Central Ohio Elementary School

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Construction Management Option

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Senior Thesis Final Report 2014

Executive Summary

This Senior Thesis Final Report intends to present analyses of three aspects of the Central Ohio Elementary School renovation/addition project. The 140 year old school was damaged by fire and forced to close. A recent availability of funding has allowed the school to undergo a complete restoration and the addition of more modern facilities. The areas of analyses include photo documentation, structural modification and alternate plumbing materials.

Analysis 1: Use of Multivista Construction Documentation

The project uses a third-party photo documentation service to visually document the construction process from pre-build site conditions to project completion. The service is an additional cost incurred by the owner. This analysis investigates the benefits of a service such as this and analyzes the potential monetary return.

Analysis 2: Use of Steel Deck and Cast-In-Place Concrete

A portion of the project is new construction that will connect two existing buildings. Precast hollow core planks will be used for the flooring system. Establishing accurate dimensions of the space has been difficult as the aging structure does not provide level surfaces or consistently straight walls from which to take the necessary measurements. The design of a steel deck and cast-in-place concrete alternative would prove more flexible and therefore eliminate the potential for delays associated with the production of replacement precast planks. Installation of the deck and concrete will also benefit other trades as highly detailed coordination will not be required as early in the project as is necessary with precast.

Analysis 3: Use of PEX Tubing for Domestic Plumbing

The plumbing system for this elementary school is designed using copper with soldered joints; the industry standard for commercial construction. Time and monetary savings are a consideration on every job and installing PEX instead of copper on this project can achieve both. This analysis estimates the actual savings, compares the friction loss associated with both systems and investigates the advantages and disadvantages of PEX.

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Project Background

The project selected for use in this research project is an elementary school located in central Ohio. The project consists of new construction and renovation work. The original building, constructed in 1874, was damaged by fire. The building was subsequently closed and the students were relocated to adjacent schools as the cost of repairs were deemed an unnecessary expense.

A district-wide push toward the neighborhood school concept revitalized interest in reopening the school. As funding became available, a plan to renovate the 28,000 square feet of existing space and add 18,000 square feet of modern amenities was developed. The school is located at the intersection of two historical districts, resulting in a compromised list of restrictions affecting exterior materials, scale and setbacks and requiring special attention paid to the brick alleyway.

The project consists of the abatement of hazardous materials, demolition of a portion of the building, complete renovation of the remaining structure, construction of the addition, completion of sitework and the demolition of an adjacent building. The construction costs are $9.07 million. The total project costs, excluding demolishing the secondary building, are $11.2 million.

The design process began on July 5, 2011. After the lengthy approval process, construction began on June 4, 2013. The substantial completion date is scheduled for 435 days later, on August 13, 2014. Contract completion, January 23, 2015, follows winter commissioning.

Figure 1: Architect's rendering of the completed project. (Hardlines Design Company)

The existing buildings are comprised of three stories. The ground floor is partially below grade but provides means of egress. The first floor is located entirely above grade and is the main point of entrance. The structures also contain attic space that will be unoccupied.

The existing building is wrapped in limestone veneer and red brick. The stone architectural features were preserved and if necessary repaired. The renovation will include new aluminum window systems installed in the existing openings. The existing space will be used mainly for classrooms and will also contain the cafeteria, restrooms, art room and offices. Some work will be needed to repair the effects of the fire. This will mainly involve replacing the existing flooring system in the rooms where the fire started with steel deck and cast-in-place concrete supported by a wide flange beam and the masonry walls. The wood joist floors that survived the fire will remain. The interior finishes will be replaced and the interior walls will be reconfigured to better accommodate the needs of a modern educational facility.

The new construction mainly occurs to the north of the existing structure and does not include attic space. This portion of the completed facility will include classrooms, the gymnasium, food preparation and storage areas and mechanical rooms. One section of new construction is located between the two existing structures and is referred to as the “Connector”. This section of the building will house offices, storage, a classroom, the music room and the facilities elevator.

The new exterior walls will be 8” CMU with limestone and brick to match the existing exterior finishes. The windows will be more modern in style than those installed in the existing building. The structure of the building will be a combination of CMU bearing walls and wide flange steel members. Precast hollow core planks with a concrete topping will be used for the floors. Cold-formed steel framing will be used for interior wall construction throughout the project. Suspended ceilings will be installed in the offices, corridors, restrooms, classrooms and all other student-oriented areas.

A majority of the heating and cooling will be accomplished using Variable Refrigerant Flow (VRF) units. These units will provide room-specific conditioning while being more efficient than traditional HVAC methods. Air handlers will be used to condition the gymnasium, cafeteria and corridors.

Power is supplied to the building from a 500 KVA pad mounted transformer. The building’s main switchboard is rated at 2000 Amps. An electrical closet is located on each floor. In the case of a power outage, a 60KW natural gas generator will provide the facility’s emergency electricity. Recessed fluorescent lights will be used throughout the building with the main exceptions being the gymnasium, which will use suspended fluorescent fixtures and mechanical rooms, which will use surface mounted fluorescent fixtures.

The delivery method for this project is Single Prime with CM advisor. The construction manager has been participating since the project's inception. Figure 2 shows the project's organizational structure.

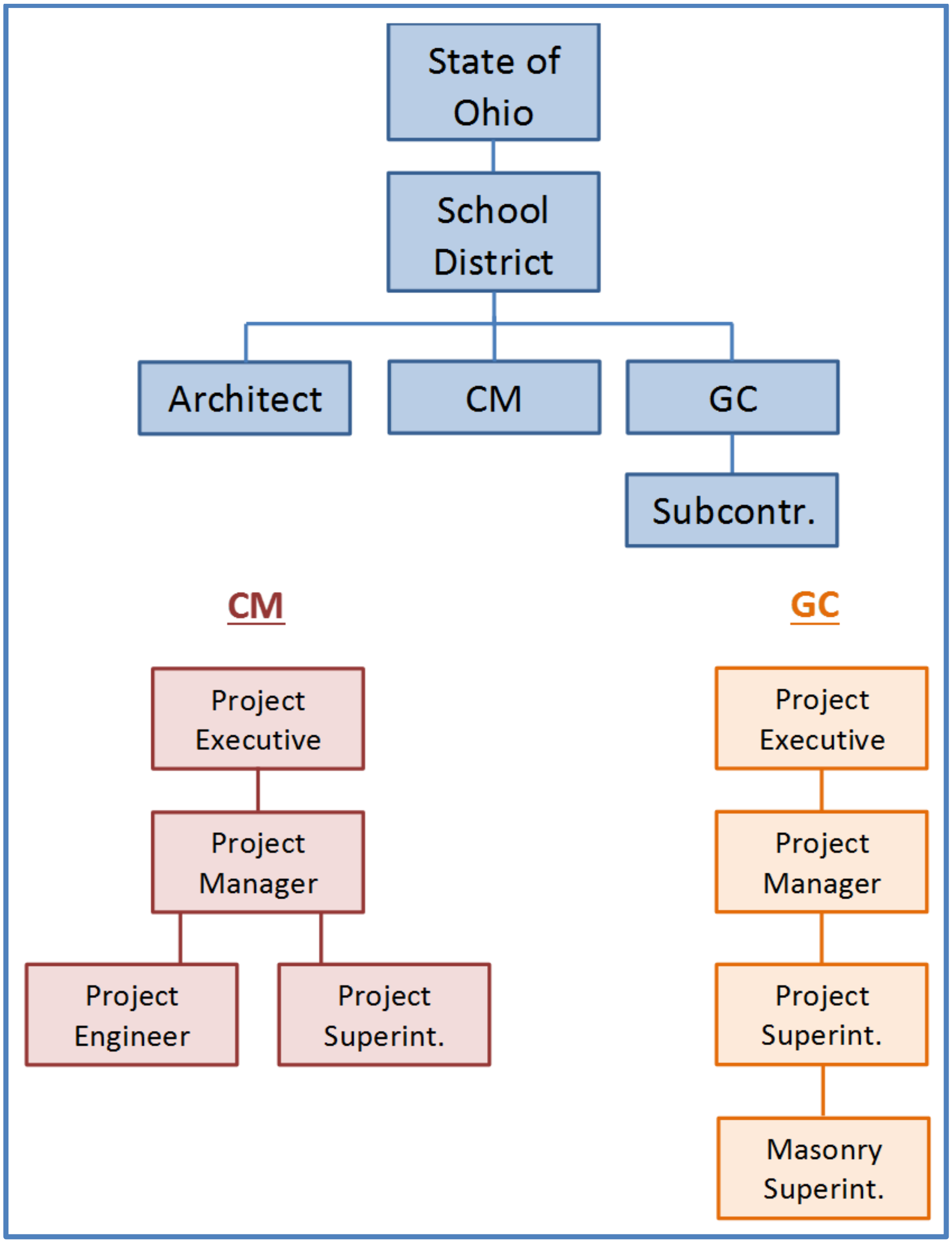


Figure 2: Project organization diagram.

Once completed, the school will provide a local solution for the educational needs of this neighborhood. The 350 children in grades K-5 will no longer need to be bused to school each day but will be able to walk to this new facility that has been meticulously renovated to accommodate a modern learning environment.

Analysis 1: Use of Multivista® Construction Documentation

Problem Identification

The viability of third party photographic construction documentation is analyzed in this section, as this service is utilized at Central Ohio Elementary School with the purpose of providing the owner with "visual as-builts" of the building.

As-built drawings are a crucial element of maintaining a building. Unfortunately, the owner is at the mercy of the conscientiousness of the contractors as it pertains to their accuracy. While the contractors are required to provide as-built drawings, they are sometimes rushed or incomplete. Often any changes made to the drawings are recollected from notes or memory, leaving open the possibility of a slightly inaccurate representation of what actually exists. The presence of photographic documentation to substantiate or dispute the drawings can be a vital tool.

Research Goal

The goal of this analysis is to research the viability of third-party photographic documentation. A case study will be used to find advantages to this service. The research will also include a background study of the particular service used on this project.

Methodology

- Review Multivista Systems, LLC's documentation to identify proposed benefits of the service.
- Interview Multivista contact to gain deeper insight into the service and obtain financial evidence of benefits.
- Interview Smoot Construction contacts to discuss benefits and shortcomings of the documentation service on current projects.
- Research the average cost of and time spent on investigatory procedures that could be rendered obsolete by this service.
- Compare cost of service to projected savings.

Background Information

The photographic documentation service for this project is being provided by Midwest Documentation, the Ohio division of Multivista Systems, LLC (Multivista). The company provides this service as well as construction webcams and construction and owner training videos for projects in the United States, Canada and United Kingdom. Multivista was the only company found to be offering photo documentation of this nature in Central Ohio.

Multivista's service includes both construction progress photography and milestone documentation. The milestone documentations are one-time photo shoots providing an exact record of the construction site at critical stages of the project. An example of this type of shoot would be the MEP Exact-Built® (Figure 3). This captures the mechanical, electrical and plumbing systems installed in the walls and ceilings following inspection but before insulation and finishes are installed. The progress photography is a series of interior and exterior photos of the project taken at regular intervals, usually monthly, throughout the project's duration. These photos provide a visual timeline of the project's progress that can be later used to identify hidden conditions or determine the timeframe of specific work.

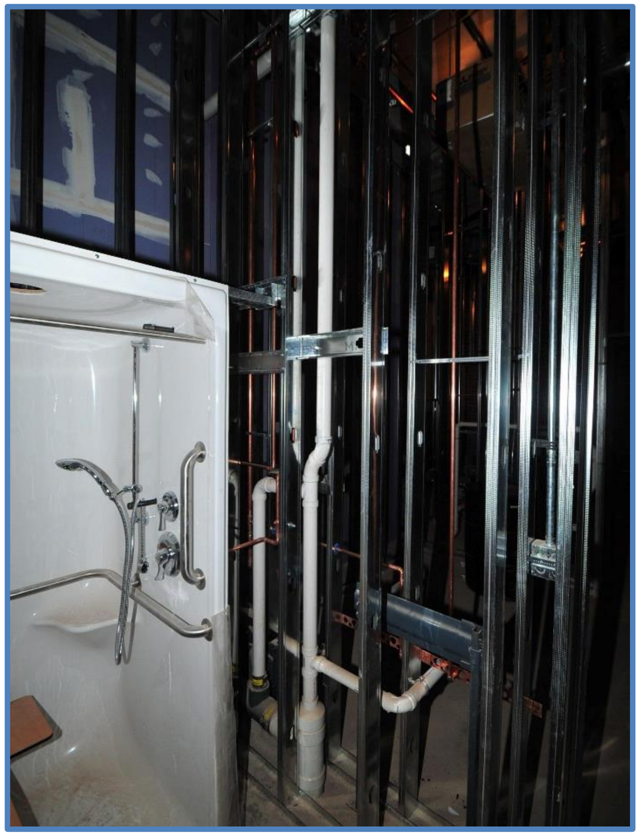


Figure 3: Example of MEP milestone photo. (Multivista®)

The service is typically contracted on a square foot pricing structure. The price per square foot varies depending on the required number of milestone photo shoots and complication level of the construction project (e.g., warehouses typically have a lower cost than hospitals). The cost for a school similar to the one used for this research project would be approximately $0.20 per square foot. This would translate into a contract cost of $9,443 for this 47,219 square foot project.

The photographers are former tradesmen, not professional photographers. They are required to have earned their 10- and 30-hour OSHA cards. The photographs are taken with wide angle lenses using high megapixel cameras. The photographers are trained at the corporate headquarters in Vancouver, British Columbia, Canada. When photographing any jobsite, the photos are always taken in the same prescribed order, so as to ensure accuracy. Additionally, taking pictures of workers is avoided when at all possible. These requirements and equipment allow for the photographers to be safe, knowledgeable of the construction process, comfortable on a construction site and able to avoid interference with ongoing work.

After the completion of a photo shoot, the photographs are accessible to the owner using Multivista web-based software. Using an architect-provided floor plan, the photographs are mapped to their location, seen in Figure 4. These photos are then available to anyone granted permission by the owner.

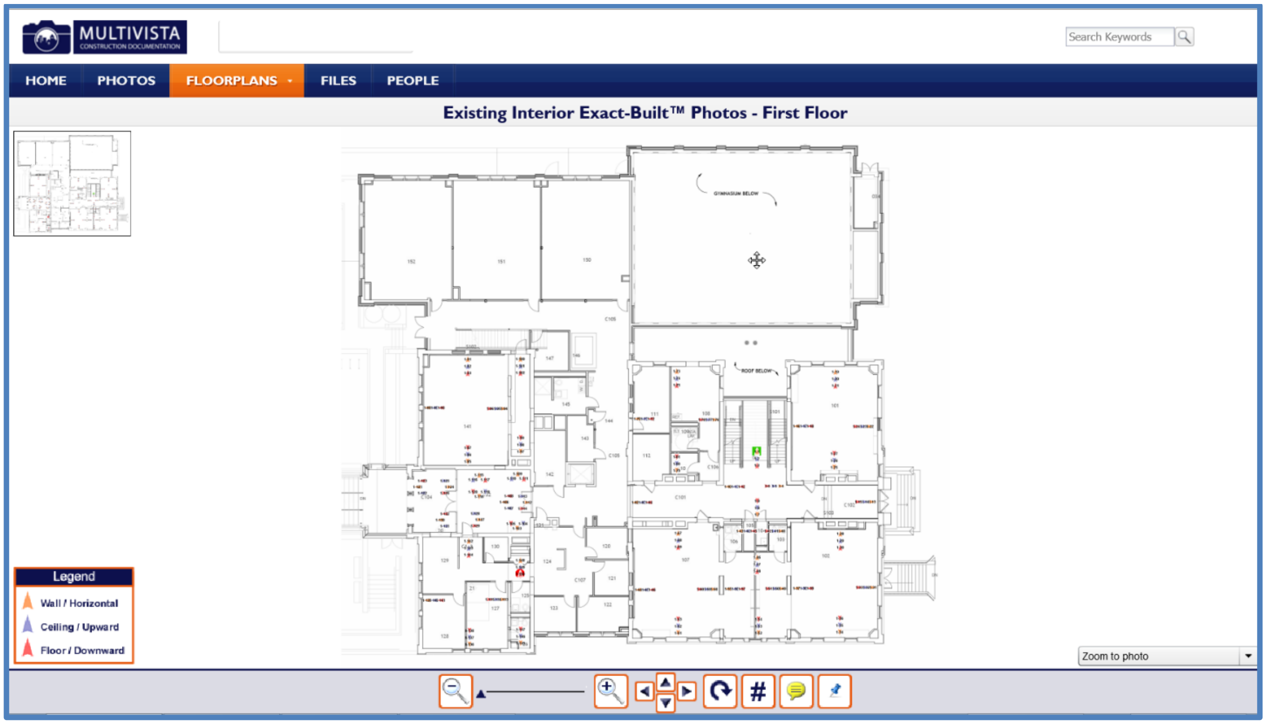


Figure 4: Example floor plan viewed on Multivista web-based software. (Multivista®)

The software uses indicators to denote available photos (Figure 5). There are separate indicators for downward, upward and horizontal photographs. All photographs can be printed, saved or emailed by the viewer. Emailed photographs are delivered as a web-link. The photo remains on the website and the recipient has access to the photo for up to 7 days. The software also allows for notations to be added to the pictures and shared with the project team. Figure 6 shows an example of an interior photo viewed using the web-based software.

The photographs are high megapixel images allowing for maximum detail and zooming capabilities. Once a photograph is selected, the viewer may cycle through adjacent photographs or choose to cycle chronologically through photographs of the same location (Figure 7). This allows for easy determination of both the most relevant view and the date of demolition or installation.

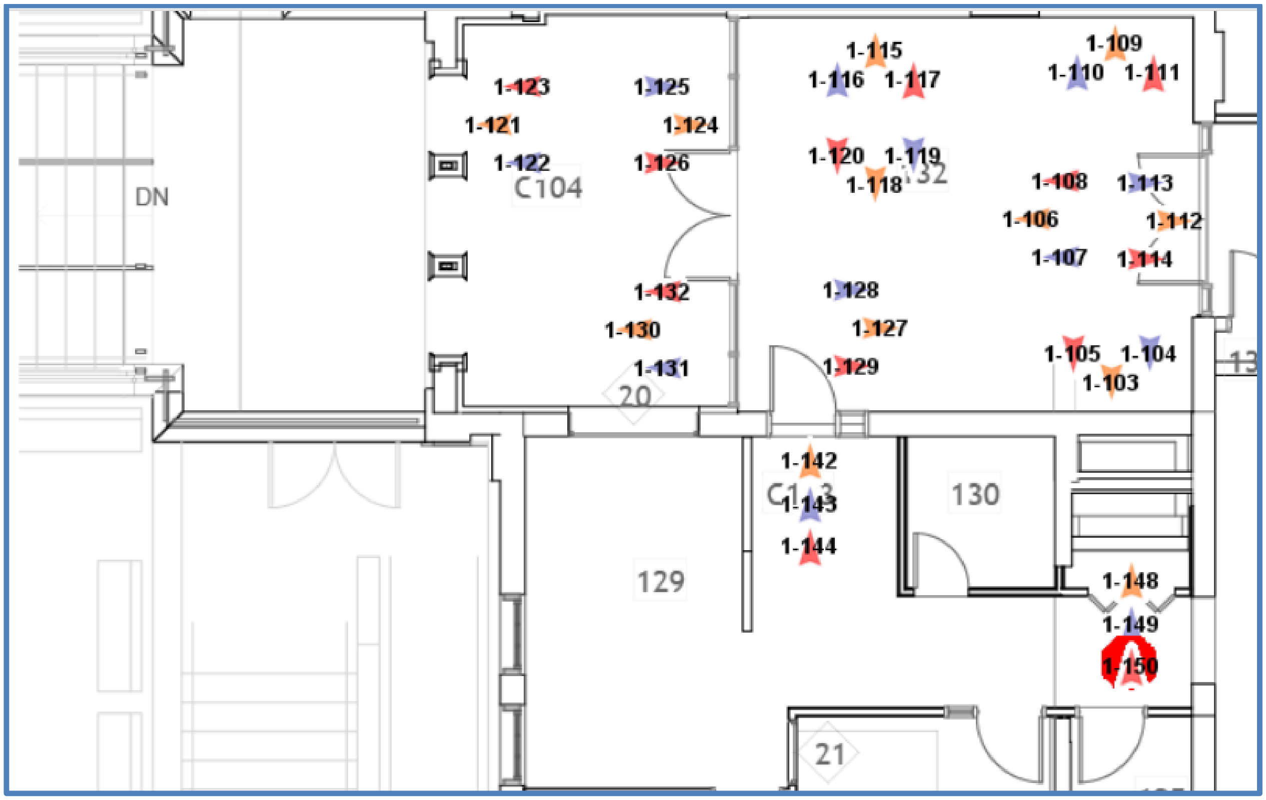


Figure 5: Enlarged view of floor plan showing photo indicators. (Multivista®)

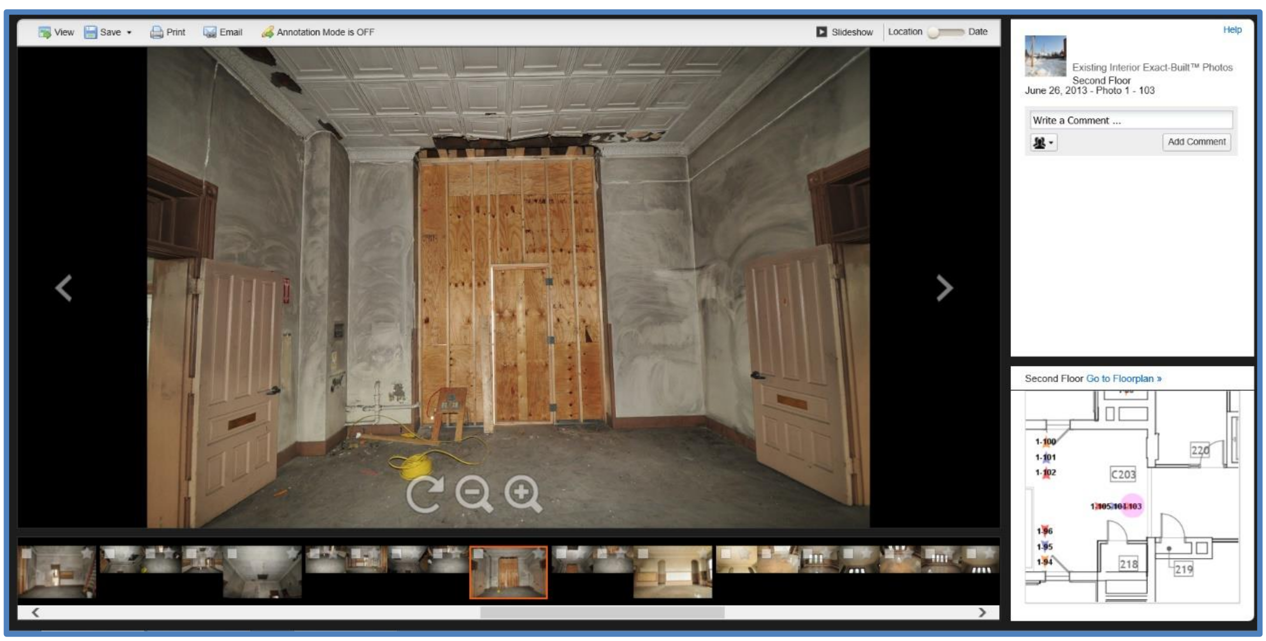


Figure 6: Example of interior photo viewed with Multivista software. (Multivista®)

Figure 7: Example of exterior progression photos. (Multivista®)

The owner has access to the photos via the web-based software for up to 6 months after the completion of the project. Following the contract's conclusion, the software and photos are available using a Multivista supplied DVD or USB flash-drive that accesses a web browser in an offline capacity. The photographs are the property of the owner and may be shared or published at the owner's discretion.

