PORTLAND STATE UNIVERSITY

Department of Civil and Environmental Engineering
CE484 Design Lab

Design Submittal Report

EWB Water Tower

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Introduction

The Jessie F. Richardson Foundation, in conjunction with the Institute on Aging at Portland State University has been working to provide accessible care for the elderly of Nicaragua. Both agencies have also prompted coordination with Engineers Without Borders to update elder-care facilities within Nicaragua. Of specific concern is the facility in the city of Jinotepe, which was originally built to handle 14 residents. The current number of residents is at 37 persons and is expected to keep increasing as the population of the aged increases. The resident population growth is causing increased costs to the home as well as the city of Jinotepe which provides water and electricity to the facility free of charge.

Figure 1 Pacific coast region of Nicaragua

Background

In the spring of 2006 an Engineers Without Borders student group, under the auspices of the Jessie F. Richardson Foundation and Portland State University's Institute on Aging, installed a secondary potable water storage tank at an elderly care facility in Jinotepe Nicaragua. The original project design was to install a pump and plumbing lines to a preexisting open top concrete tank. Upon inspection of the concrete tank it was found to not be suitable for water storage as it leaked its entire contents over the course of one evening. As a solution to the faulty tank and time constraints, a prefabricated vinyl water tank was purchased and installed on the ground next to the original elevated water tank utilizing the original pump system design. When the final inspection occurred with the facility administrator, the issue of paying for electricity to pump water from the lower tank to the main facility tank was questioned for the long term maintenance. The primary reservation brought up by the facility administrator was that the installed tank, unlike the concrete tank, should have been placed on another tower as an expansion of the current gravity feed system for the water supply.

In agreement with the facility administrator and Keren Brown Wilson of the Jessie F. Richardson Foundation, the student assessment team committed to returning the following year to remove the electrical reliance of the pump in the water supply system. Currently, the city water line supplies enough pressure to fill the elevated water storage tank and the ground-level storage tank at the site. The elevated tank directly supplies potable water into the facility. The lower tank acts solely as secondary storage unit and pumps water to the elevated tank once it is empty.

Selection of Design

The goal of this design was to provide a clear cost effective and maintainable design that fits into the cultural paradigm of this Pacific Coast region of Nicaragua. One of the alternatives considered was a solar-powered system. The physical environment as well as the application and installation of the solar power system would have been feasible. The problem with the solar system lies in the cost. Although the installation cost is possible to meet, battery replacement costs would be cost-prohibitive. The gel batteries, which are encased and sealed from the environment, are costly. The present value of battery replacement is upwards of $375, not accounting for shipping and possible installation costs.

A second alternative considered involved using human power, such as a pedal-powered bicycle pumping system. Installation costs could have been met, but we cannot guarantee that the device would be used as regularly as necessary to generate enough power.

Wind power was another alternative considered. A wind turbine could have functioned as a back-up device to the pump, but several factors make this option prohibitive. The wind turbine would require two sealed deep-cell batteries, which would need replacing every 10 years, and which would cost approximately $750 before shipping and installation. The turbine itself would require specialized mechanical maintenance which would be costly. Another hindrance to wind-turbine installation is the fact that the mast would need to be sufficiently tall to clear the trees, and the town administrators would likely not approve a structure of the required height.

The design selected, based on client expectations and cost feasibility, is a raised water tank and tower. Erecting a tower to elevate the secondary storage tank will eliminate the need for a pump system. Raising the water tank will provide hydrostatic pressure (about 0.44 PSI per foot of height) which would provide sufficient pressure for the gravity feed system that requires little or no maintenance for a design life based on the durability of the steel tower. A frame made from steel will best withstand the weather conditions and be an acceptable structure at the facility. The project is also feasible because it utilizes the talents and skills of civil and mechanical engineering students and fits within the time constraints of the volunteer workforce.

Project Design

Fundamental aspects of the design are a steel frame tower with concrete and rebar footings. The tower will provide the support for a 2500 liter water tank. The new tower will be connected, structurally, to the existing water tower to mitigate seismic risk issues. The connection will also provide a rigid support to guard the pipe connections that are susceptible to shearing due to differential settlement of the tower relative to the existing structure.

Geotechnical Recommendations

Seismic data for the country of Nicaragua shows that seismic activity is a serious potential hazard. (Hedberg, 87). According to the 1997 Uniform Building Code (UBC) and United States Geological Survey (USGS) Central America Hazard Map it was concluded that Jinotepe has been categorized Zone 4, the most severe earthquake hazard category. See Appendix.A for Managua, Nicaragua fault map.

During the course of the original assessment it was noted that the soil specific to the construction site is tuff-based non-cohesive low-density silt. Since no direct soil sampling was performed the 97-UBC was referenced and utilizing a soil S_D type the following recommendations were made:

- Allowable foundation pressure - 1000 psf (47.9 kPa)
- Lateral bearing of depth below natural grade – 100 psf per ft (15.7 kPa per m)
- Lateral sliding resistance – 130 psf (6.227 kPa)

Foundation Design

Due to the limited information regarding soil properties in Jinotepe other than preliminary basic information, it can be assumed a worst-case scenario for design purposes under ASD.

After calculations, it was determined that the maximum seismic load was 2,053 lb. See Appendix B for calculations of the seismic load. The main problem in water towers is the potential for overturning due to lateral forces such as seismic and wind loads. Thus, the main design considerations were bearing and overturning.

The foundation system will utilize 2' x 2' spread footings, 19-in thick, and reinforced with four #3 rebar, spaced at 6" o.c. in both directions under each column of the 2500L tower at mid-depth. A detailed view of the foundation design parameters can be seen in Appendix B, Foundation Design.

Tank Tower Design

The tower was designed to hold a five foot diameter, 2500L tank, ten feet in the air under gravity and seismic loading using the 97 Universal Building Code and the United States Geological Survey Central America Hazard map. The existing tower was analyzed using SAP modeling software with a 100 lb DL, 5500 lb LL, and a seismic base shear of V=.35W. Analysis concluded that the existing tower design is stable and all members are within their capacities. The loading results are available in appendix B.

Columns will be HSS3 x 3 x ⅛, the perimeter members of the tank platform will be L3 x 3 x ¼ and all other members will be L2 x 2 x ⅛. The maximum joint loading is1050 ft-lb moment and 2300 lb axial load. Considering the tower will be assembled in the field by amateur welders, an 1/8” fillet weld with a capacity of 1.28 kips per inch of weld on all contact surfaces will be sufficient to overcome any weld flaws.

A bending moment induced into the main support columns at the one-third point could be avoided by running the x-bracing all the way to the footing; however, for ease of installation, design was kept as is. Considering the low load to capacity ratios of the column members, this is acceptable.

Tank Flow Connections Design

Upon assessment of required flow between the towers, it is suggested that a PVC pipe with a 1-in diameter be used. The water supply to the tank system is provided by the city water system. The city water supply pressure fluctuates between 30 to 50psi which is sufficient to feed the elevated tanks.

A minimum inner pipe diameter of ½ inch would work for the system and the flow calculations are shown in Appendix D. The current design, however utilizes 1 inch PVC piping. The 1" diameter pipe has an inner diameter of 7/8 inches and will allow the system to manage any increased demand that is unforeseen in this analysis without being too conservative. It is also good practice to stay with the current sizing that has sufficiently supported the current potable water feeds into the facility.

Work Plan

Day 0 (before construction crew arrival): Drainage of current tank system, system disconnection from municipal water supply by facilities' maintenance
Day 1: Dig piers, install reinforcing bars, and pour piers.
Day 2: Lay out steel, cut to length, and begin tower erection.
Day 3: Tower erection.
Day 4: Tower erection, raise tank.
Day 5: Connect plumbing, check for leaks.
Day 6: Approval from administrator to close-out project prior to departure.

