Analysis and Design of a 3-Million-Gallon Tamuning Water Tank

Presented By:

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Sean Hipolito	Ethan Vargas

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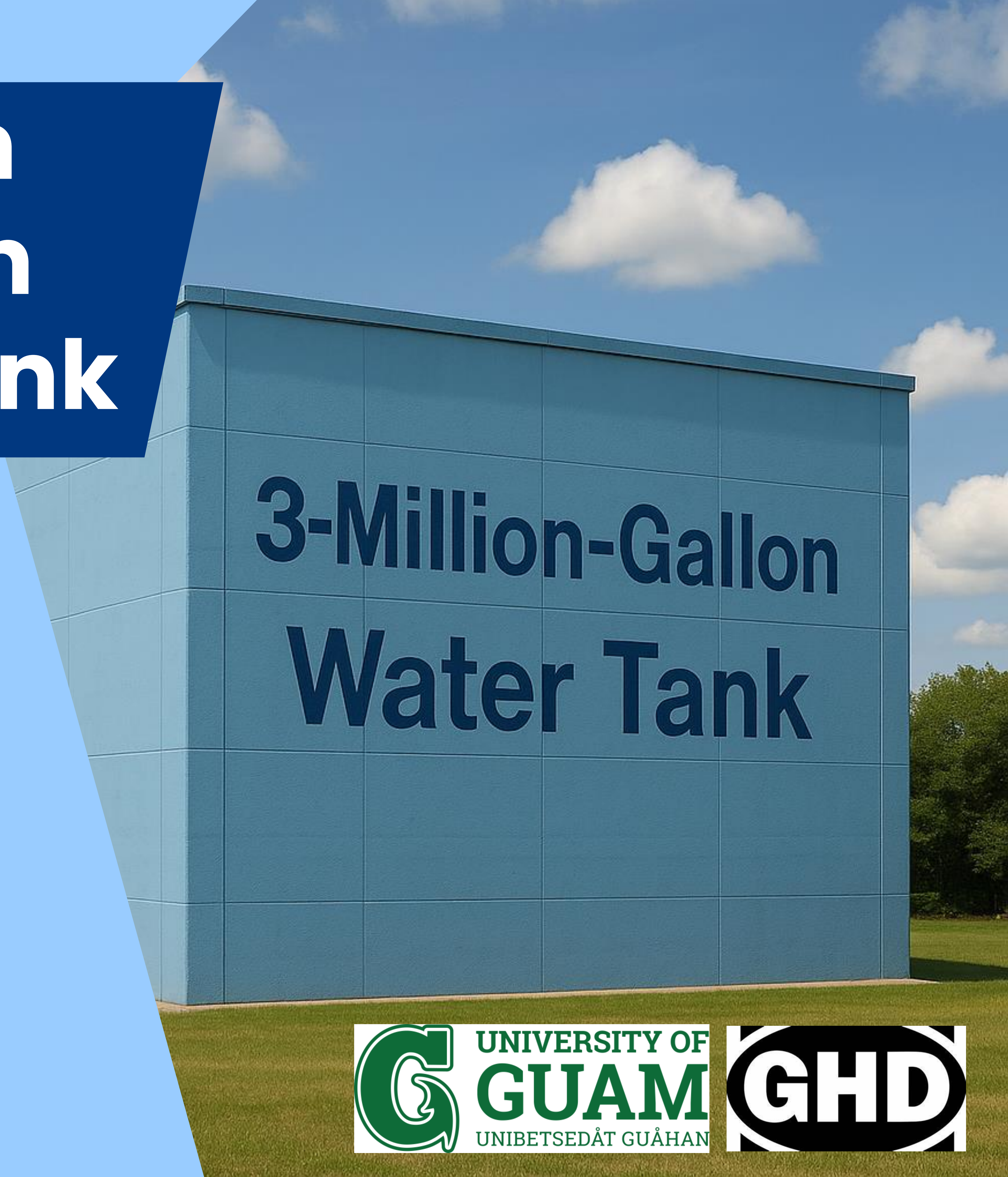


Meet the Team

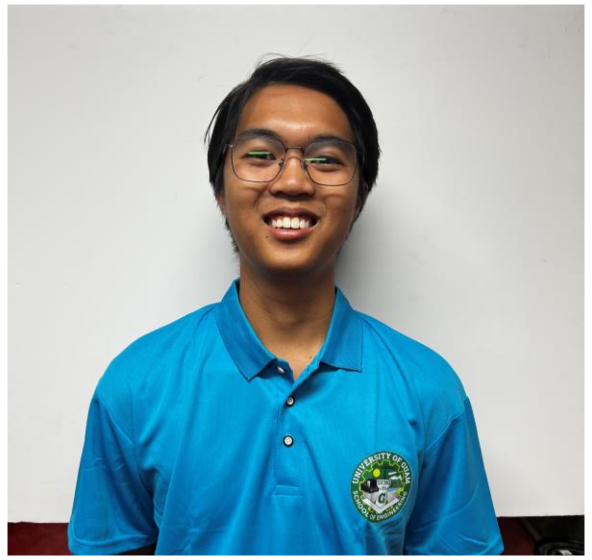
Christian Baluyut
Group Leader

Mark Carmona
Member

Sean Hipolito
Member

Daniel Mabagos
Member

Ranie Jay Ubaldo
Member



Ethan Vargas
Co-Leader

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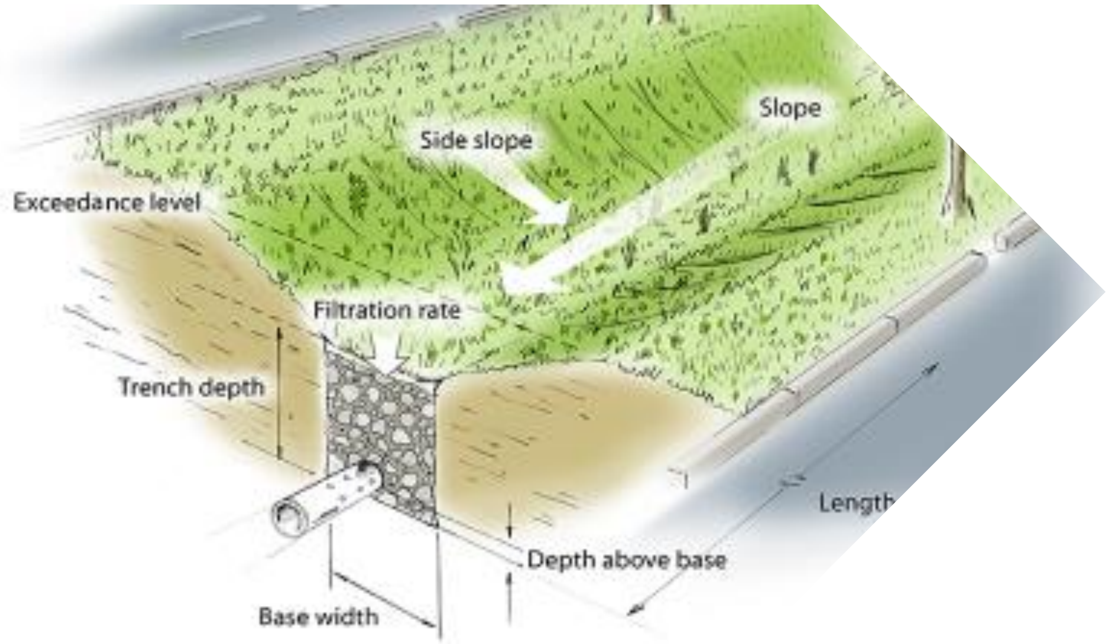
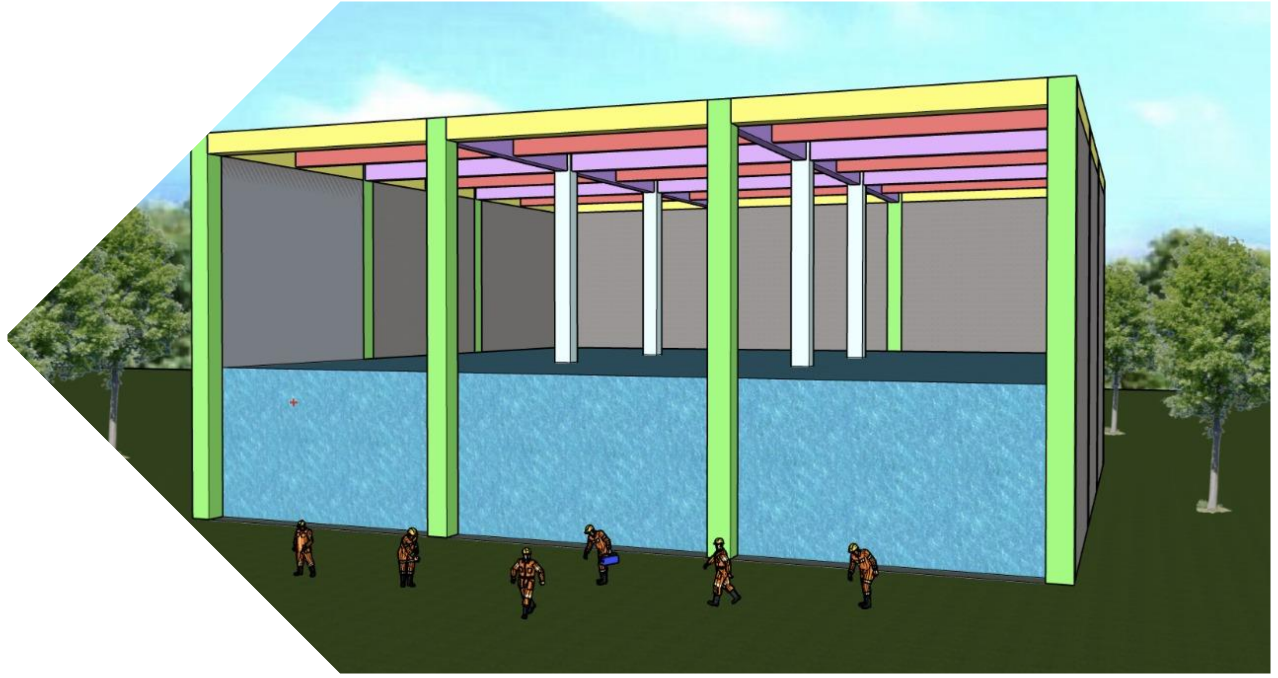




Introduction

- 1-million-gallon (MG) steel water tank
- Constructed in 1969
- Due for inspection
- Replace the existing steel water tank with a new 3 MG concrete water tank.
- Designed by GHD in 2022, the construction of a new prestressed concrete water tank is set to be completed in June 2025

Project Location

- Located in Tamuning, Guam
- Across from the Home Depot Building and near A.B. Won Pat International Airport
- Aerial view as of March 13, 2025

Problem Statement

- Design a new 3-million-gallon (MG) concrete tank.
- GHD designed a prestressed concrete water tank, but it is outside UOG SENG's curriculum
- **Capstone Project:** Create an alternative design that is within the capabilities of UOG SENG's curriculum

Consists of:

- Structural Analysis and Design
- Stormwater Analysis and Design
- Risk Analysis
- Sustainability

Objectives

Objective 1:
Structural Analysis and Design

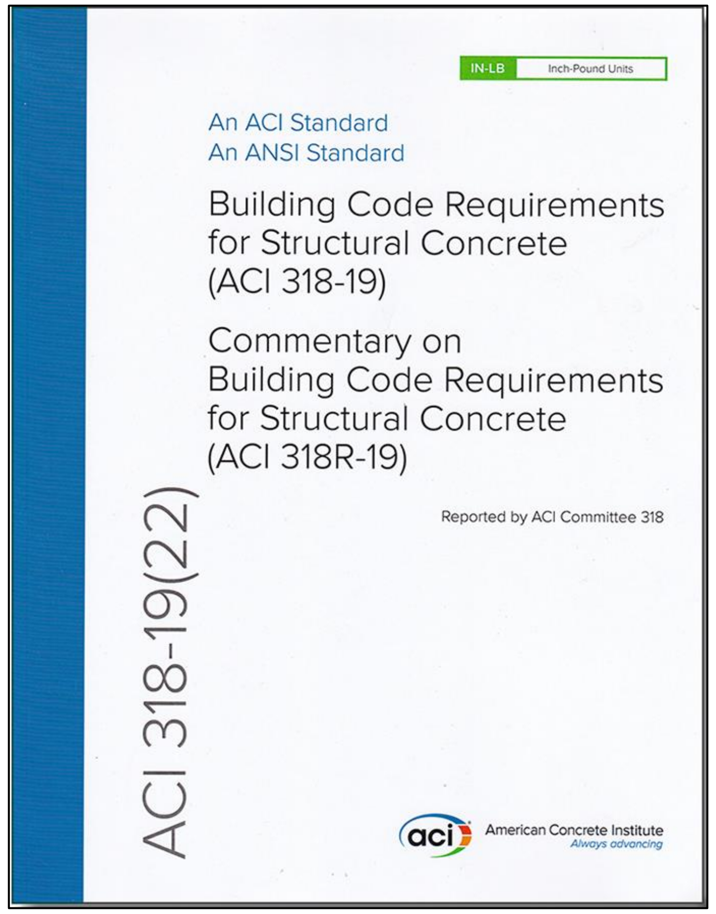
Objective 2:
Stormwater Analysis and Design

Objective 3:
Risk Analysis

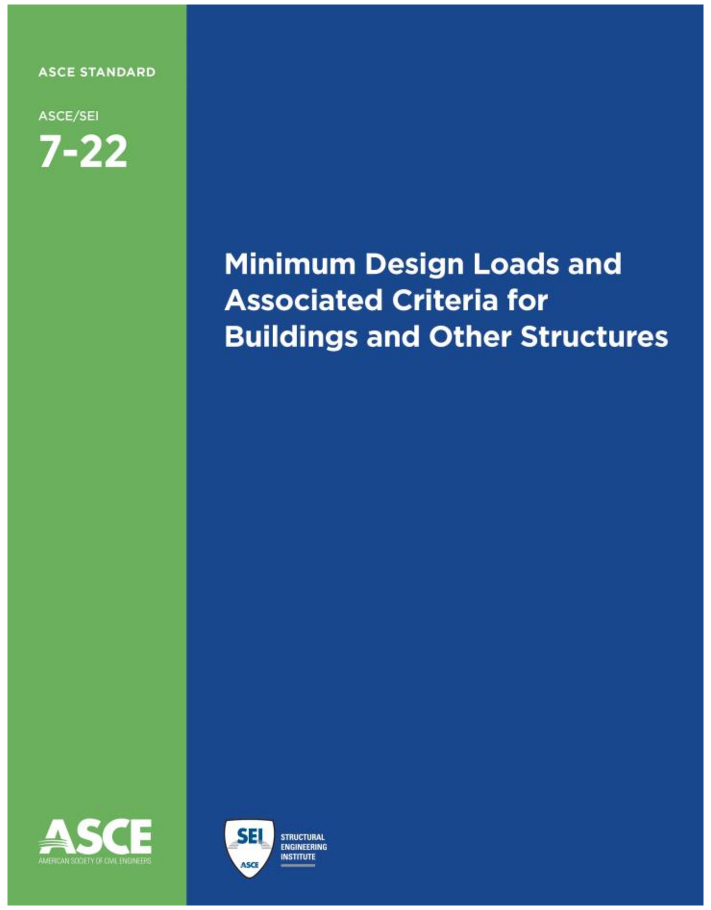
Objective 4:
Sustainability

Design Methodology

Codes and Standards

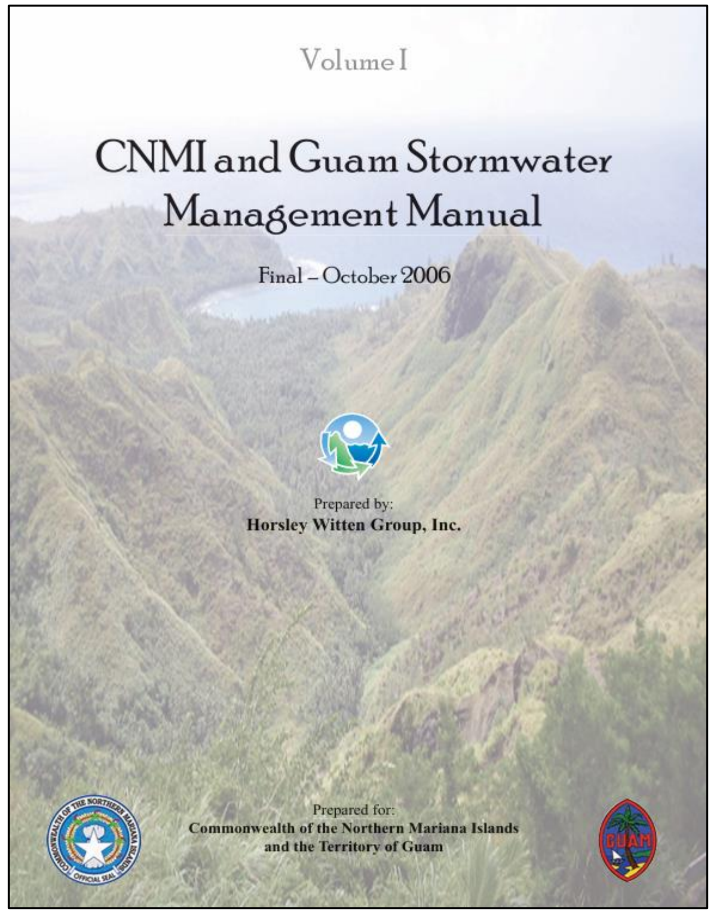


American Concrete Institute (ACI318-19)

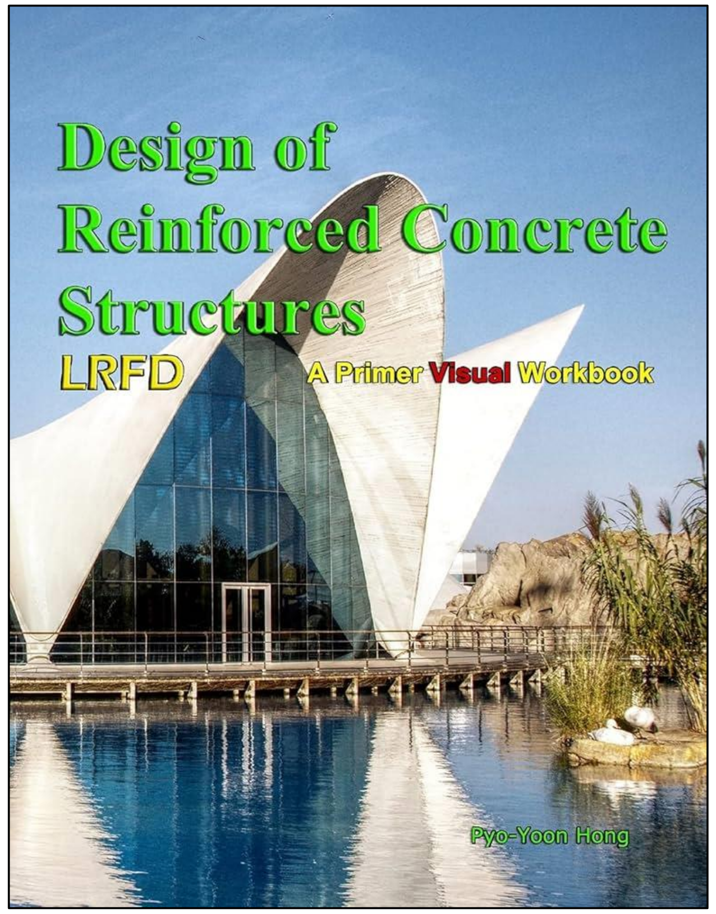


American Society of Civil Engineers (ASCE 7-22)

Other References



CNMI and Guam Stormwater Management Manual Vol 1 & 2 (2006)



Design of Reinforced Concrete Structures (2020) by Dr. Pyo-Yoon Hong

Programs

SUTStructor
ETABS
Tekla Tedds
Win TR-55

Objective 1:
Structural Analysis and Design

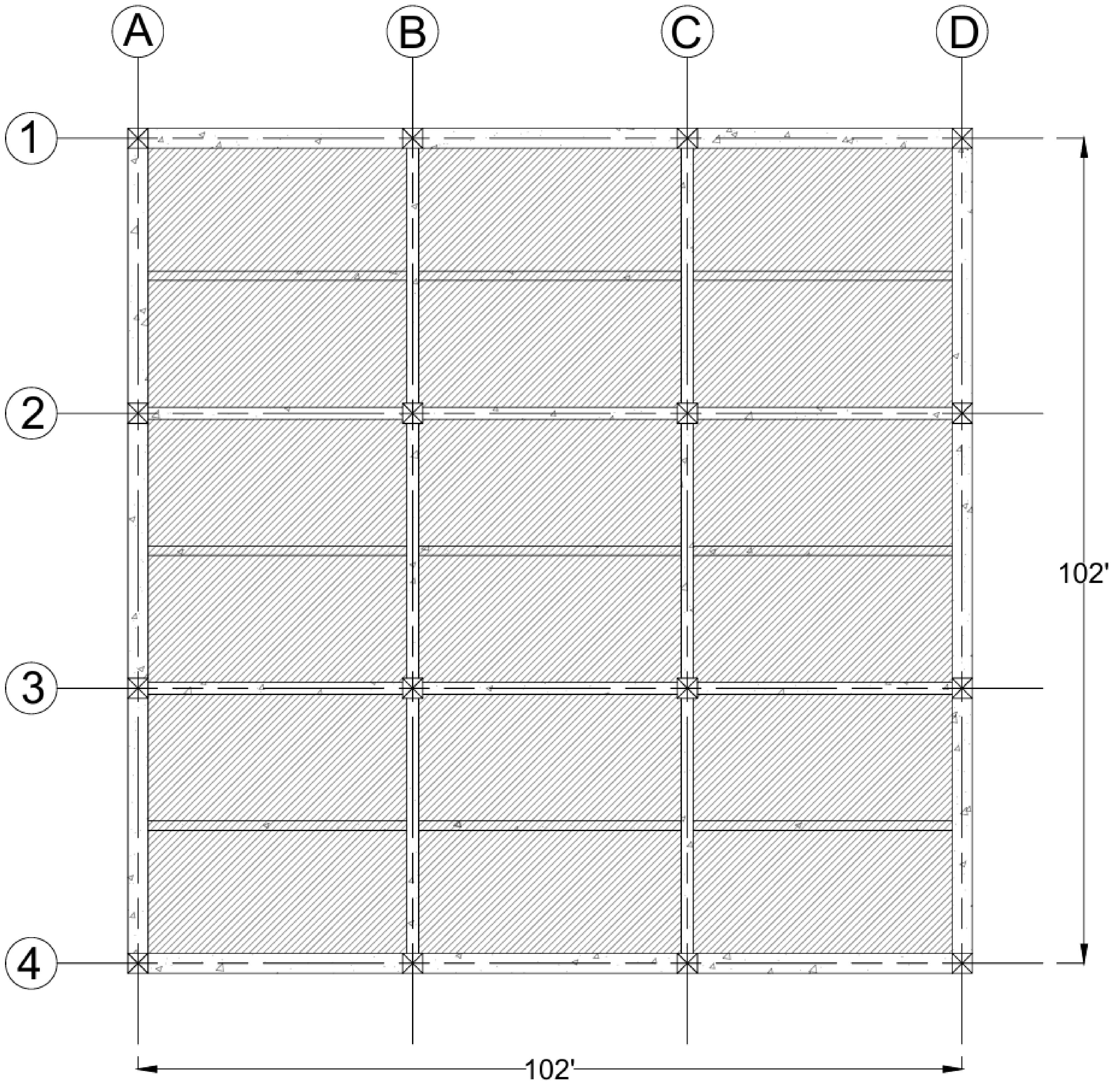
Introduction

Structural Components

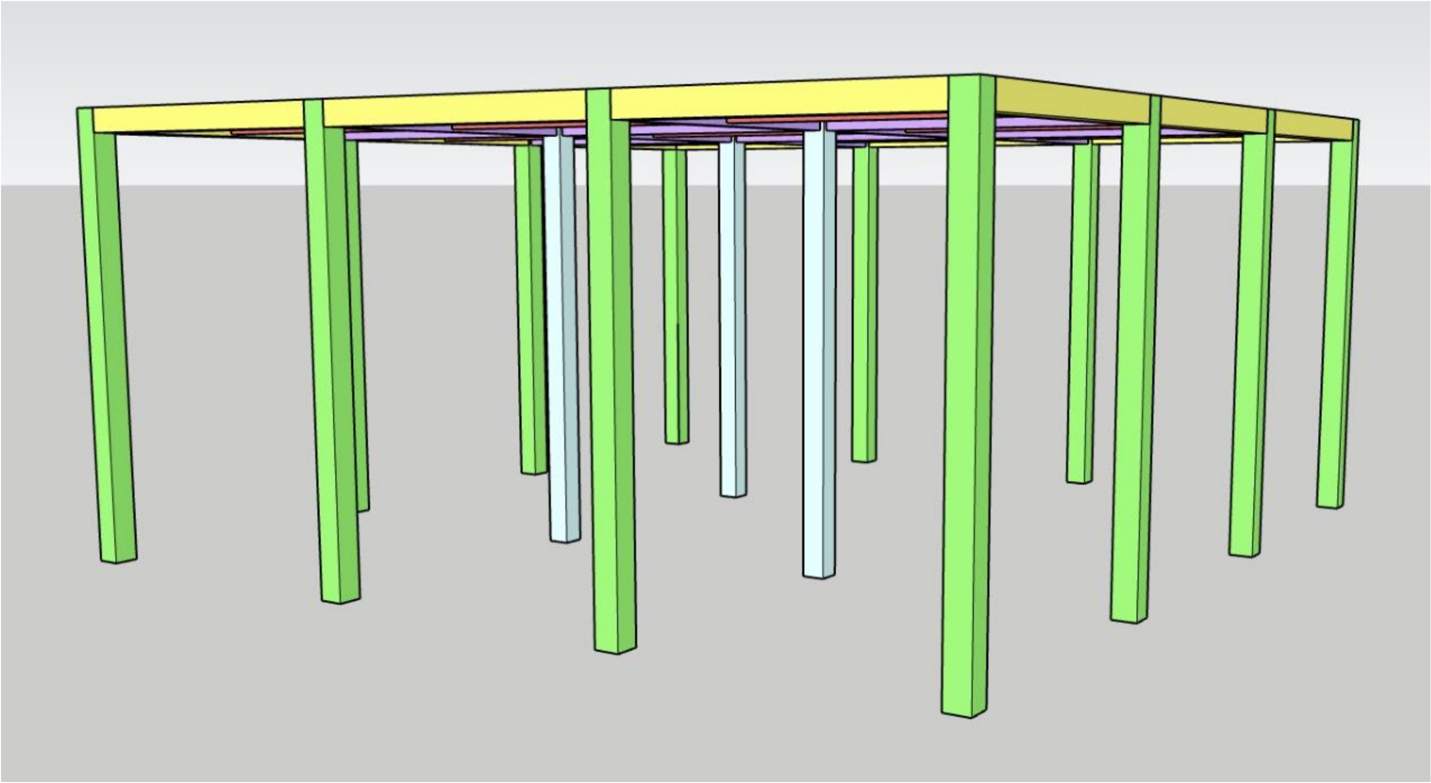
Roof Slab
Beams & Girders
Columns
Shear Walls
Isolated & Wall Footings

Modeling & Design

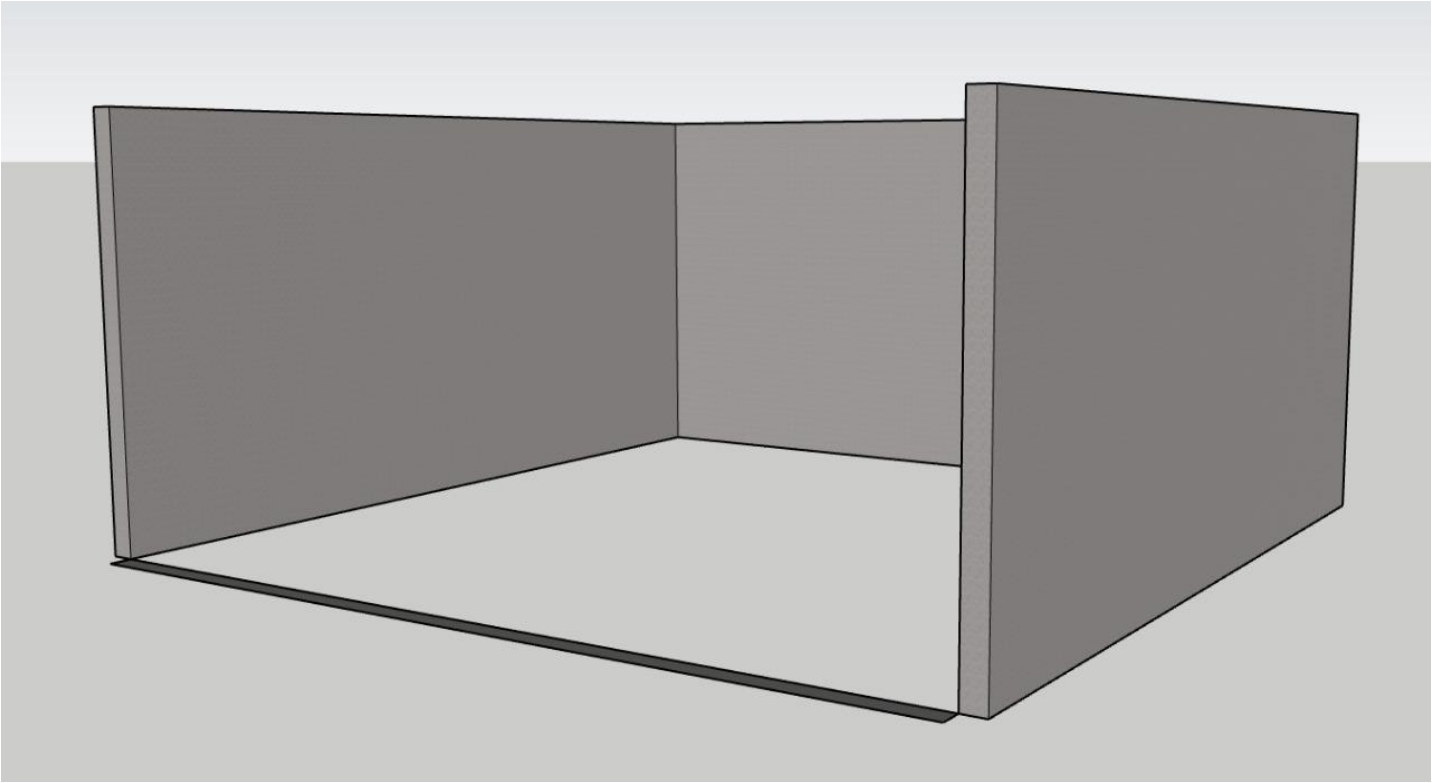
Hand Calculations & SUTStructor
Vs.
ETABS & Tekla Tedds



