monongalia general hospital

morgantown, wv

hiroki ota
structural option

topics

existing conditions

BUILDING STATISTICS

depth

BLAST AND PROGRESSIVE COLLAPSE ANALYSIS

breadth

COST AND SCHEDULE ANALYSIS

BLAST AND CONDUCTIVITY ANALYSIS OF CURTAIN WALLS

conclusion

existing conditions

view from the south east

source: turner construction company

existing conditions

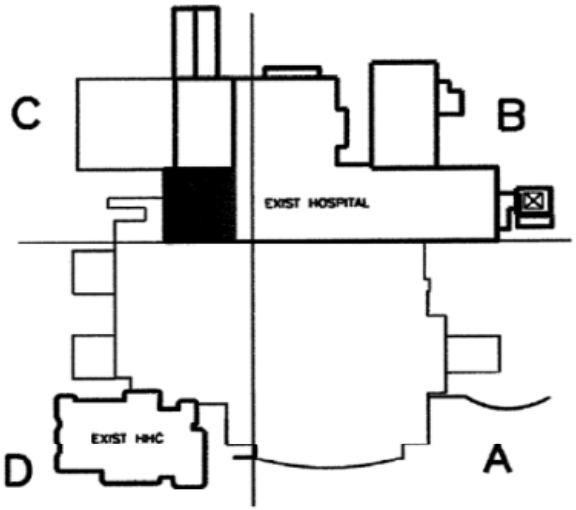
ARCHITECTURE

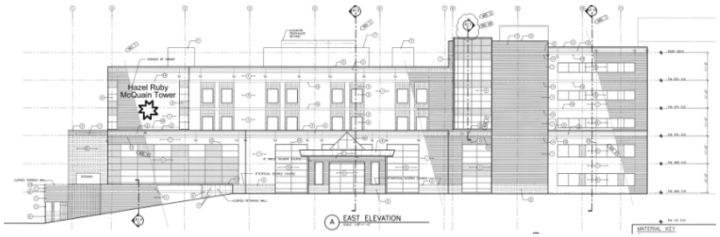
six story general hospital – 340,000 square feet

houses multiple hospital functions

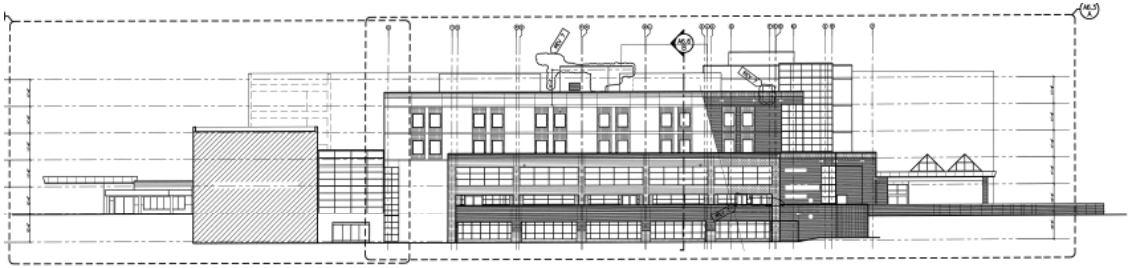
flat roof – ballasted and adhered

masonry and curtain wall façade





east elevation



south elevation

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B	structure	F	
C	I & e	G	
D	mechanical	H	

existing conditions
STRUCTURE

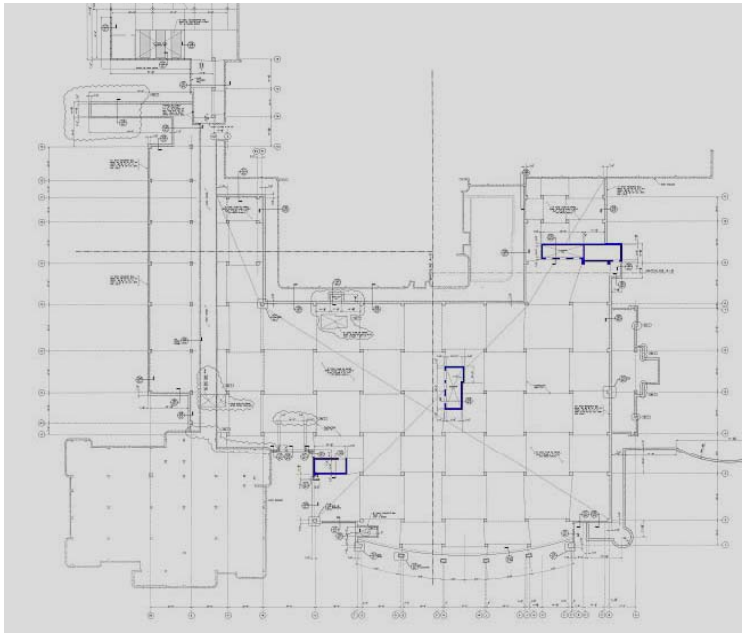
combination of concrete moment frame and shear walls

