CENTRE COURT APARTMENTS
STATE COLLEGE, PA

Structures, Natural-Local-Environmentally Enhancing-Innovatively Striving Toward The Future

Anthony P. Dente, LEED AP
Advisor: Ali Memari
4/9/08

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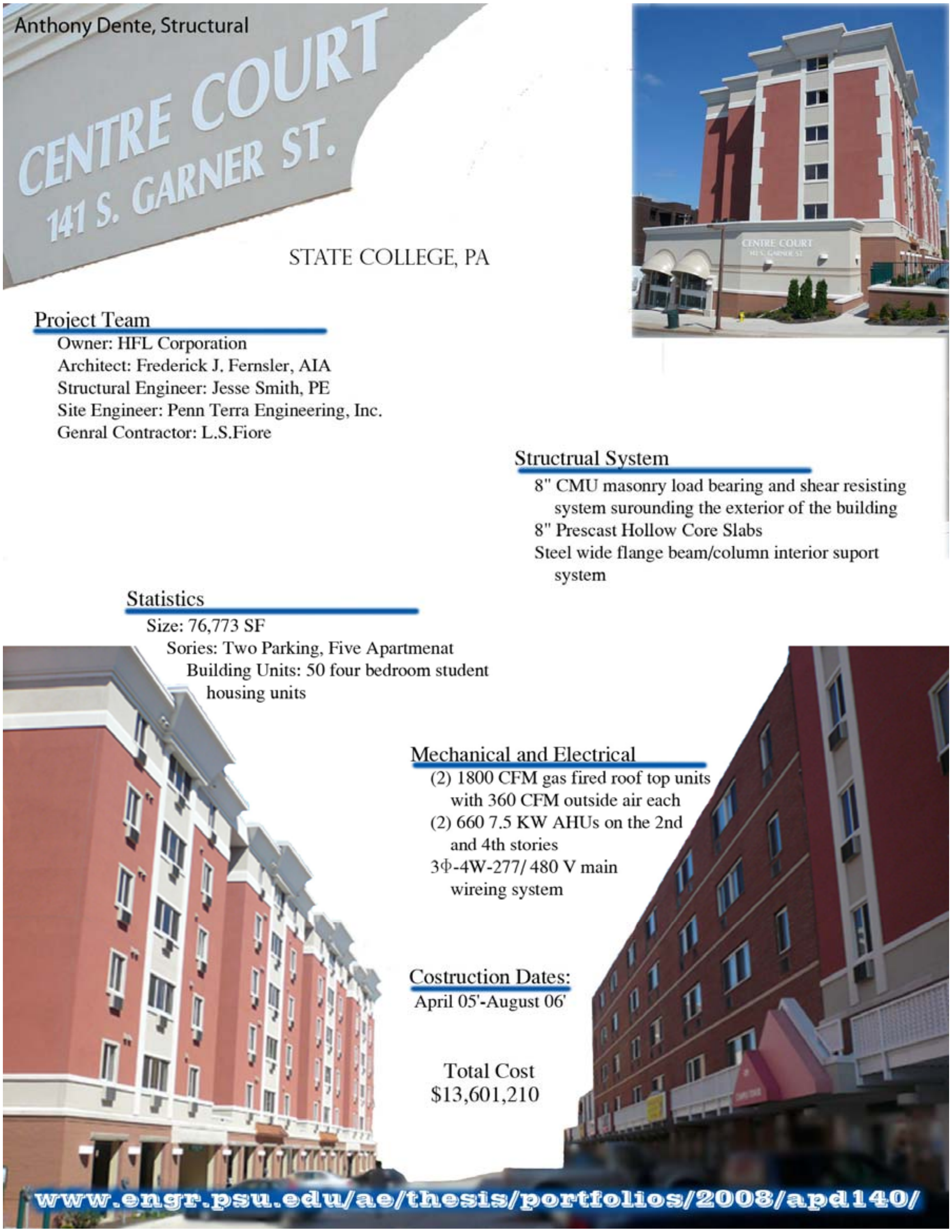

Anthony Dente, Structural

STATE COLLEGE, PA

Project Team

Owner: HFL Corporation
Architect: Frederick J. Fernsler, AIA
Structural Engineer: Jesse Smith, PE
Site Engineer: Penn Terra Engineering, Inc.
Genral Contractor: L.S.Fiore

Structrual System

8" CMU masonry load bearing and shear resisting system surounding the exterior of the building
8" Prescast Hollow Core Slabs
Steel wide flange beam/column interior suport system

Statistics

Size: 76,773 SF
Sories: Two Parking, Five Apartmenat
Building Units: 50 four bedroom student housing units

Mechanical and Electrical

(2) 1800 CFM gas fired roof top units with 360 CFM outside air each
(2) 660 7.5 KW AHUs on the 2nd and 4th stories
3Φ-4W-277/ 480 V main wireing system

Costruction Dates:

April 05'-August 06'

Total Cost
$13,601,210

www.engr.psu.edu/ae/thesis/portfolios/2008/apd140/

THIS THESIS IS DEDICATED IN LOVING MEMORY OF TWO GENTLEMAN WHO'S WIT, WISDOM, LOVE, AND GENETIC CHARACTERISTICS EQUIPPED THE AUTHOR OF THIS THESIS WITH THE PROPERLY SIZED REINFORCED FOUNDATION TO PERCEIVER THROUGH ALL ADVERSITIES WITH HOPE AND A SMILE.

I STRIVE TO ONE DAY PASS THESE SAME TREASURES TO THE NEXT GENERATION IN THE SAME OLD WAY YOU GIFTED THEM TO ME.

Pete Alderisio
November 4th, 1934 – April 4th, 2005

Jeffry F. Dente, OD
July 14th, 1957 – November 11th, 1998

Acknowledgments

The Author of this thesis would like to thank the following groups and individuals for their support and assistance whom without this report would not be possible.

Mother and Step Father
Carla and Patrick Firment

All of My Extended Family

Loving and Supporting Girlfriend
Brittany Lace Harris

Building Owner
HFL Corporation

General Contractor/ Former Employer
LSFiore

Architect
Frederick J. Fernsler, AIA

Structural Engineer
Jessie Smith, PE

Internship Employer
Weir/Andrewson & Ass.

Thesis Advisor
Dr. Ali Memari

Professors
Andy Lau, PE, LEED AP
Dr. David Riley
Professor Robert Holland
& All AE Faculty

Bruce King and All of The Straw Bale Community For Your Inspiration and Knowledge

Everyone ever involved in the Engineers for a Sustainable World

All of my classmates
You know who you are,
And how much you’re loved.

All of My Beautiful Friends of The West Side

And All the Old Cohorts from Altoona

Thank you all for everything you do.

Executive Summary

The current climate and societal state of the world is calling upon engineers to step forward and pave the path to a new sustainable future. In order for our generation to stand out as a people who persevered through the adversities that a fossil fueled industrial revolution as laid upon us, we must rethink the way we approach every issue and structural engineering shall be no exception to this rule. This will never be accomplished by merely doing less bad with minor adjustment to the materials we hold close within our comfort zones but only by reaching out to try things that haven't been done before. The author of this thesis is not proposing that the technologies used in this redesign will be the saving grace that upholds our reputation for the generation that comes but that mindset that leads one to solutions such as these will.

Building Description

The Centre Court Apartments stand at 67.5' and contain five levels of student housing atop two levels of parking, intermixed with lobby and commercial area on the ground floor. The building is wrapped with load bearing CMU hollow core blocks that also act as the lateral resisting system of the building. The floor slabs are made of 8" pre-cast hollow core planks, which bear on the CMU exterior walls and a series of wide flange beams. These then distribute the load to the concrete columns leading to the spread footing foundation below.

Redesign

The environmental and societal impact of the structural and building enclosure materials used in the Centre Court Apartments are the main focus of this redesign. The exterior walls were designed with pre-cast, non-load bearing, straw bale wall assemblies, which will bear on two-way flat plate slab with a concrete lateral resisting frame system all specified with high fly ash content replacing up to 50% of the Portland Cement content. An architectural breadth was conducted to compensate for all of the design adjustments that the redesign resulted in and compensate for with an improved environmental air quality.

Conclusion

Between the increased square footage, favorable cost comparisons, benefits to local commerce, air quality upgrades, education of advancing technologies in an area they are not as prevalent, and advanced environmental stewardship all around to say the least, the increase in scheduling, inexperienced contractors, and minor parking plan issues appear to be a sizable pill to swallow per the research contained in this document. Acting as the guinea pig for any project is a large risk although the benefits of being the first in Centre County, Pennsylvania to take the initial step to a greener structural community has potential to yield great dividends.

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Building Overview

The Centre Court Apartments were built and remain owned by HFL Corporation and are located in the borough of State College, Pennsylvania. It was designed by Frederick J. Fernsler, AIA with Jesse Smith, PE as the structural engineer. L. S. Fiore Construction was the general contractor on the project that completed its 16 month construction process in August 06’. The total cost of the project was $13.6 million, which includes a large addition to an adjacent building that will not be covered in this report. The building stands at 67.5’ and contains five levels of student housing atop two levels of parking, intermixed with lobby and commercial area on the ground floor.

Located one block from The Pennsylvania State University Campus and in the prime commercial district of the town, (State College Zoning Code C) it is an excellent location for student housing amidst bookstores, restaurants, bars, and grocery stores. Standing only 7 stories high the structure still manages to sore as one of the highest buildings in its vicinity and probably the most noticeable of all recent structures in down town State College. The rust tinted stucco finish adds a pleasant shading to the otherwise remotely brown city line of the surrounding blocks and the small voids cutting cavities in the façade separating the apartments creates the illusion of space around an otherwise commandingly tall structure nestled with its sister building of equal size to the South.

The rent to reside in the Centre Court Apartments began at $550 per person in 2006, its first year in operation. It is currently $620 per person and is set to rise to $670 per person by the fall of 2008. With four occupants per apartment, 10 apartments per floor, and 5 floors of student housing that sums to $134,000 per month. Without factoring in the commercial space bellow or the parking revenue this value is proof of the demand for student housing in such a prime location of this quaint little town in Central Pennsylvania.

Existing Structural System

Listed below are the prominent structural elements contained in Centre Court Apartments:

- 8” CMU exterior above grade and 10” CMU exterior below grade
    - Load bearing units conforming to ASTM C90
    - Net Compressive Stress = 3000 PSI
    - Above grade CMU’s contain Dur-O-Wall every other course
    - Block cells with bars are grouted a minimum 2 courses below plank bearing

- 8” pre-cast hollow core planks
    - Conform to latest edition of ACI 318
    - Steel bearing will contain weld plates spaced 4’ O.C. max.
    - F’c=5000 PSI

- Steel beams and columns
    - Typical beam sizes: W12 X 26 and W14 X 43
    - Grade 50 or ASTM A992
    - Fabricated and erected in accordance to the latest edition of AISC specifications.

- Concrete columns, footings, and slabs
    - Mixed and placed in accordance with ACI 318 “Building Code Requirements for Concrete”
    - Footings and slabs f’c = 3000
    - Columns f’c =4000

Lateral System

The lateral system is comprised of the 8” and 10” CMU walls that wrap the main elevator and stairwell cores. The top two stories of CMU’s are unreinforced. Further down the structure, the blocks are grouted where the #5 bars are present until you reach the bottom two floors that are grouted solid. (*see section below)*

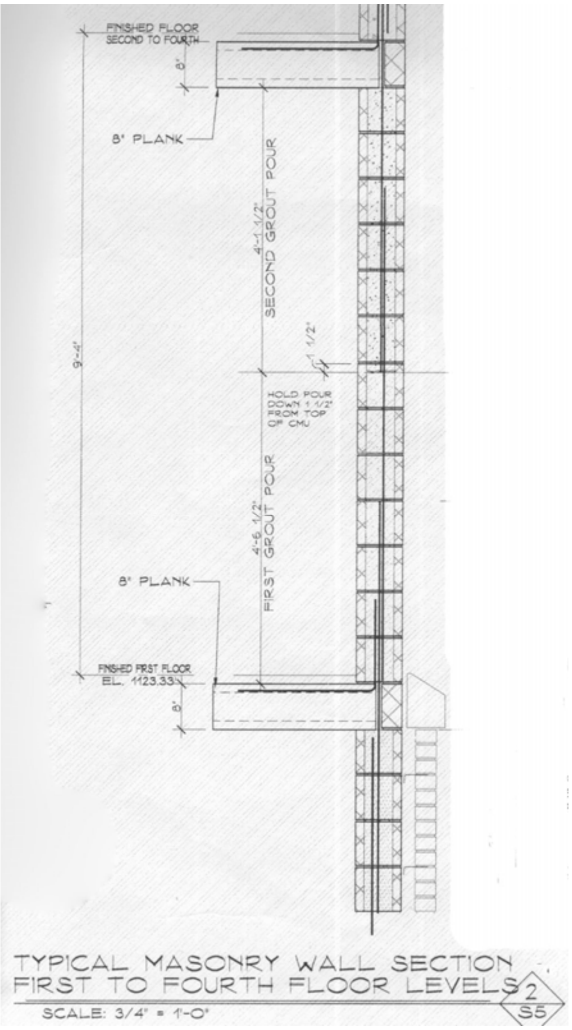


Figure 01: Existing Wall Section

Gravity System

The vertical loads of the building are also carried to the footing by the CMU system, wrapping the exterior of the building for much of the structure. The 8” precast hollow core planks distribute the floor loads to the blocks on the exterior of the building and a girder to column grid in the interior of the structure. The typical beam sizes are W12 X

26 and W14 X 43, which distribute the load to a series of W14 X 90 columns on the top 5 stories. These then connect to 20” X 24” precast concrete columns in the bottom two garage floors that then carry the load to the 6’ X 8’ concrete footings below. *(see typical structural bay bellow)*

The load-bearing CMU exterior walls dominate the structural design. This structure has a number of benefits in the Centre Court Apartments. The added convenience of bearing the pre-cast hollow core slabs. Pre-cast hollow core concrete slabs make up at least 90% of all floor slabs in the building and the concrete to concrete block connection cuts down on the number of bearing plates that would be needed if the number of slab to steel connections were increased.

Another benefit of this system is the simplification of the beam to column connections throughout the building. Since no moment frames are required, all moment connections have been completely elevated from the building. There are also two non-structural benefits to the CMU design: the fire rating requirements for apartment buildings and the way it complements the application of the aesthetic stucco applied using Dryvit exterior insulation and finishing system.

Advantages and disadvantages to this system

Being that the structure is an apartment complex architectural freedom is very important. With the precast hollow core slab design that bears a great deal on the exterior walls the intrusion of columns is decreased greatly. The Hollow core slabs also decrease on site construction time by a great deal, although a longer lead-time is often a direct cost of this trait. Including the 3-5.5” concrete topping the floor structural system can be 13.5” thick at points, which is a moderately thick floor structure for this building.

Figure 02: Sample Hollow Core Floor Slab

The Hollow core slabs in conjunction with the CMU wall offer excellent fire protection benefits. This combination also aids well to noise dampening which are both strong benefits to an apartment complex. Studies also show that insurance rates for buildings incorporating either of these technologies tend to be less than other structural options.

Existing Structural Plan

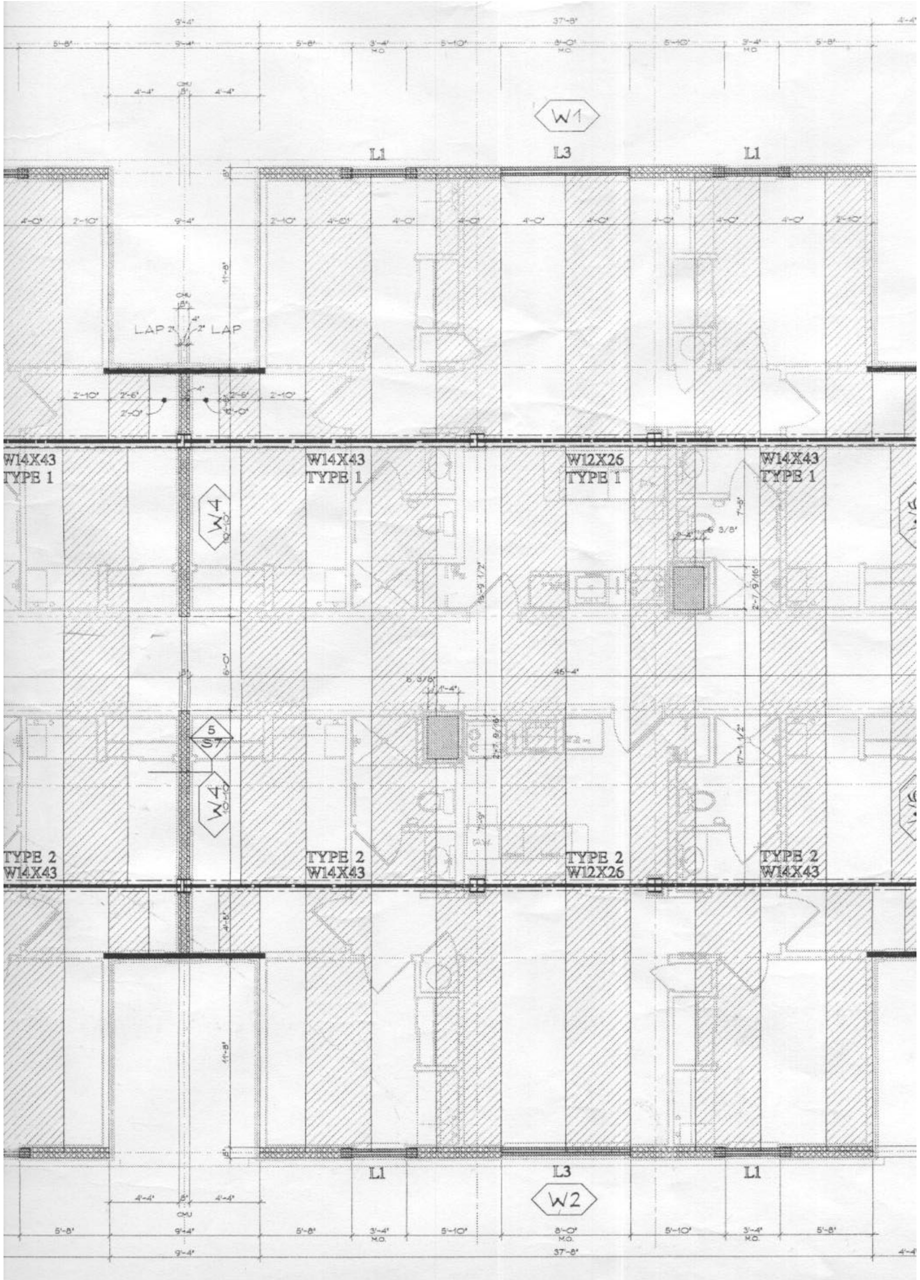


Figure 03: Existing Structural Bay

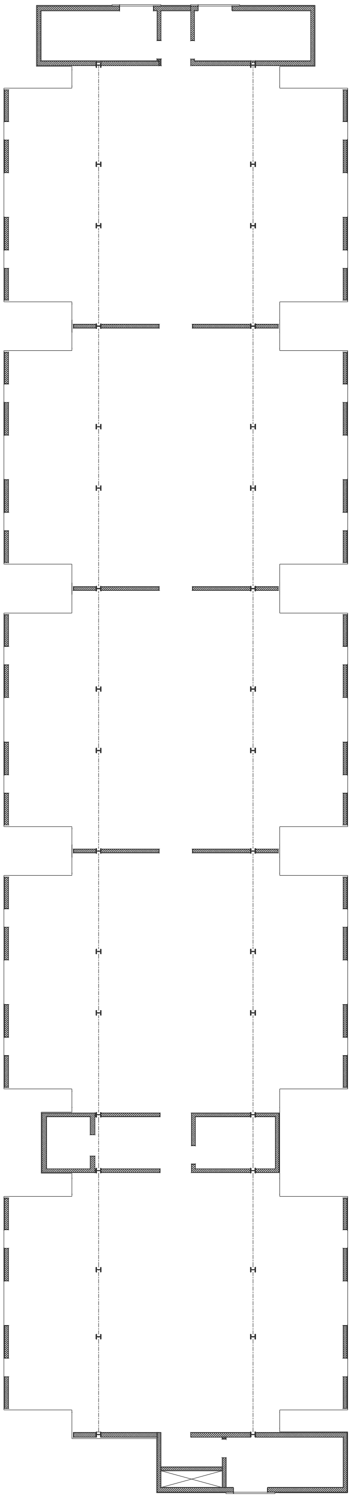


Figure 04: Typical Apartment Structural Plan

Codes and References

- State College, PA Building Code Chapter XIX – Zoning
  - Part D: C-General Commercial District
  - Part H: Off-Street Parking Regulations
- The International Building Code 2003 (original design)
- The International Building Code 2006
- The American Concrete Institute
  - Section 318-05: Structural Concrete
  - Section 530.1: Masonry
- The American Institute of Steel Construction
- CRSI 2002: Concrete Reinforcing Steel Institute
- United Steel Deck Design Manual 2002

Problem Statement

The Main ingredient of concrete is Portland cement. The process of creating Portland Cement is to mix mostly mined limestone and some silica and alumina from clays or sands through a heating process of 2700 °F, which creates lime and CO_2 that is released into the atmosphere. Virgin steel is created generically from mined iron ore, which is converted to sinter at about 2400 °F, sinter to iron at 3600 °F, and then Iron and recycled steel are converted into usable product at 3100 °F. Wood is a renewable material that takes much less embodied energy to create, although, due to poor foresting practices most of the old growth forests in the United states have been removed causing extreme damage to species survival, soil nutrients and erosion, and water retention. Certified foresting practices have developed in order to slow down these harms by attempting to only harvesting trees that have reached their maximum growing yield. Although many foresters of the old age agree that this still prohibits the natural environment of a properly matured forest that we will find in the future affects our society through water retention and soil breakdown more than we've ever expected.

The problem that will be addressed in the Centre Court Apartments is the environmental impact of the materials and systems in the building. With green building becoming more of an easily obtainable goal for owners, builders, and designers alike, it is important to not overlook any steps that can be taken to make our buildings more efficient, create less waste in construction and destruction, and use materials that have been created in the safest and most environmentally friendly way as possible. Of the 4,859,000 buildings in the United States, the USGBC has calculated that they account for the following as compared to the US as a whole:

- 65% of electricity consumption
- 36% of energy use
- 30% of greenhouse gas emissions
- 30% of raw materials use
- 30% of waste output (136 million tons annually)
- 12% of potable water consumption.

The marketability of the USGBC's LEED ranking system is growing stronger everyday and is easily visible by last year's 12,685 and over 42,512 LEED Accredited Professionals worldwide. Such an acknowledgement would place the Centre Court Apartments on a higher pedestal than its peers and would set precedence for all future downtown apartment buildings for the borough of State College, Pennsylvania. Public relations aside, the USGBC has calculated that LEED-certified projects:

- Lower operating costs and increased asset value
- Reduce waste sent to landfills
- Conserve energy and water
- Are healthier and safer for occupants
- Reduce harmful greenhouse gas emissions
- Qualify for tax rebates, zoning allowances, and other incentives in hundreds of cities

The alternative construction method presented in this thesis will not attempt to make Centre Court Apartments gain a LEED Certification, but will lay out the guidelines to become more environmentally friendly through techniques also indorsed by the LEED Ranking System. It is important that the building community keeps in mind that although LEED is a wonderful institution for our industry, it is by far the only way, or the best way to make a building more environmentally intertwined. Owners and occupants of sustainable buildings understand their role in the everyday living and breathing of the structure they inhabit. By having such constant reminders of the role you have in the functions of the building and its impacts on your health can help to make an often times neglectful student population more conscious of the how they can help. Such a building could also attract a populous of more aware caring occupants that would prefer to live in such an environment.

Solution

Structural

From a structural engineering standpoint, materials that are renewable, have low embodied energy, and/or are made with recycled content are the most preferred sustainable building elements. Due to the 67.5' height of the Centre Court Apartments, use of load bearing natural structural elements such as straw bale are prohibited by code and the bearing ability of the bales, therefore a non-load bearing straw bale wall assembly will be used. Traditionally this post and beam system is done with timber framing. Chapter 5 of the IBC 2006 height restrictions bans the use of timber frame, so a redesign of the CMU and hollow core slabs system will be done with a concrete frame and shear wall, gravity and lateral resisting system with two way flat plate slabs. A high volume of fly ash or class C pozzolans, which is a waste product from coal burning power plants, will be incorporated into the concrete design mix, replacing up to 50% of the required Portland cement. Not only does this create a safe, alternative use of contaminates from the power industry, but Portland cement is the most toxic and energy intensive ingredient in concrete due to the need of being heated to over 2700 °F as stated above.

Breadths

Building Enclosure

The straw bale walls will be built on end with a width of 12". In this orientation, the bales have better thermal qualities and their structural value is not compromised because the entire load of the building is being carried by the concrete system. Because concrete columns will be used in place of timbers this creates relative stiffness issues with caring a uniform stucco covering to protect the bales from moisture damage. Therefore the slab will extend past the frame and bear the panels completely out of the plane of the columns.

Straw bale construction on a story level of 67.5' is not a very convenient task due to the unique nature of constructing a straw bale wall. The walls will be pre-cast either on site or offsite locally, and shipped in using methods similar to those of pre-casting straw bale companies around the globe. It also goes without saying that a wall assembly such as this is not a common practice by most local contractors or estimators, therefore, a simple cost breakdown and comparison of only the structural and enclosure system will be conducted against the original. A Microsoft Project schedule will be drafted to outline the feasibility of constructing such a system.

Architecture

These straw bale wall assemblies will take the place of all CMU enclosure walls in the building, which will cause a need for alterations to the architectural layout. Due to the stucco finish that already exists on the exterior of the building, very little large aesthetical changes will need to be conducted.

The addition of a column grid to replace the load bearing CMU system will also create numerous architectural changes in particular in the parking garage and dealing with parking capacities in the local zoning code. Parking will also be affected by the building being extended to accommodate for the increased wall width of the straw panels. The narrow column spans cascading down the center of the Garages will be taken advantage of by incorporating living walls between the columns in order to increase not only the aesthetic of the garage but also the indoor environmental air quality for all occupants traversing through this space.

Depth Study: Incorporation of Concrete Frame

The structural depth of this thesis was conducted to reduce the environmental impacts of the Centre Court Apartment Structure. Due to IBC 2006 restricting the use of Timber due to height restrictions the remaining options where the traditional steel and concrete. The two best environmental adjustments to these materials practically available on the market today are the high recyclability of steel and the ability to substitute fly ash pozzolans for the Portland Cement used in concrete. In 2006, 97.5% of all structural construction steel was recycled. Although this number is nearing its maximum, as listed in the problem statement above the temperatures of 3100 °F is still required to melt this steel down again to produce new useable product. This is a tremendously high temperature that is not an optimal product cycle stage in this age of energy crisis that our globe is entering into today. Fly ash in concrete can replace up to 50% of the Portland cement used in the concrete mix. Being that the Portland cement is by far the most energy intensive and toxic ingredient in the concrete mix, the ability to alleviate 50% of this material adds tremendous energy savings and environmental benefit to the life cycle cost of your concrete mix. Due to these result, a concrete frame was designed with approximately 50% fly ash replacement.

Fly Ash Design

Fly Ash is a waste product of the coal burning industry that is collected from the smoke stacks or bottom ash from bellow the furnace. Fly ash is considered toxic waste and its disposal is a large environmental concern. Fly ash is a class C Pozzolan which are defined by ASTM standard C618 as a siliceous or siliceous and aluminous material, which in itself possesses little or no cementious value but which will, in finely divided form and in the presence of moisture, chemically reach with calcium hydroxide at ordinary temperatures to form compounds possessing cementing properties. There are 4 main types of pozzolans, volcanic material mined from the earth (the same material used to build the Pantheon), manufactured such as calcined clay, industrial by-products, and others such as rice hulls. Fly ash is less dense that cement with specific gravities of 1.9-2.8 compared 3.5 of cement which will minorly decrease the weight of the concrete. In concrete the bonding agent is calcium silicate hydrate (CSH), although, usually up to half of the cement content of the mix becomes only hydrated lime of calcium hydroxide (CH) which normally forms around the aggregate and rebar. Fly ash acts as extra silica in the mix and reacts with water to convert the CH into CSH. With the fly ashes small structure it conveniently fits in the areas around aggregate and rebar making converting the weakest and most vulnerable area of the concrete mix the strongest.

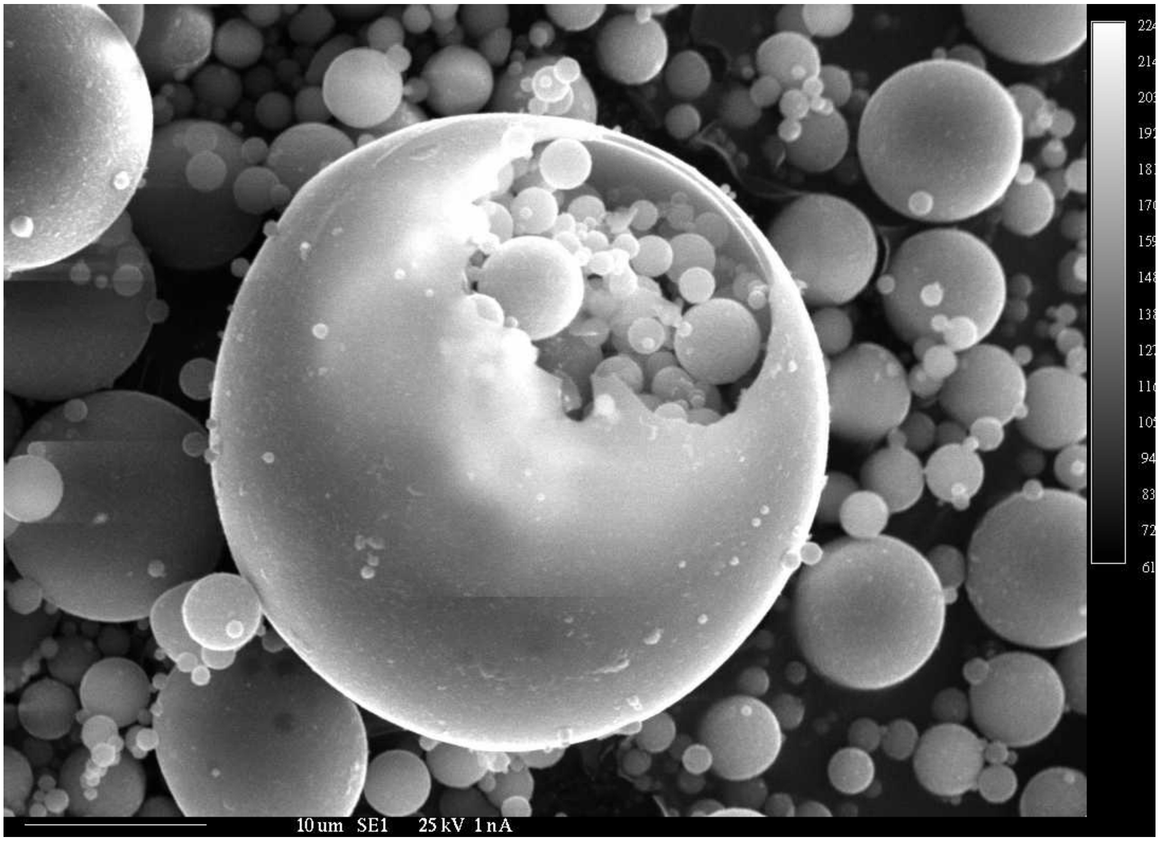


Figure 05: Microscopic photo of fly ash, Courtesy of: http://geoinfo.nmt.edu

There are many benefits to using High Content Fly Ash (HCFA) although they come along with areas of concern for the rest of the project. HCFA causes a reduction in the water demand of the mixture while increasing the workability and decreasing the amount of pocketing. This is done through the small particles packing the voids, the spherical shape of the fly ash causing less friction, and the electrostatic effect on the concrete causing less clumping. Due to this the bleed water is also drastically reduced. This cuts down on the amount of surface cracking resulting from bleed water a great deal, although premature drying and finishing are areas that are to be made very special attention. It has been found that wooden bull floats react better than aluminum. Other techniques to avoid premature drying consist of pouring and finishing at night, spraying the finished surface with two coats of liquid compound, and placing plastic or burlap tarps over the finished slabs. These and the extended set times of HCFA will have a large effect on the structure. The Normal set time of 28 days is usually increased to 56 days when using HCFA. In the Centre Court Apartment Building this will be counteract with high early strength admixtures. HCFA results in a reduced heat of hydration. This prohibits a high temperature graduation from the inner to the outer layers of concrete reducing the probability of thermal cracking. This can be a very large area of focus for cold climates therefore it is recommended that the redesign of the Centre Court Apartments be build during the summer months. If the structure was to be built during a Pennsylvania winter heaters, insulation or hot mix water should be used. Some effects on the hardened concrete are the reduced permeability brought about by combinations of the above pro's and con's dealing with water and size of particle. This results in a much greater resistance to rebar corrosion. The Hardened concrete also reduces shrinkage due to the lack of water as well. If the concrete is to be exposed to many icing salts strong attention should be paid and extensive up to date research should be collected. Early test on the matter came resulted in unfavorable numbers although more recent tests show those numbers may have been over conservative. Because the mix stays in the plastic stage for such an extended period of time special attention must be paid to using proper water reducing admixtures to keep the water/cement ratios low. The extended plastic period also results in the need of the formwork to resist more liquid load as well as the ability to leave the mix in the truck longer while pumping to the 67.5' roof of the Centre Court Apartments. The garage area of the Centre Court Apartments will be benefited aesthetically by the High content fly ash with its pleasing light tint as compared to normal concrete.

