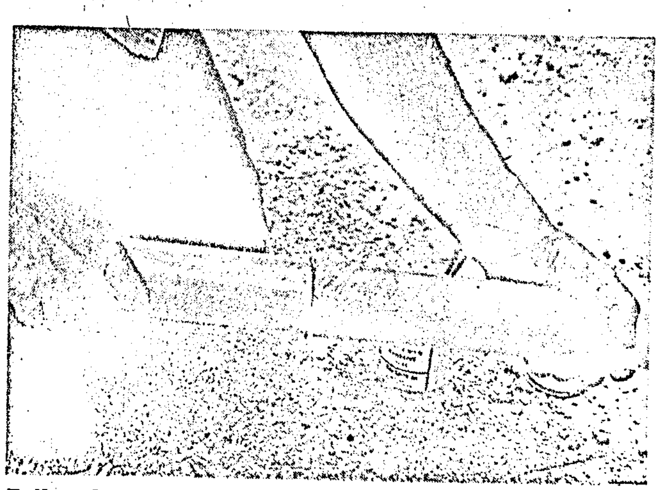
(continued on p. 128.)

Bell-and-Spigot Joints

Pipe ends are first carefully cleaned, in order to ensure a good bond—Fig. 5

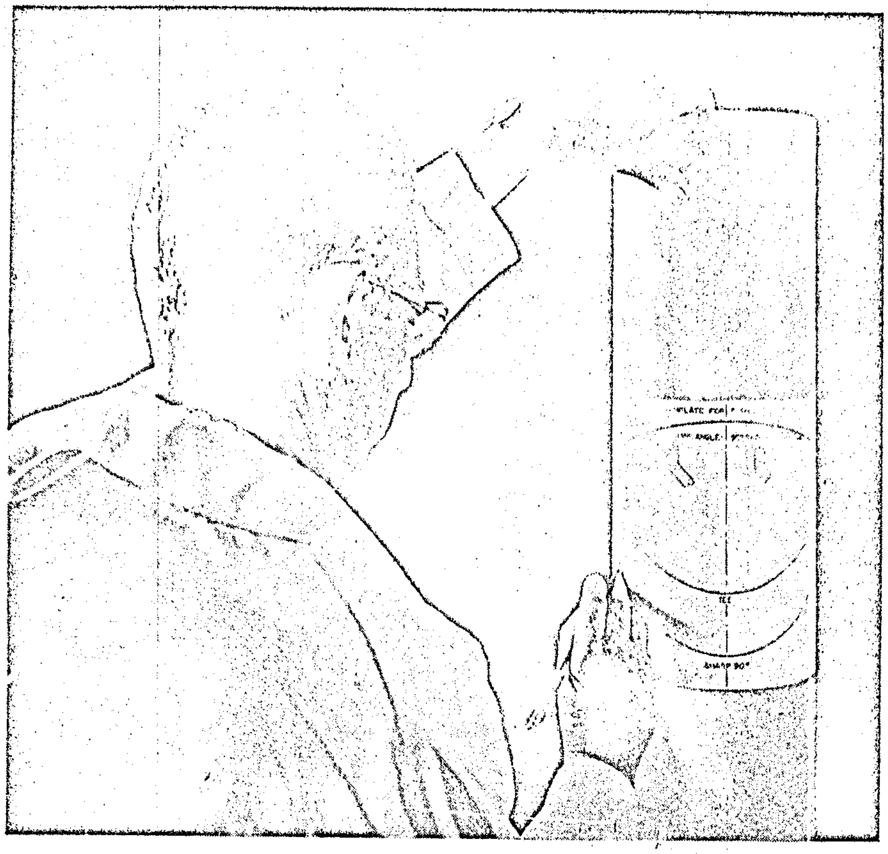


Inside of bell and outside of spigot are coated with an epoxy adhesive—Fig. 6



Bell and spigot are then assembled, using a slight turning motion—Fig. 7

Fabricating Fittings From Pipe

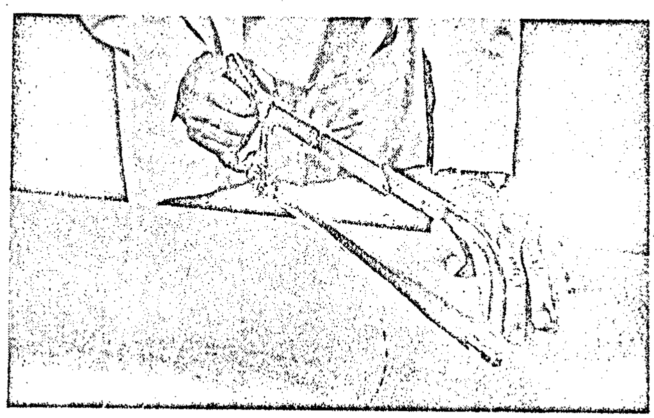


Cutting-template is first traced on surface of pipe to be used—Fig. 8

Joining Threaded Pipe

Integral threaded pipe has the obvious advantage of requiring the least number of fabrication steps. In many cases, all that is required is manual thread assembling.

In situations where threaded joints must be cemented, the only preparation is cleaning and sanding of male pipe thread and sanding crests of female thread. The cement is then applied and the threads are assembled.



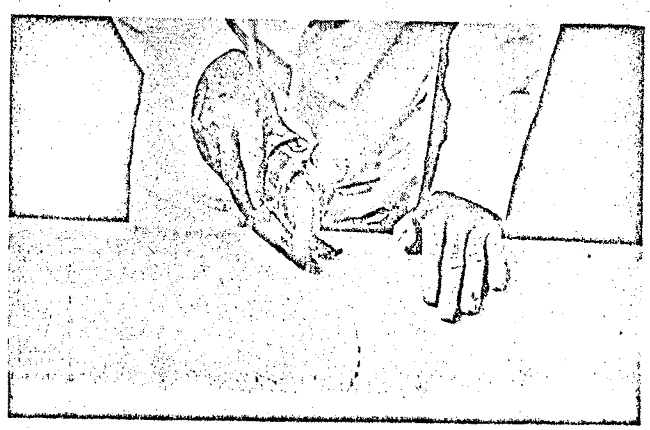
Using a hacksaw, a cut is started along line previously scribed—Fig. 9

Fabricating Fittings From Pipe

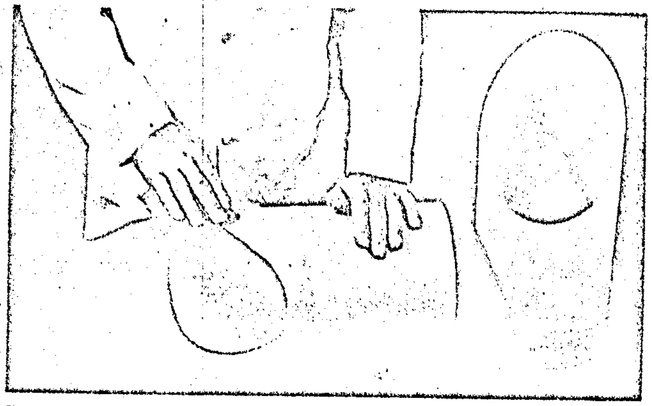
Many companies supply complete lines of standard fittings and connections that are joined to the pipe in much the same manner as the pipe is joined to other sections.

Apex Fibre-Glass Products Div. of White Sewing Machine Corp., Cleveland, Ohio, provides templates that allow joints and fittings to be fabricated directly. Templates available include tees, ells, crosses, wyes, and the like.