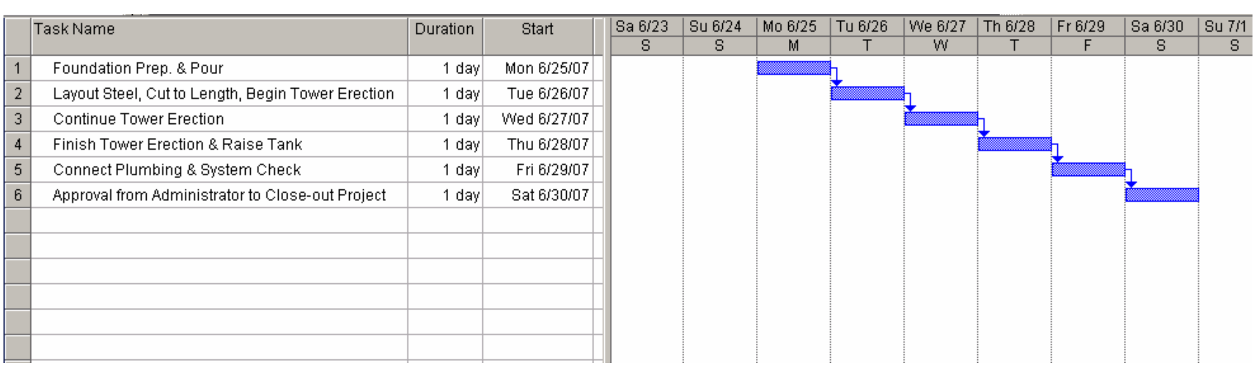


Figure 2 Project work plan with predecessor constraints

Costs

The itemized cost breakdown is as follows:

	Unit Cost	x	#Units	=	Cost of Supply
Rebar (3/8 x 20ft)…..…………………..	$ 4.00 stick	x	4 sticks	=	$ 16.00
Concrete……….…………………….	$ 35.00 P bag	x	12 bags	=	$ 420.00
Steel angle iron (L2x2x1/8)…..…….	$ 2.50 PLF	x	200ft	=	$ 500.00
Steel channel iron (L3x3x1/4)............	$ 4.45 PLF	x	45ft	=	$ 200.00
Steel tube iron (3x3)……..………....	$ 4.00 PLF	x	50ft	=	$ 200.00
PVC (1 inch x 10ft)..………………..	$ 1.50 stick	x	2 sticks	=	$ 3.00
			Total Cost	=	$ 1339.00

The labor and travel accommodations for implementation of the project design have all been paid for through financial grants provided by the Jessie F Richardson Foundation and the student chapter of Engineers Without Borders, Portland State University.

Appendix A: Geotechnical

Seismic Issues

There are three sources capable of creating seismic events in the Pacific Region of Nicaragua: the subduction zone, volcanoes, and local faults as shown in Figure 1.

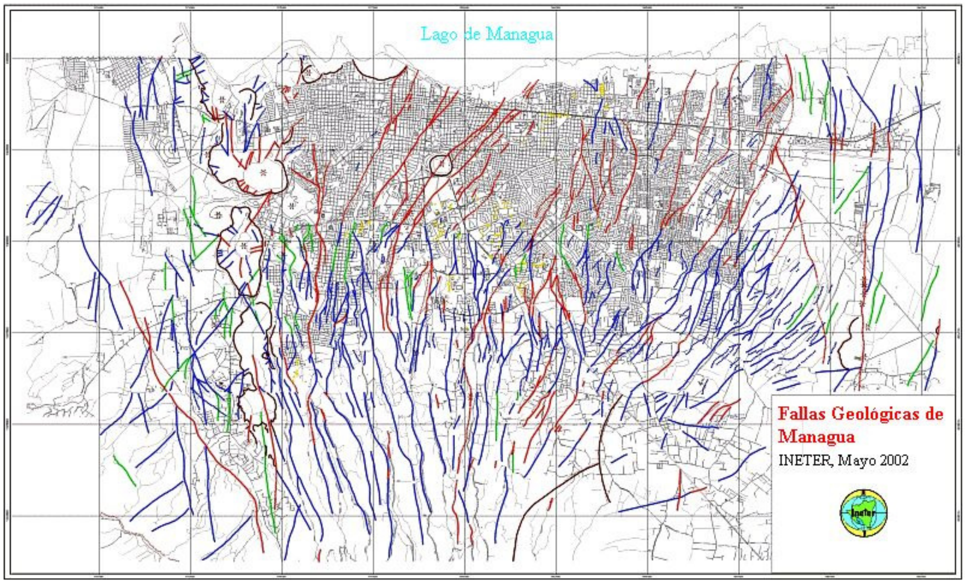


Figure 3 local faults located in the pacific coast region

Geology

The geological stratigraphy is comprised of volcanic tuff from the upper Las Sierras group, regionally called "cantera". Tuff is pyroclastic materials composed of ash and dust from volcanic eruptions. It dates from the early quaternary volcanic events. Overall, the stiffness of the soil increases gradually with depth and there is no defined demarcation between the lower stratigraphy and upper subsurface layers with in the pacific coast region of Nicaragua.

Soil Profile

The basic soil profile of silts and as observed during the site investigation, the silts have a great ability for water absorption and appear to have a low weight. For these reasons it was concluded that they have a high porosity and low density. Since no laboratory testing of the soil is available for the use of determining the foundation footing design depth and geometry, the design parameters were based on the UBC code (1997 pg 2-34 table 16-Q) for a predominately silty soil (ML) and shown as a soil Profile type S_D for seismic zone 4.

Foundation Recommendations

Since no direct soil testing was performed at the time of the site assessment the capacities of the soil were based on the UBC code (1997 pg 2-49 table 18-I-A) for soil type S_D. The code provides for the following parameters to be utilized for the footing design as:

- Allowable foundation pressure - 1000 psf (47.9 kPa)
- Lateral bearing of depth below natural grade – 100 psf per ft (15.7 kPa per m)
- Lateral sliding resistance – 130 psf (6.227 kPa)

Appendix B: Foundation Design

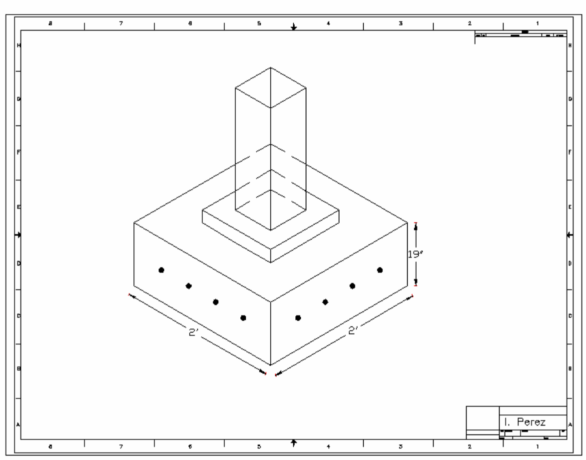
According to code, there are three types of failures that can occur: bearing, shear and turnover due to seismic or wind loads. Potential seismic activity is a greater concern because Nicaragua is under Zone 4 risk, where the seismic force for a building is

$$V_{min} = 1.6ZN_vIW/R \quad \text{(Equation 34-3, 1997 UBC).}$$

The following were assumed about the soil conditions based on region assessment, Zone 4 hazard classification, and previous data from last year's assessment at the site.

$N_v = 1.2$
$I = 1.0$
$R = 2.2$

After calculations, it was determined that the maximum seismic load was 2,053 lb. The main problem in water towers is overturning due to seismic and wind loads. Thus the main design parameter was bearing and overturning. The vertical shearing force due to moment was 3.7 kips, which was the higher force that would cause bearing in the foundation. The minimum area of the foundation with consideration for bearing is 20" x 20". Thus, the standard foundation would be 2' x 2'. With a 19" thick foundation depth, the uplift force can be neglected.
For the 5000-L tower, the seismic load would be 4045 lb, and the shear force due to overturning is 6.61 kips. In order to prevent bearing failure, the foundation needs a minimum area of 2'3" x 2'3". The uplift force of 1.16kips would then be counteracted by the 19" thick foundation.
(More information about the rebar needed.)
The foundation system will be 2' x 2' spread footings with a thickness of 19", reinforced with 4 #3 rebar spaced at 3" o.c. in both directions under each column of the 2500 L tower at mid-depth. The design foundation system for the 5000 L tower is estimated at 2'3" x 2'3" footings with 19" thickness, 4 #3 reinforced rebar spaced at 3" o.c. at mid-depth.