Figure 06: Marina City Fly Ash Structure in Chicago, IL
Courtesy of: http://www.rmajko.com/flyash.html

Some sectors of the industry refer to HCFA as "high performance concrete". This is because often times the mix results in a much higher f'c sometimes as high as double. Although there are many environmental factors that play a role in the exact increase of the concrete strength, therefore many experts of HCFA hold off from giving strength increase assumptions. It is recommended that as soon as it is known on the project that fly ash will be used and exact mix design should be determined and testing should begin. Cylinder break tests are recommended at 3, 7, 28, and 56 days because with such an extended set time it can be detrimental to the projects if errors aren't found until the 56th day. Due to this fact in the structural design that follows there were no adjustments to the f'c of 4000 PSI.

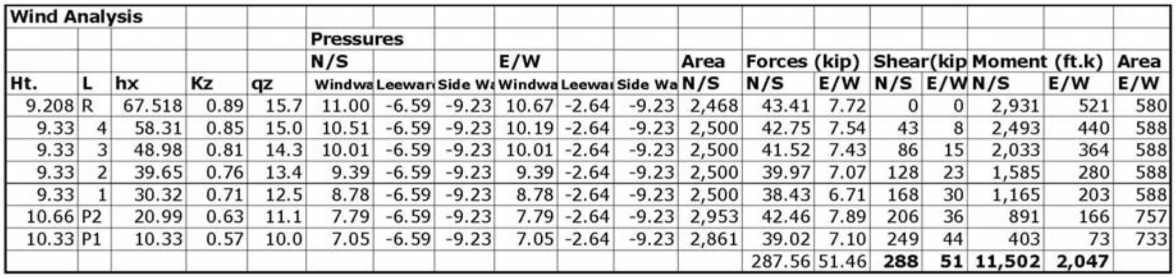
High content fly ash also has major effects on air entrainment in concrete due to high amounts of CO_2, known in the field as LOI or Loss On Ignition, which is sometime apparent in the mix without much consistency. Therefore a locally product called ProAsh of Separations Technology will be used in the Centre Court apartments. According to ASTM Standard 618 no more than 6% LOI is permitted in a concrete mix. S.T. conducts a process of electrostatic separation which separates the mineral fly ash from the CO_2 in order to guarantee a consistent, low LOI percentage. The remaining CO_2 is then returned to the power plant to be burned again as fuel also mitigating some need for raw fossil fuel extraction. This is a huge step in insuring quality concrete product in HCFA applications.

Loads

Wind Loads

Per the results of Technical Assignment One it was concluded that wind is the controlling lateral force of the Centre Court Apartments. This result backs up previous assumptions due to the buildings location in Centre County Pennsylvania and the size of the structure.

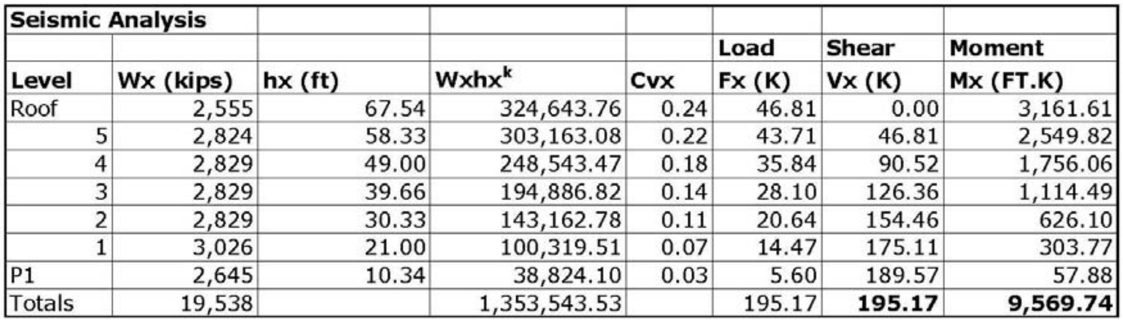
The lateral drift of the structure due to wind was calculated through the ETABS Structural Analysis Model created of the building. The loads applied to the model were calculated through ASCE-7 ’05 Chapter 6 and was treated as a solid rectangular mass, neglecting minor indentations and curvatures of the façade. The Center Court Apartments were found to be an Exposure Category B, with an importance factor of 1.0 and with wind speed V=90mph. Refer to appendix for full listing of wind calculation parameters.



Wind Analysis																		
					Pressures													
					N/S			E/W			Area	Forces (kip)		Shear(kip		Moment (ft.k)		Area
Ht.	L	hx	Kz	qz	Windwa	Leewar	Side Wa	Windwa	Leewa	Side Wa	N/S	N/S	E/W	N/S	E/W	N/S	E/W	E/W
9.208	R	67.518	0.89	15.7	11.00	-6.59	-9.23	10.67	-2.64	-9.23	2,468	43.41	7.72	0	0	2,931	521	580
9.33	4	58.31	0.85	15.0	10.51	-6.59	-9.23	10.19	-2.64	-9.23	2,500	42.75	7.54	43	8	2,493	440	588
9.33	3	48.98	0.81	14.3	10.01	-6.59	-9.23	10.01	-2.64	-9.23	2,500	41.52	7.43	86	15	2,033	364	588
9.33	2	39.65	0.76	13.4	9.39	-6.59	-9.23	9.39	-2.64	-9.23	2,500	39.97	7.07	128	23	1,585	280	588
9.33	1	30.32	0.71	12.5	8.78	-6.59	-9.23	8.78	-2.64	-9.23	2,500	38.43	6.71	168	30	1,165	203	588
10.66	P2	20.99	0.63	11.1	7.79	-6.59	-9.23	7.79	-2.64	-9.23	2,953	42.46	7.89	206	36	891	166	757
10.33	P1	10.33	0.57	10.0	7.05	-6.59	-9.23	7.05	-2.64	-9.23	2,861	39.02	7.10	249	44	403	73	733
												287.56	51.46	**288**	**51**	**11,502**	**2,047**	

Seismic Loads

The seismic design loads were calculated using Section 11 of ASCE 7-05 the equivalent lateral force design method. The original building period was calculated as 0.799s. See appendix for the complete list of deign parameters.



Seismic Analysis							
					Load	**Shear**	**Moment**
Level	**Wx (kips)**	**hx (ft)**	**Wxhx^k**	**Cvx**	**Fx (K)**	**Vx (K)**	**Mx (FT.K)**
Roof	2,555	67.54	324,643.76	0.24	46.81	0.00	3,161.61
5	2,824	58.33	303,163.08	0.22	43.71	46.81	2,549.82
4	2,829	49.00	248,543.47	0.18	35.84	90.52	1,756.06
3	2,829	39.66	194,886.82	0.14	28.10	126.36	1,114.49
2	2,829	30.33	143,162.78	0.11	20.64	154.46	626.10
1	3,026	21.00	100,319.51	0.07	14.47	175.11	303.77
P1	2,645	10.34	38,824.10	0.03	5.60	189.57	57.88
Totals	19,538		1,353,543.53		195.17	**195.17**	**9,569.74**

ETABS Analysis

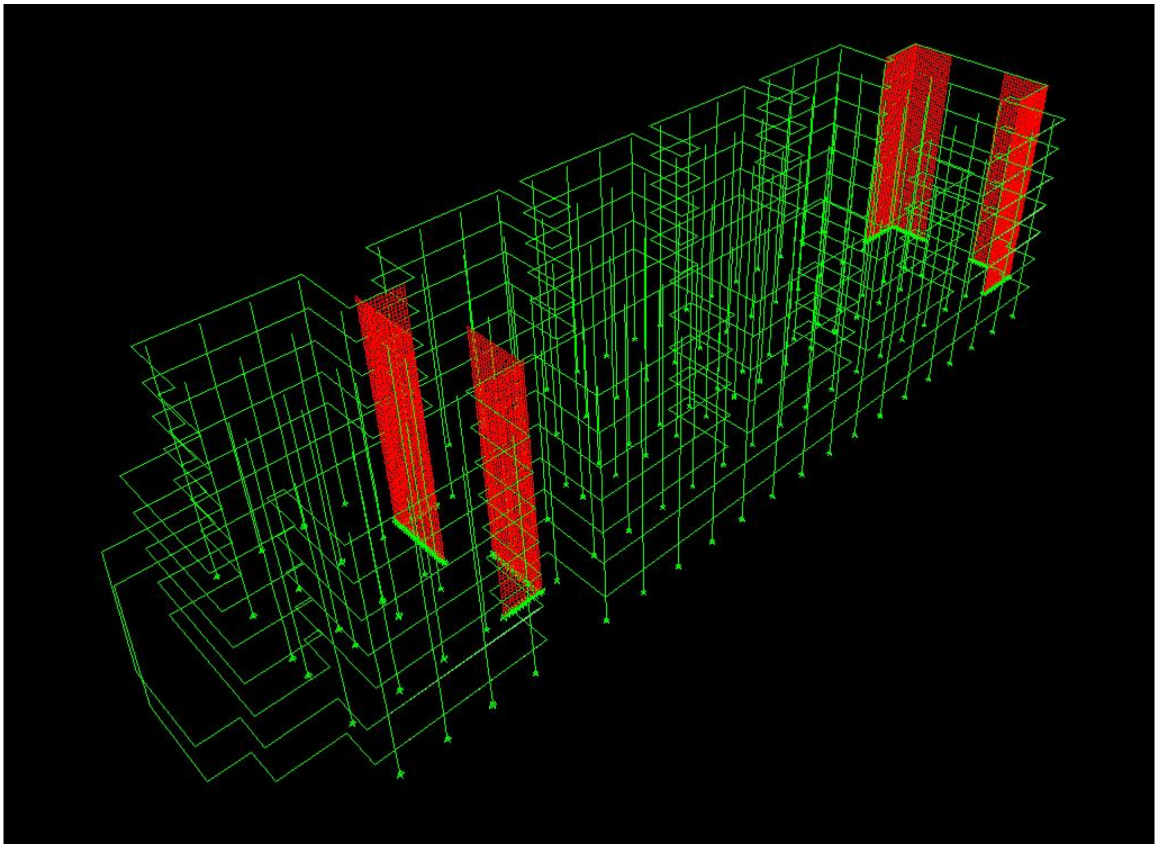


Figure 07: ETABS Original Model

ETABS version 9.1.1 was used in the modeling on the Centre Court Apartments redesigned lateral resisting system. The lateral loads will be resisted by 8 reinforced concrete shear walls, four in the north/south direction and four in the east/west direction. The center of mass and center of rigidity as outputted from the model are as follows.

ETABS Center of Rigidity & Center of Mass Output

Story	X C. of Mass (in)	X C. of Rigidity (in)	Delta X (in)	Delta X (ft)	Y C. of Mass (in)	Y C. of Rigidity (in)	Delta Y (in)	Delta Y (ft)
1	1972.4	2248.5	276.1	23.008	451.8	481.6	29.8	2.4833
2	1972.4	2249.4	277	23.083	451.8	538.1	86.3	7.1917
3	1969.4	2254.6	285.2	23.767	450.7	579.4	128.7	10.725
4	1969.4	2256.4	287	23.917	450.7	608.3	157.6	13.133
5	1969.4	2258	288.6	24.05	450.7	626.5	175.8	14.65
6	1969.4	2259.4	290	24.167	450.7	638.4	187.7	15.642
7	1969.4	2260.2	290.8	24.233	450.7	646.4	195.7	16.308

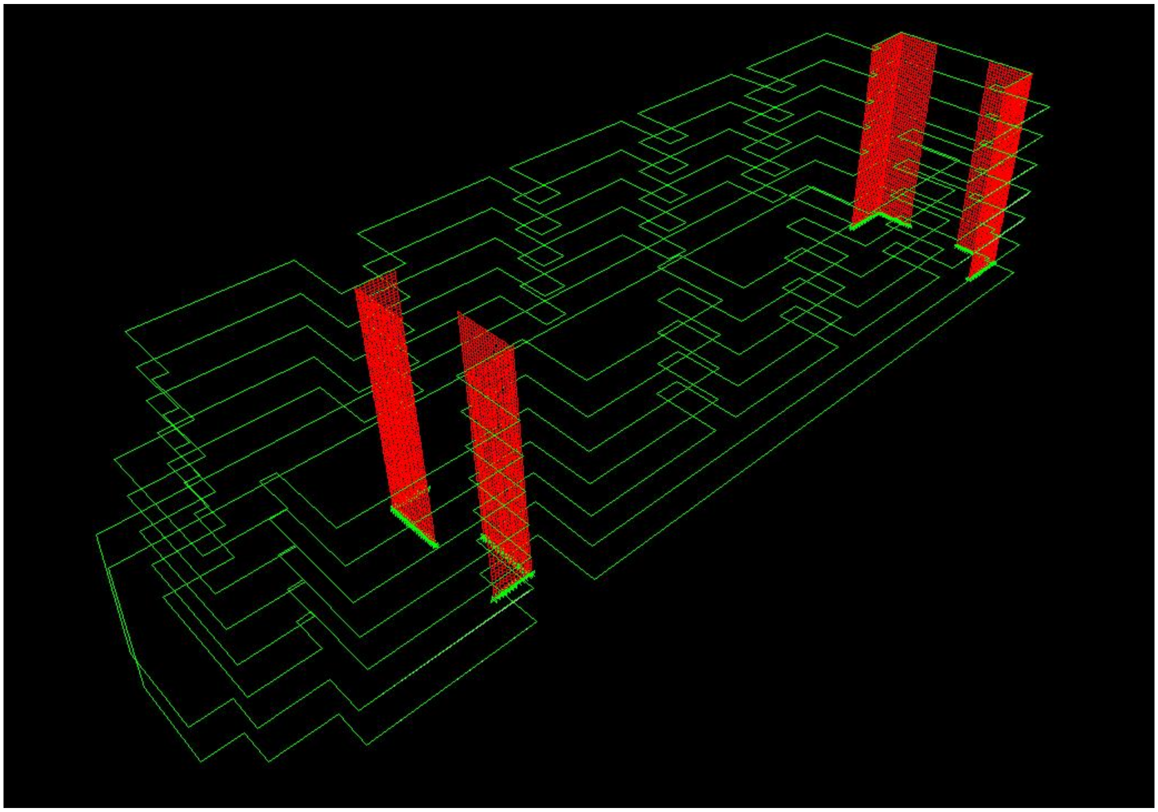


Figure 08: ETABS Shear Wall Model

Shear Walls

The loads on the shear walls were obtained through the ETABS program. All 8 Shear walls were found to be 12" thick in order to negate the need of boundary elements where columns didn't exist. The Columns were removed from the ETABS model in order to assess the proper lateral distribution to each individual shear wall. The maximum loads transferred to the shear walls from the lateral pressures and tensional effects in the north/south direction came to Vu=264 kips and Mu=6100 ft-kips. In the north/south direction both the longitudinal and transverse reinforcement where calculated to be one curtain of #6 bars at 10" O.C. and in the east/west direction one curtain of #5 bars at 10" O.C. Refer to Appendix B1 for complete shear design calculation.

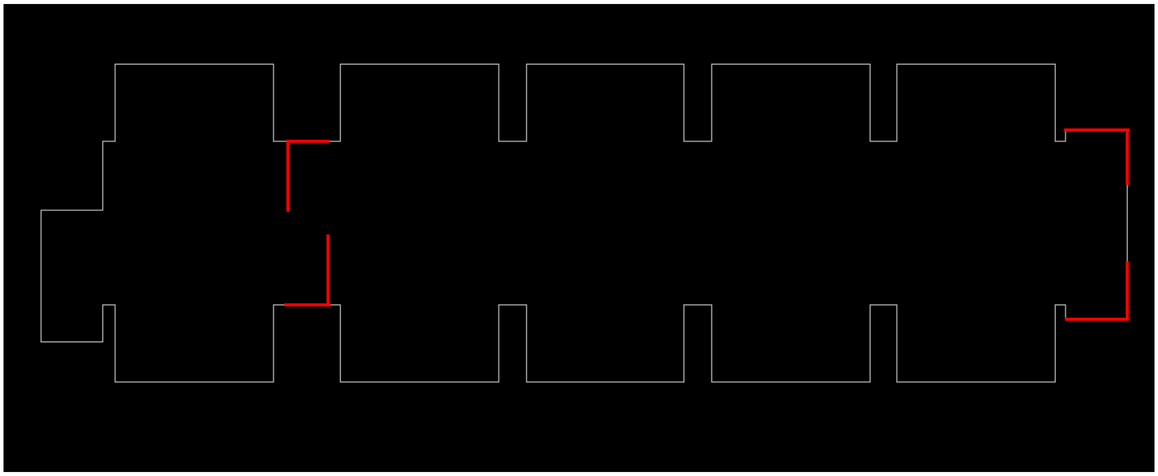
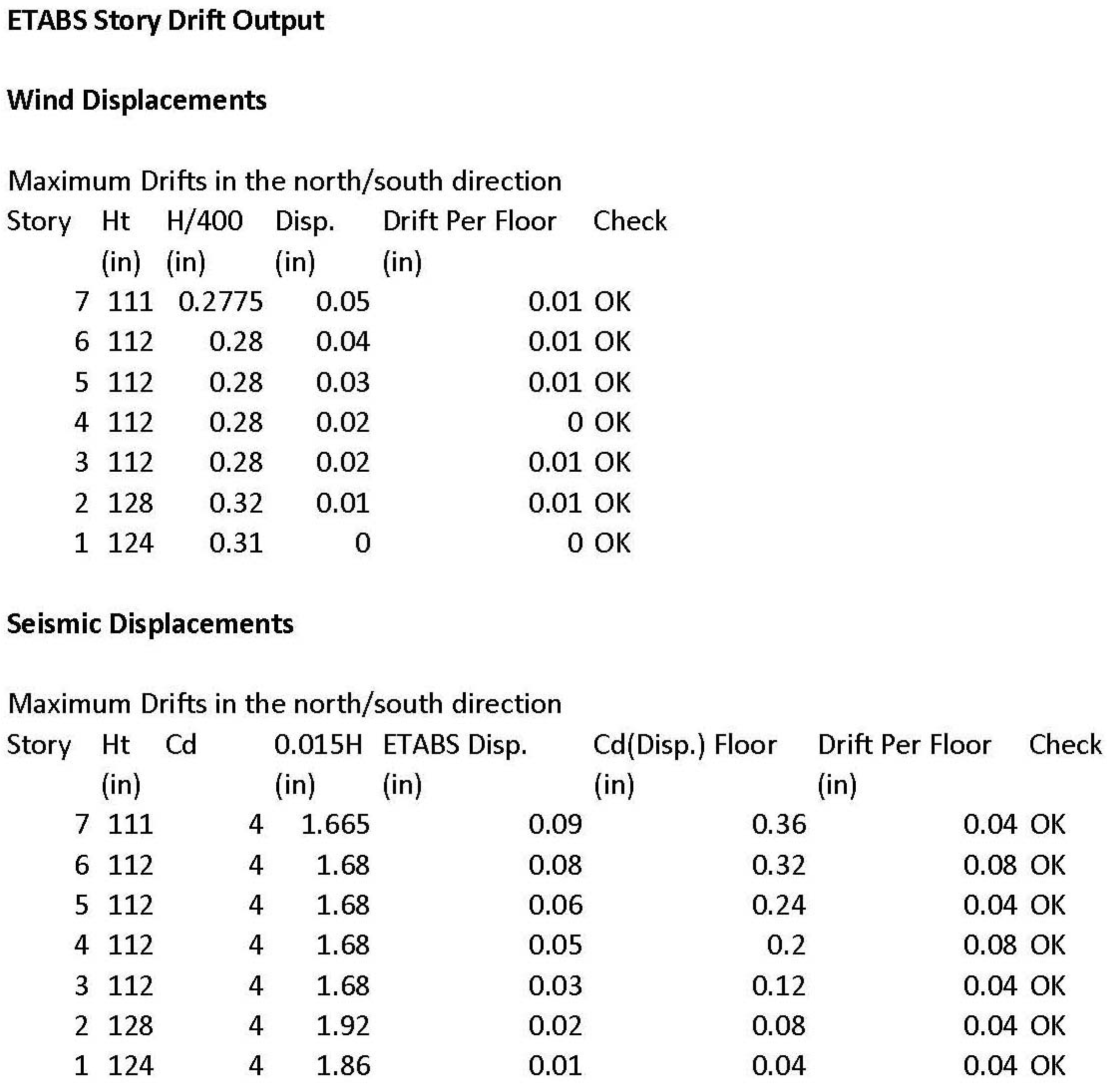


Figure 09: ETABS Shear Wall Plan

Story Drift

The ETABS story drift output due to wind were well under the Δw = H/400 = 2.02” mandated by IBC 2006 due to the increase in thickness brought about by the negation of boundary elements. The drift brought about by earthquake loading was multiplied by the Cd factor of 4 from ASCE 7 ’05 due to the ETABS modeling program outputting only a linear elastic response of the building. This was found to also be well within the limits of ΔE = 0.015(H)/(4) = 3.03”.



ETABS Story Drift Output

Wind Displacements

Maximum Drifts in the north/south direction

Story	Ht (in)	H/400 (in)	Disp. (in)	Drift Per Floor (in)	Check
7	111	0.2775	0.05	0.01	OK
6	112	0.28	0.04	0.01	OK
5	112	0.28	0.03	0.01	OK
4	112	0.28	0.02	0	OK
3	112	0.28	0.02	0.01	OK
2	128	0.32	0.01	0.01	OK
1	124	0.31	0	0	OK

Seismic Displacements

Maximum Drifts in the north/south direction

Story	Ht (in)	Cd	0.015H (in)	ETABS Disp. (in)	Cd(Disp.) Floor (in)	Drift Per Floor (in)	Check
7	111	4	1.665	0.09	0.36	0.04	OK
6	112	4	1.68	0.08	0.32	0.08	OK
5	112	4	1.68	0.06	0.24	0.04	OK
4	112	4	1.68	0.05	0.2	0.08	OK
3	112	4	1.68	0.03	0.12	0.04	OK
2	128	4	1.92	0.02	0.08	0.04	OK
1	124	4	1.86	0.01	0.04	0.04	OK

The Building periods output by the ETABS model for the primary mode shapes are 0.192s in the north/south direction and 0.1535s in the east/west direction.

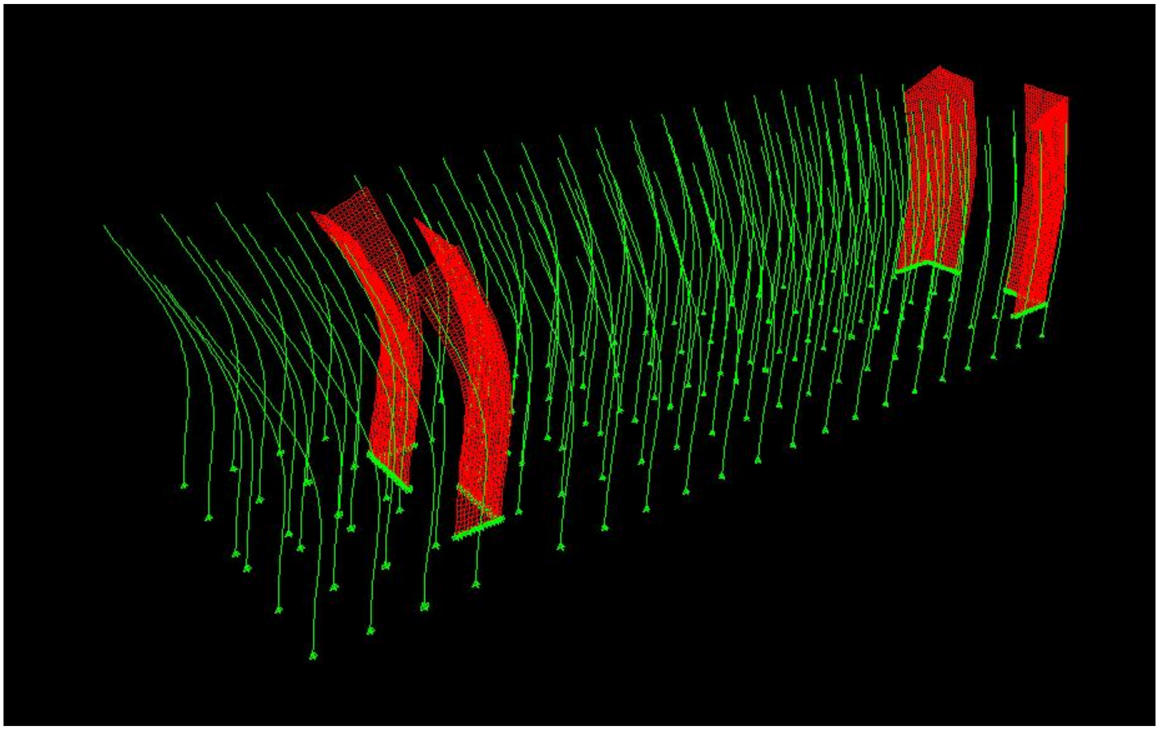


Figure 10: ETABS Model Displacement

Transfer Beam

The parking garage areas consuming 2/3 of the bottom two floors causes severe spacing issues with the conveniently uniform concrete grid of the upper five stories. As detailed in the architectural breadth bellow, 12 transfer beams will be required for entrance and exit ways of the parking garage. The span of the beams is 24' and will rest of 24" X 24" columns. With a 24' span the need of transfer beams could have been negated through carrying two 24' long spans through the building the whole way to the roof. Although with the complications of building with fly ash in an area that many concrete workers are unfamiliar with the technology the goal was to keep the rest of the project as uniform and practical as possible, therefore the transfer beams were chosen as the most viable option. The beams are connected by fixed supports at the columns resulting in maximum negative moments of Mu = 823 Ft-Kips and maximum positive moments of Mu = 717 Ft-Kips. Due to the ACI mandate to carry ¼ the positive reinforcement to the support for beams with fixed supports the (3) # 8 bars were considered as compression reinforcement in an attempt to decrease the size of the beam. According to ACI 10.7.1 the transfer beams are not to be considered deep beams due to their small span. ACI 9.5.2.1 does not require the shorter span length to be considered for long term deflections either. The beam was sized as 30" X 14" and complete calculations are included in Appendix B2, including development length in support and bar cutoffs through the beam.

Slabs and Columns

The Slabs and Columns were designed by PCA Slab and PCA Column with hand calculated deign checks included below along with the PCA outputs in Appendix B3, C1, & C2. The generally uniform column grid affords the opportunity to use a typical 7.5" slab throughout the entire structure. Due to the increases corridor live load of 100 psf as compared to the rest of the building's 40 psf in the narrow span hallway down the center of the building drop panels are required to resist punching shear problems. The drop panels will be 2' X 2" X 4" thick which is larger than the minimal PCA Slab design in order to use convenient dimensions for construction. Middle strip and column strip positive and negative moment rebar sizes and spacing is included in the appendix bellow. The maximum column moments of Mu = 12 Ft-Kips output by PCA Slab were used for the column design. The columns were designed as 16" X 16" with (4) #8 bars everywhere accept the (24) 24" X 24" columns with (14) # 10 bars supporting the transfer beams in the high and low level parking stories.

The main adjustment to the slab that came about through the additions of this redesign was that the slab was extended 1.5' past the exterior face of the column to support the straw bale panels. The relative stiffness's of the straw stucco combination as compared to the concrete columns are very different; therefore the slab extension design mitigated the need for such connections. Please refer to the building enclosures portion of this report for more details.

Breadth Study #1: Straw Bale Building Enclosure

Straw bale construction began about 40 years after the invention of the horse powered baling machine, which happened about 140 years ago. It all began in the plains of Nebraska where the oldest known standing straw bale structure recently turned 100 in 2003. Straw bale had its recent revival in the 1980's also in the United States Northwest.

Straw bale structures are typically of two genres load bearing and non-load bearing. By the philosophy of sustainable natural materials load bearing straw bale is obviously the more preferred route when applicable, although due to the height of the Centre Court Apartments a non-load bearing strategy will be used which has many benefits of its own. The most practical is that by building the structure prior to bale placement you have a reliable cover from the environment to keep you bales safe and dry. The general method of building with straw is the stacking of bales similar to masonry without mortar between the bales. The walls are then wrapped with a wire mesh incased in the layers of stucco finish. This being said there are many benefits to building with straw although they come with a number of issues that need very special attention paid to them.