Case Study

A newly constructed children's hospital in Ohio neared completion and was set to open in several weeks. As work was coming to an end, several of the ADA handrails installed in the patient bathrooms (Figure 8) detached from the wall. Destructive testing of the affected handrails discovered that the proper blocking was not present to support the handrail.

Figure 8: Typical bathroom with ADA handrail installed behind the toilet. (Multivista®)

Once the reason for the issue was determined, the concern became how many bathrooms were completed without the proper support being installed. There were 400 patient rooms in the hospital and potentially all 400 bathrooms could be missing the required backing. Completing the destructive testing and reinstallation of each handrail would be extremely expensive. Additionally, being so close to the completion date, the time necessary to complete the repairs would have delayed the opening date for the hospital, causing loss of income.

However, instead of proceeding with the demolition and investigation, they were able to consult the Multivista software to determine the extent of the problem. By using the progression photos of the bathrooms, it was determined that the walls were properly framed and that the locations of the handrails were located and marked (Figure 9). While the intention to install the blocking was evident in the progression photos, they did not provide with 100 percent certainty proof of whether or not the blocking was actually installed.

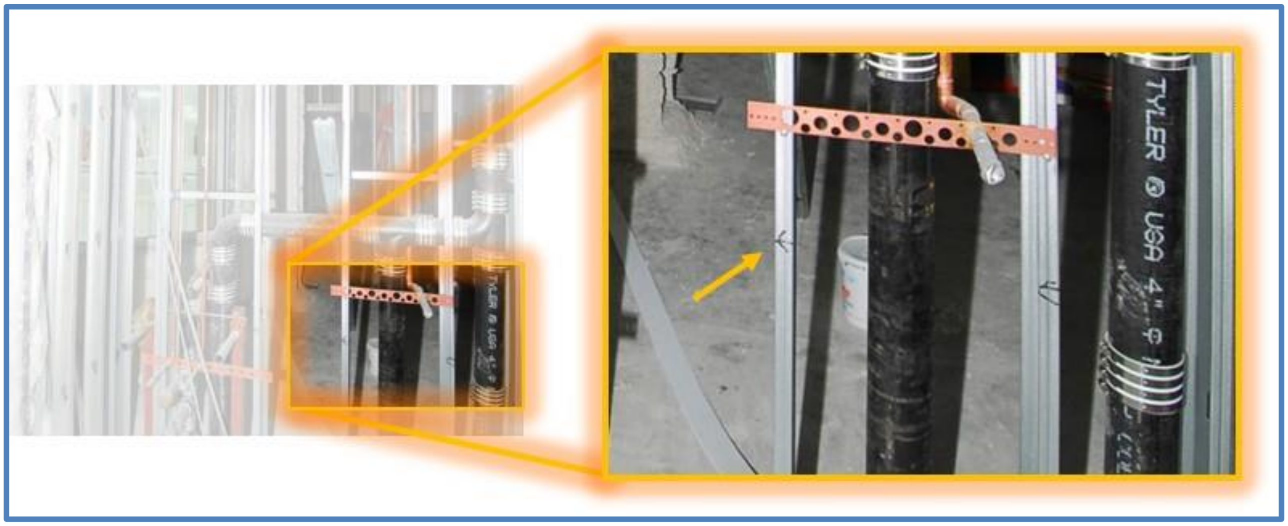


Figure 9: Photographic evidence of missing handrail blocking. (Multivista®)

Cost **without** Photo Documentation				
Activity	Time	Labor	Material	Total
Supervision	1	$84	$0	$84
Destructive Testing	2	$76	$0	$76
Repair	6	$376	$27	$403
Total	9	$536	$27	$563
Total cost for 400 bathrooms				**$225,200**

Cost **with** Photo Documentation				
Activity	Time	Labor	Material	Total
Supervision	0.5	$42	$0	$42
Demolition	1	$19	$0	$19
Repair	4.5	$282	$22	$304
Total	6	$343	$22	$365
Total Cost for 42 Bathrooms				**$15,330**

Table 1: Cost comparison for ADA handrail repairs.

Because the MEP Exact-Built® photographs show the exact condition of the wall interiors before insulation and drywall are installed, these photos were able to identify which bathrooms were lacking the handrail support. This issue was identified to be present in only 42 rooms, thus saving the cost and time of physically investigating the other 358 rooms. In addition, the client reported a savings in the 42 affected rooms because they were better prepared for the conditions in the wall and could more accurately proceed with the repairs.

The cost of investigating, repairing and reinstalling the grab bar would have been $563 per bathroom. The cost to complete this work in all 400 bathrooms would have totaled $225,200. The cost to make the same repairs in just the 42 bathrooms requiring correction was $365 per bathroom for a total of $15,330. That results in a savings of $209,870. These savings are indicated in Table 1.

The savings weren't just monetary in nature. There was also a savings of time. Using Multivista resulted in a 3 hour savings in each of the affected rooms. It also saved 9 hours per unaffected bathroom. Those savings combined for a total of 3,348 hours. This savings allowed the project to finish on-time and resulted in no lost revenue.

Sample Situations

The following are situations where having photo documentation as a reference may be beneficial.

Vertical Reinforcement between Windows

Soon after project completion and occupancy, a crack develops in a CMU bearing wall. The crack is located in a one block wide section of the wall between two windows. The drawings specified three vertical reinforcing rods to be installed in this narrow wall segment.

After reviewing the drawings, the architect became suspicious that the contractor had not installed the reinforcement. The narrow space was also to include electrical conduit making for a tight fit. The contractor maintained that the structure was completed per the drawings. Unfortunately there was no documentation to prove or disprove the contractor's claims.

The contractor was responsible for providing photographic documentation but hadn't proceeded in a manner commensurate with the intent of the contract. Adding to the potential problem was the opportunity for the issue to spread as there were multiple locations where the same situation could be present.

The most economical solution was to hire a forensic engineer to investigate the claim. The engineer was able to determine that some reinforcement was present in the wall but was unable to definitively reveal how much reinforcement was installed. Had a third-party been responsible for the photo documentation the likelihood of corroborating evidence existing would have increased.

Copper Pipe Stolen

As sometimes occurs on a construction site, tools or material can be stolen. One item that must receive particular attention as to its security is copper pipe. The high resale and recycling values make this a favorite target for theft. Often when materials are misappropriated an insurance claim is filed. One potential scenario in which photo documentation might aid in determining which entity should file an insurance claim in the event of theft is outlined below:

During the construction process a large quantity of copper pipe is discovered to be missing. The plumbing contractor claims that the pipe had already been installed and was removed from the structure. If this claim is valid, the general contractor's insurance is then responsible. However, the general contractor alleges that the pipe had not yet been installed in the area of the building the plumber was claiming it had been taken from and was still being stored by the plumbing contractor in their material trailer, making the plumber's insurance responsible.

By having access to the project's progression photos, it was easily determined that the copper pipe was installed. Accepting the evidence, the general contractor submitted the loss to his insurance.

Window Leak

After construction is completed and the building is occupied several of the windows in the renovated portion of the project begin to leak. Not knowing if the underlying issue is particular to the few windows exhibiting leaks or a more systemic problem, the school district now faces the prospect of investigating each retrofitted window.

Using photos taken following the window installation, the school can determine that only a portion of the windows are susceptible to this failure. This information saves the school district or contractor the expense of investigating and reinstalling the correctly installed windows. It also provides information about the affected windows otherwise only available through investigation, thus making the repair process more efficient.

Cost **without** Photo Documentation				
Activity	Time	Labor	Material	Total
Supervision	4	$336	$0	$336
Destructive Testing	4	$180	$0	$180
Repair	8	$752	$175	$927
Total	16	$1,268	$175	$1,443
Total cost for 101 Windows				**$145,743**

Cost **with** Photo Documentation				
Activity	Time	Labor	Material	Total
Supervision	2	$168	$0	$168
Demolition	2	$90	$0	$90
Repair	4	$376	$89	$465
Total	8	$634	$89	$723
Total Cost for 20 Windows				**$14,460**

Table 2: Cost comparison for window repairs.

Additionally, it alleviates the possibility of closing classrooms and offices while the repair work is done.

If, through the use of the photo documentation, 20 of the windows in the renovated portions of the building are found to be installed incorrectly, a savings of 90% could be achieved when compared to investigating and reinstalling all 101 windows. A 50% savings is realized with the more efficient repair of leaking windows. The remainder of the savings comes from alleviating the need to address all 101 windows.

Cracked Wall

The project's owner receives a bill from the owner of an adjacent building for repairs to cracks in the wall facing the jobsite. The neighbor asserts that the damage occurred during the excavation process for the construction project. The project's owner and contractor are able to determine that the cracks were present before the start of construction by viewing the site survey photographs.

Ceiling Leak

The ceiling of a rural elementary school classroom begins to leak. The teacher informs the principal, who in turn calls the district office. The district office dispatches a maintenance worker from another job located 30 miles from the elementary school. The worker arrives at the school 45 minutes later prepared to address the plumbing issue.

Once inside the classroom, the maintenance worker removes the ceiling tile only to find that there is no plumbing located in the ceiling. The area above the leak is void of any conduit, piping or other obstruction, leaving a roof leak as the only available cause and the use of a roofing contractor the only solution.

With access to the MEP photos, it could have quickly been determined that an issue with the roof was most likely the source of the leak. This knowledge would have saved the nearly two hours spent by the maintenance employee as well as the gas used to travel to and from the school.

Advantages and Disadvantages

Through conversations with contacts at Multivista and Smoot Elford Resource International and other industry members, the following advantages and disadvantages to third-party photo documentation were discerned.

The contracting of a third-party to be responsible for providing photographic services for a construction process allows the site superintendent to focus on tasks that he or she is more suited to accomplish. A service such as Multivista provides a trained person whose sole purpose is to exhaustively photograph the jobsite and the work occurring there.

The photos are only as useful as their organization allows them to be. A computer folder filled with unlabeled and uncategorized pictures is difficult, if not impossible, to navigate and only serves to confuse those requiring its contents. The organized nature of the software and its instant accessibility from multiple locations is a near perfect solution.

The knowledge that this service is being used on a jobsite has the unintended potential to improve production and quality of work. Workers may approach their responsibilities in a more conscientious manner if they are aware that their progress is being documented in such a detailed way.

While not the initial incentive for offering such a service, a reduction in litigation is likely. Many disputes that rise to a level requiring a litigious solution are based in ambiguity. A well-documented process will alleviate much of this uncertainty and provide evidence that better identifies responsibility.

The software solution provides a “green” alternative to as-built drawings and printed photos. The software is accessible from multiple locations. Equivalent copies of drawings and printed pictures would require a very large quantity of paper and printing supplies. The digital photos have also been used for Leadership on Energy and Environmental Design (LEED) verification purposes and are highly considered when attempting to obtain platinum certification.

Perhaps the most useful application of the service and its software is by the owner for maintenance purposes. In many instances, facilities of a mid to small size do not employ people with the technical knowledge or willingness to use a system like Building Information Modeling (BIM). This is a reasonably priced and comparably simple alternative. If a person can use a computer to access the internet, they can use this service.

The service isn’t without its deficits. The most apparent issue is the additional cost to the project. On this project the extra cost would be nearly $10,000. While the potential for savings is prevalent, it may be difficult to convince owners that the benefits will be worth the incurred expense. In the future, third-party documentation could be required by the specifications allowing for funding through the project contracts.

Despite the many benefits, this service is not a catch all. There will always be the potential to accidentally exclude a portion or portions of job. Utilization of the service doesn’t guarantee that a photo showing the needed information will be available.

While designed to be simple, there is still a small learning curve. The user must have a minimal computer competency level. Someone who struggles with computers will most likely possess an unwillingness to use the system. Additionally, an eagerness to learn and utilize the service can only be expected of those who understand its benefits. This education of benefits may be the largest hurdle to successfully incorporating the software into a construction project and facility maintenance.

Third-Party Photo Documentation Conclusion

Most contracts require the contractor to provide photo documentation of the construction process. While a site superintendent or other representative enters the job with every intention of fulfilling this contractual obligation, they are often consumed with the other aspects of their job. The result can potentially be a computer folder filled with poorly labeled pictures that thoroughly document the start of the job but wane over the course of the project.

The implementation of a third-party documentation service is a viable solution to this issue. By eliminating the photographic duties from the list of contractor responsibilities, it will free them up to concentrate on the other aspects of their job. It will also provide for a better documentation product by utilizing people trained to photograph the construction process.

With an approximate cost of $10,000 for a job the size of the one used for this research paper, potential savings could easily surpass the cost of service. Simple investigative services or window leak repairs can certainly exceed the initial cost. Or with the elimination of fifty two-hour maintenance calls over the life of the facility, the $10,000 could be recouped.

The service has the potential to reduce litigation, decrease maintenance costs, increase productivity and quality and provide a green alternative to as-builts and printed photos. Additionally, it provides a comprehensive record of the project for the owner.

Analysis 2: Use of Steel Deck and Cast-In-Place Concrete

Problem Identification

The construction documents call for a pre-cast concrete deck flooring system for the "Connector" portion of the project. The "Connector" is located between the two remaining structures, shown in white (Figure 10). This system is proving difficult to procure and install. This manifests in three separate issues.

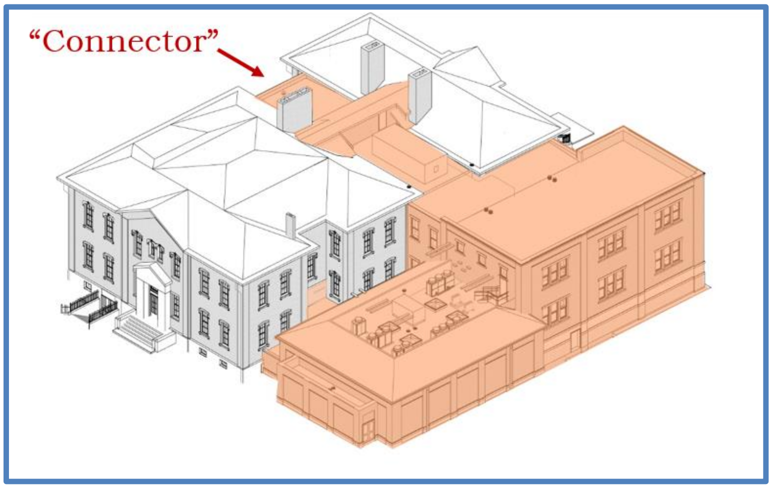


Figure 10: Isometric drawing of project, highlighting new construction. (Hardlines Design Company)

1. The planks prove difficult to install in the existing structure because of limited access and issues with exact measurements for connections.
2. The planks are unable to be altered as last minute changes to the design occur and connection points need to be moved.
3. The planks provide minimal penetrations for utility and system installation.

One issue that has plagued the Central Ohio Elementary School project is inconsistent measurements. The age of the building is the main reason for the difficulty in procuring accurate dimensions. Being more than 140 years old, the remaining structure does not provide level or plumb surfaces. The undulating walls and inclined floors lend themselves to these poor measurements. This is a difficult proposition for a pre-cast system that requires a high level of accuracy to ease installation. There is very little ability to adjust the planks onsite if errors are realized during installation.

The condition of the building as well as late changes in the room layouts have caused another potential issue with the pre-cast planks. This being the inability to alter the planks once they are produced. The relocation of chases may prove challenging. Also the anchor points for the steel beam supports may need to be moved because of unknown structural deficits in the existing structure.

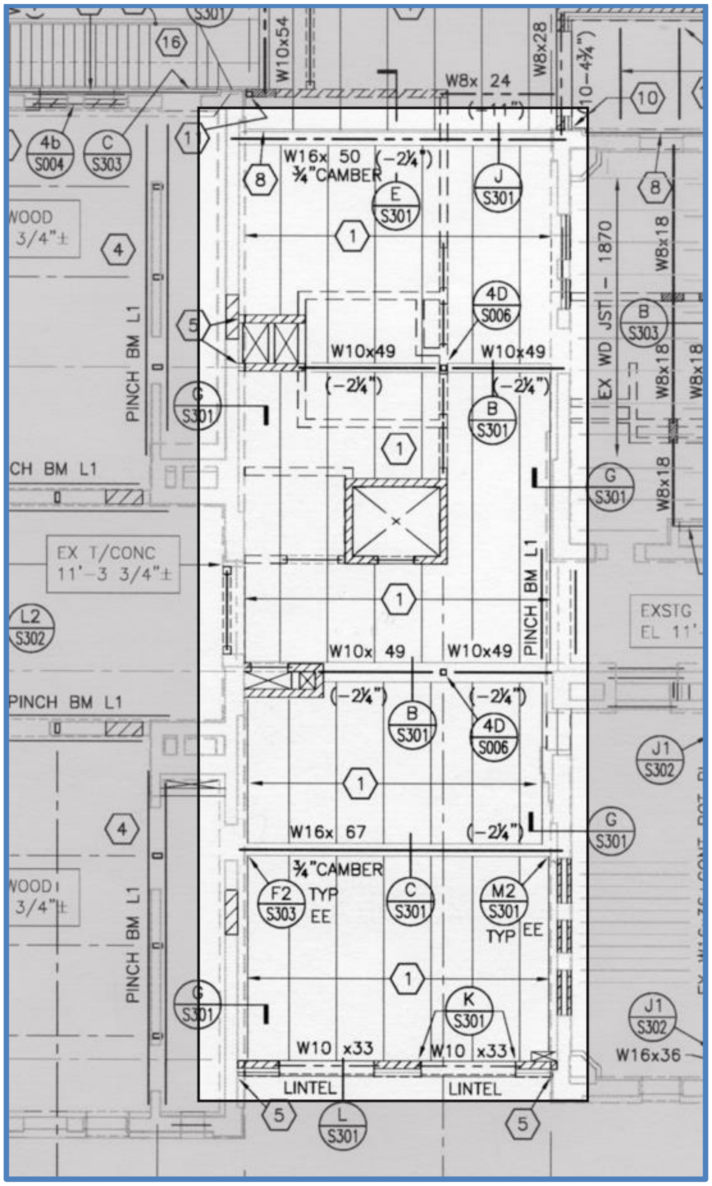


Figure 11: Connector portion of structural drawing. (Hardlines Design Company)

Research Goal

Replacing the pre-cast planks with steel decking and cast-in-place concrete could solve all three problems outlined above. First, the issue of unreliable measurements and the misaligned structure of the 140 year old building can be alleviated by the relative ease of installing the steel decking into existing structure as compared to fitting the precast planks. Onsite adjustments to the steel decking will occur routinely and with little difficulty.

Second, the aforementioned adjustability of the steel deck/cast-in-place system will allow for last minute changes to the design. It will also provide a flexibility to move the steel beam connection points on the existing masonry structure if the predetermined locations are found unreliable.

Finally, on-site placement of penetrations will be possible with the steel decking/cast-in-place concrete solution. Alterations to the project design have forced the MEP systems to change requiring the relocation of conduit, wiring and piping. This solution will enable other trades to provide better input as to modified or new requirements.

Methodology

- Estimate cost of precast concrete plank system.
- Design and estimate new system.
- Compare costs of the two systems.
- Identify additional benefits of steel decking system. (e.g. onsite alterations and penetrations)

Original Solution

The flooring system being used in the new construction portion of this project is comprised of 8" precast hollow core planks supported by W-shape steel members. In the "Connector" section of the building the planks are placed longitudinally, while the steel members are installed in the opposing direction. The steel members are anchored to the existing masonry walls. A 3" concrete topping is placed over the precast planks. Wire mesh and fiber is called for as reinforcement for the topcoat.