Appendix C: Tank Tower Design

TABLE: Steel Design 1 - Summary Data - AISC-LRFD93							
Frame	**DesignSect**	**DesignType**	**Status**	**Ratio**	**RatioType**	**Combo**	**Location**
Text	Text	Text	Text	Unitless	Text	Text	ft
6	L3X3X.25	Beam	No Messages	0.067325	PMM	DSTL31	0
8	L3X3X.25	Beam	No Messages	0.067325	PMM	DSTL31	5
13	HSS3X3X1/8	Column	No Messages	0.125045	PMM	DSTL30	6.015
14	HSS3X3X1/8	Column	No Messages	0.121147	PMM	DSTL30	0
15	HSS3X3X1/8	Column	No Messages	0.108522	PMM	DSTL31	6.015
16	HSS3X3X1/8	Column	No Messages	0.104824	PMM	DSTL32	0
17	HSS3X3X1/8	Column	No Messages	0.125045	PMM	DSTL30	6.015
18	HSS3X3X1/8	Column	No Messages	0.121147	PMM	DSTL30	0
19	HSS3X3X1/8	Column	No Messages	0.112423	PMM	DSTL31	6.015
20	HSS3X3X1/8	Column	No Messages	0.111555	PMM	DSTL31	0
21	L2X2X1/8	Beam	No Messages	0.025512	PMM	DSTL31	1.8667
22	L2X2X1/8	Beam	No Messages	0.030643	PMM	DSTL31	1.8667
23	L2X2X1/8	Beam	No Messages	0.025812	PMM	DSTL30	1.8667
24	L2X2X1/8	Beam	No Messages	0.030309	PMM	DSTL30	1.8667
25	L2X2X1/8	Brace	See WarnMsg	0.05597	PMM	DSTL30	4.0056
26	L2X2X1/8	Brace	See WarnMsg	0.335328	PMM	DSTL31	4.0056
27	L2X2X1/8	Brace	See WarnMsg	0.320336	PMM	DSTL30	4.0056
28	L2X2X1/8	Brace	See WarnMsg	0.066553	PMM	DSTL30	4.0056
29	L2X2X1/8	Brace	See WarnMsg	0.059401	PMM	DSTL31	4.0056
30	L2X2X1/8	Brace	See WarnMsg	0.320336	PMM	DSTL30	4.0056
31	L2X2X1/8	Brace	See WarnMsg	0.335328	PMM	DSTL31	4.0056
32	L2X2X1/8	Brace	See WarnMsg	0.050281	PMM	DSTL30	4.0056
9	L2X2X1/8	Beam	See WarnMsg	0.034809	PMM	DSTL31	3.5355
10	L2X2X1/8	Beam	See WarnMsg	0.034985	PMM	DSTL30	0
33	L3X3X1/4	Beam	No Messages	0.102719	PMM	DSTL31	0
34	L3X3X1/4	Beam	No Messages	0.119785	PMM	DSTL31	1
35	L3X3X1/4	Beam	No Messages	0.119786	PMM	DSTL31	0
36	L3X3X1/4	Beam	No Messages	0.119785	PMM	DSTL31	0
37	L3X3X1/4	Beam	No Messages	0.133024	PMM	DSTL30	1
38	L3X3X1/4	Beam	No Messages	0.143103	PMM	DSTL31	0
39	L3X3X1/4	Beam	No Messages	0.116155	PMM	DSTL31	1
40	L3X3X1/4	Beam	No Messages	0.116155	PMM	DSTL31	1
41	L3X3X1/4	Beam	No Messages	0.116155	PMM	DSTL31	0
42	L3X3X1/4	Beam	No Messages	0.143103	PMM	DSTL31	1
43	L3X3X1/4	Beam	No Messages	0.003227	PMM	DSTL31	3.3333
44	L3X3X1/4	Beam	No Messages	0.002575	PMM	DSTL31	3.3333
45	L3X3X1/4	Beam	No Messages	0.002606	PMM	DSTL30	3.3333
46	L3X3X1/4	Beam	No Messages	0.003529	PMM	DSTL30	3.3333

TABLE: Steel Design 2 - PMM Details - AISC-LRFD93								
Frame	DesignSect	DesignType	Status	Combo	Location	Pu	MuMajor	MuMinor
Text	Text	Text	Text	Text	ft	Lb	Lb-ft	Lb-ft
6	L3X3X.25	Beam	No Messages	DSTL31	0	56.49	-376.46	-63.06
8	L3X3X.25	Beam	No Messages	DSTL31	5	56.49	-376.46	-63.06
13	HSS3X3X1/8	Column	No Messages	DSTL30	6.015	-1191.45	1213.48	1209.43
14	HSS3X3X1/8	Column	No Messages	DSTL30	0	-821.68	1213.48	1209.43
15	HSS3X3X1/8	Column	No Messages	DSTL31	6.015	-1193.08	1211.21	-872.02
16	HSS3X3X1/8	Column	No Messages	DSTL32	0	-1114.79	-1032.61	-1031.28
17	HSS3X3X1/8	Column	No Messages	DSTL30	6.015	-1191.45	1213.48	-1209.43
18	HSS3X3X1/8	Column	No Messages	DSTL30	0	-821.68	1213.48	-1209.43
19	HSS3X3X1/8	Column	No Messages	DSTL31	6.015	-1838.36	-872.51	-1211.95
20	HSS3X3X1/8	Column	No Messages	DSTL31	0	-2573.97	-872.51	-1211.95
21	L2X2X1/8	Beam	No Messages	DSTL31	1.8667	71.74	10.27	0
22	L2X2X1/8	Beam	No Messages	DSTL31	1.8667	311.81	10.27	0
23	L2X2X1/8	Beam	No Messages	DSTL30	1.8667	85.79	10.27	0
24	L2X2X1/8	Beam	No Messages	DSTL30	1.8667	296.18	10.27	0
25	L2X2X1/8	Brace	See WarnMsg	DSTL30	4.0056	-92.4	15.67	0
26	L2X2X1/8	Brace	See WarnMsg	DSTL31	4.0056	-787.69	15.67	0
27	L2X2X1/8	Brace	See WarnMsg	DSTL30	4.0056	-748.78	15.67	0
28	L2X2X1/8	Brace	See WarnMsg	DSTL30	4.0056	-146.53	15.67	0
29	L2X2X1/8	Brace	See WarnMsg	DSTL31	4.0056	-109.95	15.67	0
30	L2X2X1/8	Brace	See WarnMsg	DSTL30	4.0056	-748.78	15.67	0
31	L2X2X1/8	Brace	See WarnMsg	DSTL31	4.0056	-787.69	15.67	0
32	L2X2X1/8	Brace	No Messages	DSTL30	4.0056	577.54	15.67	0
9	L2X2X1/8	Beam	See WarnMsg	DSTL31	3.5355	-19.19	11.7	-6.03
10	L2X2X1/8	Beam	See WarnMsg	DSTL30	0	-19.19	-12.17	4.64
33	L3X3X1/4	Beam	No Messages	DSTL31	0	-243.62	-880.43	-47.98
34	L3X3X1/4	Beam	No Messages	DSTL31	1	-243.62	923.26	72.06
35	L3X3X1/4	Beam	No Messages	DSTL31	0	-243.62	923.26	72.06
36	L3X3X1/4	Beam	No Messages	DSTL31	0	-243.62	923.26	72.06
37	L3X3X1/4	Beam	No Messages	DSTL30	1	-196.81	-1231.78	49.73
38	L3X3X1/4	Beam	No Messages	DSTL31	0	-150	-901.77	-118.16
39	L3X3X1/4	Beam	No Messages	DSTL31	1	-150	901.92	69.9
40	L3X3X1/4	Beam	No Messages	DSTL31	1	-150	901.92	69.9
41	L3X3X1/4	Beam	No Messages	DSTL31	0	-150	901.92	69.9
42	L3X3X1/4	Beam	No Messages	DSTL31	1	-150	-901.77	-118.16
43	L3X3X1/4	Beam	No Messages	DSTL31	3.3333	-50.78	29.94	0
44	L3X3X1/4	Beam	No Messages	DSTL31	3.3333	8.38	29.94	0
45	L3X3X1/4	Beam	No Messages	DSTL30	3.3333	13.71	29.94	0
46	L3X3X1/4	Beam	No Messages	DSTL30	3.3333	-72.66	29.94	0