There are 3 main types of plasters cement, lime and earth. Cement plasters have known structural properties due to wide spread industry use. This makes them good for code approval. Although, they have poor vapor permeability and are much more brittle than other plasters. This results in a required meshing; normally steel that is connected by bands through the bales. Lime plasters are good for permeability and in fact act better for water leaving the bales than that of which is entering. Downfalls to lime are its extreme time dependence for curing. Coats should be limited to 3/8" and then allowed to cure resulting in more drawn out layers. Also due to the nature of the material, in a sense converting itself back to limestone, full strength can take a much longer time to reach compared to the 28 days of cement. Earth Plasters are by far the most "sustainable" but also carry a large amount of other benefits as well. They are very water permeable and expand once they have absorbed their maximum content of water resulting in an impermeable layer. The stiffness of earth plasters compliment the relative stiffness of the bales causing a more shared distribution of the load that can take more advantage of the flexible nature of the bales during in plane loading. Erosion of earth plaster is a necessary place of concern. It is recommended that earth plaster walls be re-plastered every 2-10 years depending on climate.

The Centre Court Apartments will make use of a lime plaster because the time dependant nature of the product will be negated with an efficient assembly line process of constructing the precast panels. Once again the bales will not be intended for load bearing purposes so the extended cure times will not be of concern. The lime is also an aseptic which makes it much more resistant to any kind of mold growth and by the nature of the material the CO_2 that is released during its production is reabsorbed through into the material overtime.

Straw is the tubular agricultural waste product that connects the roots to the grain. This tubular structure offers excellent thermal capabilities. Though tests have resulted in R values ranging from R-17 to R-65 the standard acceptable value is R-30 which is used by the California Energy Commission and based off of the Oak Ridge National Laboratory Tests conducted in 1998 that have become the industry standard resulting in an R of 1.45/in. It has also been concluded that when bales are laid on edge their thermal characteristics increase immensely. This is because while the bales are laid flat the tubular nature of that straw is perpendicular to the wall face, in a sense, opening a straight passage to the conduction process of the bales. While the bales are on end the tubes run parallel with the face of the wall. Therefore due to the Centre Court Apartments not attempting to bear load with the straw and also dealing with space constraints of an already designed building and on edge design will be used.

Straw bale construction normally uses three string bales that have dimensions of 16" tall, 23" wide, and 46" long, two sting bales are also used from time to time with respective dimensions of 15"X18"X36". Also due to space constrains the Centre Court apartment plans to incorporate 2 sting bales. This size bale is also the most conveniently obtained in the locally surrounding community. Thermal and structural qualities also rely on a few other industry standards such as density. Most builders and codes assume a dry density of 6 pcf to be the optimal measure.

Moisture is normally mandated to be no more than 20% of the total bale weight, although moisture concerns bring about a number of other rules of thumb that will be implemented in this project. Although some early codes required waterproof barriers it is now recommended that these not be used unless the building is placed in an extremely wet environment. The waterproof membrane often times acts to trap moisture into the organic material just as much as it keeps it out. This is why having your stucco finish remain slightly permeable is a very good deign decision. Roof overhangs and extending window sills with drip edges should always be present and should extend far enough that most of the rainfall due to drip does not reach the plaster finish. A roof overhang sufficient to deter the majority of windblown rain is not possible in the Centre Court Apartments therefore a Drain screen design approach will be used. This is the process of attaching a vapor-permeable layer of building paper to the exterior layer of stucco followed by another layer of wire mesh and stucco with a finish layer coat of siloxane. Siloxane is a vapor permeable finishing material with high water repellency, weather resistance, its UV stable, and it prevents mold. The ground will also be sloped down from the structure to prevent rainwater drip from splashing back on the building. There are currently a number of straw bale houses in Pennsylvania that are able to stand up to the wet/cold climate that certain parts of the year bring to this area of the country. An excellent example is the structure below that is located less than 10 miles away from the Centre Court Apartments. The structure is 8 years old and during an interview with one of the co-owners of the home James Rosenberger, a professor of statistics at Penn State University, he stated there has been no sign of moisture or pest damage involved with the bales since its construction. The house has a 1.5 ft roof overhang and on a non technical not the straw that was used to build the house was gathered from the rolling grain fields directly behind the home.

Figure 11: Central Pennsylvania Straw Bale Home
Courtesy of: Anthony Dente – Document Author

Figure 12: Central Pennsylvania Straw Bale Home and Straw Field
Courtesy of: Anthony Dente – Document Author

Fire resistance is also worthy of mention. The bale wall acts similar to heavy timber in that the exterior of the material chars creating a protective layer for the inner core. This is mostly brought about by the lack of oxygen that exists within the sandwich of the plaster skins. The most referenced test to date is the tests done on July of 2006. Two walls were tested to ASTM Standard E119 at Intertek Laboratories in San Antonio, TX. The test resulted in an official 2 hour fire rating. The straw bale walls will act as all fire walls in the apartment structure. This will be the only interior use of straw bale panels in the building. All other interior walls will be standard Forest Stewardess Council wooden stud walls.

It is also very noticeable in a straw bale home that acoustics are of high quality with a Sound Transmission Class rating of 55. This is similar to a stud wall with a double layer of 1/2“ insulation on each side of the wall with batt insulation incased within. At this STC loud speech is inaudible and music can faintly be heard. 99% of the population is not annoyed.

In the United States there are currently codes in 2 states, 10 counties, and 6 cities. The main tactic for convincing code officials is to demonstrate compliance to already existing codes, most often used is the current California codes. There have also been drafts for a straw bale section of the IBC which is included in Appendix D1. One of the original authors of this code, Bruce King, included it in his book “Design of Straw Bale Buildings” and intended it to be free of copy right and open to be shared and distributed widely among the building community. This is the main reason for its inclusion in this report although keep in mind it is very much a work in progress. Some of the main requirements to name a few are:

- Moisture content < 20%
- Dry Density = 6 pcf
- No vapor barrier less than 5 perms
- Parapets are prohibited
- 6:1 Height to width ratio
- Portland Cement wall – 600 plf shear capacity
- One hour fire resistance rating.

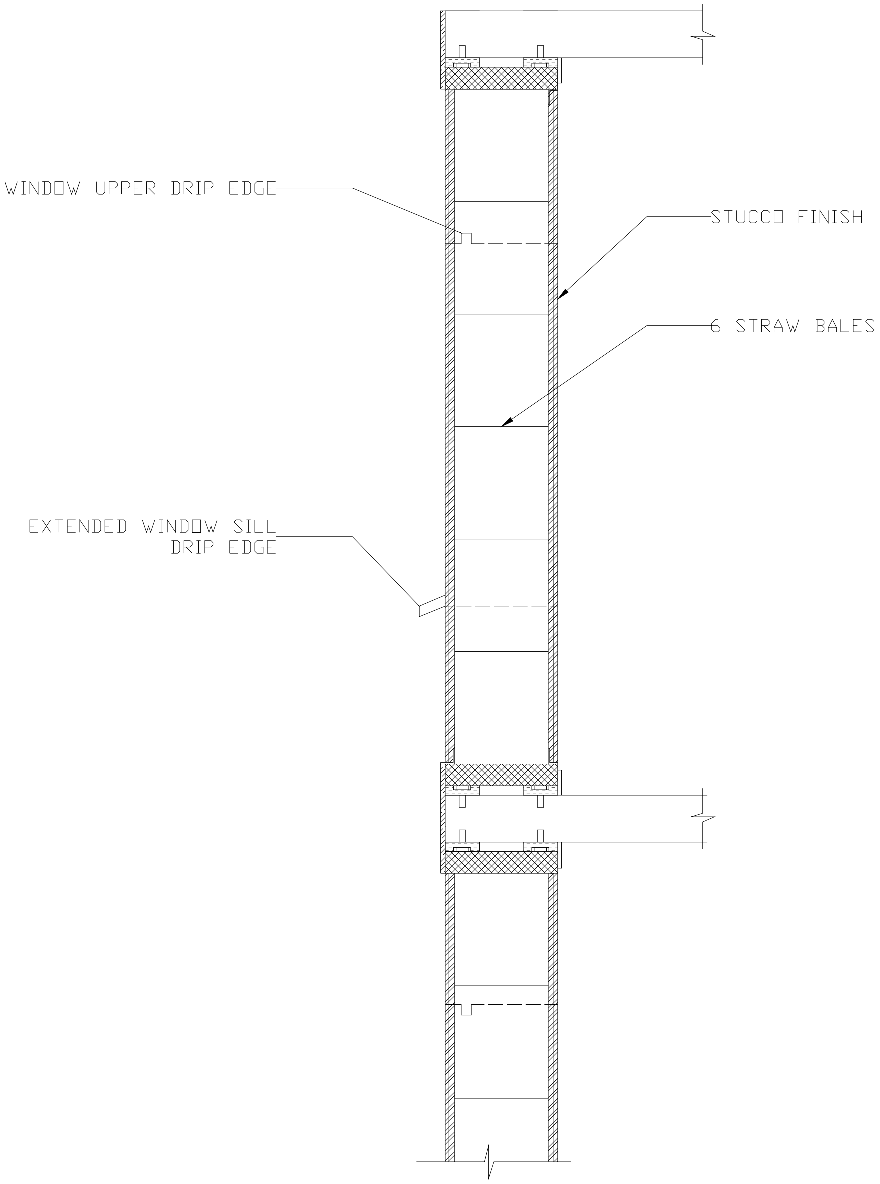


Figure 13: Straw Bale Panel Section

Pannel Design

There are a number of companies, individuals, and researchers around the globe currently taking part in precast straw bale panel production. The panels will be constructed in the parking garage areas of the bottom two floors being that they are 1’-4” taller than the upper floor of which the panels are being constructed for. The relative stiffness of the straw bale and that of the concrete frame are very different resulting in many connection difficulties and moisture concerns of poorly adhered stucco barriers. Therefore the floor slab will extend 1.5’ beyond the concrete frame to that the moisture barrier of the straw bales are not required to be interrupted by frame member at any point of the building.

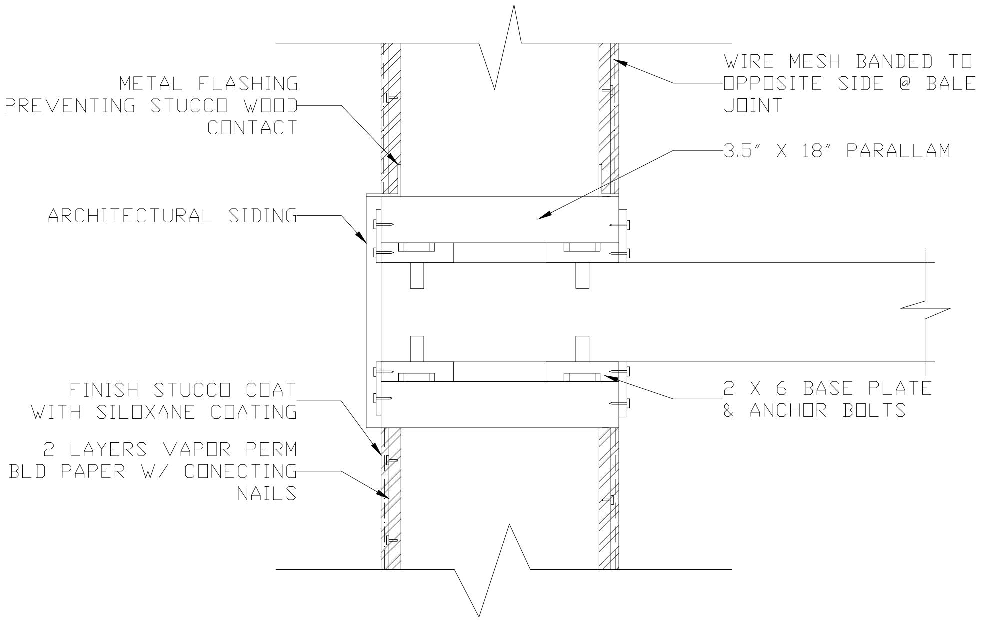


Figure 14: Straw Bale Panel Detail

The slab to slab thickness of the redesigned top five floors is 8'-8.5". (4) 3-string bales will be on edge with 6.25" panel supports on the top and bottom of each section. The panels will be incased in dimensional lumber on all four sides and connected to a sill plate that is then anchor bolted into the slab. The design is similar to the image of the Modcell product currently based in the United Kingdom.

Figure 15: Modcell Precast Panel, Courtesy of: www.modcell.co.uk

Where windows exist, voids spanning the entire height of the panel will be separated by dimensional lumber. The extending window sill will be fastened to this lumber and excess straw will be packed into the remaining open spaces. The lime stucco finish will be properly applied to the 16 gauge hexagonal woven wire mesh in varying layers with 3 coats of stucco of which the final coat will be dyed to match the shade of the stucco finish that currently exists on the building in order to create very little aesthetical change viewed by the common passerby. The panels will then be craned to the appropriate level in the same fashion at this 5 story building in The Netherlands bellow which was built by Rene Dalmeijer and his crew. This construction process is very similar to that of which will be conducted in the centre court apartments although here the lateral loads were resisted by a steel braced frame.

Figure 16: 5 Story Precast Straw Bale Structure in The Netherlands
Courtesy of: Rene Dalmeijer

Breadth Study #2: Architectural and Parking Adjustments

The building enclosure and structural framing additions to the building have caused many major drafting adjustments, although, as was the goal of the project, the overall aesthetic and attitude of the building was left unscathed.

The column grid layout forced large adjustments to the parking orientation of the bottom two stories. Per the zoning code of the Borough of State College the Centre Court Apartments originally required 133 spaces and the redesign required 134. The original parking calculations included all lobbies, foyers, common elevators, halls and stairwells which dictated by Section 1807c of the State College Zoning Code are permitted to be excluded from the area used in calculating the required parking for residential uses in the commercial zone. This requirement is 1 space per 800 square ft.. With this available leeway and the assistance of angled parking design aids in the State College Zoning Code and the 8th Edition of the Architectural Graphics Standards an angled parking layout in both the indoor and exterior parking was constructed. The final design resulted in an increase in building width of 16.2' not related to that caused by the thickness of the straw bales in the upper floors and negated the gain in available parking freedom due to an increase in building unit floor area. Due to these unfavorable results four parking spaces required by code were left unaccounted for. Due to the philosophy of sustainability that this report carries throughout, a plea to the local building code agency will be made that the slight reduction in parking is a legitimate exception to the code because a decrease in available student parking helps to influence students to park out of farther out of town. This would likely result in them not crowding the streets and emitting unneeded fossil fuels for simple distances able to be walked. It also should be noted that due to this increase each individual apartment was increased by 460 SF. It is also most likely a reasonable assumption that similar overestimation were made on the parking requirement of Building B which also equally influence the parking volume calculated for The Centre Court Apartments. This is only able to be assumed due to a lack of knowledge of the exact occupancy and floor areas of Building B.

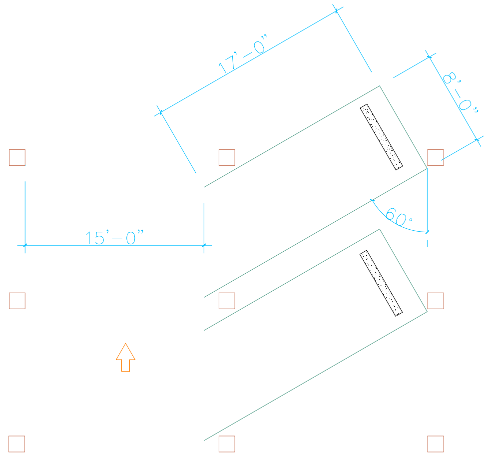


Figure 17: Burrow of State College Zoning Parking Requirements in CCA

The extreme width increase of the building was mostly brought about from the new edition of a center two column rows with a connecting span of 6’-8”. This column arrangement found to be the most convenient because it could scale the border of the upper story hallway the complete length of the building. In order to make proper use of this seemingly awkward column arrangement living walls will be constructed spanning the short width from column to column. This will not only increasing the aesthetically dead atmosphere of the pale, dirt collecting, concrete garage, but will also improve the indoor environmental air quality in the portion of the building that is the least healthy for human inhabitants. The plants will be watered by diverting portion of the roof drainage water over the living walls in the high level parking garage. This will be accomplished conveniently due to the 5 roof drains following the duck work directly down the center hall way until the high level parking garage where they then redirect towards the columns. The unconsumed water will then drain to the low level and eventually be collected in drainage bellow the building and combined with the usual drainage of the street. The Centre Court Apartments already makes use of a Storm Water Retention System (SWR) designed by Zurn Company from Erie, PA. The SWR system is a series of restricted diameter piping to reduce water flow of storm runoff. This same technique would be used to insure that the living walls would never receive too much water. The walls would consist of coconut lattice containing light weight clay media of which would hold the roots of a variety of different sedum plants. Sedums are thick, hardy, succulent plants that can survive extreme temperature variations and drought very well while maintaining the ability to absorb very large amounts of water in short periods of time. With 24, 6’-8” X 10’ living walls this will result in a significant reduction of storm water and will aid as a benefit to the community as a result. There is relatively no direct lighting that will reach the plant media. This is not a problem because the current lighting plan consists of metal halide bulbs which produce a full spectrum white light as a member of the HID lighting family. Many plant growers trust metal halide bulbs for growing purposes. Only minor changes would be required to the lighting plan therefore it is only available upon request.

HVAC & Plumbing Adjustments

Straw bale panels do not work well with in-wall air conditioning units and it is also recommended not to have baseboard heating, both of which are present in The Centre Court Apartments. This issue will be mitigated through a Duct Free Slit System. The Duct Free Split System will place outdoor condensing units on the roof of the structure that will pipe refrigerant to fan coils in each individual unit. This system negates the need of additional duct work which is the main issue behind switching to a new HVAC supplying system in an already designed building. The refrigerant used will be chlorine free negating its effect of the ozone layer as regulated by the EPA. Being that this is not a large breadth of this redesign the system has not been sized although proper research has proven that the system would be a sufficient substitute in the presence of straw bale paneling.

The current wet pipe sprinkler system will be replaced with a precaution system. This will give the occupants a chance to react to false alarms prior to water discharge. This is extremely important because as noted many times to this point of the report, any moisture in contact with the straw walls can cause many problems and need for immediate repairs. Below are a number of plans of the old and new designs of the Centre Court Apartments respectively.

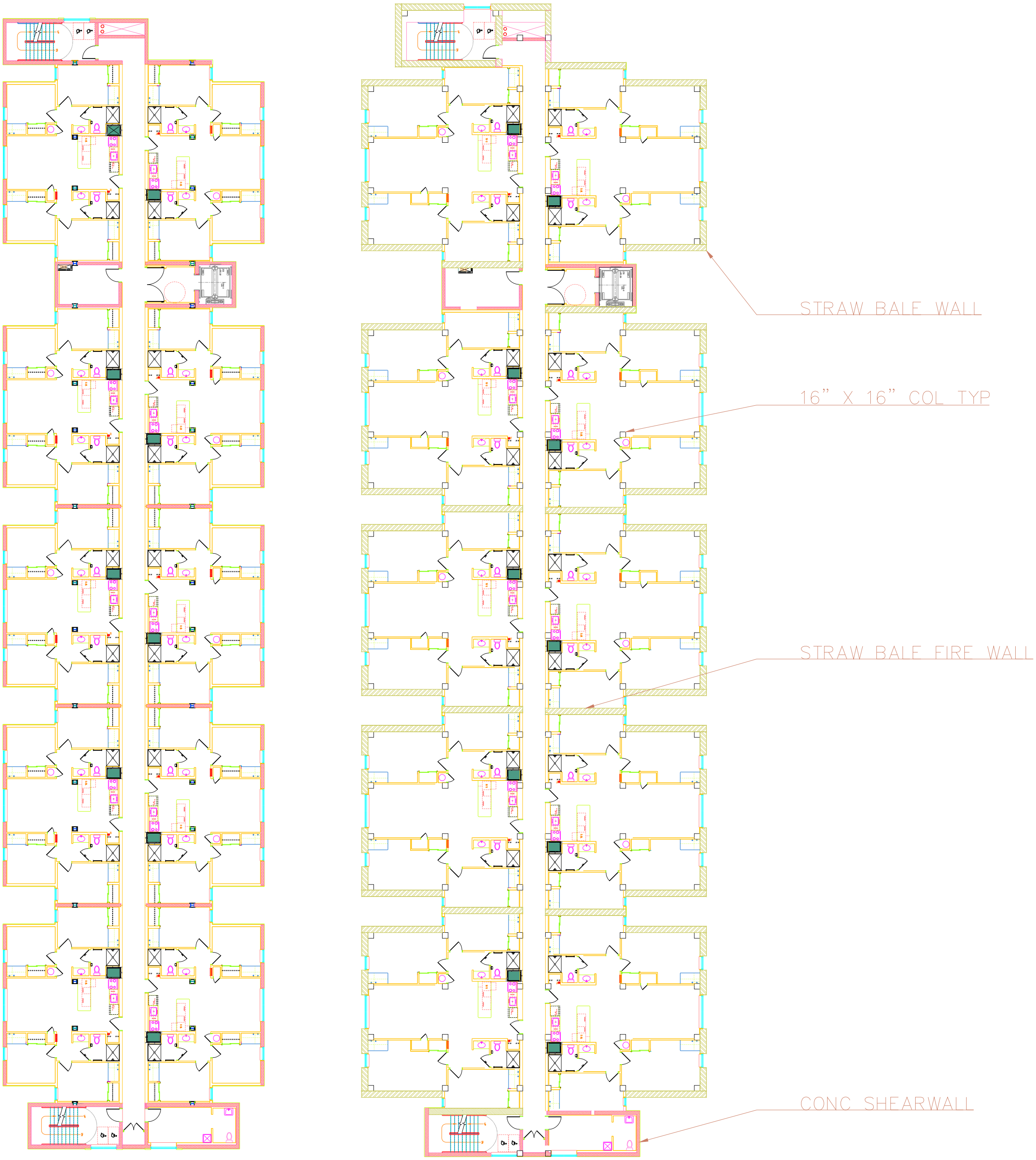


Figure 18: Existing and Redesigned 3rd Floor Plan

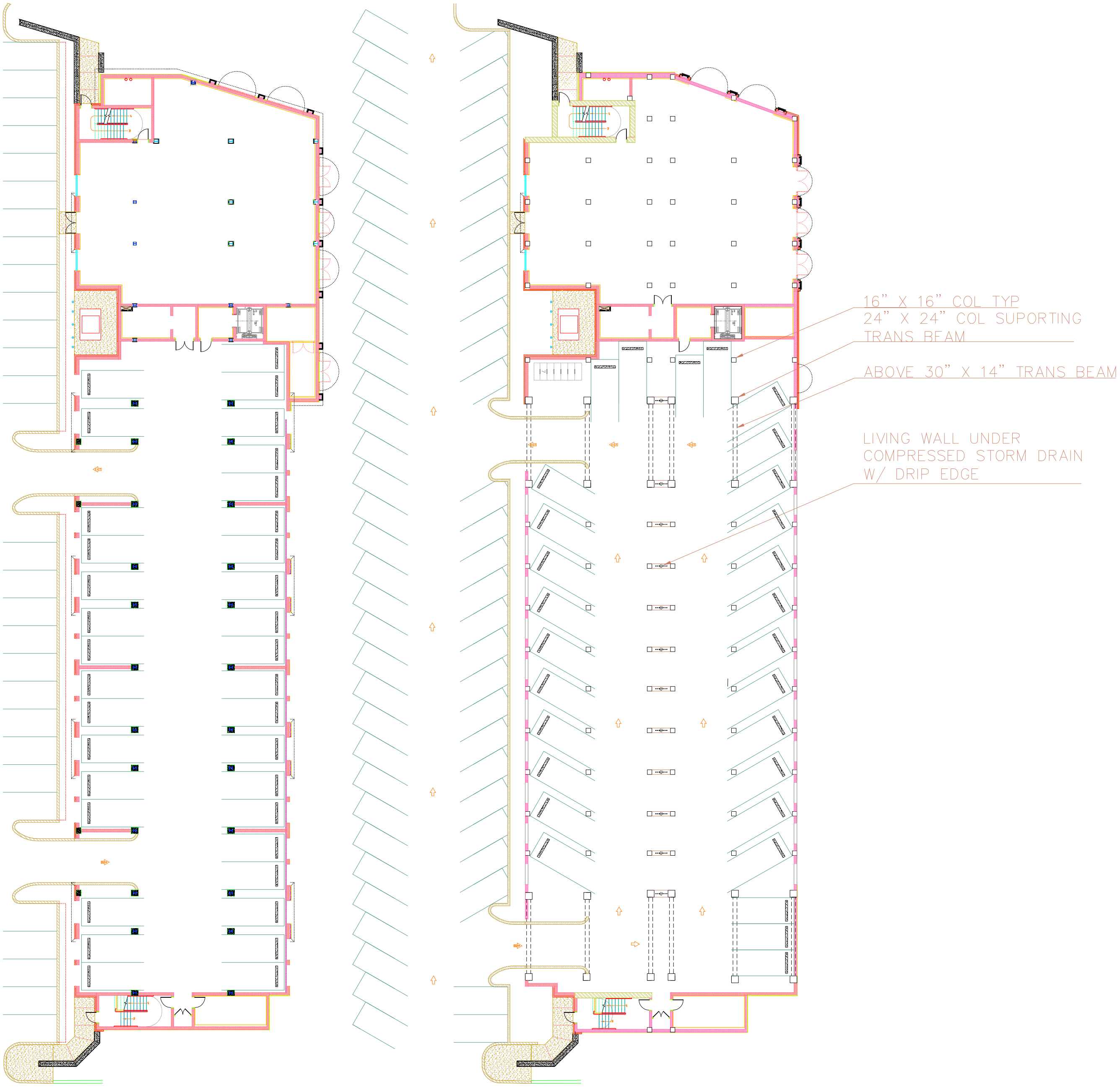


Figure 19: Existing and Redesigned High Level Parking Plan

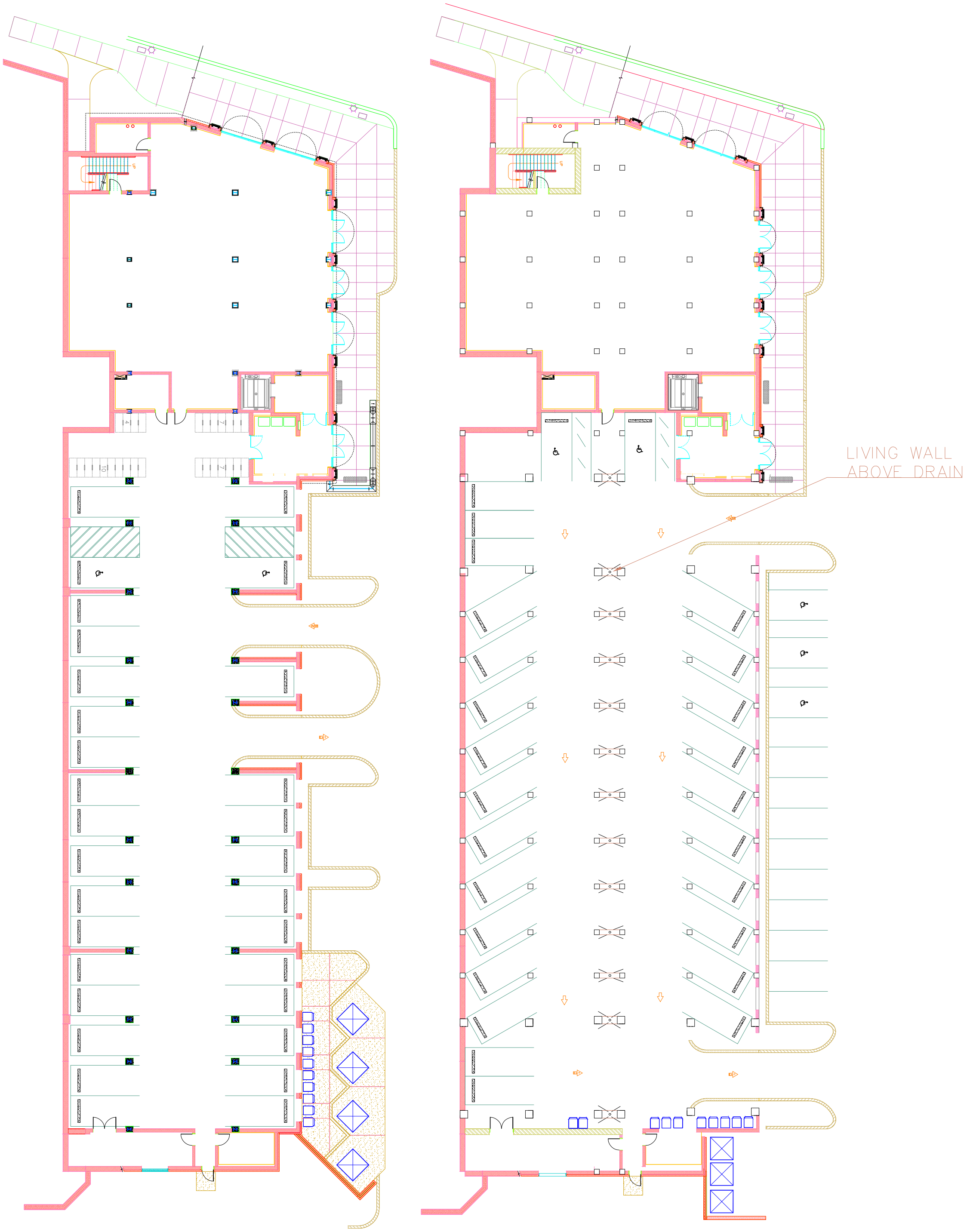


Figure 20: Existing and Redesigned Low Level Parking Plan

Cost and Scheduling Information

A cost comparison was conducted to exhibit the differences of the old construction methods versus the redesigned Centre Court Apartments. These numbers are not meant to represent the total costs of any system other than those estimated and this study was conducted only to compare costs with the knowledge that the values were obtained using the same assumptions. Construction management is not a primary breadth of this report therefore data was only collected to express the general material and estimated labor costs of the materials at hand.

The majority of the cost comparison values were obtained through RS Mean 2006 being that 2006 was a more accurate estimation of the costs at the time of construction. Only the top 5 stories wall systems and all 7 levels of slabs were considered. The Straw Bale costs were obtained by the beautiful straw supplier at Ishler Farms and Shuey's Market in on Benner Pike in State College, PA which is a approximately 54.5 miles away from the building site. They supply 2 sting bales which are the exact bale to be used in the Centre court apartments at either $5 per bale or $175 per ton which is approximately 80 bales equaling $2.1875 per bale. The labor values were estimated with the values supplied by Modcell a precast straw bale company based in the United Kingdom. They accomplish one 3 meter panel with 2 man days on the panel and 0.5 man days reducing the stucco. Values were compared with those of similar masonry, stucco, and precast qualities in RS Means to come up with a reasonable assumption of the values used. Only the end values are included in this report, exact assumptions are available upon request.