spread footing foundations >10’ below grade

(100) 24” x 24” columns

typical bay is 27’ x 27’

two way flat slab



ground floor plan

existing conditions

LIGHTING AND ELECTRICAL

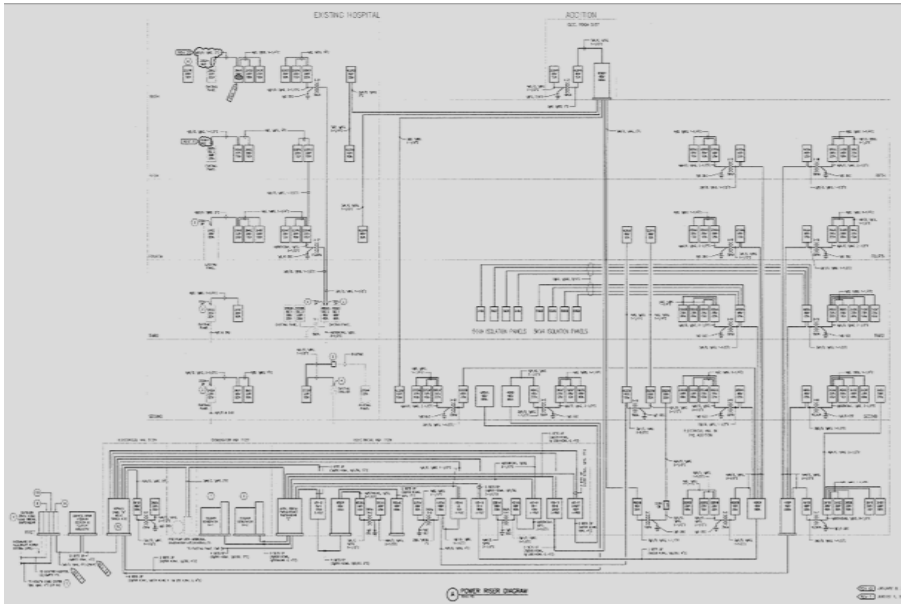
utilizes 480/277V 3Φ 4 wire and 208/120V 3Φ 4 wire system

all mechanical and medical equipment linked to 480/277V

lighting fixtures linked to 208/120V with electronic type ballasts at 95% PF

time switches provided for all exterior lighting

two 1500kW diesel engine generators



power riser diagram

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existing conditions

MECHANICAL

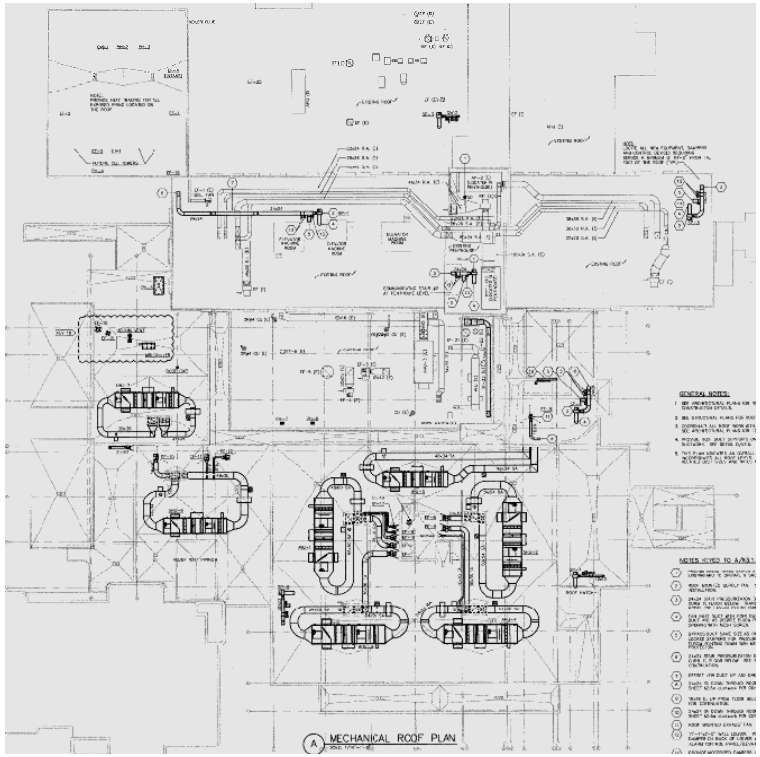
seven rooftop VAV-AHU

water-cooled chiller, cooling tower, and steam boiler are also located on the rooftop