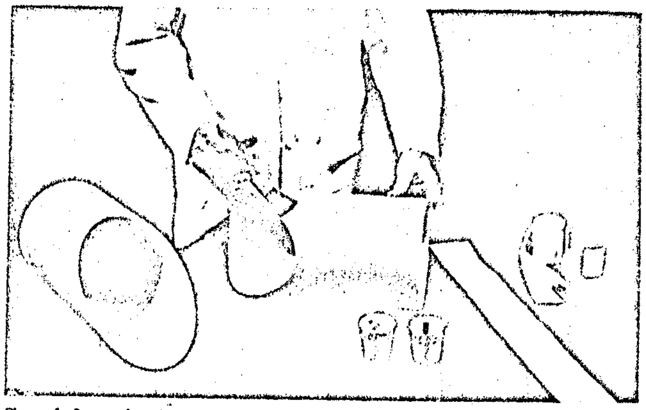
To fabricate a fitting, the template is first traced onto a section of the pipe. Cuts should be initially made with a hacksaw and then completed with a saber saw. A 1-in.-wide area next to the cut is then scuffed with a coarse sandpaper and cleaned with lacquer



Saber saw is employed to complete the cut around the pipe—Fig. 10

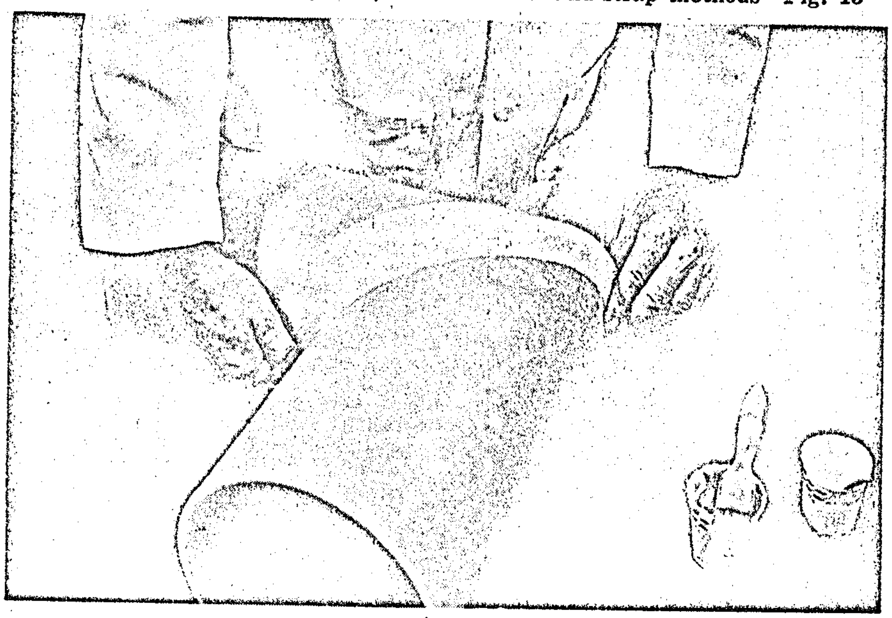


Cut ends of pipe are hand-sanded so as to scuff the area near the cut end—Fig 11



Special resin is applied both to the pipe ends and to the tape—Fig. 12

Ends are assembled and joined, as in the butt-and-strap methods—Fig. 13



thinner or naphtha. Special resin is then applied to glass tape (much as it is applied to the strap in the butt-and-strap method) and to the pipe. The tape is positioned over the joint and pressed firmly with a wood spatula to ensure impregnation of the resin. The resin will cure completely in a few hours at room temperature, or in a few minutes under heat lamps.

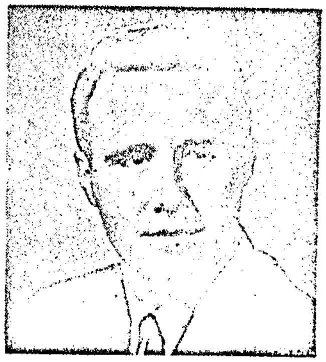
This brief survey has touched on some of the more important developments; obviously there are other successful joining techniques. The point to keep in mind is that proper joining, by whatever method, will increase both life and efficiency of the pipe.

Reinforced-plastic pipe is currently being used in such demanding industries as chemical processing, oil and gas production, gas distribution, water supply, sewage disposal, irrigation, etc. Within the next three to four years, developments such as new or improved adhesives, larger-diameter pipe, increased pressure capabilities, and the like, are expected to result in a 100% increase in the use of reinforced-plastic pipe.

Meet the Author

Thomas H. Lautenbach is marketing manager for pipe and corrosion equipment for the Corrosion Equipment Div. of Owens-Corning Fiberglas Corp.

He received his degree in chemical engineering from the University of Cincinnati, and is a member of the National Assn. of Corrosion Engineers.



Key Concepts for This Article

Active (8)	Passive (9)	Means/Methods (10)
Joining	Pipe	Strapping
Fabricating	Plastic	Cementing
	Glass fibers	Threading
	Reinforcement	Patterns
	Fittings	

(Words in bold are role indicators; numbers correspond to AIChE system. Indexing details—as described in *Chem. Eng.*, Jan. 7, 1963, p. 73—are available as Reprint No. 222 @ 50¢ per copy.)

FIELD JOINING REINFORCED PLASTIC PIPE . . .

The Butt and Strap Technique

By A. F. FONDA, Design Engineer
The Ceilcote Company, Cleveland, Ohio

PLANT ENGINEERS, in increasing number, are turning to custom-fabricated reinforced plastic pipe to solve problems in handling corrosive fluids. Plastic pipe installations —in diameters from 2 to 42 in.—are in successful corrosive service, handling acid and alkaline solutions at pressures up to 150 psi, temperatures as high as 250 F.

In corrosive applications, reinforced plastic pipe offers high chemical resistance and production reliability. Other important benefits are: (1) substantial savings in initial costs, compared to 316 stainless steel, comparable corrosion-resistant metals or lined metals; (2) elimination of costly and constant exterior protection; (3) weight about one-quarter that of steel—which means (4) faster and easier installation at lower cost; (5) quicker and simpler repairs; and (6) an extended service life.

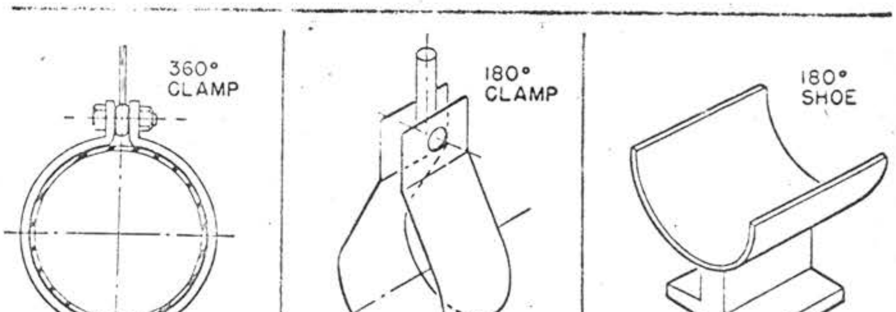


Fig. 1. Some pipe supports which minimize stresses at point of support.

And, specialized personnel are not needed to install reinforced plastic pipe. While some pipe manufacturers offer installation service, the job can be done by your plant crew; several manufacturers provide field supervisors to train pipefitters or other maintenance personnel in the simple techniques. However, it is always desirable to have a plastics engineer examine the basic design of the entire pipeline.

The importance of proper joining cannot be over-emphasized. A joint can be stronger than the pipe itself—or it can be the weakest part of the line.

Most popular methods of joining reinforced plastic pipe are the butt and strap joint, standard flange (required when combining a reinforced plastic system with metal pipe or fittings), sleeve-type joints, and threaded couplings.

This article deals exclusively with the butt and strap technique because it is the most economical. The joint is made by butting two pieces of pipe together and overwrapping the joint with successive layers of resin-saturated mat cut to predetermined widths and lengths.

The system can be used in joining pipe fabricated from thermosetting epoxy and polyester resins. It is recommended for joining straight runs, elbows, tees, and reducers.

Engineering Principles

First consideration is to make the joint as strong as the pipe itself. The major stresses involved are axial stress and hoop (bursting) stress. But, since bursting stress is a function of wall thickness, (which is relatively great at the joint) it is not a major consideration. Axial stress at the joint is the same as axial stress on the pipe; therefore, laminate construction should be the same as that of the pipe itself (normally specified by the pipe manufacturer).