Structural Design Assumptions



Frame System:
Vertical Loads



Shear Wall System:
Lateral Loads

Design Limitations: Hydrodynamic loads will not be considered for our design

Load Considerations

Gravity Loads	
Dead Load	150 pcf
Superimposed Dead Load	12 psf
Roof Live Load	20 psf

Lateral Loads	
Hydrostatic Loads	62.4 pcf
Seismic Loads (Equivalent Lateral Force Method)	19,616.83 kips

Structural Analysis

Bending Moment Diagram Comparisons for Girders in Frame B

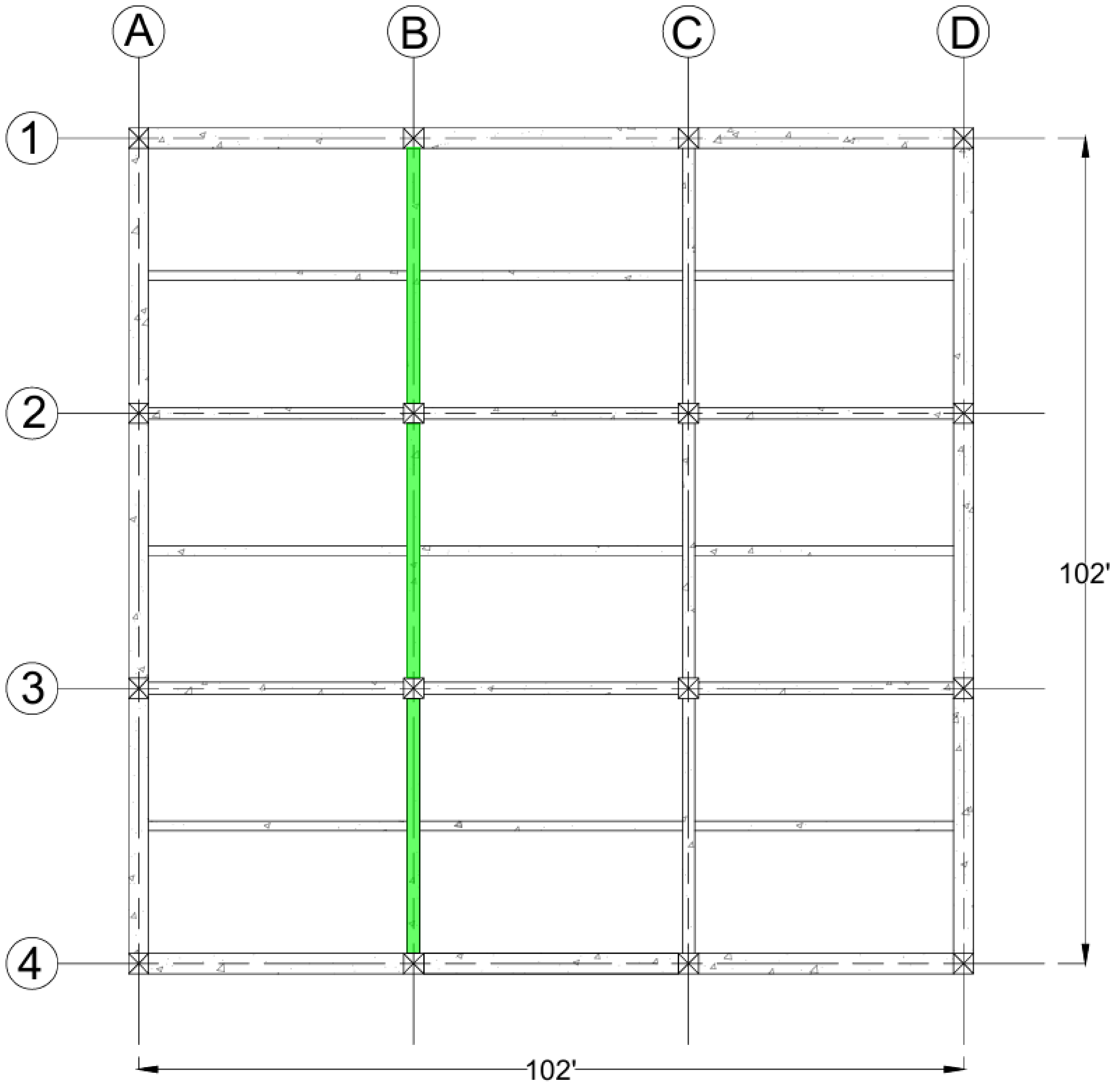
Moment Distribution Method Analysis (Hand Calculation)

vs.

SUTStructor 2D Analysis

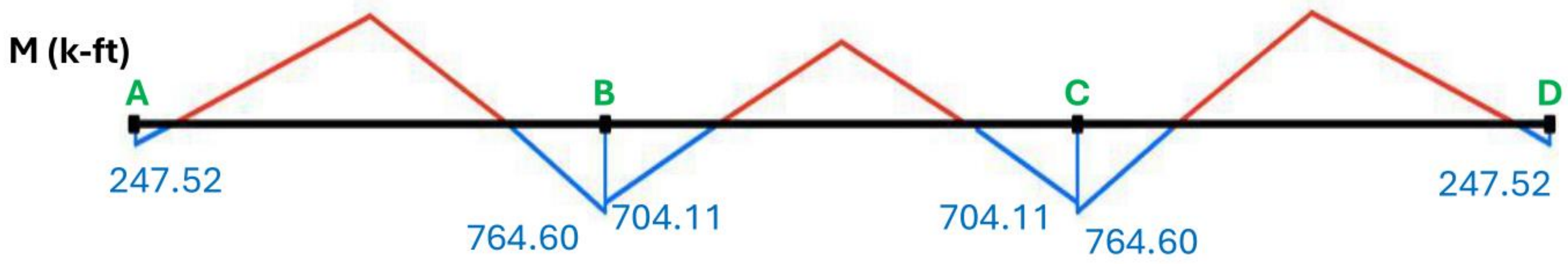
vs.

ETABS 3D Analysis

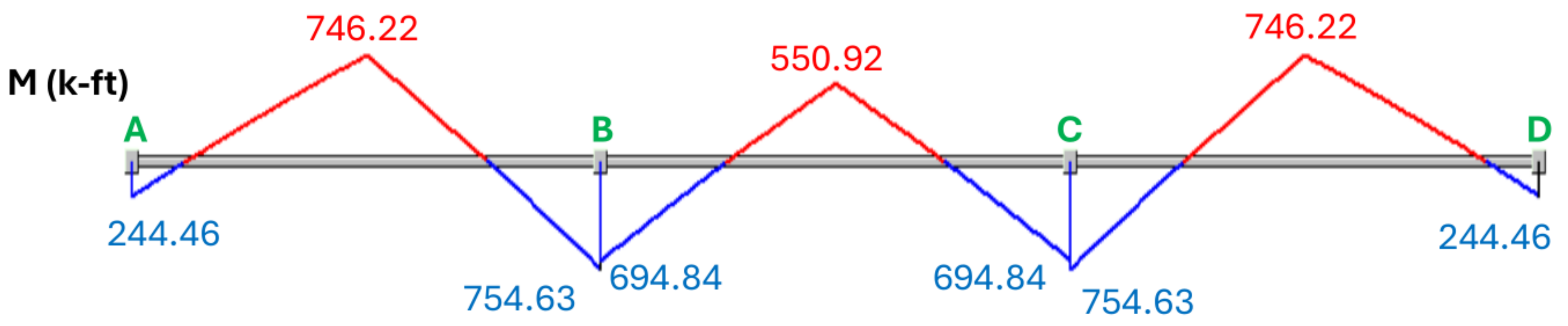


Bending Moment Diagrams for Frame B Girders

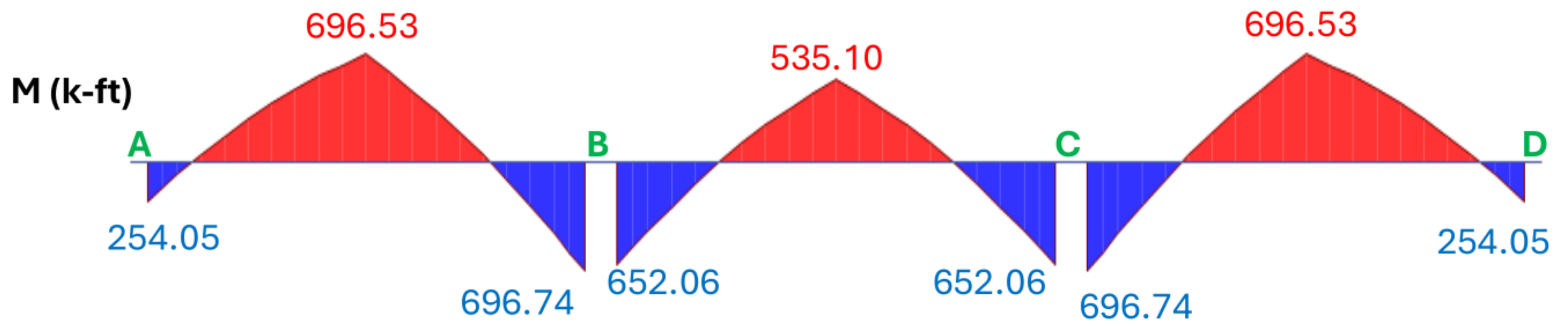
Moment Distribution Method



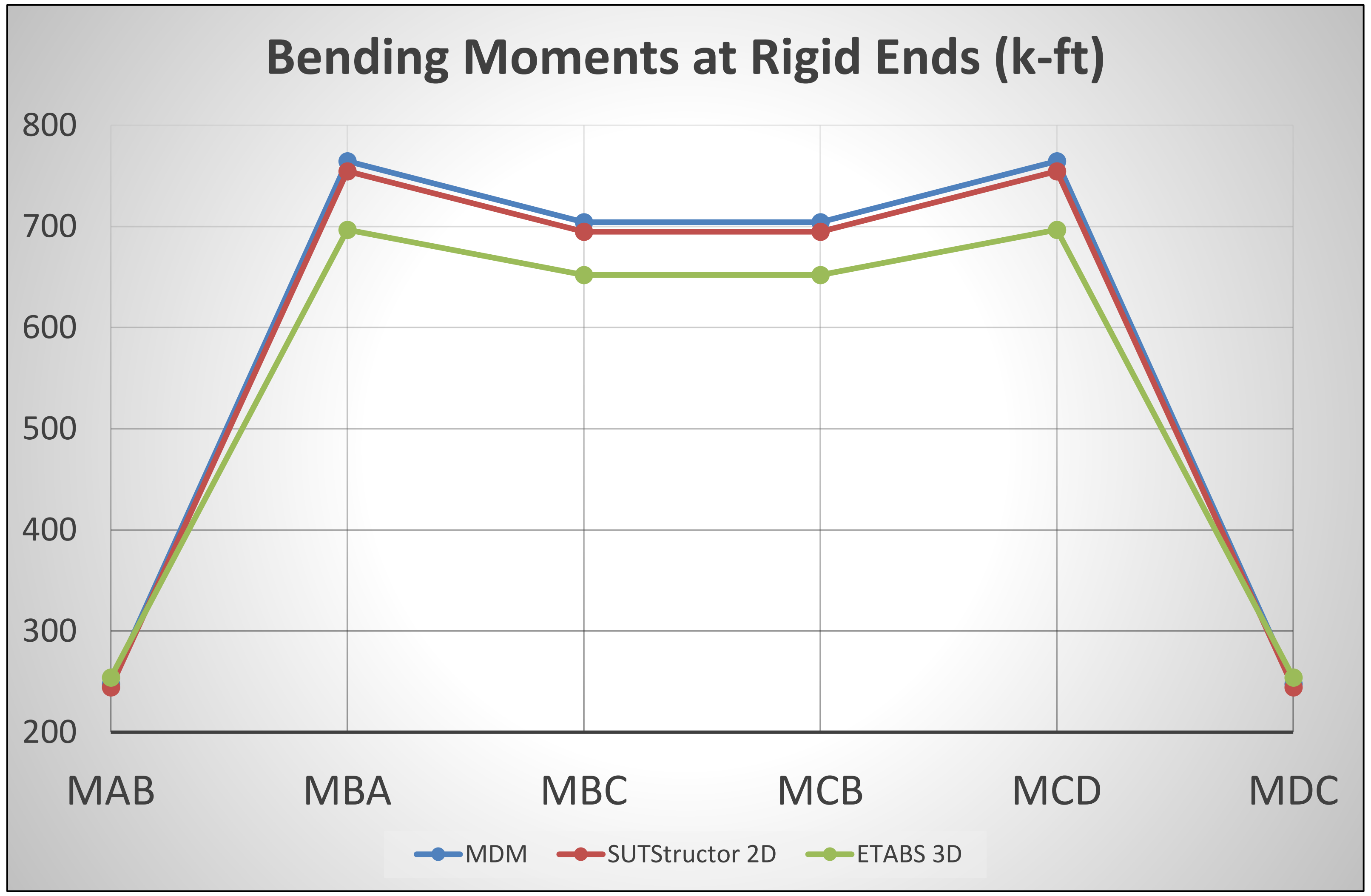
SUTStructor 2D



ETABS 3D



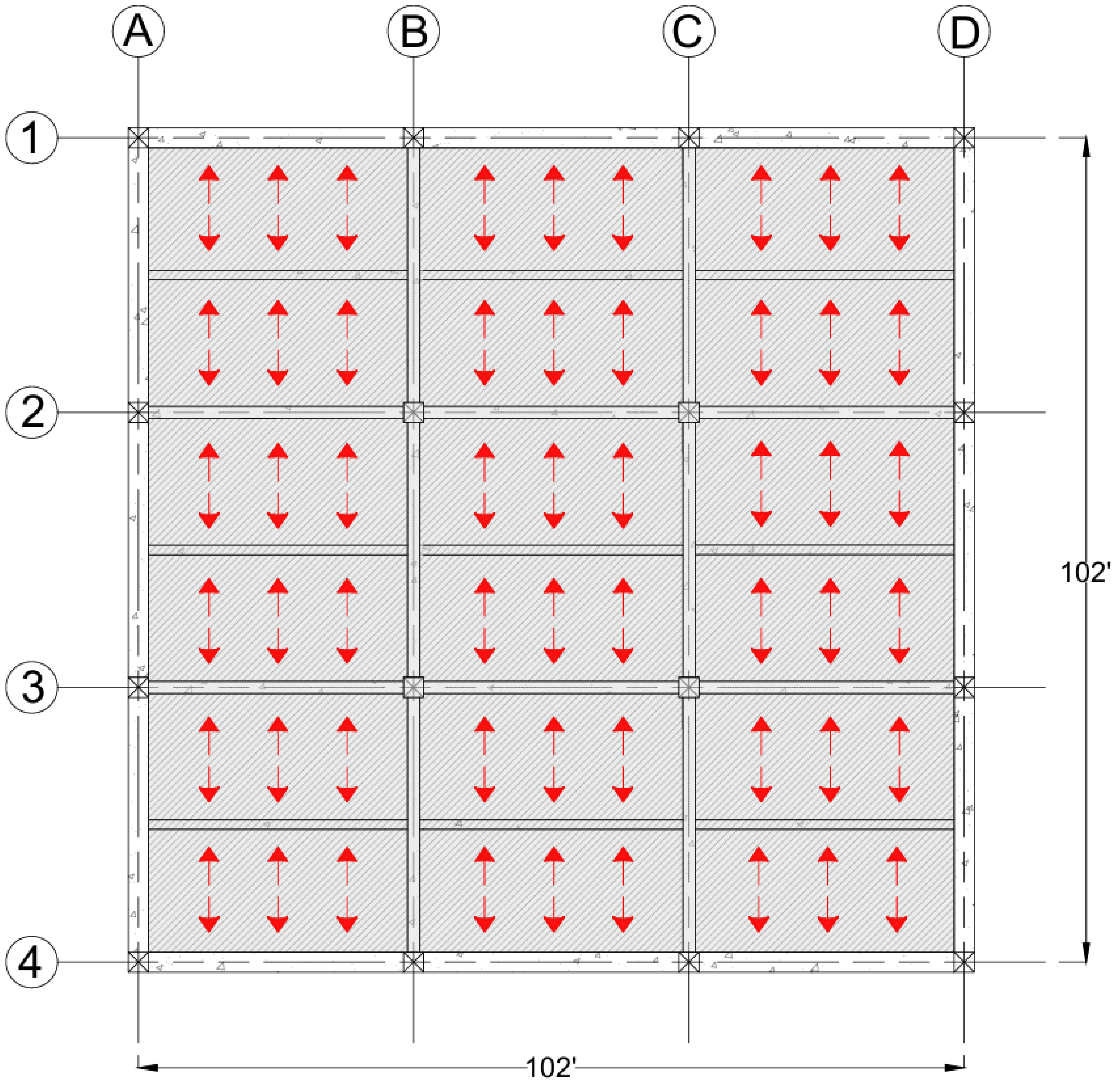
Rigid End Bending Moment Comparisons



% Difference Between MDM and Software		
Member	SUTStructor 2D	ETABS 3D
M_{AB}	1.25%	2.57%
M_{BA}	1.32%	9.74%
M_{BC}	1.33%	7.98%
M_{CB}	1.33%	7.98%
M_{CD}	1.32%	9.74%
M_{DC}	1.25%	2.57%

One-Way Roof Slab Design Parameters

One-Way Slab Design Parameters	
Yield Strength of Steel, F_y	60 ksi
Compressive Strength of Concrete, f'_c	5 ksi
Slab Span	17 ft
Support Type	Simply Supported



One-Way Roof Slab Design Process

Minimum Slab Height

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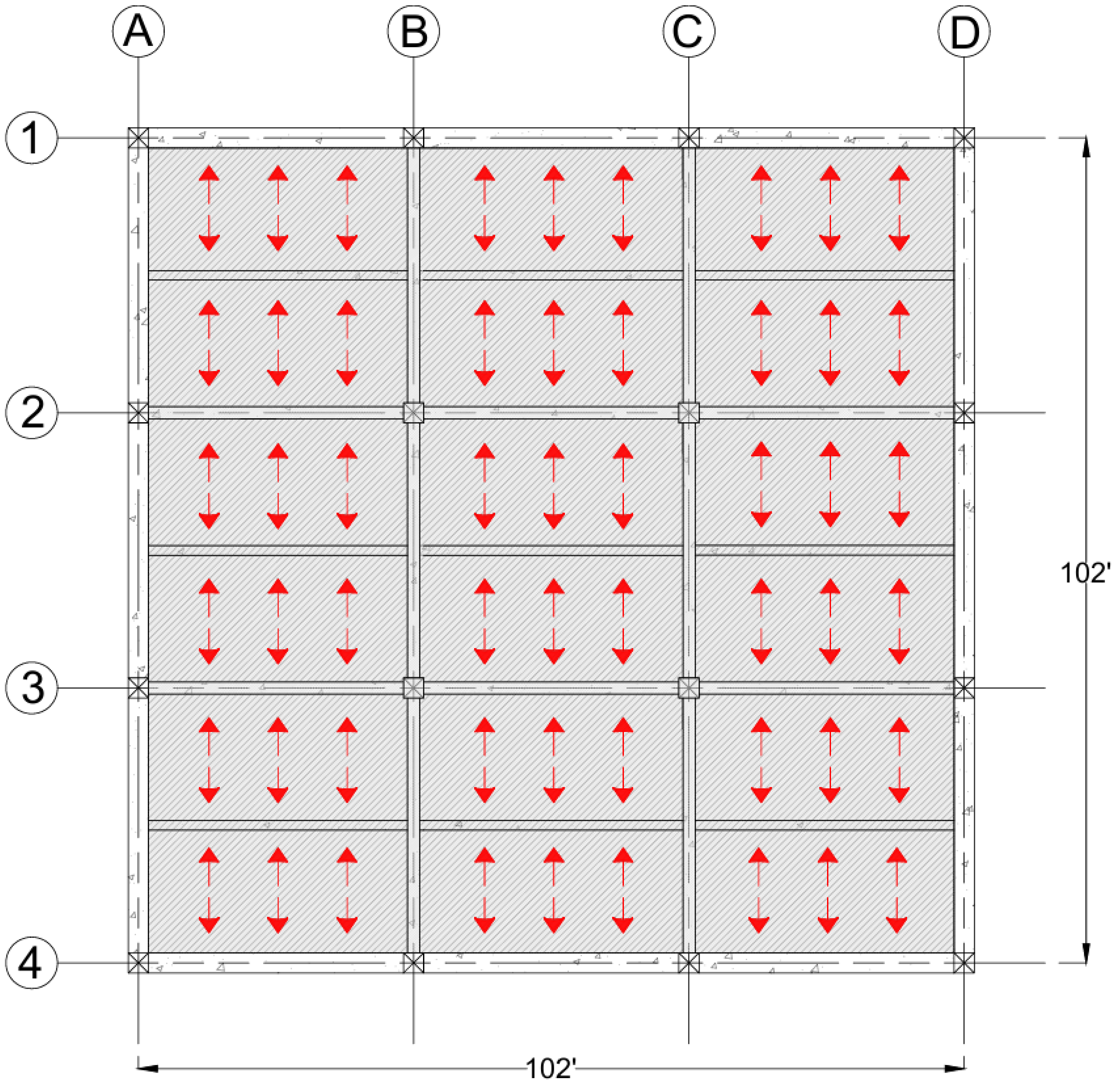
Design of Longitudinal Rebars

↓

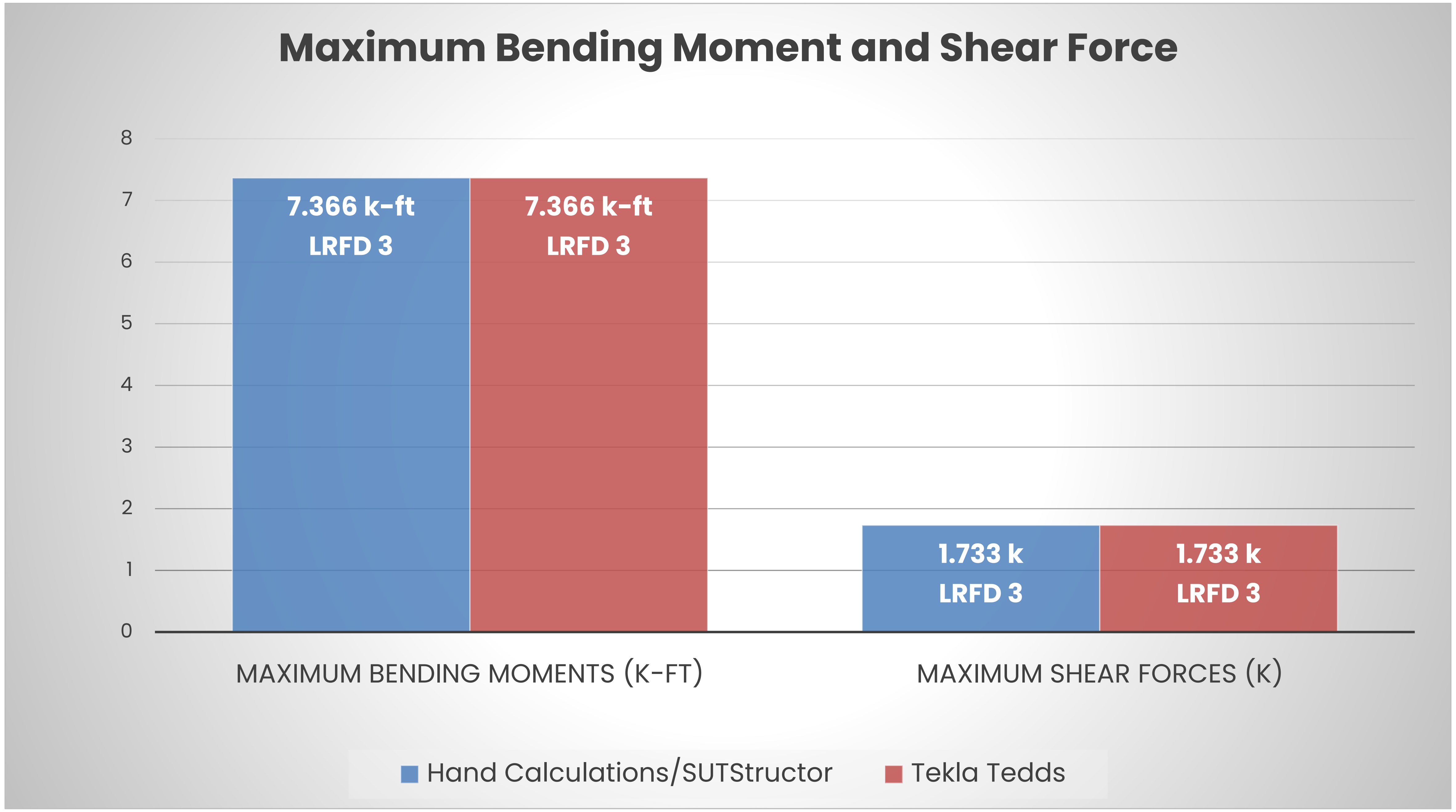
Design of Temperature Rebars

↓

Adequacy Check

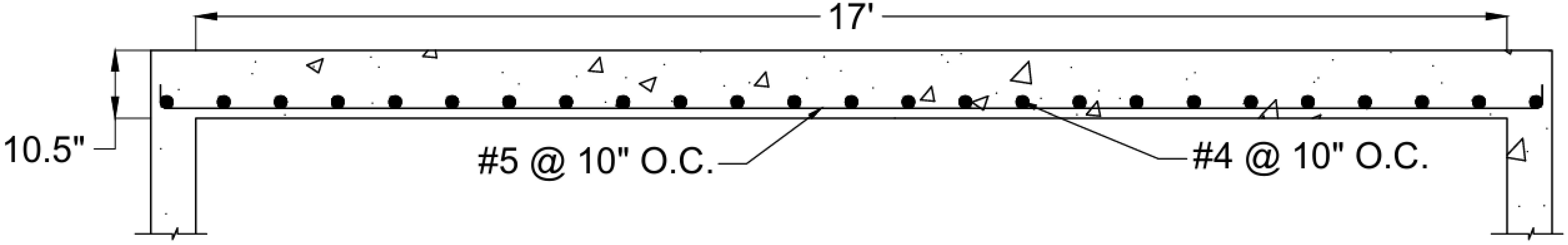


Design Forces



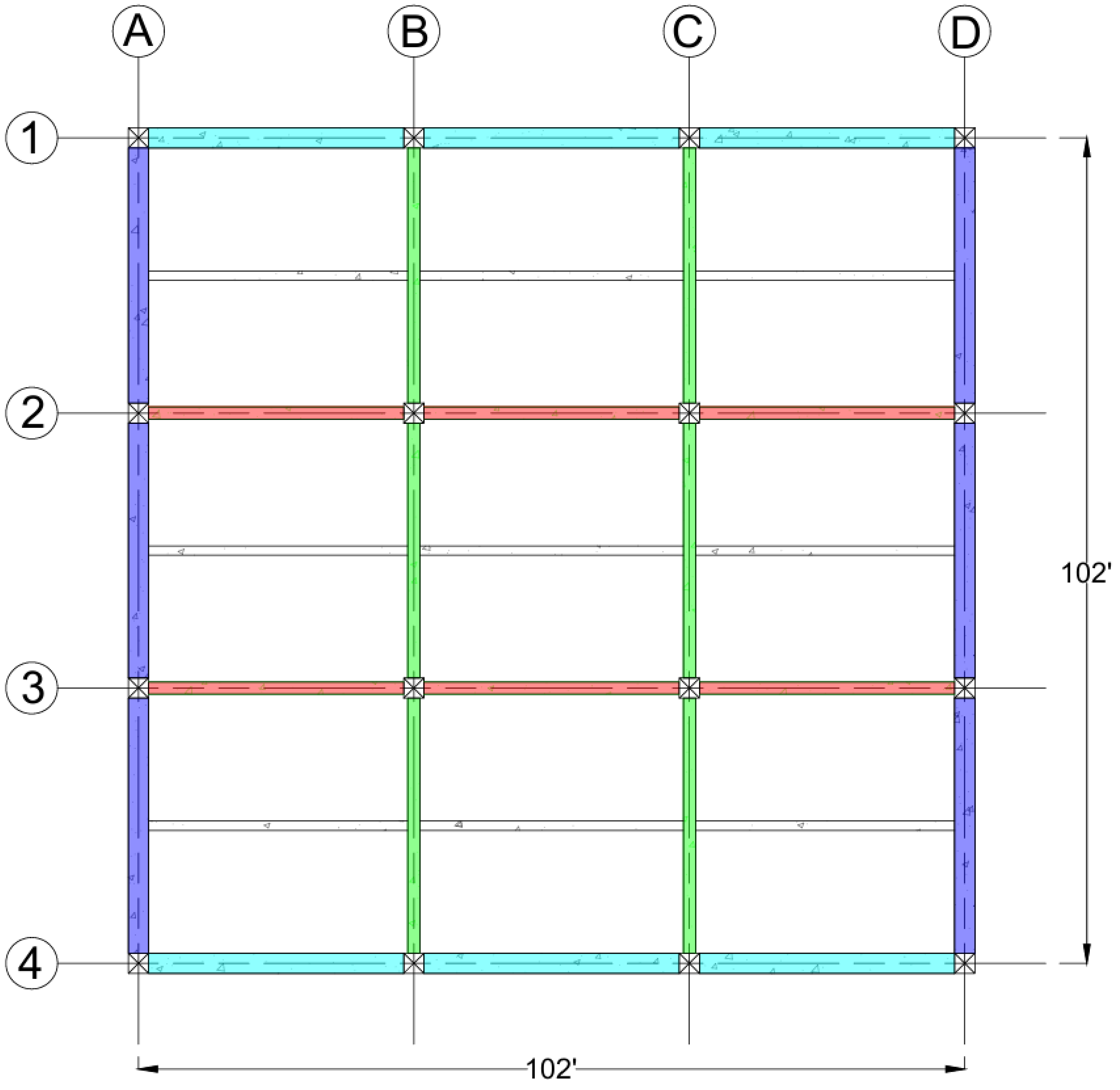
Final Design Comparison & Cross Section

Roof One-Way Slab Design Summary		
Description	Hand Calculated Design	Tekla Tedds Design
Geometry		
Slab Thickness	10.5 in	10.5 in
Flexural Design Details		
Reinforcement	#5 @ 10" O.C.	#4 @ 10" O.C.
Design Bending Moment Strength, ΦM_n	14.10 k-ft	9.13 k-ft
Demand/Capacity Ratio	0.522	0.807
Temperature Reinforcement Design Details		
Reinforcement	#4 @ 10" O.C.	#4 @ 10" O.C.
Shear Design Details		
Design Shear Strength, ΦV_n	11.06 k	5.83 k
Demand/Capacity Ratio	0.157	0.297