TABLE: Steel Design 2 - PMM Details - AISC-LRFD93							
Frame	**DesignSect**	**DesignType**	**Fy**	**E**	**Length**	**SectClass**	**FramingType**
Text	Text	Text	Lb/ft2	Lb/ft2	ft	Text	Text
6	L3X3X.25	Beam	5184000	4176000000	5	Compact	Moment Resisting Frame
8	L3X3X.25	Beam	5184000	4176000000	5	Compact	Moment Resisting Frame
13	HSS3X3X1/8	Column	5184000	4176000000	6.015	Non-Compact	Moment Resisting Frame
14	HSS3X3X1/8	Column	5184000	4176000000	4.01	Non-Compact	Moment Resisting Frame
15	HSS3X3X1/8	Column	5184000	4176000000	6.015	Non-Compact	Moment Resisting Frame
16	HSS3X3X1/8	Column	5184000	4176000000	4.01	Non-Compact	Moment Resisting Frame
17	HSS3X3X1/8	Column	5184000	4176000000	6.015	Non-Compact	Moment Resisting Frame
18	HSS3X3X1/8	Column	5184000	4176000000	4.01	Non-Compact	Moment Resisting Frame
19	HSS3X3X1/8	Column	5184000	4176000000	6.015	Non-Compact	Moment Resisting Frame
20	HSS3X3X1/8	Column	5184000	4176000000	4.01	Non-Compact	Moment Resisting Frame
21	L2X2X1/8	Beam	5184000	4176000000	5.6	Slender	Moment Resisting Frame
22	L2X2X1/8	Beam	5184000	4176000000	5.6	Slender	Moment Resisting Frame
23	L2X2X1/8	Beam	5184000	4176000000	5.6	Slender	Moment Resisting Frame
24	L2X2X1/8	Beam	5184000	4176000000	5.6	Slender	Moment Resisting Frame
25	L2X2X1/8	Brace	5184000	4176000000	8.0112	Slender	Moment Resisting Frame
26	L2X2X1/8	Brace	5184000	4176000000	8.0112	Slender	Moment Resisting Frame
27	L2X2X1/8	Brace	5184000	4176000000	8.0112	Slender	Moment Resisting Frame
28	L2X2X1/8	Brace	5184000	4176000000	8.0112	Slender	Moment Resisting Frame
29	L2X2X1/8	Brace	5184000	4176000000	8.0112	Slender	Moment Resisting Frame
30	L2X2X1/8	Brace	5184000	4176000000	8.0112	Slender	Moment Resisting Frame
31	L2X2X1/8	Brace	5184000	4176000000	8.0112	Slender	Moment Resisting Frame
32	L2X2X1/8	Brace	5184000	4176000000	8.0112	Slender	Moment Resisting Frame
9	L2X2X1/8	Beam	5184000	4176000000	7.0711	Slender	Moment Resisting Frame
10	L2X2X1/8	Beam	5184000	4176000000	7.0711	Slender	Moment Resisting Frame
33	L3X3X1/4	Beam	5184000	4176000000	1	Compact	Moment Resisting Frame
34	L3X3X1/4	Beam	5184000	4176000000	1	Compact	Moment Resisting Frame
35	L3X3X1/4	Beam	5184000	4176000000	1	Compact	Moment Resisting Frame
36	L3X3X1/4	Beam	5184000	4176000000	1	Compact	Moment Resisting Frame
37	L3X3X1/4	Beam	5184000	4176000000	1	Compact	Moment Resisting Frame
38	L3X3X1/4	Beam	5184000	4176000000	1	Compact	Moment Resisting Frame
39	L3X3X1/4	Beam	5184000	4176000000	1	Compact	Moment Resisting Frame
40	L3X3X1/4	Beam	5184000	4176000000	1	Compact	Moment Resisting Frame
41	L3X3X1/4	Beam	5184000	4176000000	1	Compact	Moment Resisting Frame
42	L3X3X1/4	Beam	5184000	4176000000	1	Compact	Moment Resisting Frame
43	L3X3X1/4	Beam	5184000	4176000000	5	Compact	Moment Resisting Frame
44	L3X3X1/4	Beam	5184000	4176000000	5	Compact	Moment Resisting Frame
45	L3X3X1/4	Beam	5184000	4176000000	5	Compact	Moment Resisting Frame
46	L3X3X1/4	Beam	5184000	4176000000	5	Compact	Moment Resisting Frame

TABLE: Element Joint Forces - Frames

Frame	Joint	OutputCase	CaseType	F1	F2	F3	M1	M2	M3
Text	Text	Text	Text	Lb	Lb	Lb	Lb-ft	Lb-ft	Lb-ft
6	7	SERV2	Combination	-56.39	-16.39	123.09	-0.03521	-266.2	-45.45
6	8	SERV2	Combination	56.39	16.39	-78.17	0.03521	-236.93	-36.5
8	6	SERV2	Combination	56.39	-16.39	-78.17	-0.03521	-236.93	36.5
8	5	SERV2	Combination	-56.39	16.39	123.09	0.03521	-266.2	45.45
9	7	SERV2	Combination	14.13	12.52	9.72	5.92	-6.02	-8.26
9	6	SERV2	Combination	-14.13	-12.52	7.65	-0.74	0.84	0.18
10	8	SERV2	Combination	-14.13	12.52	7.65	0.74	0.84	-0.18
10	5	SERV2	Combination	14.13	-12.52	9.72	-5.92	-6.02	8.26
13	8	SERV2	Combination	-128.54	-269.75	-1608.25	-887.54	236.1	-56.18
13	11	SERV2	Combination	128.54	269.75	1696.26	-235.31	1030.83	-63.31
14	11	SERV2	Combination	371.29	-54.76	-2242.39	235.31	-1030.83	63.31
14	4	SERV2	Combination	-371.29	54.76	2301.07	2.293E-14	2.47E-13	-1.519E-14
15	5	SERV2	Combination	-275.98	244.94	-1136.44	877.71	272.22	-30.27
15	12	SERV2	Combination	275.98	-244.94	1224.45	237.76	1029.5	39.59
16	12	SERV2	Combination	203.69	-5.75	-1044.41	-237.76	-1029.5	-39.59
16	2	SERV2	Combination	-203.69	5.75	1103.09	-5.23E-15	-1.535E-13	1.469E-14
17	7	SERV2	Combination	-275.98	-244.94	-1136.44	-877.71	272.22	30.27
17	13	SERV2	Combination	275.98	244.94	1224.45	-237.76	1029.5	-39.59
18	13	SERV2	Combination	203.69	5.75	-1044.41	237.76	-1029.5	39.59
18	1	SERV2	Combination	-203.69	-5.75	1103.09	9.728E-15	4.038E-13	-5.196E-14
19	6	SERV2	Combination	-128.54	269.75	-1608.25	887.54	236.1	56.18
19	14	SERV2	Combination	128.54	-269.75	1696.26	235.31	1030.83	63.31
20	14	SERV2	Combination	371.29	54.76	-2242.39	-235.31	-1030.83	-63.31
20	3	SERV2	Combination	-371.29	-54.76	2301.07	-1.672E-14	6.55E-13	-1.982E-15
21	13	SERV2	Combination	-70.18	0	6.88	0	0	0
21	11	SERV2	Combination	70.18	0	6.88	0	0	0
22	11	SERV2	Combination	0	-303.15	6.88	0	0	0
22	14	SERV2	Combination	0	303.15	6.88	0	0	0
23	14	SERV2	Combination	70.18	0	6.88	0	0	0
23	12	SERV2	Combination	-70.18	0	6.88	0	0	0
24	12	SERV2	Combination	0	281.27	6.88	0	0	0
24	13	SERV2	Combination	0	-281.27	6.88	0	0	0
25	13	SERV2	Combination	-232.3	-13.15	-253.14	0	0	0
25	8	SERV2	Combination	232.3	13.15	272.83	0	0	0
26	11	SERV2	Combination	-386.61	21.88	447.51	0	0	0
26	7	SERV2	Combination	386.61	-21.88	-427.83	0	0	0
27	7	SERV2	Combination	-2.48	43.73	-39.66	0	0	0
27	12	SERV2	Combination	2.48	-43.73	59.35	0	0	0
28	12	SERV2	Combination	-232.3	13.15	-253.14	0	0	0
28	6	SERV2	Combination	232.3	-13.15	272.83	0	0	0
29	6	SERV2	Combination	3.75	-66.27	-65.18	0	0	0
29	11	SERV2	Combination	-3.75	66.27	84.86	0	0	0
30	8	SERV2	Combination	3.75	66.27	-65.18	0	0	0
30	14	SERV2	Combination	-3.75	-66.27	84.86	0	0	0
31	14	SERV2	Combination	-386.61	-21.88	447.51	0	0	0
31	5	SERV2	Combination	386.61	21.88	-427.83	0	0	0