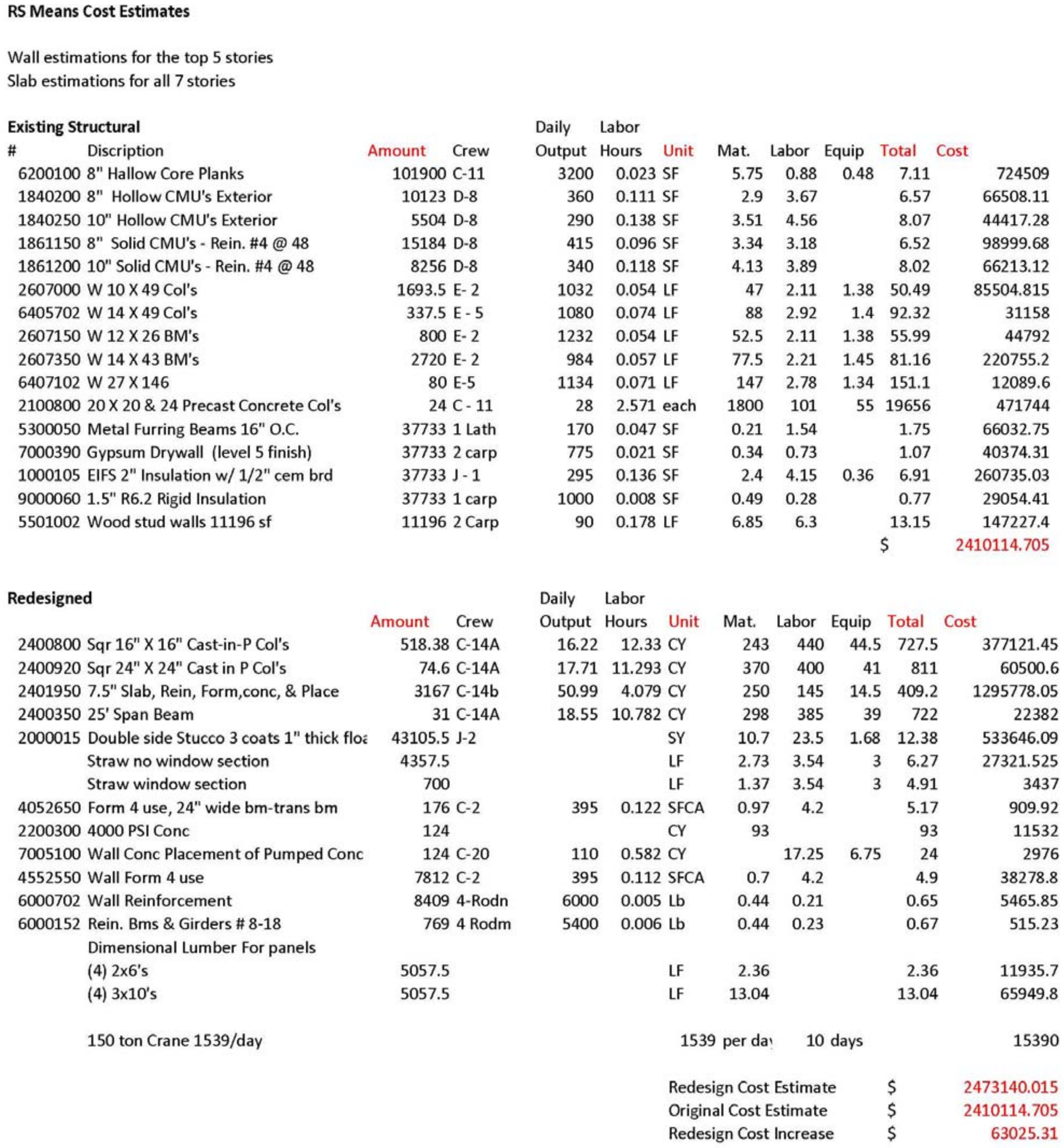
The fly ash contributions were not included into the numbers on the graph bellow. It was assumed that the values would be more accurate and better represented if the correct RS Means estimations were used for normal concrete and the cost savings of fly ash presented here in the text rather than attempting to incorporate proper multipliers on top of the multi dimensional estimations of RS Means.

Separations Technologies branch in Pennsylvania's estimates on average costs for the local area were as follow:

- Cement: $120 per ton "In Bin Cost" as it is delivered to the factory
- Fly Ash: $55-$60 per ton "in Bin Cost" as it is delivered to the factory

As stated earlier in the report, fly ash is not an admixture but a direct substitute for the cement content of the mix therefore the 55% cost saving on 50% of the ash used in the mix would result in significant material cost savings. As also stated earlier in this document the curing time is increased significantly from 28 days to 56 day. Although time did not permit a proper schedule to be calculated for the redesigned structure it is assumed that these costs would act to balance themselves out to some extent.

Although the apartment complex has already increased its rent to $670/month/resident from the original $550 in its first year on the market 3 years ago, it is assumed the massive increase in square footage will indeed still increase revenue at least a little more especially with the added increase in indoor environmental quality. With that, the knowledge that the cost increase of $63,000 was not including the added material savings of the concrete. The business case for The Centre Court Apartments redesign appears strong, let alone the fact that a large quantity of the building material with be supporting local community members less than 5 miles from the site.



RS Means Cost Estimates

Wall estimations for the top 5 stories
Slab estimations for all 7 stories

Existing Structural

				Daily	Labor						
#	Discription	Amount	Crew	Output	Hours	Unit	Mat.	Labor	Equip	Total	Cost
6200100	8" Hallow Core Planks	101900	C-11	3200	0.023	SF	5.75	0.88	0.48	7.11	724509
1840200	8" Hollow CMU's Exterior	10123	D-8	360	0.111	SF	2.9	3.67		6.57	66508.11
1840250	10" Hollow CMU's Exterior	5504	D-8	290	0.138	SF	3.51	4.56		8.07	44417.28
1861150	8" Solid CMU's - Rein. #4 @ 48	15184	D-8	415	0.096	SF	3.34	3.18		6.52	98999.68
1861200	10" Solid CMU's - Rein. #4 @ 48	8256	D-8	340	0.118	SF	4.13	3.89		8.02	66213.12
2607000	W 10 X 49 Col's	1693.5	E- 2	1032	0.054	LF	47	2.11	1.38	50.49	85504.815
6405702	W 14 X 49 Col's	337.5	E - 5	1080	0.074	LF	88	2.92	1.4	92.32	31158
2607150	W 12 X 26 BM's	800	E- 2	1232	0.054	LF	52.5	2.11	1.38	55.99	44792
2607350	W 14 X 43 BM's	2720	E- 2	984	0.057	LF	77.5	2.21	1.45	81.16	220755.2
6407102	W 27 X 146	80	E-5	1134	0.071	LF	147	2.78	1.34	151.1	12089.6
2100800	20 X 20 & 24 Precast Concrete Col's	24	C - 11	28	2.571	each	1800	101	55	19656	471744
5300050	Metal Furring Beams 16" O.C.	37733	1 Lath	170	0.047	SF	0.21	1.54		1.75	66032.75
7000390	Gypsum Drywall (level 5 finish)	37733	2 carp	775	0.021	SF	0.34	0.73		1.07	40374.31
1000105	EIFS 2" Insulation w/ 1/2" cem brd	37733	J - 1	295	0.136	SF	2.4	4.15	0.36	6.91	260735.03
9000060	1.5" R6.2 Rigid Insulation	37733	1 carp	1000	0.008	SF	0.49	0.28		0.77	29054.41
5501002	Wood stud walls 11196 sf	11196	2 Carp	90	0.178	LF	6.85	6.3		13.15	147227.4
										$	2410114.705

Redesigned

				Daily	Labor						
		Amount	Crew	Output	Hours	Unit	Mat.	Labor	Equip	Total	Cost
2400800	Sqr 16" X 16" Cast-in-P Col's	518.38	C-14A	16.22	12.33	CY	243	440	44.5	727.5	377121.45
2400920	Sqr 24" X 24" Cast in P Col's	74.6	C-14A	17.71	11.293	CY	370	400	41	811	60500.6
2401950	7.5" Slab, Rein, Form,conc, & Place	3167	C-14b	50.99	4.079	CY	250	145	14.5	409.2	1295778.05
2400350	25' Span Beam	31	C-14A	18.55	10.782	CY	298	385	39	722	22382
2000015	Double side Stucco 3 coats 1" thick floa	43105.5	J-2			SY	10.7	23.5	1.68	12.38	533646.09
	Straw no window section	4357.5				LF	2.73	3.54	3	6.27	27321.525
	Straw window section	700				LF	1.37	3.54	3	4.91	3437
4052650	Form 4 use, 24" wide bm-trans bm	176	C-2	395	0.122	SFCA	0.97	4.2		5.17	909.92
2200300	4000 PSI Conc	124				CY	93			93	11532
7005100	Wall Conc Placement of Pumped Conc	124	C-20	110	0.582	CY		17.25	6.75	24	2976
4552550	Wall Form 4 use	7812	C-2	395	0.112	SFCA	0.7	4.2		4.9	38278.8
6000702	Wall Reinforcement	8409	4-Rodn	6000	0.005	Lb	0.44	0.21		0.65	5465.85
6000152	Rein. Bms & Girders # 8-18	769	4 Rodm	5400	0.006	Lb	0.44	0.23		0.67	515.23
	Dimensional Lumber For panels										
	(4) 2x6's	5057.5				LF	2.36			2.36	11935.7
	(4) 3x10's	5057.5				LF	13.04			13.04	65949.8
	150 ton Crane 1539/day					1539 per da		10 days			15390
						Redesign Cost Estimate				$	2473140.015
						Original Cost Estimate				$	2410114.705
						Redesign Cost Increase				$	63025.31

Conclusion

All economic results aside, it is not to be forgotten that the main objective of this thesis is to show a route that could be taken in order to assume responsibility as an owner, builder, or designer for the environmental impacts of a structure you have a hand in creating. In the environmental crisis that our planet is currently undergoing, we can no longer go about any daily activities in our lives and believe that due to comfort in an old method or upfront costs that we aren't contributing to the problem. With the industry fully recognizing the feasibility of building green, although this alternative design may be an extreme example, a sustainable building can be a very natural shift in the way we build.

The column grid layout that was applied to this building was not the most optimal design, although if the design team had made these material choices from the start the concrete frame could have been integrated with much more ease. That being said the structural changes turned out sufficient.

The cost savings and environmental benefits of High Content Fly Ash Concrete turned out to be very impressive. If the size of the building had not been increased by 35,000 sf the cost savings of the material alone is believed to have been more self evident. The extended set times would have indeed set back the project schedule had that been a significant breadth of this report, although the increased workability of the mix would have had some effect on counteracting that effect. Due to the inability of pretesting specific concrete mixes in our local climate, strength additions to the mix were not available for calculations. Though research strongly indicated that a higher grade of concrete was a very probable result when using High Content Fly Ash. It is not to be forgotten that the only way to mitigate the environmentally degrading effects of the coal industry by sequestering some of it's by product is if the coal industry is causing harmful effects in the first place. That being said, while we push our culture to turn to renewable fuel sources of the future we shall never forget the increasing problems of the present.

Precast straw bale paneling is young, although it is catching on all across the globe. The design adjustments that are used to adapt this technology to the cold and wet local climate of central Pennsylvania are minor, although extremely important. High attention must be paid and all workers in contact with any form of the construction process must be well educated on the do's and don'ts of straw bale building. If this is accomplished the methods, materials, tools, and skills required on a precast straw bale construction site are no different than those found in many areas of the building industry. The benefits in cost of material, thermal qualities, acoustics, aesthetics, and the ability to use a material that would otherwise be burned as in many cases around the nation are undeniable.

The architectural changes of major parking redesigns and building extensions were found to be a result almost entirely brought about by the difficulties of implementing sustainable designs when the entire design team is not involved. In this segments of the design team were absent because the building was already built, and the scope of this research could only cover so much of the project. The main problems such as the loss of 4 parking spaces and the massive increase in building size was not influence much by the straw bale paneling or the fly ash content. With the building already exhibiting a stucco aesthetic the exterior view of the structure was altered very minimally with the top 5 floors extending 1.5 ft beyond the bottom two and a thin strip of wood cladding wrapping the building where every slab intersects the exterior walls. The living walls that were able to be installed using nothing but the storm drain water supply and metal halide lighting that already existed in the garages will do wonders for improving the aesthetics and air quality of the most dull, toxic space in the building. Not to mention the storm water retention that will result from them as well.

As a building owner of a high rise in the commercial district of the Borough of State College, PA the upfront cost, although not unfavorable, are a mood point to the reaction that a structure such as this will bring to your building and business endeavors. Respect is growing higher and higher for the members of the community that are working to improve the air quality, working conditions, natural environment and local commerce especially in a more left wing college environment such as State College. This is the type of structure that through evidence of the success of ranking systems such as LEED and other green building advocates is sure to make its way to State College, PA in a strong way. If the Centre Court Apartments would have been designed using these technologies it would have had a personality like no other in the community and surly would have benefited respectively.

That being said the Centre Court Apartments are a student housing facility in an area of town were the nights are late, the parties loud, and the alcohol in large quantities. If the inhabitants are not properly informed of the effects that can have, good and bad, on materials such as straw bale, there is a chance that this could be a terrible combination. On the other hand, green buildings offer their occupants the opportunity to experience the interconnected nature of their existence in union with the materials they live with everyday. It is the author of this thesis report’s hope that the result of the straw/student housing combination would result favorably, attracting a student body with a shared interest in living in a healthy progressive environment and one that will care and better upkeep the building they inhabit. Although, that is merely speculation and this is a matter that only time would tell.

As the Author of this thesis I would highly recommend the Centre Court Apartments implement these technologies with all do precautions to set the bar for all fellow community members, building owners, designers, contractors, and most of all structural engineers.

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Appendix A1: Loading

Load Combinations

The Load Combinations of Chapter 2 in ASCE 7-05 are listed below. Each of these load combinations were analyzed via the ETABS modeling system in computing the lateral reactions listed below.

1. 1.4(D + F)
2. 1.2(D + F + T) + 1.6(L + H) + 0.5(Lr or S or R)
3. 1.2D + 1.6(Lr or S or R) + (L or (0.8W)
4. 1.2D + 1.6W + L +0.5(Lr or S or R)
5. 1.2D + 1.0E + L + 0.2S
6. 0.9D + 1.6W + 1.6H
7. 0.9D + 1.0E + 1.6H

Gravity Loads

Gravity Loads have been calculated in accordance with ASCE 7-05 with the Live Loads interpreted from section four. These loads where used to calculate masses and uniform loads applied to the ETABS structural model of the Centre Court Apartment Building of with the results are listed below. Assumptions were made for proper distribution of Gravity Loads.

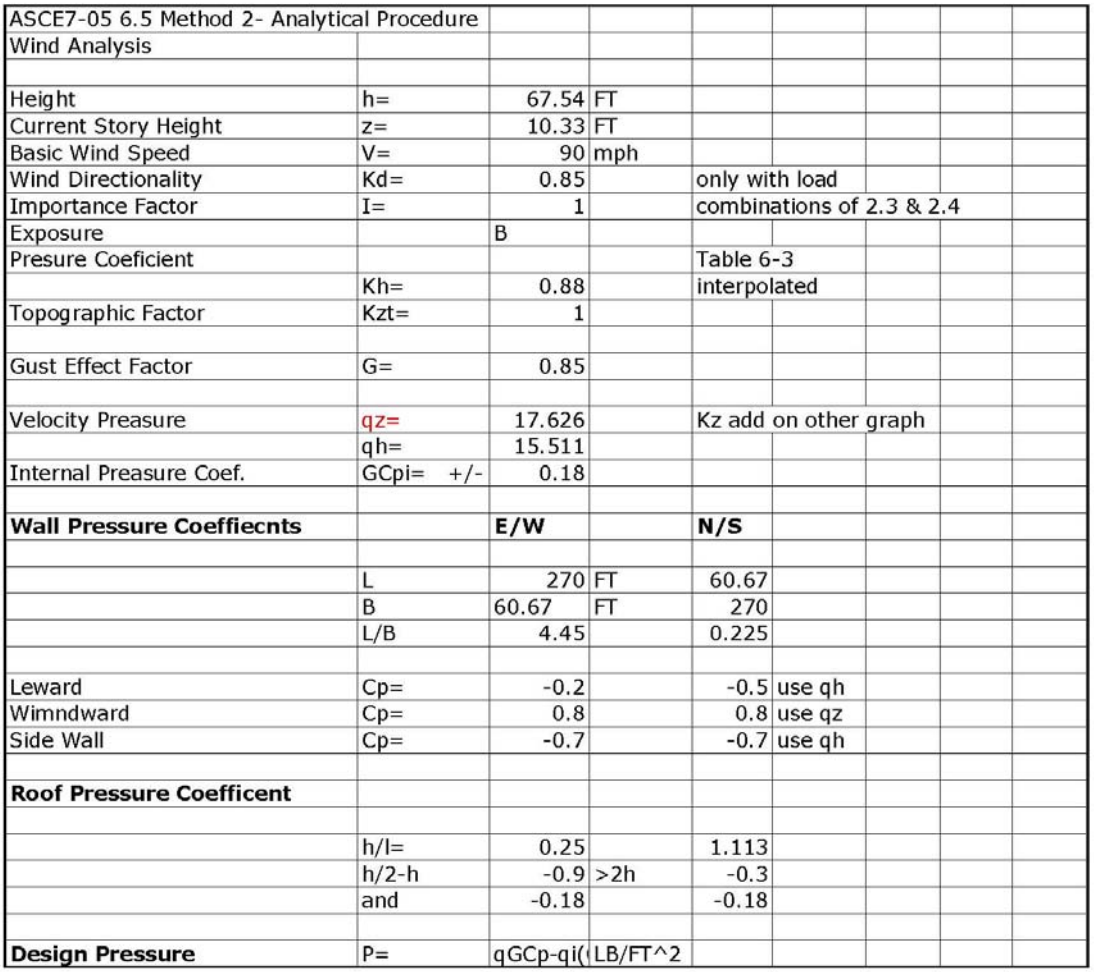
Dead Load

6.5" Slab	81.25	psf	
Concrete	150	pcf	
Partitions	15	psf	
MEP	10	psf	
Misc	5	psf	
Brick	38	psf	
Straw Bale	38.75	psf	of floor contact
Windows	8	psf	

Live Loads

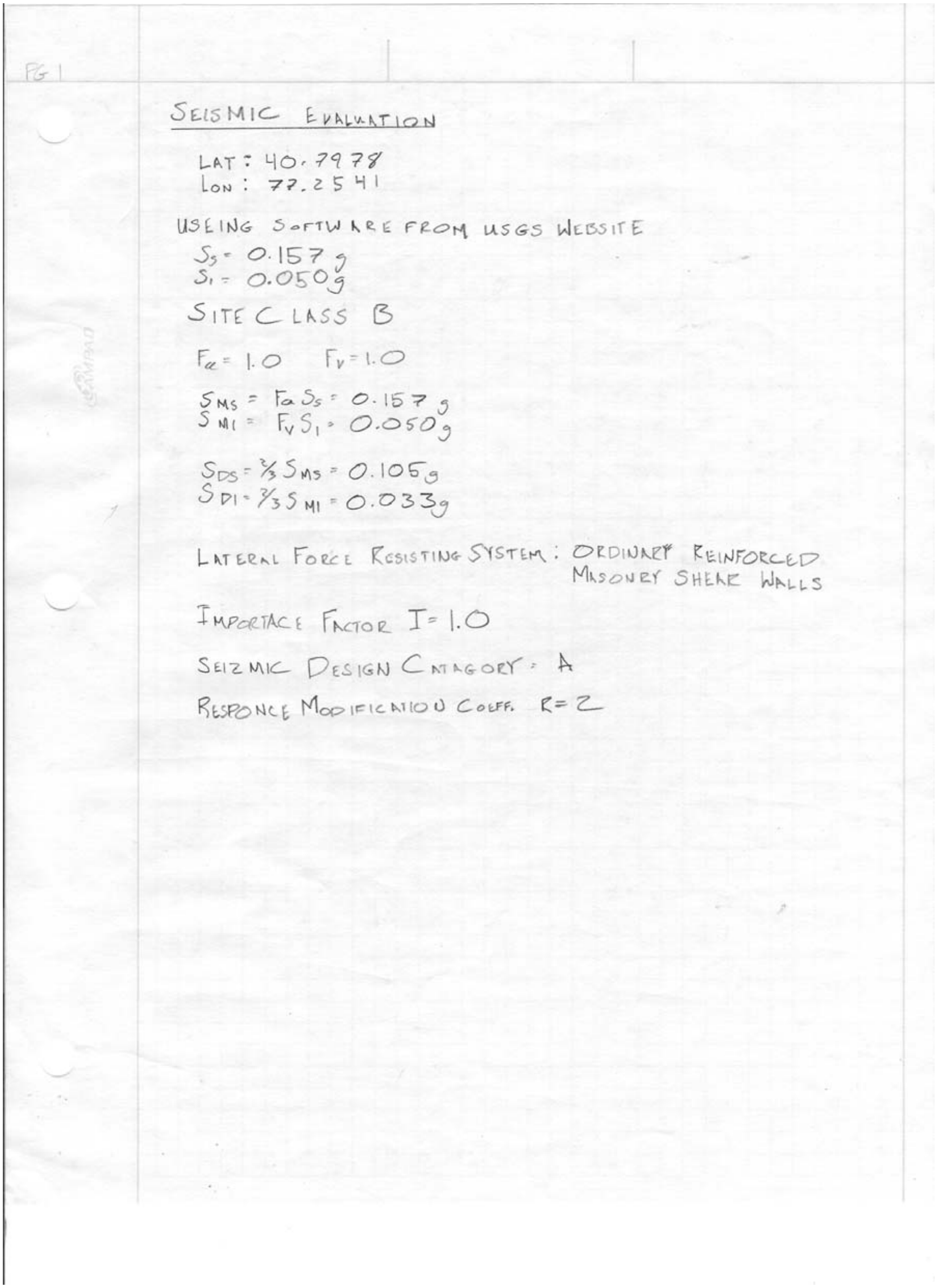
Corridors	100	psf
Garages	40	psf
Private Rooms	40	psf
Public Rooms	100	psf
Roof	20	psf
Snow	21	psf

Appendix A2: Wind Load Data



ASCE7-05 6.5 Method 2- Analytical Procedure					
Wind Analysis					
Height	h=	67.54	FT		
Current Story Height	z=	10.33	FT		
Basic Wind Speed	V=	90	mph		
Wind Directionality	Kd=	0.85		only with load	
Importance Factor	I=	1		combinations of 2.3 & 2.4	
Exposure		B			
Presure Coeficient				Table 6-3	
	Kh=	0.88		interpolated	
Topographic Factor	Kzt=	1			
Gust Effect Factor	G=	0.85			
Velocity Preasure	qz=	17.626		Kz add on other graph	
	qh=	15.511			
Internal Preasure Coef.	GCpi= +/-	0.18			
Wall Pressure Coeffiecnts		**E/W**		**N/S**	
	L	270	FT	60.67	
	B	60.67	FT	270	
	L/B	4.45		0.225	
Leward	Cp=	-0.2		-0.5	use qh
Wimndward	Cp=	0.8		0.8	use qz
Side Wall	Cp=	-0.7		-0.7	use qh
Roof Pressure Coefficent					
	h/l=	0.25		1.113	
	h/2-h	-0.9	>2h	-0.3	
	and	-0.18		-0.18	
Design Pressure	P=	qGCp-qi(	LB/FT^2		

Appendix A3: Seismic Load Data



PG 1

SEISMIC EVALUATION

LAT: 40.7978
LON: 77.2541

USEING SOFTWARE FROM USGS WEBSITE

$S_S = 0.157\,g$
$S_1 = 0.050\,g$

SITE CLASS B

$F_a = 1.0 \quad F_v = 1.0$

$S_{MS} = F_a S_S = 0.157\,g$
$S_{M1} = F_v S_1 = 0.050\,g$

$S_{DS} = \frac{2}{3} S_{MS} = 0.105\,g$
$S_{D1} = \frac{2}{3} S_{M1} = 0.033\,g$

LATERAL FORCE RESISTING SYSTEM: ORDINARY REINFORCED MASONRY SHEAR WALLS

IMPORTACE FACTOR $I = 1.0$

SEIZMIC DESIGN CATAGORY: A

RESPONCE MODIFICATION COEFF. $R = 2$

Pg 2

$T_a = C_t h_n^x$

$T_a = (0.2)(67.54')^{0.75} = 0.47$

$C_u = 1.7$

$\underline{T} = 0.47(1.7) = \underline{0.799s \quad \text{OR } 1.25\ \text{Hz}}$

$C_T = 0.2$

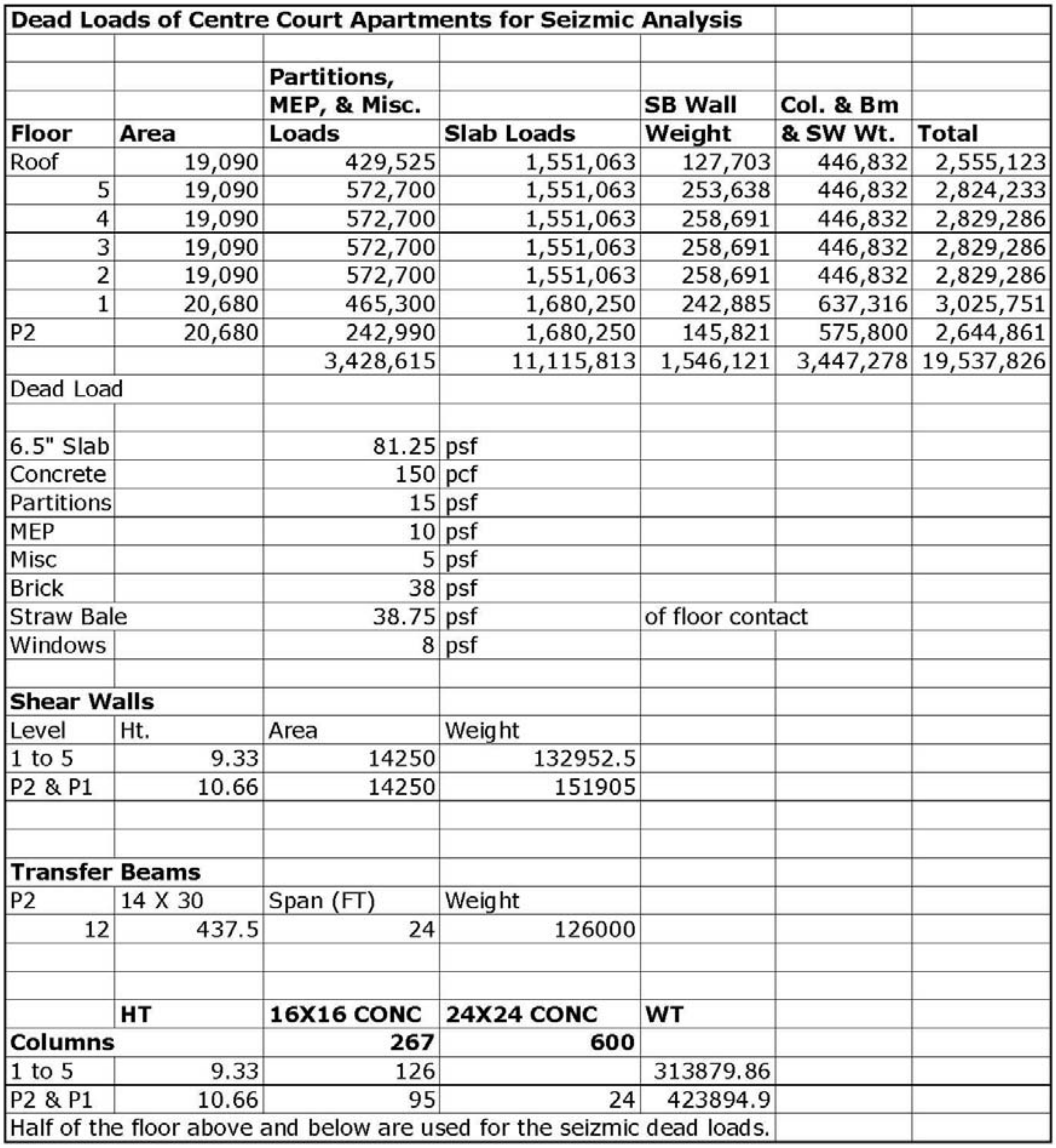
$$C_{S=MIN} \begin{cases} S_{DS}/(R/I) = 0.105/(2/1) = 0.0525 \\ S_{D1}/T[(R/I)] = 0.033/.799(2) = 0.0207 \\ \dfrac{S_{D1}T_L}{T^2(R/I)} = \dfrac{(0.033)(6)}{(0.799)(2)} = 0.1239 \end{cases}$$

$T_L = 6$

$C_S = 0.0207$

$V = C_S W = 0.0207(11{,}420^k) = 236.394$

$k = 1.15$

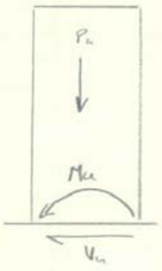


Dead Loads of Centre Court Apartments for Seizmic Analysis						
Floor	**Area**	**Partitions, MEP, & Misc. Loads**	**Slab Loads**	**SB Wall Weight**	**Col. & Bm & SW Wt.**	**Total**
Roof	19,090	429,525	1,551,063	127,703	446,832	2,555,123
5	19,090	572,700	1,551,063	253,638	446,832	2,824,233
4	19,090	572,700	1,551,063	258,691	446,832	2,829,286
3	19,090	572,700	1,551,063	258,691	446,832	2,829,286
2	19,090	572,700	1,551,063	258,691	446,832	2,829,286
1	20,680	465,300	1,680,250	242,885	637,316	3,025,751
P2	20,680	242,990	1,680,250	145,821	575,800	2,644,861
		3,428,615	11,115,813	1,546,121	3,447,278	19,537,826
Dead Load						
6.5" Slab		81.25	psf			
Concrete		150	pcf			
Partitions		15	psf			
MEP		10	psf			
Misc		5	psf			
Brick		38	psf			
Straw Bale		38.75	psf	of floor contact		
Windows		8	psf			
Shear Walls						
Level	Ht.	Area	Weight			
1 to 5	9.33	14250	132952.5			
P2 & P1	10.66	14250	151905			
Transfer Beams						
P2	14 X 30	Span (FT)	Weight			
12	437.5	24	126000			
	HT	**16X16 CONC**	**24X24 CONC**	**WT**		
Columns		**267**	**600**			
1 to 5	9.33	126		313879.86		
P2 & P1	10.66	95	24	423894.9		
Half of the floor above and below are used for the seizmic dead loads.						

Appendix B1: Shear Wall Design Calculations

N/S SHEAR WALL DESIGN

WORST CASE FOR N/S WALLS



LOADS OBTAINED FROM ETABS MODEL

$P_u = 189.8^k$
$V_u = 264^k$
$M_u = 6100^{ft\text{-}k}$

CHECK NEED OF BOUNDRY ELEMENT   TRY $t = 12''$

$I_g = \frac{1'(18.75)^3}{12} = 549.3$

$A_g = (1')\,18.75 = 18.75\ \text{FT}^2$

$\frac{P_u}{A_g} + \frac{M_u(\ell_n/2)}{I_g} \geq 0.2 f'_c$

$\frac{189.8}{18.75} + \frac{6100(18.75/2)}{549.3} \geq 0.2\,(4^{ksi})$

$\frac{10.12 + 104.1}{144} \geq 0.8$

$0.79 \geq 0.8 \longrightarrow$ No BE NESISARY

LONG. & TRANS REINFORCEMENT

ACI 21.7.2 $\rho_\ell \ \& \ \rho_t \geq 0.0025$

$V_u \geq 2A_{cv}\sqrt{f'_c}$ REQ'S 2 CURTAINS

$246 \geq 2(18.75(12) \times 12)\sqrt{4000}/1000$

$246 \geq 341.5 \longrightarrow$ NO NEED FOR TWO CURTAINS

N/S SHEAR WALL DESIGN (CONT.)