Beams & Girders Design Parameters

Design Parameters for Frame B & C Girders	
Yield Strength of Steel, F_y	60 ksi
Compressive Strength of Concrete, f'_c	5 ksi
Girder Span	34 ft
Tributary Width	34 ft
Support Type	Rigid-Ends



Beams & Girders Design Process

Determine Beam/Girder Dimensions

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Design of Longitudinal Rebars

↓

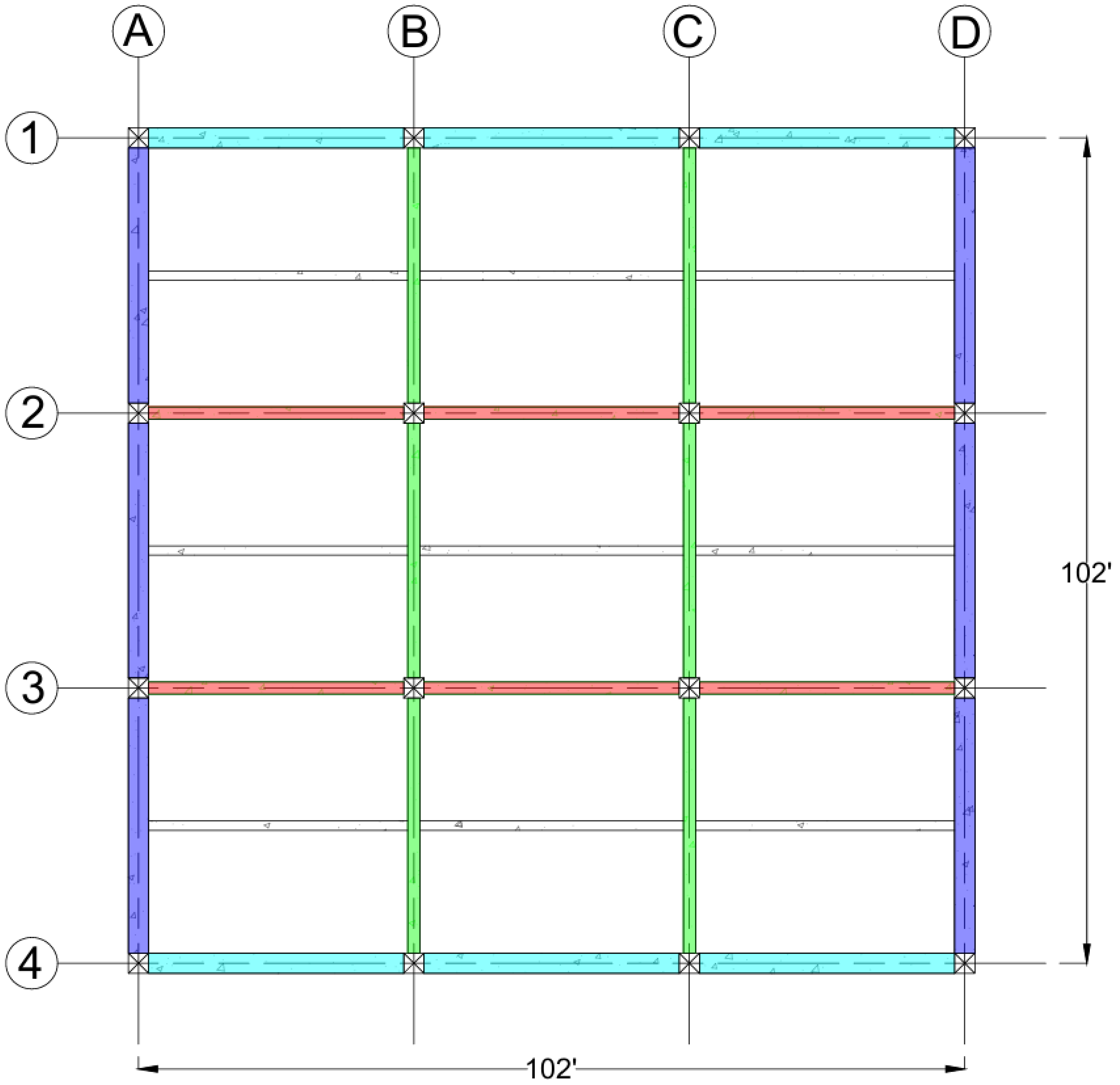
Analyze of Doubly Reinforced Section

↓

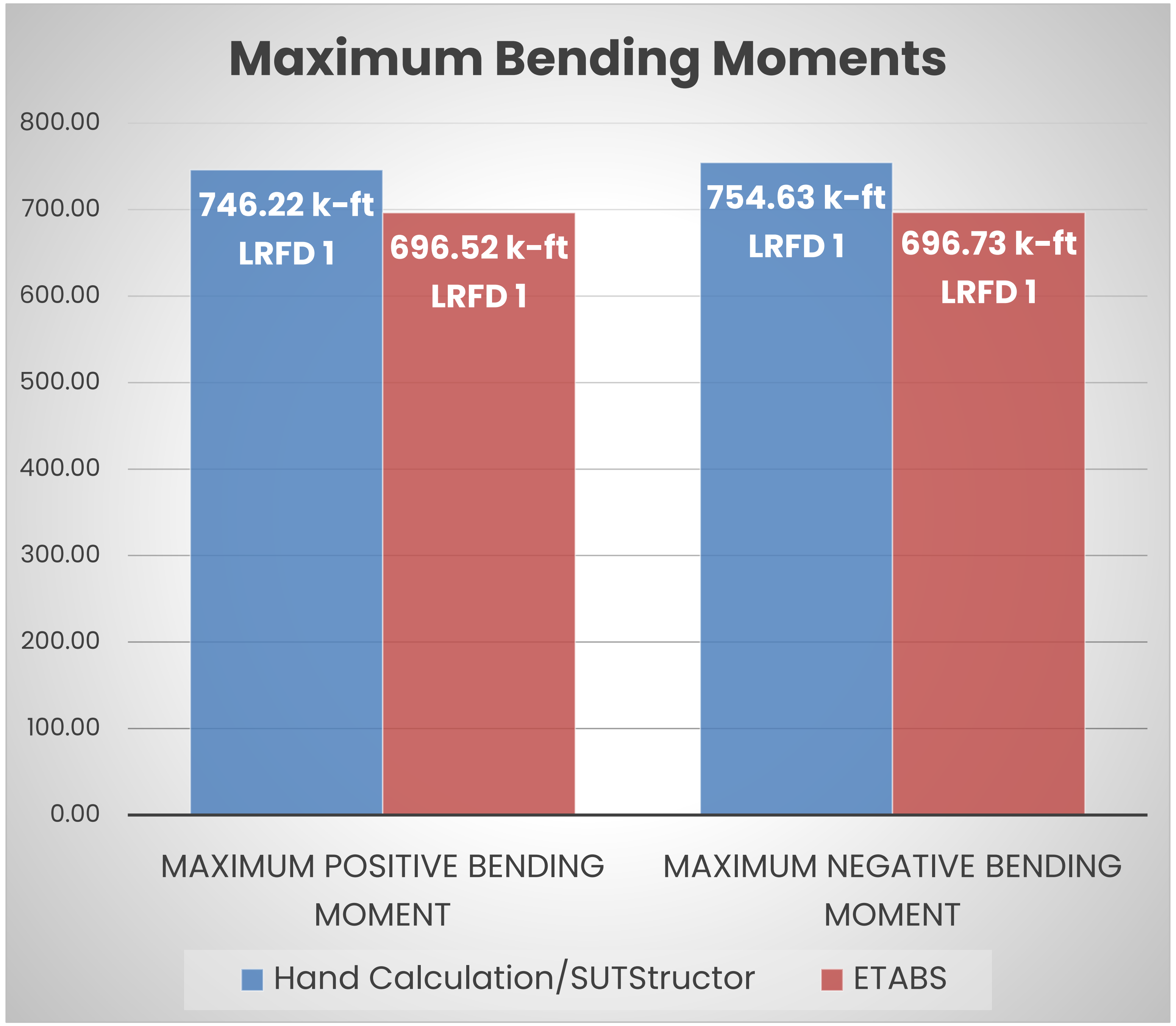
Design of Stirrups

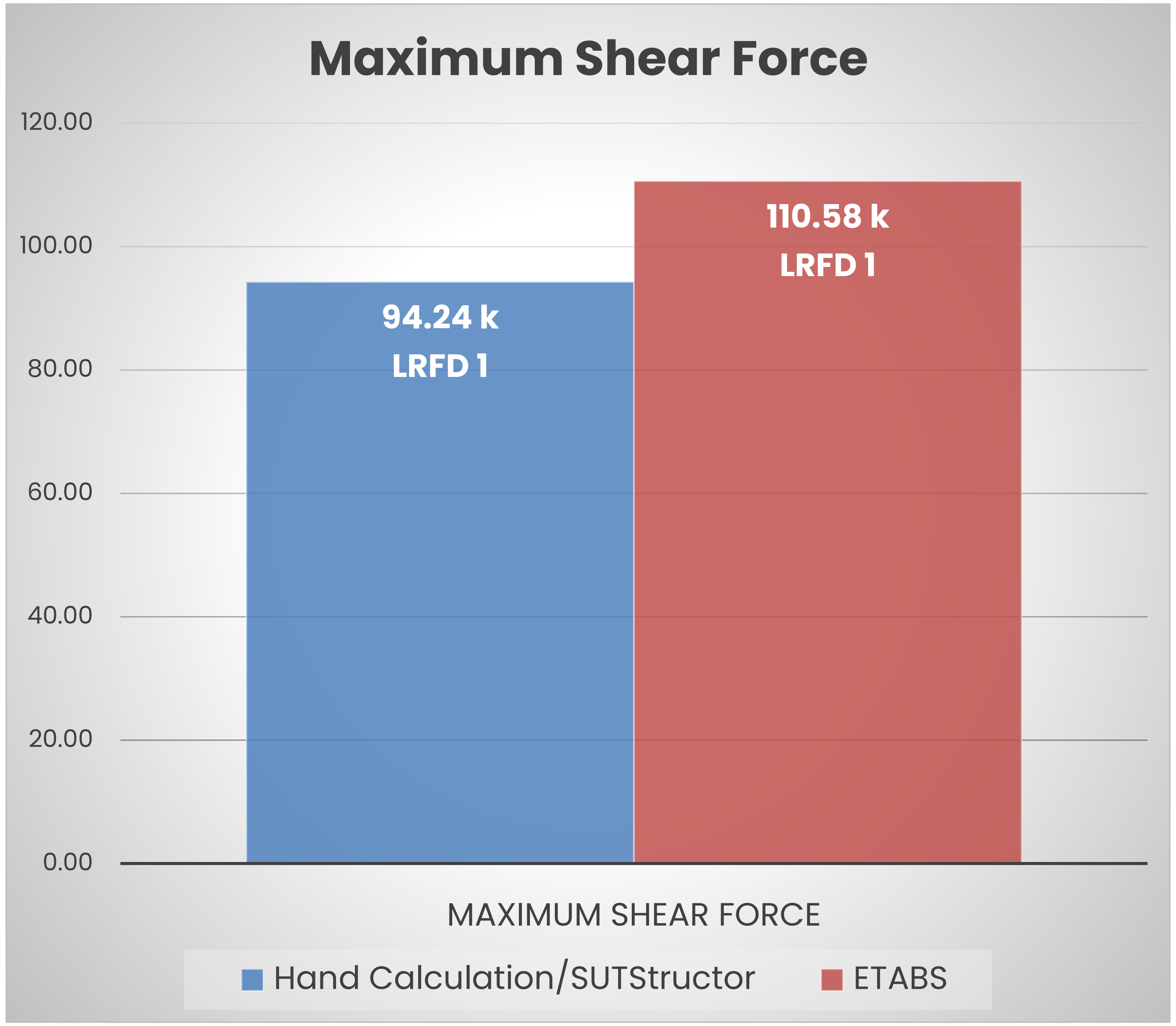
↓

Adequacy Check



Design Forces



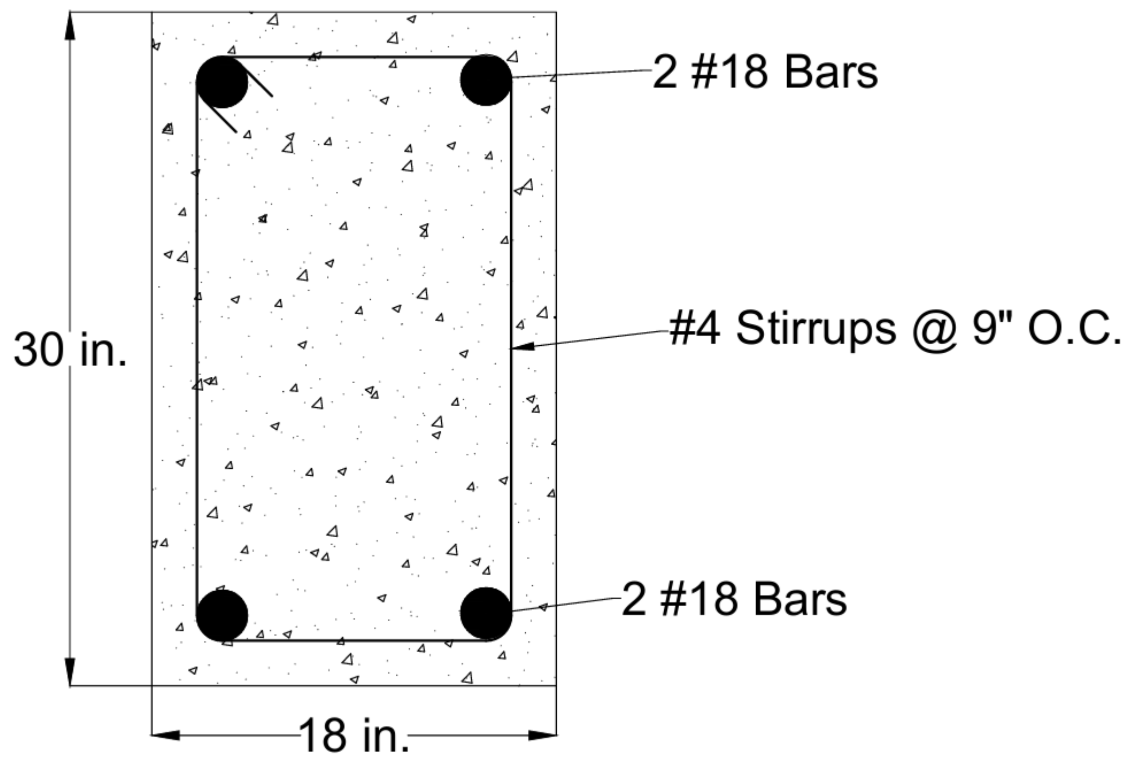


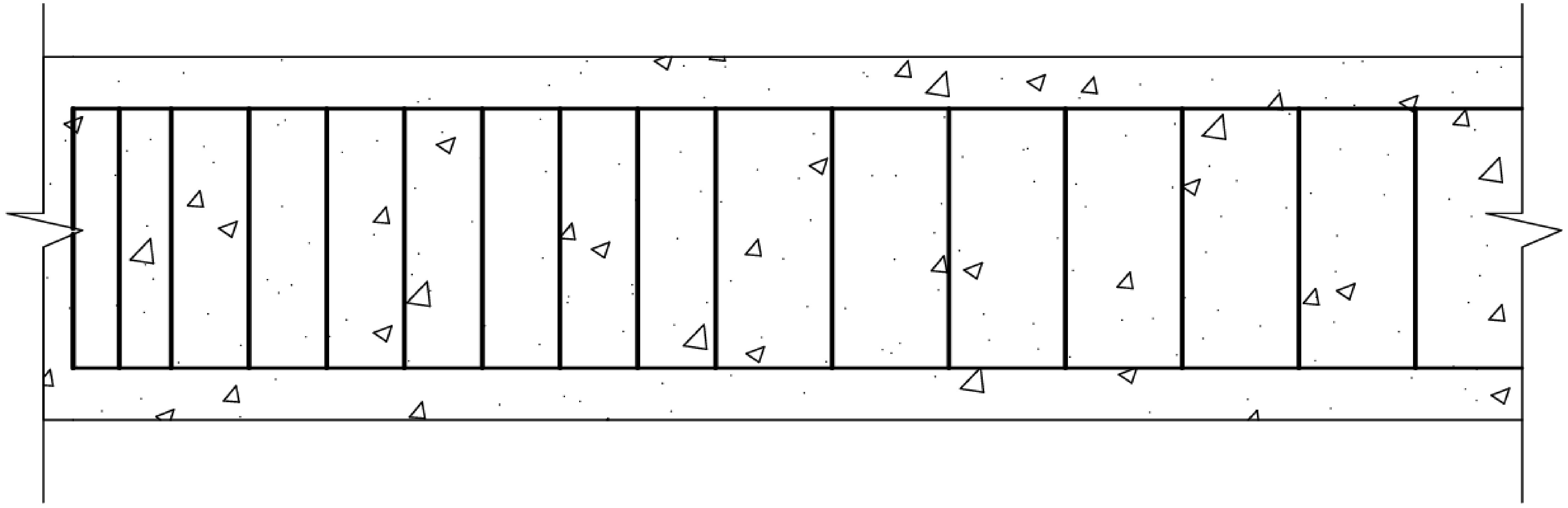
Required Steel Area Comparisons

Frame B & C Girder Comparisons	
Hand Calculated Design	ETABS Design
Required Steel Area for Maximum Positive Bending Moment	
7.021 in^2	6.0386 in^2
Required Steel Area for Maximum Negative Bending Moment	
7.111 in^2	6.0407 in^2
Required Steel Area for Maximum Shear Force	
0.0355 in^2/in	0.0451 in^2/in

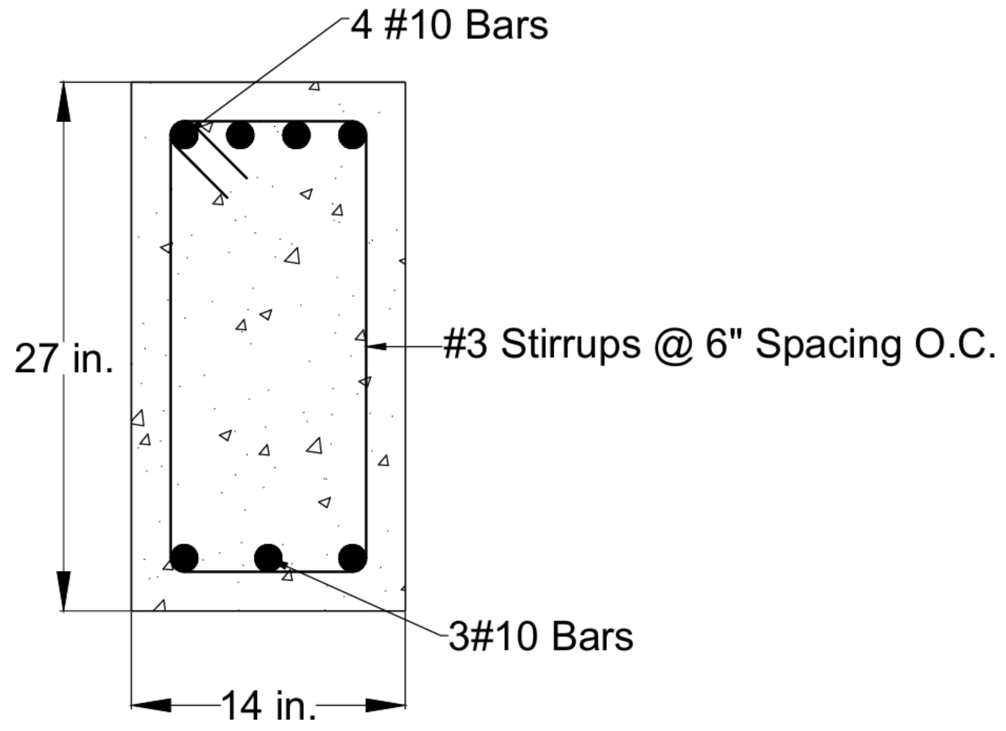
Final Design & Cross Section

Frame B & C Girder Design Summary	
Geometry	
Height	30 in
Width	18 in
Flexural Design Details (+)	
Reinforcement	2 #18 Bars
Design Bending Moment Strength, ΦM_n	856.28 k-ft
Demand/Capacity	0.871
Flexural Design Details (-)	
Reinforcement	2 #18 Bars
Design Bending Moment Strength, ΦMn	856.28 k-ft
Demand/Capacity	0.881
Shear Design Details	
Reinforcement	#4 Stirrups @ 9" O.C.
Design Shear Strength, ΦV_n	103.09 k
Demand/Capacity	0.914