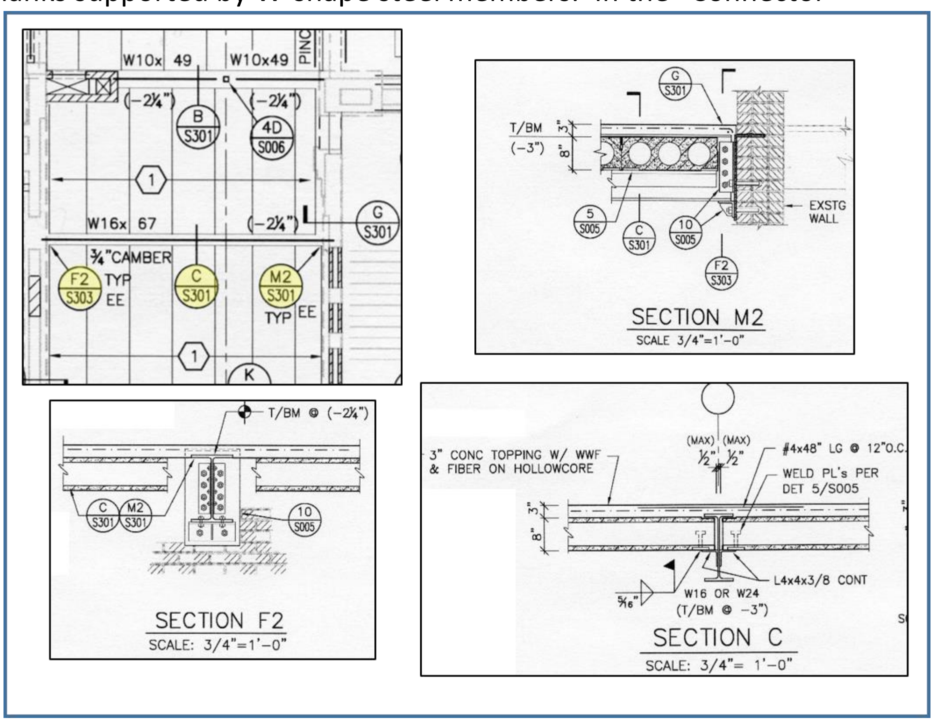


Figure 12: Details of the original floor system design – precast hollow core planks w/ 3" concrete topping. (not to scale) (Hardlines Design Company)

Cast-in-Place Solution

The proposed alternate flooring system is cast-in-place concrete over steel deck. A total concrete depth of 3.5" will be used. The concrete will be poured over Vulcraft's 1.5" VL composite steel floor deck (1.5VL22). The resulting concrete thickness above the steel deck will be 2". This will be reinforced with wire mesh. The steel decking will be supported by W-shape steel members. The main steel girders will run laterally and be installed in the same locations as those in the original design. Intermediate steel joists will be the distance between the girders. The steel deck will be oriented in the lateral direction. Type 16 pour stop will be used (Table 17, Appendix A). Type 16 was chosen to help accommodate for the inconsistencies in the masonry wall surfaces.

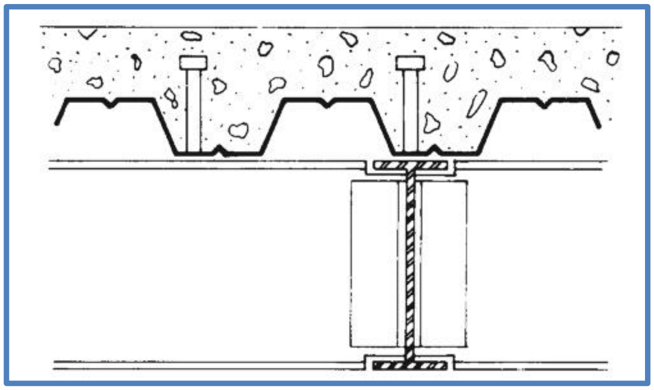


Figure 13: Example of cast-in-place concrete/steel deck solution. (Vulcraft)

Cost and Schedule

As with any alternative solution, comparisons need to be made with the original idea to determine its validity. In this case, two of the major comparisons are cost and duration. To complete these comparisons an estimate was completed using data obtained from R.S. Means (Table 3).

The estimate was performed for the first floor "Connector" portion of the project. The second floor portion that occupies the same space has an identical design. Therefore the results of the estimate are simply doubled to determine the final values.

Information for every item was not available in R.S. Means. For the steel members that weren't specifically listed a cost of $1.46 per pound was used for the material price. This was the average value of the members that were listed in the data. The labor and equipment values were assumed to be similar to the members of comparable sizes. The values for 2" deep, 22 gauge steel decking were used as no cost information was available for 1.5" deep, 22 gauge decking. Finally, the information provided for 4" elevated concrete slab was used for both the 3.5" cast-in-place slab and the 3" topcoat of the original solution. Equipment such as a crane and concrete pump are included in the crew costs (Table 13, Appendix A).

Flooring System Estimates

	Description	Qty	Unit	Crew	Daily Output	Bare Material	Bare Labor	Bare Equip.	Bare Total	Total Days	Total Cost
Steel Deck / Cast-in-Placee	W8X10	17.1	L.F.	E2	600	$14.60	$4.68	$2.55	$21.83	0.029	$373
	W8X13	27.5	L.F.	E2	600	$18.98	$4.68	$2.55	$26.21	0.046	$721
	W8X18	91.1	L.F.	E2	600	$26.28	$4.68	$2.55	$33.51	0.152	$3,053
	W8X21	19	L.F.	E2	600	$30.50	$4.68	$2.55	$37.73	0.032	$717
	W8X24	72	L.F.	E2	550	$35.00	$5.10	$2.78	$42.88	0.131	$3,087
	W8X31	57	L.F.	E2	550	$45.00	$5.10	$2.78	$52.88	0.104	$3,014
	W8X35	49.5	L.F.	E2	550	$51.00	$5.10	$2.78	$58.88	0.090	$2,915
	W10X45	50	L.F.	E2	550	$65.70	$5.10	$2.78	$73.58	0.091	$3,679
	W12X50	26	L.F.	E2	750	$73.00	$3.75	$2.04	$78.79	0.035	$2,049
	W12X58	18.5	L.F.	E2	750	$84.50	$3.75	$2.04	$90.29	0.025	$1,670
	W12X65	26.5	L.F.	E2	640	$94.90	$4.39	$2.39	$101.68	0.041	$2,695
	W12X79	45.2	L.F.	E2	640	$115.34	$4.39	$2.39	$122.12	0.071	$5,520
	Vulcraft 1.5VL22	1932	S.F.	E4	3860	$1.86	$0.43	$0.04	$2.33	0.501	$4,502
	6X6 W1.4XW1.4 Wire Mesh	19.32	C.S.F	2 Rodm	35	$14.50	$23.00	$0.00	$37.50	0.552	$725
	3.5" Concrete	1932	S.F.	C8	2613	$1.39	$0.87	$0.27	$2.53	0.739	$4,889
	Steel Deck / Cast-in-Place Flooring System Total									**2.637**	**$39,608**
Precast	W10X33	46.2	L.F.	E2	550	$48.00	$5.10	$2.78	$55.88	0.084	$2,582
	W10X49	18.5	L.F.	E2	550	$71.50	$5.10	$2.78	$79.38	0.034	$1,469
	W16X50	26.5	L.F.	E2	800	$73.00	$3.51	$1.91	$78.42	0.033	$2,078
	W16X67	25	L.F.	E2	760	$97.50	$3.70	$2.01	$103.21	0.033	$2,580
	8" Precast Hollow Core Plank	1932	S.F	C11	3200	$7.10	$1.13	$0.57	$8.80	0.604	$17,004
	6X6 W1.4XW1.4 Wire Mesh	19.32	C.S.F	2 Rodm	35	$14.50	$23.00	$0.00	$37.50	0.552	$725
	3" Topcoat Concrete	1932	S.F.	C8	2613	$1.39	$0.87	$0.27	$2.53	0.739	$4,889
	Precast Flooring System Total									**2.079**	**$31,326**

Table 3: Cost and duration estimate for first floor (second floor values are the same).

From the estimate, the total cost for the cast-in-place solution is $79, 216. The precast system requires $62,652 to complete. If the precast system is able to be installed as designed and requires no alterations or re-orders, it will cost $16,564 less than the cast-in-place concrete.

The total duration for the cast-in-place flooring system is approximately 5.25 days. This configuration will also require an additional 7-10 days of cure time. The precast solution will take approximately 4.25 days to install and require the same 7-10 days for the topcoat to cure. Comparing these values shows a one day time savings by installing the precast. This, like the cost comparison, is only valid if the precast is able to be installed as designed.

Structural Breadth

Introduction

The decision was made to place the redesigned girders in the same locations as the original beams. This effort was made because the aging masonry walls of the existing structures provide few options for solid anchoring. The original beams are located in areas determined to be capable of carrying these loads. This beam placement creates four bays in which steel deck will be placed over steel joists.

With bay AB (Figure 15, Appendix A) having a width of 26', a spacing of 6'6" would call for 5 joists. Using information from the *Vulcraft Steel Roof and Floor Deck* catalog (Table 14, Appendix A), a total slab depth of 3.5" and deck type 1.5VL22 was chosen. This allows for an unshored clear span of 7'10" when installed in a 2 span configuration. It also allows for a live load of 206 lb/ft^2 when a clear span of 6'6" is used.

Calculations for Dead and Live Loads

The dead load consists of the weight of concrete, steel deck and a miscellaneous category. Miscellaneous includes an assumed value for lighting, conduit, pipes, ductwork and other items that may be attached to the floor system.

The dead load for the girders also includes a value for the attached joists. These values were calculated by multiplying the joists' weight per foot and half their lengths. These figures were totaled for each girder and divided by the tributary area for that girder. This resulted in a uniformly distributed load approximate to the actual effect of the joists on the girder.

The live load was provided by ASCE's *Minimum Design Loads for Buildings and Other Structures*. Table 16, Appendix A is the applicable excerpt of this manual. The value for first-floor school corridor was used for the design load. A portion of the connector will be corridor space. The remaining areas will be offices, classrooms and restrooms. While these areas have a lower minimum design load, the higher value for corridors was used. This will result in somewhat over-sized beams, but will act as a safety factor for a structure that's design may still evolve.

$\boldsymbol{Concrete = 33\ {}^{lb}/_{ft^2}}$ (Table 14, Appendix A)

$\boldsymbol{Steel\ Deck = 1.78\ {}^{lb}/_{ft^2}}$ (Table 14, Appendix A)

$\boldsymbol{Misc. = 10\ {}^{lb}/_{ft^2}}$

$$\boldsymbol{Dead\ Load_{Joist} = Concrete + Deck + Misc = 33 + 1.78 + 10 = 44.8 \approx 45\ {}^{lb}/_{ft^2}}$$

$$\boldsymbol{Dead\ Load_{Girder} = Concrete + Deck + Misc. + Joist \approx 45\ {}^{lb}/_{ft^2} + Joist}$$

(load from joists, available in Table 18, Appendix A)

$\boldsymbol{Live\ Load = 100\ {}^{lb}/_{ft^2}}$

Calculations for Joist AB1

The first step in sizing the beam is to calculate the uniformly distributed load.

$$W_{dead} = Dead\ Load_{Joist} \times Tributary\ Width = 45 \times 3.25 = 146.25\ {}^{lb}/_{ft}$$

$$W_{live} = Live\ Load \times Tributary\ Width = 100 \times 3.25 = 325\ {}^{lb}/_{ft}$$

Once the load is determined, the shear values can be computed.

$$V_{dead} = \frac{W_{dead}L_{beam}}{2(1000\ {}^{lb}/_{k})} = \frac{(146.25)(17)}{2(1000\ {}^{lb}/_{k})} = 1.24\ kips$$

$$V_{live} = \frac{W_{live}L_{beam}}{2(1000\ {}^{lb}/_{k})} = \frac{(325)(17)}{2(1000\ {}^{lb}/_{k})} = 2.76\ kips$$

$$V_u = 1.2V_{dead} + 1.6V_{live} = 1.2(1.24) + 1.6(2.76) = 5.91k \cdot ft$$

Since the loading of the beams is uniformly distributed, the following equations may be used to find the moments.

$$M_{dead} = \frac{W_{dead}{L_{beam}}^2}{8(1000\ {}^{lb}/_{k})} = \frac{(146.25\ {}^{lb}/_{ft})(17ft)^2}{8(1000\ {}^{lb}/_{k})} = 5.28\ k \cdot ft$$

$$M_{live} = \frac{W_{dead}{L_{beam}}^2}{8(1000\ {}^{lb}/_{k})} = \frac{(325\ {}^{lb}/_{ft})(17ft)^2}{8(1000\ {}^{lb}/_{k})} = 11.74\ k \cdot ft$$

$$M_u = 1.2M_{dead} + 1.6M_{live} = 1.2(5.28) + 1.6(11.74) = 25.12k \cdot ft$$

Finally, the deflection and moment of inertia can be calculated.

$$\Delta_{allow} = \frac{L_{beam}(12\ {}^{in}/_{ft})}{360} = \frac{17(12)}{360} = 0.57in.$$

$$I = \frac{5W_{live}{L_{beam}}^4(12\ {}^{in}/_{ft})^4}{384(29,000,000)(\Delta_{allow})(12\ {}^{in}/_{ft})} = \frac{5(325)(17)^4(12)^4}{384(29,000,000)(0.57)(12)} = 37.17in^4$$

Table 18, Appendix A contains the calculated values for all the beams in the “Connector”. The values were found using the process and equations presented above. A majority of the beams were sized using their maximum moment. Several of the longer beams were controlled by their corresponding moment of inertia. These beams are designated on the spreadsheet. The beam layout and sizes are shown on Figure 15, Appendix A. Enlarged versions of the layout are presented as Figures 16 and 17, Appendix A.

Flooring System Conclusion

Due to the inconsistent nature of the measurements for the “Connector” section of the building, significant potential exists for installation issues with the precast. Because the precast cannot be altered in the field to fit a space lacking the necessary clearance, a new piece of decking would have to be ordered. The lead time for this would significantly delay the pouring of the concrete topping and all other work dependent on a finished floor. Also, access to this portion of the building is limited. Moving the planks to their installation locations will prove challenging.

The use of the proposed cast-in-place system would essentially alleviate any problems created by the uneven wall surfaces and limited access. The decking and pour stop can be readily adjusted on site to fit the space and is easily transported through the building for final placement. This flexibility also allows for the possible adjustment of the supporting steel members if any of the anchor points are found to be incapable of carrying the required loads, a situation the precast cannot be adapted for.

The inability to modify the precast planks also provides difficulty in accommodating room reconfiguration and changes in the MEP systems. The project has undergone several design iterations causing a need to relocate services. The cast-in-place alternative can easily be adjusted to provide for additional or relocated penetrations and chases. These changes can even occur after the concrete is poured. This is not the case with the precast system. The MEP systems need to be adapted for the floor system instead of the floor system being able to conform to the needs of the MEP system.

The steel deck/cast-in-place solution carries a 26% cost increase and adds one day to the installation time. The $16,564 change in cost would account for 0.18% of the construction cost. Both of these increases are only present if no alterations to the precast planks are required; as a reorder of any portion of the precast system would cause delays and costs that would exceed these differences. Additionally, the convenience of the cast-in-place system’s flexibility makes it a viable alternative.

Analysis 3: Use of PEX Tubing for Domestic Plumbing

Problem Identification

The cost of copper pipe and its installation is high compared to other plumbing materials. Additionally, the urban setting of this and many school building projects provides challenges in securing equipment and materials. One of the most sought after materials is copper piping which is often stolen from storage and from installations. This issue potentially causes delays in construction and an increase in costs.

Research Goal

The goal of this analysis is to identify the benefits and deficits of using cross-linked polyethylene (PEX) tubing in lieu of the prescribed copper pipe. Replacing the copper pipe used for the domestic supply plumbing with PEX tubing should reduce material and labor costs and decrease schedule duration allotted for installation.

The switch to PEX will also alleviate the constant risk of theft associated with copper pipe. PEX is not readily sought after for resale or recycling as copper is. Additionally, advantages such as energy efficiency, flameless installation, and corrosion resistance further serve to illustrate the need to consider this alternative.

Methodology

- Identify the benefits and deficits of PEX compared with copper piping.
- Perform cost and labor estimates of plumbing system utilizing copper pipe.
- Design PEX plumbing system. Perform cost and labor estimates of new system.
- Compare material and labor costs of the two systems as well as schedule differences.

Original Solution

The domestic plumbing system has been designed using type L copper pipe. The sizes for cold water range from 3" to ½". The hot water ranges in size from 2" to ½". The hot water return is comprised of 1" and ¾" pipe. The supply lines for the fixtures are 1" for the water closets, ¾" for the urinals and ½" for the lavatories, drinking fountains, shower and floor sinks. The system will be installed using soldered joints.

Water service enters the building in the northwest corner of the structure. The plumbing lines travel through the ceiling space on the ground and first floors. Fixtures on these floors are fed by drops, while fixtures on the second floor are fed by floor penetrations. After feeding the gang bathrooms on the ground floor, the cold, hot and hot water return lines penetrate the first floor in a chase located toward the southwest corner of the building. The facility will have 19 water closets, 6 urinals, 30 lavatories, 3 floor sinks, 3 drinking fountains and 1 shower.

PEX Solution

The proposed alternate plumbing system is one utilizing PEX tubing for all domestic piping sized 2" and smaller. The system will use both straight length and coiled tubing. Pipes sized 1¼", 1½" and 2" will be 20' lengths of straight tubing. Smaller pipes, ½", ¾" and 1", will be coiled tubing.

The system will be installed in the same trunk and branch layout as the copper pipe. PEX fittings will be used for the larger pipes. The ½", ¾" and 1" branches will be installed without the use of 90° elbows. This alternate system was designed using Uponor® AquaPEX tubing and Uponor® ProPEX fittings. The ProPEX fittings were chosen because they possess a larger inside diameter than standard PEX fittings. During the connection process, the PEX tubing is stretched to accommodate the larger ends of the fittings.


Figure 14: ProPEX tee fitting (foreground) and standard PEX insert fitting. (Uponor®)

Cost & Schedule

Estimates of cost and labor were performed and compared. Type L copper pipe and fixture material costs were obtained from Venango Supply, a plumbing supply company located in Seneca, PA. The prices were comparable to those available online from manufacturers. The Uponor brand PEX material prices were acquired from the Uponor website (Table 19, Appendix B).

Pipe Estimates (Material)

Pipe	Pipe Length (ft)			PEX		Copper	
Size (in)	Hot	Cold	All	Cost/ft	Cost	Cost/ft	Cost
2	115	126	241	$10.82	$2,606.66	$12.03	$2,899.23
1½	156	104	260	$5.36	$1,394.64	$7.87	$2,046.20
1¼	228	29	257	$4.56	$1,170.76	$5.08	$1,305.56
1	122	282	404	$2.18	$881.33	$3.57	$1,442.28
¾	479	102	581	$1.21	$703.88	$2.33	$1,353.73
½	361	415	776	$0.71	$548.24	$1.45	$1,125.20
Totals	**1461**	**1058**	**2519**		**$7,305.51**		**$10,172.20**

Table 4: Comparison of PEX tubing and copper pipe material prices.

The price of ProPEX fittings is considerably higher than that of the corresponding copper fitting. However, the ability to install the ½”, ¾” and 1” PEX tubing without the need for elbows to change direction eliminates 428 fittings. Pricing for PEX fittings is available in Tables 20 and 21, Appendix B.

90° Elbow Fitting Estimate (Material)

Pipe Size (in)	Qty	PEX		Copper	
		Cost/Unit	Cost	Cost/Unit	Cost
2	14	$68.70	$961.80	$17.96	$251.44
1½	10	$16.65	$166.50	$9.86	$98.60
1¼	13	$12.50	$162.50	$5.75	$74.75
1	52	$5.05		$3.86	$200.72
¾	100	$2.45		$1.57	$157.00
½	276	$1.95		$0.70	$193.20
Totals			**$1,290.80**		**$975.71**

Table 5: Comparison of PEX and copper 90 degree elbows material prices.

Tee Fitting Estimate (Material)

Pipe Size (in)	Qty	PEX		Copper	
		Cost/Unit	Cost	Cost/Unit	Cost
2	7	$84.60	$592.20	$31.74	$222.18
1½	7	$19.90	$139.30	$20.36	$142.52
1¼	13	$14.25	$185.25	$12.07	$156.91
1	11	$5.70	$62.70	$8.92	$98.12
¾	13	$3.15	$40.95	$2.87	$37.31
½	6	$1.95	$11.70	$1.19	$7.14
Totals			**$1,032.10**		**$664.18**

Table 6: Comparison of PEX and copper Tee fixture material prices.

The material and labor costs are combined for the pipe insulation. Published information was not readily available. A combined price of $5.00 per foot was quoted by both Dalton Deeter, Roy C. Deeter Plumbing and Heating, Cochranton, PA and Gregory Costa, McKamish, Inc., Pittsburgh, PA. This price was the same for both PEX and copper pipe systems. However, because of the increased R-Value of PEX, insulation is not required on cold water lines to prevent condensation.

Pipe Insulation (Material + Labor)

Type	L (ft)	PEX		Copper	
		Cost/ft	Cost	Cost/ft	Cost
Hot	1461	$5.00	$7,305.00	$5.00	$7,305.00
Cold	1058	$0.00	$0.00	$5.00	$5,290.00
Totals			**$7,305.00**		**$12,595.00**

Table 7: Comparison of pipe insulation material and labor costs.

Labor rates for the installation of PEX tubing and copper pipe were obtained from the Mechanical Contractors Association of America's (MCAA) *Web-Based Labor Estimating Manual (WebLEM).* (Tables 22 and 23, Appendix B)

Pipe Estimates (Labor)

Pipe Size (in)	Pipe Length (ft)			PEX		Copper	
	Hot	Cold	All	Hours/ft	Hours	Hours/ft	Hours
2	115	126	241	0.05	12.05	0.09	21.69
1½	156	104	260	0.05	13.00	0.08	20.80
1¼	228	29	257	0.05	12.85	0.08	20.56
1	122	282	404	0.05	20.20	0.07	28.28
¾	479	102	581	0.05	29.05	0.06	34.86
½	361	415	776	0.05	38.80	0.06	46.56
Totals	**1461**	**1058**	**2519**		**125.95**		**172.75**
Cost *(based of Federal prevailing wage rates of $54.14/hr.)*					***$6,818.93***		***$9,352.69***

Table 8: Comparison of PEX tubing and copper pipe labor prices.

