Thesis Proposal

Medical Office Building

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Advisor:

Executive Summary

This report proposes value-engineering changes to the Medical Office Building in Malvern, Pa. The building site is in a corporate park with several low to medium rise buildings. It is an extension of an existing complex and joins the previous buildings with a sky bridge. Although mostly office space, the building does include a small auditorium that is used for conferences and stockholder meetings. The open office space and auditorium benefit from the 28’ square bays that are the basis of the structural system. The gravity system is composed of filigree slabs and beams resting on cast in place concrete columns. The lateral system is made up of cast in place frames in the east-west direction, and beams on torsion girders in the north-south direction.

Four systems are being considered for redesign.

- Slab - Pre-stressed two-way slab on drop panels
- Lateral System - Two shear wall cores around interior stairwells
- Mechanical System - Under floor air distribution system for the open office area
- Lighting - Specialized lighting for the auditorium

The introduction of a two-way pre-stressed slab system puts the design of the floor system back in the hands of the engineer of record. This allows for optimization that may not be present in the filigree system. Preliminary analysis of a two-way system also showed that the floor to ceiling height could be increased 6”. The analysis of a new floor system will take one week, but an additional week is required to conduct research.

The current lateral system appears to have been developed to fit into the filigree beam system. By replacing the beams, frames, and torsion girders with shear walls it may be possible to optimize design. Despite the possibility of higher cost, the potential for easier construction and a more efficient system make shear walls a competitive solution. Two weeks will be taken to design the walls, and another week to design the footings.

An under floor air distribution system (UFAD) is a good solution for open office spaces. The flexibility this system introduces may compensate the necessity for better maintenance. There is also a potential for energy savings versus the traditional mixing ventilation system. Research into the available types of UFAD will take a week and the design of the system will take another week. Additionally, if time permits, one week will be taken to perform a computational fluid dynamics analysis of the system.

The lighting system in the auditorium will be redesigned from the conventional down lighting scheme. The new system will use shelved T5 lamps as the standard lighting system and introduce a row of track lights for the presentation area. A week will be taken to design both the conventional lighting system and the new presentation lighting system.

The overall value of the project will be determined based on an increased value as measured by expanded space and improved comfort or utility that does not increase the price by more than 3%. The entire analysis will take ten weeks, with the final presentation being delivered both orally and in written form.

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Introduction

The Medical Office Building resides in a corporate park in Malvern, PA. The park has several low to medium height buildings that are clustered on moderately spaced sites. The Medical Office Building is an extension of an existing complex, and is used mostly as office space for two departments. However, an auditorium in the basement serves as the central location for meetings and conferences for the entire complex. A sky bridge on the third floor joins the Medical Office Building to a neighboring building allowing indoor travel between the existing complex.

The structural system of the Medical Office building is predominantly concrete, although steel trusses are used to span the atrium along the southwest wall. Filigree slabs and beams resting on cast in place concrete columns serve as the gravity system in the building. The lateral system consists of frames in the east-west direction and beams on torsion girders in the north-south direction. Columns are aligned on square bays measuring twenty-eight (28) feet to a side, except for the southwestern curve, which uses a radial alignment for the exterior columns. Due to slope and varying basement levels the building height ranges from roughly 40' above grade to as much as 68' above grade.

The slope of the site also plays an important role in the architecture of the complex. The existing buildings are both the same height, but are built on different levels of the site. A sky bridge between the two existing buildings aligns the second highest floor with the third highest floor in the second building. Continuing this line requires that the third building sky bridge join the second highest floor of the second building to the third highest floor in the third building. (Figure 1) Although not connected by a bridge, the other floors have a visual line by having the same floor-to-floor height, and thus similar fenestration. One notable difference between the existing buildings and the Medical office building was the choice to use a raised floor system to allow under floor access for electrical and telecommunication trades. Another system unique to the Medical Office Building is the filigree beam system, which introduces further limitations to the design. The most notable of these limitations is the beam on torsion girder lateral system, but also includes the channeling of overhead plenum space and black boxing of slab design. An alternative design may be able to alleviate these problems, while still meeting the requirements imposed by architecture.