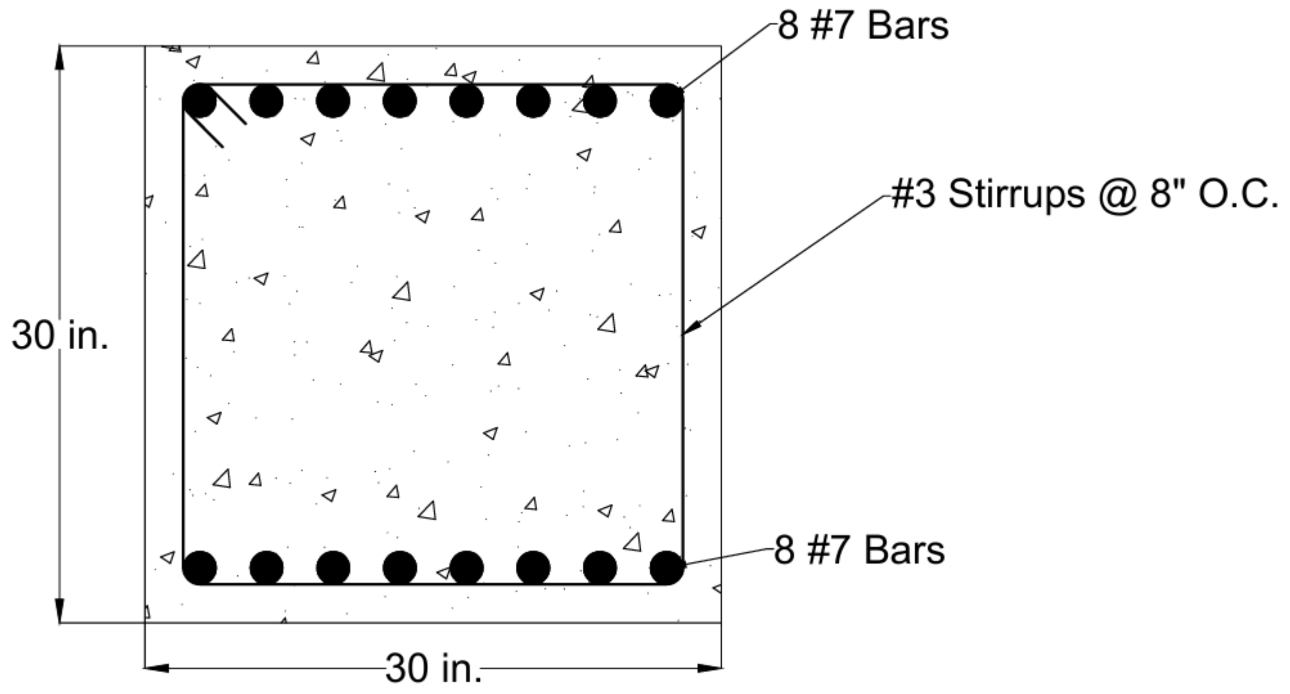




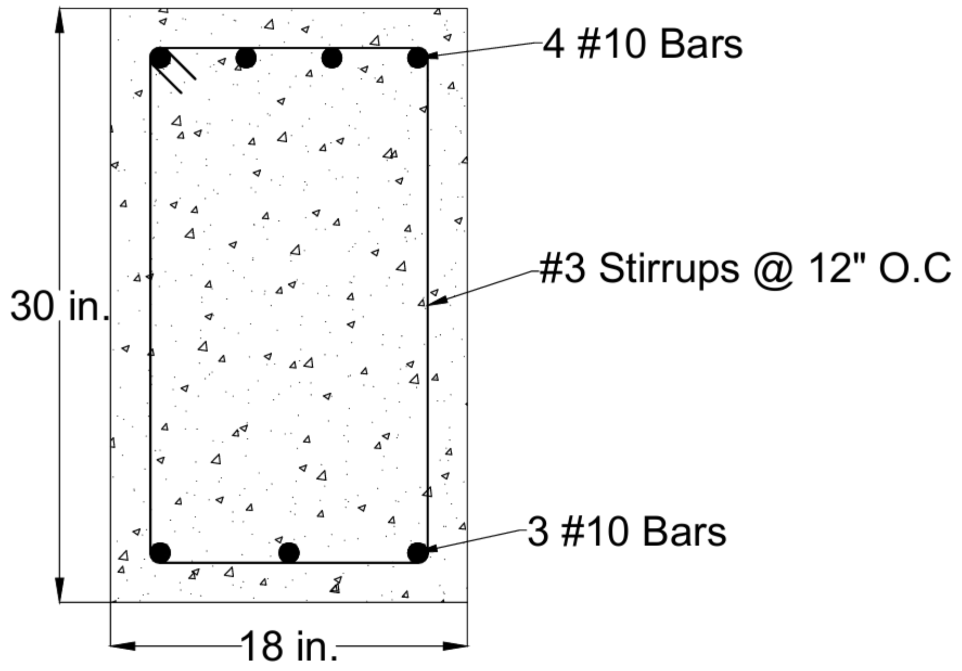
Final Design & Cross Sections



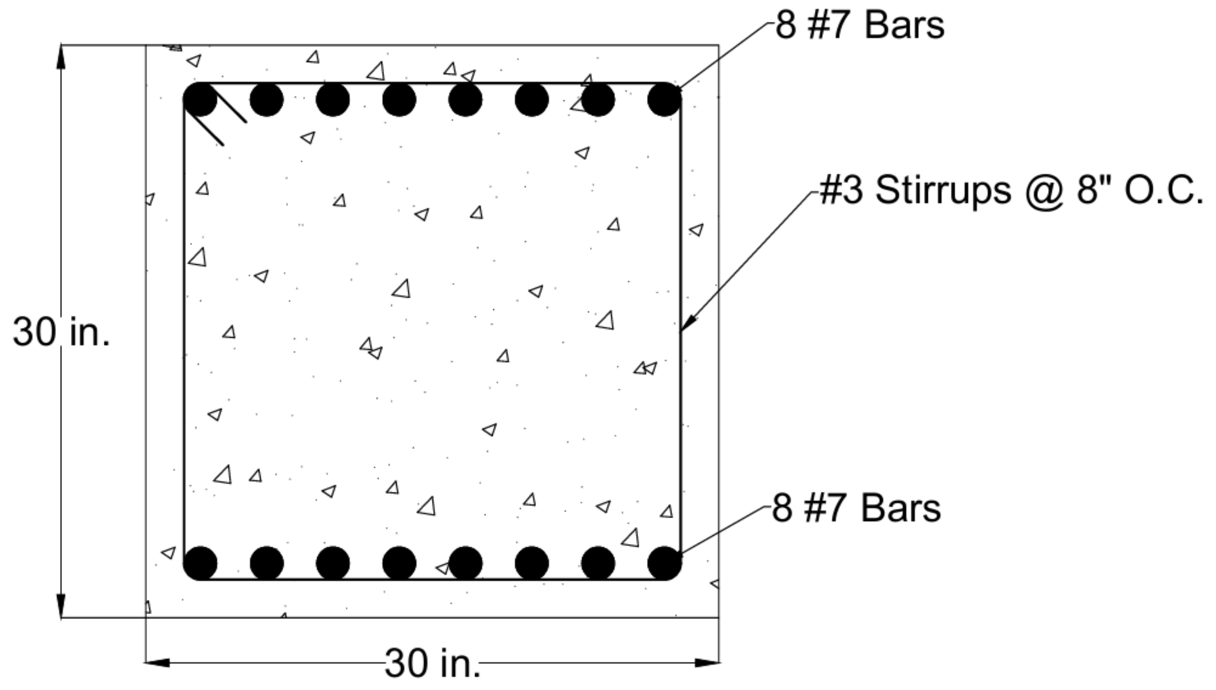
Beam



Frame 1 & 4 Girders



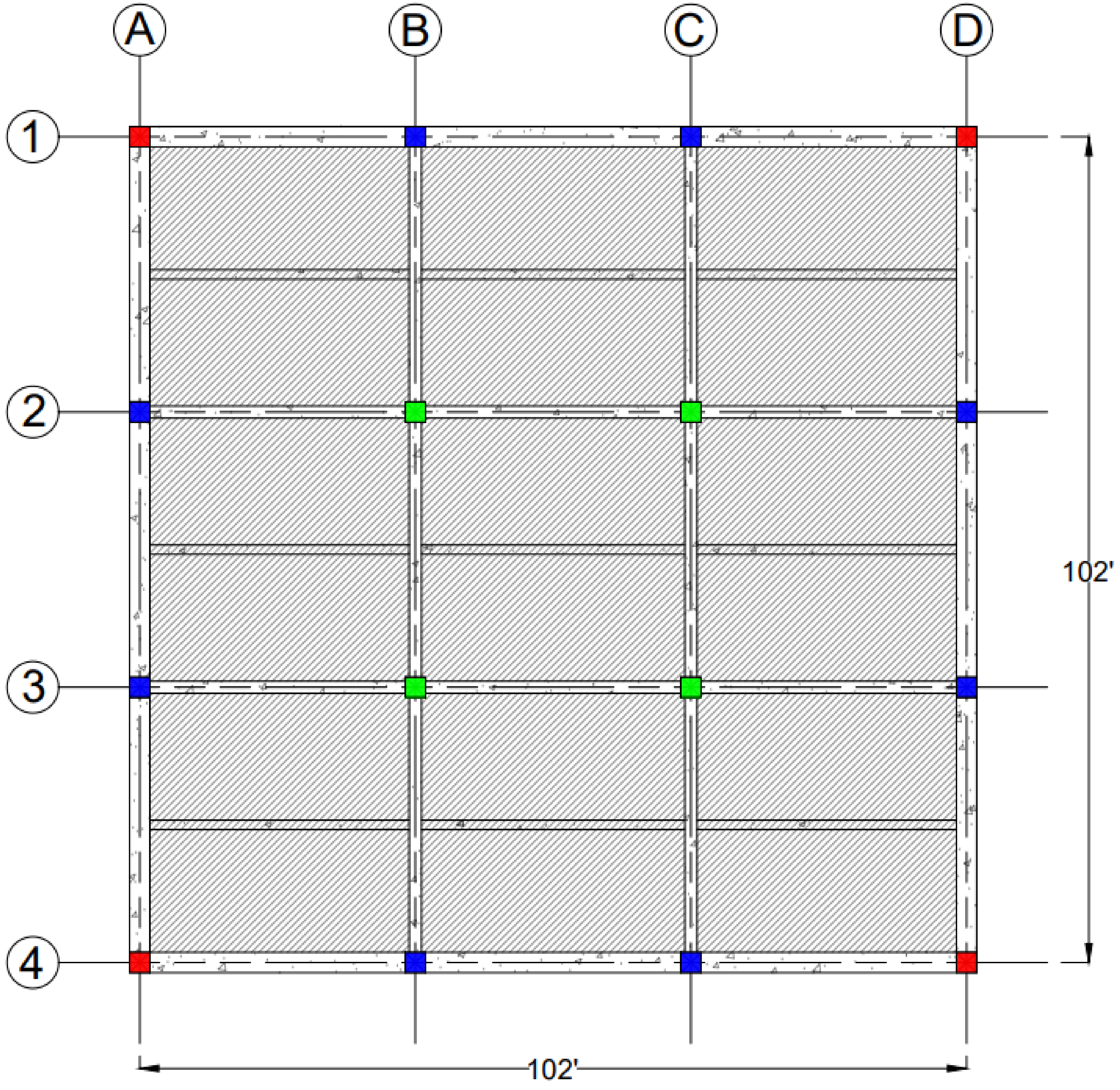
Frame 2 & 3 Girders



Frame A & D Girders

Column Design Parameters

Design Parameters for B2, B3, C2, & C3 Columns	
Yield Strength of Steel, F_y	60 ksi
Compressive Strength of Concrete, f_c'	5 ksi
Column Height	47 ft
Support Type	Pinned - Rigid
Sway or Non-Sway	Non-Sway
Slender or Nonslender	Slender



Column Design Process

Determine Column Dimensions
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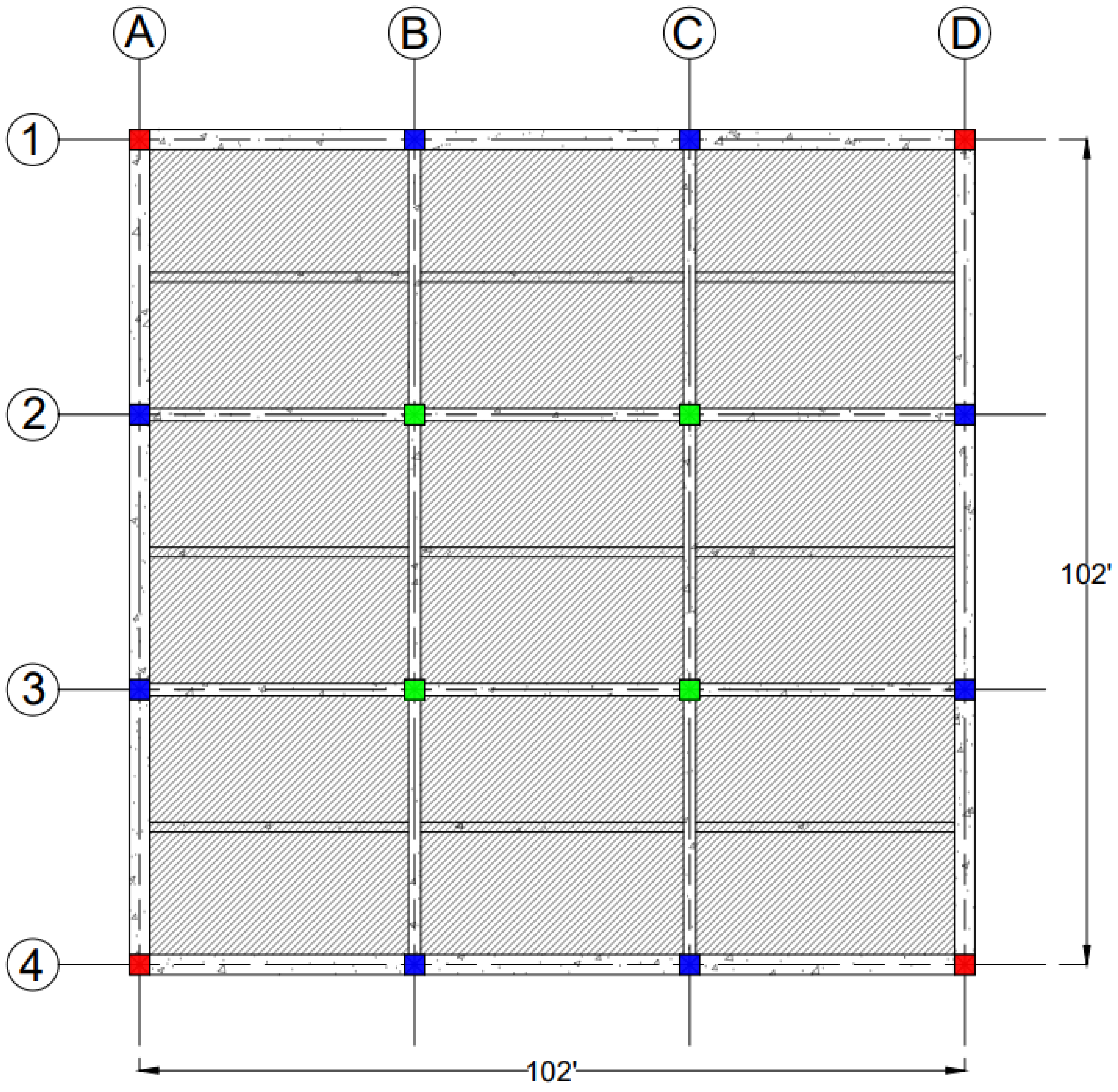
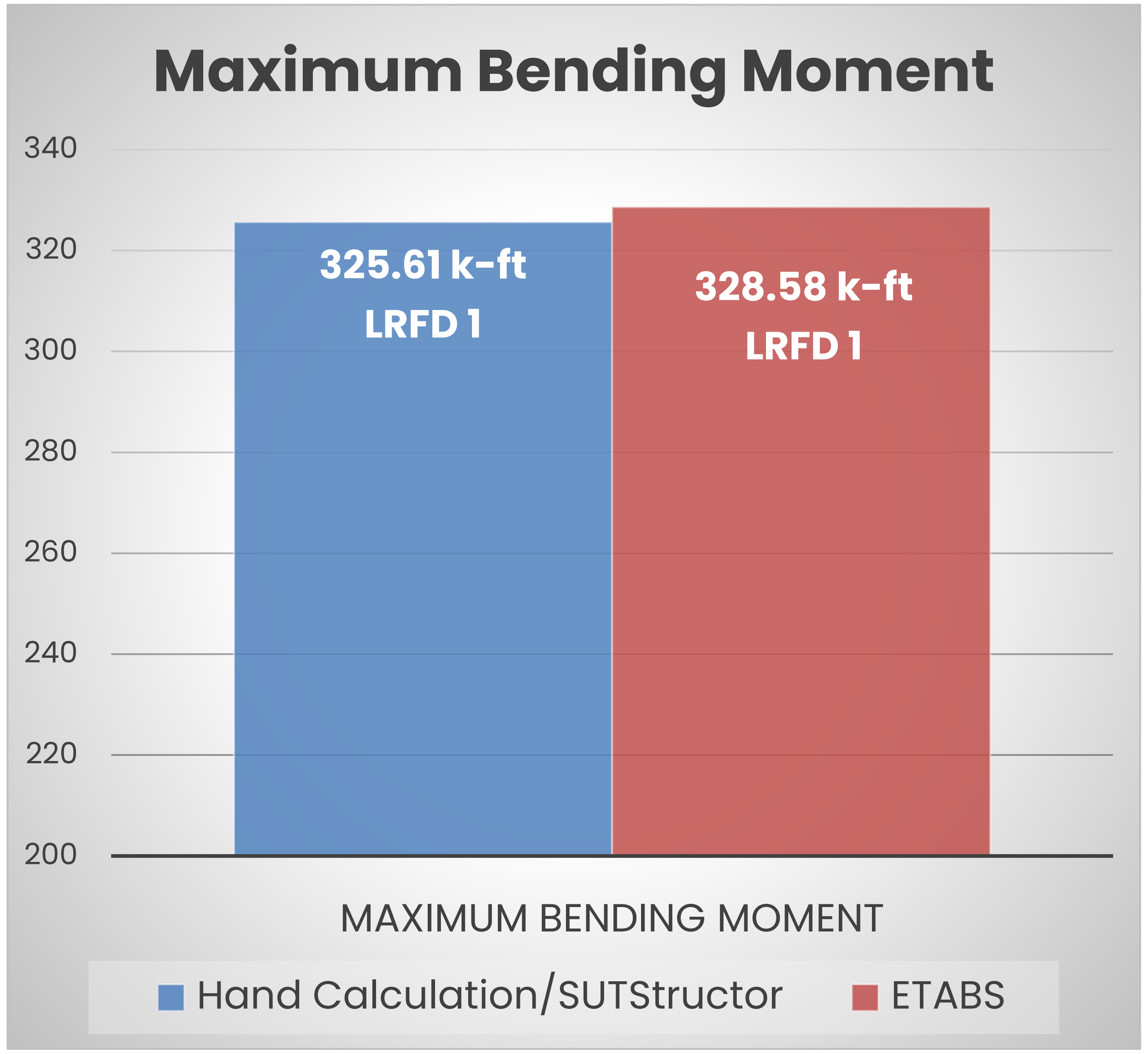
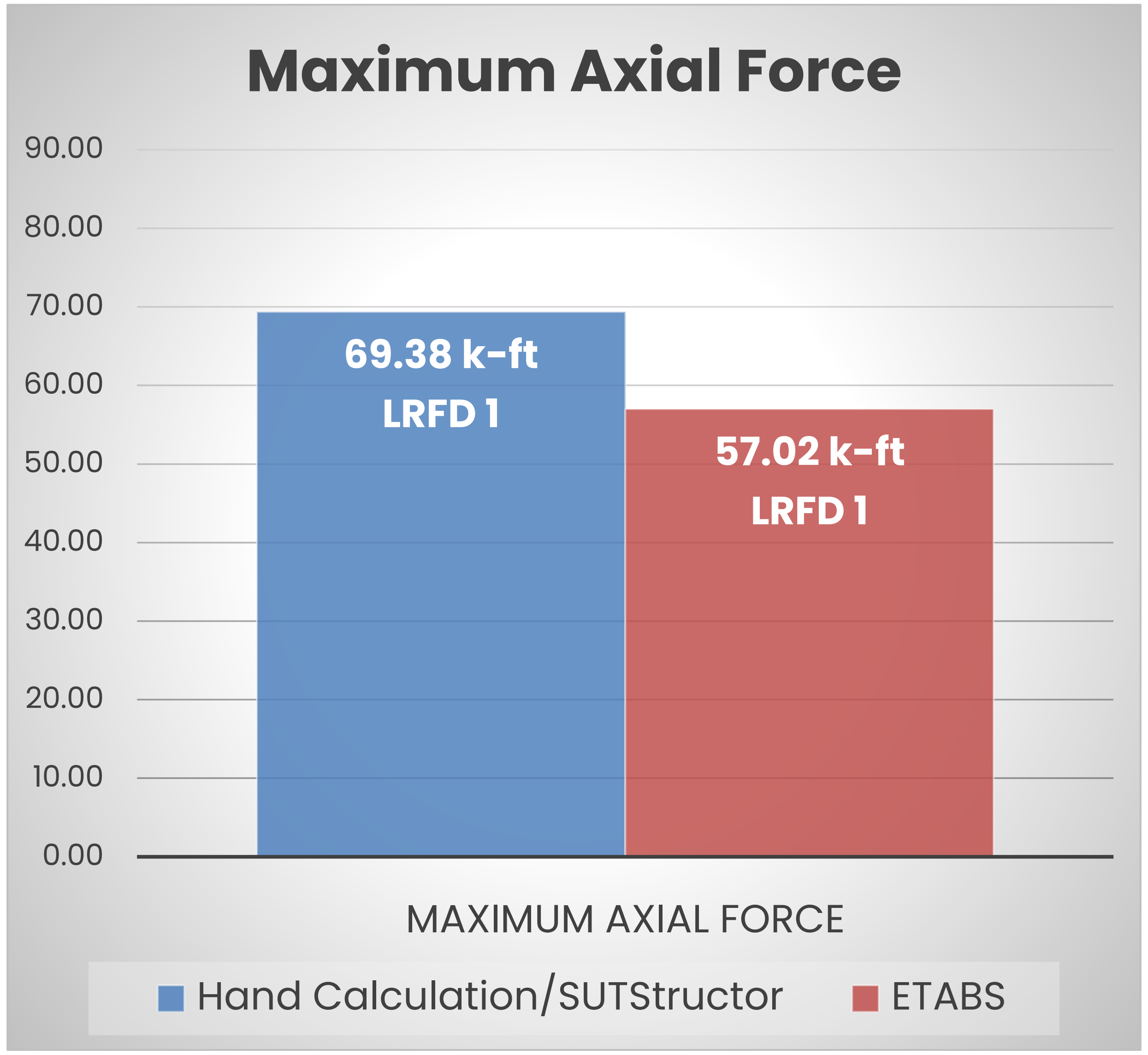
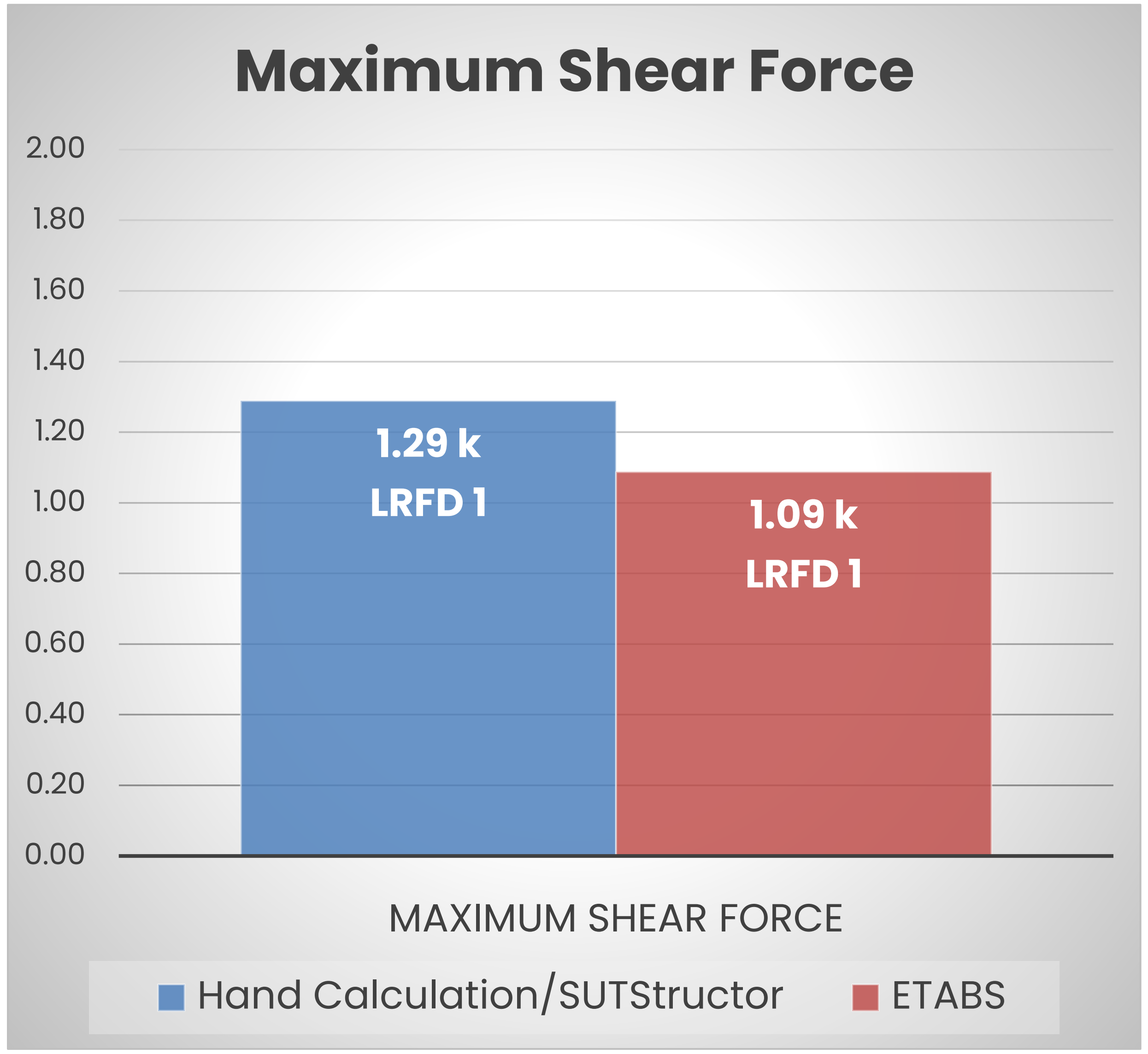
Design of Longitudinal Rebars
↓
Design of Ties
↓
Check Slenderness
↓
Moment Magnification Method
↓
Adequacy Check



Design Forces





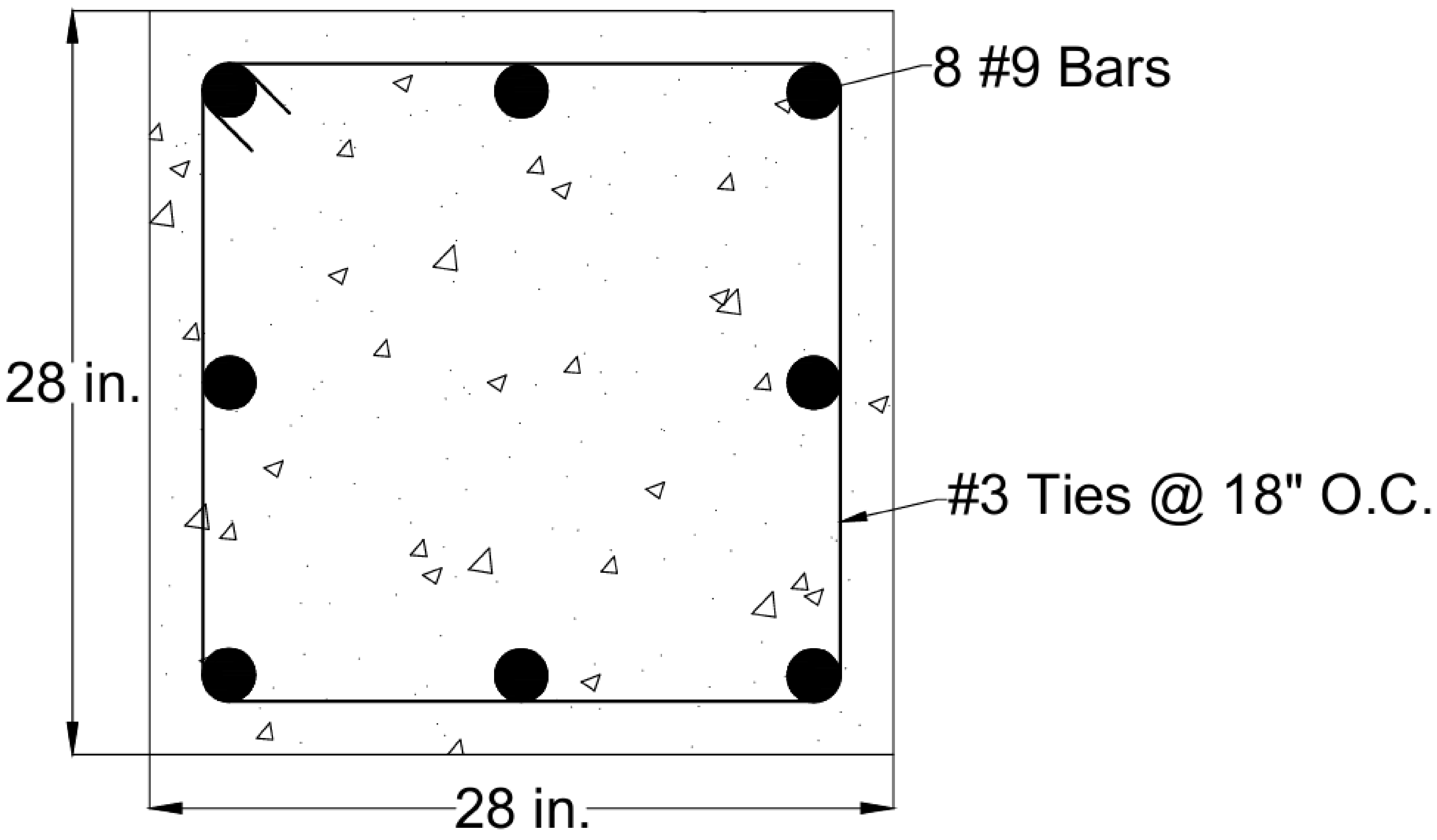


Required Steel Area Comparisons

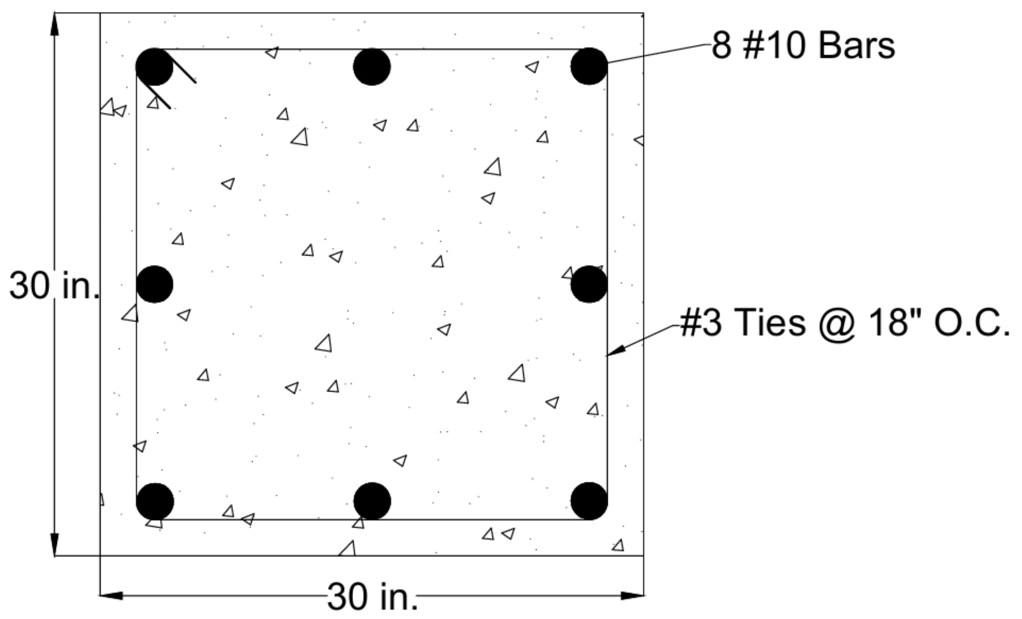
Column B2, B3, C2, & C3 Comparisons	
Hand Calculated Design	ETABS Design
Required Steel Area for Maximum Axial Force and Bending Moment Interaction	
7.84 in^2	7.84 in^2
Required Steel Area for Maximum Shear Force	
0.011 in^2/in	0.0248 in^2/in

Final Design & Cross Section

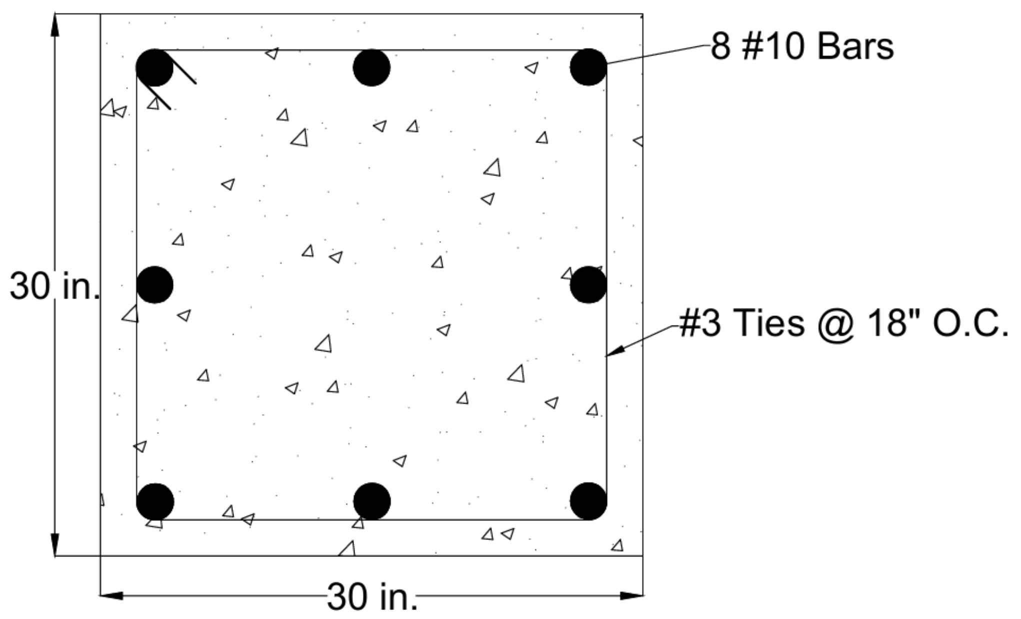
Column B2, B3, C2, & C3 Design Summary	
Geometry	
Cross-Section Dimensions	28 in x 28 in
Axial Force and Bending Moment Interaction Design Details	
Reinforcement	8 #9 rebars
Design Axial Strength, ΦP_n	1,964.56 k
Demand/Capacity	0.166
Design Bending Moment Strength, ΦM_n	469.09 k-ft
Demand/Capacity	0.148
Shear Design Details	
Reinforcement	#3 ties @18" O.C.
Design Shear Strength, ΦV_n	64.89 k
Demand/Capacity	0.020