The width of the strapping material is of critical importance. This width, actually the *shear length* of the pipe joint, must be long enough to withstand the shear stresses. Shear length is equal to one-half the width of the strap joint which will be subjected to interlaminar shear stresses.

Resin interlaminar shear strength has been tested at about 3300 psi. To make the pipe shear strength equal to the axial strength of the pipe, the minimum theoretical shear length can be calculated (see box).

$$\text{Minimum Shear Length (SL)} = \frac{\text{pipe tensile strength} \times \text{wall thickness}}{\text{resin interlaminar shear strength}}$$

Example: (For pipe wall thickness of ¼ in.)
Laminate tensile strength = 10,000 psi
Interlaminar shear strength = 3300 psi

$$SL = \frac{10{,}000 \times 0.25}{3300} = 0.75 \text{ in.}$$

Since shear length is equal to half the strap width, minimum width of strapping is 1.5 in. In actual practice, the joint is usually much wider—to insure against shear failure and possible leaks. Normally, custom-fabricated plastic pipe is built with a safety factor of approximately 8 to 1. For the ¼-in. pipe wall thickness used in this example, Table I indicates strap width should be 2 in.

Step 1. Supporting the Pipe

On new installations, plant engineers faced with the choice between a temporary or permanent supporting structure should work with the permanent structure from the outset. All too often, temporary supports collapse or move excessively before permanent supports can be built. This puts undue stress (which can cause permanent damage) on the pipe and joints. If temporary supports must be used, maintain proper spacing, as shown in Table II.

Figure 1 shows some recommended pipe supports which minimize stresses at the point of support.

Step 2. Preparing the Surface

The bond on a thermosetting plastic pipe joint is mechanical or adhesive—not chemical. This means that the surfaces over which bonding materials (mat and resin) are placed must be absolutely free of oils, fatty acids or other foreign materials. And, the surfaces to be joined must be roughened with a power sander, file or by hand, using "O" grit sandpaper.

Ends of pipe cut on the jobsite must be coated with clear catalyzed resin before alignment.

Step 3. Aligning the Pipe

Correct alignment of the two butted sections of pipe is essential; extra time and care invested in alignment will assure minimum stress on the complete system.

Where a series of joints is to be

Fig. 2. Tabbing the pipe ends together with two or more reinforced plastic patches will hold the alignment until strap joint can be made.

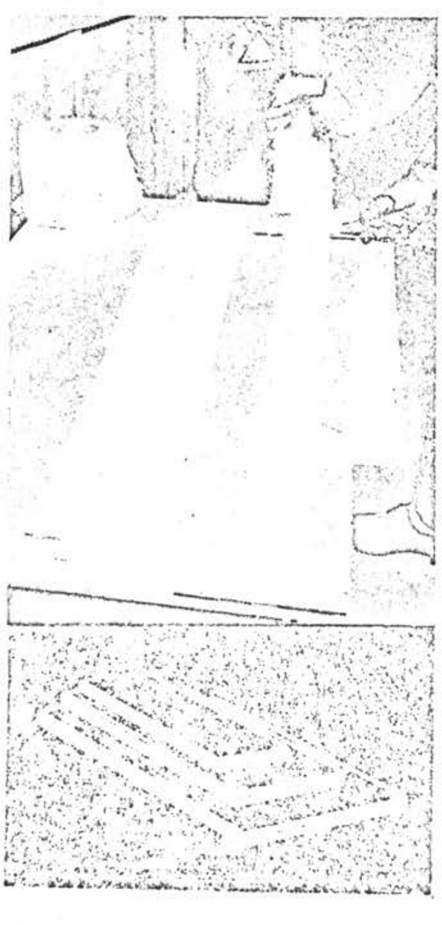


Fig. 3. Stepped placement of the mat in the multiple layer application method assures a smooth overlap of layers.

made, tabbing the pipe ends together with two or more reinforced plastic patches will hold the alignment until the final strap joint can be made. Tabs can be made of 2-in. square mat, one or two layers thick. See Fig. 2

Step 4. Preparing [illegible] Mat

Strapping material most commonly used for making joints is fiberglass mat, made of chopped strand glass fibers (chemical grade), with a weight of 1½ oz per sq ft. The width of mat required for strapping is indicated in Table I.

Another material is woven roving, a cloth spun from continuous fiberglass filament. It provides greater strength in the laminate; is used where higher strength is required in the axial direction.

The length of mat or roving is determined by the pipe diameter. It should be long enough to completely surround the pipe, with a minimum one-inch overlap. For pipes over 12 in. in diameter, it is more practical to make joints in two or more sections for handling convenience.

Excessive moisture in the reinforcement, either mat or roving, from rain, condensation or high humidity will cause a milky discoloration and some strength loss. If moisture is suspected in the reinforcement, it should be oven-dried at 180 F before using.

To provide a smooth flowing joint, with no abrupt surface changes, each butt joint is made with several different widths of strap, as indicated in Table I.

Step 5. Preparing the Resin

A proper bond requires the use of proper resin, preferably the resin used in fabricating the original pipe. An important factor in making a joint is to obtain a correct mixing ratio that will allow sufficient time or pot life for resin to completely saturate the reinforcing materials, yet short enough to prevent resin drainage and sagging. Pot life of a resin mixture is that time after the liquid resin is catalyzed until the resin takes on a gelatinous or stringy state; it will vary with the ambient temperature and the resin temperature.

Because a heat-producing chemical reaction is the curing medium, the pipe manufacturer will usually give resin mixing instructions for ambient temperatures. For every 15-degree rise in temperature, the pot life will generally be cut in half, while for every 15-degree drop, the pot life will double. As a general rule, if the pot life is over one hour long, a complete cure will not be obtained without application of heat from an outside source.

Step 6. Making the Joint

There are various methods of butt and strap joining. Most commonly used are:

Single Layer Application—the saturation and application of individual layers of reinforcing material on the joint until the desired thickness is reached. This method produces an adequate joint, but it takes time and usually requires longer pot life to complete. If pot life is prolonged, the joining material may sag from

Fig. 4. Saturated mat layers are positioned on the joint with the widest mat placed on top.

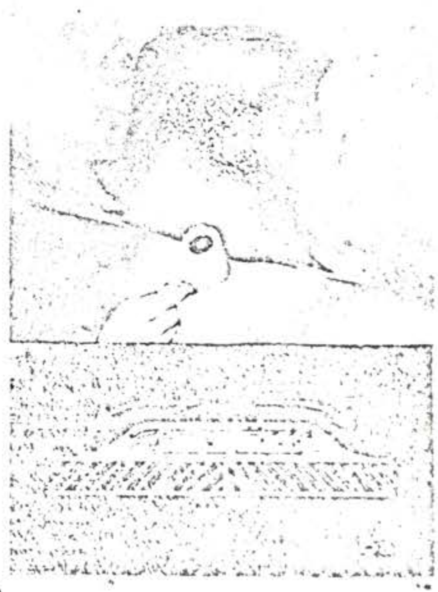


Fig. 5. Paint rollers are used to roll the mat from the center to the edges to eliminate possible air entrapment.

[illegible]	Strap Thickness Inches							
	3/16	1/4	5/16	3/8	7/16	1/2	5/8	3/4
[illegible]	3	[illegible]	4	4	[illegible]	4	4	[illegible]
[illegible]		2	3	4	[illegible]	[illegible]	4	[illegible]
[illegible]					3	3	[illegible]	5

Table I. Recommended widths, layers of mat for various strap thicknesses.

Table II. Hanger spacing determined by pipe diameter, pipewall thickness.