hot and cold water provided to all toilets, examination and operation rooms, and kitchen

electrical duct heating provided in all rooms and hallways

mechanical systems connected to generators



mechanical roof plan

existing conditions
CONSTRUCTION

december 2005 – july 2008

design-build

guaranteed maximum price set at $68,000,000 by the Turner Construction Company

ground broken with 70% completion of construction documents

source: turner construction company

depth

BLAST AND PROGRESSIVE COLLAPSE ANALYSIS

to incorporate blast and collapse resistant design to mitigate catastrophic scenarios in the event of a terrorist attack

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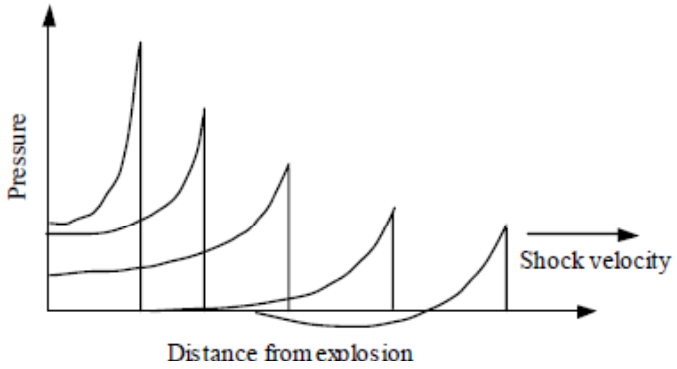
depth

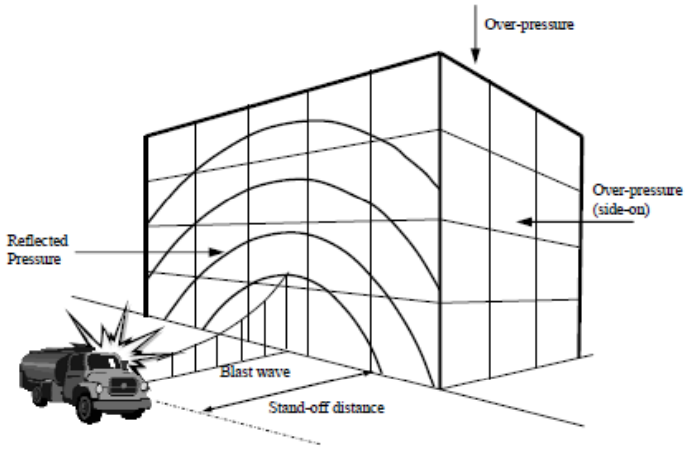
BLAST ANALYSIS

blast loads are directly proportional to the stress wave propagation resulting in a dynamic loading situation on the structure

open-air and confined blast

building is engulfed by the shockwave, creates complex loading pattern around the structure





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B	collapse	F	
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D	indirect	H	