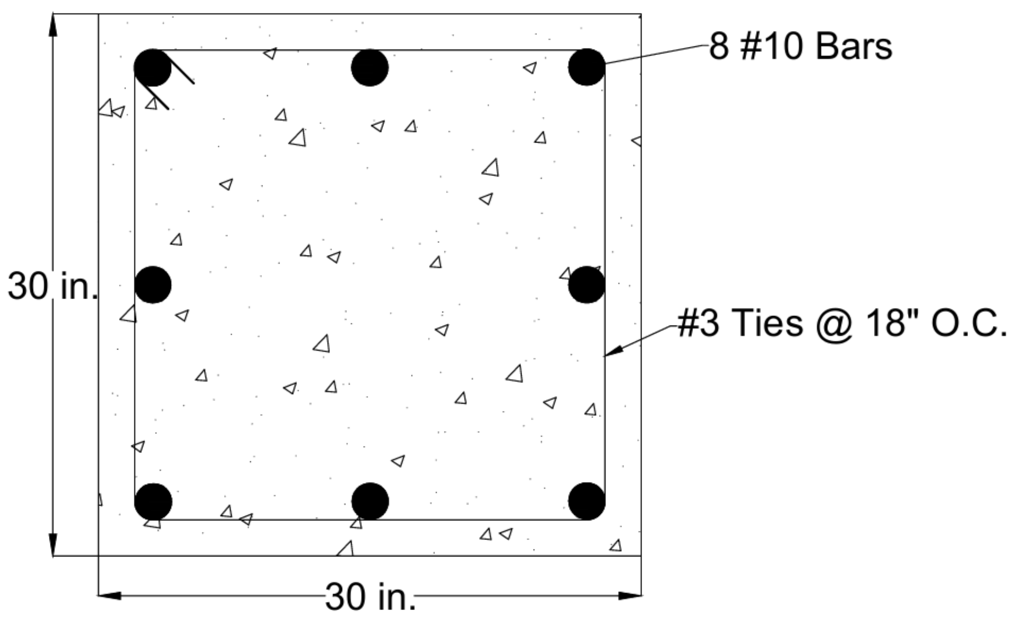
Final Design & Cross Sections



Columns A1, A4, D1, D4



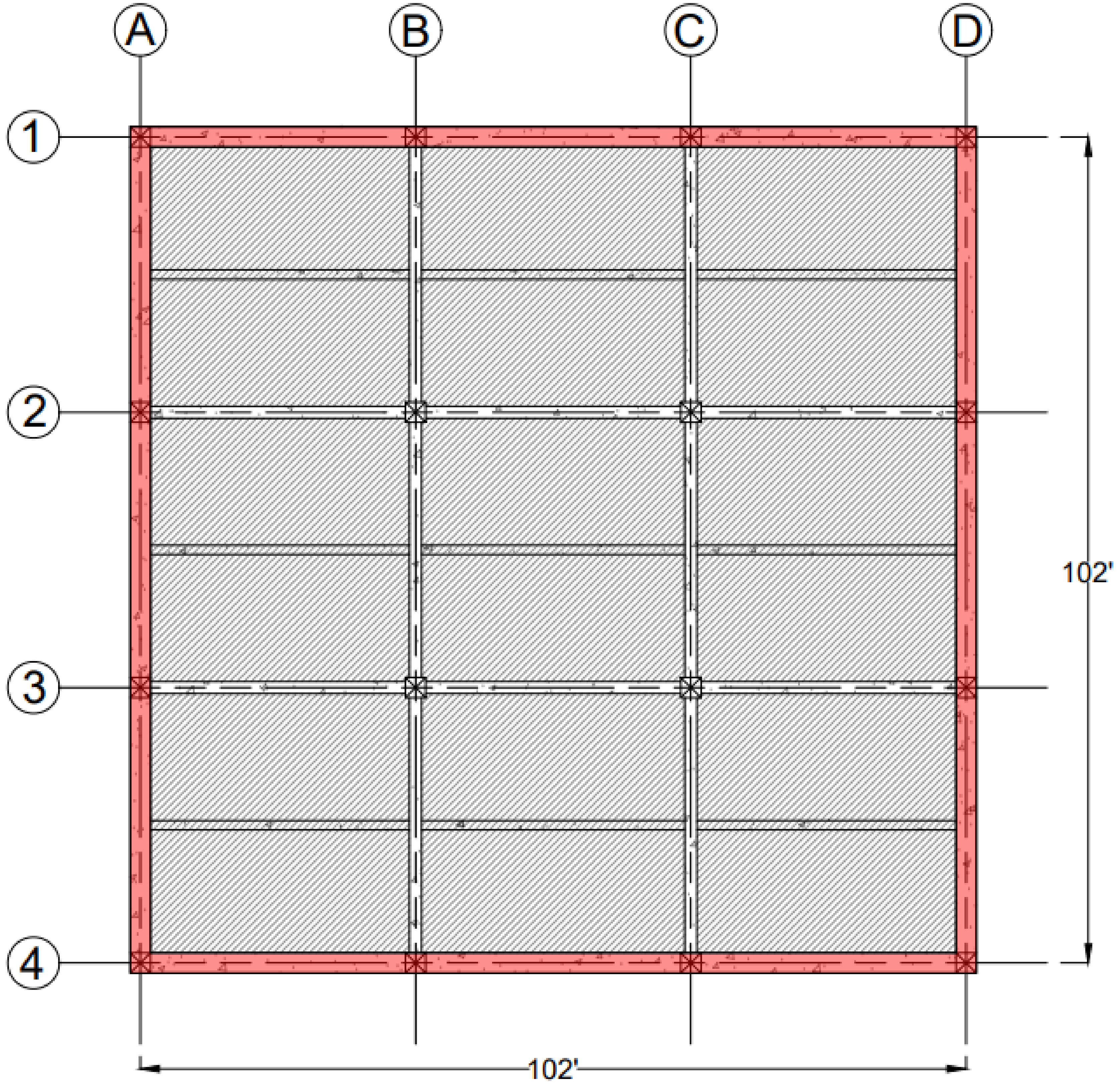
Columns A2, A3, D2, D3



Columns B1, C1, B4, C4

Shear Wall Design Parameters

Design Parameters for Shear Wall	
Yield Strength of Steel, F_y	60 ksi
Compressive Strength of Concrete, f_c'	5 ksi
Wall Height	47 ft
Wall Length	102 ft
Support Type	Pinned - Pinned



Shear Wall Design Process

Determination of Wall Thickness

↓

Design for In-Plane Transverse Reinforcement

↓

Design for In-Plane Longitudinal Reinforcement

↓

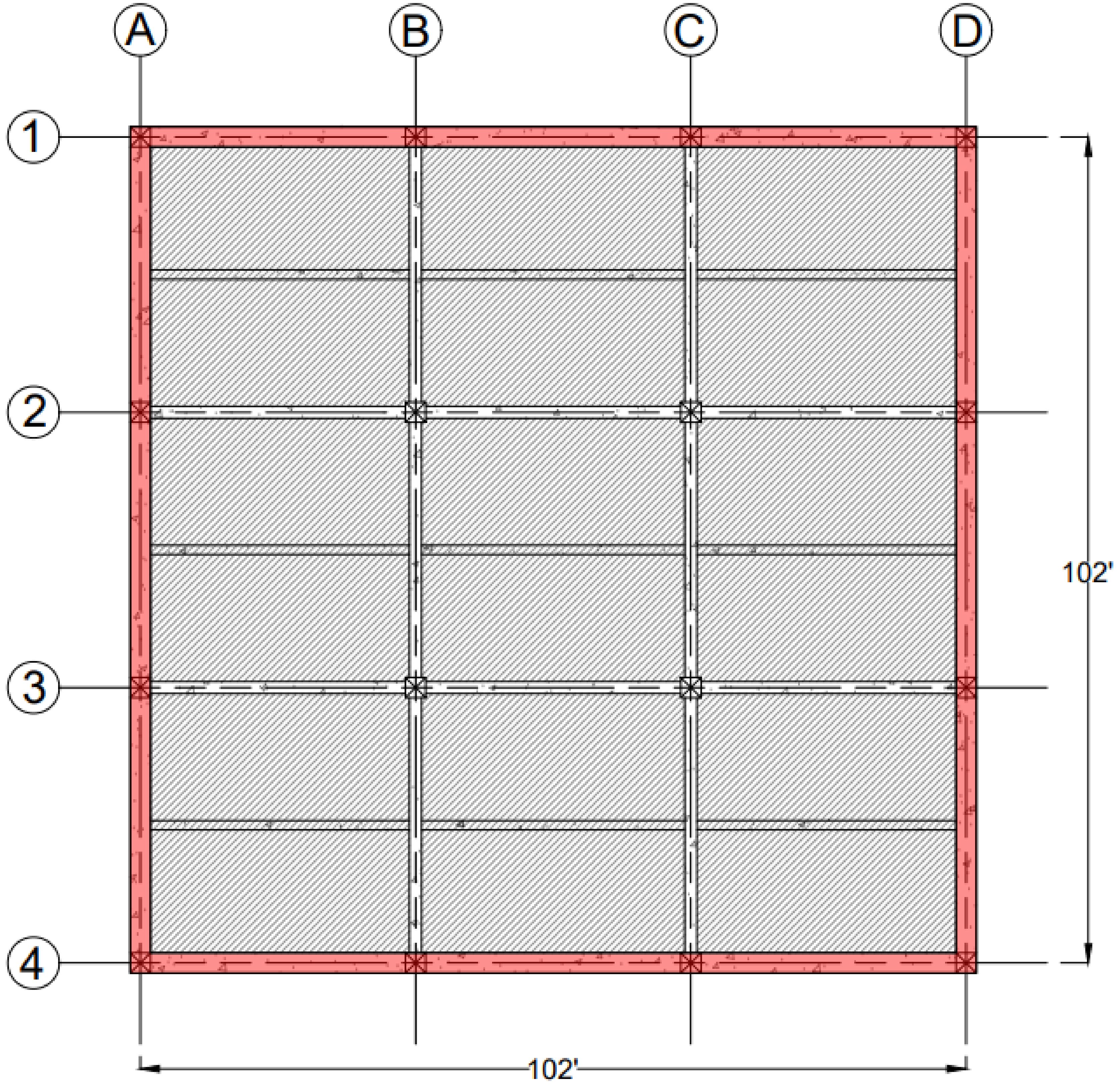
Design for Out-of-Plane Longitudinal Reinforcement

↓

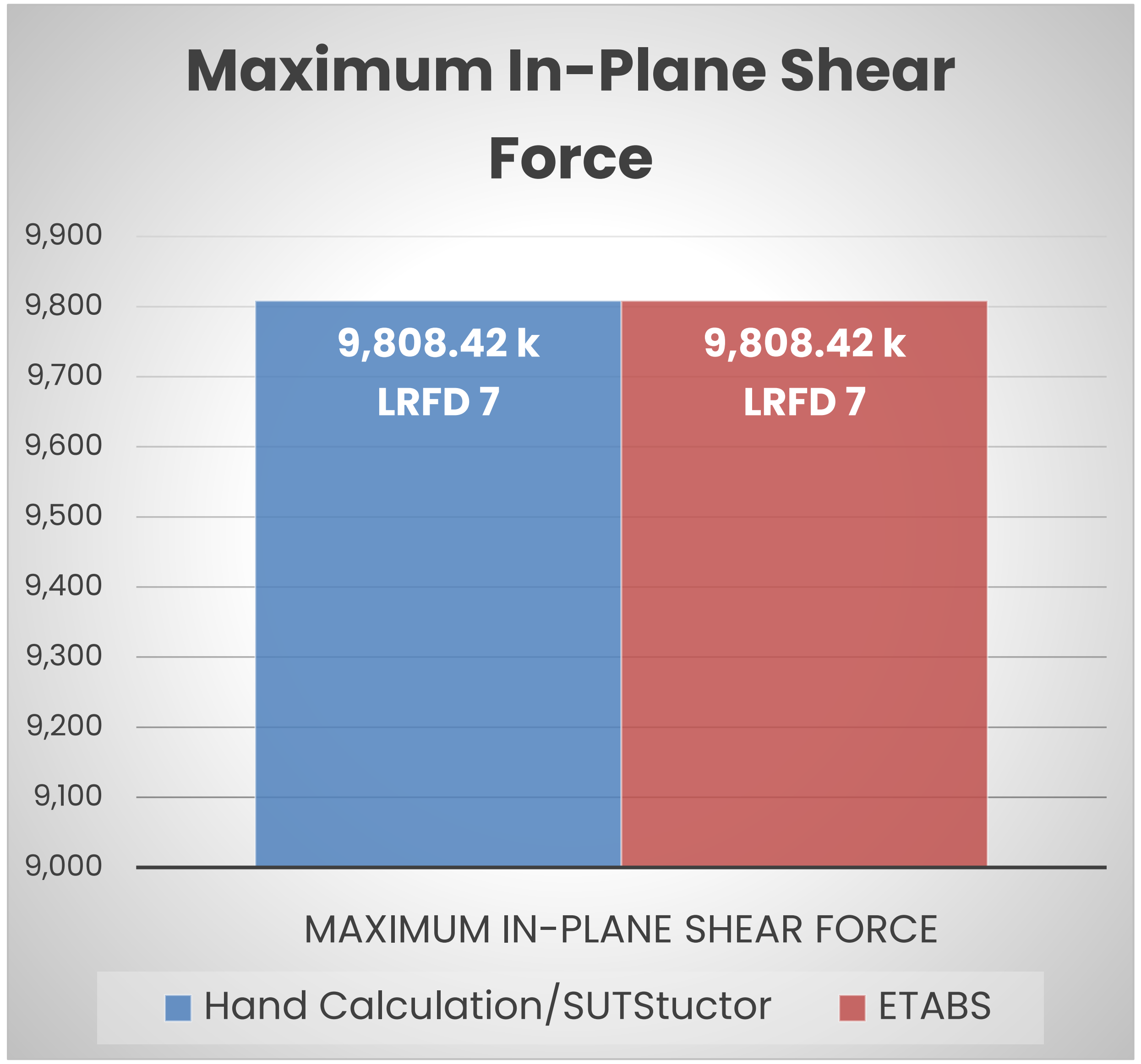
Design for Out-of-Plane Transverse Reinforcement

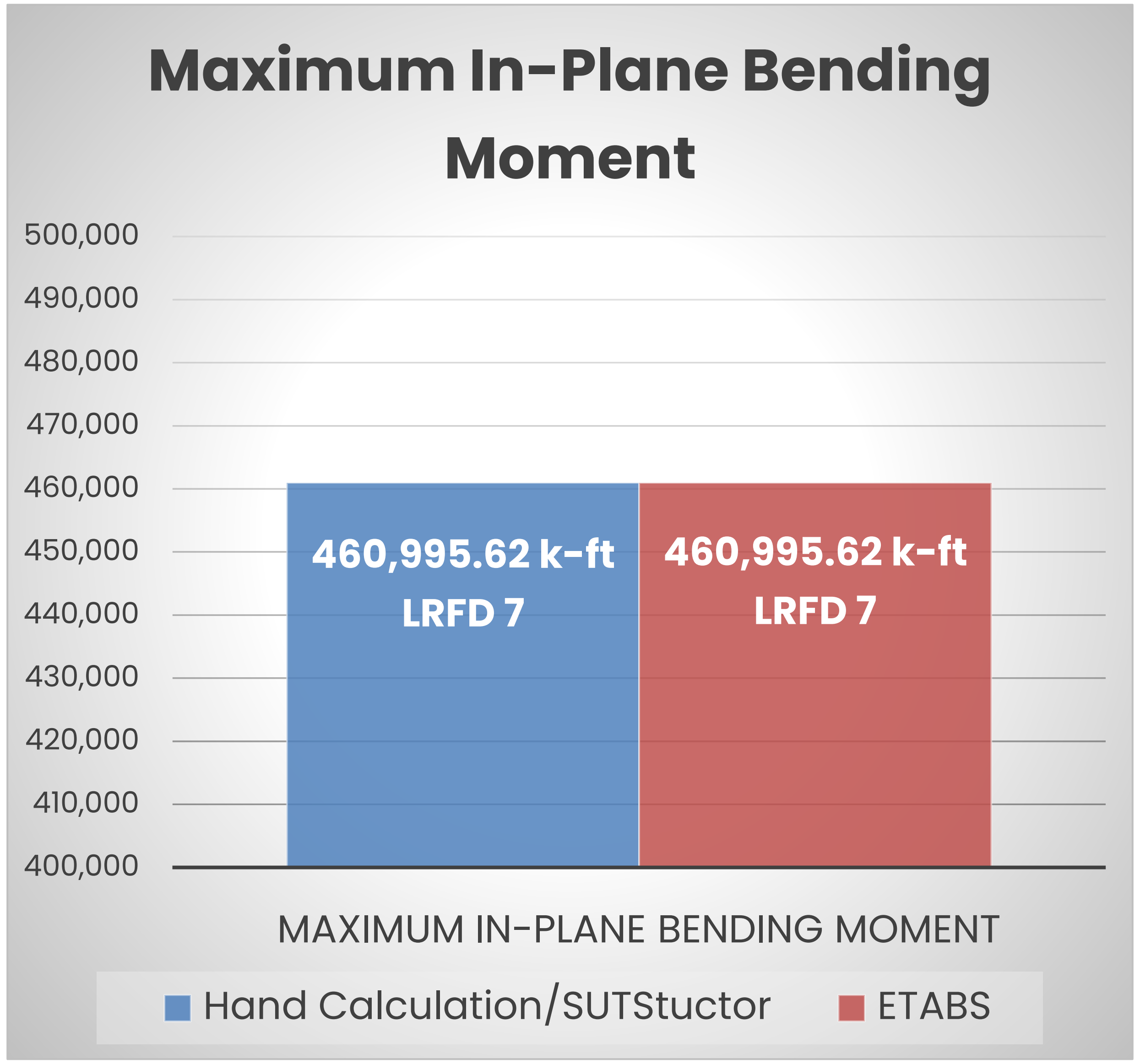
↓

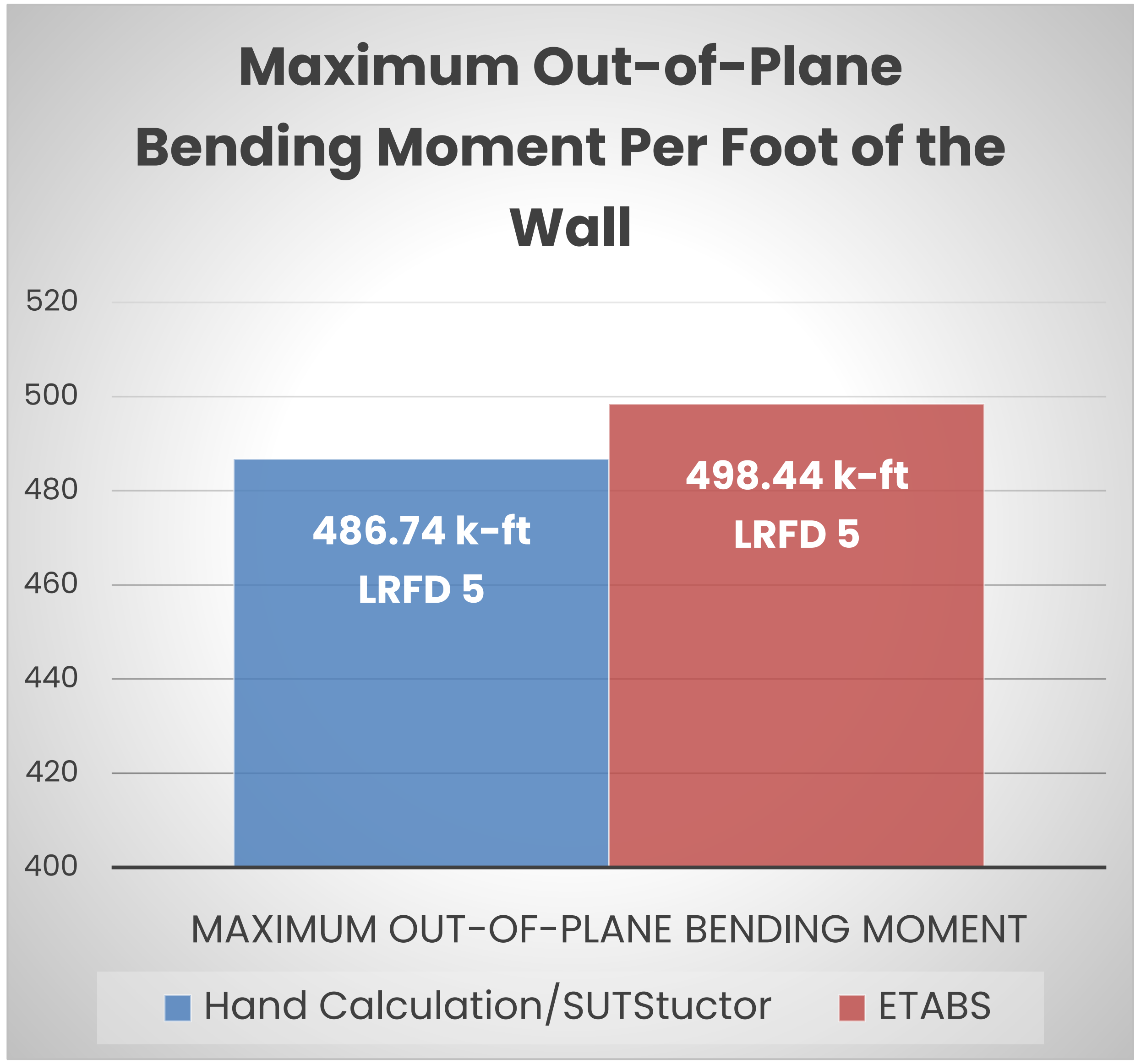
Adequacy Check



Design Forces





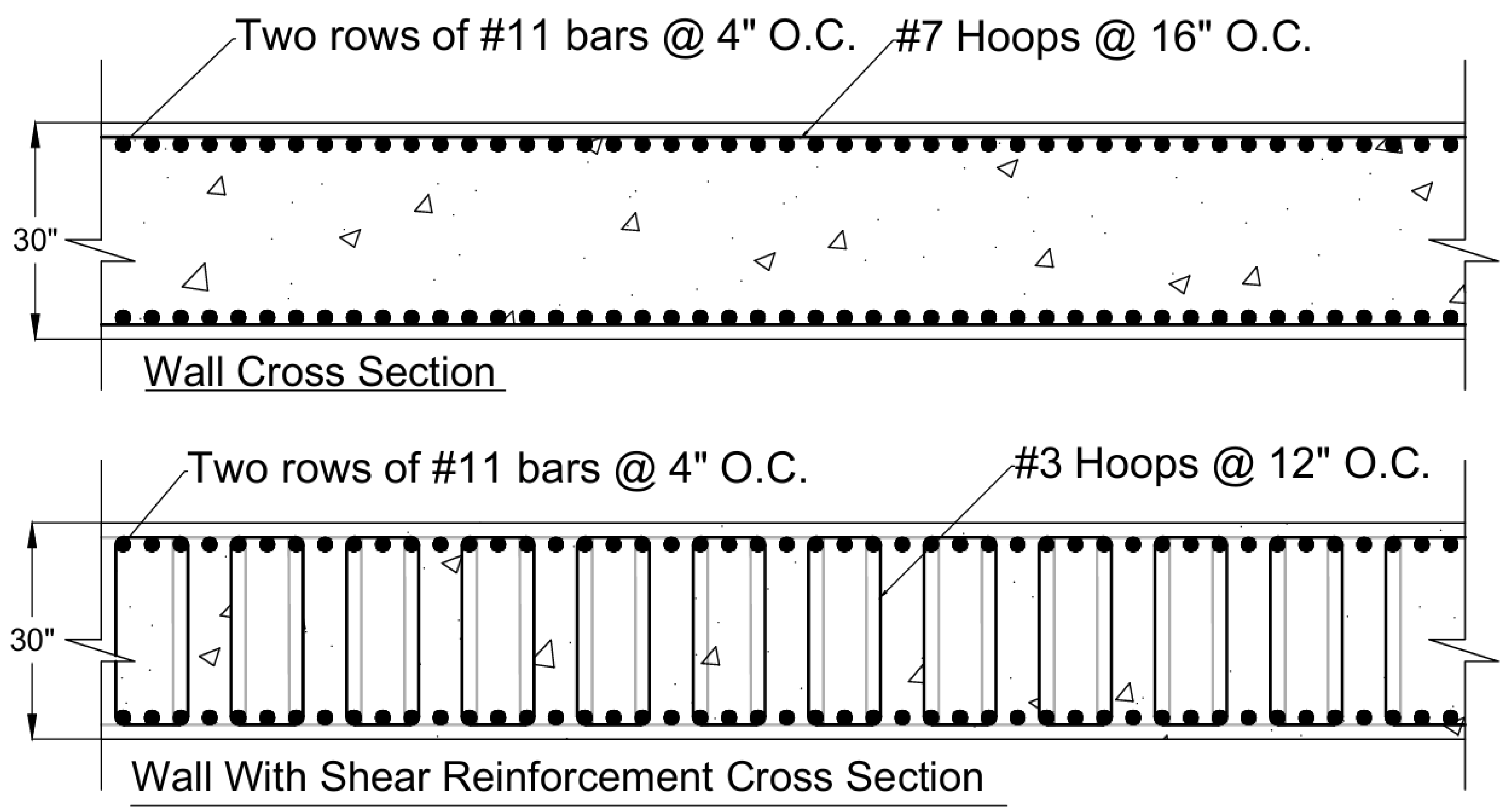


Required Steel Area Comparisons

Shear Wall Comparisons	
Hand Calculated Design	ETABS Design
Required Steel Area for In and Out-of-Plane Bending Moments	
954.72 in^2	1,148.32 in^2
Required Steel Area for In-Plane Shear Force	
0.075 in^2/in	0.075 in^2/in

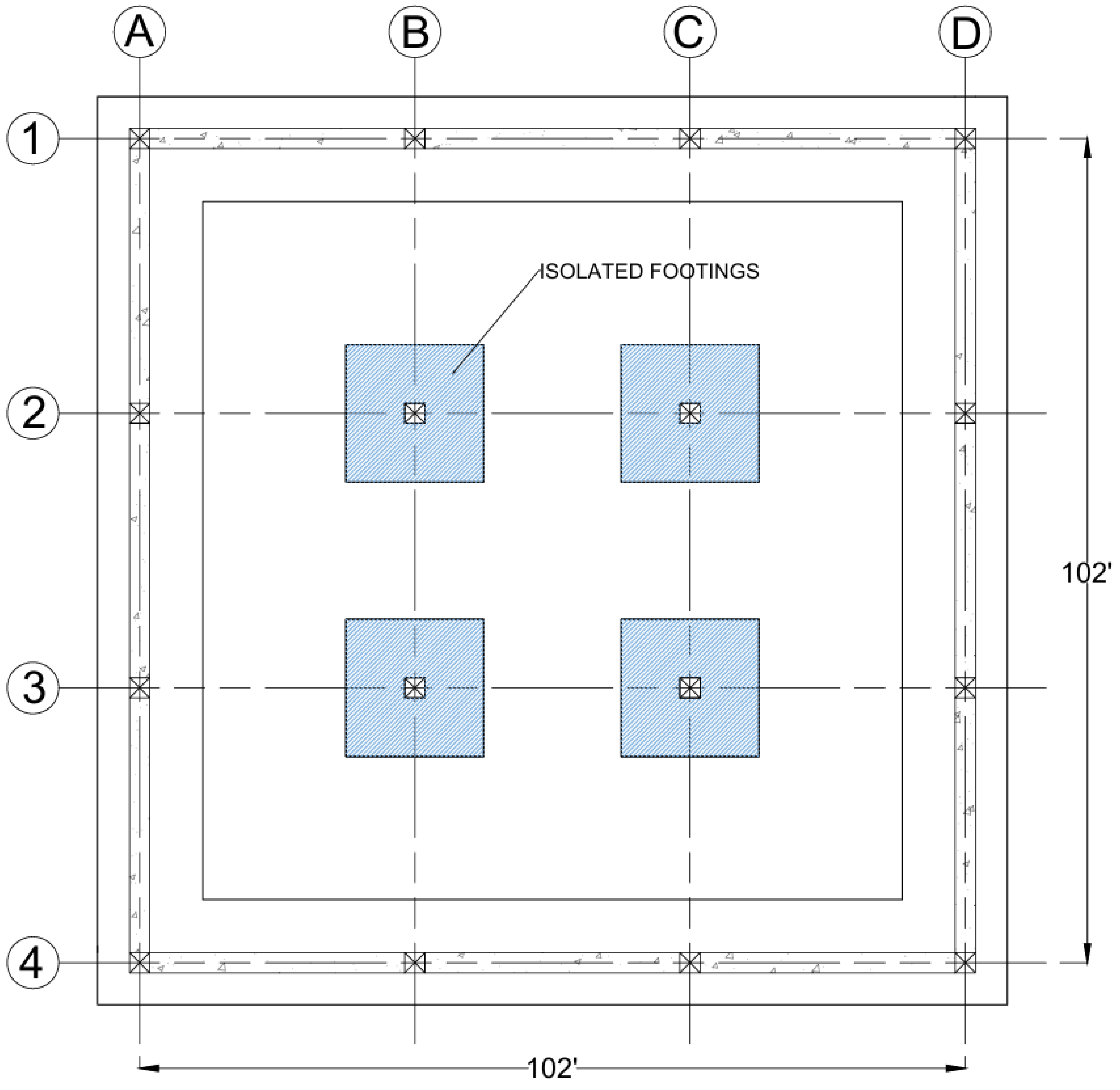
Final Design & Cross Section

Shear Wall Design	
Item	Hand Calculated Design
Geometry	
Thickness	30 in
In-Plane Shear Design Details	
Reinforcement	#7 Hoops @ 16" O.C.
Design Shear Strength, ΦV_n	9,973.12 k
Demand/Capacity	0.98
In-Plane Bending Moment Design Details	
Reinforcement	Two Rows of #11 Bars @ 4" O.C.
Design Bending MomentStrength, ΦM_n	2,005,361.91 k-ft
Demand/Capacity	0.230
Out-of-Plane Bending Moment Design Details	
Reinforcement	Two Rows of #11 Bars @ 4" O.C.
Design Bending Moment Strength, ΦM_n	490.85 k-ft
Demand/Capacity	0.962
Out-of-Plane Shear Design Details	
Reinforcement	#3 Stirrups @ 12" O.C.
Design Shear Strength, ΦV_n	54.30 k
Demand/Capacity	0.910