PIPE DIAMETER (INCHES)	MAXIMUM RECOMMENDED SPAN IN FEET*						
	PIPE WALL THICKNESS, INCHES						
	3/16	1/4	5/16	3/8	7/16	1/2	[illegible]
2	7½	8					
3	8¼	8¾					
4	9	9½	10				
6	10	10½	11	11½			
8		11½	12	12½	13		
10		12	12¾	13¼	13¾	14¼	
12		12¾	13¼	13¾	14½	15	15¾
14			13¾	14½	15	15½	16¼
16			14¼	15	15½	16	17
18			14¾	15½	16	16½	17½
20			15¼	15¾	16½	17	18
24			16¼	16¾	17¼	17¾	18¾

*For liquids of 1.3 specific gravity

...e pipe at the lower side, resin may drain from the reinforcement in the upper portion, or an incomplete cure may result. Sagging creates a channel into which air is drawn before cure, causing the joint to leak.

Multiple Layer Application—highly recommended, this method involves the pre-saturation of reinforcement, followed by application of many layers at one time to the joint. It saves considerable time in mat saturation as well as mat application, and eases removal of entrapped air.

Figure 3 shows this method of application for a 7/16-in.-thick joint. Nine layers of mat are pre-saturated and positioned on a work table covered with cardboard or film. The bottom three layers are 6 in. wide, middle three layers are 4 in. wide, and top three layers are 3 in. wide.

Stepped placement of the mat at one end assures a smoother overlap, as shown in Fig. 3. Each layer is only partially saturated before the succeeding layer is placed on top, because as the upper layers are partially saturated, the lower layers will become completely saturated.

The saturated layers are positioned on the joint, with the widest mat on top, Fig. 4. An equal amount of material covers each side of the joint, to obtain equal bond to each pipe section.

Rolling the mat, from the center to the edges, eliminates air entrapment, Fig. 5. Paint rollers, 3 in. wide, do this job; air can also be dispersed by using a stiff bristled 2-in.-wide paint brush, dabbing the air pockets and pushing them to the edges. Either method will cause the fibers to interlock, creating a dense laminate with strength equivalent to that of the pipe itself.

Step 7. Curing the Joint

To obtain maximum strength, a complete cure must be obtained in the resin. Conditions affecting cure are: (1) atmospheric temperature; (2) humidity; (3) heat developed during cure.

The latter is governed by the accuracy to which the pipe manufacturer's instructions are followed in adding the catalyst and promoters. Although temperature and humidity often cannot be controlled by the pipefitters, every practical effort should be made to work at temperatures between 65 and 85 F.

When conditions of extreme cold or rain are present, a shelter should be erected, when practical, to shield the pipe. Cold weather will slow down the cure.

Make Thick Joints in Layers

When joints over 3/8 in. thick are being made (particularly in hot weather), an excess amount of heat may be produced by making joints in a single layup. Make the joint in two separate layups, using half the mat for each stage. Time lapse for the second layup is not an important factor, as long as it is not applied until after the joint begins to cool. No surface preparations are necessary for the second layup.

In addition to being as strong as the pipe itself and withstanding comparable stresses, a good joint must *appear* to be good. It must give a *feeling* of security to the men who work around a piping system handling corrosive fluids.

Step 8. Inspecting the Joint

From an operating standpoint, the joint must be completely reliable, completely leak-proof. Dependable visual signs of a good pipe joint include:

1) Dense laminate with no large air pockets under surface.

2) Well-saturated fibers—no dry fibers visible.

3) Joint thickness equal to the wall thickness of the pipe.

4) Hardness equivalent to the pipe. Comparative hardness can be judged by tapping the pipe and the joint to see if a similar sound is obtained. A dull sound on the joint indicates an under-cured joint.

The eight steps described in this article make up the rules-of-the-road for preparing material and making the joint. In actual practice, the following work sequence is normally followed: providing shelter and external heat, if required; cleaning and roughing the surface to be strapped; aligning the pipe on proper supports; cutting and laying out the mat or woven roving strapping materials; preparing the resin, mixing the catalyst; applying the joining materials to the joint; rolling out entrapped air; inspecting joint. End

hand lay-up

The simplicity of the hand lay-up process reduces the factors which must be given special consideration in design. Still, the following factors are important and should be considered.

DESIGN FOR ACCESS TO ALL POINTS

Hand lay-up facilitates fabrication of large sections in one piece. Yet, pieces must not be so large that fabricators cannot reach all points. Keep body-movements limits in mind and be certain that any point can be easily reached with resin, reinforcement, or for roll out. Ignoring this factor inevitably runs up job and tool costs. With parts having large surface areas, it is possible to pivot the mold for easier accessibility by either rotating it or tilting it. In large molds such as boat hulls, the laminating is frequently accomplished from scaffolding overhanging the mold.

DESIGN FOR EASY PART REMOVAL

Design should be such that the part can be easily removed from mold without damage. Molding a "grapple point" in the part so hoisting will cause mold to drop off, can help. Flanges may be molded on part of edge for wedging. Air or water ports designed into mold can permit injection of air or water pressure to release part.

MECHANICAL FASTENERS

When geometry does not permit joining by hand lay-up, (when half the joint is metal or where unusual stress concentrations are present), parts may be joined mechanically. Bolts and self-tapping threaded fasteners are most common.

THREADED FASTENERS

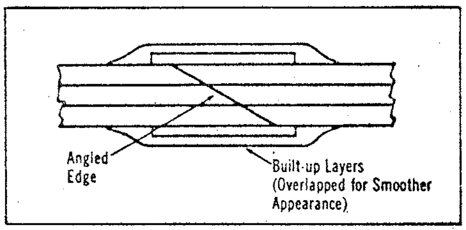
When threaded fasteners are used, they should always be perpendicular to reinforcement plies. Edge fastening should never be used. When used, threaded fasteners should have edge and side distances equal to at least $2\frac{1}{2}$ times fastener diameter and spacing should exceed 3 times fastener diameter.

ADHESIVE BONDING

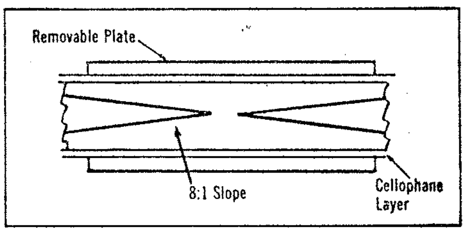
For adhesive bonding, flanges of sufficient size to provide a good base for adhesive should be incorporated into the design of parts to be joined.

STIFFENING

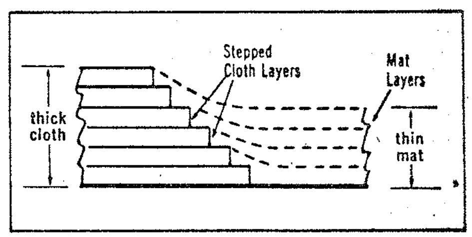
Because of its low modulus, Fiberglas often requires stiffening against deflection on large areas. The simplest (but not always the most economical) method of achieving stiffness is to increase laminate thickness. Local stiffeners may also be added into laminate during hand lay-up. Such stiffeners should always be designed into part where localized loading occurs.



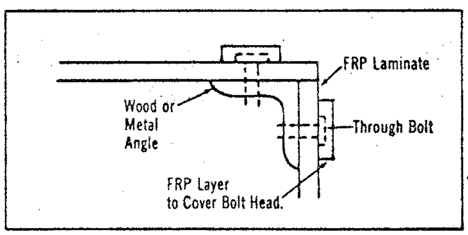
JOINTS
SIMPLE BUTT
When premolded sheets are joined, edges are angled to give more bonding area. Then laminate layers are built up on both sides to desired strength.



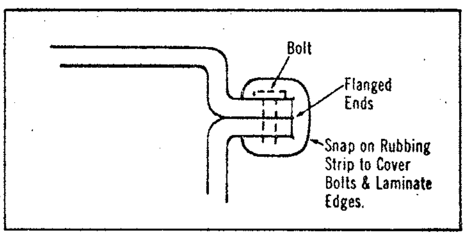
OPTIMUM APPEARANCE
For smooth surface a double tapered joint cured between removable plates is required. Slope of angle should be 8:1. Cellophane placed between plate and laminate will facilitate plate removal.