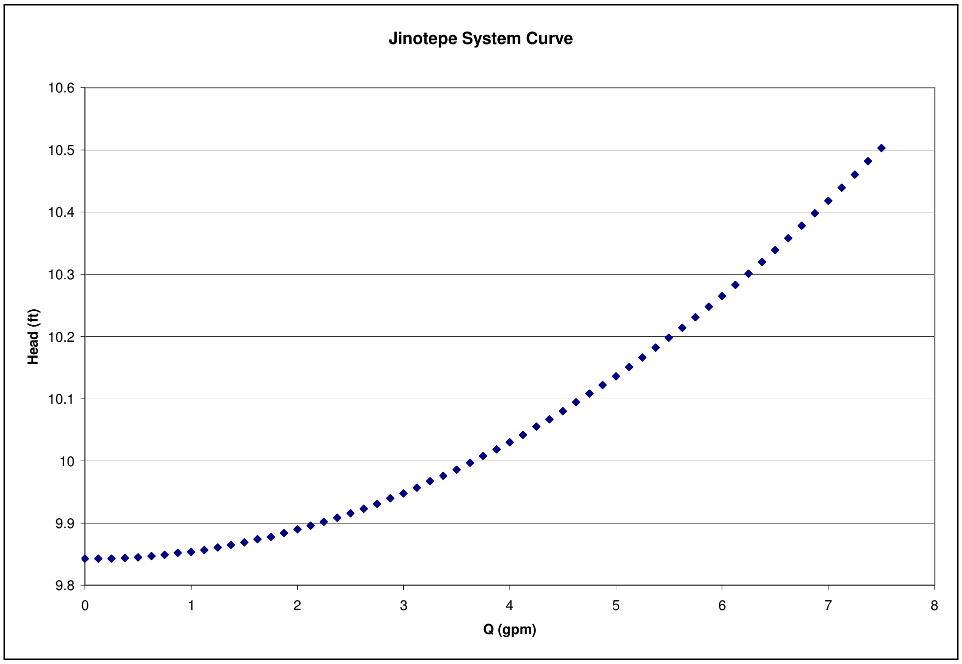
TABLE: Element Joint Forces - Frames									
Frame	Joint	OutputCase	CaseType	F1	F2	F3	M1	M2	M3
Text	Text	Text	Text	Lb	Lb	Lb	Lb-ft	Lb-ft	Lb-ft
32	5	SERV2	Combination	-2.48	-43.73	-39.66	0	0	0
32	13	SERV2	Combination	2.48	43.73	59.35	0	0	0
33	5	SERV2	Combination	-29.95	-226.96	1471.13	-871.83	-5.35E-15	-23.44
33	9	SERV2	Combination	29.95	226.96	-900.64	-314.05	5.35E-15	-6.51
34	9	SERV2	Combination	-44.24	-226.96	878.18	314.05	-5.339E-15	6.51
34	10	SERV2	Combination	44.24	226.96	-307.7	-906.99	5.339E-15	-50.75
35	10	SERV2	Combination	1.126E-12	-226.96	285.24	906.99	-5.353E-15	50.75
35	15	SERV2	Combination	-1.126E-12	226.96	285.24	-906.99	5.353E-15	-50.75
36	15	SERV2	Combination	44.24	-226.96	-307.7	906.99	-4.72E-15	50.75
36	16	SERV2	Combination	-44.24	226.96	878.18	-314.05	4.72E-15	-6.51
37	16	SERV2	Combination	29.95	-226.96	-900.64	314.05	-4.72E-15	6.51
37	7	SERV2	Combination	-29.95	226.96	1471.13	871.83	4.72E-15	23.44
38	6	SERV2	Combination	-113.83	-161.43	1471.13	-886.77	-3.562E-15	-92.86
38	17	SERV2	Combination	113.83	161.43	-900.64	-299.12	3.562E-15	-20.97
39	17	SERV2	Combination	-27.65	-161.43	878.18	299.12	-5.008E-15	20.97
39	18	SERV2	Combination	27.65	161.43	-307.7	-892.06	5.008E-15	-48.62
40	18	SERV2	Combination	4.821E-13	-161.43	285.24	892.06	-5.343E-15	48.62
40	19	SERV2	Combination	-4.821E-13	161.43	285.24	-892.06	5.343E-15	-48.62
41	19	SERV2	Combination	27.65	-161.43	-307.7	892.06	-4.68E-15	48.62
41	20	SERV2	Combination	-27.65	161.43	878.18	-299.12	4.68E-15	-20.97
42	20	SERV2	Combination	113.83	-161.43	-900.64	299.12	-4.681E-15	20.97
42	8	SERV2	Combination	-113.83	161.43	1471.13	886.77	4.681E-15	92.86
43	9	SERV2	Combination	50.23	0	22.46	0	0	0
43	17	SERV2	Combination	-50.23	0	22.46	0	0	0
44	10	SERV2	Combination	-8.29	0	22.46	0	0	0
44	18	SERV2	Combination	8.29	0	22.46	0	0	0
45	15	SERV2	Combination	-8.29	0	22.46	0	0	0
45	19	SERV2	Combination	8.29	0	22.46	0	0	0
46	16	SERV2	Combination	50.23	0	22.46	0	0	0
46	20	SERV2	Combination	-50.23	0	22.46	0	0	0
6	7	SERV1	Combination	-49.78	3.373E-13	22.46	-5.108E-14	-14.9	-5.75
6	8	SERV1	Combination	49.78	-3.373E-13	22.46	5.108E-14	14.9	5.75
8	6	SERV1	Combination	63.01	-3.423E-13	22.46	5.116E-14	14.37	-3.2
8	5	SERV1	Combination	-63.01	3.423E-13	22.46	-5.116E-14	-14.37	3.2
9	7	SERV1	Combination	14.13	12.52	9.76	6.02	-6.12	-4.43
9	6	SERV1	Combination	-14.13	-12.52	7.61	-0.64	0.73	-3.65
10	8	SERV1	Combination	-14.13	12.52	9.76	6.02	6.12	4.43
10	5	SERV1	Combination	14.13	-12.52	7.61	-0.64	-0.73	3.65
13	8	SERV1	Combination	62.96	-457.36	-1135.33	-1123.79	-21.02	-55.14
13	11	SERV1	Combination	-62.96	457.36	1223.34	-1266.58	-2.93	-63.18
14	11	SERV1	Combination	52.96	262.95	-1044.53	1266.58	2.93	63.18
14	4	SERV1	Combination	-52.96	-262.95	1103.2	-5.133E-13	-5.908E-15	1.217E-14
15	5	SERV1	Combination	-84.48	57.33	-1609.36	641.46	15.1	-31.32
15	12	SERV1	Combination	84.48	-57.33	1697.37	-793.51	-4.25	39.46
16	12	SERV1	Combination	-114.64	311.96	-2242.28	793.51	4.25	-39.46
16	2	SERV1	Combination	114.64	-311.96	2300.95	-4.178E-13	-3.125E-15	3.627E-14
17	7	SERV1	Combination	-62.96	-457.36	-1135.33	-1123.79	21.02	55.14
17	13	SERV1	Combination	62.96	457.36	1223.34	-1266.58	2.93	63.18
18	13	SERV1	Combination	-52.96	262.95	-1044.53	1266.58	-2.93	-63.18
18	1	SERV1	Combination	52.96	-262.95	1103.2	9.943E-14	-4.392E-15	-6.981E-15

TABLE: Element Joint Forces - Frames									
Frame	**Joint**	**OutputCase**	**CaseType**	**F1**	**F2**	**F3**	**M1**	**M2**	**M3**
Text	Text	Text	Text	Lb	Lb	Lb	Lb-ft	Lb-ft	Lb-ft
19	6	SERV1	Combination	84.48	57.33	-1609.36	641.46	-15.1	31.32
19	14	SERV1	Combination	-84.48	-57.33	1697.37	-793.51	4.25	-39.46
20	14	SERV1	Combination	114.64	311.96	-2242.28	793.51	-4.25	39.46
20	3	SERV1	Combination	-114.64	-311.96	2300.95	-5.927E-13	1.979E-16	7.087E-15
21	13	SERV1	Combination	-60.34	0	6.88	0	0	0
21	11	SERV1	Combination	60.34	0	6.88	0	0	0
22	11	SERV1	Combination	0	-292.21	6.88	0	0	0
22	14	SERV1	Combination	0	292.21	6.88	0	0	0
23	14	SERV1	Combination	80.01	0	6.88	0	0	0
23	12	SERV1	Combination	-80.01	0	6.88	0	0	0
24	12	SERV1	Combination	0	292.21	6.88	0	0	0
24	13	SERV1	Combination	0	-292.21	6.88	0	0	0
25	13	SERV1	Combination	64.62	3.66	82.99	0	0	0
25	8	SERV1	Combination	-64.62	-3.66	-63.31	0	0	0
26	11	SERV1	Combination	-64.62	3.66	82.99	0	0	0
26	7	SERV1	Combination	64.62	-3.66	-63.31	0	0	0
27	7	SERV1	Combination	-20.5	362.11	-400.09	0	0	0
27	12	SERV1	Combination	20.5	-362.11	419.78	0	0	0
28	12	SERV1	Combination	89.68	-5.08	111.37	0	0	0
28	6	SERV1	Combination	-89.68	5.08	-91.69	0	0	0
29	6	SERV1	Combination	-14.27	252.11	295.25	0	0	0
29	11	SERV1	Combination	14.27	-252.11	-275.57	0	0	0
30	8	SERV1	Combination	20.5	362.11	-400.09	0	0	0
30	14	SERV1	Combination	-20.5	-362.11	419.78	0	0	0
31	14	SERV1	Combination	-89.68	-5.08	111.37	0	0	0
31	5	SERV1	Combination	89.68	5.08	-91.69	0	0	0
32	5	SERV1	Combination	14.27	252.11	295.25	0	0	0
32	13	SERV1	Combination	-14.27	-252.11	-275.57	0	0	0
33	5	SERV1	Combination	29.4	-194.2	1375.73	-640.82	0.001244	24.47
33	9	SERV1	Combination	-29.4	194.2	-805.25	-449.67	-0.001244	4.93
34	9	SERV1	Combination	-5.52	-194.2	782.79	449.67	0.001244	-4.93
34	10	SERV1	Combination	5.52	194.2	-212.31	-947.22	-0.001244	-0.59
35	10	SERV1	Combination	-0.96	-194.2	189.85	947.22	0.001244	0.59
35	15	SERV1	Combination	0.96	194.2	380.63	-851.83	-0.001244	-1.54
36	15	SERV1	Combination	11.06	-194.2	-403.09	851.83	0.001244	1.54
36	16	SERV1	Combination	-11.06	194.2	973.57	-163.5	-0.001244	9.52
37	16	SERV1	Combination	-54.48	-194.2	-996.03	163.5	0.001244	-9.52
37	7	SERV1	Combination	54.48	194.2	1566.52	1117.77	-0.001244	-44.96
38	6	SERV1	Combination	-29.4	-194.2	1375.73	-640.82	-0.001244	-24.47
38	17	SERV1	Combination	29.4	194.2	-805.25	-449.67	0.001244	-4.93
39	17	SERV1	Combination	5.52	-194.2	782.79	449.67	-0.001244	4.93
39	18	SERV1	Combination	-5.52	194.2	-212.31	-947.22	0.001244	0.59
40	18	SERV1	Combination	0.96	-194.2	189.85	947.22	-0.001244	-0.59
40	19	SERV1	Combination	-0.96	194.2	380.63	-851.83	0.001244	1.54
41	19	SERV1	Combination	-11.06	-194.2	-403.09	851.83	-0.001244	-1.54
41	20	SERV1	Combination	11.06	194.2	973.57	-163.5	0.001244	-9.52
42	20	SERV1	Combination	54.48	-194.2	-996.03	163.5	-0.001244	9.52
42	8	SERV1	Combination	-54.48	194.2	1566.52	1117.77	0.001244	44.96
43	9	SERV1	Combination	34.91	0	22.46	0	0	0
43	17	SERV1	Combination	-34.91	0	22.46	0	0	0