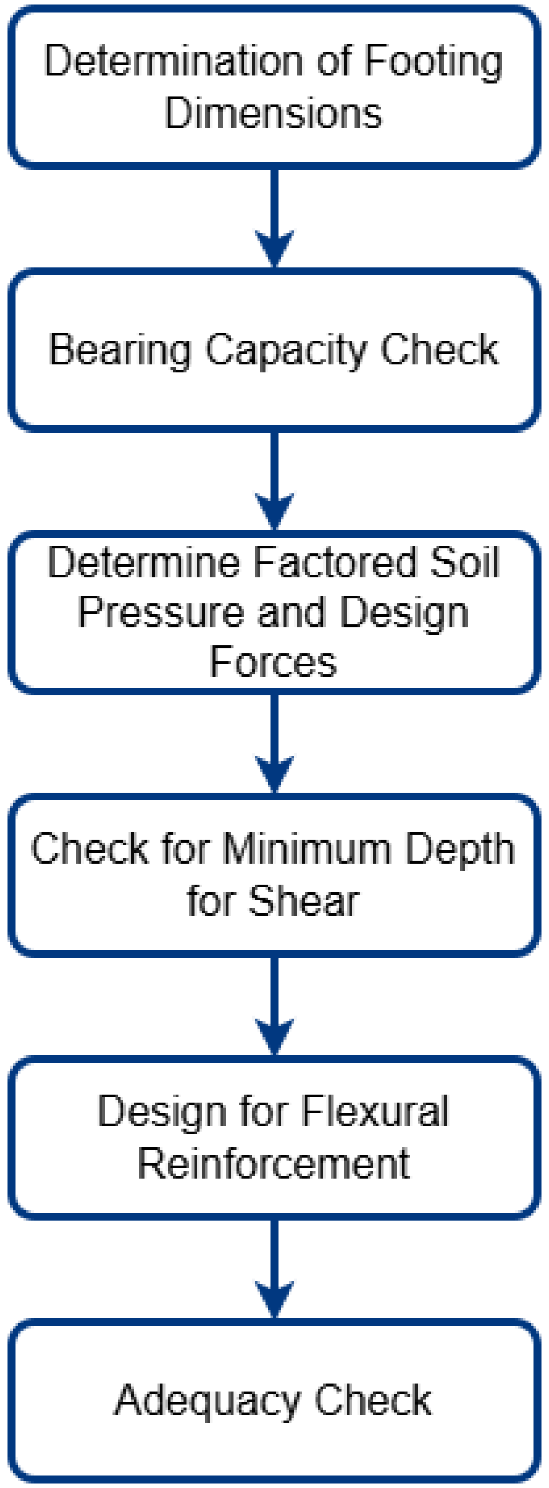


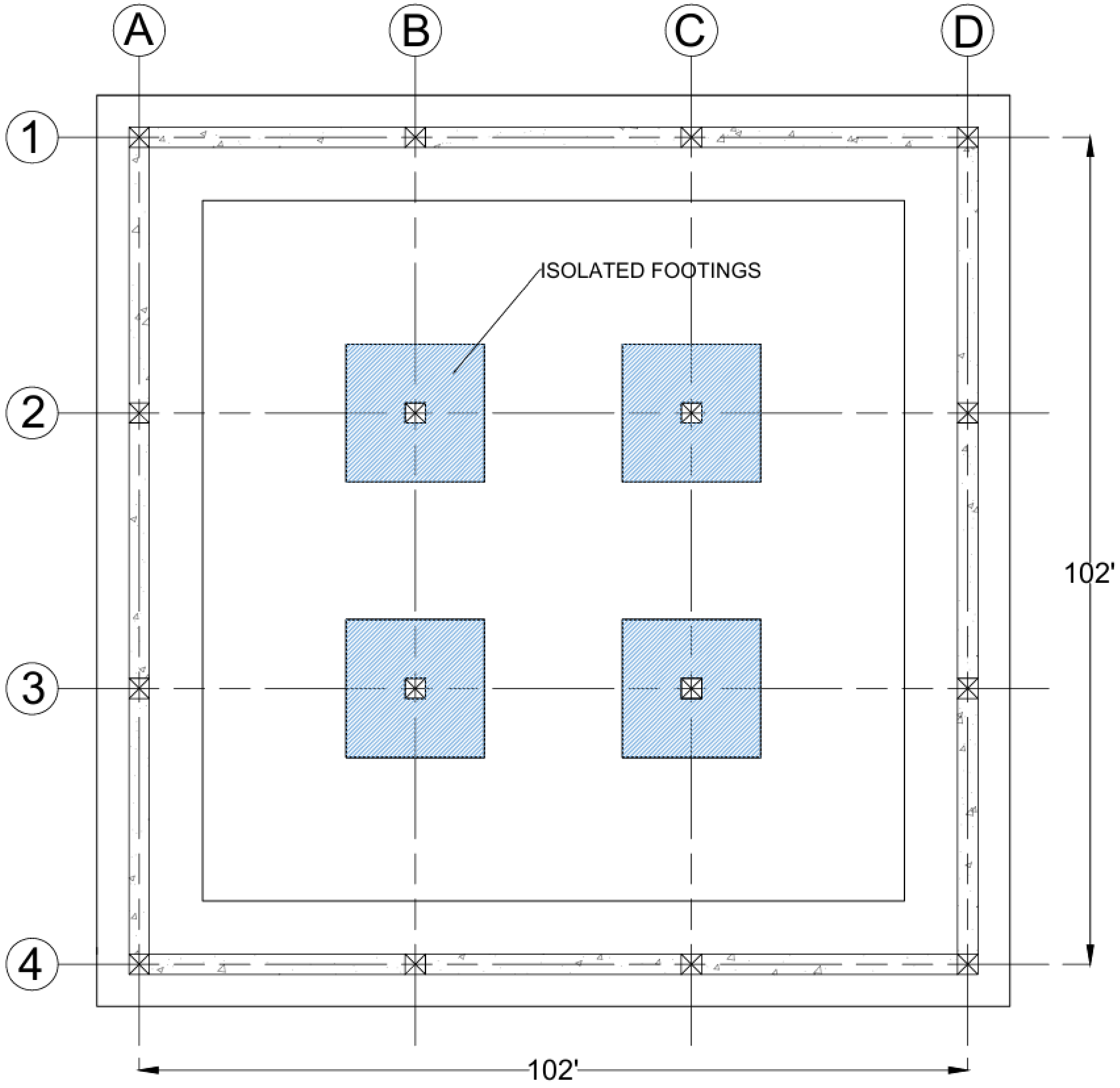
Isolated Footing Design Parameters

Design Parameters for Isolated Footings	
Yield Strength of Steel, F_y	60 ksi
Compressive Strength of Concrete, f_c'	4 ksi
Water Height	40 ft
Unit weight of Water	62.4 pcf

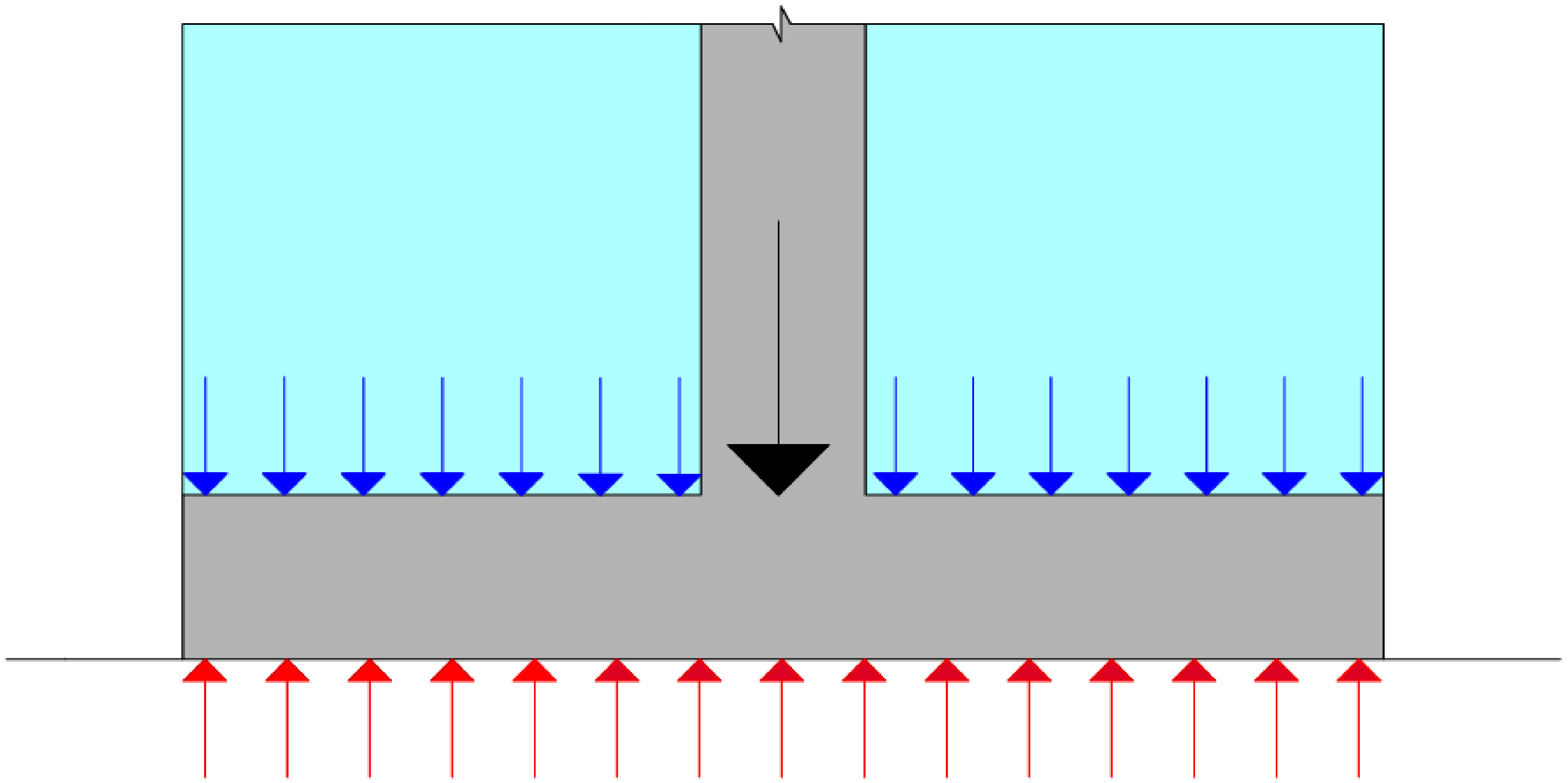


Isolated Footing Design Process



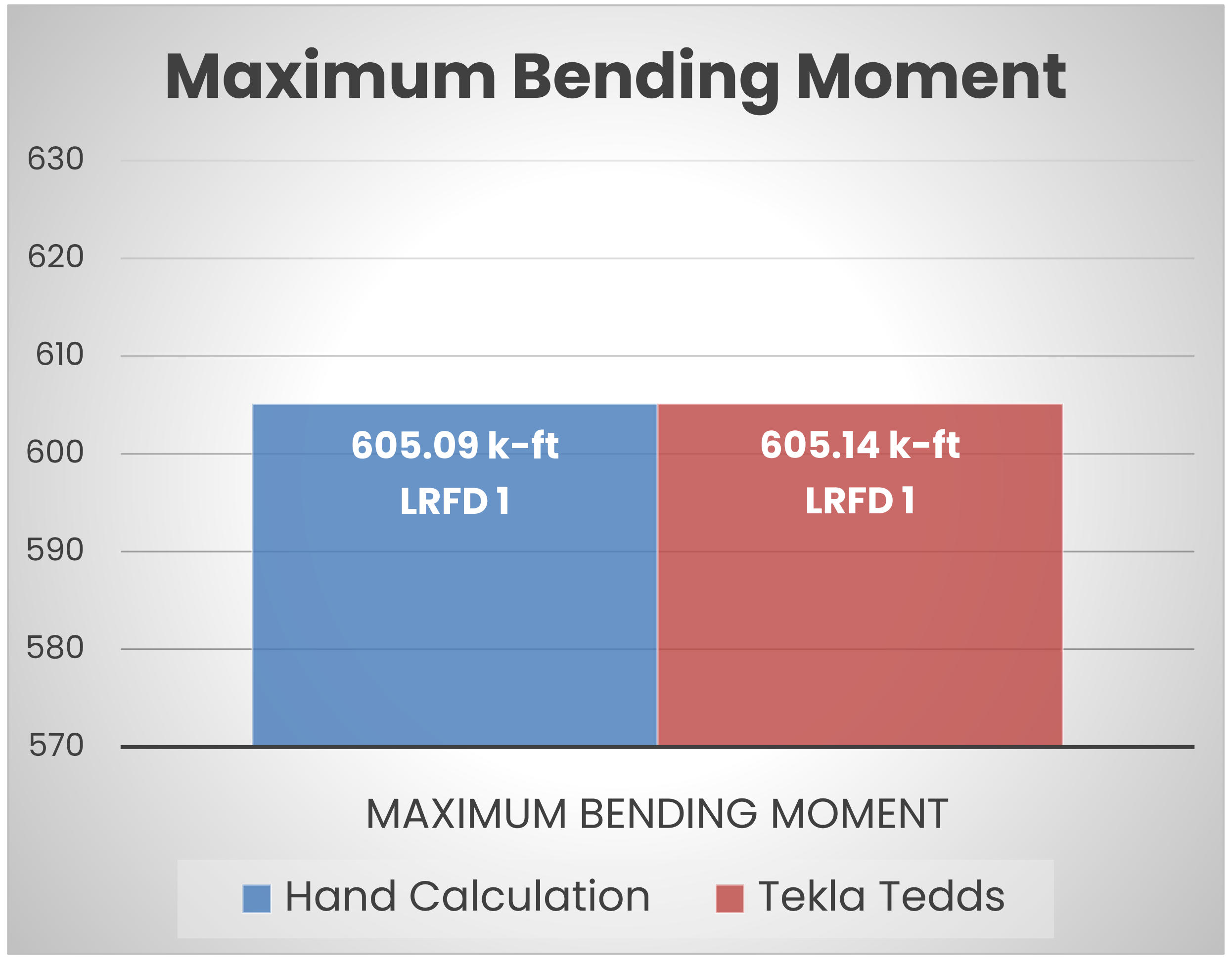


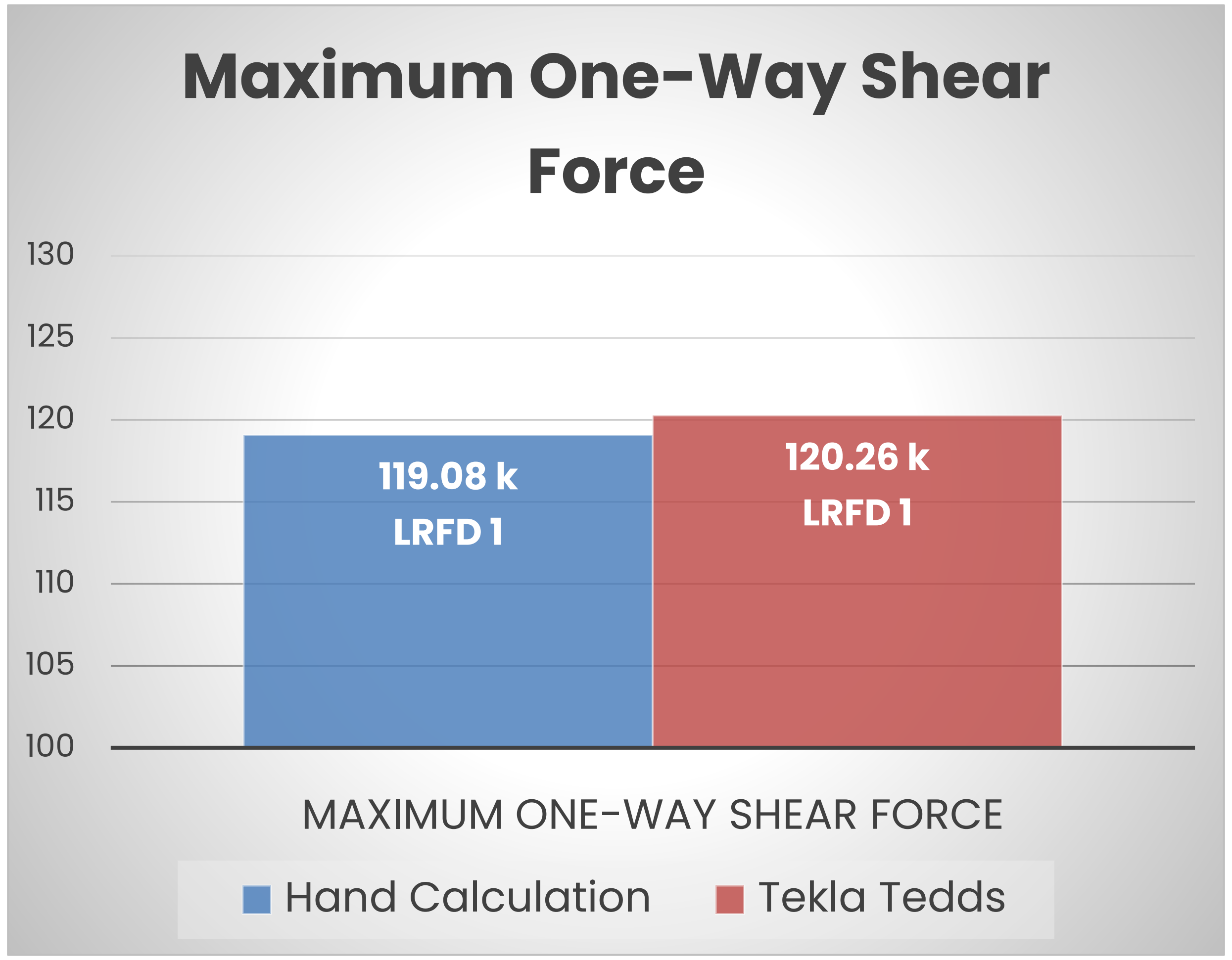
Loading Diagram

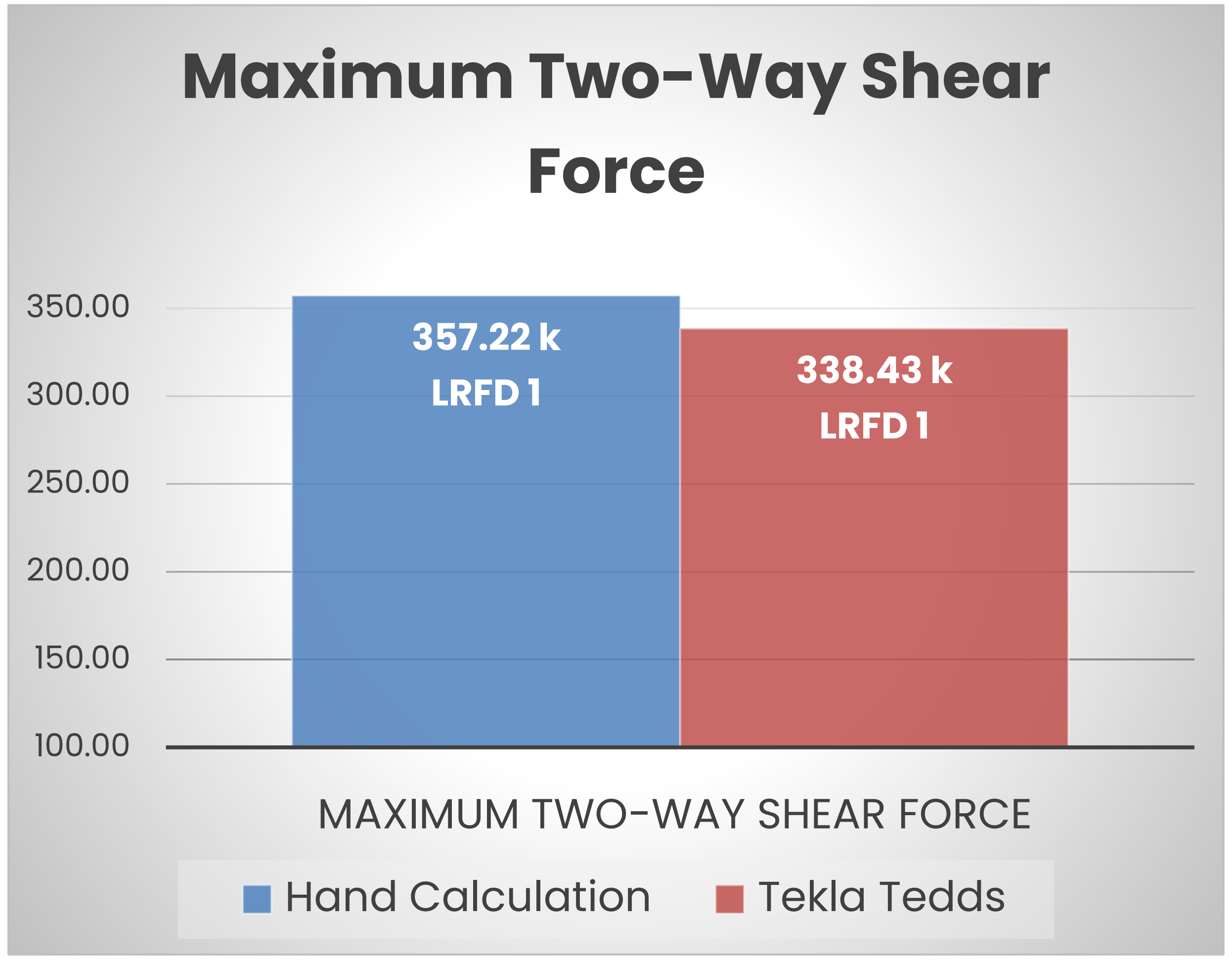


Bearing Pressure Check		
Description	Hand Calculated Design	Tekla Tedds Design
Allowable Bearing Pressure	4 ksf	4 ksf
Maximum Bearing Pressure	3.878 ksf	3.878 ksf
Demand/Capacity	0.970	0.970

Design Forces

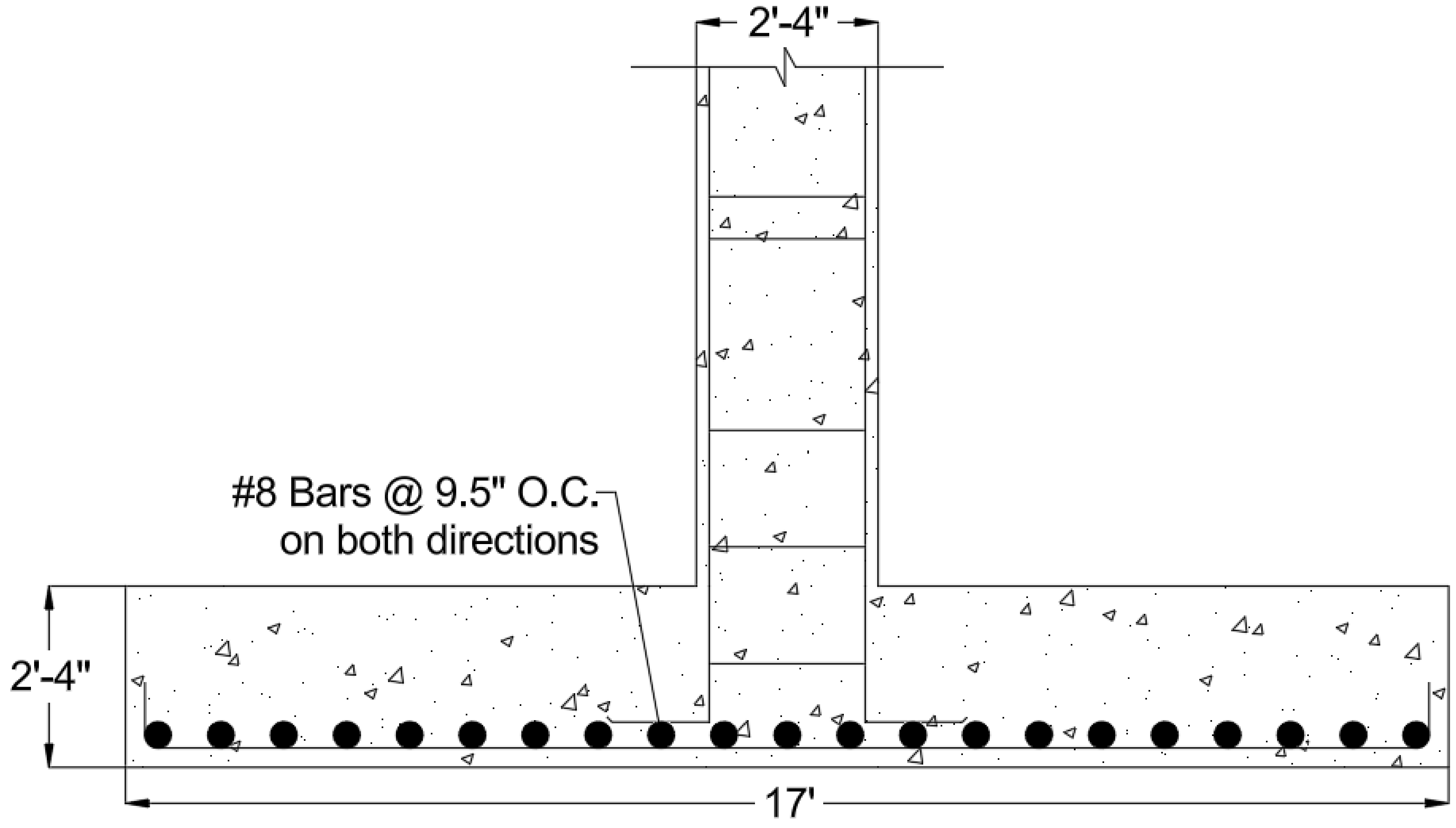






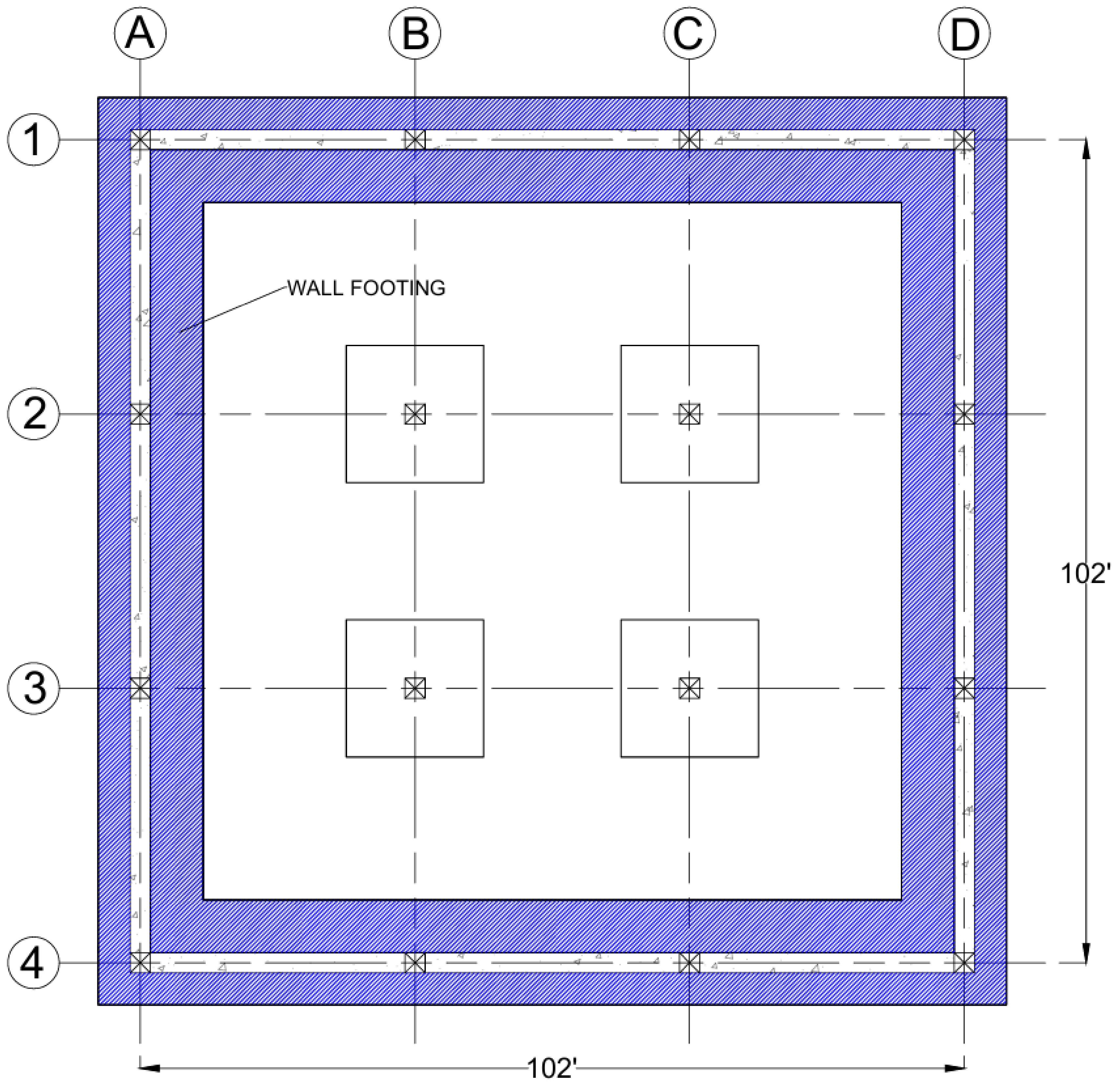
Final Design & Cross Section

Isolated Footing Designs		
Description	Hand Calculated Design	Tekla Tedds Design
Geometry		
Width x Length	17 ft x 17 ft	17 ft x 17 ft
Thickness	28 in	28 in
Flexural Design Details		
Reinforcement	21 #8 rebar@ 9.5" O.C.	24 #6 rebar @ 8.5" O.C.
Design Bending Moment Strength, ϕM_n	1,775.48 k-ft	1,148.48 k-ft
Demand/Capacity	0.341	0.544
One-Way Shear Design Details		
Design One-Way Shear Strength, ϕV_n	474.15 k	244.20 k
Demand/Capacity	0.251	0.492
Two-Way Shear Design Details		
Design Two-Way Shear Strength, ϕV_n	976.20 k	961.63 k
Demand/Capacity	0.366	0.352