Figure 1 – Medical Office Building sketch showing the architectural features of the sky bridge

Changes in areas other than the structural system may also lead to improved value in the building. Value in this case shall be defined as providing greater occupancy satisfaction, as measured by usable space, thermal comfort, and lighting levels, for little to no increase in cost. With these requirements in mind the following systems will be evaluated:

- Slab Redesign - Pre-stressed two-way slab on drop panels
- Lateral System Redesign - Two shear wall cores around interior stairwells
- Mechanical System Redesign - Under floor air distribution system for the open office area
- Lighting Redesign - Specialized lighting for the auditorium

Slab Redesign

One of concerns associated with a proprietary system is that the engineer of record must take responsibility for the functioning of said system, without knowing the details of the design. This concern alone should be cause enough for any engineer to be skeptical of implementing a proprietary system. Another benefit of having an engineer design the floor system is that they may be able to make value-engineering judgments that would result in a better product.

In the Medical Office Building the proprietary system includes both the slab and the beams that support the slab. The depth of the current system is 18” at the beam. A preliminary analysis (Appendix I) of a two-way system showed that the total depth could be reduced 6” by introducing a two-way slab system. This means that the drop ceiling could be raised 6”, thus creating more open space, and meeting one of the criteria for value. The cost of the two-way system is estimated at $2.7 million (Appendix I), which is less than 8% the original cost of the entire building.

The benefits of a two-way slab system can be improved further by utilizing pre-stressing. Although pre-stressing will raise the cost of the slab it would likely decrease the depth of the system even further. Another way of reducing thickness would be to implement drop panels to reduce the clear span of the slab. Although the panels would add depth near the columns, the drop ceiling could still be placed based on the slabs, because there would be open plenum space in both directions in a beam free system. It is important to note that having thinner floor systems can create vibration concerns, and inherently do not provide enough benefits as an individual modification when building height is not a concern.

Even with the possible shortcomings of the system, a pre-stressed two-way slab provides several benefits that may affect the design of other building systems. Therefore an exploration of a two-way pre-stressed concrete slab on drop panels will be conducted. This analysis will include a research period to learn the design procedure for pre-stressed systems before the actual floor system redesign.

Lateral System Redesign

Another system affected by the use of the filigree beam floor system was the lateral support system. The current system of frames and beams on torsion girders appears to be more of a design around the floor system, than a properly developed lateral support system. One of the main problems with the current system is that large torsion moments, due to wind, result in massive shearing forces and threats of overturning and uplifting in the extreme frames.

To mitigate the problem of torsion, the lateral system should be more centralized. However, centralizing the frames would be difficult due to space considerations. A suitable alternative to frames is shear walls. The shear walls could be built around the two stairwells (Figure 2), which are both located along the east-west centerline of the building. The shear walls would still generate torsion under wind loading, because of the eccentricity of the eastern stairwell. However, the overall torsion should be reduced and the dangers of overturning the shear wall should be far less than with the beams on torsion girders.