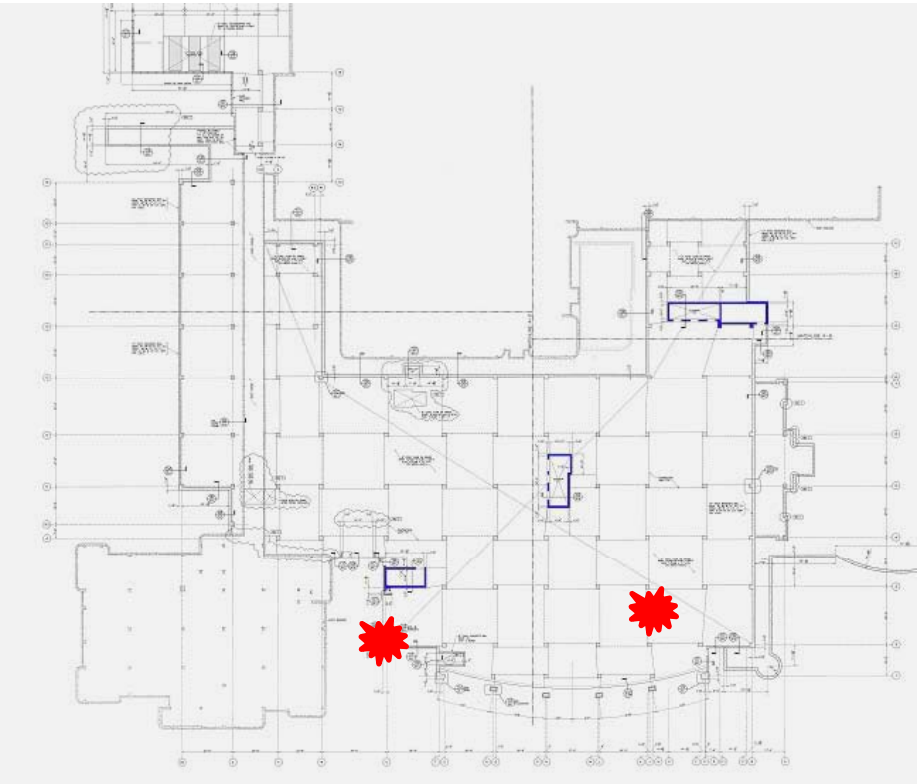
depth

BLAST ANALYSIS

confined blasts are extremely hard to analyze – fluid dynamics and solid dynamics

blast is assumed to have eliminated a column

open-air blast will be analyzed in the breadth section

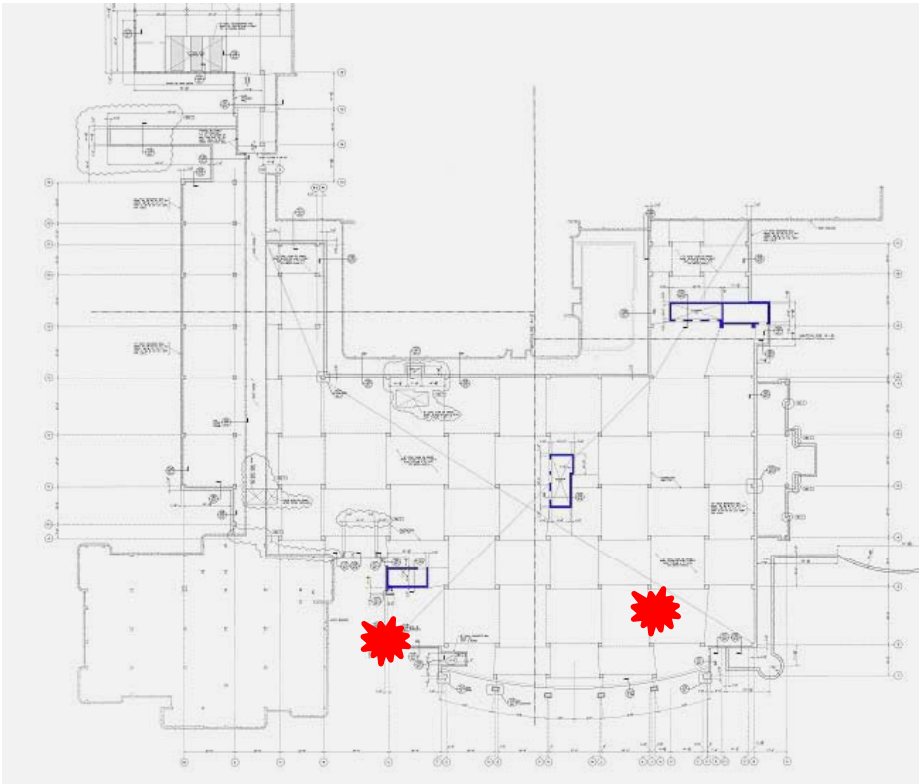


depth

PROGRESSIVE COLLAPSE ANALYSIS

collapse is caused by “the spread of an initial local failure from element to element, eventually resulting in the collapse of an entire structure or a disproportionately large part of it.”

blast is assumed to have eliminated a column, triggering a collapse scenario



depth
DESIGN

assumed to be a medium level of protection building

two methods used for design
- -indirect design method
- -direct design method, alternate path

indirect design to determine required steel reinforcement

direct design to determine new floor design

designs compared for effectiveness (also discussed in breadth)

depth

INDIRECT DESIGN

indirect design yielded the following results:

Tie	*Tie Force (kips)*	$As_{REQ'D}$ (in^2)	$As_{PROV'D}$ (in^2)
Peripheral	9.9	0.176	0.93
Internal (E-W)	6.02 $/ft_{width}$	0.107 $/ft_{width}$	1.607 $/ft_{width}$
Internal (N-S)	5.31 $/ft_{width}$	0.0945 $/ft_{width}$	0.408 $/ft_{width}$
Horizontal	14.8	0.263 $/ft_{width}$	0.33 $/ft_{width}$
Vertical	123.3	2.19	6
Corner Column	121.3	2.16	6

existing design is adequate, but new detailing is required…

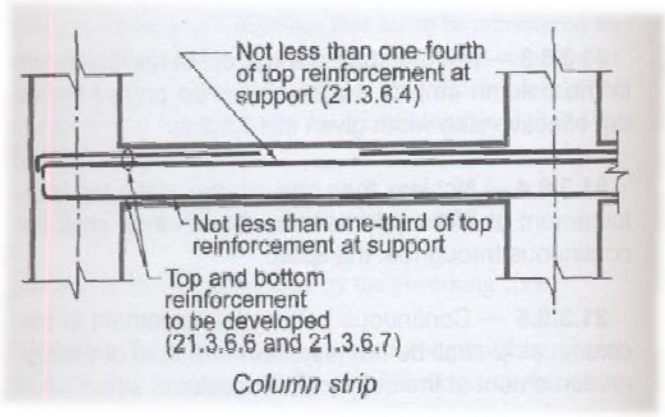
depth

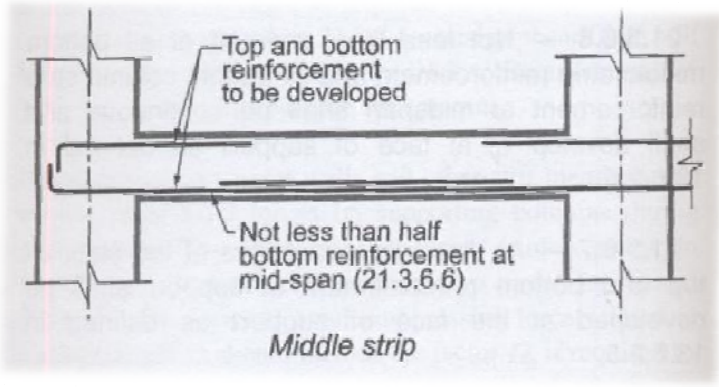
INDIRECT DESIGN

additional detailing is required…

per UFC 4-023-03, reinforcements must be continuous

research by Corey, Hayes, Mehrdad, and Serkan: “seismic detailing can be compatible with collapse mitigation”





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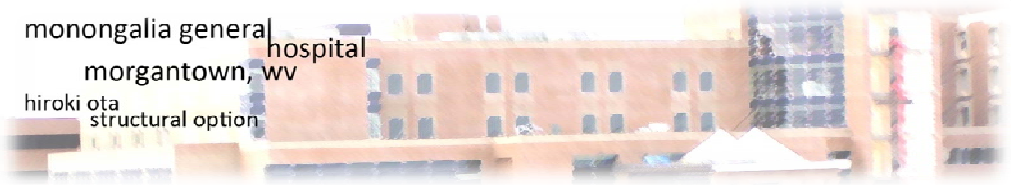