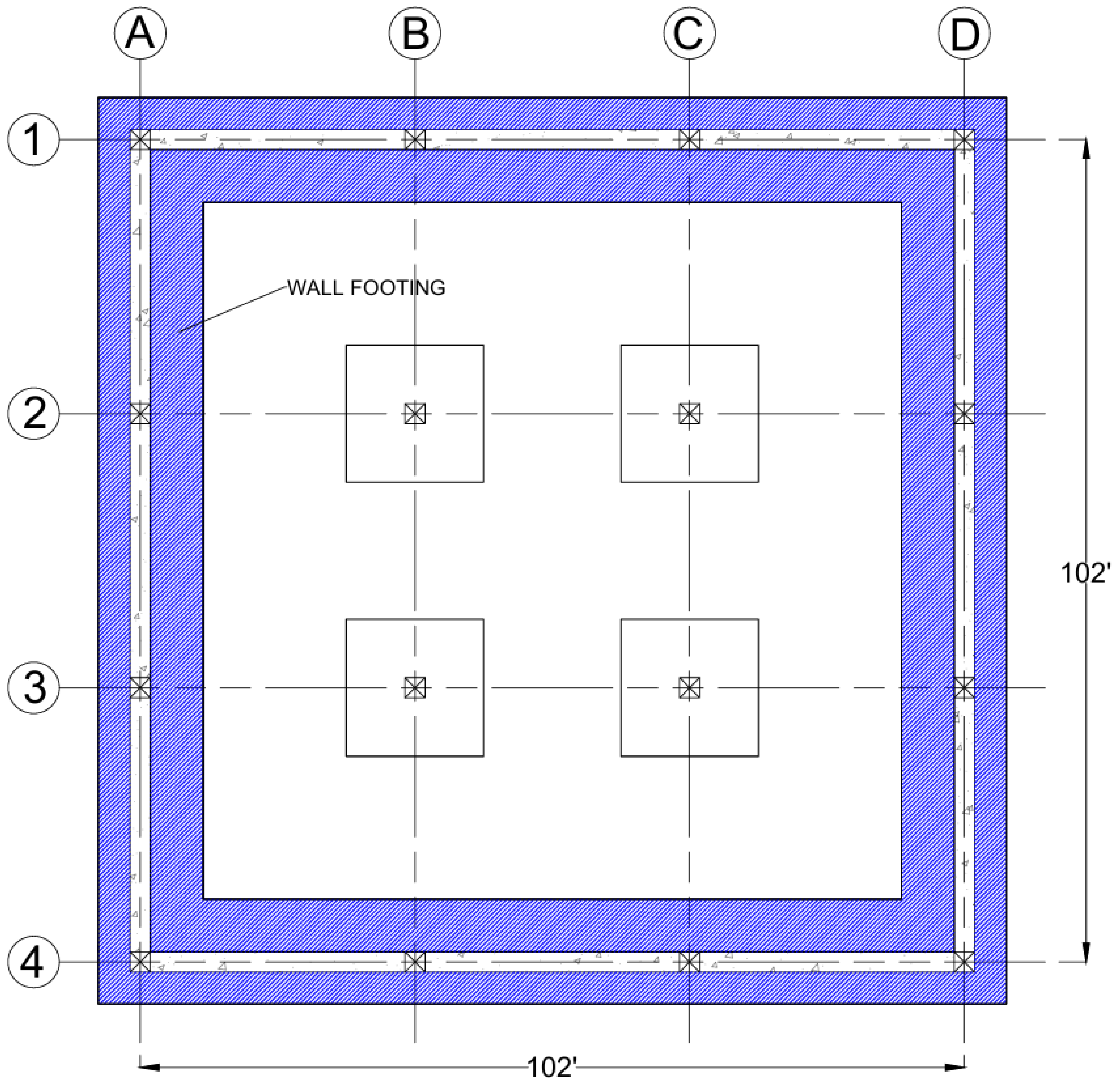
Wall Footing Design Parameters

Design Parameters for Wall Footings	
Yield Strength of Steel, F_y	60 ksi
Compressive Strength of Concrete, f_c'	4 ksi
Water Height	40 ft
Unit Weight of Water	62.4 pcf
Backfill Height	5 ft
Unit Weight of Soil	120 pcf

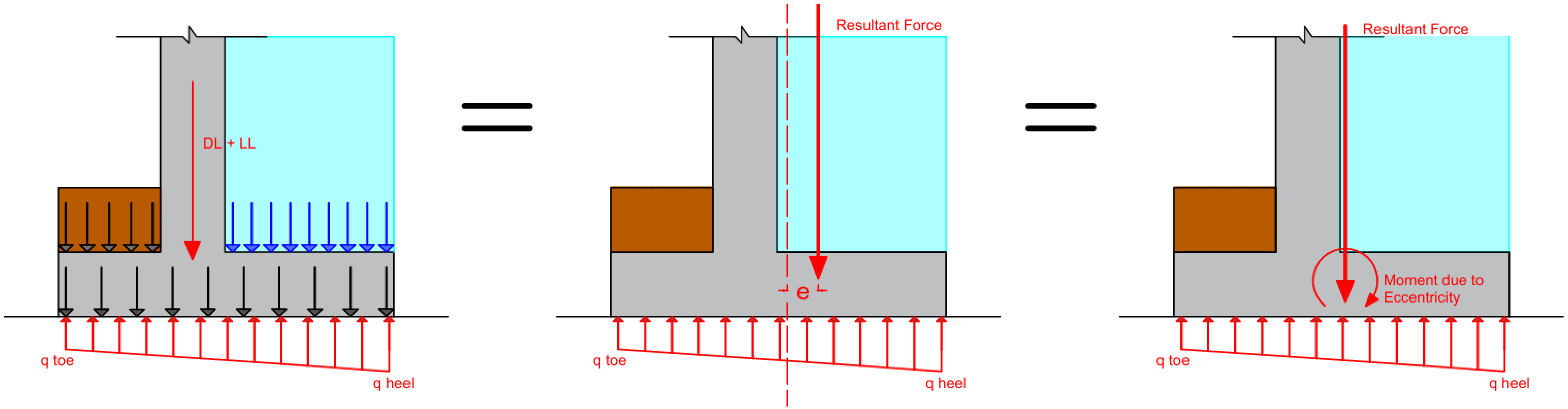


Wall Footing Design Process

1. Determination of Footing Dimensions
2. Bearing Capacity Check
3. Determine Factored Soil Pressure and Design Forces
4. Check for Minimum Depth for Shear
5. Design for Flexural Reinforcement
6. Design for Shrinkage and Temperature Reinforcement
7. Adequacy Check

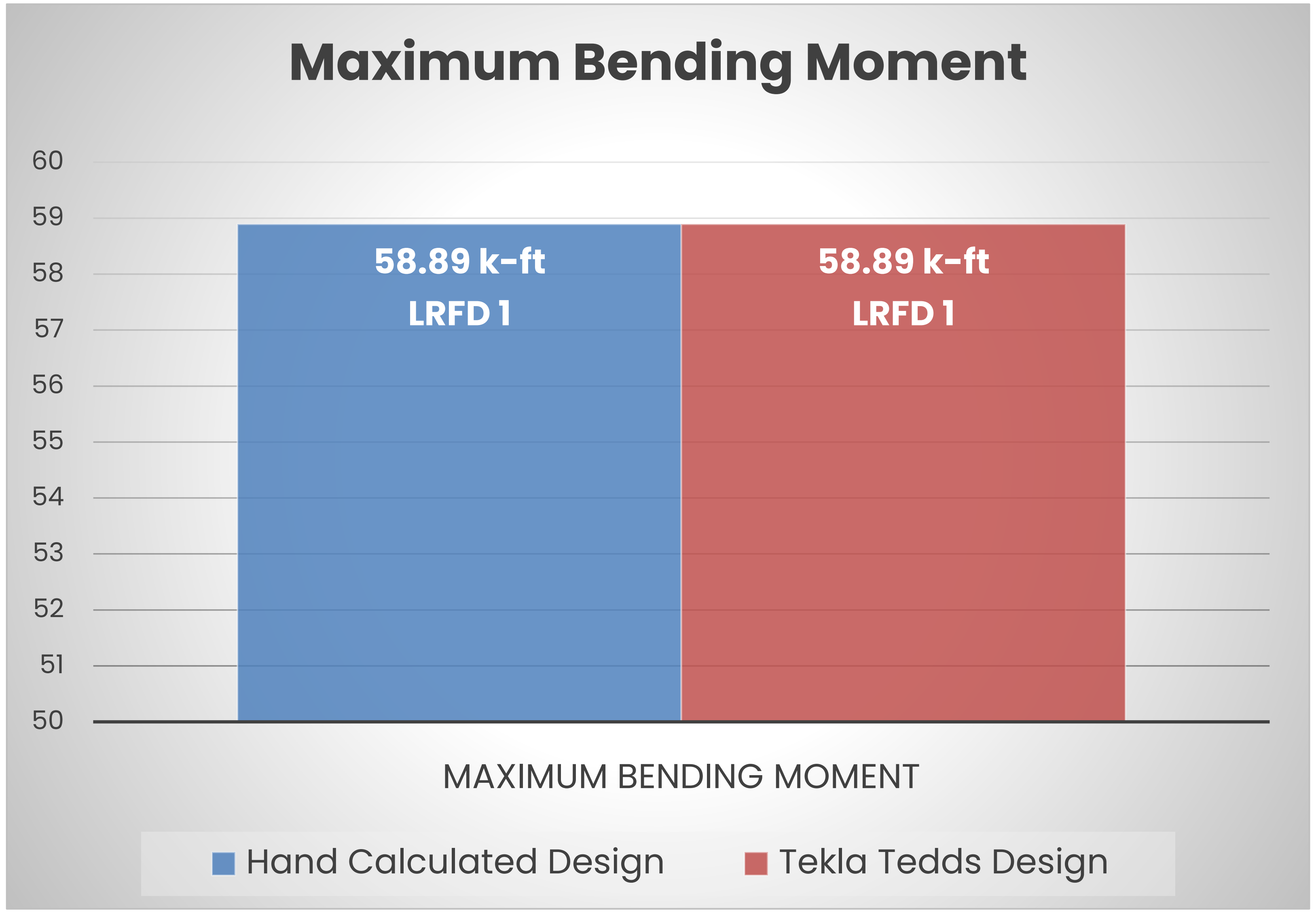


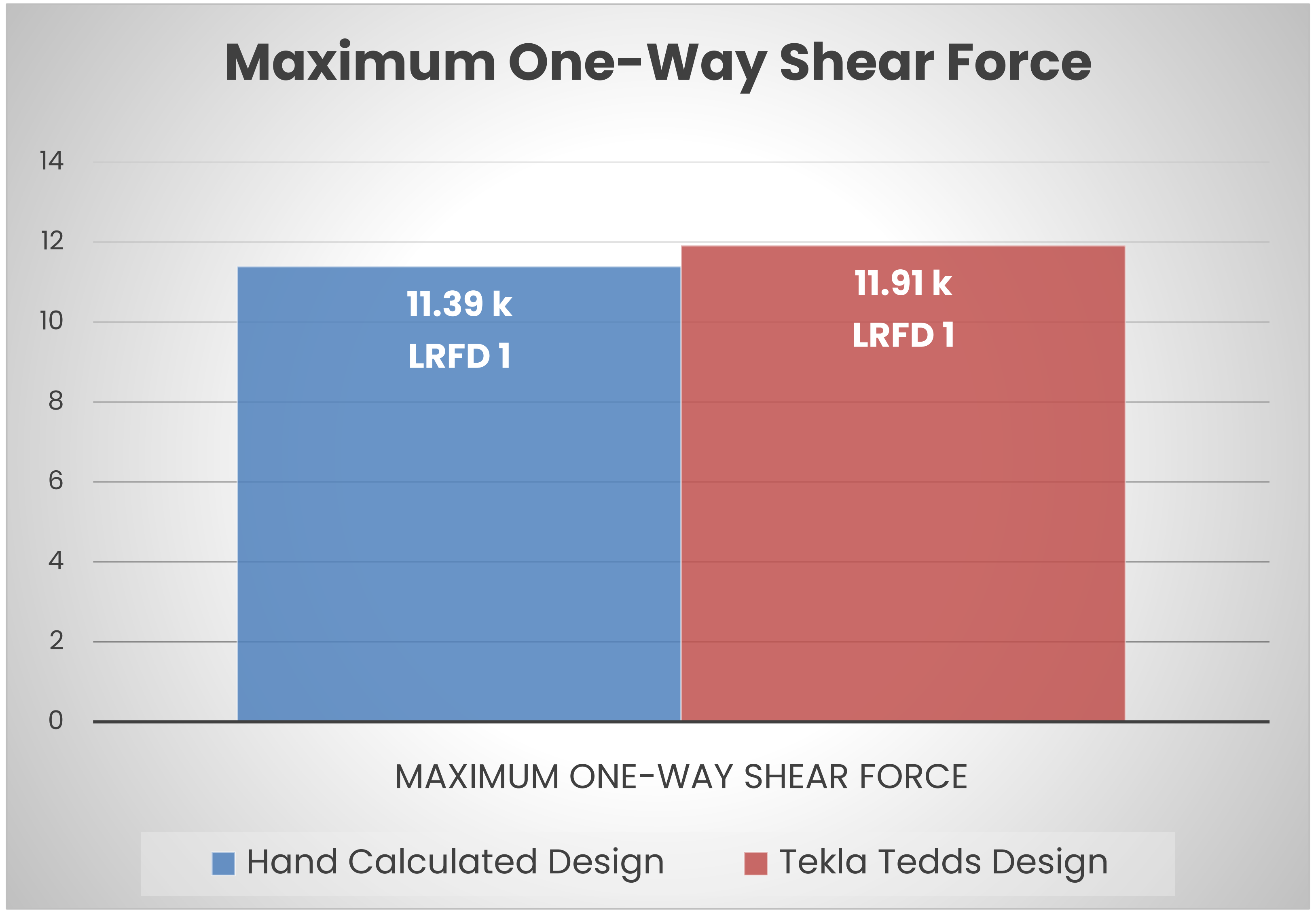
Loading Diagram



Bearing Pressure Check		
Description	Hand Calculated Design	Tekla Tedds Design
Allowable Bearing Pressure	4 ksf	4 ksf
Maximum Bearing Pressure	3.961 ksf	3.952 ksf
Demand/Capacity	0.990	0.988

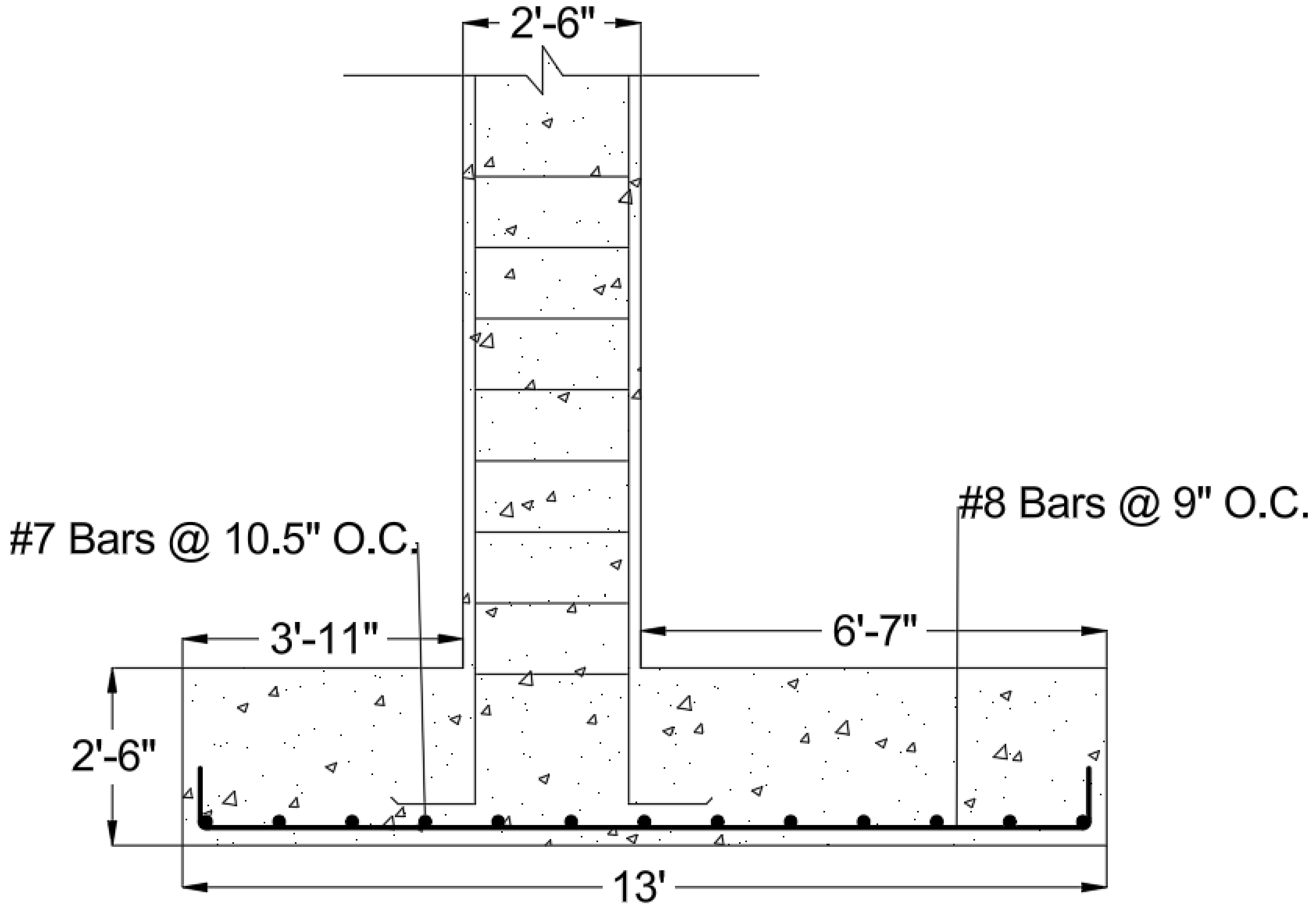
Design Forces





Final Design & Cross Section

Wall Footing Design Summary and Comparison		
Description	Hand Calculated Design	Tekla Tedds Design
Geometry		
Breadth	13 ft	13 ft
Thickness	30 in	30 in
Flexural Design Details		
Reinforcement	#8 @ 9" O.C.	#7 @ 11" O.C.
Design Bending Moment Strength, ϕM_n	121.56 k-ft	76.82 k-ft
Demand/Capacity	0.484	0.767
One-Way Shear Design Details		
Design One-Way Shear Strength, ϕV_n	30.17 k	15.37 k
Demand/Capacity	0.377	0.775
Temperature Reinforcement Design Details		
Reinforcement	#7 @ 10.5" O.C.	#7 @ 11" O.C.



Objective 2:
Stormwater Analysis and Design

Stormwater Analysis

Stormwater Components

Dry Swale

Grass Channel

Sediment Forebay

Infiltration Basin

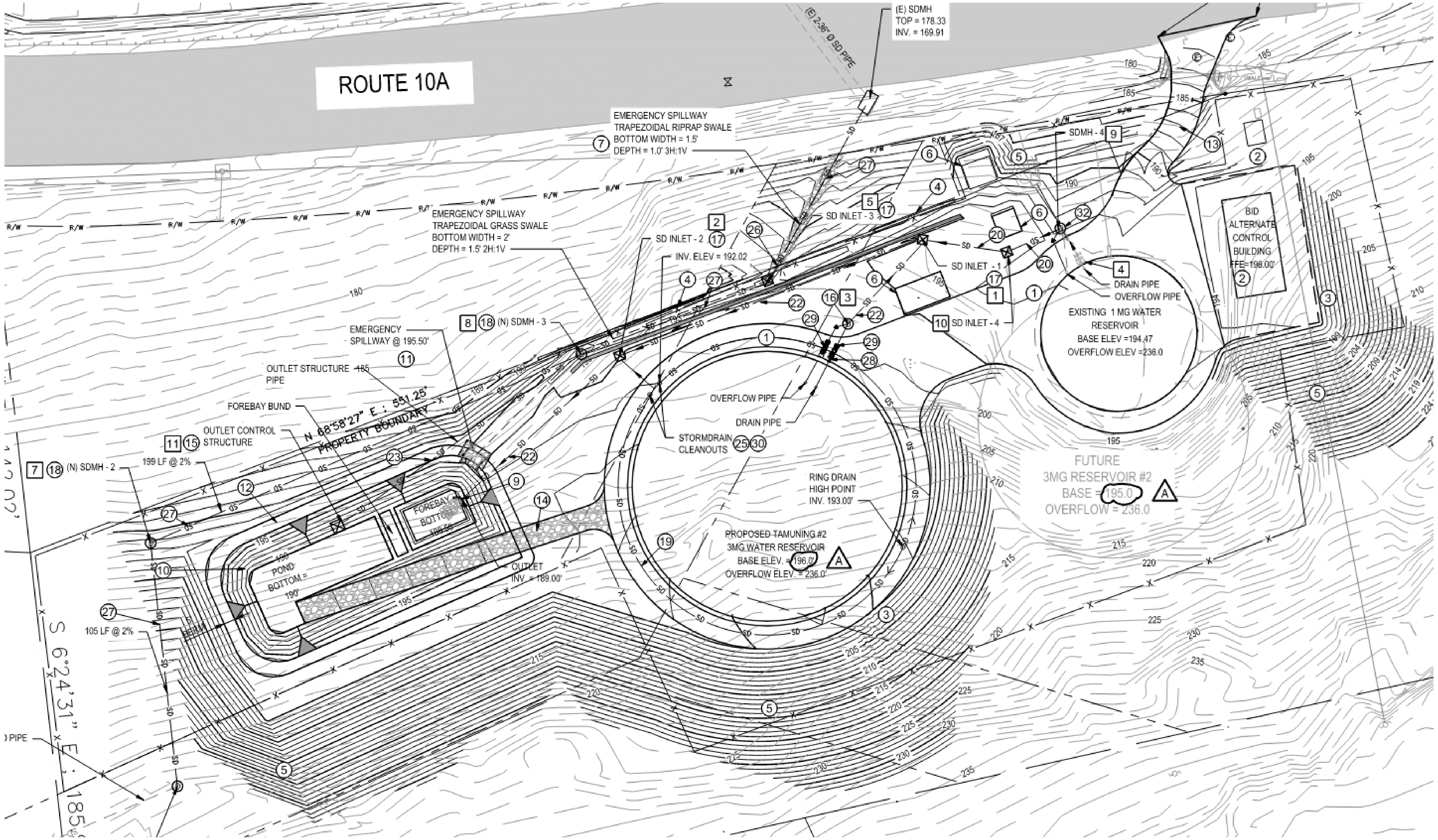
Emergency Spillway

Methodology

CNMI & Guam Stormwater Management Manual Vol. 1&2

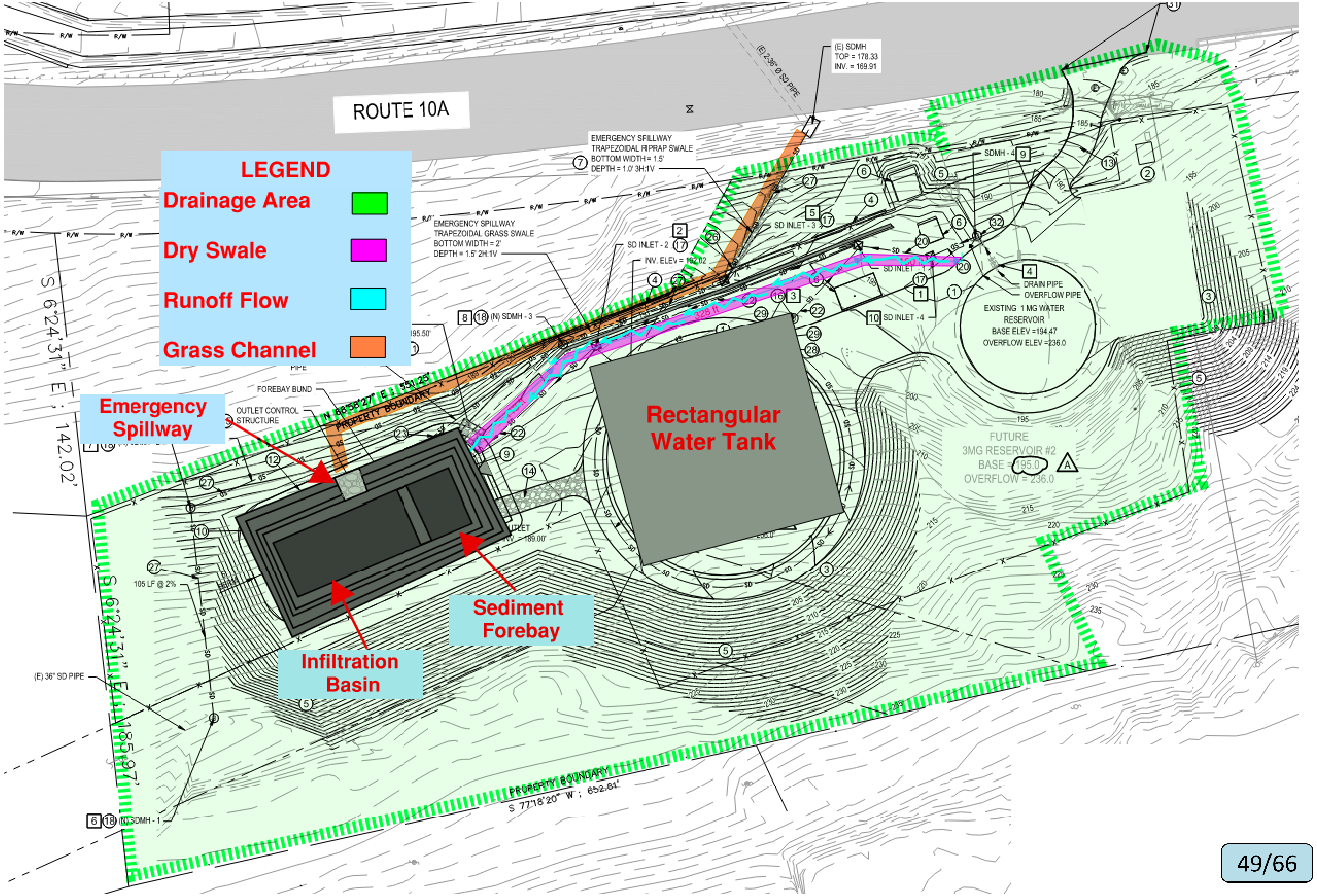
and

WIN TR-55



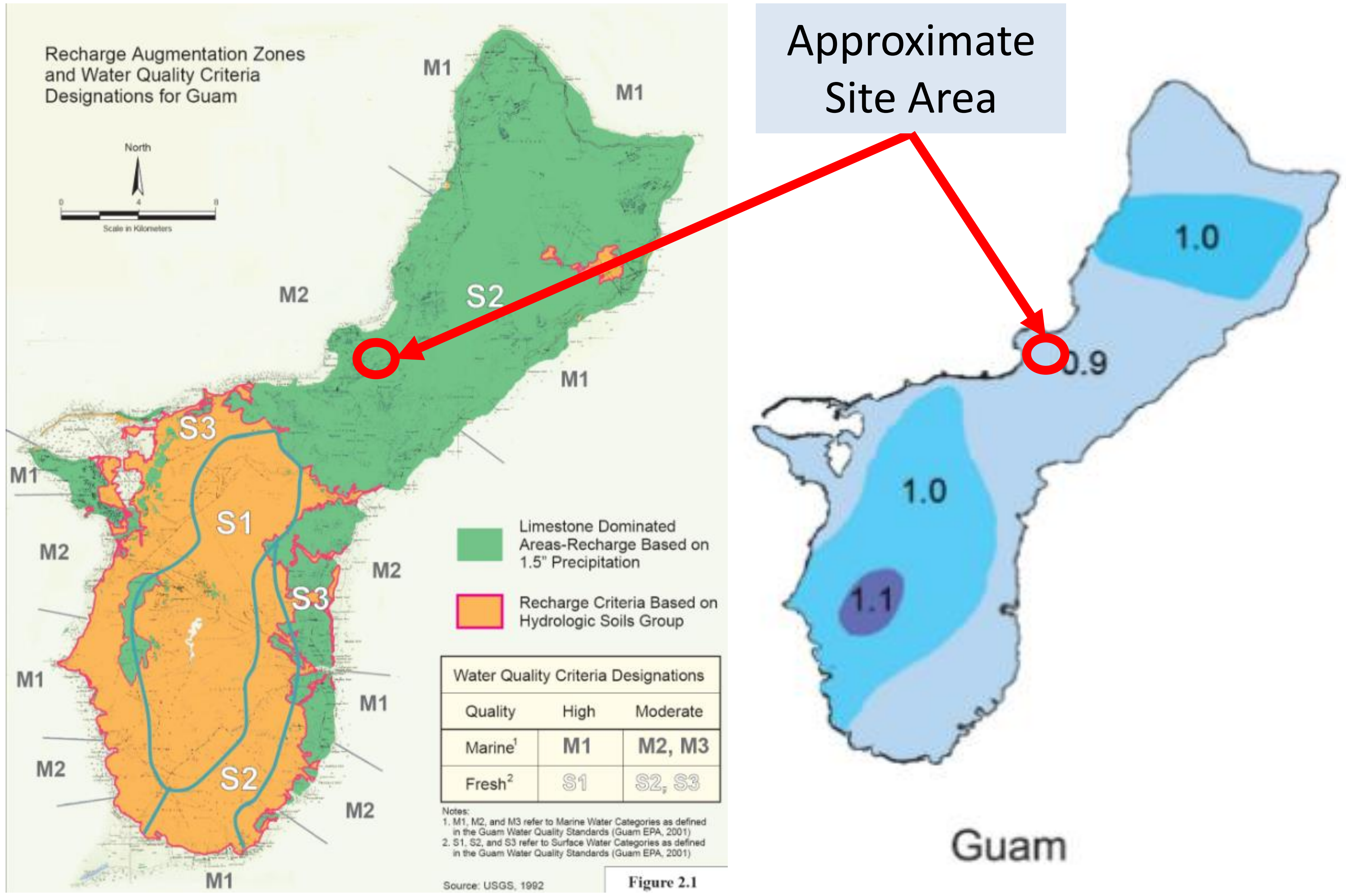
Stormwater Analysis

Drainage Areas		
Item	Hand Calculated Design	GHD Design
Overall Site Area	2.99 ac.	2.99 ac.
Site Drainage Area	2.99 ac.	2.23 ac.
Post Dev. Impervious area	0.40 ac.	0.99 ac.