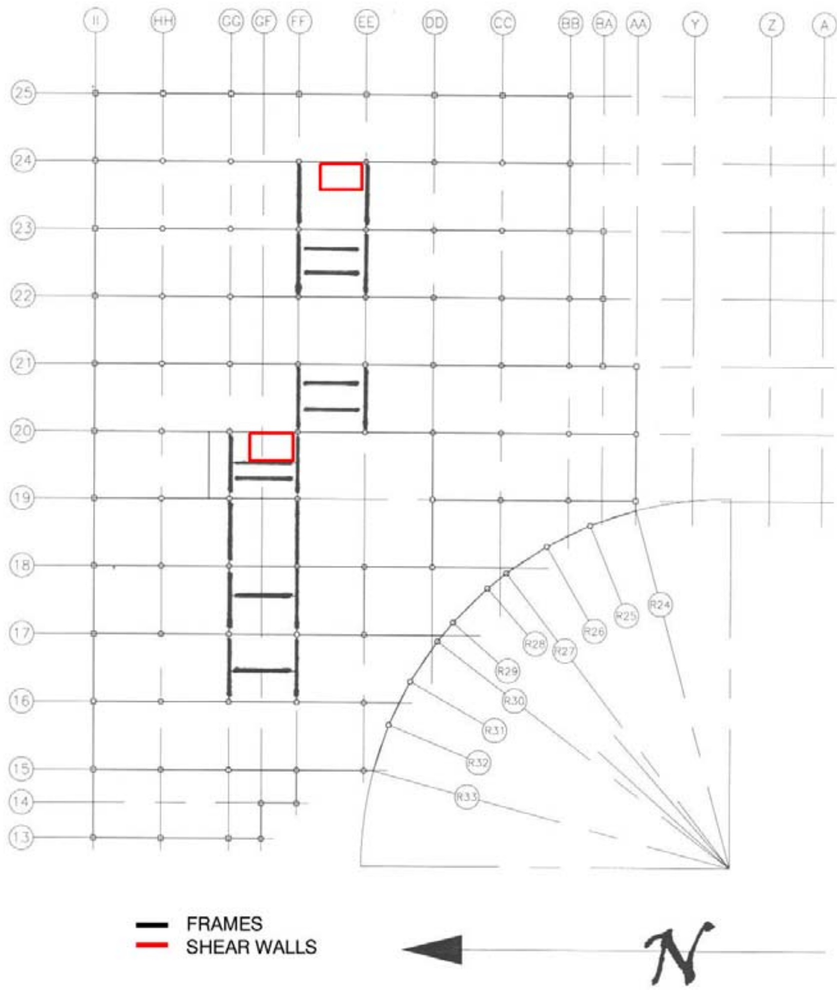

Figure 2 – Proposed shear walls at stairwells overlaying existing frame system

A redesign of the lateral support system would also impact the design of the foundation system. These effects are considered secondary because they will not inversely affect the design of the shear walls. Even though a full analysis of the new foundation system will not be undertaken, the foundations that support the new shear cores will be designed for the appropriate loads.

The cost of the shear walls versus the frames will depend on the required thickness of the shear walls. It is not unreasonable to assume that the shear walls may be more expensive, but easier to construct than the numerous frames. The true value of a shear wall system will be apparent after a complete analysis. The analysis will include an initial estimate of shear wall size based on tributary area, a second analysis based on relative stiffness, and finally an analysis of the foundations to resist overturning and uplift.

Mechanical System Redesign

The Medical Office Building was built with a raised floor system that is used to distribute telecommunications and electric cables throughout the building. This is use of the under floor plenum is advantageous because it eliminates the costs of cable baskets, reduces ceiling plenum heights, and allows outlets to be separated from columns. At the same time, the electric panels on the floor often become cracked, and the ceiling plenum still houses the Heating Ventilation and Air Conditioning (HVAC) System.

An alternative to overhead air distribution HVAC systems is an under floor air distribution system. The current floor system is only raised 6”, which is too narrow for UFAD, but by taking advantage of the 6” that can be gained by moving to a two-way slab system, it may be possible to incorporate UFAD. There are both benefits and disadvantages to such a system.

The major advantage of UFAD is that it is flexible. This feature would be incredibly helpful in the bullpens of the open office spaces in the Medical Office Building, where diffusers could be moved to suit any configuration of the workspaces. On the other hand, with the diffusers at floor level, more dust will collect in the ducts and diffusers, this will result in air quality issues unless proper maintenance is regularly performed. It is also difficult to predict the human comfort of such a system, because it does result in a perfectly mixed condition. It is also important to note that although supply ducts would no longer occupy ceiling space, return ducts would still be necessary.

The value of this system will not be cost, as both installation and life cycle costing will be higher, due in part to the stricter maintenance requirements. However, if the system can provide an environment of equal or better human comfort than the mixing system and at a lower energy cost, then it might justify the higher price. Proving the equivalence of the systems will require a Computational Fluid Dynamics analysis, since design techniques for mixing diffusers will not apply. A research period will also be required to determine the type of UFAD system and diffusers that will be utilized.

Lighting Redesign

One of the main features of the Medical Office Building is the multipurpose auditorium in the basement. The auditorium is actually three rooms which are typically combined, but can be separated to host several small conferences simultaneously. Only one of the rooms is equipped with a projector, and the only lighting in the auditorium is down lighting (Figure 3). This system is simple and effective, but does not provide dynamic lighting for presentations.

Figure 3 – Picture showing the existing lighting configuration for the auditorium

The current design of the auditorium suggests that most presentations will utilize all three rooms of the auditorium. Since a projector has already been provided for these larger gatherings, it seems reasonable that additional lighting be provided as well. Simply adding new lighting would not be an appropriate solution since the additional utility is not worth the additional cost. Therefore a value engineering solution would create an alternative lighting system of equal quality that provides the specialized presentation lighting.