The labor information for PEX and copper fittings was also acquired from MCAA's *WebLEM*. (Tables 24 and 25, Appendix B)

90° Elbow Fitting Estimate (Labor)

Pipe Size (in)	Qty	PEX		Copper	
		Hrs./Unit	Hours	Hrs./Unit	Hours
2	14	0.25	3.50	0.85	11.90
1½	10	0.20	2.00	0.74	7.40
1¼	13	0.17	2.21	0.70	9.10
1	52		0.00	0.63	32.76
¾	100		0.00	0.53	53.00
½	276		0.00	0.40	110.40
Totals			**7.71**		**224.56**
Cost *($54.14/hr.)*			***$417.50***		***$12,157.68***

Table 9: Comparison of PEX and copper 90 degree elbow labor prices.

Tee Fitting Estimate (Labor)

Pipe Size (in)	Qty	PEX		Copper	
		Hrs./Unit	Hour	Hrs./Unit	Hour
2	7	0.35	2.45	1.26	8.82
1½	7	0.27	1.89	1.09	7.63
1¼	13	0.23	2.99	1.03	13.39
1	11	0.19	2.09	0.92	10.12
¾	13	0.15	1.95	0.77	10.01
½	6	0.12	0.72	0.57	3.42
Totals			**12.09**		**53.39**
Cost *($54.14/hr.)*			***$654.55***		***$2,890.53***

Table 10: Comparison of PEX and copper Tee fittings labor prices.

Total Costs

Category	PEX			Copper		
	Materials	Labor	Mat.+Labor	Materials	Labor	Mat.+Labor
Pipe	$7,305.51	$6,818.93	$14,124.44	$10,172.20	$9,352.69	$19,524.89
90°	$1,290.80	$417.50	$1,708.30	$975.71	$12,157.68	$13,133.39
Tee	$1,032.10	$654.55	$15,832.74	$664.18	$2,890.53	$32,658.28
Insulation	$7,305.00		$7,305.00	$12,595.00		$12,595.00
Totals			**$38,970.48**			**$77,911.56**

Table 11: Comparison of total costs of installation for PEX and copper systems.

The comparison of the total costs for the PEX and copper systems shows a cost savings of $38,941.08 for the PEX alternative. This is a savings of 50%. In addition to a lower total cost, the PEX system also saves 305 man-hours of installation time.

Advantages and Disadvantages

The previous section highlighted two of the more advantageous benefits of PEX systems. A 50% monetary savings and 67% savings in installation time will benefit any project. These, however are not the only advantages to PEX.

Another benefit to this system is the alleviation of open flames in plumbing installations. The soldering of copper joints requires the use of a propane torch. The ProPEX fixtures are pressure fit and only require an expander tool to prepare the tubing to receive the fitting. This type of joint also mitigates the opportunity of “dry fit” joints, an issue created when a copper joint is fit together but mistakenly not soldered together.

Due to the fewer number of fittings required, PEX systems are less likely to leak. Fittings are a likely point of failure in any plumbing system, therefore, fewer fittings equates to fewer opportunities for leaks. Instances of leaks are also lessened by PEX’s ability to expand, resulting in less chance of rupture from freezing than with rigid copper pipe.

Additionally, the material itself has multiple advantages. Polyethylene is resistant to corrosion and is not affected by acidic water, resulting in no buildup of scale and other flow reducing debris and no metallic taste to the water. The material also is less likely than copper pipe to transmit sounds associated with the flow of water.

The PEX product is not without deficits, however. Installing PEX fittings requires equipment that contractors need to rent or purchase. This equipment carries with it a learning curve. Employees will need to be trained and productivity will not be maximized until they are comfortable with the new process.

PEX has been in production for more than 30 years and has proved durable for at least that length of time. Copper, however, has a longer history and in some installations is found to be more than 100 years old. There is no way of knowing if PEX will share that longevity.

The copper material carries with it several benefits that PEX does not. Copper pipe is bacteriostatic, which means it is resistant to the growth of bacteria. Copper pipe will not burn in the case of a fire and it is UV resistant, allowing it to be used in exterior situations. PEX does not share any of those characteristics.

Plumbing Breadth

Introduction

To compare the Type L copper pipe system to the alternate PEX/ProPEX system, the friction loss was calculated for each. The fixture most distant from the domestic water supply was chosen. This fixture was a lavatory on the first floor and was located at the end of the hot water supply loop. Each system contained ½", ¾", 1", 1¼", 1½" and 2" pipe as well as 90 degree elbows and Tees (Figure 18, Appendix B).

A design velocity of 4ft/s was chosen for use throughout the system. This velocity was chosen in order to reduce the likelihood of noise caused by flowing water.

Calculations for 2" Type L Copper Pipe

The initial step in finding the friction loss of the 2" copper pipe is to convert the design velocity (ft/s) into the equivalent flow (gal/min).

$$velocity\left({}^{ft}/_{s}\right) \times area(ft^2) \times 7.48\,{}^{gal}\big/_{ft^3} \times 60\,{}^{s}/_{min} = flow({}^{gal}/_{min})$$

Area = cross sectional area of bore (Table 26, Appendix B), converted to ft²

$$4\,{}^{ft}/_{s} \times 3.09in^2 \times \frac{1ft^2}{144in^2} \times 7.48\,{}^{gal}\big/_{ft^3} \times 60\,{}^{s}/_{min} = 38.53\,{}^{gal}/_{min}$$

Once the flow is found, the friction loss can be calculated using the *Hazen-Williams formula*.

$$P = \frac{4.52 \times Q^{1.85}}{C^{1.85} \times d^{4.87}} \quad \textit{(Hazen-Williams formula)}$$

P = friction loss (psi/ft)

Q = flow (gal/min)

d = average inside diameter (in) (Table 26, Appendix B)

C = Hazen-Williams Coefficient (typical design value for copper = 130) (Table 27, Appendix B)

$$P = \frac{4.52 \times 38.53^{1.85}}{130^{1.85} \times 1.985^{4.87}} = 0.0169 \, {}^{psi}/_{ft}$$

The final step is to determine the length of 2" pipe and the equivalent lengths for the fittings (Table 28, Appendix B). The total equivalent length is then multiplied by the friction loss to find the total friction loss for that section of the system (Table 12).

Pipe Size (in)	Velocity (ft/s)	Flow (gal/min)	Friction Loss (psi/ft)	System Components	Equivalent Length of Component	Number of Components	Total Equivalent Length (ft)	Total Friction Loss (psi)
2				Straight Pipe	89.00	1	89.00	
				90° Elbow	5.50	5	27.50	
				Tee	0.50	1	0.50	
	4.00	38.53	0.0169				117.00	1.9769

Table 12: Portion of Table 33, Appendix B for 2" copper pipe.

The same process was completed for ½", ¾", 1", 1¼" and 1½" Type L copper pipe using a spreadsheet (Table 33, Appendix B). This spreadsheet also calculated the total friction loss for the most distant fixture.

A spreadsheet was also used to calculate the total friction loss for the same fixture using PEX tubing and ProPEX fittings (Table 34, Appendix B). Tables 29-32, Appendix B were used to find the friction loss and equivalent lengths for the tubing and fittings respectively.

The total friction loss calculated for each material did not include head loss due to elevation change, as the intent was to compare the effects of one material to the other and the elevation change is the same for both. Additionally, the friction loss for elements of the system located before the occurrence of 2" pipe were not considered, as again, the intent was to compare the copper and PEX systems and no PEX was used for pipe sizes larger than 2".

The total friction loss for the copper pipe system was 23.24 psi. The total friction loss for the PEX system was 24.45 psi. This equates to an increase of 1.21 psi when using PEX instead of Type L copper pipe.

PEX Tubing Conclusion

For years, PEX tubing has been replacing copper pipe in residential construction. However, it has not been as widely in the commercial market. The benefits that endear PEX to residential installers are the lower material costs and shorter installation times. Additionally, since PEX requires fewer fittings, there are not as many opportunities for system failures. These qualities should be just as advantageous to commercial construction.

For this elementary school, the plumbing system was designed using Type L copper pipe. An alternate PEX system was proposed in order to compare the two. The PEX system used the same sized pipe as the copper system, with the largest available size being 2". Everything larger than 2" remained copper. The alternate system also followed the same trunk and branch design as the copper. The only main difference came in the elimination of 90 degree fittings for the ½", 3/4" and 1" PEX tubing. These sized pipes do not require fittings for direction changes.

After estimating the labor and material costs for the two systems, it was apparent that there was a definite advantage to the alternate system. The material required for the PEX system took 305 fewer hours to install than the copper system. It also saved $38,941. Those are 67% and 50% reductions, respectively.

The remaining concern was whether the smaller inside diameter of the PEX and its fittings cause an appreciable reduction in water pressure when compared to the copper pipe and fittings. To calculate the friction loss of the two systems, the furthest most fixture was chosen. Over the course of more than 650 feet of pipe, the PEX had a greater friction loss by 1.2108 psi.

Considering the impressive cost savings and the minimal decrease in pressure, the PEX system appears to be a viable alternative for this elementary school construction project.

Conclusion

The elementary school construction project chosen for the basis of this thesis combines the renovation of a 140 year old, 28,000 ft^2 building with the addition of 18,000 ft^2 of modern facilities. The analyses completed as part of this assignment are studies of alternate services or systems that provide some advantages. They are not meant to be a critique of the current design or process. Thank you to everyone who had a hand in the completion of this report.

Analysis 1: Use of Multivista® Construction Documentation

A relatively new service, third-party photo documentation provides the project owner with reliable and detailed images of the project. Offering milestone photo shoots and progression photos, the web-based software included with the service allows for simple access to the product from multiple locations. Once the project is completed, the pictures serve as an exact representation of building and its systems that maintenance and facility workers can use to increase their productivity. The reasonable pricing structure makes this service something that should be considered for every construction project.

Analysis 2: Use of Steel Deck and Cast-in-Place Concrete

The precast concrete plank flooring system designed for this building had the potential to delay the schedule and did not provide for the most accommodating solution to the "Connector" portion of the building. A steel deck/cast-in-place concrete solution provides for an easier installation as it is not as constrained by limited access, can be adjusted onsite to fit difficult areas and prepared in the field to accommodate last minute changes and MEP installations. This alternate solution increases the schedule by just one day and the total construction cost by less than 0.2%; both reasonable expenses when weighed against the benefits.

Analysis 3: Use of PEX tubing for Domestic Water

The domestic water system for this school was designed using copper with soldered joints. While copper is the industry standard, a PEX system delivers cost and schedule reductions without major deficit. Using the same sized pipe and "trunk and branch" installation, the PEX system reduces costs by 50%, labor by 67% and contributes the other benefits associated with PEX. With only a minimal reduction in water pressure, this alternative to the copper system will benefit the project in many ways.

Appendix A:

Use of Steel Deck and Cast-In-Place Concrete

Crews

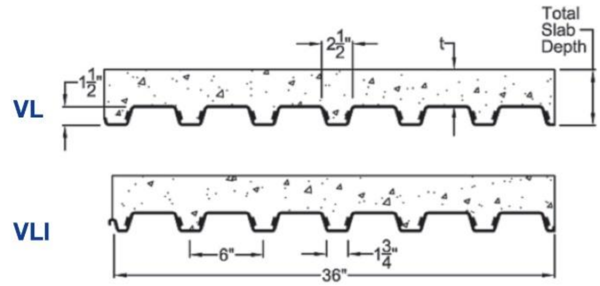
Crew No.	Bare Costs		Incl. Subs O&P		Cost Per Labor-Hour	
Crew C-8	**Hr.**	**Daily**	**Hr.**	**Daily**	**Bare Costs**	**Incl. O&P**
1 Labor Foreman (outside)	$38.65	$309.20	$59.65	$477.20	$40.80	$61.95
3 Laborers	36.65	879.60	56.55	1357.20		
2 Cement Finishers	44.05	704.80	65.10	1041.60		
1 Equip. Oper. (medium)	48.90	391.20	74.15	593.20		
1 Concrete Pump (Small)		710.40		781.44	12.69	13.95
56 L.H., Daily Totals		$2995.20		$4250.64	$53.49	$75.90
Crew C-11	**Hr.**	**Daily**	**Hr.**	**Daily**	**Bare Costs**	**Incl. O&P**
1 Struc. Steel Foreman (outside)	$53.10	$424.80	$93.70	$749.60	$50.39	$86.34
6 Struc. Steel Workers	51.10	2452.80	90.20	4329.60		
1 Equip. Oper. (crane)	50.25	402.00	76.20	609.60		
1 Equip. Oper. (oiler)	43.55	348.40	66.00	528.00		
1 Lattice Boom Crane, 150 Ton		1838.00		2021.80	25.53	28.08
72 L.H., Daily Totals		$5466.00		$8238.60	$75.92	$114.43
Crew E-2	**Hr.**	**Daily**	**Hr.**	**Daily**	**Bare Costs**	**Incl. O&P**
1 Struc. Steel Foreman (outside)	$53.10	$424.80	$93.70	$749.60	$50.19	$85.24
4 Struc. Steel Workers	51.10	1635.20	90.20	2886.40		
1 Equip. Oper. (crane)	50.25	402.00	76.20	609.60		
1 Equip. Oper. (oiler)	43.55	348.40	66.00	528.00		
1 Lattice Boom Crane, 90 Ton		1529.00		1681.90	27.30	30.03
56 L.H., Daily Totals		$4339.40		$6455.50	$77.49	$115.28
Crew E-4	**Hr.**	**Daily**	**Hr.**	**Daily**	**Bare Costs**	**Incl. O&P**
1 Struc. Steel Foreman (outside)	$53.10	$424.80	$93.70	$749.60	$51.60	$91.08
3 Struc. Steel Workers	51.10	1226.40	90.20	2164.80		
1 Welder, Gas Engine, 300 amp		142.00		156.20	4.44	4.88
32 L.H., Daily Totals		$1793.20		$3070.60	$56.04	$95.96

Table 13: Description of crews as defined by R.S. Means.

VULCRAFT

1.5 VL, VLI

Maximum Sheet Length 42'-0
Extra Charge for Lengths Under 6'-0
ICBO Approved (N0. 3415)



Interlocking side lap is not drawn to show actual detail.

STEEL SECTION PROPERTIES

Deck Type	Design Thickness in.	Deck Weight psf	Section Properties I_p in⁴/ft	S_p in³/ft	I_n in⁴/ft	S_n in³/ft	V_a lbs/ft	F_y ksi
1.5VL22	0.0295	1.78	0.143	0.169	0.177	0.179	2754	50
1.5VL20	0.0358	2.14	0.186	0.224	0.222	0.231	3322	50
1.5VL19	0.0418	2.49	0.230	0.271	0.260	0.282	3857	50
1.5VL18	0.0474	2.82	0.272	0.311	0.295	0.324	4350	50
1.5VL16	0.0598	3.54	0.373	0.404	0.373	0.411	4336	40

(N=9.35) NORMAL WEIGHT CONCRETE (145 PCF)

COMPOSITE

TOTAL SLAB DEPTH	DECK TYPE	SDI Max. Unshored Clear Span 1 SPAN	2 SPAN	3 SPAN	Superimposed Live Load, PSF Clear Span (ft.-in.) 5'-0	5'-6	6'-0	6'-6	7'-0	7'-6	8'-0	8'-6	9'-0	9'-6	10'-0	10'-6	11'-0	11'-6	12'-0
	1.5VL22	5'-10	7'-10	7'-10	314	279	230	206	186	169	154	141	130	120	111	100	87	76	67
3.50	1.5VL20	7'-0	9'-4	9'-6	345	306	275	249	227	187	171	157	144	133	124	108	94	82	73
(t=2.00)	1.5VL19	7'-11	10'-3	10'-8	372	330	296	268	244	224	186	171	157	145	134	116	101	88	78
33 PSF	1.5VL18	8'-8	11'-0	11'-2	395	351	315	285	260	238	220	204	168	156	142	123	107	94	82
	1.5VL16	8'-10	11'-0	11'-4	397	353	316	286	261	239	221	205	169	156	145	135	119	105	92
	1.5VL22	5'-6	7'-5	7'-5	366	325	267	239	216	196	179	164	151	139	129	119	111	103	96
4.00	1.5VL20	6'-7	8'-10	8'-11	400	356	319	289	239	217	198	182	167	155	143	133	124	115	108
(t=2.50)	1.5VL19	7'-5	9'-9	10'-1	400	383	344	311	283	235	215	197	182	168	156	145	135	126	115
39 PSF	1.5VL18	8'-1	10'-5	10'-7	400	400	365	330	301	276	254	211	194	180	167	156	145	136	122
	1.5VL16	8'-3	10'-5	10'-9	400	400	365	330	301	276	255	211	194	180	167	155	145	136	127
	1.5VL22	5'-3	7'-1	7'-1	400	345	307	275	248	225	205	188	173	159	147	136	127	118	109
4.50	1.5VL20	6'-3	8'-5	8'-6	400	400	366	303	274	249	227	208	192	177	164	152	142	132	123
(t=3.00)	1.5VL19	7'-1	9'-3	9'-7	400	400	393	356	325	269	246	226	208	192	179	166	155	144	135
45 PSF	1.5VL18	7'-8	9'-11	10'-1	400	400	400	378	344	316	262	241	222	206	191	178	166	155	145
	1.5VL16	7'-10	9'-11	10'-3	400	400	400	377	344	315	262	240	222	205	190	177	165	155	145
	1.5VL22	5'-0	6'-9	6'-9	400	391	347	311	280	254	232	213	195	180	167	154	143	133	124
5.00	1.5VL20	6'-0	8'-1	8'-2	400	400	400	343	310	281	257	236	217	200	186	172	160	149	139
(t=3.50)	1.5VL19	6'-9	8'-11	9'-2	400	400	400	400	335	304	278	255	235	218	202	188	175	163	153
51 PSF	1.5VL18	7'-3	9'-6	9'-8	400	400	400	400	389	324	297	272	251	233	216	201	187	175	164
	1.5VL16	7'-5	9'-6	9'-10	400	400	400	400	388	323	295	271	250	232	215	200	187	175	164
	1.5VL22	4'-10	6'-6	6'-6	400	400	388	348	314	285	260	238	219	202	186	173	160	149	138
5.50	1.5VL20	5'-9	7'-9	7'-10	400	400	400	383	346	314	287	263	243	224	208	193	179	167	156
(t=4.00)	1.5VL19	6'-5	8'-6	8'-9	400	400	400	400	374	340	311	286	263	243	226	210	196	183	171
57 PSF	1.5VL18	7'-0	9'-1	9'-4	400	400	400	400	400	363	331	305	281	260	241	225	210	196	183
	1.5VL16	7'-1	9'-2	9'-5	400	400	400	400	400	361	330	303	279	259	240	224	209	195	183
	1.5VL22	4'-8	6'-4	6'-4	400	400	400	385	347	315	288	263	242	223	206	191	178	165	153
6.00	1.5VL20	5'-6	7'-5	7'-6	400	400	400	400	383	348	318	292	269	248	230	213	199	185	173
(t=4.50)	1.5VL19	6'-2	8'-2	8'-5	400	400	400	400	400	377	344	316	291	270	250	232	217	202	189
63 PSF	1.5VL18	6'-8	8'-9	9'-0	400	400	400	400	400	400	367	337	311	288	267	249	232	217	203
	1.5VL16	6'-10	8'-10	9'-1	400	400	400	400	400	399	365	335	309	286	266	248	231	216	202

Notes: 1. Minimum exterior bearing length required is 1.50 inches. Minimum interior bearing length required is 3.00 inches. If these minimum lengths are not provided, web crippling must be checked.
2. Always contact Vulcraft when using loads in excess of 200 psf. Such loads often result from concentrated, dynamic, or long term load cases for which reductions due to bond breakage, concrete creep, etc. should be evaluated.
3. All fire rated assemblies are subject to an upper live load limit of 250 psf.

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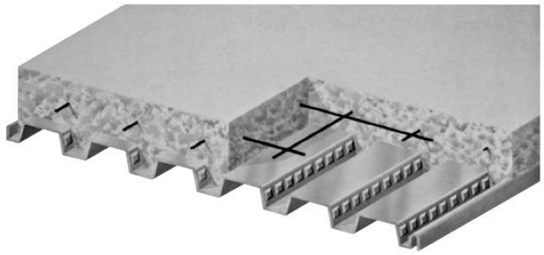
Table 14: Steel deck and concrete slab information from Vulcraft Steel Roof and Floor Deck catalog.