depth

INDIRECT DESIGN

additional detailing is required…

use of type 2 mechanical splices at third points of floor height

use of type 2 mechanical splices to maintain continuity on horizontal members

use of 135 degree seismic hooks at horizontal and vertical ties

depth

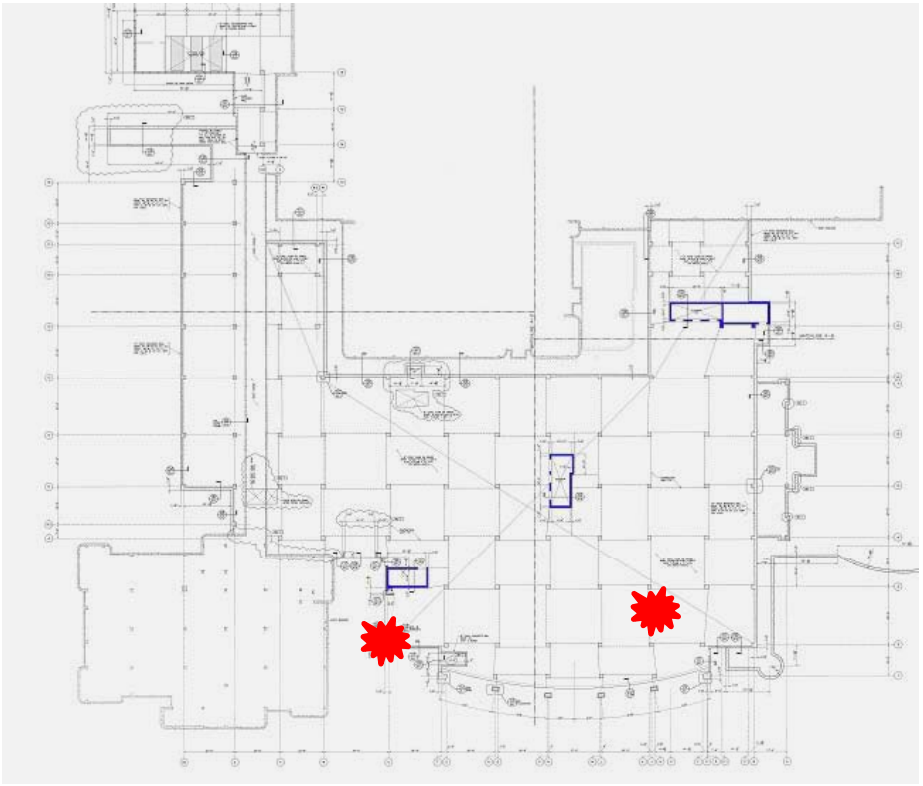
DIRECT DESIGN

two locations analyzed

- column in the lobby removed, 54’ span
- corner column removed, 30’-4” cantilever situation

existing slab analyzed

post-tensioned slab designed



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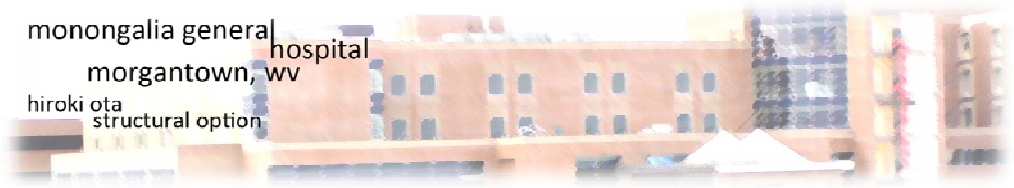

depth

DIRECT DESIGN

first location, 54’ span – two way slab design:

t = 8”	f’c = 5000 psi			
	Frame A		*Frame B*	
	M^+	M^-	M^+	M^-
Column Strip	(19) #5	(33) #5	(18) #5	(33) #5
Middle Strip	(25) #5	(57) #5	(10) #5	(25) #5

first location, 54’ span – post-tensioned slab design:

t = 10”	f’c = 5000 psi	f’ci = 3000 psi	fpu = 270 ksi
	Reinforcement	*Tendons*	
	#10 @ 12” o.c.	(39) ½” Φ 7 wire	

depth

DIRECT DESIGN

second location, 30'-4" cantilever – two way slab design:

t = 8"	f'c = 5000 psi				
	Frame C			*Frame D*	
	M^-_{EXT}	M^+_{INT}	M^-_{INT}	M^-_{EXT}	M^+_{INT}	M^-_{INT}
Column Strip	(32) #5	(50) #5	(61) #5	(31) #5	(31) #5	(20) #5
Middle Strip	(10) #5	(13) #5	(27) #5	(23) #5	(27) #5	(16) #5

second location, 30'-4" cantilever – post-tensioned slab design:

t = 10"	f'c = 5000 psi	f'ci = 3000 psi	fpu = 270 ksi
	Reinforcement	*Tendons*	
	N/A	(30) ½" Φ 7 wire	

breadth
COST ANALYSIS

the indirect and direct designs will be further analyzed for cost

extra 30 tons due to detailing changes

Existing Conditions: Elevated Slab					
	Quantity	*Unit Cost*	*Labor Cost*	*Equipment Cost*	*Total Cost*
5000 psi Concrete	5290.89 yd^3	111.00			$587,285.46
Placement	5290.89 yd^3		13.55	4.94	$97,828.00
Reinforcing Steel	1230 tons	990.00	475.00		$1,801,950.00
Formwork	49689 ft^2	1.55	3.43		$247,451.22
Slab Finishing	198755 ft^2		0.68		$135,153.40
				Total	$2,869,668.08
Redesigned Conditions: Elevated Slab (Indirect Design)					
	Quantity	*Unit Cost*	*Labor Cost*	*Equipment Cost*	*Total Cost*
5000 psi Concrete	5290.89 yd^3	111.00			$587,285.46
Placement	5290.89 yd^3		13.55	4.94	$97,828.00
Reinforcing Steel	1260 tons	990.00	475.00		$1,845,900.00
Formwork	49689 ft^2	1.55	3.43		$247,451.22
Slab Finishing	198755 ft^2		0.68		$135,153.40
				Total	$2,928,268.08
				Difference: Redesign - Existing	$43,950.00