TABLE: Element Joint Forces - Frames									
Frame	**Joint**	**OutputCase**	**CaseType**	**F1**	**F2**	**F3**	**M1**	**M2**	**M3**
Text	Text	Text	Text	Lb	Lb	Lb	Lb-ft	Lb-ft	Lb-ft
44	10	SERV1	Combination	-4.56	0	22.46	0	0	0
44	18	SERV1	Combination	4.56	0	22.46	0	0	0
45	15	SERV1	Combination	-12.02	0	22.46	0	0	0
45	19	SERV1	Combination	12.02	0	22.46	0	0	0
46	16	SERV1	Combination	65.55	0	22.46	0	0	0
46	20	SERV1	Combination	-65.55	0	22.46	0	0	0
6	7	DSTL33	Combination	-0.46	-23.41	163.97	-0.05031	-370.37	-58.75
6	8	DSTL33	Combination	0.46	23.41	-123.54	0.05031	-348.4	-58.32
8	6	DSTL33	Combination	0.46	-23.41	-123.54	-0.05031	-348.4	58.32
8	5	DSTL33	Combination	-0.46	23.41	163.97	0.05031	-370.37	58.75
9	7	DSTL33	Combination	1.13	1.06	9.3	9.9	-9.91	-6.22
9	6	DSTL33	Combination	-1.13	-1.06	6.34	-2.5	2.51	5.83
10	8	DSTL33	Combination	-1.13	1.06	6.34	2.5	2.51	-5.83
10	5	DSTL33	Combination	1.13	-1.06	9.3	-9.9	-9.91	6.22
13	8	DSTL33	Combination	-278.15	-37.46	-447.94	-66.33	345.89	-20.61
13	11	DSTL33	Combination	278.15	37.46	527.15	-12.18	1469.29	-74.07
14	11	DSTL33	Combination	423.34	-52.97	-1093.89	12.18	-1469.29	74.07
14	4	DSTL33	Combination	-423.34	52.97	1146.69	-8.066E-15	3.554E-13	-2.435E-14
15	5	DSTL33	Combination	-299.73	2.01	226.07	52.3	380.27	16.4
15	12	DSTL33	Combination	299.73	-2.01	-146.86	15.68	1474.04	72.92
16	12	DSTL33	Combination	398.06	-33.48	617.51	-15.68	-1474.04	-72.92
16	2	DSTL33	Combination	-398.06	33.48	-564.71	-1.457E-17	-2.181E-13	1.265E-14
17	7	DSTL33	Combination	-299.73	-2.01	226.07	-52.3	380.27	-16.4
17	13	DSTL33	Combination	299.73	2.01	-146.86	-15.68	1474.04	-72.92
18	13	DSTL33	Combination	398.06	33.48	617.51	15.68	-1474.04	72.92
18	1	DSTL33	Combination	-398.06	-33.48	-564.71	8.014E-16	5.792E-13	-6.697E-14
19	6	DSTL33	Combination	-278.15	37.46	-447.94	66.33	345.89	20.61
19	14	DSTL33	Combination	278.15	-37.46	527.15	12.18	1469.29	74.07
20	14	DSTL33	Combination	423.34	52.97	-1093.89	-12.18	-1469.29	-74.07
20	3	DSTL33	Combination	-423.34	-52.97	1146.69	8.624E-15	9.322E-13	-5.42E-15
21	13	DSTL33	Combination	-7.03	0	6.19	0	0	0
21	11	DSTL33	Combination	7.03	0	6.19	0	0	0
22	11	DSTL33	Combination	0	-33.48	6.19	0	0	0
22	14	DSTL33	Combination	0	33.48	6.19	0	0	0
23	14	DSTL33	Combination	7.03	0	6.19	0	0	0
23	12	DSTL33	Combination	-7.03	0	6.19	0	0	0
24	12	DSTL33	Combination	0	2.22	6.19	0	0	0
24	13	DSTL33	Combination	0	-2.22	6.19	0	0	0
25	13	DSTL33	Combination	-433.61	-24.54	-482.03	0	0	0
25	8	DSTL33	Combination	433.61	24.54	499.74	0	0	0
26	11	DSTL33	Combination	-450.55	25.5	518.91	0	0	0
26	7	DSTL33	Combination	450.55	-25.5	-501.19	0	0	0
27	7	DSTL33	Combination	0.49	-8.71	18.72	0	0	0
27	12	DSTL33	Combination	-0.49	8.71	-1.01	0	0	0
28	12	DSTL33	Combination	-433.61	24.54	-482.03	0	0	0
28	6	DSTL33	Combination	433.61	-24.54	499.74	0	0	0
29	6	DSTL33	Combination	1.33	-23.49	-17.73	0	0	0
29	11	DSTL33	Combination	-1.33	23.49	35.45	0	0	0
30	8	DSTL33	Combination	1.33	23.49	-17.73	0	0	0
30	14	DSTL33	Combination	-1.33	-23.49	35.45	0	0	0