VULCRAFT



SLAB INFORMATION

Total Slab Depth, in.	Theo. Concrete Volume		Recommended Welded Wire Fabric
	$Yd^3 / 100\ ft^2$	ft^3 / ft^2	
3 1/2	0.78	0.211	6x6 - W1.4xW1.4
4	0.94	0.253	6x6 - W1.4xW1.4
4 1/2	1.09	0.294	6x6 - W1.4xW1.4
4 3/4	1.17	0.315	6x6 - W1.4xW1.4
5	1.24	0.336	6x6 - W2.1xW2.1
5 1/2	1.40	0.378	6x6 - W2.1xW2.1
5 3/4	1.48	0.398	6x6 - W2.1xW2.1
6	1.55	0.419	6x6 - W2.1xW2.1

(N=14.15) LIGHTWEIGHT CONCRETE (110 PCF)

TOTAL SLAB DEPTH	DECK TYPE	SDI Max. Unshored Clear Span			Superimposed Live Load, PSF Clear Span (ft.-in.)														
		1 SPAN	2 SPAN	3 SPAN	5'-0	5'-6	6'-0	6'-6	7'-0	7'-6	8'-0	8'-6	9'-0	9'-6	10'-0	10'-6	11'-0	11'-6	12'-0
3.50 (t=2.00) 26 PSF	1.5VL22	6'-4	8'-5	8'-6	278	247	222	185	167	152	139	124	105	89	76	66	57	50	44
	1.5VL20	7'-8	9'-7	9'-11	305	271	243	220	201	184	154	135	114	97	83	72	62	54	48
	1.5VL19	8'-8	10'-7	11'-0	329	292	262	237	216	198	173	145	122	104	89	77	67	58	51
	1.5VL18	9'-6	11'-4	11'-9	350	311	279	252	230	211	184	153	129	110	94	81	71	62	54
	1.5VL16	9'-8	11'-5	11'-10	352	312	280	253	231	212	195	171	144	122	105	91	79	69	61
4.00 (t=2.50) 30 PSF	1.5VL22	6'-0	8'-1	8'-1	324	288	258	215	194	177	161	148	136	126	113	98	85	75	66
	1.5VL20	7'-3	9'-7	9'-9	355	315	283	256	233	195	178	164	151	140	123	106	92	81	71
	1.5VL19	8'-2	10'-7	10'-11	382	339	304	275	251	230	212	178	164	152	131	113	99	86	76
	1.5VL18	8'-11	11'-4	11'-5	400	360	323	292	266	244	225	209	175	162	139	120	104	91	80
	1.5VL16	9'-1	11'-4	11'-8	400	360	323	292	266	244	225	209	195	162	151	134	116	102	90
4.50 (t=3.00) 35 PSF	1.5VL22	5'-9	7'-8	7'-8	372	330	275	246	223	202	185	170	156	145	134	125	116	106	93
	1.5VL20	6'-11	9'-2	9'-4	400	361	324	293	246	223	204	188	173	160	149	139	129	114	101
	1.5VL19	7'-9	10'-1	10'-5	400	388	348	315	287	264	221	203	188	174	162	151	140	122	107
	1.5VL18	8'-6	10'-10	11'-0	400	400	369	334	305	279	258	239	200	186	173	161	147	129	114
	1.5VL16	8'-7	10'-10	11'-2	400	400	369	334	304	279	257	239	199	185	172	160	150	140	126
4.75 (t=3.25) 37 PSF	1.5VL22	5'-7	7'-7	7'-7	396	352	293	263	237	216	197	181	167	154	143	133	124	115	108
	1.5VL20	6'-9	9'-0	9'-1	400	385	345	312	262	238	218	200	184	171	159	148	138	129	118
	1.5VL19	7'-7	9'-11	10'-3	400	400	371	336	306	281	235	216	200	185	172	160	150	140	126
	1.5VL18	8'-3	10'-7	10'-9	400	400	393	356	324	298	274	231	213	198	184	171	160	150	133
	1.5VL16	8'-5	10'-7	11'-0	400	400	392	355	324	297	274	230	212	197	183	171	159	149	140
5.00 (t=3.50) 39 PSF	1.5VL22	5'-6	7'-5	7'-5	400	374	311	279	252	229	209	192	177	164	152	141	131	123	115
	1.5VL20	6'-7	8'-10	8'-11	400	400	367	332	278	253	231	212	196	181	168	157	146	137	128
	1.5VL19	7'-5	9'-9	10'-1	400	400	394	356	325	273	250	230	212	197	183	170	159	149	140
	1.5VL18	8'-1	10'-5	10'-7	400	400	400	378	344	316	291	245	226	210	195	182	170	159	149
	1.5VL16	8'-3	10'-5	10'-9	400	400	400	377	343	315	291	244	225	209	194	181	169	159	149
5.75 (t=4.25) 46 PSF	1.5VL22	5'-2	7'-0	7'-0	400	400	367	329	297	270	247	227	209	193	179	166	155	145	135
	1.5VL20	6'-2	8'-4	8'-5	400	400	400	362	327	298	272	250	231	214	199	185	172	161	151
	1.5VL19	7'-0	9'-2	9'-6	400	400	400	400	383	322	295	271	250	232	215	201	187	175	165
	1.5VL18	7'-7	9'-10	10'-0	400	400	400	400	400	372	314	289	267	247	230	214	200	188	176
	1.5VL16	7'-9	9'-10	10'-2	400	400	400	400	400	371	312	287	265	246	229	213	199	187	175

Notes:
1. Minimum exterior bearing length required is 1.50 inches. Minimum interior bearing length required is 3.00 inches. If these minimum lengths are not provided, web crippling must be checked.
2. Always contact Vulcraft when using loads in excess of 200 psf. Such loads often result from concentrated, dynamic, or long term load cases for which reductions due to bond breakage, concrete creep, etc. should be evaluated.
3. All fire rated assemblies are subject to an upper live load limit of 250 psf.

COMPOSITE

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Table 15: Concrete slab information from Vulcraft Steel Roof and Floor Deck catalog.

TABLE 4-1 MINIMUM UNIFORMLY DISTRIBUTED LIVE LOADS, L_o, AND MINIMUM CONCENTRATED LIVE LOADS (continued)

Occupancy or Use	Uniform psf (kN/m²)	Conc. lb (kN)
Roofs		
Ordinary flat, pitched, and curved roofs	20 (0.96)[h]	
Roofs used for promenade purposes	60 (2.87)	
Roofs used for roof gardens or assembly purposes	100 (4.79)	
Roofs used for other special purposes	[i]	[i]
Awnings and canopies		
Fabric construction supported by a lightweight rigid skeleton structure	5 (0.24) nonreduceable	
All other construction	20 (0.96)	
Primary roof members, exposed to a work floor		
Single panel point of lower chord of roof trusses or any point along primary structural members supporting roofs over manufacturing, storage warehouses, and repair garages		2,000 (8.9)
All other occupancies		300 (1.33)
All roof surfaces subject to maintenance workers		300 (1.33)
Schools		
Classrooms	40 (1.92)	1,000 (4.45)
Corridors above first floor	80 (3.83)	1,000 (4.45)
First-floor corridors	100 (4.79)	1,000 (4.45)
Scuttles, skylight ribs, and accessible ceilings		200 (0.89)
Sidewalks, vehicular driveways, and yards subject to trucking	250 (11.97)[e]	8,000 (35.60)[f]
Stadiums and arenas		
Bleachers	100 (4.79)[d]	
Fixed seats (fastened to floor)	60 (2.87)[d]	
Stairs and exit ways	100 (4.79)	[g]
One- and two-family residences only	40 (1.92)	
Storage areas above ceilings	20 (0.96)	
Storage warehouses (shall be designed for heavier loads if required for anticipated storage)		
Light	125 (6.00)	
Heavy	250 (11.97)	
Stores		
Retail		
First floor	100 (4.79)	1,000 (4.45)
Upper floors	75 (3.59)	1,000 (4.45)
Wholesale, all floors	125 (6.00)	1,000 (4.45)
Vehicle barriers	See Section 4.4	
Walkways and elevated platforms (other than exit ways)	60 (2.87)	
Yards and terraces, pedestrian	100 (4.79)	

[a] Floors in garages or portions of a building used for the storage of motor vehicles shall be designed for the uniformly distributed live loads of Table 4-1 or the following concentrated load: (1) for garages restricted to passenger vehicles accommodating not more than nine passengers, 3,000 lb (13.35 kN) acting on an area of 4.5 in. by 4.5 in. (114 mm by 114 mm) footprint of a jack; and (2) for mechanical parking structures without slab or deck that are used for storing passenger car only, 2,250 lb (10 kN) per wheel.
[b] Garages accommodating trucks and buses shall be designed in accordance with an approved method, which contains provisions for truck and bus loadings.
[c] The loading applies to stack room floors that support nonmobile, double-faced library book stacks subject to the following limitations: (1) The nominal book stack unit height shall not exceed 90 in. (2290 mm); (2) the nominal shelf depth shall not exceed 12 in. (305 mm) for each face; and (3) parallel rows of double-faced book stacks shall be separated by aisles not less than 36 in. (914 mm) wide.
[d] In addition to the vertical live loads, the design shall include horizontal swaying forces applied to each row of the seats as follows: 24 lb per linear ft of seat applied in a direction parallel to each row of seats and 10 lb per linear ft of seat applied in a direction perpendicular to each row of seats. The parallel and perpendicular horizontal swaying forces need not be applied simultaneously.
[e] Other uniform loads in accordance with an approved method, which contains provisions for truck loadings, shall also be considered where appropriate.
[f] The concentrated wheel load shall be applied on an area of 4.5 in. by 4.5 in. (114 mm by 114 mm) footprint of a jack.
[g] Minimum concentrated load on stair treads (on area of 4 in.^{2} [2,580 mm^2]) is 300 lb (1.33 kN).
[h] Where uniform roof live loads are reduced to less than 20 lb/ft^2 (0.96 kN/m^2) in accordance with Section 4.9.1 and are applied to the design of structural members arranged so as to create continuity, the reduced roof live load shall be applied to adjacent spans or to alternate spans, whichever produces the greatest unfavorable effect.
[i] Roofs used for other special purposes shall be designed for appropriate loads as approved by the authority having jurisdiction.

TABLE 4-2 LIVE LOAD ELEMENT FACTOR, K_{LL}

Element	K_{LL}[a]
Interior columns	4
Exterior columns without cantilever slabs	4
Edge columns with cantilever slabs	3
Corner columns with cantilever slabs	2
Edge beams without cantilever slabs	2
Interior beams	2
All other members not identified including:	1
Edge beams with cantilever slabs	
Cantilever beams	
One-way slabs	
Two-way slabs	
Members without provisions for continuous shear transfer normal to their span	

[a] In lieu of the preceding values, K_{LL} is permitted to be calculated.

Minimum Design Loads for Buildings and Other Structures **13**

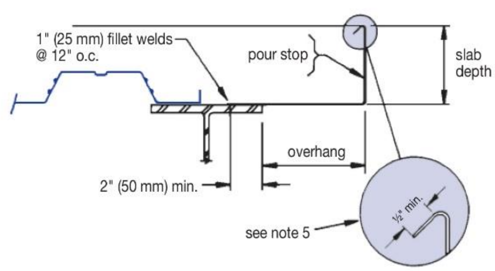
Table 16: Applicable portion of Table 4-1 of ASCE 7-10

ANSI/SDI-C-1.0 ATTACHMENT C2
SDI Pour Stop Selection Table

SLAB DEPTH (INCHES)	OVERHANG (INCHES) 0	1	2	3	4	5	6	7	8	9	10	11	12
	POUR STOP TYPES												
4.00	20	20	20	20	18	18	16	14	12	12	12	10	10
4.25	20	20	20	18	18	16	16	14	12	12	12	10	10
4.50	20	20	20	18	18	16	16	14	12	12	12	10	10
4.75	20	20	18	18	16	16	14	14	12	12	10	10	10
5.00	20	20	18	18	16	16	14	14	12	12	10	10	
5.25	20	18	18	16	16	14	14	12	12	12	10	10	
5.50	20	18	18	16	16	14	14	12	12	12	10	10	
5.75	20	18	16	16	14	14	12	12	12	12	10	10	
6.00	18	18	16	16	14	14	12	12	12	10	10	10	
6.25	18	18	16	14	14	12	12	12	12	10	10		
6.50	18	16	16	14	14	12	12	12	12	10	10		
6.75	18	16	14	14	14	12	12	12	10	10	10		
7.00	18	16	14	14	12	12	12	12	10	10	10		
7.25	16	16	14	14	12	12	12	10	10	10			
7.50	16	14	14	12	12	12	12	10	10	10			
7.75	16	14	14	12	12	12	10	10	10	10			
8.00	14	14	12	12	12	12	10	10	10				
8.25	14	14	12	12	12	10	10	10	10				
8.50	14	12	12	12	12	10	10	10					
8.75	14	12	12	12	12	10	10	10					
9.00	14	12	12	12	10	10	10						
9.25	12	12	12	12	10	10	10						
9.50	12	12	12	10	10	10							
9.75	12	12	12	10	10	10							
10.00	12	12	10	10	10	10							
10.25	12	12	10	10	10								
10.50	12	12	10	10	10								
10.75	12	10	10	10									
11.00	12	10	10	10									
11.25	12	10	10										
11.50	10	10	10										
11.75	10	10											
12.00	10	10											

TYPES	DESIGN THICKNESS
20	0.0358
18	0.0474
16	0.0598
14	0.0747
12	0.1046
10	0.1345

COMPOSITE



NOTES: This Selection Chart is based on following criteria:

1. Normal weight concrete (150 PCF).
2. Horizontal and vertical deflection is limited to ¼" maximum for concrete dead load.
3. Design stress is limited to 20 KSI for concrete dead load temporarily increased by one-third for the construction live load of 20 PSF.
4. Pour Stop Selection Chart does not consider the effect of the performance, deflection, or rotation of the pour stop support which may include both the supporting composite deck and/or the frame.
5. Vertical leg return lip is recommended for all types (gages).

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Table 17: Pour stop selection table.

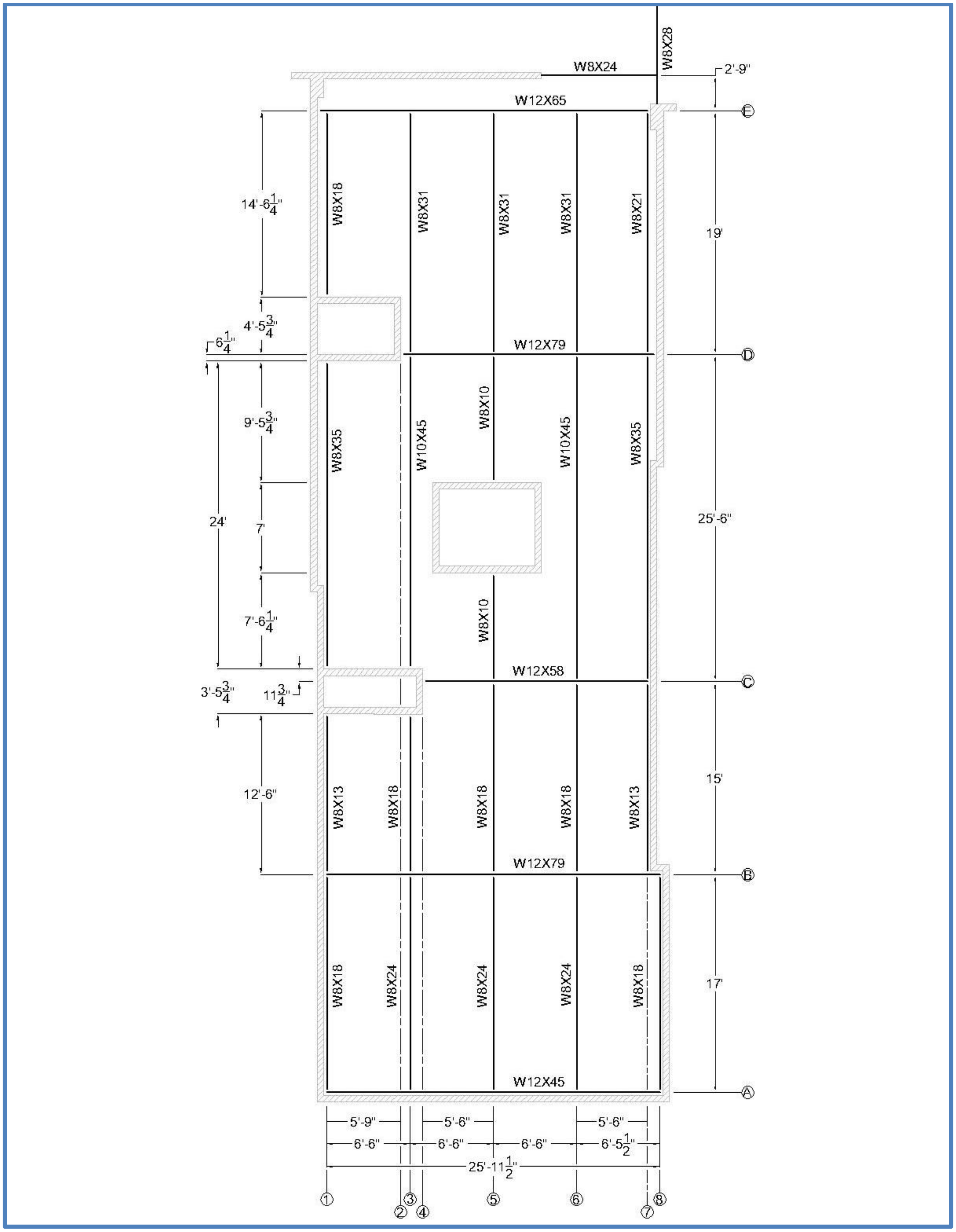

Figure 15: Drawing of beam locations and sizes.

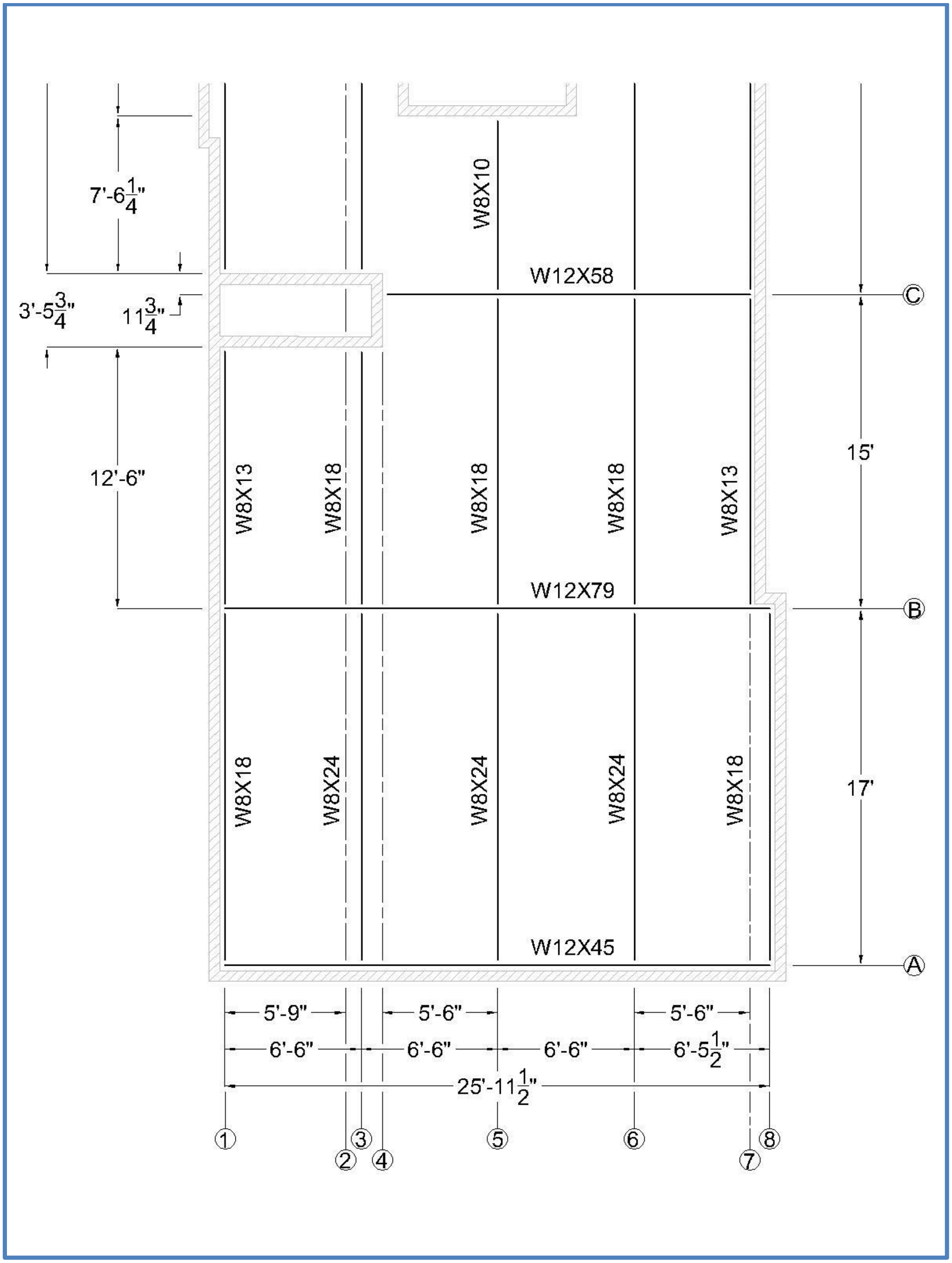

Figure 16: Enlarged portion of Figure 15.

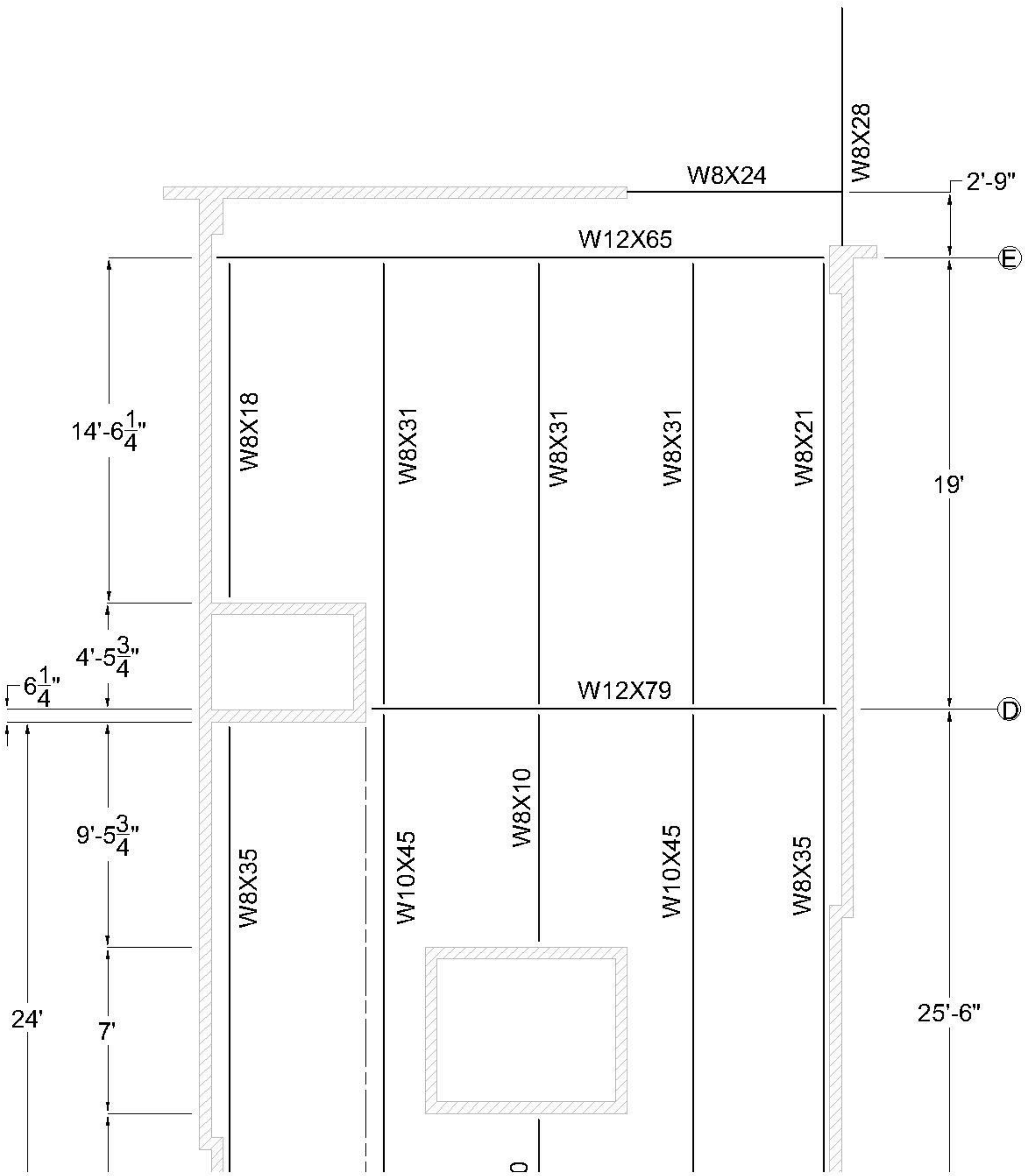

Figure 17: Enlarged portion of Figure 15.