breadth
COST ANALYSIS

Existing Conditions: Elevated Slab					
	Quantity	*Unit Cost*	*Labor Cost*	*Equipment Cost*	*Total Cost*
5000 psi Concrete	5290.89 yd^3	111.00			$587,285.46
Placement	5290.89 yd^3		13.55	4.94	$97,828.00
Reinforcing Steel	1230 tons	990.00	475.00		$1,801,950.00
Formwork	49689 ft^2	1.55	3.43		$247,451.22
Slab Finishing	198755 ft^2		0.68		$135,153.40
				Total	$2,869,668.08
Existing Conditions: Elevated Slab (8" Thick) After Redesign (Direct Design)					
	Quantity	*Unit Cost*	*Labor Cost*	*Equipment Cost*	*Total Cost*
5000 psi Concrete	5290.89 yd^3	111.00			$587,285.46
Placement	5290.89 yd^3		13.55	4.94	$97,828.00
Reinforcing Steel	5500 tons	990.00	475.00		$8,057,500.00
Formwork	49689 ft^2	1.55	3.43		$247,451.22
Slab Finishing	198755 ft^2		0.68		$135,153.40
				Total	$9,125,218.08
				Difference: Redesign - Existing	$6,255,550.00

two-way slab by direct design hikes the reinforcing steel cost

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breadth
COST ANALYSIS

post-tensioned slab increases the cost

Existing Conditions: Elevated Slab					
	Quantity	*Unit Cost*	*Labor Cost*	*Equipment Cost*	*Total Cost*
5000 psi Concrete	5290.89 yd^3	111.00			$587,285.46
Placement	5290.89 yd^3		13.55	4.94	$97,828.00
Reinforcing Steel	1230 tons	990.00	475.00		$1,801,950.00
Formwork	49689 ft^2	1.55	3.43		$247,451.22
Slab Finishing	198755 ft^2		0.68		$135,153.40
				Total	$2,869,668.08
Redesigned Conditions: PT Slab (Direct Design)					
	Quantity	*Unit Cost*	*Labor Cost*	*Equipment Cost*	*Total Cost*
5000 psi Concrete	6613.62 yd^3	111.00			$587,285.46
Placement	6613.62 yd^3		13.55	4.94	$97,828.00
Reinforcing Steel	500 tons	990.00	475.00		$293,000.00
Prestressing Steel	600 tons	1800.00	475.00		$1,365,000.00
Formwork	62111.3 ft^2	1.55	3.43		$247,451.22
Slab Finishing	198755 ft^2		0.68		$135,153.40
				Total	$2,958,864.00
				Difference: Redesign - Existing	$89,195.95

breadth

COST ANALYSIS

comparison of two designs

Design Method	*Major Cost Contributors*	*Total Cost of Construction*	*Difference to Existing Construction*	*Impact to Overall Project Cost*
Indirect Design Method	Reinforcing Steel $1,801,950.00	$2,869,668.08	$43,950.00	+0.077%
Direct Design Method-PT-Slab	Reinforcing Steel $293,000.00 Prestressing Steel $1,365,000.00	$2,958,864.00	$89,195.95	+0.156%
	Difference	$89,195.92	$45,245.95	

both designs have minimal impact on the overall project volume

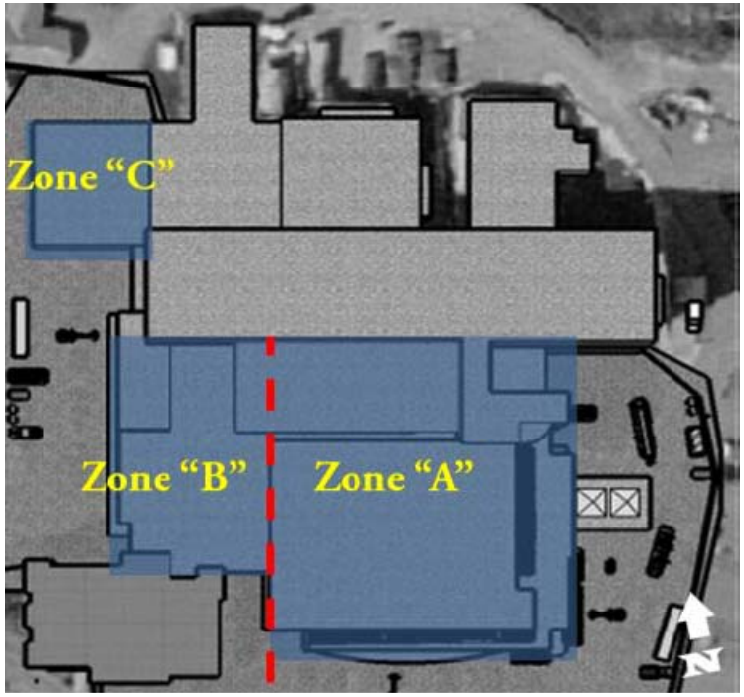
the designs' impact on the schedule will also be analyzed