$\rho_t = \frac{A_{TRANS}}{A_{cv}}$ $\qquad \rho_l = \frac{A_{LONG}}{A_{cv}}$

$A_{cv} = 12''(12'') = 144 \ IN^2/FT$

$A_{s\,LONG} \ REQ'D = 0.0025(144) = 0.36 \ IN^2/FT$

$\#5's \quad A_s = 0.31 \ IN^2$

$\frac{0.36}{12''} = \frac{0.31}{s} = \quad S_{REQ'D} = 10.33'' < 18''$ ✓

TRY $\boxed{\#5's \ HORZ \ \& \ VERT \ @ \ 10'' \ O.C.}$ $\quad \boxed{18.75' \times 12'' \ WALL}$

NOMINAL SHEAR CAPACITY

$V_n = A_{cv}(\alpha_c \sqrt{f'_c} + \rho_t f_y)$

$\frac{h_w}{l_w} = \frac{67.5}{18.75} = 3.6 > 2 \quad \therefore \quad \alpha_c = 2.0$

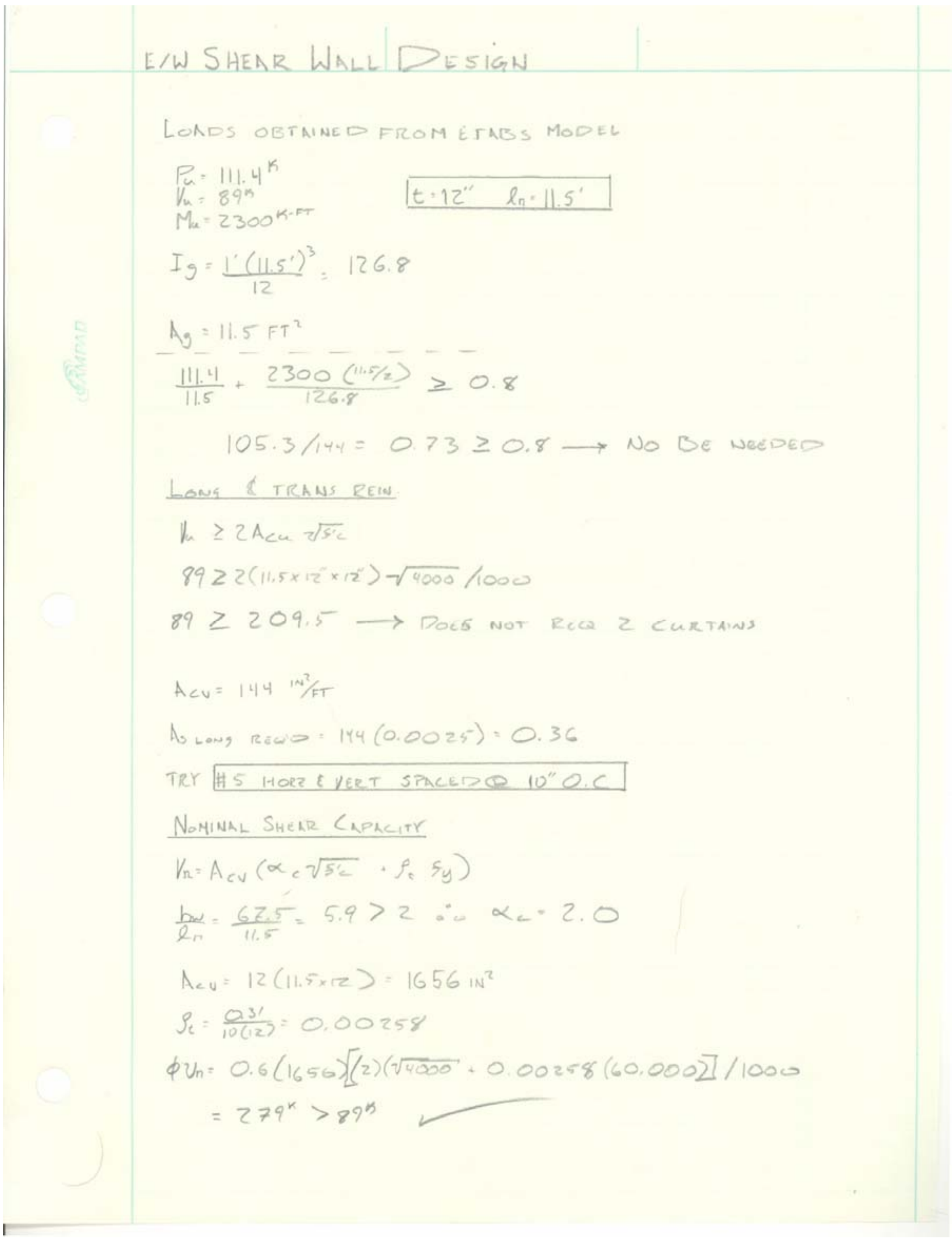
$A_{cv} = 12(18.75 \cdot 12) = 2700 \ IN^2$

$\rho_t = \frac{0.31}{10(12)} = 0.00258$

$V_n = 2700(2\sqrt{4000} + 0.00258(60{,}000))/1000$

$V_n = 759^K$

$759(.6) = 455.4^K > 264^K$ ✓



E/W SHEAR WALL DESIGN

LOADS OBTAINED FROM ETABS MODEL

$P_u = 111.4^K$

$V_u = 89^K$

$M_u = 2300^{K\text{-}FT}$

$\boxed{t = 12'' \quad \ell_n = 11.5'}$

$I_g = \frac{1'(11.5')^3}{12} = 126.8$

$A_g = 11.5\ FT^2$

$\frac{111.4}{11.5} + \frac{2300\,(11.5/2)}{126.8} \geq 0.8$

$105.3/144 = 0.73 \geq 0.8 \rightarrow$ NO BE NEEDED

LONG & TRANS REIN.

$V_u \geq 2A_{cv}\sqrt{f'_c}$

$89 \geq 2(11.5\times12''\times12'')\sqrt{4000}/1000$

$89 \geq 209.5 \rightarrow$ DOES NOT REQ 2 CURTAINS

$A_{cv} = 144\ IN^2/FT$

$A_{s\ LONG\ REQ'D} = 144(0.0025) = 0.36$

TRY $\boxed{\text{\#5 HORZ \& VERT SPACED @ 10'' O.C}}$

NOMINAL SHEAR CAPACITY

$V_n = A_{cv}(\alpha_c\sqrt{f'_c} + \rho_t f_y)$

$\frac{h_w}{\ell_n} = \frac{67.5}{11.5} = 5.9 > 2 \therefore \alpha_c = 2.0$

$A_{cv} = 12(11.5\times12) = 1656\ IN^2$

$\rho_t = \frac{0.31}{10(12)} = 0.00258$

$\phi V_n = 0.6(1656)[(2)(\sqrt{4000} + 0.00258(60{,}000)]/1000$

$= 279^K > 89^K$ ✓

Appendix B2: Transfer Beam Calculation

1

TRANSFER BEAM CALCULATION

$\text{TRIB AREA} = 17.5 \times 12' = 210 \underset{\text{FLRS}}{(5)} = 1050\ \text{FT}^2$

$\text{COL WT} = 2488\ ^{\text{lb}}/_{\text{FLR}}(5)(1.2) = 14928\ ^{\text{lbs}}$

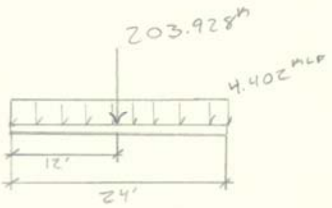
$\text{MEP + PART} = 20\ \text{PSF}$
$6.5''\ \text{SLAB} = \underline{82}\ \text{PSF}$
$102\ \text{PSF}$

$\text{BEAM SWt } (24\times38) = \frac{24\times38}{144}(150) = 950\ \text{PLF}$

$\text{ROOF LIVE} = 20\ \text{PSF}$
$\text{LIVE} = 40\ \text{PSF}$

PSF/
$(1.2)(102)(1050) + (1.6)(210)(4)(40) + (1.6)(210)(20)$
$= 189{,}000\ \text{lbs} + \underset{\text{COL WTS}}{14928} = 203.928^{\text{K}}$

PLF/
$(1.2)(102)(17.5) + (1.6)(17.5)(40) + (1.2)(950) =$
$= 4.402^{\text{KLF}}$



$$M_{\text{ENDS}} = \frac{Wl^2}{12} + \frac{Pl}{8} = \frac{4.402(24)^2}{12} + \frac{203.928(24)}{8}$$
$$211.296 + 611.784$$

$$M_{\text{ENDS}} = 823.08^{\text{FT-K}}(12) = 9876.96^{\text{IN-K}}$$

$$M_{\text{CENTER}} = \frac{Wl^2}{24} + \frac{Pl}{8} = 105.648 + 611.784$$
$$M_{\text{CENTER}} = 717.432^{\text{FT-K}}(12) = 8609.184^{\text{IN-K}}$$

CONSIDER COMPRESSION REINFORCEMENT FROM POS. MOM. STEEL CARRIED TO END

1/3 OF POS MOM BARS CARRIED TO SUPORT
ASSUME (7) #8's $\times$ (1/3) = 3 BARS

EDUCATED ASSUMPTION $b = 14$ $d = 26$ FOR END MOMENTS

DESIGN POS MOM. STEEL

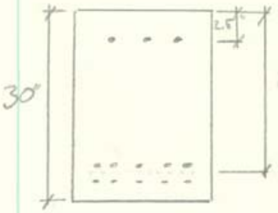
$$R = \frac{M_u}{\phi b d^2} = \frac{8609.184}{0.9(14)(26^2)} = 1010.8$$

FROM TABLE A5 IN D. of C.S. 13TH ED

$$\rho = 0.0195$$

$A_s = 0.0123(14)(26) = 4.48\ \text{in}^2$ USE (6) #8 BARS

1/3 (6) = 2 BARS — STILL USE 3 TO BE CONSERVATIVE CARRIED TO SUPORT



(3) #8's $A_s = 2.37\ \text{in}^2$

TRY (10) #8's $A_s = 7.9\ \text{in}^2$

ASSUM $f'_s = f_y$ & $f_s = f_y$

$$A_{s2} = 7.9 - 2.37 = 5.53\ \text{in}^2$$

$$a_2 = \frac{(A_s - A'_s) f_y}{0.85 f'_c b} = \frac{5.53(60)}{0.85(4)(14)} = 6.97\ \text{in}$$

CHECK $f'_s = f_y$

$d' = 2.5"$ $\quad \frac{d'}{a} = \frac{2.5}{6.97} = 0.36$

$$\left(\frac{d'}{a}\right)_{\text{LIM}} = \frac{1}{\beta_1}\left(1 - \frac{f_y}{87000}\right)$$

$$= \frac{1}{0.85}\left(1 - \frac{60{,}000}{87{,}000}\right) = 0.365 > 0.36 \therefore$$

COMP. STL YIELDS & $f_s = f_y$ ✓

CHECK IF $f_s = f_y$ FOR TEN STL & WETHER THE SEC IS TEN CONTROLED

$$\frac{a}{d} = \frac{6.97}{26.5} = 0.263 < 0.503$$

TABLE A-4 OF REIN. CONC. MECH & DESIGN 4TH ED

THUS $d_t = 30 - 1.5 - 0.375 - \frac{1}{2} = 27.625$

$$\frac{a}{d_t} = \frac{6.97}{27.625} = 0.2523 < 0.319 \quad \therefore \phi = 0.9$$

$$\frac{a_{TenConLim}}{d_t} = 0.375\beta_1 = 0.319$$

$$A_{s\,MIN} = \frac{3\sqrt{4000}}{60{,}000} \times 14(26.5) = 1.1732 \geq \frac{200(14)(26.5)}{60{,}000}$$

$$1.2366 \checkmark$$

$$\phi M_n = \phi[A'_s f_y (d - d')]$$

$$BM_1: \quad 0.9\left[\frac{2.37(60)(26.5 - 2.5)}{12}\right] = 255.96$$

$$BM_2: \quad 0.9\left[\frac{(7.9 - 2.37)60(26.5 - \frac{6.97}{2})}{12}\right] = 572.73$$

$$828.7^{FT \cdot K} > 823.08^{FT \cdot K} \checkmark$$

WORKS

RE DESIGN POS MOM SECTION

$$R = \frac{8609.184}{0.9(14)(26.5)^2} = 0.973$$

$$\rho = 0.0187(14)(26.5) = 6.94 \Rightarrow \underline{(9)\ \#8\ \text{BARS}} \checkmark$$

$$\Downarrow$$

$\underline{\text{USE (10) \#8's}}$

$\therefore$ 3 BARS CARRIED TO SUPORT ✓

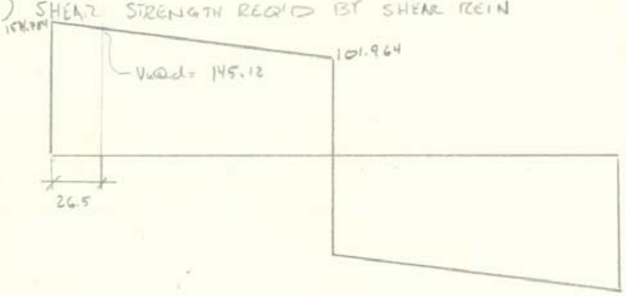
4

SHEAR REINFORCEMENT DESIGN

1) SHEAR STRENGTH OF BEAM W/ OUT STIRRUPS

$V_c = 2\sqrt{4000}(14)(26.5)/1000 = 46.93$

2) SHEAR STRENGTH REQ'D BY SHEAR REIN



$V_s = V_u/\phi - V_c = \frac{145.12}{0.75} - 46.93 = 146.6$

3) $V_s < 8\sqrt{4000}(14)(26.5) = 187$ OK

$4\sqrt{4000}(14)(26.5) > V_s \quad \therefore \quad S_{MAX} = MIN \begin{cases} 26.5/4 = \underline{6.625''} = \underline{7''} \\ 12 \end{cases}$

93.86

4)

$A_{v\,MIN} = MAX \begin{cases} 0.75\sqrt{f'c}\, b_w\, s/f_{yt} & 0.077 \\ 50 b\, s/f_{yt} & \underline{0.082}\ in^2 \end{cases} \rightarrow 1$ LEG

5)

$S = A_v f_{yt}\, d/V = 0.31(60000)26.5/146.6 = 3.36$

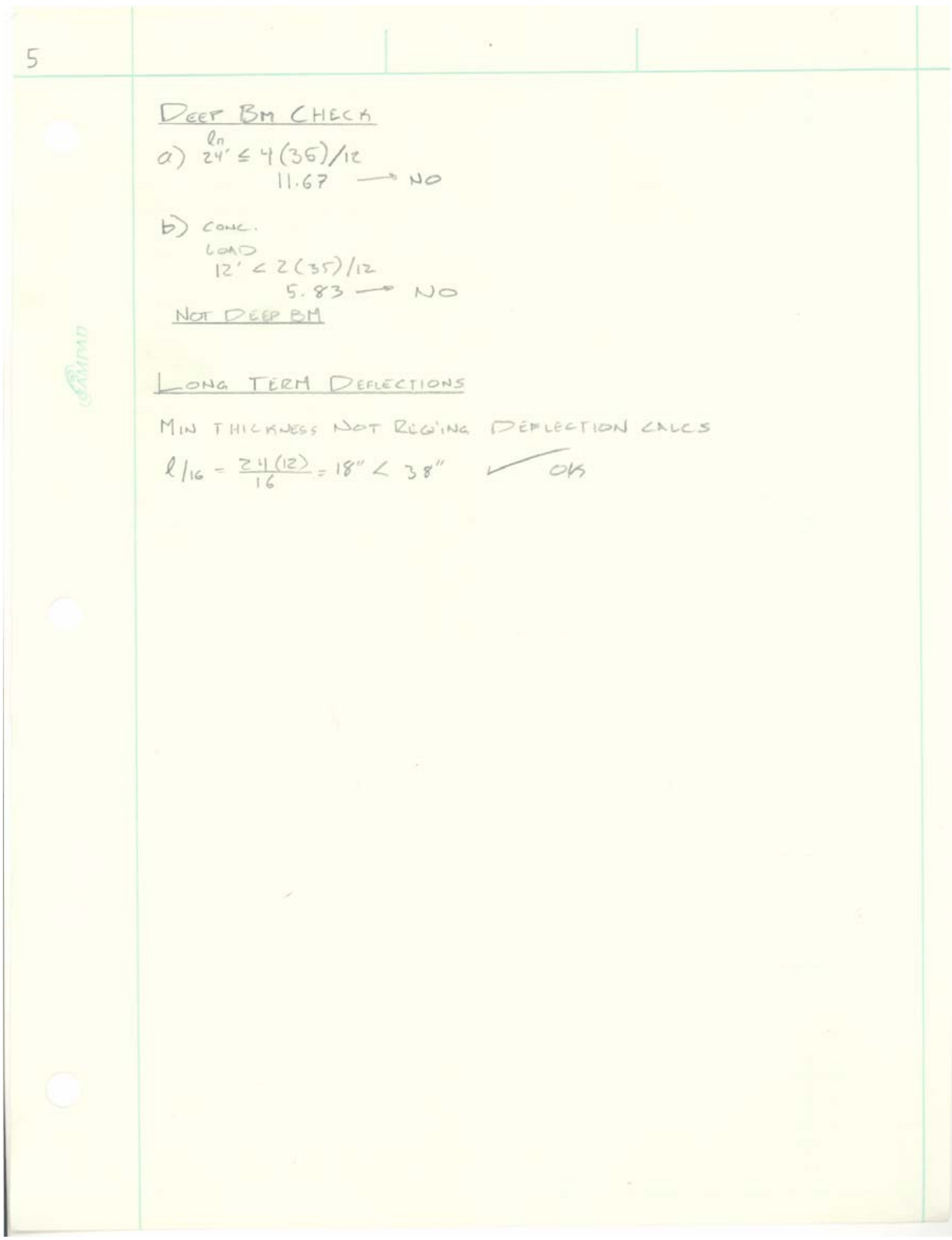
USE (1) #5 @ 3" O.C. FOR 75" THEN (1) @ 4" O.C. TO CENTER OF BM

TRY (1) #5 @ 4"

$\phi V_n = \phi V_c + \phi V_s = 0.75\left(47 + \frac{0.31(60)(26.5)}{4}\right) = 127$

$l_v = \frac{(154.284 - 127)(12)}{4.402} = 75''$

THIS IS NOT OPTIMAL SHEAR REINFORCEMENT AND IT IS RECOMENDED TO WIDEN THE BEAM ALTHOUGH WITH VALUE ENGR. NOT THE MAIN CONCERN OF THIS PROJECT TIME CONSTRAINTS ENCOURAGE THE DESIGN BE LEFT AS IS.



5

DEEP BM CHECK

a) $\overset{\ell_n}{24'} \leq 4(35)/12$
$11.67 \longrightarrow$ NO

b) CONC. LOAD
$12' < 2(35)/12$
$5.83 \longrightarrow$ NO

NOT DEEP BM

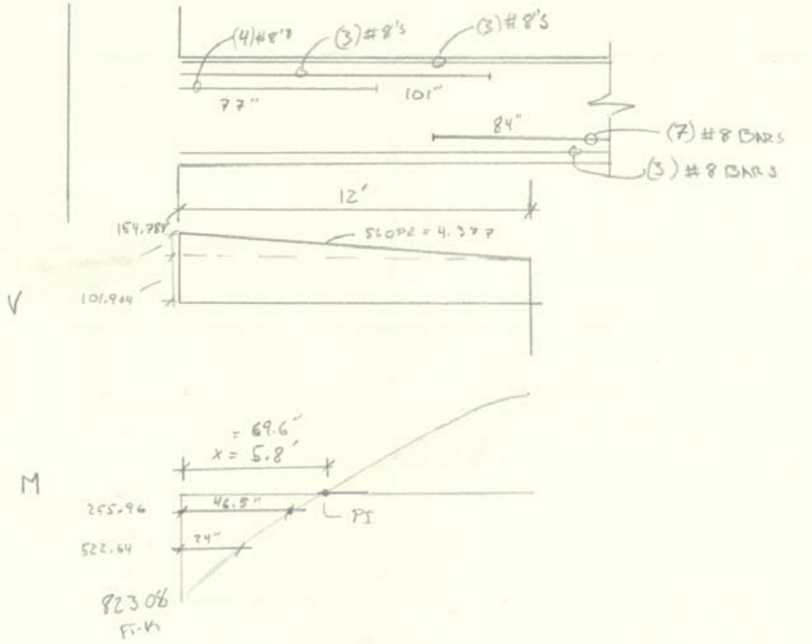
LONG TERM DEFLECTIONS

MIN THICKNESS NOT REQ'ING DEFLECTION CALCS

$\ell/16 = \frac{24(12)}{16} = 18'' < 38''$ ✓ OK

6

BAR CUTOFF POINTS



SOLVE FOR PI

$$823.08 = 101.08(x) + (52.824 - 4.377(x))(x) + (4.377x)(x)\left(\tfrac{1}{2}\right)$$

$$2.1885x^2 + 154.788x + 823.08$$

$\underline{x = 5.8'}$

CUT OFF INCRIMENTS FOR BARS 4 BARS, 3 BARS, 3 BARS

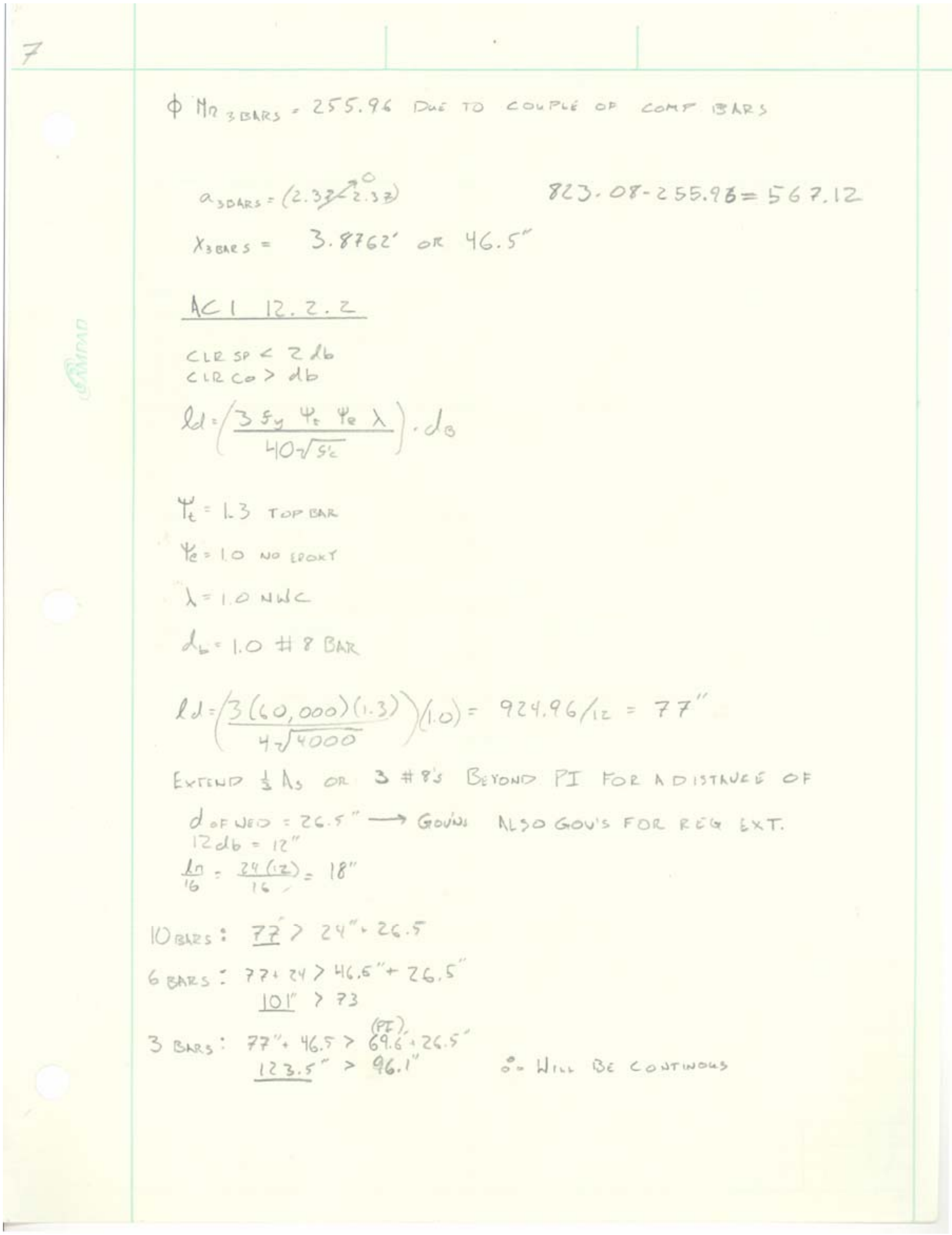
$$\phi Mn_{6\,BARS} = 255.96 + 0.9\left[\frac{(4.74 - 2.37)60\left(26.5 - \frac{2.99}{2}\right)}{12}\right]$$

$$= 522.64$$

$$a_{6\,BARS} = \frac{(4.74 - 2.37)(60)}{0.85(4)(14)} = 2.99$$

$$823.08 - 522.64 = 300.44$$

$X_{6\,BARS} = 1.997'$ or 24"



$\phi M_{n\,3\,BARS} = 255.96$ DUE TO COUPLE OF COMP BARS

$a_{3\,BARS} = (2.33 \overset{0}{-} 2.33)$

$823.08 - 255.96 = 567.12$

$X_{3\,BARS} = 3.8762'$ OR $46.5''$

<u>ACI 12.2.2</u>

CLR SP < 2 db
CLR Co > db

$$l_d = \left(\frac{3 f_y \psi_t \psi_e \lambda}{40\sqrt{f'_c}}\right) \cdot d_B$$

$\psi_t = 1.3$ TOP BAR

$\psi_e = 1.0$ NO EPOXY

$\lambda = 1.0$ NWC

$d_b = 1.0$ #8 BAR

$$l_d = \left(\frac{3(60{,}000)(1.3)}{4\sqrt{4000}}\right)(1.0) = 924.96/12 = 77''$$

EXTEND $\frac{1}{3}A_s$ OR 3 #8's BEYOND PI FOR A DISTANCE OF

d OF WEB $= 26.5'' \longrightarrow$ GOV'NS ALSO GOV'S FOR REG EXT.
$12 d_b = 12''$
$\frac{l_n}{16} = \frac{24(12)}{16} = 18''$

10 BARS: $\underline{77''} > 24'' + 26.5$

6 BARS: $77 + 24 > 46.5'' + 26.5''$
$\underline{101''} > 73$

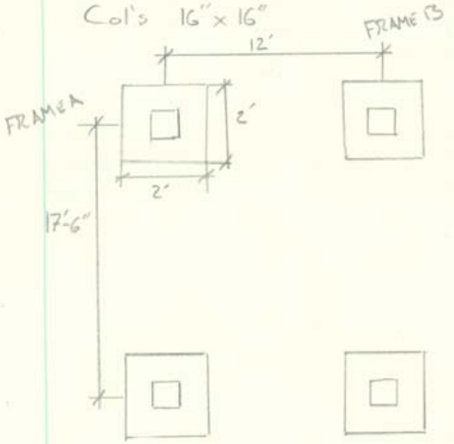
3 BARS: $77'' + 46.5 > \overset{(PI)}{69.6'} + 26.5''$
$\underline{123.5''} > 96.1''$ ∴ WILL BE CONTINOUS

Appendix B3: 2 Way Slab Design Calculations

1

TYPICAL SLAB CALCULATION

Col's 16" × 16"



LL = 100

$D_{MEP+PART} = 25$

SLAB THICKNESS = 7.5"

$D_{SW} = \frac{7.5}{12}(150) = 93.75$ PSF

$W_u = 1.2(119) + 1.6(100) = 302.8$ PSF

$$M_o = \frac{W_u L_n^2 L_2}{8} = \frac{302.8(7.5)(12 - \frac{16}{12})^2}{8}$$

$$= 32.3^{\text{FT-K}}$$

FRAME A

$M^+ = 0.35(32.3) = 11.3'^{K}$

$M^- = 0.65(32.3) = 21'^{K}$

M_s $M_s^- = 0.25(21) = 5.25$
$M_s^+ = 0.4(11.3) = 4.52$

$d = 7.5 - 3/4 - 0.75 = 6"$

ASSUME #4 BAR

C_s $M^- = 0.75(21) = 15.75$
$M^+ = 0.6(11.3) = 6.78$

FRAME B

$$M_o = \frac{0.33(12)(17.5 - 16/12)^2}{8} = 118.7'^{K}$$

$M^+ = 0.35(118.7) = 41.5$
$M^- = 0.65(118.7) = 77.2$

$d = 7.5 - 0.75 - 0.25 = 6.5$

M_s $M^- = 0.25(77.2) = 19.3$
$M^+ = 0.4(41.5) = 16.3$

C_s $M^- = 0.75(77.2) = 57.9$
$M^+ = 0.6(41.5) = 24.9$

2

BAR CUTOFFS

W/ DROP PANELS

CS

FRAME A TOP STEEL = $0.33\,\ell_n = 0.33(10.67) = 3.52'$

FRAME B $= 0.33\,\ell_n = 0.33(16.17) = 5.34'$

BOT STL IS CONT.