Steel Beam Calculation Spreadsheet

	Beam	Tributary Width (ft)	Beam Length (ft)	Dead Load (psf)		Live Load (psf)	W_D (lb/ft)	W_L (lb/ft)	M_D (k·ft)	M_L (k·ft)	**M_U (k·ft)**	V_D (kips)	V_L (kips)	**V_U (kips)**	Δ_{allow} (in.)	**I ($in.^4$)**	Beam Shape	Beam Wt. (lb.)
				Deck	Joists													
Joists	AB 1	3.25	17.0	45.0		100.0	146.25	325.00	5.28	11.74	**25.12**	1.24	2.76	**5.91**	0.57	**37.17**	w8x 18	306.00
	AB 2	6.50	17.0	45.0		100.0	292.50	650.00	10.57	23.48	**50.25**	2.49	5.53	**11.82**	0.57	**74.33**	w8x 24	408.00
	AB 3	6.50	17.0	45.0		100.0	292.50	650.00	10.57	23.48	**50.25**	2.49	5.53	**11.82**	0.57	**74.33**	w8x 24	408.00
	AB 4	6.48	17.0	45.0		100.0	291.56	647.92	10.53	23.41	**50.09**	2.48	5.51	**11.79**	0.57	**74.09**	w8x 24	408.00
	AB 5	3.23	17.0	45.0		100.0	145.31	322.92	5.25	11.67	**24.96**	1.24	2.74	**5.87**	0.57	**36.93**	w8x 18	306.00
	BC 1	3.25	12.5	45.0		100.0	146.25	325.00	2.86	6.35	**13.58**	0.91	2.03	**4.35**	0.42	**14.77**	w8x 13	162.50
	BC 2	6.50	12.5	45.0		100.0	292.50	650.00	5.71	12.70	**27.17**	1.83	4.06	**8.69**	0.42	**29.55**	w8x 18	225.00
	BC 3	6.50	15.0	45.0		100.0	292.50	650.00	8.23	18.28	**39.12**	2.19	4.88	**10.43**	0.50	**51.06**	w8x 18	270.00
	BC 4	6.00	15.0	45.0		100.0	270.00	600.00	7.59	16.88	**36.11**	2.03	4.50	**9.63**	0.50	**47.13**	w8x 18	270.00
	BC 5	2.75	15.0	45.0		100.0	123.75	275.00	3.48	7.73	**16.55**	0.93	2.06	**4.41**	0.50	**21.60**	w8x 13	195.00
	CD 1	3.75	24.0	45.0		100.0	168.75	375.00	12.15	27.00	**57.78**	2.03	4.50	**9.63**	0.80	**120.66**	w8x 35	840.00
	CD 2	6.50	24.5	45.0		100.0	292.50	650.00	21.95	48.77	**104.37**	3.58	7.96	**17.04**	0.82	**222.49**	w10x 45	1102.50
	CD 3.1	6.50	7.5	45.0		100.0	292.50	650.00	2.06	4.57	**9.78**	1.10	2.44	**5.22**	0.25	**6.38**	w8x 10	75.00
	CD 3.2	6.50	9.6	45.0		100.0	292.50	650.00	3.37	7.49	**16.02**	1.40	3.12	**6.68**	0.32	**13.39**	w8x 10	96.00
	CD 4	6.00	25.5	45.0		100.0	270.00	600.00	21.95	48.77	**104.37**	3.44	7.65	**16.37**	0.85	**231.57**	w10x 45	1147.50
	CD 5	3.25	25.5	45.0		100.0	146.25	325.00	11.89	26.42	**56.53**	1.86	4.14	**8.87**	0.85	**125.43**	w8x 35	892.50
	DE 1	3.75	14.6	45.0		100.0	168.75	375.00	4.50	9.99	**21.38**	1.23	2.74	**5.86**	0.49	**27.16**	w8x 18	262.80
	DE 2	6.50	19.0	45.0		100.0	292.50	650.00	13.20	29.33	**62.77**	2.78	6.18	**13.21**	0.63	**103.77**	w8x 31	589.00
	DE 3	6.50	19.0	45.0		100.0	292.50	650.00	13.20	29.33	**62.77**	2.78	6.18	**13.21**	0.63	**103.77**	w8x 31	589.00
	DE 4	6.00	19.0	45.0		100.0	270.00	600.00	12.18	27.08	**57.94**	2.57	5.70	**12.20**	0.63	**95.79**	w8x 31	589.00
	DE 5	3.25	19.0	45.0		100.0	146.25	325.00	6.60	14.67	**31.38**	1.39	3.09	**6.61**	0.63	**51.89**	w8x 21	399.00
Girders	A 18	8.50	26.0	45.0	4.2	100.0	417.78	850.00	35.19	71.59	**156.78**	5.42	11.03	**24.16**	0.87	**346.06**	w12x 50	1297.92
	B 17	16.00	25.0	45.0	7.3	100.0	836.96	1600.00	65.39	125.00	**278.47**	10.46	20.00	**44.55**	0.83	**581.90**	w12x 79	1975.00
	C 47	20.25	18.5	45.0	7.1	100.0	1055.63	2025.00	44.96	86.24	**191.94**	9.74	18.69	**41.59**	0.62	**296.42**	w12x 58	1070.58
	D 37	22.25	20.2	45.0	12.1	100.0	1270.48	2225.00	64.85	113.58	**259.55**	12.84	22.48	**51.38**	0.67	**427.39**	w12x 79	1596.46
	E 18	10.88	26.5	45.0	5.8	100.0	552.67	1087.50	48.51	95.46	**210.96**	7.32	14.41	**31.84**	0.88	**471.06**	w12x 65	1722.50

(highlighted) denotes beams whose size is controlled by I_X.

Table 18: Steel Beam Calculation Spreadsheet

Appendix B:

Use of PEX Tubing for Domestic Plumbing

4/9/2014

Uponor AquaPEX Tubing Coil — White

Part No.	Part Description	Coils/Pallet	List Price/Ea.	Prod. Details
F1040250	1/4" Uponor AquaPEX White, 100-ft. coil	50	$60.50	
F1090375	3/8" Uponor AquaPEX White, 400-ft. coil	18	$247.20	
F1120375	3/8" Uponor AquaPEX White, 1,000-ft. coil	12	$617.95	
F1040500	1/2" Uponor AquaPEX White, 100-ft. coil	22	$70.65	
F1060500	1/2" Uponor AquaPEX White, 300-ft. coil	18	$211.85	
F1100500	1/2" Uponor AquaPEX White, 500-ft. coil	12	$353.20	
F1120500	1/2" Uponor AquaPEX White, 1,000-ft. coil	8	$706.25	
F1040750	3/4" Uponor AquaPEX White, 100-ft. coil	22	$121.15	
F1060750	3/4" Uponor AquaPEX White, 300-ft. coil	12	$363.20	
F1100750	3/4" Uponor AquaPEX White, 500-ft. coil	8	$605.35	
F1041000	1" Uponor AquaPEX White, 100-ft. coil	12	$218.15	
F1061000	1" Uponor AquaPEX White, 300-ft. coil	5	$654.55	
F1101000	1" Uponor AquaPEX White, 500-ft. coil	6	$1,091.00	
F1061250	1 1/4" Uponor AquaPEX White, 100-ft. coil	7	$455.55	
F1021250	1 1/4" Uponor AquaPEX White, 300-ft. coil	2	$1,366.40	
F1061500	1 1/2" Uponor AquaPEX White, 100-ft. coil	7	$536.40	
F1021500	1 1/2" Uponor AquaPEX White, 300-ft. coil	2	$1,609.15	
F1062000	2" Uponor AquaPEX White, 100-ft. coil	5	$1,081.60	
F1052000	2" Uponor AquaPEX White, 200-ft. coil	3	$2,163.20	
F1022000	2" Uponor AquaPEX White, 300-ft. coil	2	$3,244.85	
F1063000	3" Uponor AquaPEX White, 100-ft. coil	1	$1,921.15	
F1023000	3" Uponor AquaPEX White, 350-ft. coil	1	$6,724.05	

Note: 3" Uponor AquaPEX tubing uses WIPEX fittings.

Table 19: PEX tubing price list - 4/9/14 (Uponor)

uponor

4/9/2014

ProPEX Elbow

ProPEX EP and LF Brass Elbows make 90-degree or 45-degree connections directional changes in an for Uponor AquaPEX system.

Note: ProPEX Tool is required. ProPEX Rings sold separately.

	Part No.	Part Description	Pkg. Qty.	List Price/Ea.	Prod. Details
	Q4760500	ProPEX EP Elbow, 1/2" PEX x 1/2" PEX	25	$1.95	
	Q4760750	ProPEX EP Elbow, 3/4" PEX x 3/4" PEX	25	$2.45	
	LF4710750	ProPEX LF Brass Elbow, 3/4" PEX x 3/4" PEX	25	$12.25	
	Q4761000	ProPEX EP Elbow, 1" PEX x 1" PEX	10	$5.05	
	LF4711000	ProPEX LF Brass Elbow, 1" PEX x 1" PEX	10	$19.70	
	Q4761250	ProPEX EP Elbow, 1 1/4" PEX x 1 1/4" PEX	1	$12.50	
	Q4761500	ProPEX EP Elbow, 1 1/2" PEX x 1 1/2" PEX	1	$16.65	
NEW	Q4761515	ProPEX EP 45 Elbow, 1 1/2" PEX x 1 1/2" PEX	1	$15.15	
	Q4762000	ProPEX EP Elbow, 2" PEX x 2" PEX	1	$68.70	
NEW	Q4762020	ProPEX EP 45 Elbow, 2" PEX x 2" PEX	1	$68.70	

Table 20: PEX 90 degree elbow price list - 4/9/14 (Uponor)

uponor

4/9/2014

ProPEX Tee

ProPEX EP, LF Brass and Brass Tees make diverting connections for Uponor PEX tubing in supply and return mains. Branch size is listed last in the part description.

Note: ProPEX Tool is required. ProPEX Rings sold separately.

Part No.	Part Description	Pkg. Qty.	List Price/Ea.	Prod. Details
Q4755050	ProPEX EP Tee, 1/2" PEX x 1/2" PEX x 1/2" PEX	25	$1.95	
LF4705050	ProPEX LF Brass Tee, 1/2" PEX x 1/2" PEX x 1/2" PEX	25	$10.55	
Q4757575	ProPEX EP Tee, 3/4" PEX x 3/4" PEX x 3/4" PEX	25	$3.15	
LF4707575	ProPEX LF Brass Tee, 3/4" PEX x 3/4" PEX x 3/4" PEX	25	$17.15	
Q4751010	ProPEX EP Tee, 1" PEX x 1" PEX x 1" PEX	10	$5.70	
LF4701010	ProPEX LF Brass Tee, 1" PEX x 1" PEX x 1" PEX	10	$31.70	
Q4751313	ProPEX EP Tee, 1 1/4" PEX x 1 1/4" PEX x 1 1/4" PEX	1	$14.25	
Q4751515	ProPEX EP Tee, 1 1/2" PEX x 1 1/2" PEX x 1 1/2" PEX	1	$19.90	
Q4752000	ProPEX EP Tee, 2" PEX x 2" PEX x 2" PEX	1	$84.60	

Table 21: PEX Tee fitting price list - 4/9/14 (Uponor)

MCAA Web-Based Labor Estimating Manual *(WebLEM)*

PIPING SYSTEMS, Component Method, Pipe , PEX (Cross Linked Polyethylene), Crimp Ring or Expansion/Shrink Joint
Please Note: Labor units from the Component Method and the Work Activity Method below are not intended to be combined in one estimate. The two methods are not designed to be used together, but instead they give the contractor a choice. As a result, you can only expand one of the two folders below at one time.

Dia. In.	Man Hours
0.3750	0.05
0.5000	0.05
0.7500	0.05
1.0000	0.05
1.2500	0.05
1.5000	0.05
2.0000	0.05

Notes:

1. All units are based on 300 foot coils except 2' which is based on 100' coils.

Date last updated 09/19/2009

1385 Piccard Drive Rockville, MD 20850 | Phone: 301-869-5800 Fax: 301-990-9690

Table 22: PEX installation labor rates. (MCAA)

MCAA Web-Based Labor Estimating Manual *(WebLEM)*

PIPING SYSTEMS, Component Method, Pipe, Copper, Hard , 95/5 Solder (Lead Free Solder)
Please Note: Labor units from the Component Method and the Work Activity Method below are not intended to be combined in one estimate. The two methods are not designed to be used together, but instead they give the contractor a choice. As a result, you can only expand one of the two folders below at one time.

Dia. In.	Type K	Type L	Type M
	20 Ft.		
0.2500	0.06	0.06	0.06
0.3750	0.06	0.06	0.06
0.5000	0.06	0.06	0.06
0.6250	0.06	0.06	0.06
0.7500	0.07	0.06	0.06
1.0000	0.07	0.07	0.07
1.2500	0.08	0.08	0.07
1.5000	0.08	0.08	0.08
2.0000	0.1	0.09	0.09
2.5000	0.12	0.12	0.11
3.0000	0.15	0.14	0.13
3.5000	0.17	0.16	0.15
4.0000	0.2	0.18	0.17
5.0000	0.29	0.26	0.25
6.0000	0.37	0.32	0.3
8.0000	0.49	0.44	0.42
10.0000	0.62	0.55	0.52
12.0000	0.75	0.66	0.64

NOTE: O.D. = Size + 1/8"

Note: Supports not inlcuded.

Date last updated 09/14/2009

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Table 23: Copper pipe installation labor rates. (MCAA)

MCAA Web-Based Labor Estimating Manual *(WebLEM)*

PIPING SYSTEMS, Component Method, Fittings, Copper, Pressure , 95/5 Solder Joint (Lead Free Solder)

Please Note: Labor units from the Component Method and the Work Activity Method below are not intended to be combined in one estimate. The two methods are not designed to be used together, but instead they give the contractor a choice. As a result, you can only expand one of the two folders below at one time.

Dia. In.	90° Elbow Short Radius	90° Elbow Long Radius	90° Elbow Short Radius Street	Fitting 90° Elbow Short Radius (FTG x FTG)	90° Elbow Long Radius Street	45° Elbow Short Radius	45° Elbow Short Radius Street	45° Elbow (FTGxFTG)	Tee
0.1250	0.4	0.4	0.22	0.05	0.22	0.4			0.57
0.2500	0.4	0.4	0.22	0.05	0.22	0.4	0.22		0.57
0.3750	0.4	0.4	0.22		0.22	0.4	0.22	0.05	0.57
0.5000	0.4	0.4	0.22	0.05	0.22	0.4	0.22	0.05	0.57
0.6250	0.47	0.47	0.26	0.05	0.26	0.47	0.26		0.68
0.7500	0.53	0.53	0.29	0.05	0.29	0.53	0.29	0.05	0.77
0.8750		0.58				0.58			0.85
1.0000	0.63	0.63	0.34	0.05	0.34	0.63	0.34	0.05	0.92
1.2500	0.7	0.7	0.38	0.05	0.38	0.7	0.37		1.03
1.5000	0.74	0.74	0.4	0.05	0.4	0.74	0.4		1.09
2.0000	0.85	0.86	0.46	0.06	0.46	0.85	0.45		1.26
2.5000	[illegible]	1.38	0.71		0.73	1.36	0.71		[illegible]
3.0000	1.64	1.66	0.86	0.08	0.88	1.63	0.85		2.43
3.5000	1.91	1.94	1		1.02	1.9	0.99		2.84
4.0000	2.19	2.24	1.15		1.18	2.18	1.14		3.26
5.0000	4.16					4.12			6.14
6.0000	5.05					4.99			7.4
8.0000	6.98					6.84			10.08

Table 24: PEX fitting installation labor rates. (MCAA)

MCAA Web-Based Labor Estimating Manual *(WebLEM)*

PIPING SYSTEMS, Component Method, Fittings, PEX (Cross Linked Polyethylene), Crimp Ring or Expansion/Shrink Joint , PEX Fittings
Please Note: Labor units from the Component Method and the Work Activity Method below are not intended to be combined in one estimate. The two methods are not designed to be used together, but instead they give the contractor a choice. As a result, you can only expand one of the two folders below at one time.

Dia. In.	90° Elbow Short Radius	Tee	Male Adapter PEX x MPT	Female Adapter PEX x FPT
0.3750				
0.5000	0.09	0.12	0.07	0.35
0.7500	0.12	0.15	0.08	0.48
1.0000	0.14	0.19	0.1	0.57
1.2500	0.17	0.23	0.12	0.67
1.5000	0.2	0.27	0.13	0.74
2.0000	0.25	0.35	0.16	0.89

Table 25: Copper fitting installation rates. (MCAA)

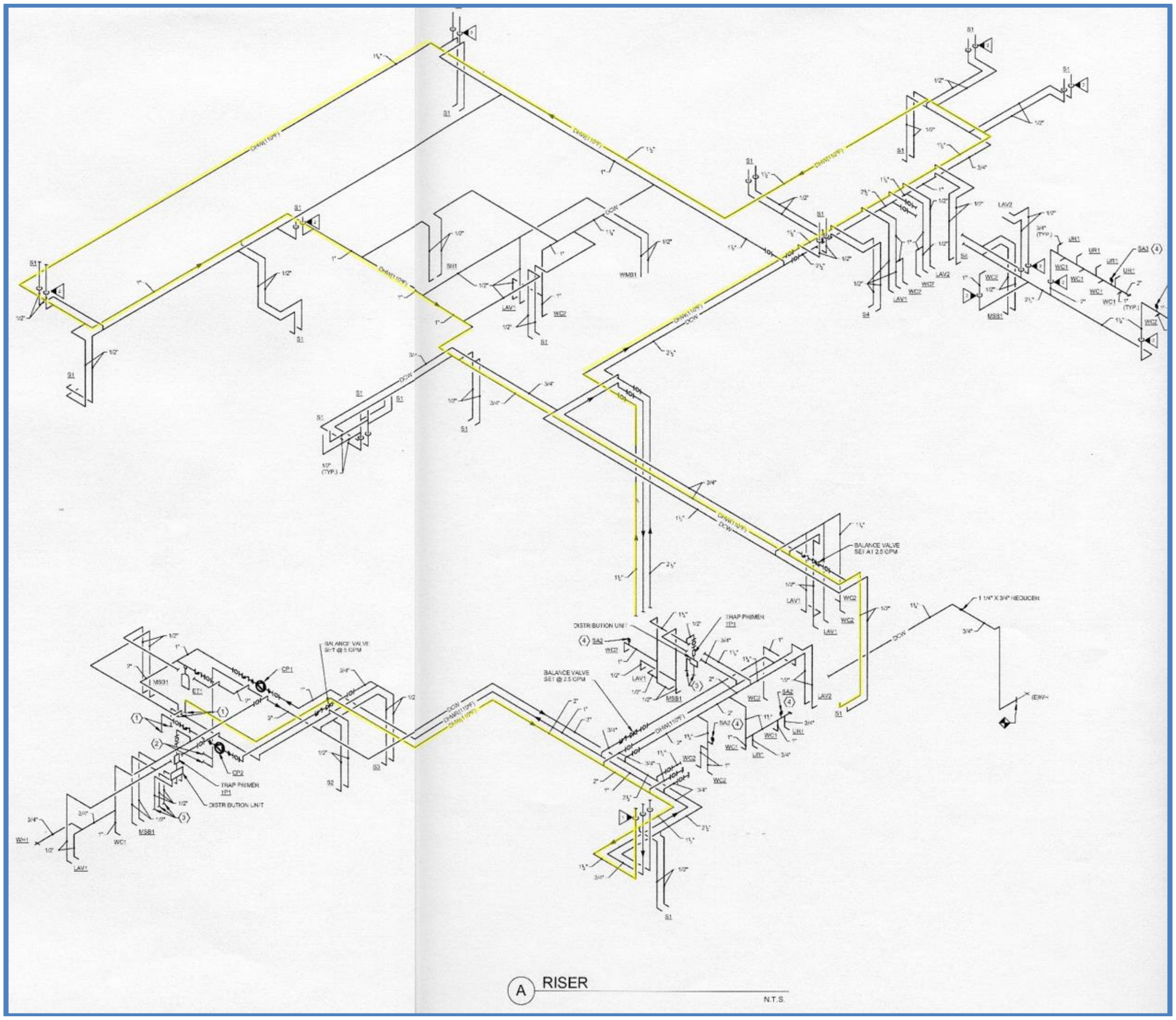

Figure 18: Riser diagram, highlighting domestic hot water for furthest most fixture. (Hardlines Design Company)