The new lighting system for the auditorium would completely replace the down lighting system with shelved lines of T5 fluorescents. A row of fixed track lighting will also be placed to highlight the presentation area of the auditorium. Once placed, this new system should be more attractive, and effective than the current design. Typical fixtures from Philips and Sylvania will be used as much as possible to limit unusual designs.

Schedule

In order to be prepared for the final presentation, the redesign must be completed within ten weeks. Five of these weeks will be devoted to the redesign of the structural systems, and five weeks for the redesigns of the other systems. The time required for each system is related to the complexity of the system and the required design methods. The exact breakdown is summarized in table 1.

Two-way pre-stressed slab	**2 weeks**
- Research of pre-stressed design	1 week
- Design of two-way slab	1 week
Shear Walls	**3 weeks**
- Initial design based on tributary area of wind loads	1 week
- Refined design based on a relative stiffness analysis	1 week
- Design of footings to resist uplift and overturning	1 week
Under Floor Air Distribution System	**3 weeks**
- Research of UFAD systems	1 week
- Design of system	1 week
- CFD simulation of system	1 week
Specialized Auditorium Lighting	**2 weeks**
- Redesign of general lighting	1 week
- Design of presentation lighting	1 week
Total	**10 weeks**

Table 1 – Schedule of processes of building system redesigns

The process of preparing the presentation will have to be accomplished concurrently with the completion of each task. If necessary the CFD analysis of the UFAD system can be eliminated without significant consequences to the value analysis of the system.

Evaluation

The proposed changes to the Medical Office Building are intended to be value-engineering adjustments. They do not represent a major change to the general functioning of the system, but rather offer alternatives. The measure of the effectiveness of the changes will be reflected by either a lower cost, or a greater utility with little or no increase in cost. It is anticipated that the combination of these systems will result in greater utility with a slight increase in cost. If the final increase in cost is less than 3% of the original building price of $35 million, or $1 million dollars, the changes will be considered a successful redesign.

If the entire complement of systems does not meet the requirements of value engineering, then a further analysis of system combinations will be necessary. If a certain combination of systems meets the cost requirement then that combination will be recommended as an effective value engineering solution. If no combination of systems meets the cost limitation, then the current design will be considered the optimum available design and no changes will be recommended.

Appendix I

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Two-way Slab

$l_1 = 28'$
$l_2 = 28'$
$w_L = 100$ psf
$w_D = 25$ psf

Minimum thickness for column supported slabs w/o edge beams
exterior : $\frac{l_n}{30}$ ← controls
interior : $\frac{l_n}{33}$

$h_{min} = \frac{28(12)}{30} = 11.2''$ choose $11.5''$ ∴ deflection ok.

$w_{slab} = \frac{11.5}{12}(150) = 144$ psf ∴ $w_D = 169$ psf

Using direct design method
$1.4D = 236.6$ psf
$1.2D + 1.6L = 362.8$ psf ← controls

$M_o = \frac{w_u l_2 l_n^2}{8} = \frac{362.8(28)^3}{8} = 995523.2'lb = 995.52'k$

$M_- = .65 M_o = 647.09'k$
$M_+ = .35 M_o = 348.43'k$

Assume #8 bars
$d = h - .75 - \frac{d_b}{2} = 11.5 - .75 - \frac{1}{2} = 10.25''$

$M_u \le \phi M_n = \phi .85 f'_c ba (d - \frac{a}{2})$

Column strip : $b = 2 \times \frac{L}{4} = 2 \times \frac{28(12)}{4} = 168''$
Middle strip : $b = \frac{L}{2} = \frac{28(12)}{2} = 168''$

for an interior bay column strip takes 75% M_- and 60% M_+

Column(-): Assume $\phi = .9$
$.75(647.09)(12) = .9(.85)(4)(168)a(10.25 - \frac{a}{2})$
$257.04a^2 - 5269.32a + 5823.81 = 0 \Rightarrow a = 1.17$

$A_s = .85 \frac{f'_c}{f_y} ba = .85 \frac{4}{60}(168)(1.17) = 11.14 \text{ in}^2$ ∴ need 15 #8's $A_s = 11.85 \text{ in}^2$

$a = \frac{A_s f_y}{.85 f'_c b} = \frac{11.85(60)}{.85(4)(168)} = 1.24''$

$\varepsilon_t = \frac{d - a/\beta_1}{a/\beta_1}(0.003) = \frac{10.25 - 1.46}{1.46}(0.003) = 0.018 > 0.005$ ∴ $\phi = .9$

$\phi M_n = \phi A_s f_y (d - \frac{a}{2}) = .9(11.85)(60)(10.25 - \frac{1.24}{2}) = 6162.24''k = 513.52'k$

$513.52'k > .75(647.09) = 485.32'k$ o.k.