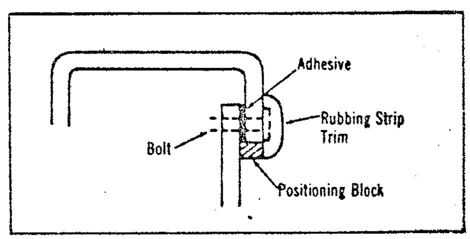
TAPERED
Where thin mat laminates join heavy cloth sections, a tapered joint is formed by stepping cloth layers and joining mat layers over steps.



CORNERS
The simple corner uses premolded sheet reinforced with glass cloth and resin. For strength, a wood or metal angle may be incorporated or the butt itself carried around corner.

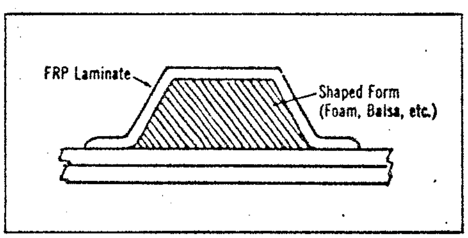


Flanged edges bolted together require trim to hide joint. Though bolts are shown, self-tapping screws or rivets may be used to hold parts together.

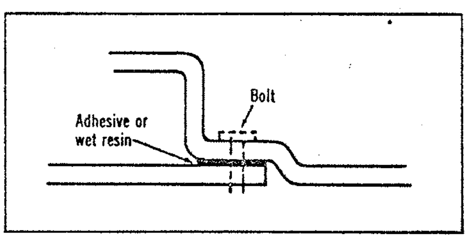


Lapped sections are held in place mechanically with adhesive or wet resin between sections as seal. Trim hides edges. Fastening may be bolts, screws or rivets.

BEST PROCEDURE IS CORNER INTEGRAL WITH STRUCTURE WITH NO JOINTS.



STIFFENERS
BUILT-UP
Built-up stiffeners incorporated in laminate may be cardboard, balsa, foam plastic or metal. They should be designed to spread loads over wide area.



INTEGRAL
Integral stiffeners are most easily incorporated as flanges at a joint to provide dual function. Pads or gussets are desirable where stiffeners intersect a flat, flexible area.

hand lay-up

PHYSICAL PROPERTIES AND ESTIMATED MATERIALS COSTS OF LAMINATES MADE OF POLYESTER RESIN AND VARIOUS GLASS COMPOSITIONS

Laminate	Type of Construction: Plies	Type of Construction: Material	Thickness (ins.)	% Glass Content	Tens. (psi)	Flex. Str. (psi)	Mod. x10⁶ (psi)	Impact ft. lb/ in. of Notch	Wgt. Glass /sq. ft.	Wgt. Resin /sq. ft.	Wgt. Lam. /sq. ft.	Cost (Cents) Glass /sq. ft.	Cost (Cents) Resin /sq. ft.	Cost (Cents) Lam. /sq. ft.
1	2	2 oz. mat.	0.125	28.2	14,050	23,400	0.92	9.0	4.0 oz.	10.2 oz.	14.2 oz.	11.5	12.8	24.3
2	1 1	1000 Cloth 2 oz. Mat	0.100	28.4	10,500	18,550	0.89	8.2	3.1 oz.	7.8 oz.	10.9 oz.	12.2	9.8	22.0
3	1 2	1000 Cloth 1.5 oz. Mat	0.110	32.0	13,850	22,100	1.10	9.8	4.1 oz.	8.7 oz.	12.8 oz.	15.2	10.9	26.1
4	1 2	1000 Cloth 2 oz. Mat	0.130	30.1	14,950	21,400	0.95	9.8	5.1 oz.	11.8 oz.	16.9 oz.	18.0	14.8	32.8
5	1 3	1000 Cloth 2 oz. Mat	0.180	32.0	13,200	18,750	0.92	12.0	7.1 oz.	15.1 oz.	22.2 oz.	23.8	18.9	42.7
6	1 1 1	1000 Cloth 1.5 oz. Mat 1000 Cloth	0.120	24.9	9,090	37,600	1.47	8.2	3.7 oz.	11.2 oz.	14.9 oz.	17.2	14.0	31.2
7	1 2 1	1000 Cloth 1.5 oz. Mat 1000 Cloth	0.180	22.6	10,500	28,400	1.20	9.7	5.2 oz.	17.8 oz.	23.0 oz.	21.6	22.3	43.9
8	1 3	1½ oz. Mat 2415 Fabmat	0.254	39.2	30,300	42,800	1.59	31.2	14.01 oz.	21.99 oz.	36.0 oz.	42.7	27.4	70.1
9	1 1 1	1000 Cloth 24 oz. W.R. 1000 Cloth	0.092	42.5	18,500	28,500	0.78	—	5.0 oz.	6.7 oz.	11.7 oz.	19.6	8.4	28.0
10	1 1 1	1000 Cloth 1.5 oz. Mat 24 oz. W.R.	0.125	38.3	17,050	22,850	1.25	31.5	5.4 oz.	8.6 oz.	14.0 oz.	17.6	10.8	28.4
11	2	24 oz. W.R.	0.080	52.7	38,950	44,900	1.85	36.3	5.0 oz.	4.5 oz.	9.5 oz.	13.6	5.6	19.2
12	1 1 1	24 oz. W.R. 1.5 oz. Mat 24 oz. W.R.	0.100	53.2	29,000	45,900	2.20	45.8	7.0 oz.	6.2 oz.	13.2 oz.	23.2	7.8	31.0
13	1 1 1	2 oz. Mat 24 oz. W.R. 1000 Cloth	0.125	36.0	11,500	23,000	0.73	—	5.9 oz.	10.5 oz.	16.4 oz.	19.0	13.1	32.1
14	1 2	1.5 oz. Mat 24 oz. W.R.	0.100	47.0	22,200	41,800	1.01	22.2	7.0 oz.	7.9 oz.	14.9 oz.	23.2	9.9	33.1
15	1 1 1 1	1.5 oz. Mat 24 oz. W.R. 1.5 oz. Mat 1000 Cloth	0.100	47.9	24,900	31,400	1.11	25.8	6.8 oz.	7.5 oz.	14.3 oz.	21.9	9.4	31.3

Mat — Weights based on oz./sq. ft. — 2 oz. mat refers to 2 oz./sq. ft.
Cloth & Woven Roving — Weights based on oz./sq. yd. — 24 oz. W.R. = 24 oz./sq. yd.
1000 Cloth = 10 oz./sq. yd.

Examples do not include gel coat.
[illegible] T.M. of Fiberglas Industries) weights based on 4.2 oz./sq. ft.

APPENDIX G

COST / PERFORMANCE TABLES

THICKNESS DESIGN

Design thickness may be obtained by one of three methods:

Comparative—where thickness of a part in another material is known.

Theoretical—where specific strength requirements are known.

Empirical—using accumulated experience on successful applications.

Each of these methods is discussed in detail on this and the following pages.

COMPARATIVE DESIGN

Applications of competitive materials can serve as a basis for determining wall thickness. Knowing the thickness in which a part is made or designed in a competitive material, the chart below can be used to calculate required thickness in FRP using the following formula:

$$\text{Required FRP th.} = \text{Thickness of Comp. Matl.} \times \frac{\text{Factor For FRP}}{\text{Factor For Comp. Matl.}}$$

Let's take a few examples to see how simple it is:

EXAMPLE 1

A part in 6061-0 Aluminum is 0.050 inches thick. For equal Stiffness how thick must a spray-up part be:

a) From the table:

Factor for Aluminum is .126
Factor for Spray-up is .292

b) Substituting in formula:

$$FRP = .05 \times \frac{.292}{.126}$$

FRP=.116″

FOR EQUAL STIFFNESS AN FRP SPRAY-UP PART .116″ THICK WILL DO THE SAME JOB AS .050″ THICK ALUMINUM.