TABLE 2b. Dimensions and Physical Characteristics of Copper Tube: TYPE L

Nominal or Standard Size, inches	Nominal Dimensions, inches			Calculated Values (based on nominal dimensions)				
	Outside Diameter	Inside Diameter	Wall Thickness	Cross Sectional Area of Bore, sq inches	Weight of Tube Only, pounds per linear ft	Weight of Tube & Water, pounds per linear ft	Contents of Tube per linear ft Cu ft	Contents of Tube per linear ft Gal
1/4	.375	.315	.030	.078	.126	.160	.00054	.00405
3/8	.500	.430	.035	.145	.198	.261	.00101	.00753
1/2	.625	.545	.040	.233	.285	.386	.00162	.0121
5/8	.750	.666	.042	.348	.362	.506	.00232	.0174
3/4	.875	.785	.045	.484	.455	.664	.00336	.0251
1	1.125	1.025	.050	.825	.655	1.01	.00573	.0429
1 1/4	1.375	1.265	.055	1.26	.884	1.43	.00875	.0655
1 1/2	1.625	1.505	.060	1.78	1.14	1.91	.0124	.0925
2	2.125	1.985	.070	3.09	1.75	3.09	.0215	.161
2 1/2	2.625	2.465	.080	4.77	2.48	4.54	.0331	.248
3	3.125	2.945	.090	6.81	3.33	6.27	.0473	.354
3 1/2	3.625	3.425	.100	9.21	4.29	8.27	.0640	.478
4	4.125	3.905	.110	12.0	5.38	10.1	.0764	.571
5	5.125	4.875	.125	18.7	7.61	15.7	.130	.971
6	6.125	5.845	.140	26.8	10.2	21.8	.186	1.39
8	8.125	7.725	.200	46.9	19.3	39.6	.326	2.44
10	10.125	9.625	.250	72.8	30.1	61.6	.506	3.78
12	12.125	11.565	.280	105	40.4	85.8	.729	5.45

Table 26: Physical characteristics of Type L copper pipe. (Copper Tube Handbook)

DESIGN COEFFICIENT TABLES

Hazen-Williams Friction Factor (C)

Pipe Material	Values for C		
	Range High/Low	Average Value	Typical Design Value
Plastic, PVC, Polyethylene pipe or tubing	160/150	150-155	150
Cement or mastic lined iron or steel pipe	160/130	148	140
Copper, brass, lead, tin or glass pipe or tubing	150/120	140	130
Wood Stave	145/110	120	110
Welded or Seamless Steel	150/80	130	100
Cast and ductile iron	150/80	130	100
Concrete	152/85	120	100
Corrugated steel	-	60	60

Table 27: Hazen -Williams Design Coefficients (CECALC)

TABLE 7. Pressure Loss in Fittings and Valves Expressed as Equivalent Length of Tube, feet

Nominal or Standard Size, in	Fittings					Valves			
	Standard Ell		90° Tee		Coupling				
	90°	45°	Side Branch	Straight Run		Ball	Gate	Btfly	Check
3/8	.5	—	1.5	—	—	—	—	—	1.5
1/2	1	.5	2	—	—	—	—	—	2
5/8	1.5	.5	2	—	—	—	—	—	2.5
3/4	2	.5	3	—	—	—	—	—	3
1	2.5	1	4.5	—	—	.5	—	—	4.5
1 1/4	3	1	5.5	.5	.5	.5	—	—	5.5
1 1/2	4	1.5	7	.5	.5	.5	—	—	6.5
2	5.5	2	9	.5	.5	.5	.5	7.5	9
2 1/2	7	2.5	12	.5	.5	—	1	10	11.5
3	9	3.5	15	1	1	—	1.5	15.5	14.5
3 1/2	9	3.5	14	1	1	—	2	—	12.5
4	12.5	5	21	1	1	—	2	16	18.5
5	16	6	27	1.5	1.5	—	3	11.5	23.5
6	19	7	34	2	2	—	3.5	13.5	26.5
8	29	11	50	3	3	—	5	12. 5	39

Table 28: Equivalent Length of copper fittings. (Copper Tube Handbook)

½" Uponor AquaPEX (100% Water)

PSI Loss Per 100 Feet of Tubing

Velocity (ft/s)	GPM	40°F 4°C	60°F 16°C	80°F 27°C	100°F 38°C	120°F 49°C	140°F 60°C	160°F 71°C	180°F 82°C
1.5	0.83	1.70	1.44	1.33	1.25	1.18	1.12	1.07	1.03
1.6	0.88	1.89	1.61	1.49	1.40	1.32	1.26	1.20	1.15
1.7	0.94	2.10	1.79	1.66	1.55	1.47	1.40	1.34	1.28
1.8	0.99	2.31	1.97	1.83	1.71	1.62	1.54	1.48	1.42
1.9	1.05	2.54	2.16	2.01	1.88	1.78	1.70	1.62	1.56
2.0	1.10	2.77	2.36	2.19	2.06	1.95	1.86	1.78	1.71
2.1	1.16	3.01	2.57	2.39	2.24	2.12	2.02	1.94	1.86
2.2	1.22	3.26	2.78	2.59	2.43	2.30	2.19	2.10	2.02
2.3	1.27	3.51	3.01	2.80	2.63	2.49	2.37	2.27	2.19
2.4	1.33	3.78	3.24	3.01	2.83	2.68	2.56	2.45	2.36
2.5	1.38	4.05	3.47	3.23	3.04	2.88	2.75	2.63	2.53
2.6	1.44	4.33	3.72	3.46	3.25	3.09	2.94	2.82	2.71
2.7	1.49	4.62	3.97	3.70	3.48	3.30	3.15	3.02	2.90
2.8	1.55	4.92	4.23	3.94	3.71	3.51	3.35	3.22	3.10
2.9	1.60	5.23	4.49	4.19	3.94	3.74	3.57	3.42	3.29
3.0	1.66	5.54	4.77	4.44	4.18	3.97	3.79	3.63	3.50
3.1	1.71	5.86	5.05	4.70	4.43	4.20	4.02	3.85	3.71
3.2	1.77	6.19	5.33	4.97	4.68	4.45	4.25	4.07	3.92
3.3	1.82	6.53	5.63	5.25	4.94	4.69	4.48	4.30	4.14
3.4	1.88	6.87	5.93	5.53	5.21	4.95	4.73	4.54	4.37
3.5	1.93	7.22	6.23	5.82	5.48	5.21	4.98	4.78	4.60
3.6	1.99	7.58	6.55	6.11	5.76	5.47	5.23	5.02	4.84
3.7	2.04	7.95	6.87	6.41	6.04	5.74	5.49	5.27	5.08
3.8	2.10	8.32	7.19	6.72	6.34	6.02	5.76	5.53	5.33
3.9	2.15	8.71	7.53	7.03	6.63	6.30	6.03	5.79	5.58
4.0	2.21	9.10	7.87	7.35	6.93	6.59	6.30	6.05	5.84
4.1	2.26	9.49	8.22	7.68	7.24	6.89	6.59	6.33	6.10
4.2	2.32	9.90	8.57	8.01	7.56	7.19	6.88	6.60	6.37
4.3	2.38	10.31	8.93	8.35	7.88	7.49	7.17	6.89	6.64
4.4	2.43	10.73	9.30	8.69	8.20	7.80	7.47	7.17	6.92
4.5	2.49	11.15	9.67	9.04	8.54	8.12	7.77	7.47	7.20
4.6	2.54	11.59	10.05	9.40	8.88	8.44	8.08	7.77	7.49
4.7	2.60	12.03	10.44	9.76	9.22	8.77	8.40	8.07	7.78
4.8	2.65	12.48	10.83	10.13	9.57	9.11	8.72	8.38	8.08
4.9	2.71	12.93	11.23	10.50	9.92	9.45	9.04	8.69	8.39
5.0	2.76	13.39	11.63	10.88	10.29	9.79	9.37	9.01	8.69
5.1	2.82	13.86	12.04	11.27	10.65	10.14	9.71	9.34	9.01
5.2	2.87	14.34	12.46	11.66	11.02	10.50	10.05	9.67	9.33
5.3	2.93	14.82	12.88	12.06	11.40	10.86	10.40	10.00	9.65
5.4	2.98	15.31	13.31	12.47	11.79	11.23	10.75	10.34	9.98
5.5	3.04	15.80	13.75	12.88	12.18	11.60	11.11	10.69	10.31
5.6	3.09	16.31	14.19	13.29	12.57	11.98	11.47	11.04	10.65
5.7	3.15	16.82	14.64	13.72	12.97	12.36	11.84	11.39	11.00
5.8	3.20	17.34	15.10	14.14	13.38	12.75	12.22	11.75	11.34
5.9	3.26	17.86	15.56	14.58	13.79	13.14	12.59	12.12	11.70
6.0	3.31	18.39	16.02	15.02	14.21	13.54	12.98	12.49	12.06
6.1	3.37	18.93	16.50	15.46	14.63	13.95	13.37	12.86	12.42
6.2	3.42	19.47	16.98	15.91	15.06	14.36	13.76	13.24	12.79
6.3	3.48	20.02	17.46	16.37	15.50	14.77	14.16	13.63	13.16
6.4	3.54	20.58	17.95	16.83	15.94	15.19	14.56	14.02	13.54
6.5	3.59	21.14	18.45	17.30	16.38	15.62	14.97	14.41	13.92
6.6	3.65	21.72	18.95	17.78	16.83	16.05	15.39	14.81	14.31
6.7	3.70	22.29	19.46	18.26	17.29	16.49	15.81	15.22	14.70

¾" Uponor AquaPEX (100% Water)

PSI Loss Per 100 Feet of Tubing

Velocity (ft/s)	GPM	40°F 4°C	60°F 16°C	80°F 27°C	100°F 38°C	120°F 49°C	140°F 60°C	160°F 71°C	180°F 82°C
1.5	1.65	1.08	0.92	0.86	0.81	0.76	0.73	0.70	0.67
1.6	1.76	1.21	1.03	0.96	0.90	0.85	0.81	0.78	0.75
1.7	1.87	1.34	1.15	1.07	1.00	0.95	0.90	0.87	0.83
1.8	1.98	1.48	1.27	1.18	1.11	1.05	1.00	0.96	0.92
1.9	2.09	1.62	1.39	1.29	1.22	1.15	1.10	1.05	1.01
2.0	2.20	1.77	1.52	1.41	1.33	1.26	1.20	1.15	1.11
2.1	2.31	1.92	1.65	1.54	1.45	1.37	1.31	1.26	1.21
2.2	2.43	2.08	1.79	1.67	1.57	1.49	1.42	1.37	1.31
2.3	2.54	2.25	1.94	1.81	1.70	1.61	1.54	1.48	1.42
2.4	2.65	2.42	2.09	1.94	1.83	1.74	1.66	1.59	1.53
2.5	2.76	2.60	2.24	2.09	1.97	1.87	1.78	1.71	1.65
2.6	2.87	2.78	2.40	2.24	2.11	2.00	1.91	1.83	1.77
2.7	2.98	2.97	2.56	2.39	2.25	2.14	2.04	1.96	1.89
2.8	3.09	3.16	2.73	2.55	2.40	2.28	2.18	2.09	2.02
2.9	3.20	3.36	2.90	2.71	2.55	2.43	2.32	2.23	2.15
3.0	3.31	3.56	3.08	2.88	2.71	2.58	2.46	2.37	2.28
3.1	3.42	3.77	3.26	3.05	2.87	2.73	2.61	2.51	2.42
3.2	3.53	3.98	3.45	3.22	3.04	2.89	2.76	2.65	2.56
3.3	3.64	4.20	3.64	3.40	3.21	3.05	2.92	2.80	2.70
3.4	3.75	4.42	3.83	3.58	3.38	3.22	3.08	2.95	2.85
3.5	3.86	4.65	4.03	3.77	3.56	3.39	3.24	3.11	3.00
3.6	3.97	4.88	4.24	3.96	3.74	3.56	3.40	3.27	3.15
3.7	4.08	5.12	4.44	4.16	3.93	3.74	3.57	3.43	3.31
3.8	4.19	5.36	4.66	4.36	4.12	3.92	3.75	3.60	3.47
3.9	4.30	5.61	4.87	4.56	4.31	4.10	3.93	3.77	3.64
4.0	4.41	5.86	5.10	4.77	4.51	4.29	4.11	3.95	3.81
4.1	4.52	6.12	5.32	4.98	4.71	4.48	4.29	4.12	3.98
4.2	4.63	6.38	5.55	5.20	4.91	4.68	4.48	4.31	4.15
4.3	4.74	6.65	5.79	5.42	5.12	4.88	4.67	4.49	4.33
4.4	4.85	6.92	6.02	5.64	5.34	5.08	4.87	4.68	4.51
4.5	4.96	7.20	6.27	5.87	5.55	5.29	5.06	4.87	4.70
4.6	5.07	7.48	6.51	6.10	5.77	5.50	5.27	5.07	4.89
4.7	5.18	7.76	6.77	6.34	6.00	5.71	5.47	5.26	5.08
4.8	5.29	8.05	7.02	6.58	6.23	5.93	5.68	5.47	5.27
4.9	5.40	8.35	7.28	6.82	6.46	6.15	5.90	5.67	5.47
5.0	5.51	8.65	7.54	7.07	6.69	6.38	6.11	5.88	5.68
5.1	5.62	8.95	7.81	7.33	6.93	6.61	6.33	6.09	5.88
5.2	5.73	9.26	8.08	7.58	7.18	6.84	6.56	6.31	6.09
5.3	5.84	9.57	8.36	7.84	7.42	7.08	6.78	6.53	6.30
5.4	5.95	9.89	8.64	8.11	7.67	7.32	7.01	6.75	6.52
5.5	6.06	10.21	8.93	8.37	7.93	7.56	7.25	6.97	6.73
5.6	6.17	10.54	9.21	8.65	8.19	7.81	7.48	7.20	6.96
5.7	6.28	10.87	9.51	8.92	8.45	8.06	7.73	7.44	7.18
5.8	6.39	11.21	9.80	9.20	8.71	8.31	7.97	7.67	7.41
5.9	6.50	11.55	10.10	9.48	8.98	8.57	8.22	7.91	7.64
6.0	6.61	11.89	10.41	9.77	9.26	8.83	8.47	8.15	7.87
6.1	6.72	12.24	10.72	10.06	9.53	9.09	8.72	8.40	8.11
6.2	6.83	12.60	11.03	10.36	9.81	9.36	8.98	8.65	8.35
6.3	6.94	12.96	11.35	10.65	10.10	9.63	9.24	8.90	8.60
6.4	7.05	13.32	11.67	10.96	10.38	9.91	9.51	9.15	8.84
6.5	7.17	13.68	11.99	11.26	10.68	10.19	9.77	9.41	9.09
6.6	7.28	14.06	12.32	11.57	10.97	10.47	10.05	9.67	9.35
6.7	7.39	14.43	12.65	11.89	11.27	10.75	10.32	9.94	9.60

Table 29: 1/2" and 3/4" AquaPEX tubing friction loss. (Uponor)

1" Uponor AquaPEX (100% Water)

PSI Loss Per 100 Feet of Tubing									
Velocity (ft/s)	GPM	40°F 4°C	60°F 16°C	80°F 27°C	100°F 38°C	120°F 49°C	140°F 60°C	160°F 71°C	180°F 82°C
1.5	2.73	0.78	0.67	0.62	0.59	0.56	0.53	0.51	0.49
1.6	2.91	0.87	0.75	0.70	0.66	0.62	0.59	0.57	0.55
1.7	3.09	0.97	0.83	0.78	0.73	0.69	0.66	0.63	0.61
1.8	3.27	1.07	0.92	0.86	0.81	0.77	0.73	0.70	0.68
1.9	3.46	1.17	1.01	0.94	0.89	0.84	0.81	0.77	0.74
2.0	3.64	1.28	1.11	1.03	0.97	0.92	0.88	0.85	0.81
2.1	3.82	1.40	1.21	1.12	1.06	1.01	0.96	0.92	0.89
2.2	4.00	1.51	1.31	1.22	1.15	1.09	1.04	1.00	0.96
2.3	4.18	1.63	1.41	1.32	1.24	1.18	1.13	1.08	1.04
2.4	4.37	1.76	1.52	1.42	1.34	1.27	1.22	1.17	1.13
2.5	4.55	1.89	1.63	1.53	1.44	1.37	1.31	1.26	1.21
2.6	4.73	2.02	1.75	1.64	1.54	1.47	1.40	1.35	1.30
2.7	4.91	2.16	1.87	1.75	1.65	1.57	1.50	1.44	1.39
2.8	5.09	2.30	1.99	1.86	1.76	1.67	1.60	1.54	1.48
2.9	5.28	2.44	2.12	1.98	1.87	1.78	1.70	1.63	1.58
3.0	5.46	2.59	2.25	2.10	1.99	1.89	1.81	1.74	1.67
3.1	5.64	2.74	2.38	2.23	2.10	2.00	1.92	1.84	1.77
3.2	5.82	2.90	2.52	2.36	2.23	2.12	2.03	1.95	1.88
3.3	6.00	3.06	2.66	2.49	2.35	2.24	2.14	2.06	1.98
3.4	6.19	3.22	2.80	2.62	2.48	2.36	2.26	2.17	2.09
3.5	6.37	3.39	2.95	2.76	2.61	2.48	2.38	2.29	2.20
3.6	6.55	3.56	3.10	2.90	2.74	2.61	2.50	2.40	2.32
3.7	6.73	3.73	3.25	3.04	2.88	2.74	2.63	2.52	2.43
3.8	6.91	3.91	3.41	3.19	3.02	2.87	2.75	2.65	2.55
3.9	7.09	4.09	3.56	3.34	3.16	3.01	2.88	2.77	2.68
4.0	7.28	4.27	3.73	3.49	3.31	3.15	3.02	2.90	2.80
4.1	7.46	4.46	3.89	3.65	3.45	3.29	3.15	3.03	2.93
4.2	7.64	4.65	4.06	3.81	3.60	3.43	3.29	3.17	3.06
4.3	7.82	4.85	4.23	3.97	3.76	3.58	3.43	3.30	3.19
4.4	8.00	5.05	4.41	4.14	3.92	3.73	3.58	3.44	3.32
4.5	8.19	5.25	4.59	4.30	4.07	3.88	3.72	3.58	3.46
4.6	8.37	5.46	4.77	4.47	4.24	4.04	3.87	3.73	3.60
4.7	8.55	5.66	4.95	4.65	4.40	4.20	4.02	3.87	3.74
4.8	8.73	5.88	5.14	4.83	4.57	4.36	4.18	4.02	3.88
4.9	8.91	6.09	5.33	5.01	4.74	4.52	4.34	4.17	4.03
5.0	9.10	6.31	5.53	5.19	4.91	4.69	4.49	4.33	4.18
5.1	9.28	6.54	5.72	5.37	5.09	4.86	4.66	4.48	4.33
5.2	9.46	6.76	5.92	5.56	5.27	5.03	4.82	4.64	4.48
5.3	9.64	6.99	6.13	5.75	5.45	5.20	4.99	4.80	4.64
5.4	9.82	7.22	6.33	5.95	5.64	5.38	5.16	4.97	4.80
5.5	10.01	7.46	6.54	6.14	5.82	5.56	5.33	5.13	4.96
5.6	10.19	7.70	6.75	6.34	6.01	5.74	5.51	5.30	5.12
5.7	10.37	7.94	6.97	6.55	6.21	5.92	5.68	5.47	5.29
5.8	10.55	8.19	7.19	6.75	6.40	6.11	5.86	5.65	5.46
5.9	10.73	8.44	7.41	6.96	6.60	6.30	6.05	5.82	5.63
6.0	10.92	8.69	7.63	7.17	6.80	6.49	6.23	6.00	5.80
6.1	11.10	8.95	7.86	7.39	7.01	6.69	6.42	6.18	5.97
6.2	11.28	9.21	8.09	7.60	7.21	6.89	6.61	6.37	6.15
6.3	11.46	9.47	8.32	7.82	7.42	7.09	6.80	6.55	6.33
6.4	11.64	9.74	8.56	8.05	7.63	7.29	7.00	6.74	6.51
6.5	11.82	10.01	8.79	8.27	7.85	7.49	7.19	6.93	6.70
6.6	12.01	10.28	9.04	8.50	8.06	7.70	7.39	7.12	6.89
6.7	12.19	10.56	9.28	8.73	8.28	7.91	7.60	7.32	7.07

1¼" Uponor AquaPEX (100% Water)