Column(+): Assume $\phi = .9$ $M_{+col} = .6(348.43) = 209.06'k$
$257.04a^2 - 5269.32a + 2508.72 = 0 \Rightarrow a = 0.49''$
$A_s = .85(\frac{4}{60})(168)(0.49) = 4.66 \text{ in}^2$ ∴ need 6 #8's $A_s = 4.74 \text{ in}^2$
$a = \frac{4.74(60)}{.85(168)(4)} = 0.50''$ $\varepsilon_t = \frac{10.25 - .59}{.59}(0.003) = 0.049 > 0.005$ ∴ $\phi = .9$
$\phi M_n = .9(4.74)(60)(10.25 - \frac{.50}{2}) = 2559.6''k = 213.3'k$

$213.3'k > 209.06'k$ o.k.

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Middle (−): Assume $\Phi = .9$ $M_{-mid} = .25(647.09) = 161.77'k$

$257.04a^2 - 5269.32a + 1941.24 = 0 \Rightarrow a = 0.38''$

$A_s = .85\frac{4}{60}(168)(0.38) = 3.62\ in^2$ $\therefore$ 5 #8's $A_s = 3.95\ in^2$

$a = \frac{3.95(60)}{.85(168)(4)} = 0.41''$ $\varepsilon_t = \frac{10.25-.49}{.49}(0.003) = 0.060 > 0.005$ $\therefore \phi = .9$

$\Phi M_n = .9(3.95)(60)(10.25 - \frac{.41}{2}) = 2142.60''k = 178.55'k$

$178.55'k > 161.77'k$ o.k.

Middle (+): Assume $\phi = .9$ $M_{+mid} = .40(348.43) = 139.37'k$

$257.04a^2 - 5269.32a + 1672.46 = 0 \Rightarrow a = 0.32''$

$A_s = .85\frac{4}{60}(168)(0.32) = 3.05\ in^2$ $\therefore$ 4 #8's $A_s = 3.16\ in^2$

$a = \frac{3.16(60)}{.85(168)(4)} = 0.33''$ $\varepsilon_t = \frac{10.25-.39}{.39}(0.003) = 0.076 > 0.005$ $\therefore \phi = .9$

$\phi M_n = .9(3.16)(60)(10.25 - \frac{.33}{2}) = 1720.90''k = 143.41'k$

$143.41'k > 139.37'k$ o.k.

$A_{s\,min} = 0.0016\,bh = 0.0018(168)(11.5) = 3.48''$ $\therefore$ need 5 #8's $A_s = 3.95\ in^2$

Shear

Assume 26" ϕ columns $\frac{b_o}{4} = 26 + d$

$b_o = 4(26 + 10.25) = 145''$

$V_c = 4\sqrt{f'_c}\,b_o d = 4\sqrt{4000}(145)(10.25) = 375995\ lb. = 376.00\ k$ ← controls

$V_c = (\frac{40d}{b_o} + 2)\sqrt{f'_c}\,b_o d = (\frac{40(10.25)}{145} + 2)\sqrt{4000}(145)(10.25) = 453787\ lb. = 453.79\ k$

$\Phi V_c = .75(376.00) = 282.00\ k$

$V_u = w_u(L^2 - (\frac{b_o}{4})^2) = 362.8(28^2 - (\frac{145}{48})^2) = 281124\ lb. = 281.12\ k$

$282.00\ k > 281.12\ k$ o.k.

System	Material $/S.F.	Installation $/S.F.	Total $/S.F.	Sandwich Depth	Fire Rating	Consider Further?
Existing (CIP slab on beam)	4.68	10.46	14.78	18”	3 hr	X
Composite Slab on Beam	8.42	10.09	18.47	34”	≈2 hr. (spray)	N
Slab on Steel Joists	7.85	6.17	14.09	26”	≤2 hr	N
Flat Plate	4.24	7.48	11.51	11.5”	3 hr	Y
Precast Concrete Panels and Beams	4.96	1.70	6.83	36”	3 hr	Y