EXAMPLE 2

A part in stainless steel is .002″ thick. For equal stiffness how thick must a hand lay-up of 1000 cloth be.

a) From the table:

Factor for stainless is .089
Factor for laminate is .228

b) Substituting in formula:

$$FRP = .002 \times \frac{.228}{.089}$$

FRP=.0052

FOR EQUAL STIFFNESS A PART .0052 THICK OF FRP IS REQUIRED.

These examples will provide the required thickness in FRP. It must be remembered that the processes also have thickness limitations.

In the first case, a part 0.116″ is required. This is very feasible in the case of either spray-up or hand lay-up. In example two, the required thickness is 0.0052″ in FRP. This cannot be obtained with either process and if a part in FRP is desired, the minimum practical thickness must be employed.

A few things to keep in mind:

a) Select most critical property for comparison.
b) Select most logical FRP method to reduce need for repeated trial and error.
c) Note: Typical thickness used in some common applications are shown on page 12, column 1.

DESIGN (PHYSICAL PROPERTIES) COST/PEFORMANCE COMPARISON FOR MATERIALS

					Bending Strength			Stiffness			Tensile Strength			Tensile Elongation		
Material	Glass Content By Wt.	Matl. Cost ¢/lb. (A)	Density lb./cu. in.	Space Filling ¢/cu. in.	10^3 psi	Thickness in. (B)	Matl. Cost for 100 sq. in. ¢ (D)	Flexural Modulus 10^6 psi	Thickness in. (B)	Matl. Cost for 100 sq. in. ¢ (D)	10^3 psi	Thickness in. (C)	Matl. Cost for 100 sq. in. ¢ (D)	Tensile Modulus 10^6 psi	Thickness in. (C)	Matl. Cost for 100 sq. in. ¢ (D)
Layup Mat—M710 Araton	35%	30	0.0535	1.6	25	0.110	17.5	1.0	0.272	43.5	14	0.072	11.5	1.0	0.100	16.0
Layup Mat—M700 Fine	25%	28	0.0526	1.5	18	0.129	19.3	0.8	0.292	43.8	12	0.084	12.6	0.7	0.143	21.5
Sprayup Roving	25%	23	0.0526	1.2	18	0.129	15.5	0.8	0.292	35.1	12	0.084	10.1	0.7	0.143	17.2
Layup-1000 Cloth	45%	49	0.057	2.8	37	0.090	26.0	1.7	0.228	63.8	28	0.036	10.1	1.7	0.059	16.5
Layup-woven Roving	50%	31	0.059	1.8	40	0.087	15.6	2.0	0.216	38.9	40	0.025	4.5	2.0	0.050	9.0
Fabmat-2415 Layup	40%	31	0.055	1.7	35	0.093	15.8	1.8	0.223	37.9	28	0.036	6.2	1.5	0.067	11.4
Aluminum, 6061-0 Alloy		50	0.098	4.9	12	0.158	77.5	10.0	0.126	61.7	12	0.083	40.6	10.0	0.010	44.9
Steel, 1010 Alloy		7	0.238	2.0	28	0.103	20.3	30.0	0.087	17.2	28	0.036	7.1	30.0	0.003	0.6
Stainless Steel, 302 Alloy		57	0.290	16.5	35	0.092	152.0	28.0	0.089	147.0	30	0.033	54.5	28.0	0.004	6.6
Plywood, Ext-DFPA A-C		10	0.022	0.2	2	0.389	8.6	1.6	0.232	5.1	2	0.526	11.6	N.A.	N.A.	N.A.
Polystyrene, Gen. Purpose		18	0.038	0.7	14	0.146	9.9	0.5	0.346	23.4	8	0.126	8.6	0.4	0.250	17.0

A. Based on cost of materials selected at time of printing.
B. Thickness comes from calculation of a simple beam 2 inch by 1 inch with a concentrated load of 100 lbs. at the center.
C. Thickness comes from calculation of a simple beam (2 inch by 1 inch) with a 1000 lb. load in tensile.
D. Cost is for a bar of material 100 inches by 1 inch by indicated thickness.
N.A.—Not Available

APPENDIX H

ENGINEERING SPECIFICATION REFERENCES

STRUCTURAL DESIGN PROPERTY RANGES FOR TECHITE® REINFORCED PLASTIC MORTAR PIPE

1. MATERIALS
   1.1 Reinforcement - borosilicate "E"-type fibrous glass
   1.2 Matrix - isophthalic polyester resin
   1.3 Filler - silica sand in 2 sizes: .02", .04"

2. DIMENSIONS
   2.1 Nominal internal diameters 8" thru 54" (3" increments, typical)
   2.2 Wall thickness - 0.15" min, 1.5" max (larger sizes can't be made with less than about 0.30" thickness)
   2.3 Specific Weight: .06 to .08 lbs/in³

3. STRENGTHS (Ranges shown reflect process capabilities, not standard product values. Note that more strength costs more)

Mode	Short-Term Ultimate Strength (psi), S ⚠1			$S_{initial}/S_{50 years}$ ⚠2
	Tensile	Compressive ⚠3	Shear	
HOOP	15,000 - 45,000	10,000		4.0
AXIAL	3,000 - 20,000	10,000		4.0
Cross-Laminate		10,000	2000	4.0
Inter-Laminal			1200	

NOTES: ⚠1 Values shown are for Static Loading; for cyclic loads use ½ the static values.
⚠2 Relationship is linear on log-log scale.
⚠3 Elastic buckling may govern - see below

4. ELASTICITY (Again, ranges are process capabilities, not standards)
   4.1 Youngs Modulus

creep @120°F

MODE	Short-Term Ultimate Modulus (psi × 10^{-6}), E		$E_{initial}/E_{50 Years}$
	Tensile	Compressive	
HOOP	1.5 - 3.0	1.5 - 2.0	2.0
AXIAL	0.8 - 2.0	1.0 - 1.5	

   4.2 Buckling (Elastic): $\sigma_{max} = 0.4 E \frac{t}{R}$ psi Axial, $= 2 \frac{Et^3}{D^3}$ psi Ring
   where t = wall thickness, R = mean radius, D = mean diameter
   4.3 Poisson's Ratio = μ = 0.25

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cc: J. Tooley
cc: T. Aoki [illegible]

United Technology Center
CALCULATION SHEET

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DATE 9-10-70

TITLE [illegible] Pipe [illegible] Strength Design [illegible]

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PAGE 1
OF

Nom. Dia. (in)	Minimum Wall Thickness (in)	Ultimate Strengths (psi) Axial Tension	Axial Compress.	Axial Comp. Buckling	Design Factor of Safety* Axial Tension	Axial Compress.	Axial Comp. Buckling
8	0.17	7500	10,000	9500	6	4	3
10	0.17	7500	↓	7600	6	↓	↓
12	0.18	7000	↓	6700	6	↓	↓
15	0.19	6700	↓	5700	8	↓	↓
18	0.21	6000	↓	5200	↓	↓	↓
21	0.21	6000	↓	4500	↓	↓	↓
24	0.24	5300	↓	4500	↓	↓	↓
27	0.26	4900	↓	4300	↓	↓	↓
30	0.29	4400	↓	4300	↓	↓	↓
33	0.32	3900	↓	4300	↓	↓	↓
36	0.35	3600	↓	4300	↓	↓	↓
39	0.38	3300	↓	4300	↓	↓	↓
42	0.40	4700	↓	4200	↓	↓	↓
45	0.42	4500	↓	4200	↓	↓	↓
48	0.44	4300	↓	4100	↓	↓	↓

*NOTE: To obtain recommended design strength for normal service conditions, divide ultimate strength by factor of safety

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United Technology Center
CALCULATION SHEET

MADE BY R. Gjerdrock | W.O. NO. L601-F028 | PAGE 1 OF 1
CHECKED BY T. Cech | TITLE CASCADE SEWER DISTRICT – 14", 16", AND 18" ø SEWER FORCE MAIN – SEATTLE
DATE 8-28-68

TECHITE PIPE PROPERTIES

REQ'D: MODULUS OF ELASTICITY FOR SURGE AND WATER HAMMER ANALYSIS, AND THE EFFECT OF TIME ON THIS MODULUS.