breadth

SCHEDULE ANALYSIS

the schedule is broken down into three major zones

a task in one zone is completed and then the next zone's task will commence



breadth

SCHEDULE ANALYSIS

summary of schedule change

	Area A Work Days	
Original Schedule	137	
Indirect	138	-
Direct	-	165
Difference	-1	-28

	Area B Work Days	
Original Schedule	89	
Indirect	87	-
Direct	-	107
Difference	+2	-18

post-tensioned design delays the project by 46 days

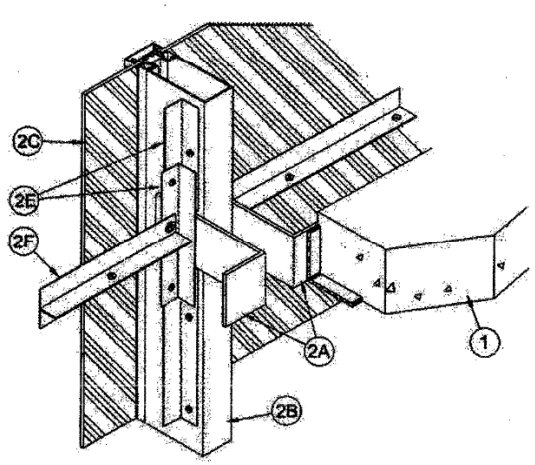
increasing the amount of reinforcement is the better choice

breadth

CURTAIN WALL DESIGN

the existing curtain wall will be analyzed against blast loads as per ASTM F 2248-03

two alternatives were also designed



breadth

CURTAIN WALL DESIGN

summary of analysis and design

Glass Type	*Load Resistance*	*Maximum Charge Capacity*
1/4” THK, Heat Strengthened, 1 Lite, Existing	98 PSF	100 lb_{TNT}
1/4” THK, Heat Strengthened, 2 Lite	195 PSF	300 lb_{TNT}
1/4” THK Fully Tempered, 1 Lite	217 PSF	400 lb_{TNT}
Demand	**98 PSF**	**100 lb_{TNT}**

thermal conductivity analysis was also conducted for these designs

breadth

CURTAIN WALL DESIGN

conductive properties of heat strengthened, 1 lite curtain wall

	Summer	*Winter*
*∑R (hr*ft²*° F/BTU)*	0.97	0.89
*U (BTU/hr*ft2*° F)*	1.03	1.13
Q (BTU/hr) per panel	275	873

conductive properties of heat strengthened, 2 lite curtain wall

	Summer	*Winter*
*∑R (hr*ft²*° F/BTU)*	1.8	2.06
*U (BTU/hr*ft2*° F)*	0.56	0.49
Q (BTU/hr) per panel	149	378

conductive properties of fully tempered, 1 lite curtain wall

	Summer	*Winter*
*∑R (hr*ft²*° F/BTU)*	4.43	4.35
*U (BTU/hr*ft2*° F)*	0.23	0.23
Q (BTU/hr) per panel	61	177

breadth

CURTAIN WALL DESIGN

cost per square foot by curtain wall construction type

Glass Type	*Cost per square foot*
1/4” THK, Heat Strengthened, 1 Lite, Existing	$5.30
1/4” THK, Heat Strengthened, 2 Lite	$10.60
1/4” THK Fully Tempered, 1 Lite	$16.95

considering the blast resistance, thermal properties, and the cost, fully tempered 1 lite construction is the best choice

conclusion

RECOMMENDATIONS

the existing structural system is more than adequate to mitigate a collapse situation

1 lite, fully tempered curtain wall will provide better thermal properties for the building as well as resist a 400 lb charge

the analysis and design conducted in this thesis is not meant to save the structure but to save lives, other precautionary measures must be taken

conclusion

CLOSING REMARKS

Thank you to

The Pennsylvania State University Architectural Engineering Department

The Turner Construction Company

My family and friends

monongalia general hospital

morgantown, wv

hiroki ota
structural option