TABLE: Element Joint Forces - Frames									
Frame	**Joint**	**OutputCase**	**CaseType**	**F1**	**F2**	**F3**	**M1**	**M2**	**M3**
Text	Text	Text	Text	Lb	Lb	Lb	Lb-ft	Lb-ft	Lb-ft
31	14	DSTL33	Combination	-450.55	-25.5	518.91	0	0	0
31	5	DSTL33	Combination	450.55	25.5	-501.19	0	0	0
32	5	DSTL33	Combination	0.49	8.71	18.72	0	0	0
32	13	DSTL33	Combination	-0.49	-8.71	-1.01	0	0	0
33	5	DSTL33	Combination	-100.63	-58.58	83.14	-42.44	-7.871E-15	-81.37
33	9	DSTL33	Combination	100.63	58.58	-66.05	-32.15	7.871E-15	-19.26
34	9	DSTL33	Combination	-51.77	-58.58	45.84	32.15	-7.858E-15	19.26
34	10	DSTL33	Combination	51.77	58.58	-28.76	-69.45	7.858E-15	-71.03
35	10	DSTL33	Combination	1.613E-12	-58.58	8.54	69.45	-7.871E-15	71.03
35	15	DSTL33	Combination	-1.613E-12	58.58	8.54	-69.45	7.871E-15	-71.03
36	15	DSTL33	Combination	51.77	-58.58	-28.76	69.45	-6.968E-15	71.03
36	16	DSTL33	Combination	-51.77	58.58	45.84	-32.15	6.968E-15	-19.26
37	16	DSTL33	Combination	100.63	-58.58	-66.05	32.15	-6.968E-15	19.26
37	7	DSTL33	Combination	-100.63	58.58	83.14	42.44	6.968E-15	81.37
38	6	DSTL33	Combination	-104.77	35.04	83.14	-63.78	-5.518E-15	-84.77
38	17	DSTL33	Combination	104.77	-35.04	-66.05	-10.82	5.518E-15	-20
39	17	DSTL33	Combination	-50.93	35.04	45.84	10.82	-7.362E-15	20
39	18	DSTL33	Combination	50.93	-35.04	-28.76	-48.11	7.362E-15	-70.93
40	18	DSTL33	Combination	6.937E-13	35.04	8.54	48.11	-7.832E-15	70.93
40	19	DSTL33	Combination	-6.937E-13	-35.04	8.54	-48.11	7.832E-15	-70.93
41	19	DSTL33	Combination	50.93	35.04	-28.76	48.11	-6.891E-15	70.93
41	20	DSTL33	Combination	-50.93	-35.04	45.84	-10.82	6.891E-15	-20
42	20	DSTL33	Combination	104.77	35.04	-66.05	10.82	-6.891E-15	20
42	8	DSTL33	Combination	-104.77	-35.04	83.14	63.78	6.891E-15	84.77
43	9	DSTL33	Combination	2.49	0	20.21	0	0	0
43	17	DSTL33	Combination	-2.49	0	20.21	0	0	0
44	10	DSTL33	Combination	-0.42	0	20.21	0	0	0
44	18	DSTL33	Combination	0.42	0	20.21	0	0	0
45	15	DSTL33	Combination	-0.42	0	20.21	0	0	0
45	19	DSTL33	Combination	0.42	0	20.21	0	0	0
46	16	DSTL33	Combination	2.49	0	20.21	0	0	0
46	20	DSTL33	Combination	-2.49	0	20.21	0	0	0
6	7	DSTL32	Combination	8.99	4.931E-13	20.21	-7.244E-14	-11.36	-2.03
6	8	DSTL32	Combination	-8.99	-4.931E-13	20.21	7.244E-14	11.36	2.03
8	6	DSTL32	Combination	9.91	-4.891E-13	20.21	7.094E-14	10.61	1.61
8	5	DSTL32	Combination	-9.91	4.891E-13	20.21	-7.094E-14	-10.61	-1.61
9	7	DSTL32	Combination	1.13	1.06	9.36	10.05	-10.05	-0.75
9	6	DSTL32	Combination	-1.13	-1.06	6.28	-2.36	2.36	0.37
10	8	DSTL32	Combination	-1.13	1.06	9.36	10.05	10.05	0.75
10	5	DSTL32	Combination	1.13	-1.06	6.28	-2.36	-2.36	-0.37
13	8	DSTL32	Combination	-4.58	-305.48	227.66	-403.84	-21.42	-19.12
13	11	DSTL32	Combination	4.58	305.48	-148.45	-1485.43	-7.5	-73.9
14	11	DSTL32	Combination	-31.42	400.9	617.35	1485.43	7.5	73.9
14	4	DSTL32	Combination	31.42	-400.9	-564.54	-7.741E-13	-5.85E-15	1.474E-14
15	5	DSTL32	Combination	-26.16	-266.01	-449.53	-285.21	12.97	14.91
15	12	DSTL32	Combination	26.16	266.01	528.74	-1457.57	-2.76	72.74
16	12	DSTL32	Combination	-56.7	420.4	-1093.72	1457.57	2.76	-72.74
16	2	DSTL32	Combination	56.7	-420.4	1146.53	-5.893E-13	-3.34E-15	4.349E-14
17	7	DSTL32	Combination	4.58	-305.48	227.66	-403.84	21.42	19.12
17	13	DSTL32	Combination	-4.58	305.48	-148.45	-1485.43	7.5	73.9

Appendix D: Tank Flow Connections Design



The supply requirements for the community specify a supply flow rate, Q, of 7.5 Gallons per minute. This is equivalent to .002 Cubic feet per second. The maximum elevation of the water in the full tanks indicates 10.5 ft of hydraulic head. The analysis assumes an average water temperature of 60 degrees Fahrenheit.

Inspection of the energy grade lines for the current and future system indicates they are equivalent in terms of analysis and sizing of elements.

Sizing of the pipe elements of the new system should be a close match to the system in use.

The Bernoulli equation allows us to calculate the energy flow through the system. Starting from point one, when the tank is full, to point two where the check valve indicates the end of our system.

For gravity feed systems with the check valve fully open:

Bernoulli

$$Z_1 + \frac{P_1}{\gamma} + \frac{V_1^2}{2*g} = Z_2 + \frac{P_2}{\gamma} + \frac{V_2^2}{2*g} + H_{loss}$$

$$10.5 + 0 + 0 = 0 + 0 + 0 + H_{l0ss}$$

The head loss in the system is the sum of two factors, the friction losses and the minor losses.

$$H_{loss} = h_f + h_m$$

The friction loss is defined by the Darcy Weisbach equation:

$$FrictionLoss$$
$$h_f = \frac{f*L}{d^5}\left(\frac{Q^2}{39.68}\right)$$
$$MinorLoss$$
$$h_m = \frac{\sum k*Q^2}{39.68*d^4}$$

Combining the equations above gives:

$$\text{Eqn 4 : Hloss} = \frac{f*L}{d^5}\left(\frac{Q^2}{39.68}\right) + \frac{\sum k*Q^2}{39.68*d^4} = 10.5\text{ cfs}$$

This will require us to assume a friction factor, f=.03, later in the analysis Moody's Diagram is used to check this assumption.

The total length of pipes active in either system is L = 20 feet.

The $\sum$ K values for the system components:

<u>K values</u>

- Enter tank from pipe
  - Flush 0.5
  - Projecting 1
- Exit tank from pipe 1
- 90 degree threaded bend 0.9
- Check valve open 3

$$\sum K = 1(1) + 1(1) + .9(2) + 3(1) = 6.8$$

Then

$$\text{Eqn 4 becomes: } \frac{.03*20ft}{d^5}\left(\frac{(.oo2cfs)^2}{39.68}\right) + \frac{6.8*(.002cfs)^2}{39.68*d^4} = 10.5\text{ cfs}$$

We can now solve for the unknown value of pipe diameter, d.
The assumed friction value of .03 gives a diameter of .0236 feet or .282 inches.

We can now find the appropriate friction factor using the moody diagram.

<u>When f=.03 and d= .021</u>

$$A = \frac{\pi * d^2}{4} = \frac{\pi * (.0236 ft)^2}{4} = 4.37 * 10^{-4} ft$$

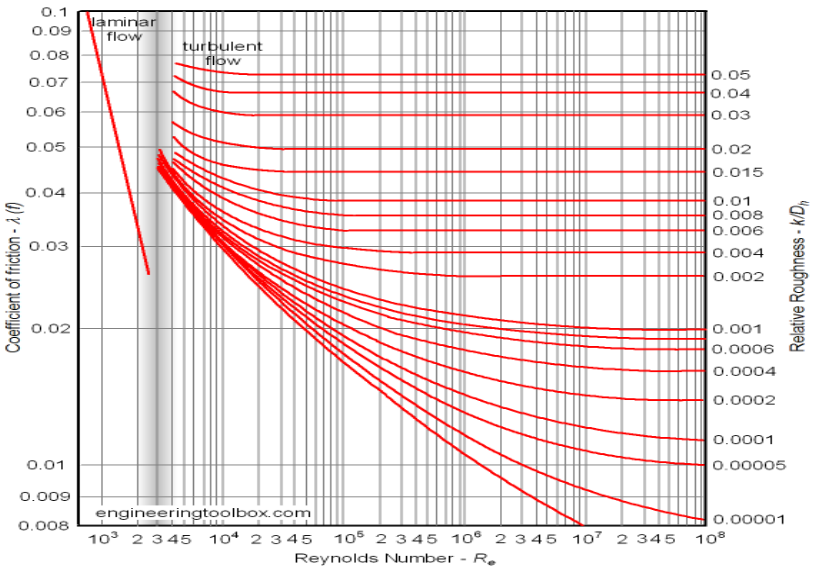
$$V = \frac{Q}{A} = \frac{.002 cfs}{4.37 * 10^{-4} ft} = 4.57 \frac{ft}{s}$$

$$\text{Re} = \frac{V * d}{\nu} = \frac{4.57 \frac{ft}{s} * .0236 ft}{1.22 * 10^{-5} \frac{ft^2}{s}} = 1 * 10^4$$

$$\frac{\varepsilon}{d} = \frac{1 * 10^{-5}}{.0236 ft} = 4.24 * 10^{-4}$$

Moody

$$f\left(RE, \frac{\varepsilon}{d}\right) = f\left(1 * 10^4, 4.24 * 10^{-4}\right) = 0.031$$



Evaluating equation 4 with the new friction factor allows us to arrive at the minimum diameter for our system.

Eqn 4 becomes: $\frac{.031 * 20 ft}{d^5}\left(\frac{(.oo2 cfs)^2}{39.68}\right) + \frac{6.8 * (.002 cfs)^2}{39.68 * d^4} = 10.5$ cfs

$d = .023715 ft = .285 inches$ Minimum!

A minimum inner pipe diameter of ½ inch would work for the system. The current design uses PVC piping with an outer diameter of 1". The 1" diameter pipe has an inner diameter of 7/8 inches, this will allow the system to manage any increased demand that is unforeseen in this analysis without being too conservative. It is also good practice to stay with the current sizing that has sufficiently supported the current potable water feeds into the facility.