MS

	FRAME A	FRAME B
TOP STL	$0.22(\ell_n) = 0.22(10.67) = 2.35'$	$0.22(16.17) = 3.56'$
BOT STL	$0.15(\ell_n) = 0.15(10.67) = 1.6'$	$0.15(16.17) = 2.43'$

SHEAR

COL: $V_c = 4\sqrt{f'_c}\;b_o d$ $\qquad b_o = \left[16 + \frac{(6.25+4)}{2}\right]4 = 105''$

$= 4\sqrt{4000}\,(105)\,10.25$ $\qquad d = 6.25+4 = 10.25$

$V_c = 272.3^K$

DROP PANEL $\qquad b_o = [24 + 6.25]\,4 = 121$

$V_c = 4\sqrt{4000}\,(121)(6.25)$

$V_c = 191.32^K$

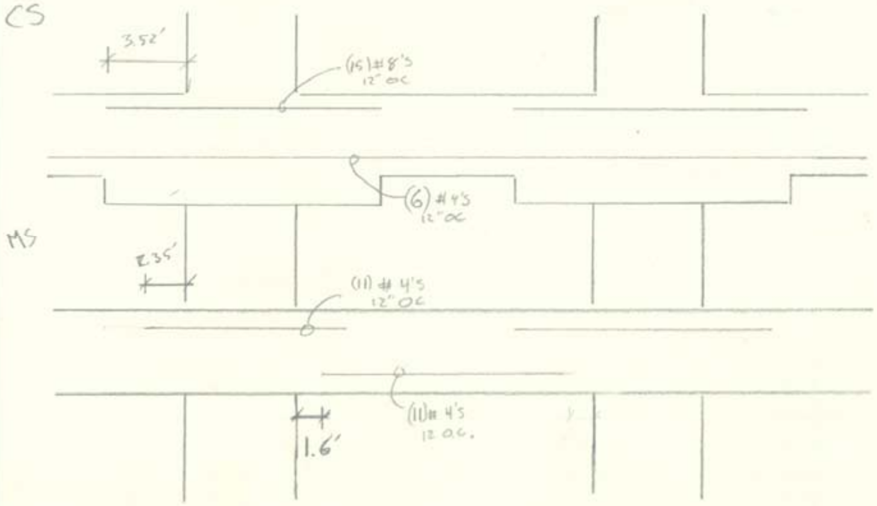
COL $V_u = 0.3028\left([17.5(12)] - \left(\frac{16+10.25}{144}\right)^2\right) = 63.58^K < V_c$ ✓

DROP $V_u = 0.3028\left(17.5(12) - \left(\frac{16+6.85}{144}\right)^2\right) = 63.58^K < V_c$ ✓

OVERSIZED FOR SIMPLE DIM. OF DROP PANELS

3

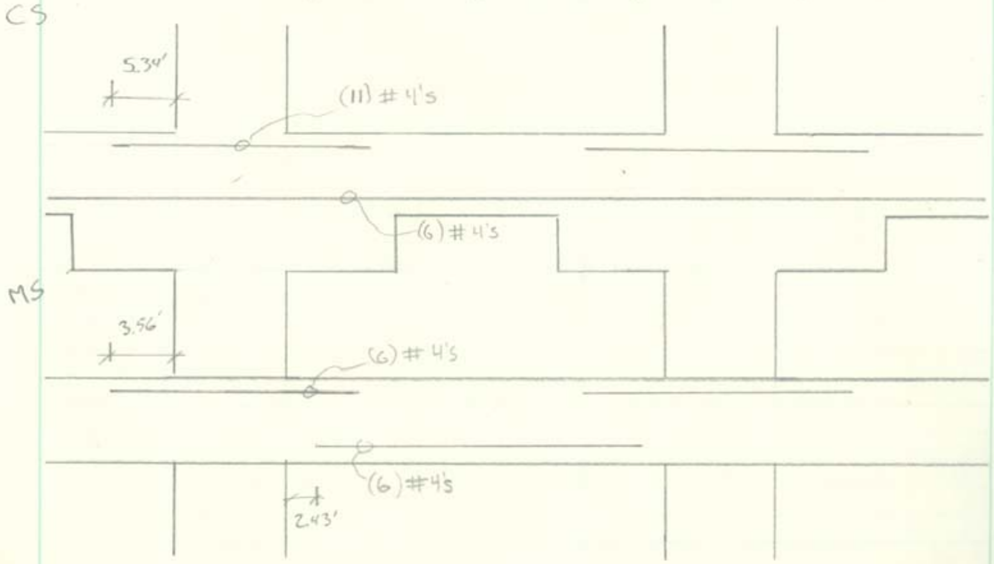
FRAME A	CS		MS	
	M^-	M^+	M^-	M^+
1) MOMENT	15.75	6.78	5.25	4.52
2) WIDTH, b DROP PANELS	4' = 48"	6' = 72"	11.5' = 138"	138"
3) EFFECTIVE d	6"	6"	6"	6"
4) $M_n = \frac{M_u}{0.9}$	17.5	7.53	5.83	5
5) $R = \frac{M_n(12000)}{bd^2}$	121.5	34.86	14.1	12.1
6) ρ TABLE A.5	0.002	0.0005	0.0003	0.0003
7) $A_s = \rho d b$	0.576	0.216	0.25	0.25
8) A_s MIN $= 0.002bt$	0.72	1.08	2.07	2.07
9) $N = \frac{A_s}{A_b}$	4 BARS	6 BARS	11 BARS	11 BARS
10) $N_{MIN} = b/2t$	4	5	10	10
11) BARS USED	(4) #4 @ 12" O.C.	(6) # 4's @ 12" O.C.	(11) # 4's @ 12" O.C.	(11) # 4's @ 12" O.C.



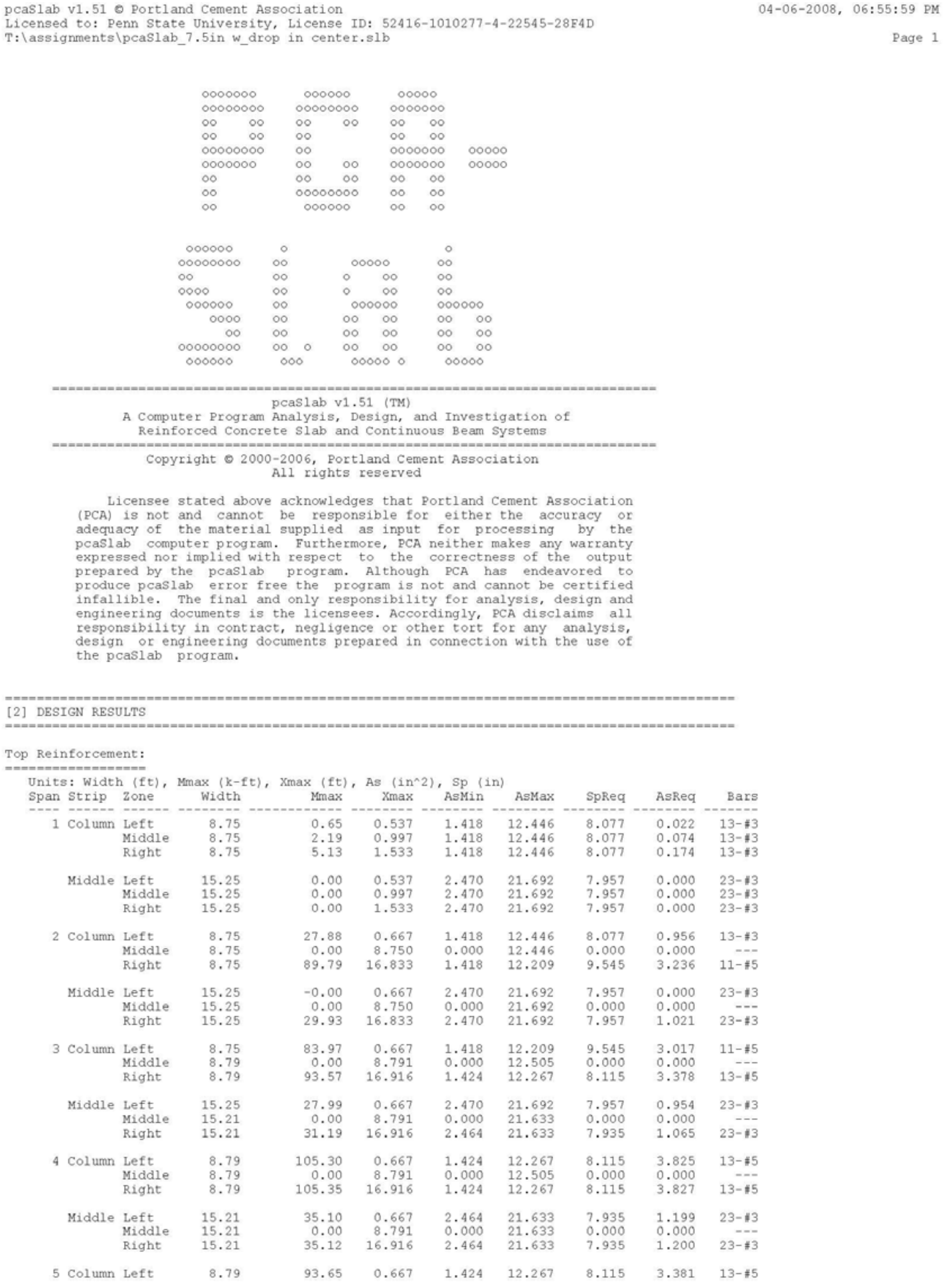
4 ~

FRAME B

	CS		MS	
	M^-	M^+	M^-	M^+
1) MOMENT	57.9	24.9	19.3	16.3
2) WIDTH b	4' = 48"	6' = 72"	6' = 72"	6' = 72"
3) EFFECTIVE d	6.5	6.5	6.5	6.5
4) $M_n = \frac{M_u}{.9}$	64	27.7	21	18
5) $R = \frac{M_n(12000)}{bd^2}$	378.7	109.3	82.8	71
6) ρ TABLE A.5	0.0067	0.0018	0.0013	0.0012
7) $A_s = \rho d b$	2.09	0.8424	0.6084	0.5616
8) $A_{s\,MIN} = 0.0026t$	0.72	1.08	1.08	1.08
9) $N = \frac{A_s}{A_b}$	11 BARS	6 BARS	6 BARS	6 BARS
10) $N_{MIN} = b/2t$	4	5	5	5
11) BARS USED	(11) #4's 4" O.C.	(6) #4's 12" O.C.	(6) #4's	(6) #4's



Appendix C1: PCA Slab Output



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      =============================================================================
                                  pcaSlab v1.51 (TM)
               A Computer Program Analysis, Design, and Investigation of
                 Reinforced Concrete Slab and Continuous Beam Systems
      =============================================================================
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===============================================================================================
[2] DESIGN RESULTS
===============================================================================================

Top Reinforcement:
==================
   Units: Width (ft), Mmax (k-ft), Xmax (ft), As (in^2), Sp (in)
   Span Strip  Zone      Width         Mmax     Xmax    AsMin    AsMax    SpReq    AsReq    Bars
   ---- ------ ------ -------- ------------ -------- -------- -------- -------- -------- -------
      1 Column Left       8.75         0.65    0.537    1.418   12.446    8.077    0.022   13-#3
               Middle     8.75         2.19    0.997    1.418   12.446    8.077    0.074   13-#3
               Right      8.75         5.13    1.533    1.418   12.446    8.077    0.174   13-#3

        Middle Left      15.25         0.00    0.537    2.470   21.692    7.957    0.000   23-#3
               Middle    15.25         0.00    0.997    2.470   21.692    7.957    0.000   23-#3
               Right     15.25         0.00    1.533    2.470   21.692    7.957    0.000   23-#3

      2 Column Left       8.75        27.88    0.667    1.418   12.446    8.077    0.956   13-#3
               Middle     8.75         0.00    8.750    0.000   12.446    0.000    0.000     ---
               Right      8.75        89.79   16.833    1.418   12.209    9.545    3.236   11-#5

        Middle Left      15.25        -0.00    0.667    2.470   21.692    7.957    0.000   23-#3
               Middle    15.25         0.00    8.750    0.000   21.692    0.000    0.000     ---
               Right     15.25        29.93   16.833    2.470   21.692    7.957    1.021   23-#3

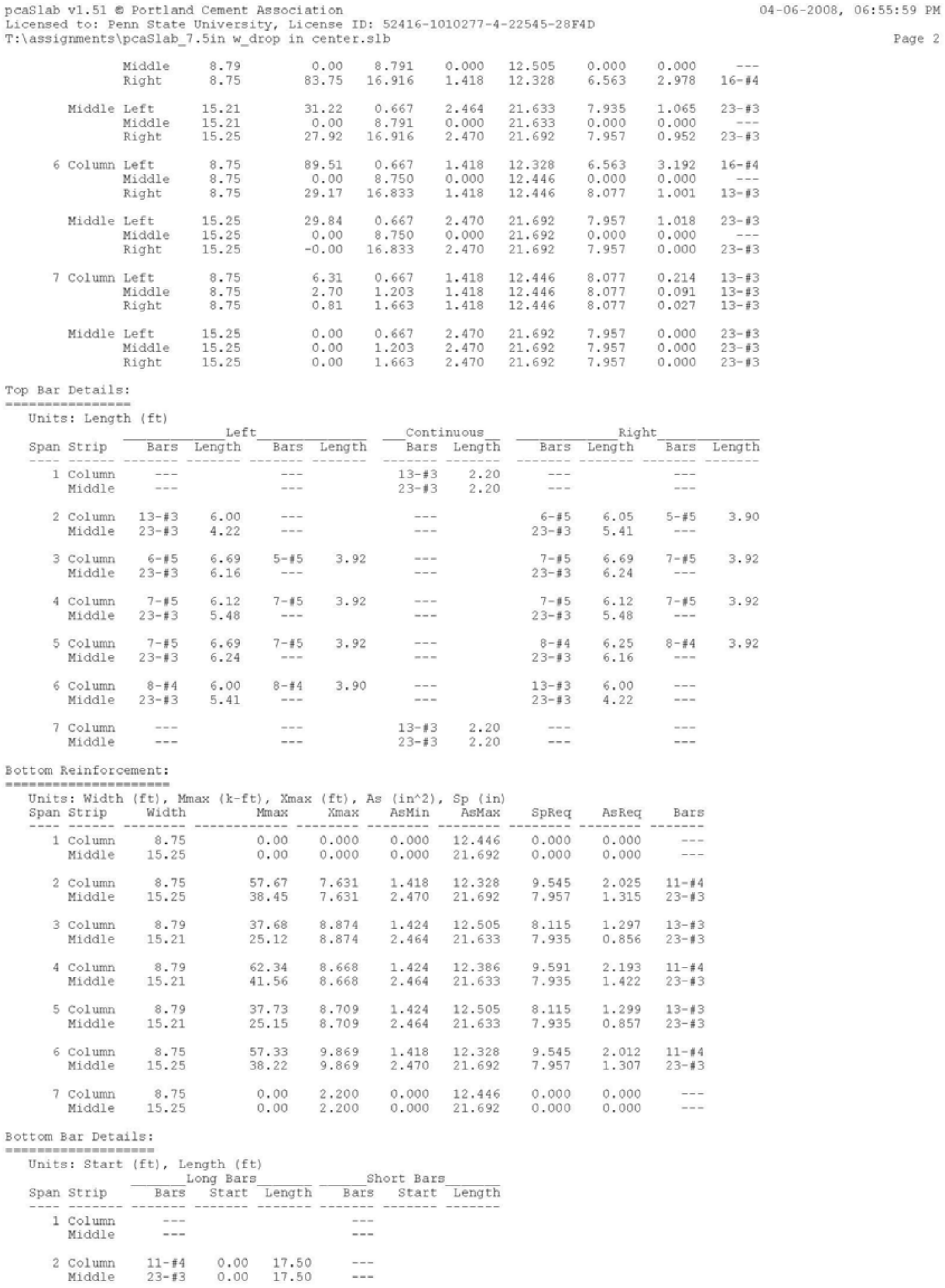
      3 Column Left       8.75        83.97    0.667    1.418   12.209    9.545    3.017   11-#5
               Middle     8.79         0.00    8.791    0.000   12.505    0.000    0.000     ---
               Right      8.79        93.57   16.916    1.424   12.267    8.115    3.378   13-#5

        Middle Left      15.25        27.99    0.667    2.470   21.692    7.957    0.954   23-#3
               Middle    15.21         0.00    8.791    0.000   21.633    0.000    0.000     ---
               Right     15.21        31.19   16.916    2.464   21.633    7.935    1.065   23-#3

      4 Column Left       8.79       105.30    0.667    1.424   12.267    8.115    3.825   13-#5
               Middle     8.79         0.00    8.791    0.000   12.505    0.000    0.000     ---
               Right      8.79       105.35   16.916    1.424   12.267    8.115    3.827   13-#5

        Middle Left      15.21        35.10    0.667    2.464   21.633    7.935    1.199   23-#3
               Middle    15.21         0.00    8.791    0.000   21.633    0.000    0.000     ---
               Right     15.21        35.12   16.916    2.464   21.633    7.935    1.200   23-#3

      5 Column Left       8.79        93.65    0.667    1.424   12.267    8.115    3.381   13-#5
```



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Licensed to: Penn State University, License ID: 52416-1010277-4-22545-28F4D
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               Middle     8.79         0.00    8.791    0.000   12.505    0.000    0.000     ---
               Right      8.75        83.75   16.916    1.418   12.328    6.563    2.978   16-#4

        Middle Left      15.21        31.22    0.667    2.464   21.633    7.935    1.065   23-#3
               Middle    15.21         0.00    8.791    0.000   21.633    0.000    0.000     ---
               Right     15.25        27.92   16.916    2.470   21.692    7.957    0.952   23-#3

      6 Column Left       8.75        89.51    0.667    1.418   12.328    6.563    3.192   16-#4
               Middle     8.75         0.00    8.750    0.000   12.446    0.000    0.000     ---
               Right      8.75        29.17   16.833    1.418   12.446    8.077    1.001   13-#3

        Middle Left      15.25        29.84    0.667    2.470   21.692    7.957    1.018   23-#3
               Middle    15.25         0.00    8.750    0.000   21.692    0.000    0.000     ---
               Right     15.25        -0.00   16.833    2.470   21.692    7.957    0.000   23-#3

      7 Column Left       8.75         6.31    0.667    1.418   12.446    8.077    0.214   13-#3
               Middle     8.75         2.70    1.203    1.418   12.446    8.077    0.091   13-#3
               Right      8.75         0.81    1.663    1.418   12.446    8.077    0.027   13-#3

        Middle Left      15.25         0.00    0.667    2.470   21.692    7.957    0.000   23-#3
               Middle    15.25         0.00    1.203    2.470   21.692    7.957    0.000   23-#3
               Right     15.25         0.00    1.663    2.470   21.692    7.957    0.000   23-#3

Top Bar Details:
================
   Units: Length (ft)
               _____________Left______________  ___Continuous__  _____________Right_____________
   Span Strip     Bars  Length    Bars  Length     Bars  Length     Bars  Length    Bars  Length
   ---- ------ ------- ------- ------- -------  ------- -------  ------- ------- ------- -------
      1 Column     ---             ---            13-#3    2.20      ---             ---
        Middle     ---             ---            23-#3    2.20      ---             ---

      2 Column   13-#3    6.00     ---              ---              6-#5    6.05    5-#5    3.90
        Middle   23-#3    4.22     ---              ---             23-#3    5.41     ---

      3 Column    6-#5    6.69    5-#5    3.92      ---              7-#5    6.69    7-#5    3.92
        Middle   23-#3    6.16     ---              ---             23-#3    6.24     ---

      4 Column    7-#5    6.12    7-#5    3.92      ---              7-#5    6.12    7-#5    3.92
        Middle   23-#3    5.48     ---              ---             23-#3    5.48     ---

      5 Column    7-#5    6.69    7-#5    3.92      ---              8-#4    6.25    8-#4    3.92
        Middle   23-#3    6.24     ---              ---             23-#3    6.16     ---

      6 Column    8-#4    6.00    8-#4    3.90      ---             13-#3    6.00     ---
        Middle   23-#3    5.41     ---              ---             23-#3    4.22     ---

      7 Column     ---             ---            13-#3    2.20      ---             ---
        Middle     ---             ---            23-#3    2.20      ---             ---

Bottom Reinforcement:
=====================
   Units: Width (ft), Mmax (k-ft), Xmax (ft), As (in^2), Sp (in)
   Span Strip     Width         Mmax     Xmax    AsMin    AsMax    SpReq    AsReq    Bars
   ---- ------ -------- ------------ -------- -------- -------- -------- -------- -------
      1 Column     8.75         0.00    0.000    0.000   12.446    0.000    0.000     ---
        Middle    15.25         0.00    0.000    0.000   21.692    0.000    0.000     ---

      2 Column     8.75        57.67    7.631    1.418   12.328    9.545    2.025   11-#4
        Middle    15.25        38.45    7.631    2.470   21.692    7.957    1.315   23-#3

      3 Column     8.79        37.68    8.874    1.424   12.505    8.115    1.297   13-#3
        Middle    15.21        25.12    8.874    2.464   21.633    7.935    0.856   23-#3

      4 Column     8.79        62.34    8.668    1.424   12.386    9.591    2.193   11-#4
        Middle    15.21        41.56    8.668    2.464   21.633    7.935    1.422   23-#3

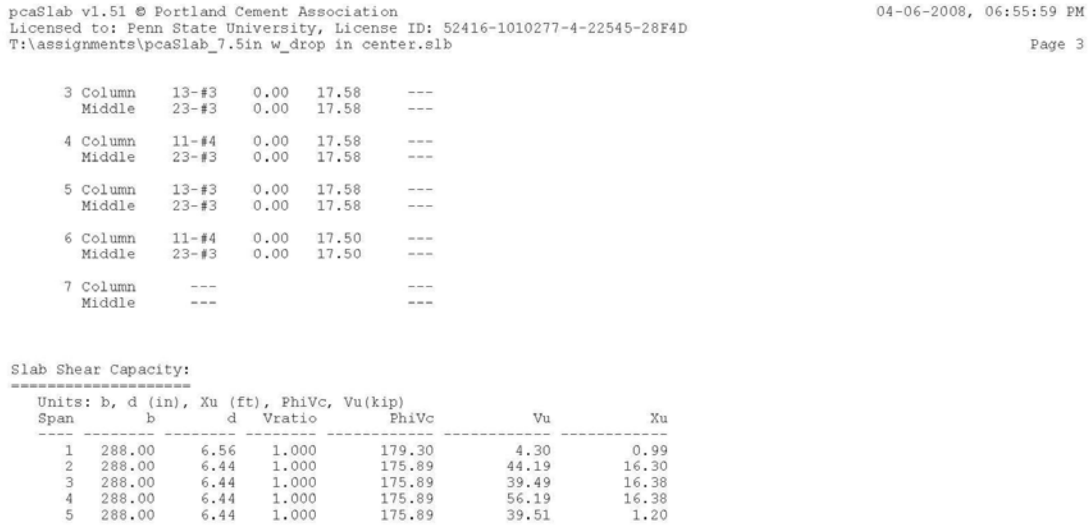
      5 Column     8.79        37.73    8.709    1.424   12.505    8.115    1.299   13-#3
        Middle    15.21        25.15    8.709    2.464   21.633    7.935    0.857   23-#3

      6 Column     8.75        57.33    9.869    1.418   12.328    9.545    2.012   11-#4
        Middle    15.25        38.22    9.869    2.470   21.692    7.957    1.307   23-#3

      7 Column     8.75         0.00    2.200    0.000   12.446    0.000    0.000     ---
        Middle    15.25         0.00    2.200    0.000   21.692    0.000    0.000     ---

Bottom Bar Details:
===================
   Units: Start (ft), Length (ft)
                _______Long Bars_______ ______Short Bars_______
   Span Strip      Bars   Start  Length    Bars   Start  Length
   ---- ------- ------- ------- ------- ------- ------- -------
      1 Column      ---                     ---
        Middle      ---                     ---

      2 Column    11-#4    0.00   17.50     ---
        Middle    23-#3    0.00   17.50     ---
```



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      3 Column    13-#3    0.00   17.58      ---
        Middle    23-#3    0.00   17.58      ---

      4 Column    11-#4    0.00   17.58      ---
        Middle    23-#3    0.00   17.58      ---

      5 Column    13-#3    0.00   17.58      ---
        Middle    23-#3    0.00   17.58      ---

      6 Column    11-#4    0.00   17.50      ---
        Middle    23-#3    0.00   17.50      ---

      7 Column      ---                      ---
        Middle      ---                      ---


Slab Shear Capacity:
====================
   Units: b, d (in), Xu (ft), PhiVc, Vu(kip)
   Span        b        d   Vratio        PhiVc           Vu           Xu
   ---- -------- -------- -------- ------------ ------------ ------------
      1   288.00     6.56    1.000       179.30         4.30         0.99
      2   288.00     6.44    1.000       175.89        44.19        16.30
      3   288.00     6.44    1.000       175.89        39.49        16.38
      4   288.00     6.44    1.000       175.89        56.19        16.38
      5   288.00     6.44    1.000       175.89        39.51         1.20
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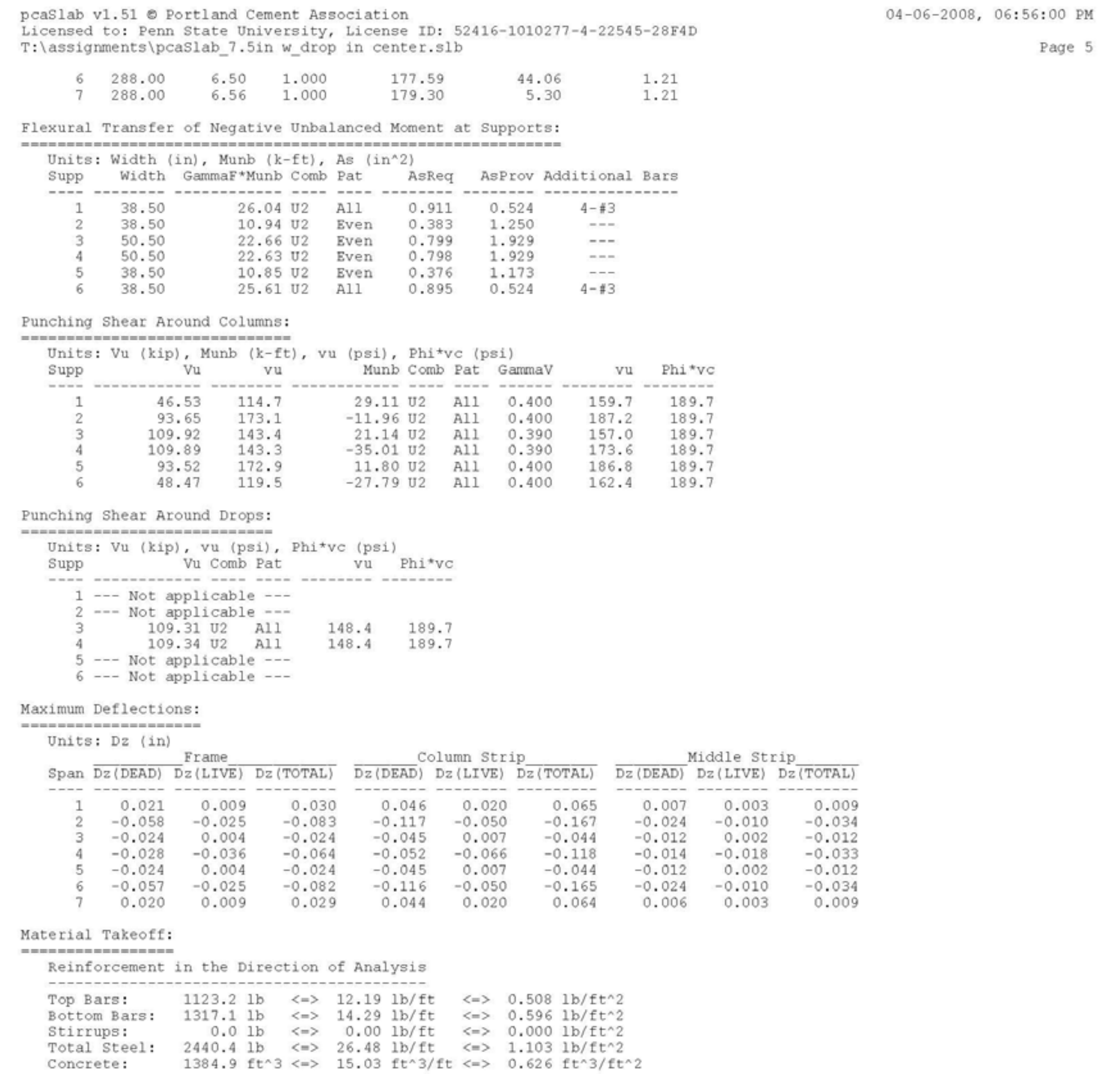

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pcaSlab v1.51 © Portland Cement Association                                            04-06-2008, 06:56:00 PM
Licensed to: Penn State University, License ID: 52416-1010277-4-22545-28F4D
T:\assignments\pcaSlab_7.5in w_drop in center.slb                                                        Page 5

      6   288.00     6.50    1.000       177.59       44.06         1.21
      7   288.00     6.56    1.000       179.30        5.30         1.21

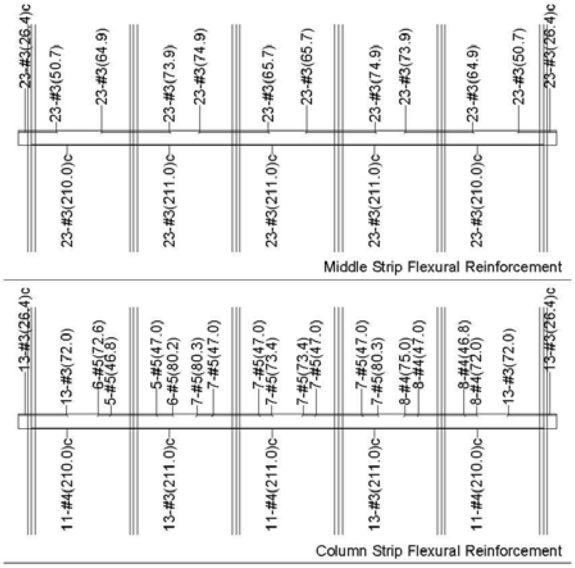
Flexural Transfer of Negative Unbalanced Moment at Supports:
============================================================
   Units: Width (in), Munb (k-ft), As (in^2)
   Supp    Width  GammaF*Munb Comb Pat      AsReq    AsProv Additional Bars
   ---- -------- ------------ ---- ---- -------- -------- ---------------
      1    38.50        26.04 U2   All     0.911    0.524     4-#3
      2    38.50        10.94 U2   Even    0.383    1.250      ---
      3    50.50        22.66 U2   Even    0.799    1.929      ---
      4    50.50        22.63 U2   Even    0.798    1.929      ---
      5    38.50        10.85 U2   Even    0.376    1.173      ---
      6    38.50        25.61 U2   All     0.895    0.524     4-#3

Punching Shear Around Columns:
==============================
   Units: Vu (kip), Munb (k-ft), vu (psi), Phi*vc (psi)
   Supp           Vu       vu         Munb Comb Pat  GammaV       vu   Phi*vc
   ---- ------------ -------- ------------ ---- ---- ------ -------- --------
      1        46.53    114.7        29.11 U2   All   0.400    159.7    189.7
      2        93.65    173.1       -11.96 U2   All   0.400    187.2    189.7
      3       109.92    143.4        21.14 U2   All   0.390    157.0    189.7
      4       109.89    143.3       -35.01 U2   All   0.390    173.6    189.7
      5        93.52    172.9        11.80 U2   All   0.400    186.8    189.7
      6        48.47    119.5       -27.79 U2   All   0.400    162.4    189.7

Punching Shear Around Drops:
============================
   Units: Vu (kip), vu (psi), Phi*vc (psi)
   Supp           Vu Comb Pat        vu   Phi*vc
   ---- ------------ ---- ---- -------- --------
      1 --- Not applicable ---
      2 --- Not applicable ---
      3       109.31 U2   All     148.4    189.7
      4       109.34 U2   All     148.4    189.7
      5 --- Not applicable ---
      6 --- Not applicable ---