PSI Loss Per 100 Feet of Tubing									
Velocity (ft/s)	GPM	40°F 4°C	60°F 16°C	80°F 27°C	100°F 38°C	120°F 49°C	140°F 60°C	160°F 71°C	180°F 82°C
1.5	4.08	0.60	0.52	0.49	0.46	0.43	0.41	0.40	0.38
1.6	4.35	0.68	0.58	0.54	0.51	0.49	0.46	0.44	0.43
1.7	4.62	0.75	0.65	0.60	0.57	0.54	0.52	0.49	0.48
1.8	4.90	0.83	0.72	0.67	0.63	0.60	0.57	0.55	0.53
1.9	5.17	0.91	0.79	0.73	0.69	0.66	0.63	0.60	0.58
2.0	5.44	0.99	0.86	0.80	0.76	0.72	0.69	0.66	0.64
2.1	5.71	1.08	0.94	0.87	0.82	0.78	0.75	0.72	0.69
2.2	5.98	1.17	1.02	0.95	0.90	0.85	0.81	0.78	0.75
2.3	6.26	1.27	1.10	1.03	0.97	0.92	0.88	0.85	0.81
2.4	6.53	1.36	1.18	1.11	1.04	0.99	0.95	0.91	0.88
2.5	6.80	1.46	1.27	1.19	1.12	1.07	1.02	0.98	0.95
2.6	7.07	1.57	1.36	1.27	1.20	1.14	1.09	1.05	1.01
2.7	7.34	1.67	1.45	1.36	1.29	1.22	1.17	1.12	1.08
2.8	7.62	1.78	1.55	1.45	1.37	1.30	1.25	1.20	1.16
2.9	7.89	1.89	1.65	1.54	1.46	1.39	1.33	1.28	1.23
3.0	8.16	2.01	1.75	1.64	1.55	1.47	1.41	1.36	1.31
3.1	8.43	2.13	1.85	1.74	1.64	1.56	1.50	1.44	1.39
3.2	8.70	2.25	1.96	1.84	1.74	1.65	1.58	1.52	1.47
3.3	8.98	2.37	2.07	1.94	1.83	1.75	1.67	1.61	1.55
3.4	9.25	2.50	2.18	2.04	1.93	1.84	1.76	1.70	1.64
3.5	9.52	2.63	2.29	2.15	2.04	1.94	1.86	1.79	1.72
3.6	9.79	2.76	2.41	2.26	2.14	2.04	1.95	1.88	1.81
3.7	10.06	2.90	2.53	2.37	2.25	2.14	2.05	1.97	1.90
3.8	10.34	3.03	2.65	2.49	2.36	2.25	2.15	2.07	2.00
3.9	10.61	3.18	2.78	2.61	2.47	2.35	2.25	2.17	2.09
4.0	10.88	3.32	2.90	2.73	2.58	2.46	2.36	2.27	2.19
4.1	11.15	3.47	3.03	2.85	2.70	2.57	2.47	2.37	2.29
4.2	11.42	3.62	3.17	2.97	2.81	2.68	2.57	2.48	2.39
4.3	11.70	3.77	3.30	3.10	2.94	2.80	2.68	2.58	2.49
4.4	11.97	3.92	3.44	3.23	3.06	2.92	2.80	2.69	2.60
4.5	12.24	4.08	3.58	3.36	3.18	3.04	2.91	2.80	2.71
4.6	12.51	4.24	3.72	3.49	3.31	3.16	3.03	2.92	2.82
4.7	12.78	4.40	3.86	3.63	3.44	3.28	3.15	3.03	2.93
4.8	13.06	4.57	4.01	3.77	3.57	3.41	3.27	3.15	3.04
4.9	13.33	4.74	4.16	3.91	3.70	3.54	3.39	3.27	3.15
5.0	13.60	4.91	4.31	4.05	3.84	3.67	3.52	3.39	3.27
5.1	13.87	5.08	4.46	4.20	3.98	3.80	3.64	3.51	3.39
5.2	14.14	5.26	4.62	4.34	4.12	3.93	3.77	3.63	3.51
5.3	14.42	5.44	4.78	4.49	4.26	4.07	3.90	3.76	3.63
5.4	14.69	5.62	4.94	4.64	4.41	4.21	4.04	3.89	3.76
5.5	14.96	5.81	5.10	4.80	4.55	4.35	4.17	4.02	3.88
5.6	15.23	5.99	5.27	4.96	4.70	4.49	4.31	4.15	4.01
5.7	15.50	6.18	5.44	5.11	4.85	4.63	4.45	4.29	4.14
5.8	15.78	6.38	5.61	5.27	5.01	4.78	4.59	4.42	4.27
5.9	16.05	6.57	5.78	5.44	5.16	4.93	4.73	4.56	4.41
6.0	16.32	6.77	5.96	5.60	5.32	5.08	4.88	4.70	4.54
6.1	16.59	6.97	6.13	5.77	5.48	5.23	5.02	4.84	4.68
6.2	16.86	7.17	6.31	5.94	5.64	5.39	5.17	4.99	4.82
6.3	17.13	7.38	6.49	6.11	5.80	5.54	5.32	5.13	4.96
6.4	17.41	7.58	6.68	6.29	5.97	5.70	5.48	5.28	5.10
6.5	17.68	7.79	6.87	6.46	6.14	5.86	5.63	5.43	5.25
6.6	17.95	8.01	7.05	6.64	6.31	6.03	5.79	5.58	5.39
6.7	18.22	8.22	7.25	6.82	6.48	6.19	5.95	5.73	5.54

Table 30: 1" and 1-1/4" AquaPEX tubing friction loss. (Uponor)

1½" Uponor AquaPEX (100% Water)

PSI Loss Per 100 Feet of Tubing									
Velocity (ft/s)	GPM	40°F 4°C	60°F 16°C	80°F 27°C	100°F 38°C	120°F 49°C	140°F 60°C	160°F 71°C	180°F 82°C
1.5	5.68	0.49	0.42	0.39	0.37	0.35	0.34	0.32	0.31
1.6	6.06	0.55	0.47	0.44	0.42	0.40	0.38	0.36	0.35
1.7	6.44	0.61	0.53	0.49	0.46	0.44	0.42	0.40	0.39
1.8	6.82	0.67	0.58	0.54	0.51	0.49	0.46	0.45	0.43
1.9	7.20	0.74	0.64	0.60	0.56	0.54	0.51	0.49	0.47
2.0	7.58	0.80	0.70	0.65	0.62	0.59	0.56	0.54	0.52
2.1	7.96	0.88	0.76	0.71	0.67	0.64	0.61	0.59	0.57
2.2	8.34	0.95	0.83	0.77	0.73	0.69	0.66	0.64	0.61
2.3	8.71	1.03	0.89	0.83	0.79	0.75	0.72	0.69	0.67
2.4	9.09	1.10	0.96	0.90	0.85	0.81	0.77	0.74	0.72
2.5	9.47	1.19	1.03	0.97	0.91	0.87	0.83	0.80	0.77
2.6	9.85	1.27	1.11	1.04	0.98	0.93	0.89	0.86	0.83
2.7	10.23	1.36	1.18	1.11	1.05	1.00	0.96	0.92	0.89
2.8	10.61	1.45	1.26	1.18	1.12	1.06	1.02	0.98	0.95
2.9	10.99	1.54	1.34	1.26	1.19	1.13	1.08	1.04	1.01
3.0	11.37	1.63	1.42	1.33	1.26	1.20	1.15	1.11	1.07
3.1	11.75	1.73	1.51	1.41	1.34	1.28	1.22	1.18	1.13
3.2	12.12	1.83	1.60	1.50	1.42	1.35	1.29	1.24	1.20
3.3	12.50	1.93	1.68	1.58	1.50	1.43	1.37	1.31	1.27
3.4	12.88	2.03	1.78	1.67	1.58	1.50	1.44	1.39	1.34
3.5	13.26	2.14	1.87	1.75	1.66	1.58	1.52	1.46	1.41
3.6	13.64	2.24	1.96	1.84	1.75	1.66	1.60	1.54	1.48
3.7	14.02	2.35	2.06	1.94	1.83	1.75	1.68	1.61	1.56
3.8	14.40	2.47	2.16	2.03	1.92	1.83	1.76	1.69	1.63
3.9	14.78	2.58	2.26	2.12	2.01	1.92	1.84	1.77	1.71
4.0	15.16	2.70	2.37	2.22	2.11	2.01	1.93	1.85	1.79
4.1	15.53	2.82	2.47	2.32	2.20	2.10	2.01	1.94	1.87
4.2	15.91	2.94	2.58	2.42	2.30	2.19	2.10	2.02	1.96
4.3	16.29	3.06	2.69	2.53	2.40	2.29	2.19	2.11	2.04
4.4	16.67	3.19	2.80	2.63	2.50	2.38	2.29	2.20	2.13
4.5	17.05	3.32	2.91	2.74	2.60	2.48	2.38	2.29	2.21
4.6	17.43	3.45	3.03	2.85	2.70	2.58	2.48	2.38	2.30
4.7	17.81	3.58	3.15	2.96	2.81	2.68	2.57	2.48	2.39
4.8	18.19	3.72	3.27	3.07	2.92	2.78	2.67	2.57	2.49
4.9	18.57	3.86	3.39	3.19	3.03	2.89	2.77	2.67	2.58
5.0	18.94	4.00	3.51	3.31	3.14	2.99	2.87	2.77	2.68
5.1	19.32	4.14	3.64	3.42	3.25	3.10	2.98	2.87	2.77
5.2	19.70	4.28	3.77	3.54	3.36	3.21	3.08	2.97	2.87
5.3	20.08	4.43	3.90	3.67	3.48	3.32	3.19	3.08	2.97
5.4	20.46	4.58	4.03	3.79	3.60	3.44	3.30	3.18	3.07
5.5	20.84	4.73	4.16	3.92	3.72	3.55	3.41	3.29	3.18
5.6	21.22	4.88	4.30	4.05	3.84	3.67	3.52	3.40	3.28
5.7	21.60	5.03	4.44	4.18	3.96	3.79	3.64	3.51	3.39
5.8	21.98	5.19	4.57	4.31	4.09	3.91	3.75	3.62	3.50
5.9	22.35	5.35	4.72	4.44	4.22	4.03	3.87	3.73	3.61
6.0	22.73	5.51	4.86	4.58	4.35	4.15	3.99	3.85	3.72
6.1	23.11	5.67	5.00	4.71	4.48	4.28	4.11	3.96	3.83
6.2	23.49	5.84	5.15	4.85	4.61	4.41	4.23	4.08	3.94
6.3	23.87	6.01	5.30	4.99	4.74	4.53	4.36	4.20	4.06
6.4	24.25	6.18	5.45	5.13	4.88	4.66	4.48	4.32	4.18
6.5	24.63	6.35	5.60	5.28	5.02	4.80	4.61	4.44	4.30
6.6	25.01	6.52	5.76	5.43	5.16	4.93	4.74	4.57	4.42
6.7	25.38	6.70	5.91	5.57	5.30	5.06	4.87	4.69	4.54

2" Uponor AquaPEX (100% Water)

PSI Loss Per 100 Feet of Tubing									
Velocity (ft/s)	GPM	40°F 4°C	60°F 16°C	80°F 27°C	100°F 38°C	120°F 49°C	140°F 60°C	160°F 71°C	180°F 82°C
1.5	9.75	0.35	0.30	0.28	0.27	0.25	0.24	0.23	0.22
1.6	10.39	0.39	0.34	0.32	0.30	0.28	0.27	0.26	0.25
1.7	11.04	0.43	0.38	0.35	0.33	0.32	0.30	0.29	0.28
1.8	11.69	0.48	0.41	0.39	0.37	0.35	0.33	0.32	0.31
1.9	12.34	0.52	0.46	0.43	0.40	0.38	0.37	0.35	0.34
2.0	12.99	0.57	0.50	0.47	0.44	0.42	0.40	0.39	0.37
2.1	13.64	0.62	0.54	0.51	0.48	0.46	0.44	0.42	0.41
2.2	14.29	0.68	0.59	0.55	0.52	0.50	0.48	0.46	0.44
2.3	14.94	0.73	0.64	0.60	0.57	0.54	0.52	0.50	0.48
2.4	15.59	0.79	0.69	0.64	0.61	0.58	0.56	0.54	0.52
2.5	16.24	0.85	0.74	0.69	0.66	0.63	0.60	0.58	0.56
2.6	16.89	0.91	0.79	0.74	0.70	0.67	0.64	0.62	0.60
2.7	17.54	0.97	0.85	0.79	0.75	0.72	0.69	0.66	0.64
2.8	18.19	1.03	0.90	0.85	0.80	0.77	0.73	0.71	0.68
2.9	18.84	1.10	0.96	0.90	0.85	0.81	0.78	0.75	0.73
3.0	19.49	1.16	1.02	0.96	0.91	0.87	0.83	0.80	0.77
3.1	20.14	1.23	1.08	1.02	0.96	0.92	0.88	0.85	0.82
3.2	20.79	1.30	1.14	1.07	1.02	0.97	0.93	0.90	0.87
3.3	21.44	1.38	1.21	1.13	1.08	1.03	0.98	0.95	0.91
3.4	22.09	1.45	1.27	1.20	1.13	1.08	1.04	1.00	0.97
3.5	22.74	1.53	1.34	1.26	1.19	1.14	1.09	1.05	1.02
3.6	23.39	1.60	1.41	1.32	1.26	1.20	1.15	1.11	1.07
3.7	24.04	1.68	1.48	1.39	1.32	1.26	1.21	1.16	1.12
3.8	24.69	1.76	1.55	1.46	1.38	1.32	1.27	1.22	1.18
3.9	25.34	1.85	1.62	1.53	1.45	1.38	1.33	1.28	1.24
4.0	25.99	1.93	1.70	1.60	1.52	1.45	1.39	1.34	1.29
4.1	26.64	2.02	1.77	1.67	1.58	1.51	1.45	1.40	1.35
4.2	27.29	2.10	1.85	1.74	1.65	1.58	1.52	1.46	1.41
4.3	27.94	2.19	1.93	1.82	1.72	1.65	1.58	1.52	1.47
4.4	28.59	2.28	2.01	1.89	1.80	1.72	1.65	1.59	1.54
4.5	29.24	2.38	2.09	1.97	1.87	1.79	1.72	1.65	1.60
4.6	29.89	2.47	2.18	2.05	1.95	1.86	1.79	1.72	1.66
4.7	30.54	2.57	2.26	2.13	2.02	1.93	1.86	1.79	1.73
4.8	31.18	2.66	2.35	2.21	2.10	2.01	1.93	1.86	1.80
4.9	31.83	2.76	2.44	2.29	2.18	2.08	2.00	1.93	1.86
5.0	32.48	2.86	2.53	2.38	2.26	2.16	2.07	2.00	1.93
5.1	33.13	2.96	2.62	2.46	2.34	2.24	2.15	2.07	2.00
5.2	33.78	3.07	2.71	2.55	2.42	2.32	2.23	2.15	2.08
5.3	34.43	3.17	2.80	2.64	2.51	2.40	2.30	2.22	2.15
5.4	35.08	3.28	2.90	2.73	2.59	2.48	2.38	2.30	2.22
5.5	35.73	3.39	2.99	2.82	2.68	2.56	2.46	2.37	2.30
5.6	36.38	3.50	3.09	2.91	2.77	2.65	2.54	2.45	2.37
5.7	37.03	3.61	3.19	3.01	2.86	2.73	2.63	2.53	2.45
5.8	37.68	3.72	3.29	3.10	2.95	2.82	2.71	2.61	2.53
5.9	38.33	3.84	3.39	3.20	3.04	2.91	2.80	2.70	2.61
6.0	38.98	3.95	3.49	3.30	3.13	3.00	2.88	2.78	2.69
6.1	39.63	4.07	3.60	3.39	3.23	3.09	2.97	2.86	2.77
6.2	40.28	4.19	3.71	3.50	3.32	3.18	3.06	2.95	2.85
6.3	40.93	4.31	3.81	3.60	3.42	3.27	3.15	3.03	2.94
6.4	41.58	4.43	3.92	3.70	3.52	3.37	3.24	3.12	3.02
6.5	42.23	4.55	4.03	3.80	3.62	3.46	3.33	3.21	3.11
6.6	42.88	4.68	4.14	3.91	3.72	3.56	3.42	3.30	3.19
6.7	43.53	4.81	4.26	4.02	3.82	3.66	3.52	3.39	3.28

Table 31: 1-1/2" and 2" AquaPEX tubing friction loss. (Uponor)

1/2" ProPEX Fittings

Elbows	Equivalent Length (ft.)
1/2" Brass Elbow	3.0
1/2" EP Elbow	3.7
Couplings	
1/2" Brass Coupling	1.0
1/2" EP Coupling	1.0
Brass Tees	
1/2" x 1/2" x 1/2" Flow-through	1.0
1/2" x 1/2" x 1/2" Branch	2.0
EP Tees	
1/2" x 1/2" x 1/2" Flow-through	1.0
1/2" x 1/2" x 1/2" Branch	2.3

3/4" ProPEX Fittings

Elbows	Equivalent Length (ft.)
3/4" Brass Elbow	2.2
3/4" EP Elbow	2.3
Couplings	
3/4" Brass Coupling	0.3
3/4" EP Coupling	0.2
Brass Tees	
3/4" x 3/4" x 3/4" Flow-through	0.3
3/4" x 3/4" x 3/4" Branch	0.8
EP Tees	
3/4" x 3/4" x 3/4" Flow-through	0.2
3/4" x 3/4" x 3/4" Branch	0.8
Brass Reducing Tees	
3/4" x 3/4" x 1/2" Flow-through	0.3
3/4" x 3/4" x 1/2" Branch	2.0
EP Reducing Tees	
3/4" x 3/4" x 1/2" Flow-through	0.2
3/4" x 3/4" x 1/2" Branch	2.3

1" ProPEX Fittings

Elbows	Equivalent Length (ft.)
1" Brass Elbow	3.4
1" EP Elbow	4.6
Couplings	
1" Brass Coupling	0.2
1" EP Coupling	0.2
Brass Tees	
1" x 1" x 1" Flow-through	0.2
1" x 1" x 1" Branch	2.0
EP Tees	
1" x 1" x 1" Flow-through	0.2
1" x 1" x 1" Branch	2.0
Brass Reducing Tees	
1" x 1" x 3/4" Flow-through	0.2
1" x 1" x 3/4" Branch	0.8
1" x 1" x 1/2" Flow-through	0.2
1" x 1" x 1/2" Branch	2.0
EP Reducing Tees	
1" x 1" x 3/4" Flow-through	0.2
1" x 1" x 3/4" Branch	0.8
1" x 1" x 1/2" Flow-through	0.2
1" x 1" x 1/2" Branch	2.3

1 1/4" ProPEX Fittings

Elbows	Equivalent Length (ft.)
1 1/4" Brass Elbow	9.61
1 1/4" EP Elbow	10.03
Couplings	
1 1/4" Brass Coupling	1.48
Brass Tees	
1 1/4" Flow-through	1.64
1 1/4" Branch	8.78
EP Tees	
1 1/4" Flow-through	3.78
1 1/4" Branch	8.56

1 1/2" ProPEX Fittings

Elbows	Equivalent Length (ft.)
1 1/2" Brass Elbow	10.85
1 1/2" EP Elbow	11.50
Couplings	
1 1/2" Brass Coupling	2.73
Brass Tees	
1 1/2" Flow-through	2.07
1 1/2" Branch	11.62
EP Tees	
1 1/2" Flow-through	1.83
1 1/2" Branch	10.60

2" ProPEX Fittings

Elbows	Equivalent Length (ft.)
2" Brass Elbow	11.29
Couplings	
2" Brass Coupling	1.38
Brass Tees	
2" Flow-through	1.56
2" Branch	12.07

Table 32: ProPEX Fittings Equivalent Lengths (Uponor)

Friction Loss to Most Distant Fixture (Copper)

Pipe Size (in)	Velocity (ft/s)	Flow (gal/min)	Friction Loss (psi/ft)	System Components	Equivalent Length of Component	Number of Components	Total Equivalent Length (ft)	Total Friction Loss (psi)
2				Straight Pipe	89.00	1	89.00	
				90° Elbow	5.50	5	27.50	
				Tee	0.50	1	0.50	
	4.00	38.53	0.0169				117.00	1.9769
1½				Straight Pipe	321.00	1	321.00	
				90° Elbow	4.00	8	32.00	
				Tee	0.50	7	3.50	
	4.00	22.19	0.0235				356.50	8.3599
1¼				Straight Pipe	80.00	1	80.00	
				90° Elbow	3.00	2	6.00	
				Tee (Branch)	0.50	1	0.50	
	4.00	15.71	0.0288				86.50	2.4946
1				Straight Pipe	103.00	1	103.00	
				90° Elbow	2.50	4	10.00	
				Tee (Branch)	4.50	5	22.50	
	4.00	10.29	0.0367				135.50	4.9729
¾				Straight Pipe	64.00	1	64.00	
				90° Elbow	2.00		0.00	
				Tee	3.00	1	3.00	
	4.00	6.03	0.0502				67.00	3.3613
½				Straight Pipe	15.00	1	15.00	
				90° Elbow	1.00	8	8.00	
				Tee	2.00	2	4.00	
	4.00	2.90	0.0767				27.00	2.0711
Total Friction Loss to Most Distant Fixture								**23.2366**

Table 33: Total friction loss in copper pipe to most distant fixture.

Friction Loss to Most Distant Fixture (PEX)

Pipe Size (in)	Velocity (ft/s)	Flow (gal/min)	Friction Loss (psi/ft)	System Components	Equivalent Length of Component	Number of Components	Total Equivalent Length (ft)	Total Friction Loss (psi)
2				Straight Pipe	89.00	1	89.00	
				90° Elbow	11.29	5	56.45	
				Tee (Branch)	1.56	1	1.56	
	4.00	25.99	0.0170				147.01	2.4992
1½				Straight Pipe	321.00	1	321.00	
				90° Elbow	10.85	8	86.80	
				Tee (Branch)	2.07	7	14.49	
	4.00	15.16	0.0237				422.29	10.0083
1¼				Straight Pipe	80.00	1	80.00	
				90° Elbow	9.61	2	19.22	
				Tee (Thru)	1.64	1	1.64	
	4.00	10.88	0.0290				100.86	2.9249
1				Straight Pipe	103.00	1	103.00	
				90° Elbow	3.40	0	0.00	
				Tee (Thru)	2.00	5	10.00	
	4.00	7.28	0.0373				113.00	4.2149
¾				Straight Pipe	64.00	1	64.00	
				90° Elbow	2.20	0	0.00	
				Tee (Thru)	0.80	1	0.80	
	4.00	4.41	0.0510				64.80	3.3048
½				Straight Pipe	15.00	1	15.00	
				90° Elbow	3.00	0	0.00	
				Tee (Branch)	2.00	2	4.00	
	4.00	2.21	0.0787				19.00	1.4953
Total Friction Loss to Most Distant Fixture								**24.4474**

Table 34: Total friction loss in PEX tubing to most distant fixture.

Appendix C:

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Appendix D:

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Appendix E:

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