Appendix E: Design Plan Set

97 Uniform Building Code Utilized

The following pages were referenced for:

- The geotechnical recommendations for design
- Foundation criteria for design
- Seismic considerations for structural design

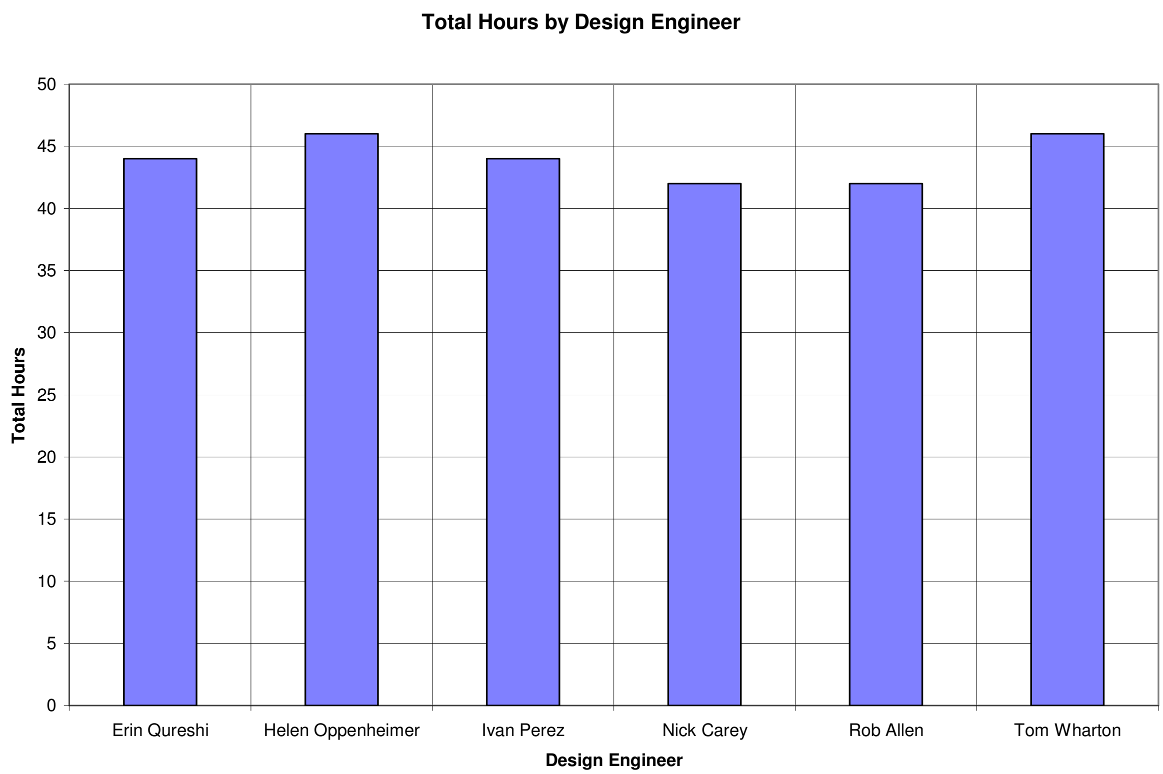
Breakdown of Billable Hours

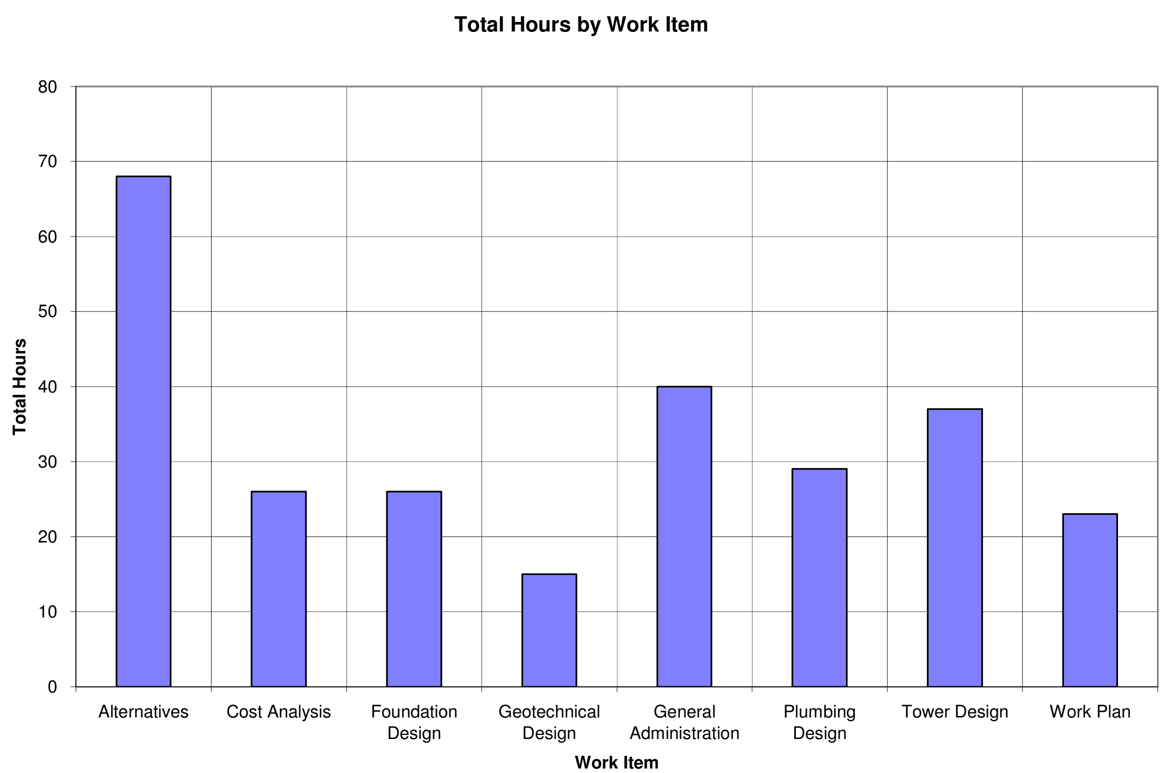
Reported Hours for Billing

General Administration: 40 hours
Meetings with clients, preparation of reports and presentations, project meetings.
Alternatives: 68 hours
Establishment, research, analysis and recommendation of alternative designs.
Geotechnical Design: 15 hours
Analysis of seismicity and soil conditions, design of soil footings.
Foundation Design: 26 hours
Analysis of wind loads, design of foundation.
Tower Design: 37 hours
Design of tower in SAP.
Pipes and Connections Design: 29 hours
Analysis of desired flow rate, design pipe sizings.
Establishment of Work Plan: 23 hours
Logistics analysis for materials and labor.
Cost Analysis: 26 hours
Analysis of capitol and maintenance costs.

Project Time Performance Tracking — PORTLAND STATE UNIVERSITY

Name	Project Type	Estimated Start	Estimated Finish	Total Hours
Tom Wharton	Project Management	12-Jan-2007	2-May-2007	23
Nick Carey	Paper/Presentation Prep	12-Jan-2007	2-May-2007	5
Ivan Perez	Paper/Presentation Prep	12-Jan-2007	2-May-2007	12
Nick Carey	Cost Analysis	20-Mar-2007	15-Apr-2007	26
Helen Oppenheimer	Geotechnical Design	6-Apr-2007	22-Apr-2007	15
Erin Qureshi	Work Plan	20-Mar-2007	25-Apr-2007	23
Ivan Perez	Foundation Design	8-Mar-2007	25-Apr-2007	26
Rob Allen	Pipes/Connections Design	4-Mar-2007	29-Apr-2007	29
Tom Wharton	Tower Design	5-Apr-2007	26-Apr-2007	21
Helen Oppenheimer	Tower Design	5-Apr-2007	26-Apr-2007	9
Erin Qureshi	Tower Design	5-Apr-2007	26-Apr-2007	7
Nick Carey	Alternatives	10-Feb-2007	12-Mar-2007	13
Helen Oppenheimer	Alternatives	10-Feb-2007	12-Mar-2007	20
Erin Qureshi	Alternatives	10-Feb-2007	12-Mar-2007	14
Rob Allen	Alternatives	10-Feb-2007	12-Mar-2007	15
Ivan Perez	Alternatives	10-Feb-2007	12-Mar-2007	6
TOTAL				**264**


Total Hours by Design Engineer
50
45
40
35
30
25
20
15
10
5
0
Total Hours
Erin Qureshi
Helen Oppenheimer
Ivan Perez
Nick Carey
Rob Allen
Tom Wharton
Design Engineer


Total Hours by Work Item
80
70
60
50
40
30
20
10
0
Total Hours
Alternatives
Cost Analysis
Foundation Design
Geotechnical Design
General Administration
Plumbing Design
Tower Design
Work Plan
Work Item

References

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