Maximum Deflections:
====================
   Units: Dz (in)
        __________Frame____________  _______Column Strip________  ________Middle Strip_______
   Span Dz(DEAD) Dz(LIVE) Dz(TOTAL)  Dz(DEAD) Dz(LIVE) Dz(TOTAL)  Dz(DEAD) Dz(LIVE) Dz(TOTAL)
   ---- -------- -------- ---------  -------- -------- ---------  -------- -------- ---------
      1    0.021    0.009     0.030     0.046    0.020     0.065     0.007    0.003     0.009
      2   -0.058   -0.025    -0.083    -0.117   -0.050    -0.167    -0.024   -0.010    -0.034
      3   -0.024    0.004    -0.024    -0.045    0.007    -0.044    -0.012    0.002    -0.012
      4   -0.028   -0.036    -0.064    -0.052   -0.066    -0.118    -0.014   -0.018    -0.033
      5   -0.024    0.004    -0.024    -0.045    0.007    -0.044    -0.012    0.002    -0.012
      6   -0.057   -0.025    -0.082    -0.116   -0.050    -0.165    -0.024   -0.010    -0.034
      7    0.020    0.009     0.029     0.044    0.020     0.064     0.006    0.003     0.009

Material Takeoff:
=================
   Reinforcement in the Direction of Analysis
   ------------------------------------------
   Top Bars:      1123.2 lb   <=>  12.19 lb/ft    <=>  0.508 lb/ft^2
   Bottom Bars:   1317.1 lb   <=>  14.29 lb/ft    <=>  0.596 lb/ft^2
   Stirrups:         0.0 lb   <=>   0.00 lb/ft    <=>  0.000 lb/ft^2
   Total Steel:   2440.4 lb   <=>  26.48 lb/ft    <=>  1.103 lb/ft^2
   Concrete:      1384.9 ft^3 <=>  15.03 ft^3/ft <=>  0.626 ft^3/ft^2
```



Middle Strip Flexural Reinforcement

Column Strip Flexural Reinforcement

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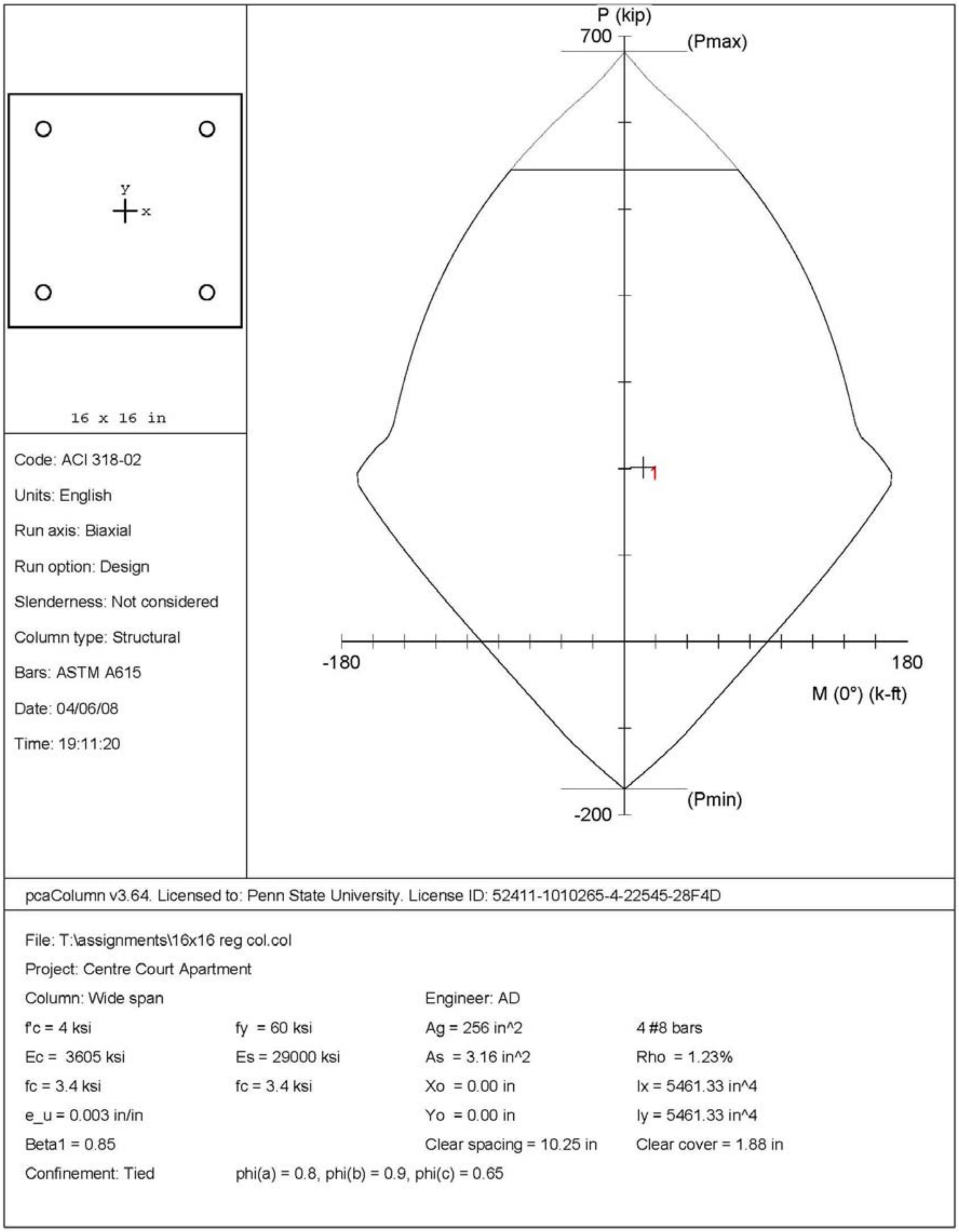
Project: Centre Court Appartments

Frame: Larger Bay

Engineer: AD

Appendix C2: PCA Column Output



Code: ACI 318-02

Units: English

Run axis: Biaxial

Run option: Design

Slenderness: Not considered

Column type: Structural

Bars: ASTM A615

Date: 04/06/08

Time: 19:11:20

pcaColumn v3.64. Licensed to: Penn State University. License ID: 52411-1010265-4-22545-28F4D

File: T:\assignments\16x16 reg col.col

Project: Centre Court Apartment

Column: Wide span

Engineer: AD

f'c = 4 ksi
fy = 60 ksi
Ag = 256 in^2
4 #8 bars

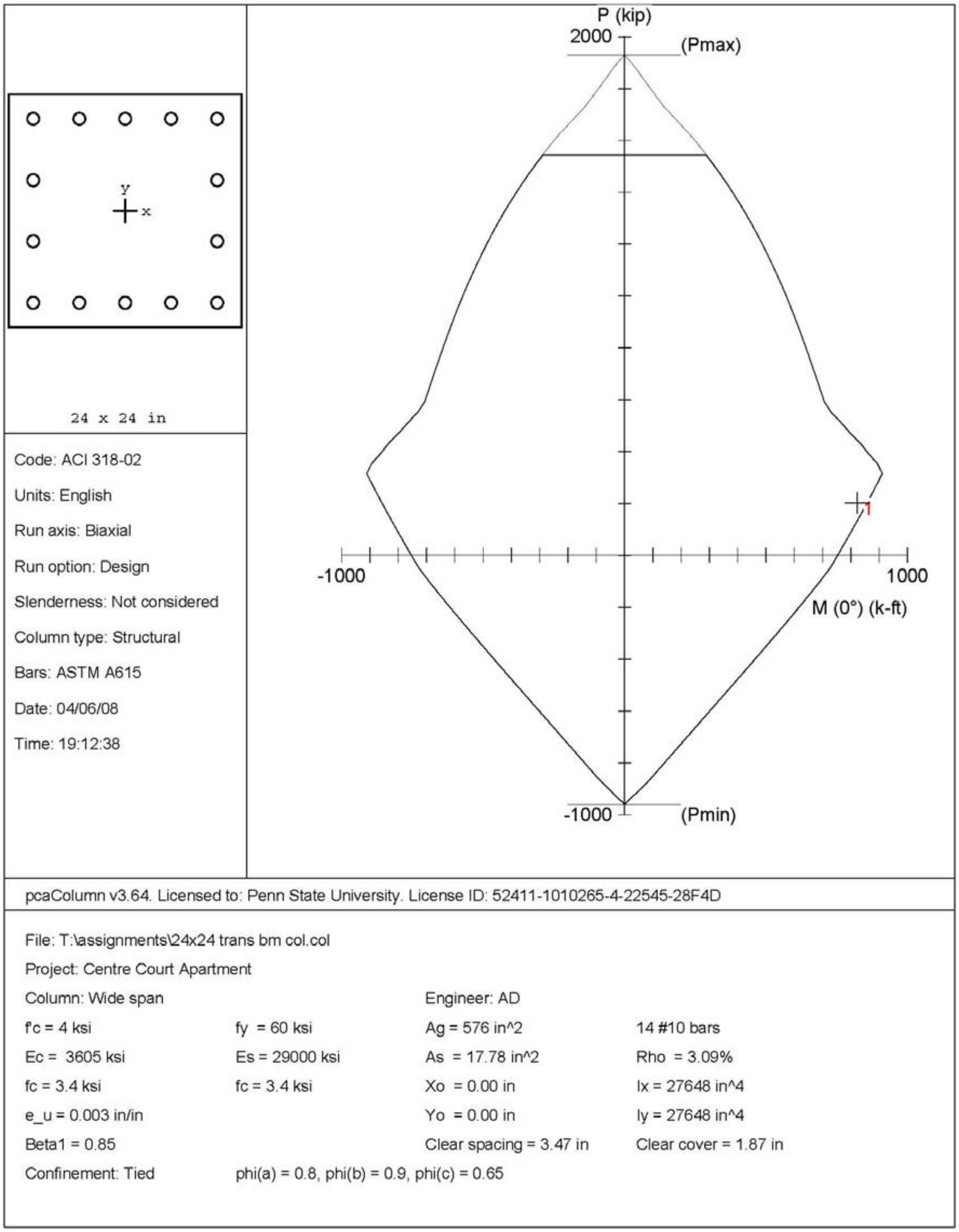
Ec = 3605 ksi
Es = 29000 ksi
As = 3.16 in^2
Rho = 1.23%

fc = 3.4 ksi
fc = 3.4 ksi
Xo = 0.00 in
Ix = 5461.33 in^4

e_u = 0.003 in/in
Yo = 0.00 in
Iy = 5461.33 in^4

Beta1 = 0.85
Clear spacing = 10.25 in
Clear cover = 1.88 in

Confinement: Tied
phi(a) = 0.8, phi(b) = 0.9, phi(c) = 0.65



Code: ACI 318-02

Units: English

Run axis: Biaxial

Run option: Design

Slenderness: Not considered

Column type: Structural

Bars: ASTM A615

Date: 04/06/08

Time: 19:12:38

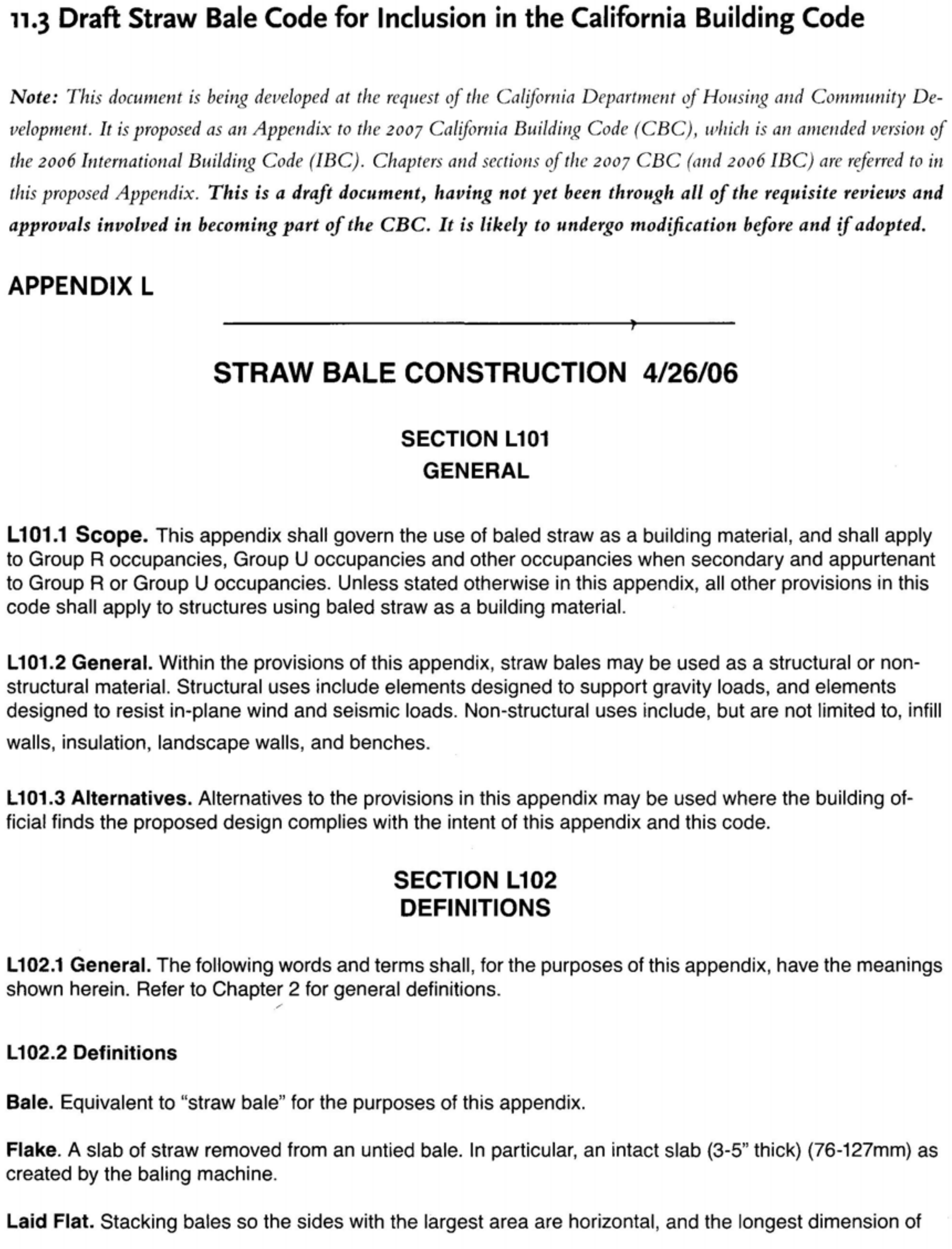
pcaColumn v3.64. Licensed to: Penn State University. License ID: 52411-1010265-4-22545-28F4D

File: T:\assignments\24x24 trans bm col.col

Project: Centre Court Apartment

Column: Wide span		Engineer: AD	
f'c = 4 ksi	fy = 60 ksi	Ag = 576 in^2	14 #10 bars
Ec = 3605 ksi	Es = 29000 ksi	As = 17.78 in^2	Rho = 3.09%
fc = 3.4 ksi	fc = 3.4 ksi	Xo = 0.00 in	Ix = 27648 in^4
e_u = 0.003 in/in		Yo = 0.00 in	Iy = 27648 in^4
Beta1 = 0.85		Clear spacing = 3.47 in	Clear cover = 1.87 in
Confinement: Tied	phi(a) = 0.8, phi(b) = 0.9, phi(c) = 0.65		

Appendix D1: Draft IBC Straw Bale Code



11.3 Draft Straw Bale Code for Inclusion in the California Building Code

Note: *This document is being developed at the request of the California Department of Housing and Community Development. It is proposed as an Appendix to the 2007 California Building Code (CBC), which is an amended version of the 2006 International Building Code (IBC). Chapters and sections of the 2007 CBC (and 2006 IBC) are referred to in this proposed Appendix.* ***This is a draft document, having not yet been through all of the requisite reviews and approvals involved in becoming part of the CBC. It is likely to undergo modification before and if adopted.***

APPENDIX L

STRAW BALE CONSTRUCTION 4/26/06

SECTION L101
GENERAL

L101.1 Scope. This appendix shall govern the use of baled straw as a building material, and shall apply to Group R occupancies, Group U occupancies and other occupancies when secondary and appurtenant to Group R or Group U occupancies. Unless stated otherwise in this appendix, all other provisions in this code shall apply to structures using baled straw as a building material.

L101.2 General. Within the provisions of this appendix, straw bales may be used as a structural or non-structural material. Structural uses include elements designed to support gravity loads, and elements designed to resist in-plane wind and seismic loads. Non-structural uses include, but are not limited to, infill walls, insulation, landscape walls, and benches.

L101.3 Alternatives. Alternatives to the provisions in this appendix may be used where the building official finds the proposed design complies with the intent of this appendix and this code.

SECTION L102
DEFINITIONS

L102.1 General. The following words and terms shall, for the purposes of this appendix, have the meanings shown herein. Refer to Chapter 2 for general definitions.

L102.2 Definitions

Bale. Equivalent to “straw bale” for the purposes of this appendix.

Flake. A slab of straw removed from an untied bale. In particular, an intact slab (3-5” thick) (76-127mm) as created by the baling machine.

Laid Flat. Stacking bales so the sides with the largest area are horizontal, and the longest dimension of this area is parallel with the wall plane.

Laid On-edge. Stacking bales so the sides with the largest area are vertical and the longest dimension of this area is horizontal and parallel with the wall plane.

Loadbearing. A strawbale wall or other element which bears the gravity loads (dead and live) of the roof and/or floor above. (compare with "Structural")

Mesh. An openwork fabric of linked strands of metal, plastic, or natural fiber, embedded in plaster to provide tensile reinforcement and/or bonding. (also sometimes lath)

Moisture Barrier. A continuous barrier capable of stopping the passage of water.

Non-Loadbearing. (see non-structural)

Non-Structural. A strawbale wall or other element which supports only its own weight, and may resist out-of-plane lateral loads.

Pins. Metal rod, wood dowel, or bamboo, driven into, or secured on the surface of stacked bales for purposes of connection or stability.

Plaster. Gypsum, lime, lime-cement, or cement plasters, as defined by this code and Section L106 of this appendix, or clay plaster and earth-cement plaster as defined in Section L106.9 and L106.10.

Running Bond. The placement of straw bales such that the head joints in successive courses are offset at least one quarter the bale length.

Skin. The compilation of plaster and reinforcing, if any, on the surface of stacked bales.

Structural. A strawbale wall or other element.which supports gravity loads (dead and live) and/or resists in-plane lateral loads.

Stack Bond. The placement of straw bales such that head joints in successive courses are vertically aligned.

Straw. The dry stems of cereal grains left after the seed heads have been substantially removed.

Straw Bale. A rectangular compressed block of straw, bound by polypropylene strings or baling wire.

Strawbale. The adjective form of straw bale.

Straw-clay. A mix of loose straw and clay binder.

Three-String Bale. A straw bale bound by three strings or wires. Typically with approximate dimensions of 15" x 23" x 42 to 48" long. (380mm x 584mm x 1066 to 1219mm)

Truth Window. An area of a strawbale wall left without its finish, to allow view of the straw otherwise concealed by its finish.

Two-String Bale. A straw bale bound by two strings or wires. Typically with approximate dimensions of 16" or 14"" x 18" x 36 to 45" long (406mm or 356mm x 457mm x 914 to 1143mm)

Vapor-Permeable Membrane. A material or covering having a permeance rating of 5 perms or greater, when tested in accordance with the dessicant method using Procedure A of ASTM E 96. A vapor-permeable material permits the passage of moisture vapor. (This definition is shown for convenience and is identical to that shown in Chapter 2)

Vapor Retarder. A vapor-resistant material, membrane or covering such as foil, plastic sheeting or insulation facing having a permeance rating of 1 perm or less, when tested in accordance with the dessicant method using Procedure A of ASTM E 96. Vapor retarders limit the amount of moisture vapor that passes through a material or wall assembly. (This definition is shown for convenience and is identical to that shown in Chapter 2)

SECTION L103
BALES

L103.1 Shape. Bales shall be rectangular in shape. However, the use of non-rectangular bales, such as circular bales, is not precluded.

L103.2 Size. Bales used within a continuous wall shall be of consistent height and width to ensure even distribution of loads within the wall system.

L103.3 Ties. Bales shall be bound with ties of polypropylene string or baling wire. Bales with broken or loose ties shall be firmly retied.

L103.4 Moisture content. The moisture content of bales, at the time of procurement, and at the time of application of the first coat of plaster or installation of an other weather protective finish, shall not exceed 20 percent of the total weight of the bale. The moisture content of bales shall be determined by use of a moisture meter designed for use with baled straw or hay, equipped with a probe of sufficient length to reach the center of the bale, or by other acceptable means. At least ten bales, and not less than 5 percent, randomly selected from the bales to be used, may be tested to determine if all of the bales for the building are of acceptable moisture content.

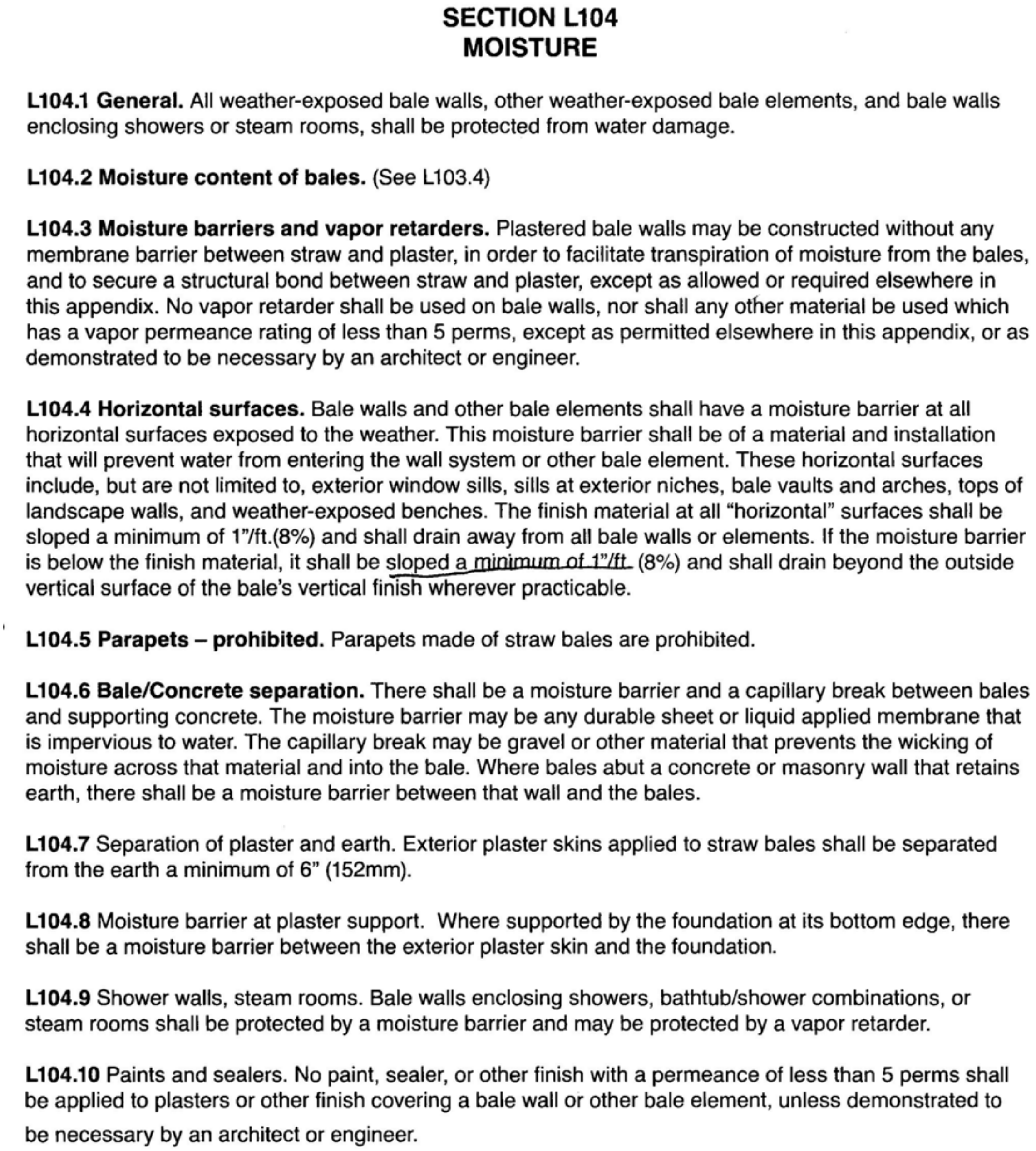
L103.5 Density. Bales shall have a minimum dry density of 6.0 pounds per cubic foot (92 kg/cubic meter). The dry density shall be determined by reducing the actual bale weight by the weight of the moisture content in pounds (kg), and dividing by the volume of the bale in cubic feet (cubic meters). At least five bales, and not less than 2 percent, randomly selected from the bales to be used, may be tested to determine if all of the bales for the building are of acceptable density.

L103.6 Partial bales. Custom-made partial bales shall be firmly retied, and where possible use the same number of ties as the standard size bales.

L103.7 Types of straw. Bales of various types of straw, including wheat, rice, rye, barley, oat, and similar grain plants, shall be acceptable if they meet the minimum requirements of this Section for density, shape, moisture content, and ties. Bales of hay and other grasses containing seed shall not be used as a building material.

L103.8 Protection of bales prior to installation. Bales shall be stored in such a manner as to protect them from weather and other sources of moisture damage.

L103.9 Unacceptable bales. Bales which show signs of damage due to moisture, including but not limited to mold or fungus growth, or associated discoloration, even if they are of an acceptable moisture content and density, shall not be used.



SECTION L104
MOISTURE

L104.1 General. All weather-exposed bale walls, other weather-exposed bale elements, and bale walls enclosing showers or steam rooms, shall be protected from water damage.

L104.2 Moisture content of bales. (See L103.4)

L104.3 Moisture barriers and vapor retarders. Plastered bale walls may be constructed without any membrane barrier between straw and plaster, in order to facilitate transpiration of moisture from the bales, and to secure a structural bond between straw and plaster, except as allowed or required elsewhere in this appendix. No vapor retarder shall be used on bale walls, nor shall any other material be used which has a vapor permeance rating of less than 5 perms, except as permitted elsewhere in this appendix, or as demonstrated to be necessary by an architect or engineer.

L104.4 Horizontal surfaces. Bale walls and other bale elements shall have a moisture barrier at all horizontal surfaces exposed to the weather. This moisture barrier shall be of a material and installation that will prevent water from entering the wall system or other bale element. These horizontal surfaces include, but are not limited to, exterior window sills, sills at exterior niches, bale vaults and arches, tops of landscape walls, and weather-exposed benches. The finish material at all “horizontal” surfaces shall be sloped a minimum of 1”/ft.(8%) and shall drain away from all bale walls or elements. If the moisture barrier is below the finish material, it shall be sloped a minimum of 1”/ft. (8%) and shall drain beyond the outside vertical surface of the bale’s vertical finish wherever practicable.

L104.5 Parapets – prohibited. Parapets made of straw bales are prohibited.

L104.6 Bale/Concrete separation. There shall be a moisture barrier and a capillary break between bales and supporting concrete. The moisture barrier may be any durable sheet or liquid applied membrane that is impervious to water. The capillary break may be gravel or other material that prevents the wicking of moisture across that material and into the bale. Where bales abut a concrete or masonry wall that retains earth, there shall be a moisture barrier between that wall and the bales.

L104.7 Separation of plaster and earth. Exterior plaster skins applied to straw bales shall be separated from the earth a minimum of 6” (152mm).

L104.8 Moisture barrier at plaster support. Where supported by the foundation at its bottom edge, there shall be a moisture barrier between the exterior plaster skin and the foundation.

L104.9 Shower walls, steam rooms. Bale walls enclosing showers, bathtub/shower combinations, or steam rooms shall be protected by a moisture barrier and may be protected by a vapor retarder.

L104.10 Paints and sealers. No paint, sealer, or other finish with a permeance of less than 5 perms shall be applied to plasters or other finish covering a bale wall or other bale element, unless demonstrated to be necessary by an architect or engineer.

SECTION L105
STRUCTURE

L105.1 Scope. Buildings constructed with straw bales shall comply with this Section, and with all other structural provisions of this code unless stated otherwise in this appendix.

L105.2 General. Strawbale buildings may use any type of structural system allowed by this code and this appendix.

L105.3 Foundations. Foundations for strawbale walls and other straw bale elements may be of any foundation type permitted by this code. Such foundations shall comply with Chapter 18, and shall be designed to allow design loads from the skins, bales, and any structural framing at the base of the wall to pass into the ground.

L105.4 Alternate foundations. Alternate foundations and foundation systems may be used, if designed by an architect or engineer.

L105.5 Wall height. Structural and non-structural strawbale walls shall be limited by a 6:1 ratio of stacked bale height to bale width, unless otherwise shown by an architect or engineer to adequately resist buckling from gravity loads and out of plane seismic and wind loads. Walls may exceed this height limitation by having a structural element restraining the wall horizontally, at or below the height limitation, as designed by an architect or engineer.

L105.6 Configuration of bales. Bales may be laid flat or on-edge as limited in height by L105.5. Bales in walls with reinforced plasters may be in a running or stack bond. Bales in walls with unreinforced plaster shall be in a running bond only.

L105.7 Pre-compression of strawbale walls.

L105.7.1 When not required:

a) For non-structural walls.
b) For walls designed or allowed to resist lateral forces only.
c) For walls bearing gravity roof loads, when the full dead load of the roof is imposed and remains on the wall for at least 28 days before plastering. No design snow load greater than 20 psf (80kg/sq.m) is allowed. No floor loads may be supported by walls which are not pre-compressed.

L105.7.2 When required. All walls bearing gravity loads, which are not described in L105.6.1, shall be pre-compressed to a force equal to or greater than the design loads on the wall.

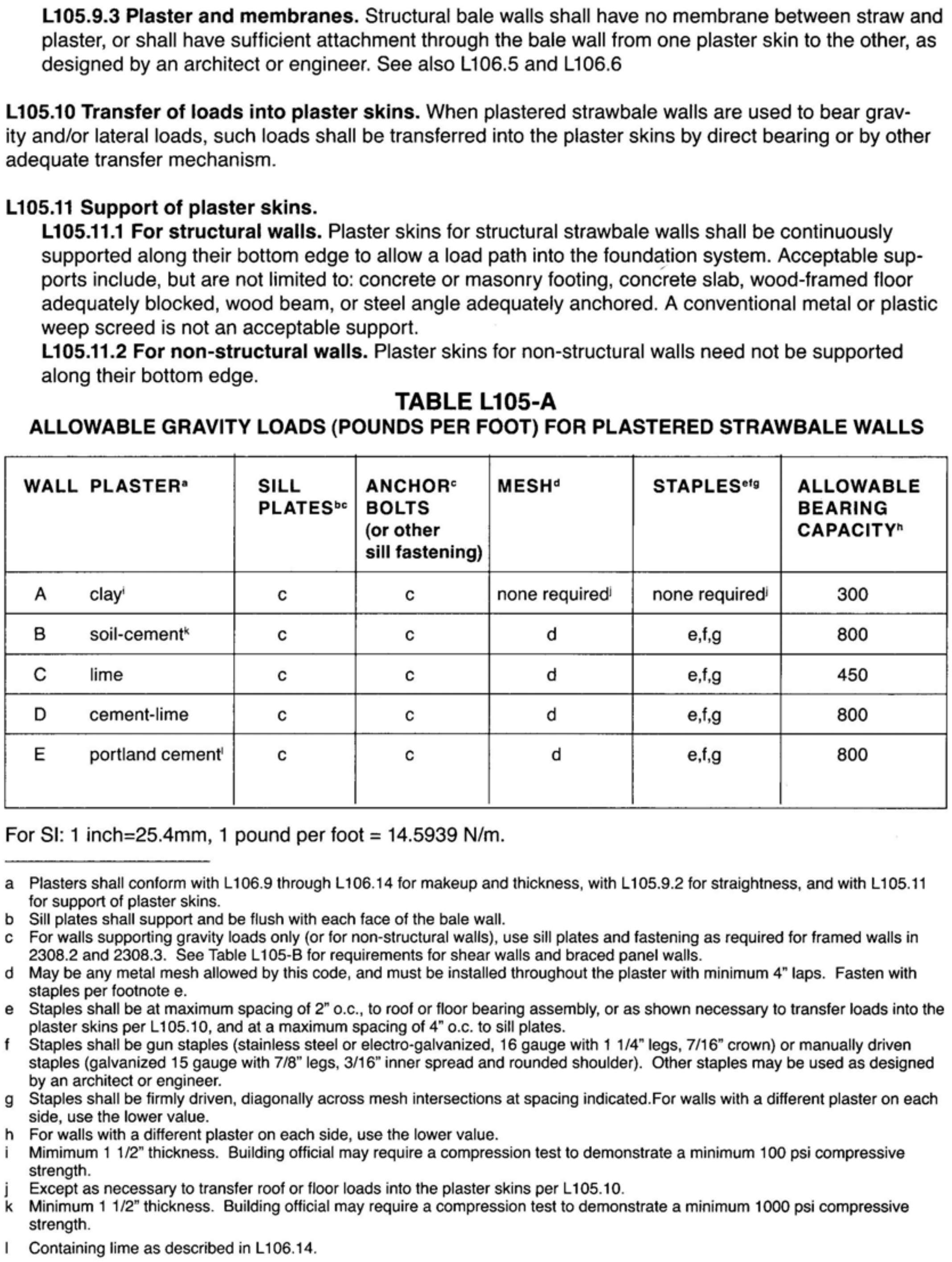
L105.8 Voids and stuffing. Voids in the field of structural strawbale walls shall be limited to 6" (152mm) in width, and shall be firmly stuffed with flakes of straw or with straw-clay, before the application of plaster.

L105.9 Plaster skins.

L105.9.1 General. Plaster skins on structural walls may be of any type allowed by Section L106, except gypsum plaster, and shall also be limited by Table L105-A, and Table L105-B.

L105.9.2 Straightness. On structural walls, plaster skins shall be straight, as a function of the bale wall surface they are applied to, as follows:

a) Across the face of a bale – Straw bulges shall not protrude more than ¾" (19mm) across 2' (610mm) of its height or length.
b) Across the face of a bale wall – Straw bulges shall not protrude from the vertical plane of a bale wall more than 2½" (64mm) over 8' (2438mm).
c) Offset of bales – The vertical face of adjacent bales may not be offset more than ¾" (19mm)



L105.9.3 Plaster and membranes. Structural bale walls shall have no membrane between straw and plaster, or shall have sufficient attachment through the bale wall from one plaster skin to the other, as designed by an architect or engineer. See also L106.5 and L106.6

L105.10 Transfer of loads into plaster skins. When plastered strawbale walls are used to bear gravity and/or lateral loads, such loads shall be transferred into the plaster skins by direct bearing or by other adequate transfer mechanism.

L105.11 Support of plaster skins.

L105.11.1 For structural walls. Plaster skins for structural strawbale walls shall be continuously supported along their bottom edge to allow a load path into the foundation system. Acceptable supports include, but are not limited to: concrete or masonry footing, concrete slab, wood-framed floor adequately blocked, wood beam, or steel angle adequately anchored. A conventional metal or plastic weep screed is not an acceptable support.

L105.11.2 For non-structural walls. Plaster skins for non-structural walls need not be supported along their bottom edge.

TABLE L105-A
ALLOWABLE GRAVITY LOADS (POUNDS PER FOOT) FOR PLASTERED STRAWBALE WALLS

WALL	PLASTER[a]	SILL PLATES[bc]	ANCHOR[c] BOLTS (or other sill fastening)	MESH[d]	STAPLES[efg]	ALLOWABLE BEARING CAPACITY[h]
A	clay[i]	c	c	none required[j]	none required[j]	300
B	soil-cement[k]	c	c	d	e,f,g	800
C	lime	c	c	d	e,f,g	450
D	cement-lime	c	c	d	e,f,g	800
E	portland cement[l]	c	c	d	e,f,g	800

For SI: 1 inch=25.4mm, 1 pound per foot = 14.5939 N/m.

---

[a] Plasters shall conform with L106.9 through L106.14 for makeup and thickness, with L105.9.2 for straightness, and with L105.11 for support of plaster skins.

[b] Sill plates shall support and be flush with each face of the bale wall.