SUMMARY: THE MODULUS OF ELASTICITY MOST AFFECTING WATER HAMMER AND SURGE IS THE HOOP TENSILE MODULUS (CIRCUMFERENTIAL TENSION). AS THIS MODULUS IS DEPENDENT TO A LARGE EXTENT ON THE RELATIVE AMOUNT OF HOOP-ORIENTED GLASS IN THE PIPE WALL, IT WILL VARY SOMEWHAT WITH PIPE CLASS RATING.

THE EFFECTS OF TIME ON THIS MODULUS, AS PRESENTED HEREIN, ARE PREDICTED VALUES BASED ON 3 MOS., 6 MOS., 9 MOS., AND ONE YEAR DATA ON 5% D-LOAD REDUCTION OF TECHITE IMMERSED IN pH 3.5 SULFURIC ACID. [TEST: E67-005] THE EFFECT IS A REDUCTION OF "E" PROPORTIONAL TO THE LOG_{10} OF TIME (FELT TO BE A CONSERVATIVE ESTIMATE)

TIME	HOOP TENSILE ELASTIC MODULUS, PSI	
	CLASS 100 PRESS.	CLASS 150 PRESS.
INITIAL VALUE	2.2×10^6	3.2×10^6
50 YEAR VALUE	1.8×10^6	2.7×10^6

hand lay-up laminates

One of the important properties of glass cloth and woven roving laminates is the variation in physical properties with direction. The Charts below illustrate this. Note that strengths are greatest at 90° and 180° dropping to the lowest point at 45°. This indicates that, in design, reinforcement should be parallel to maximum stress.
Mat laminates do not exhibit this directional characteristic. This non-directionality is utilized in composite laminates to add strength to woven products in their weak areas.

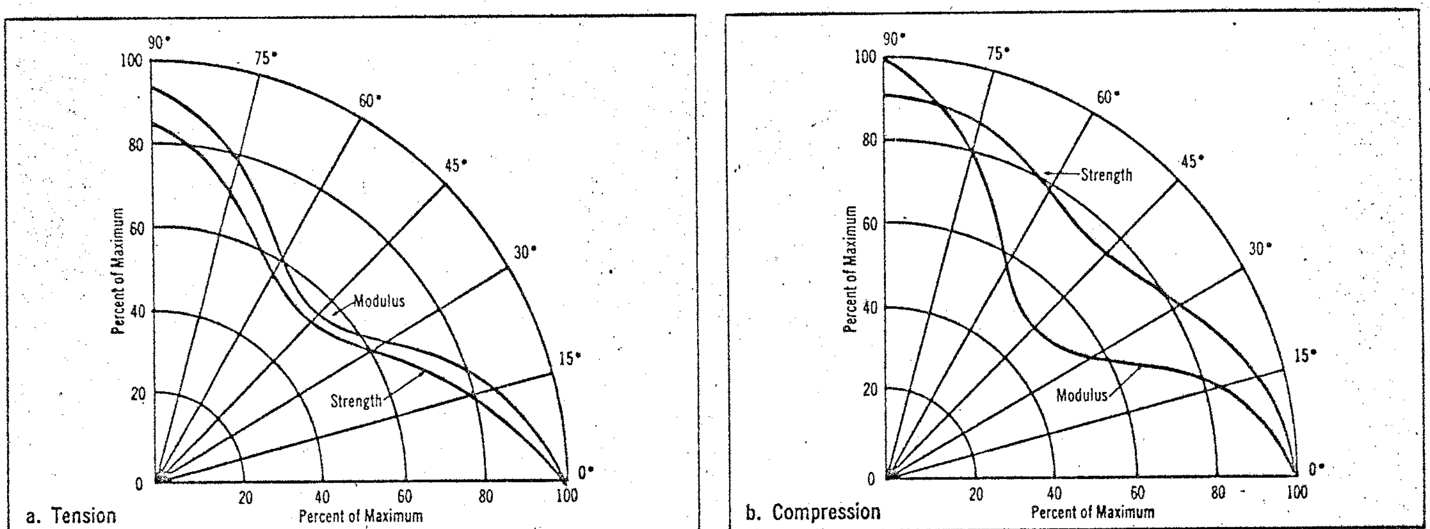


Fig. 5-1. Directional Properties of Parallel-Laminated 10 Ounce Cloth and Polyester Resin, Contact Molded Wet Condition

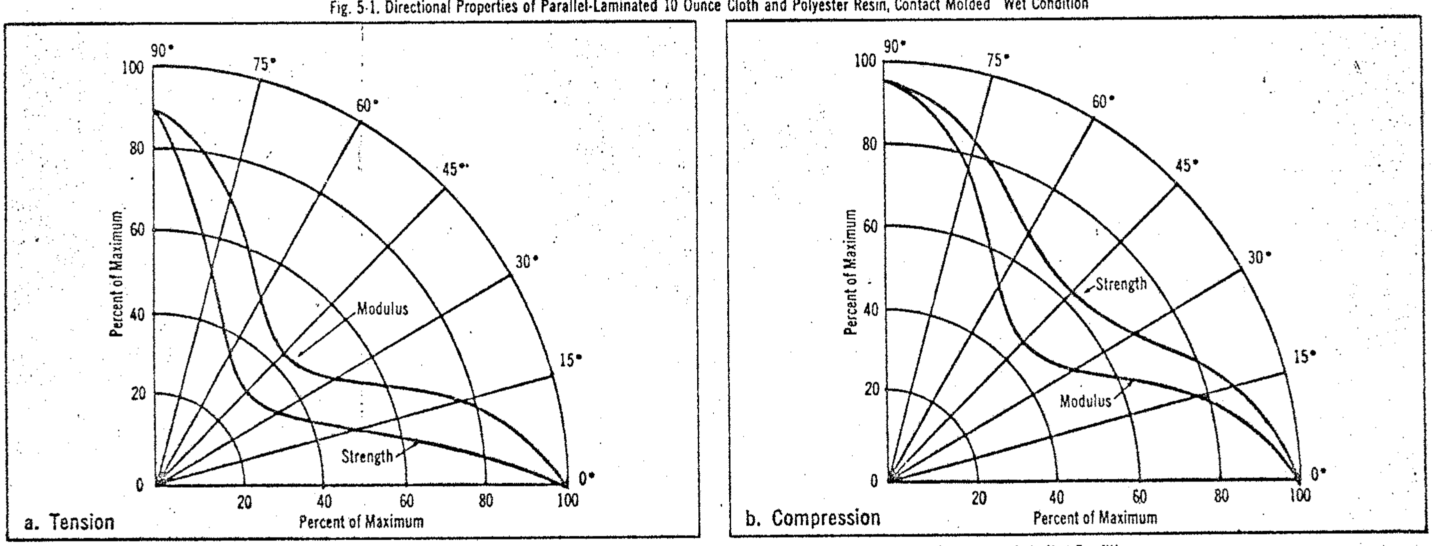


Fig. 5-2. Directional Properties of Parallel-Laminated 25-27 Ounce Woven Roving and Polyester Resin, Contact Molded - Wet Condition

DESIGNING WALL THICKNESS . . . EMPIRICAL METHOD

hand lay-up or spray-up

EMPIRICAL DESIGN

Over the years, a body of useful performance data has been accumulated on a broad range of successful Hand Lay-up and Spray-up applications. If these data do not immediately "solve" design problems, they almost certainly will provide a basis for reasonable interpolation.

Hand Lay-up or Spray-up Wall Thickness—

Automotive Fender	.150" to .200"
Large Protective Housing	.100" to .125"
Boat Hull; 12 feet	.150" to .175"
Corrugated Panel	.045" to .080"

The table on page 13 gives values which allow the designer to determine the amount of Fiberglas needed to build laminate thicknesses (in the case of spray-up) and the number of plies (in the case of lay-up), with any of the reinforcements discussed.