[c] For walls supporting gravity loads only (or for non-structural walls), use sill plates and fastening as required for framed walls in 2308.2 and 2308.3. See Table L105-B for requirements for shear walls and braced panel walls.

[d] May be any metal mesh allowed by this code, and must be installed throughout the plaster with minimum 4" laps. Fasten with staples per footnote e.

[e] Staples shall be at maximum spacing of 2" o.c., to roof or floor bearing assembly, or as shown necessary to transfer loads into the plaster skins per L105.10, and at a maximum spacing of 4" o.c. to sill plates.

[f] Staples shall be gun staples (stainless steel or electro-galvanized, 16 gauge with 1 1/4" legs, 7/16" crown) or manually driven staples (galvanized 15 gauge with 7/8" legs, 3/16" inner spread and rounded shoulder). Other staples may be used as designed by an architect or engineer.

[g] Staples shall be firmly driven, diagonally across mesh intersections at spacing indicated.For walls with a different plaster on each side, use the lower value.

[h] For walls with a different plaster on each side, use the lower value.

[i] Mimimum 1 1/2" thickness. Building official may require a compression test to demonstrate a minimum 100 psi compressive strength.

[j] Except as necessary to transfer roof or floor loads into the plaster skins per L105.10.

[k] Minimum 1 1/2" thickness. Building official may require a compression test to demonstrate a minimum 1000 psi compressive strength.

[l] Containing lime as described in L106.14.

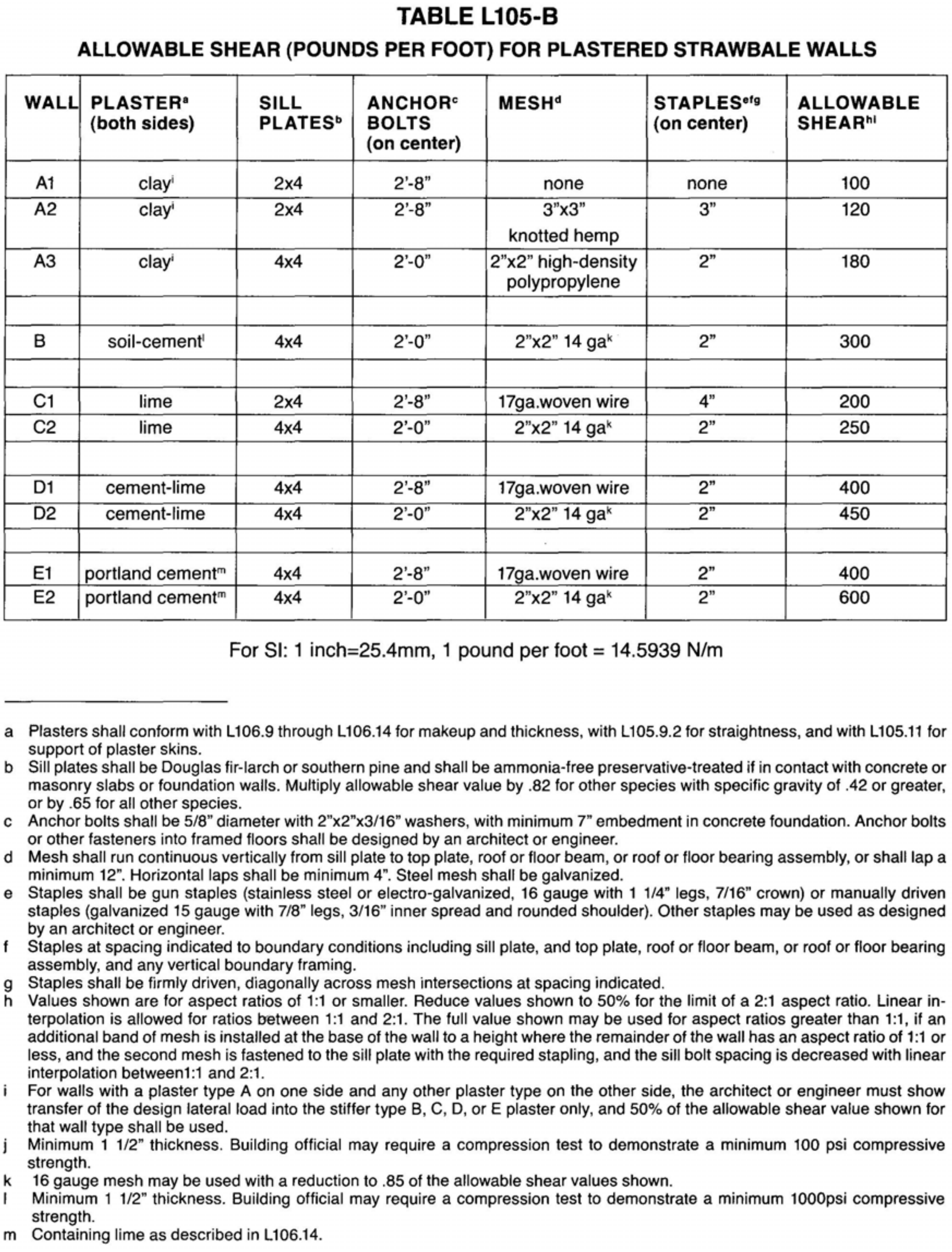


TABLE L105-B

ALLOWABLE SHEAR (POUNDS PER FOOT) FOR PLASTERED STRAWBALE WALLS

WALL	PLASTER[a] (both sides)	SILL PLATES[b]	ANCHOR[c] BOLTS (on center)	MESH[d]	STAPLES[e,f,g] (on center)	ALLOWABLE SHEAR[h,i]
A1	clay[i]	2x4	2'-8"	none	none	100
A2	clay[i]	2x4	2'-8"	3"x3" knotted hemp	3"	120
A3	clay[i]	4x4	2'-0"	2"x2" high-density polypropylene	2"	180
B	soil-cement[l]	4x4	2'-0"	2"x2" 14 ga[k]	2"	300
C1	lime	2x4	2'-8"	17ga.woven wire	4"	200
C2	lime	4x4	2'-0"	2"x2" 14 ga[k]	2"	250
D1	cement-lime	4x4	2'-8"	17ga.woven wire	2"	400
D2	cement-lime	4x4	2'-0"	2"x2" 14 ga[k]	2"	450
E1	portland cement[m]	4x4	2'-8"	17ga.woven wire	2"	400
E2	portland cement[m]	4x4	2'-0"	2"x2" 14 ga[k]	2"	600

For SI: 1 inch=25.4mm, 1 pound per foot = 14.5939 N/m

---

[a] Plasters shall conform with L106.9 through L106.14 for makeup and thickness, with L105.9.2 for straightness, and with L105.11 for support of plaster skins.

[b] Sill plates shall be Douglas fir-larch or southern pine and shall be ammonia-free preservative-treated if in contact with concrete or masonry slabs or foundation walls. Multiply allowable shear value by .82 for other species with specific gravity of .42 or greater, or by .65 for all other species.

[c] Anchor bolts shall be 5/8" diameter with 2"x2"x3/16" washers, with minimum 7" embedment in concrete foundation. Anchor bolts or other fasteners into framed floors shall be designed by an architect or engineer.

[d] Mesh shall run continuous vertically from sill plate to top plate, roof or floor beam, or roof or floor bearing assembly, or shall lap a minimum 12". Horizontal laps shall be minimum 4". Steel mesh shall be galvanized.

[e] Staples shall be gun staples (stainless steel or electro-galvanized, 16 gauge with 1 1/4" legs, 7/16" crown) or manually driven staples (galvanized 15 gauge with 7/8" legs, 3/16" inner spread and rounded shoulder). Other staples may be used as designed by an architect or engineer.

[f] Staples at spacing indicated to boundary conditions including sill plate, and top plate, roof or floor beam, or roof or floor bearing assembly, and any vertical boundary framing.

[g] Staples shall be firmly driven, diagonally across mesh intersections at spacing indicated.

[h] Values shown are for aspect ratios of 1:1 or smaller. Reduce values shown to 50% for the limit of a 2:1 aspect ratio. Linear interpolation is allowed for ratios between 1:1 and 2:1. The full value shown may be used for aspect ratios greater than 1:1, if an additional band of mesh is installed at the base of the wall to a height where the remainder of the wall has an aspect ratio of 1:1 or less, and the second mesh is fastened to the sill plate with the required stapling, and the sill bolt spacing is decreased with linear interpolation between1:1 and 2:1.

[i] For walls with a plaster type A on one side and any other plaster type on the other side, the architect or engineer must show transfer of the design lateral load into the stiffer type B, C, D, or E plaster only, and 50% of the allowable shear value shown for that wall type shall be used.

[j] Minimum 1 1/2" thickness. Building official may require a compression test to demonstrate a minimum 100 psi compressive strength.

[k] 16 gauge mesh may be used with a reduction to .85 of the allowable shear values shown.

[l] Minimum 1 1/2" thickness. Building official may require a compression test to demonstrate a minimum 1000psi compressive strength.

[m] Containing lime as described in L106.14.

L105.14 Resistance to out-of-plane lateral loads. Plastered strawbale walls are capable of withstanding out-of-plane design loads prescribed in this code with the following limitations:

1. Walls with reinforced plasters shall be limited by a 6:1 ratio of stacked bale height to bale width per L105.5.
2. Walls with unreinforced plasters shall be limited by a 4:1 ratio of stacked bale height to bale width.
3. Walls with unreinforced plasters or no plaster, and with internal or external pins, shall be limited by a 6:1 ratio of stacked bale height to bale width. Pins may be ½" (13mm) diameter steel, wood or bamboo. Internal pins shall be installed vertically at a maximum 2' (61mm) spacing into the bales from top course to bottom course, with the bottom course being connected to its support similarly with pins or other approved means. Pins may be continuous or may overlap through one bale course. External pins shall have full lateral bearing on the sill plate and the roof or floor bearing member, and shall be tightly tied through the wall to an opposing pin with polypropylene string at 30" maximum spacing.

L105.15 Prescriptive design using structural strawbale walls.

L105.15.1 General. Plastered strawbale walls may be used structurally, without design by an architect or engineer, as described in this subsection. Such walls shall also comply with L105.5 through L105.11, and 105.14 of this Section and shall comply with other Sections of this appendix as applicable.

L105.15.2 Load and other limitations. As described in 2308.2 - 3 through 7, and 2308.2.2.

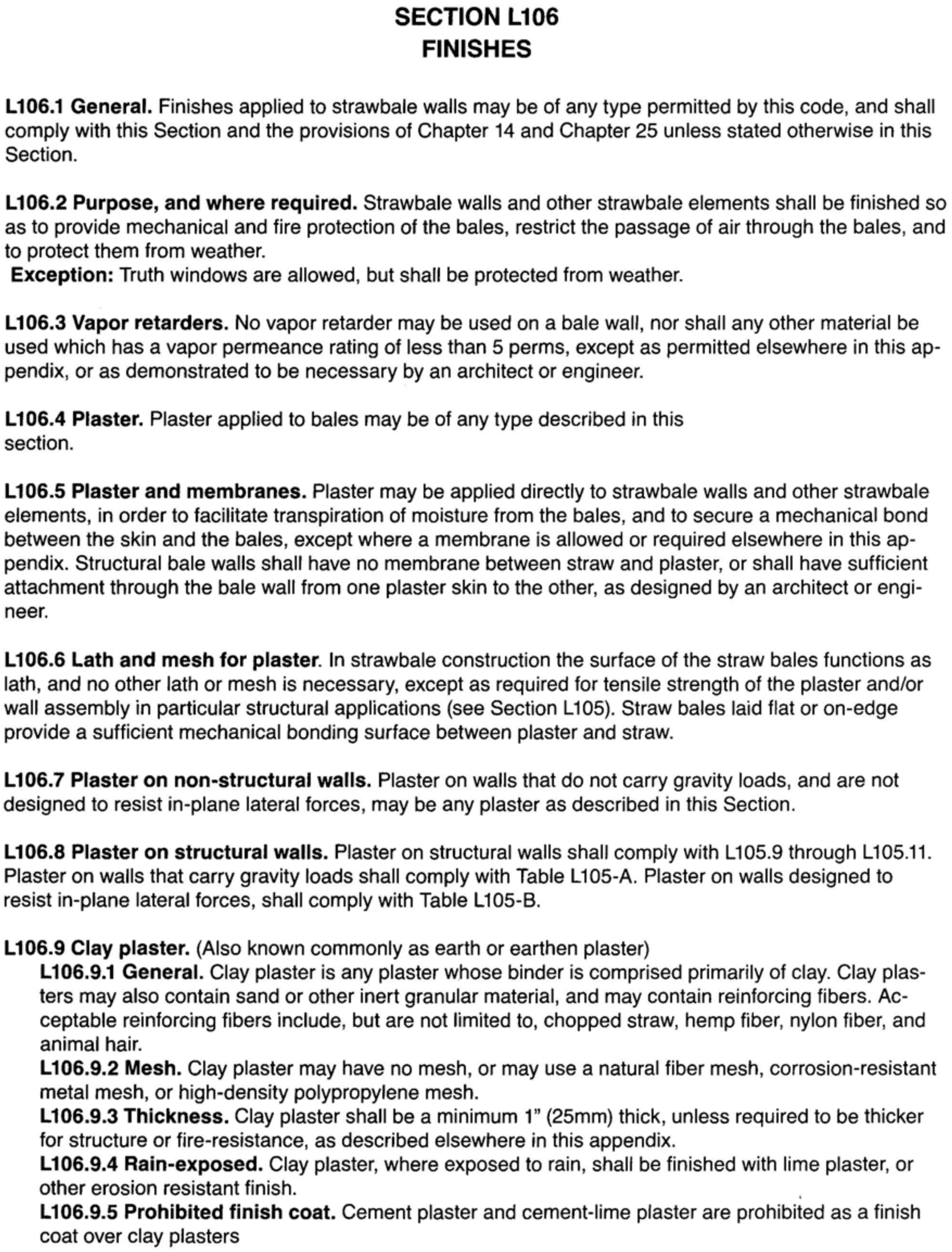
L105.15.3 Gravity load bearing walls. Limited to wall types B, C, D, and E in Table L105-A. Type A walls may be used if they are demonstrated to support design loads no greater than the allowable load.

L105.15.4 Braced panels. Strawbale shear walls may be used as braced panels per the requirements and limitations in 2308.9.3 Bracing, and per 2308.12 Additional requirements for conventional construction in Seismic Design Category D or E. Strawbale shear wall types B, C, D, and E, shown in Table L105-B, may be used in situations where braced wall panel types 2., 3., 4., 6., and 7. are allowed. Strawbale shear wall type A may be use in situations where braced wall panel types 1. and 5. are allowed.

L105.16 Connection of framed walls to strawbale walls. Framed walls perpendicular to, or at an angle to a straw bale wall assembly, need only be fastened to the bottom and top wood members of the strawbale wall per framing connections permissible in this code. Where such connection is not possible, the abutting stud shall be connected to alternating straw bale courses with a 1/2" (1.25cm) diameter steel, wood, or bamboo dowel with minimum 8" (20cm) penetration.

L105.17 Alternate Performance Design Criteria. When plastered strawbale walls or other elements are engineered, they may use the model of restrained, thin shell, reinforced concrete, as in the American Concrete Institute's ACI-318 Manual. This model may be used for all reinforced plasters, including those without cement. Such design and analysis shall be made in accordance with the following:

a) General. Strawbale structural systems and elements shall be designed using engineering principles, fundamental engineering behavior, and principles of mechanics.
b) Rationality. Strawbale structural elements shall be designed based on a rational analysis in accordance with established principles of mechanics. These elements shall provide a complete load path capable of transferring all loads and forces from their point of origin to the load-resisting elements based on a rational connection of components.
c) System Characteristics. Strength, stiffness and toughness (ductility) characteristics, of the bales and their skins, shall be considered in the design of the system.



SECTION L106
FINISHES

L106.1 General. Finishes applied to strawbale walls may be of any type permitted by this code, and shall comply with this Section and the provisions of Chapter 14 and Chapter 25 unless stated otherwise in this Section.

L106.2 Purpose, and where required. Strawbale walls and other strawbale elements shall be finished so as to provide mechanical and fire protection of the bales, restrict the passage of air through the bales, and to protect them from weather.
Exception: Truth windows are allowed, but shall be protected from weather.

L106.3 Vapor retarders. No vapor retarder may be used on a bale wall, nor shall any other material be used which has a vapor permeance rating of less than 5 perms, except as permitted elsewhere in this appendix, or as demonstrated to be necessary by an architect or engineer.

L106.4 Plaster. Plaster applied to bales may be of any type described in this section.

L106.5 Plaster and membranes. Plaster may be applied directly to strawbale walls and other strawbale elements, in order to facilitate transpiration of moisture from the bales, and to secure a mechanical bond between the skin and the bales, except where a membrane is allowed or required elsewhere in this appendix. Structural bale walls shall have no membrane between straw and plaster, or shall have sufficient attachment through the bale wall from one plaster skin to the other, as designed by an architect or engineer.

L106.6 Lath and mesh for plaster. In strawbale construction the surface of the straw bales functions as lath, and no other lath or mesh is necessary, except as required for tensile strength of the plaster and/or wall assembly in particular structural applications (see Section L105). Straw bales laid flat or on-edge provide a sufficient mechanical bonding surface between plaster and straw.

L106.7 Plaster on non-structural walls. Plaster on walls that do not carry gravity loads, and are not designed to resist in-plane lateral forces, may be any plaster as described in this Section.

L106.8 Plaster on structural walls. Plaster on structural walls shall comply with L105.9 through L105.11. Plaster on walls that carry gravity loads shall comply with Table L105-A. Plaster on walls designed to resist in-plane lateral forces, shall comply with Table L105-B.

L106.9 Clay plaster. (Also known commonly as earth or earthen plaster)
L106.9.1 General. Clay plaster is any plaster whose binder is comprised primarily of clay. Clay plasters may also contain sand or other inert granular material, and may contain reinforcing fibers. Acceptable reinforcing fibers include, but are not limited to, chopped straw, hemp fiber, nylon fiber, and animal hair.
L106.9.2 Mesh. Clay plaster may have no mesh, or may use a natural fiber mesh, corrosion-resistant metal mesh, or high-density polypropylene mesh.
L106.9.3 Thickness. Clay plaster shall be a minimum 1" (25mm) thick, unless required to be thicker for structure or fire-resistance, as described elsewhere in this appendix.
L106.9.4 Rain-exposed. Clay plaster, where exposed to rain, shall be finished with lime plaster, or other erosion resistant finish.
L106.9.5 Prohibited finish coat. Cement plaster and cement-lime plaster are prohibited as a finish coat over clay plasters

L106.9.6 Additives. Additives may be used to increase the plaster's workability, durability, strength, or water resistance.

L106.9.7 Separation of wood and clay plaster. No separation or moisture barrier is required between untreated wood and clay plaster.

L106.10 Earth-cement plaster. (Also known commonly as soil-cement, stabilized earth, or pise')

L106.10.1 General. Earth-cement plaster is comprised of earth (free of organic matter) and Portland cement, and may include sand or other inert granular material, and may contain reinforcing fibers.

L106.10.2 Mesh. Earth-cement plaster shall use any corrosion-resistant metal mesh permitted by this code, and as described in Section L105 if used on a structural wall.

L106.10.3 Thickness. Earth-cement plaster shall be a minimum of 1½" (38mm) thick.

L106.11 Gypsum plaster.

L106.11.1 General. Gypsum plaster shall comply with Section 2511 of this code.

LL06.11.2 Restriction of use. Gypsum plaster is limited to use on interior surfaces, and on non-structural walls, except as a finish coat over an allowed structural plaster.

L106.12 Lime plaster.

L106.12.1 General. Lime plaster is any plaster whose binder is comprised primarily of calcium hydroxide (CaOH). This includes Type N or Type S hydrated lime, natural hydraulic lime, or quicklime. Lime plasters shall comply with ASTM Standards C5 and C206. The plaster may be applied in 2 coats, provided that the combined thickness is at least 7/8" (22mm), and each coat is no greater than 5/8" (16mm).

L106.13 Cement-lime plaster.

L106.13.1 General. Cement-lime plaster shall comply with Section 2508 of the 1997 UBC, except that the plaster may be applied in 2 coats, provided that the combined thickness is at least 7/8" (22mm), and each coat is no greater than 5/8" (16mm).

L106.14 Portland cement plaster.

L106.14.1 General. Portland cement plaster shall comply with Section 2512 of this code, except that the amount of lime in all plaster coats shall be a minimum of 1 part lime per 6 parts cement so as to allow a minimum acceptable vapor permeability. The plaster may be applied in 2 coats, provided that the combined thickness is at least 7/8" (22mm), and each coat is no greater than 5/8" (16mm). The combined thickness of all plaster coats shall be no more than 1½" (38m).

L106.15 Alternate plasters. Plasters, or variations, which do not fit in any other category described in this Section, may be allowed if such plasters are demonstrated to be appropriate for the particular application.

L106.16 Finishes over plaster. Other finishes, as permitted elsewhere in this code, may be applied over the plaster, except as prohibited in L106.17.

L106.17 Prohibited plasters and finishes. Any plaster or finish with a cumulative perm rating of <5 perms is prohibited on straw bale walls or other bale elements, unless demonstrated to be necessary by an architect or engineer.

L106.18 Separation of wood and plaster. Where wood framing or wood sheathing occur in strawbale walls, such wood surfaces shall be separated from any plaster finish with No. 15 asphalt felt, grade 'D' paper, or other approved material per Section 1404.2 of this code, unless the wood is preservative-treated or naturally durable.

Exception: Clay plasters. See L106.9.7

SECTION L107
FIRE-RESISTANCE

L107.1 Fire-resistance rating.

L107.2.1 Rating with plaster finish. Plastered strawbale walls have a 1-hour fire-resistance rating, provided the components of the wall fit within the following parameters:

a) Bales may be laid flat or on-edge.
b) The bale wall must have a minimum unplastered thickness of 12" (304mm).
c) Bales may be installed in a running bond or stack bond, but vertical joints in a stack bond, and continuous vertical gaps at any posts within both types of wall, must be fire-stopped with straw-clay, or equivalent.
d) The wall must be finished on both sides and exposed ends with a plaster of any type allowed by this appendix, and clay plasters must be a minimum 1 ½" (38mm) thick, and a minimum of 2 layers.

L107.2.2 Rating with other finishes. Strawbale walls covered with finish materials other than, or in addition to plaster, shall be deemed to have the equivalent fire resistive rating as wood-frame construction covered with the same finish materials.

L107.3 Permitted in types of construction. Strawbale walls with a 1-hour fire-resistance rating per Section L107.2 are permitted wherever combustible 1-hour walls are allowed by Chapter 6. Such walls and unrated strawbale walls with any finish allowed by this code are permitted wherever combustible no-hour walls are allowed by Chapter 6.

L107.4 Openings in rated walls. Openings and penetrations in any strawbale wall rated and required to be rated for a particular fire-resistance rating and for a particular application, shall satisfy the same requirements for openings and penetrations in walls with the same fire-resistance rating and application as stated elsewhere in this code.

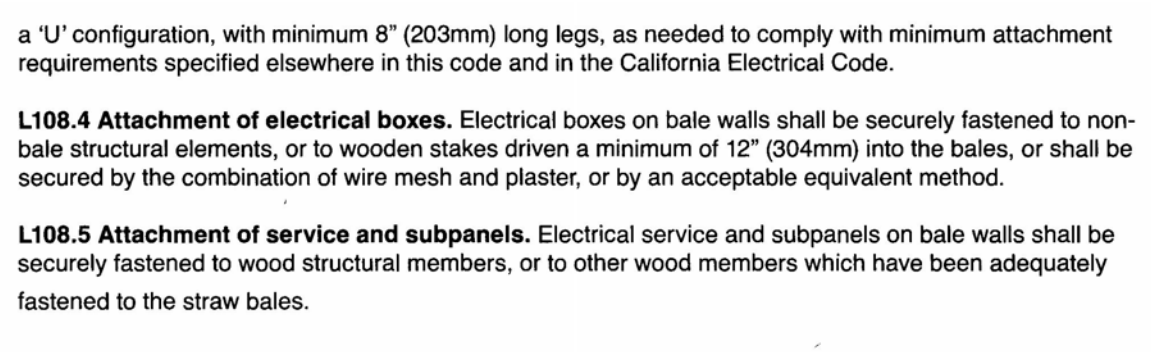
L107.5 Clearance to fireplaces and chimneys. Strawbale surfaces adjacent to fireplaces or chimneys shall have a minimum 1/4" (6mm) thick plaster coat of any type permitted by this appendix, and shall maintain the specified clearances to the plaster finish as required to combustibles in Sections 2111, 2112, and 2113, or as required by manufacturers of prefabricated fireplaces and chimneys, or as required to combustibles elsewhere in this code.

SECTION L108
ELECTRICAL

L108.1 Scope. Wiring and other elements of the electrical system, within or on bale walls, shall comply with all Sections of this code which govern electrical systems and with the California Electrical Code, unless otherwise stated in this Section.

L108.2 Wiring. Type NM or UF cable may be used, or wiring may be run in metallic or non-metallic conduit. Wiring which is unprotected by conduit shall be installed a minimum of 2" (50mm) from the face of the bale, except as necessary to enter or exit a junction box. The wiring shall be pushed into joints between bales, or into the bale itself, or the bales may be channeled to receive the wire.

L108.3 Wiring attachment. Where not held securely between bales or within a bale, and not attached via staples to a wood member, wiring on straw bale walls shall be attached with minimum 17 ga. wire in



a 'U' configuration, with minimum 8" (203mm) long legs, as needed to comply with minimum attachment requirements specified elsewhere in this code and in the California Electrical Code.

L108.4 Attachment of electrical boxes. Electrical boxes on bale walls shall be securely fastened to non-bale structural elements, or to wooden stakes driven a minimum of 12" (304mm) into the bales, or shall be secured by the combination of wire mesh and plaster, or by an acceptable equivalent method.

L108.5 Attachment of service and subpanels. Electrical service and subpanels on bale walls shall be securely fastened to wood structural members, or to other wood members which have been adequately fastened to the straw bales.