When more than one type of Fiberglas reinforcement is required, in large parts such as boats, for example, empirical design is most beneficial as data is not normally available for all possible combinations of materials nor are design loads accurately known. It is suggested that, for structural uses, data on the actual laminate to be used be obtained from a qualified testing laboratory.

EXAMPLE 1
Determine the expected thickness of a laminate consisting of 1 ply 10 oz. cloth, 1 ply 2 oz. mat, 5 plies 24 oz. roving.

Cloth	— 1 ply	— .016"
2 oz. Mat	— 1 ply	— .058"
Roving	— 5 plies	— .185"
	Total thickness	.259"

EXAMPLE 2
Determine glass deposition oz./sq. ft. needed for a .200" Spray-up. 8 oz. is .237"—an interpolation for 7 oz. will give .200".

ESTIMATING MANUFACTURING COSTS

Typical ranges of manufacturing cost, in terms of dollars per pound of FRP materials, are listed below. Numbers in this table include the cost of materials, labor and processing.

Typical Manufacturing Costs (Less Tooling*)

Spray Up	50-1 00 (¢/lb)
Hand Lay Up	75-2 00 (¢/lb)

Once thickness is determined by either Comparative, Theoretical or Empirical design, the volume of the part can be calculated.

(Volume = surface area of part X thickness of part)

To calculate the weight of material required to make a product of Fiberglas-reinforced plastics, multiply your estimate of the part's volume by the density of material (see Table on p. 11). Then multiply the weight of the part by a cost per-pound value to get an approximate manufacturing cost for the product.

Your choice of cost per lb. should be based on your judgment of the complexity, required appearance, severity of end use, molding difficulty and size of the product. Add at least 25 per cent for very low volumes, very small parts or special performance requirements. Packaging costs are not included.

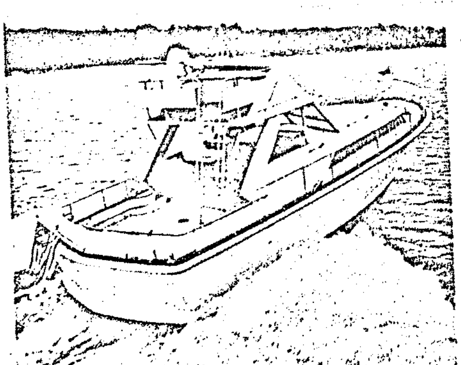
***Tooling Costs**

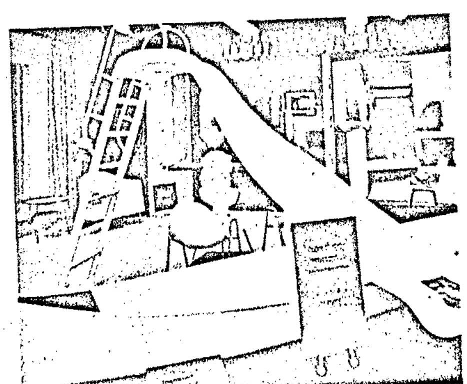
Tooling costs depend on:

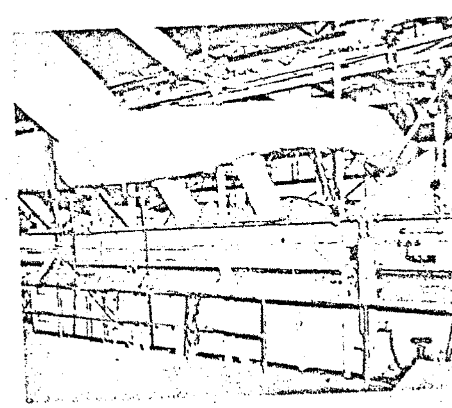
1. Process used.
2. Surface finish required on part.
3. Size and complexity of part.
4. Materials in construction of mold.
5. Number of parts to be produced.

Since the effect of these variables cannot be easily estimated, a designer or manufacturer should consult a mold-make as soon as values for these variables are available.

1. 38' large yacht.
2. FRP pool slide and FRP canoe.
3. FRP fume duct for corrosion resistance.







APPENDIX I

CONTRACTUAL AGREEMENT

TECHITE BRIDGE

PROPOSED BRIDGE FOR POLY CANYON ENTRANCE

by

Robert Purdy

Merrilee Amy

Robert MacEwan

California Polytechnic State University

San Luis Obispo, California

1973

School of Architecture
and
Environmental Design

Grade:________________
Recorded by:____________

Checked:____________________
Submitted:__________________
Approved:___________________

This agreement made this 5th day of February in the year Nineteen Hundred and Seventy-Three, by and between

1. California Polytechnic State University

2. School of Architecture and Environmental Design, George J. Hasslein, FAIA, Dean

3. Hans Mager, Project Coordinator and Advisor for first quarter of research.

4. Albert W. Draves, Advisor for second quarter of research and proposed construction.

hereinafter known as the School, and

1. Robert Purdy

2. Merrilee Amy

3. Robert MacEwan

hereinafter known as the Students, witness, that the School and the Students for consideration hereinafter named agree as follows.

ARTICLE I

Scope of the Work

A. The project shall consist of the design, the preparation of plans, the structural analysis of a bridge, utilizing the material TECHITE PIPE, a product of United Technology Center, div. of UNITED AIRCRAFT.

B. If, after the research has proven the material to be usable for proposed bridge, and there is enough time in the academic school year of Spring quarter, 1973; the students would utilize acquired knowledge during research period to construct the proposed bridge in Poly Canyon.

C. The School of Architecture will oversee the design phase and structural analysis phase.

D. The Students shall procure the materials as donations from various companies.

E. All labor required to do the work shall be done in a manor of good faith and workmanship that would be expected by the School.

F. Progress reports and checks shall be done as the advisor deems necessary in agreement with the Students.

ARTICLE II

Time of Completion

A. The completion of this contract shall be on or before June 9, 1973.

ARTICLE III

Contract Sum

A. The School in keeping with the scope of the project shall compensate the Students with credit in CONE 461 and CONE 462 (Purdy and MacEwan) and ARCE 461 and ARCE 462 (Amy) subject to the following conditions:

1. The Students shall perform as per contract agreement.

2. The Students shall control all labor such that each of these persons herein known as the Students shall provide an equal amount of labor.

ARTICLE IV

Use of Premises:

A. The Students shall confine his apparatus, the storage of materials, and the operation of his workmen to the limits indicated by law, ordinances, permits, or directions of Cal Poly and shall not unreasonably incumber the premises with his material.

B. The School of Architecture will supply the use of the shop, stress lab, and equipment; checkout of equipment therein to the Students as limited by the shop schedule.

C. The Students shall be responsible for identification and care of checked out equipment and for the return of all tools to the proper schools.

D. The arrangement for use of State equipment will be made at a future date.

ARTICLE V

Public Safety:

A. The Students shall be responsible for public safety and shall enforce same during construction and completion of this contract.

B. All necessary safety precautions set forth by the School shall be recognized and enforced by the Students.

ARTICLE VI

Ownership of Drawing:

A. Should the Students have time to build the proposed bridge, the School shall assume ownership of all presentations, reports, and the construction project at the completion of this contract.

In witness whereof the parties hereto executed this agreement, the day and year above written.

SCHOOL:

1. [signature] Hans Mager
Project Coordinater and Advisor (first quarter)

2. [signature] Albert W. Draves
Advisor (second quarter)

STUDENTS:

1. [signature] Robert Purdy

2. [signature] Merrilee Amy

3. [signature] Robert MacEwan

BIBLIOGRAPHY

PERIODICALS

Fonda, A.F.: Field Joining Reinforced Plastic Pipe, Plant Engineering Magazine, March 1963

Lautenbach, T.: Joining Glass Fiber Reinforced Pipe, Chemical Engineering, August 3, 1964

Szymanski, W.A.: Reinforced Polyester Piping Systems, Chemical Engineering Progress, April, 1965

MANUFACTURER'S REFERENCE MANUAL

Techite Pipe, United Technology Center, Division of United Aircraft, 1972