Unified Sizing Criteria

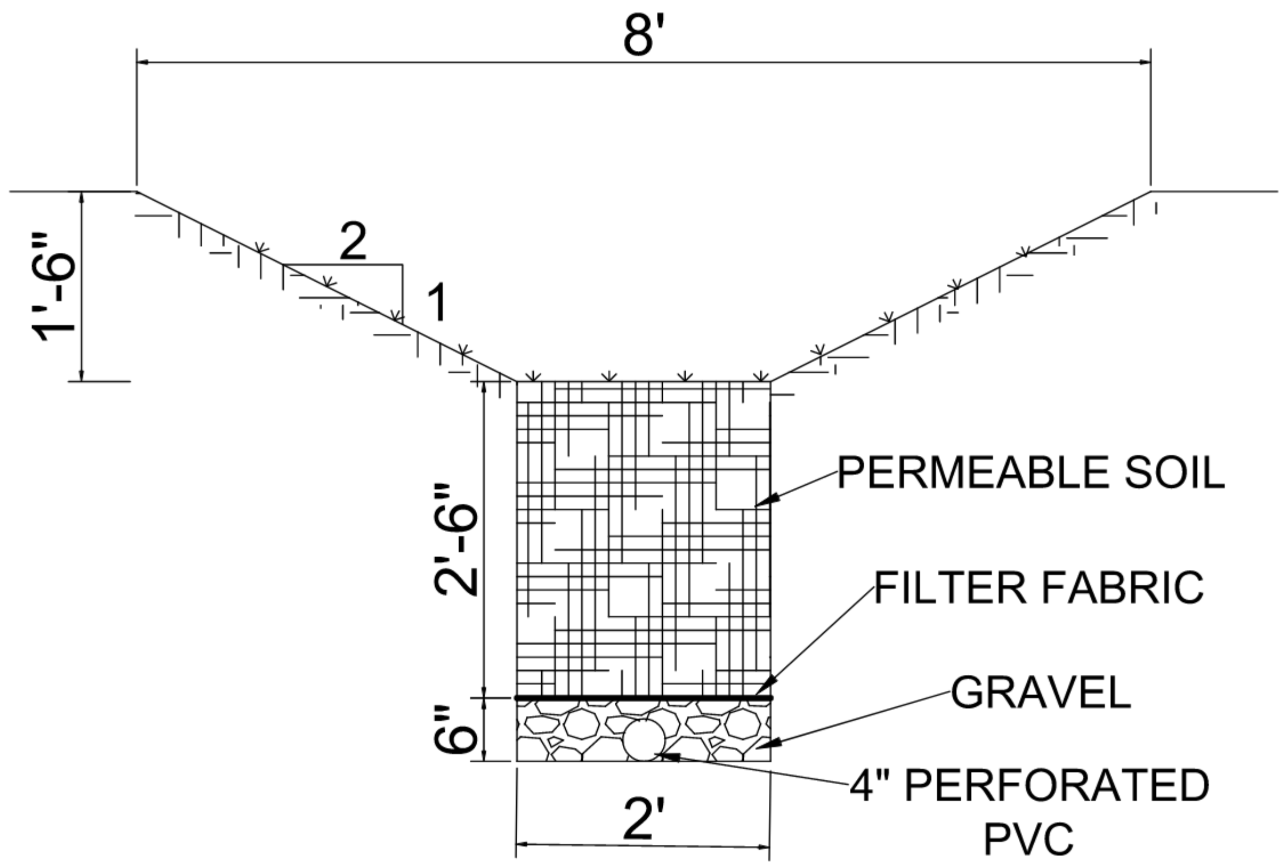
Unified Sizing Criteria		
Criteria	Hand Calculated Design	GHD Design
Recharge, Re_v	2,178 $ft.^3$	5,398 $ft.^3$
Water Quality, WQ_v	2,178 $ft.^3$	5,398 $ft.^3$
Channel Protection, Cp_v	Waived	Waived
Overbank Flood Control Q_{p-25}, Vs	21,105 $ft.^3$	17,619 $ft.^3$



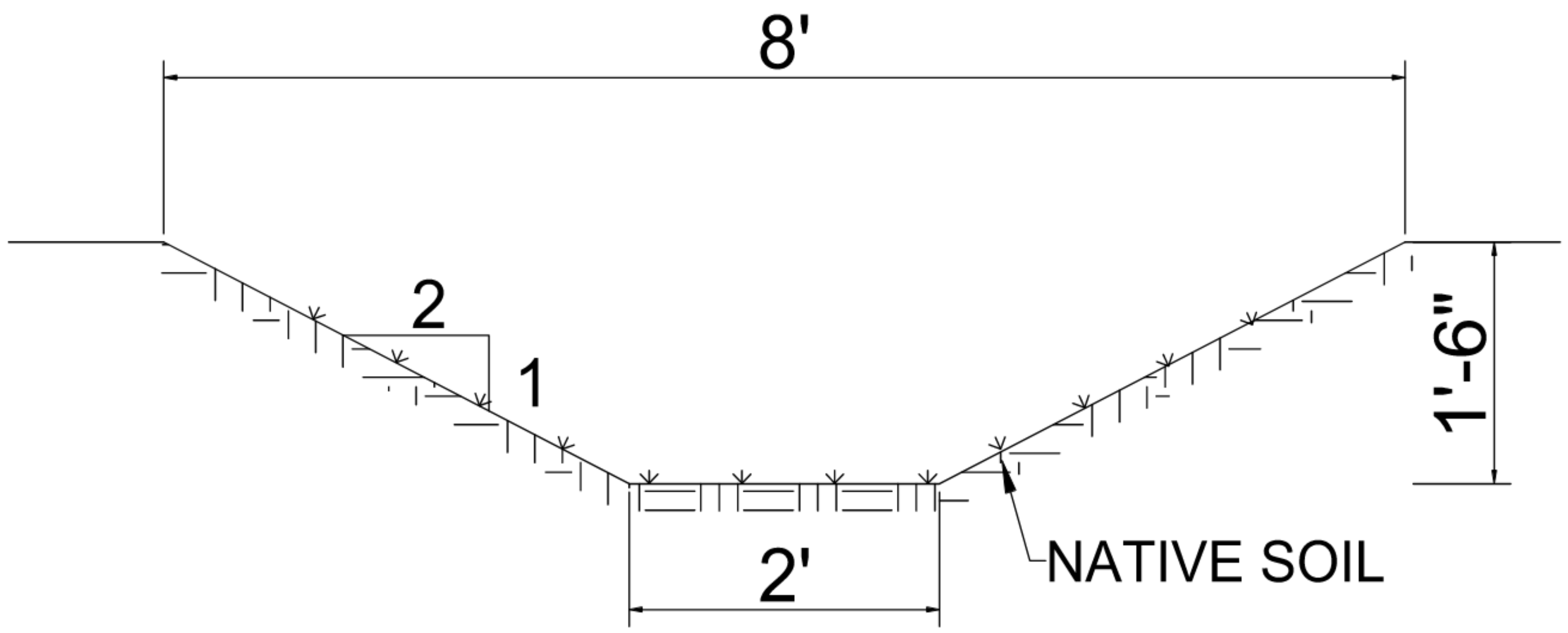
Stormwater Design

Tr-55 Peak Discharge Data	
Peak Discharge for 1-year storm	0.60 cfs
Peak Discharge for 2-year storm	2.50 cfs
Peak Discharge for 10-year storm	4.37 cfs

Dry Swale Design



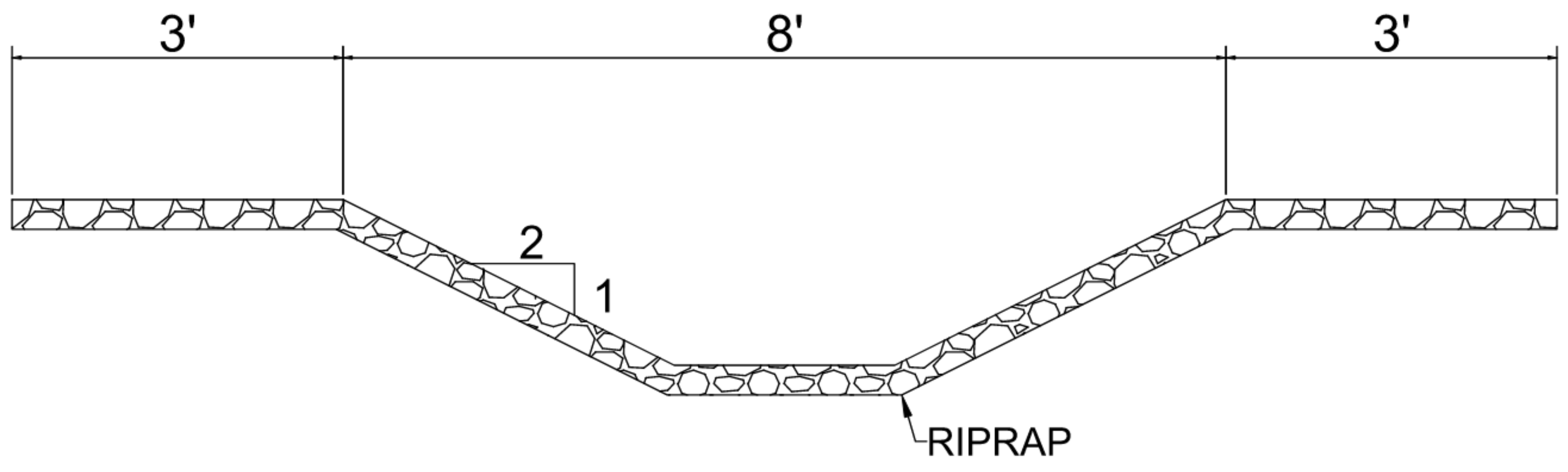
Grass Channel Design



Stormwater Design

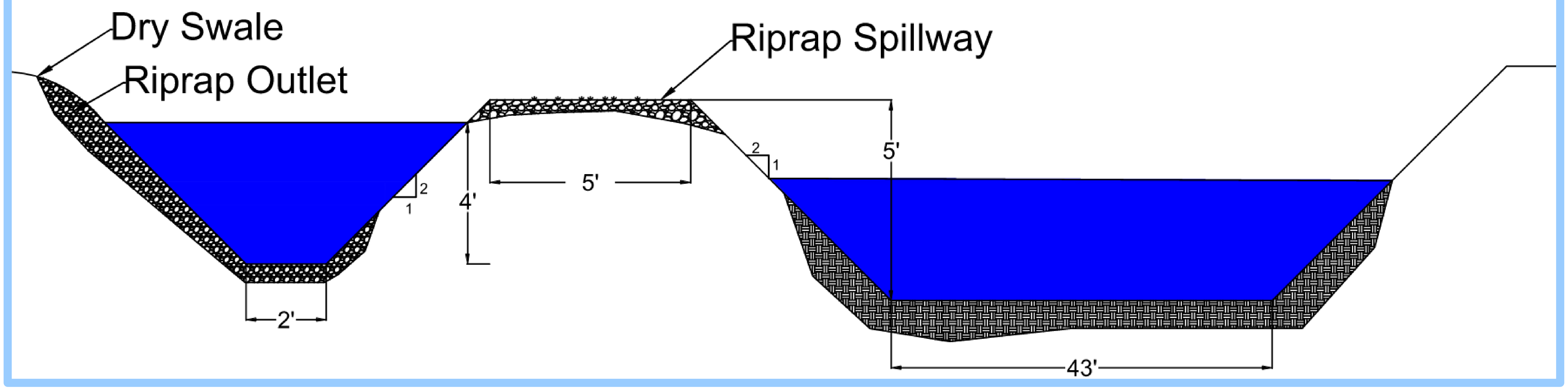
Volume		
Stormwater component	Hand Calculated Design	GHD Design
Sediment Forebay	656 $ft.^3$	691.06 $ft.^3$
Infiltration Basin	21,527 $ft.^3$	18,734.90 $ft.^3$
Emergency Spill Way	23,422 $ft.^3$	21,656.15 $ft.^3$

Emergency Spillway



Sediment Forebay Design

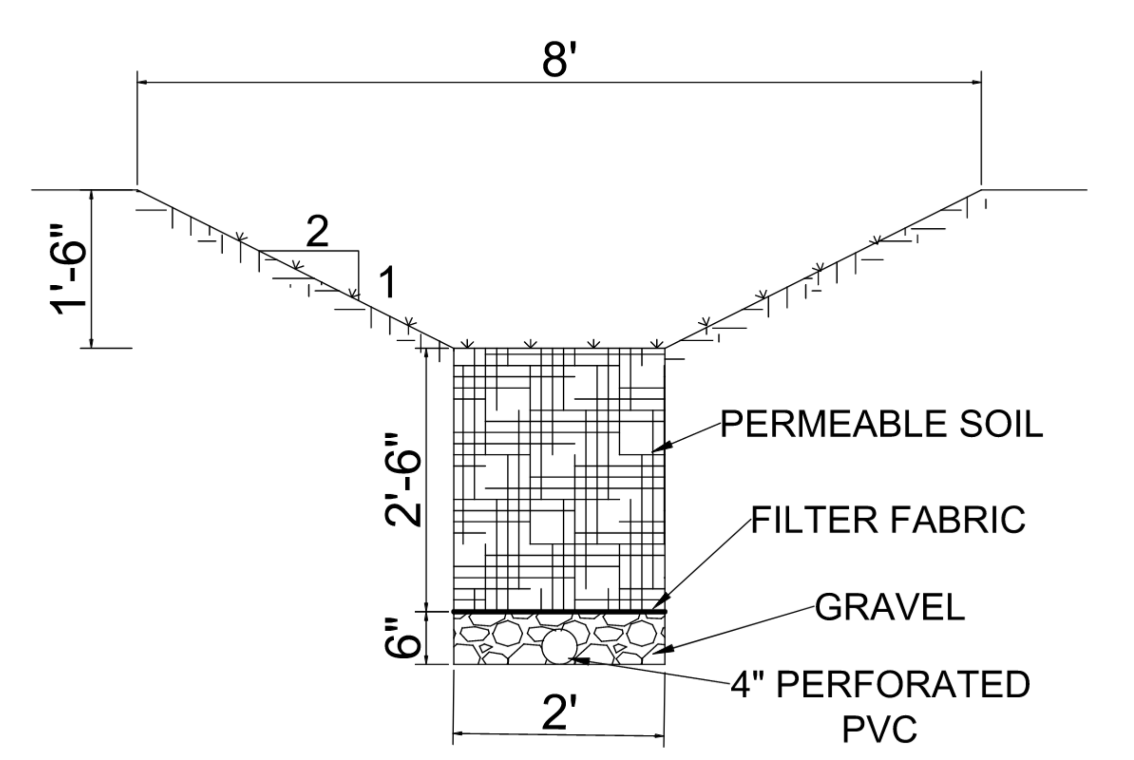
Infiltration Basin Design



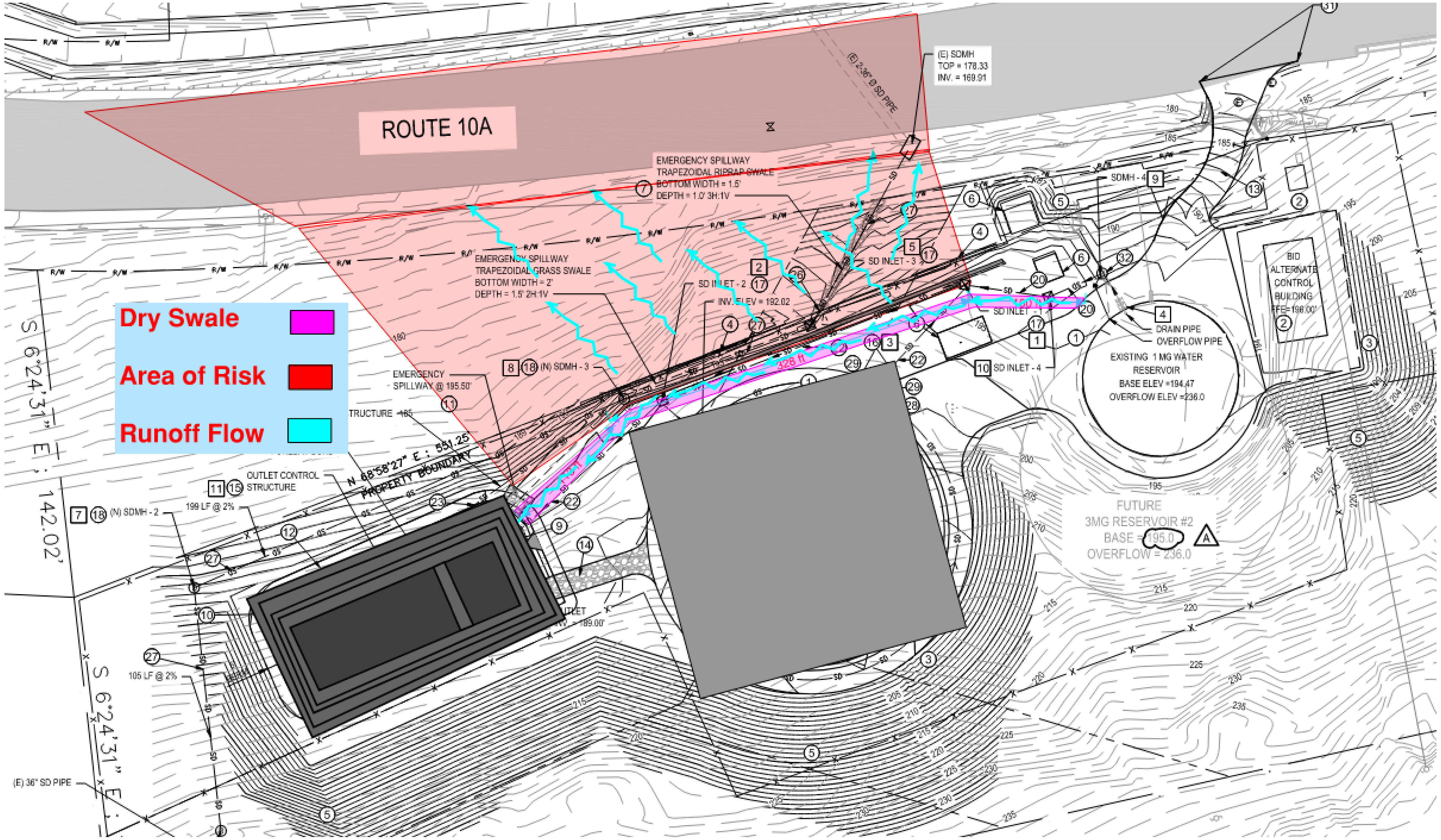
Objective 3:
Risk Analysis

Risk Identification

Original Dry Swale Design

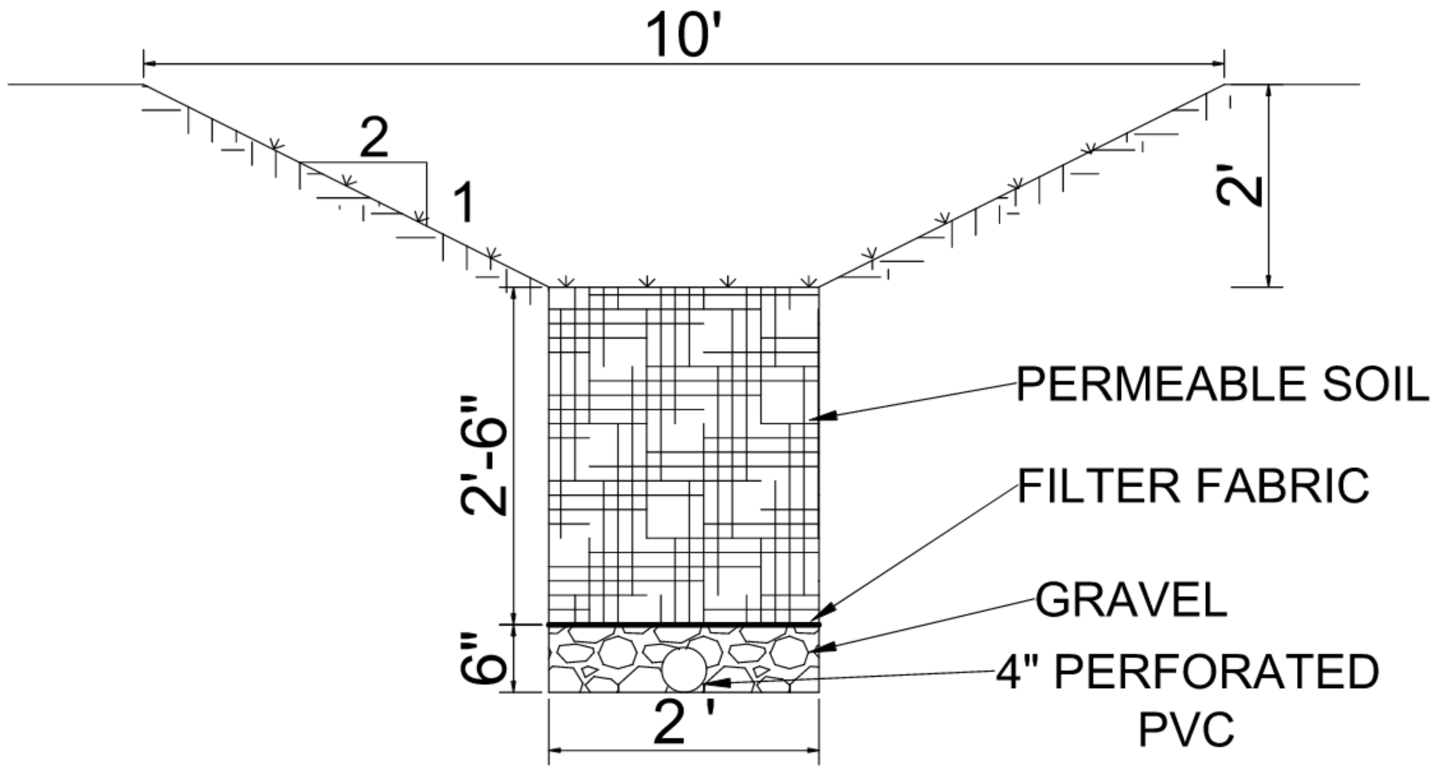


Discharge per storm event	Volume	$Q_p > Q_{0,\ max\ dry\ swale}$
$Q_{0,\ max\ dry\ swale}$	11 cfs	
Q_{p-10}	4.37 cfs	OK
Q_{p-25}	10.8 cfs	OK
Q_{p-50}	15.3 cfs	NG

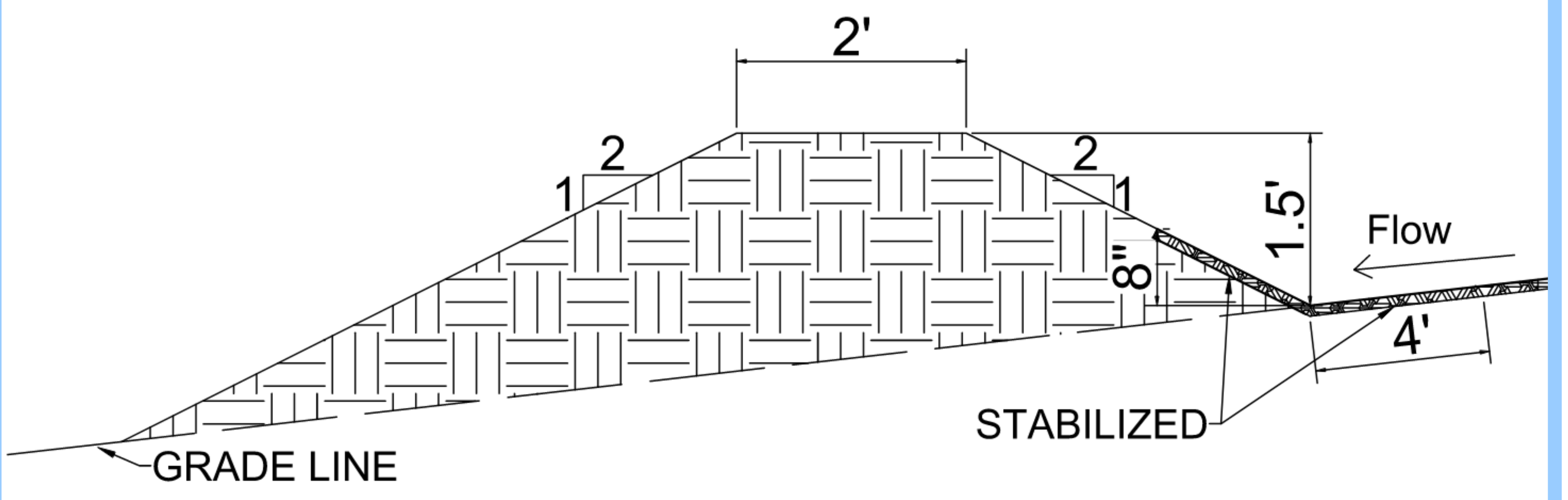


Risk Mitigation

Option 1: Increase Dry Swale



Option 2: Install Earth Dike/Berm

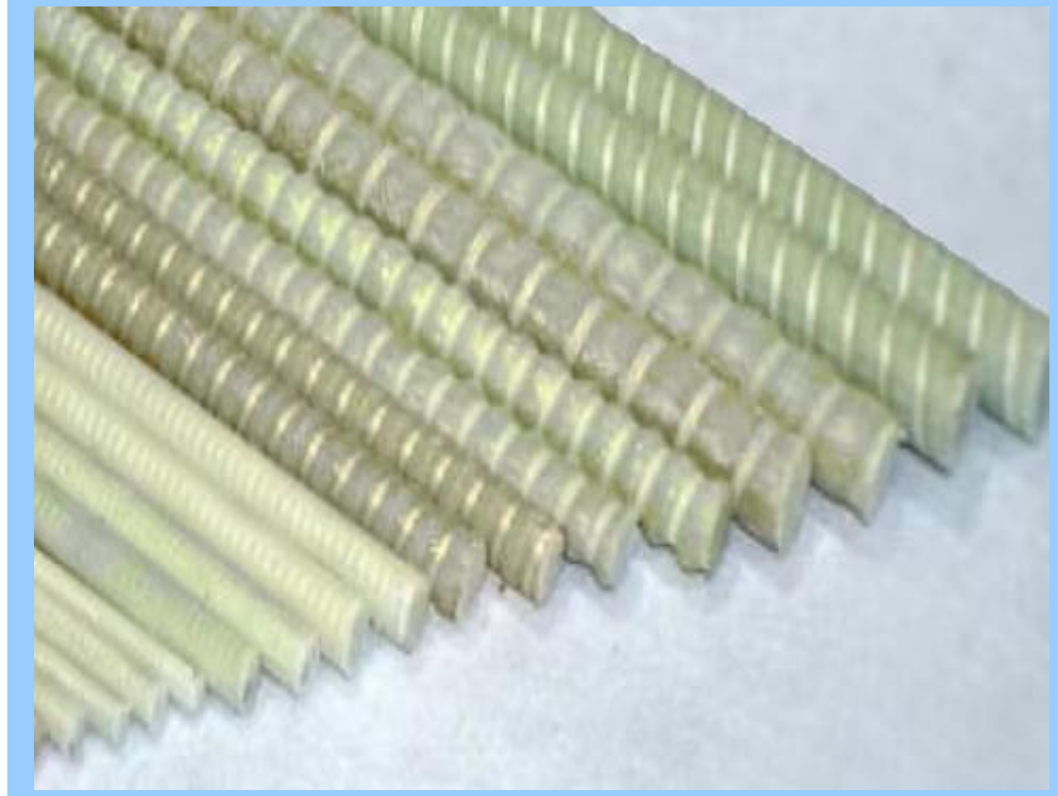


Comparison of Possible Risk Mitigation Designs	
Option 1: Increased Dry Swale	Option 2: Install Earth Dike/Berm
Q_{max} = 20.68 cfs	Q_{max} = 2.31 cfs
Unit Price per yd^3 = \$72.39	Unit Price per yd^3 = \$65.26
Overall Cost = \$17,406	Overall Cost = \$11,588

RSMeans data from GORDIAN®

Objective 4: Sustainability

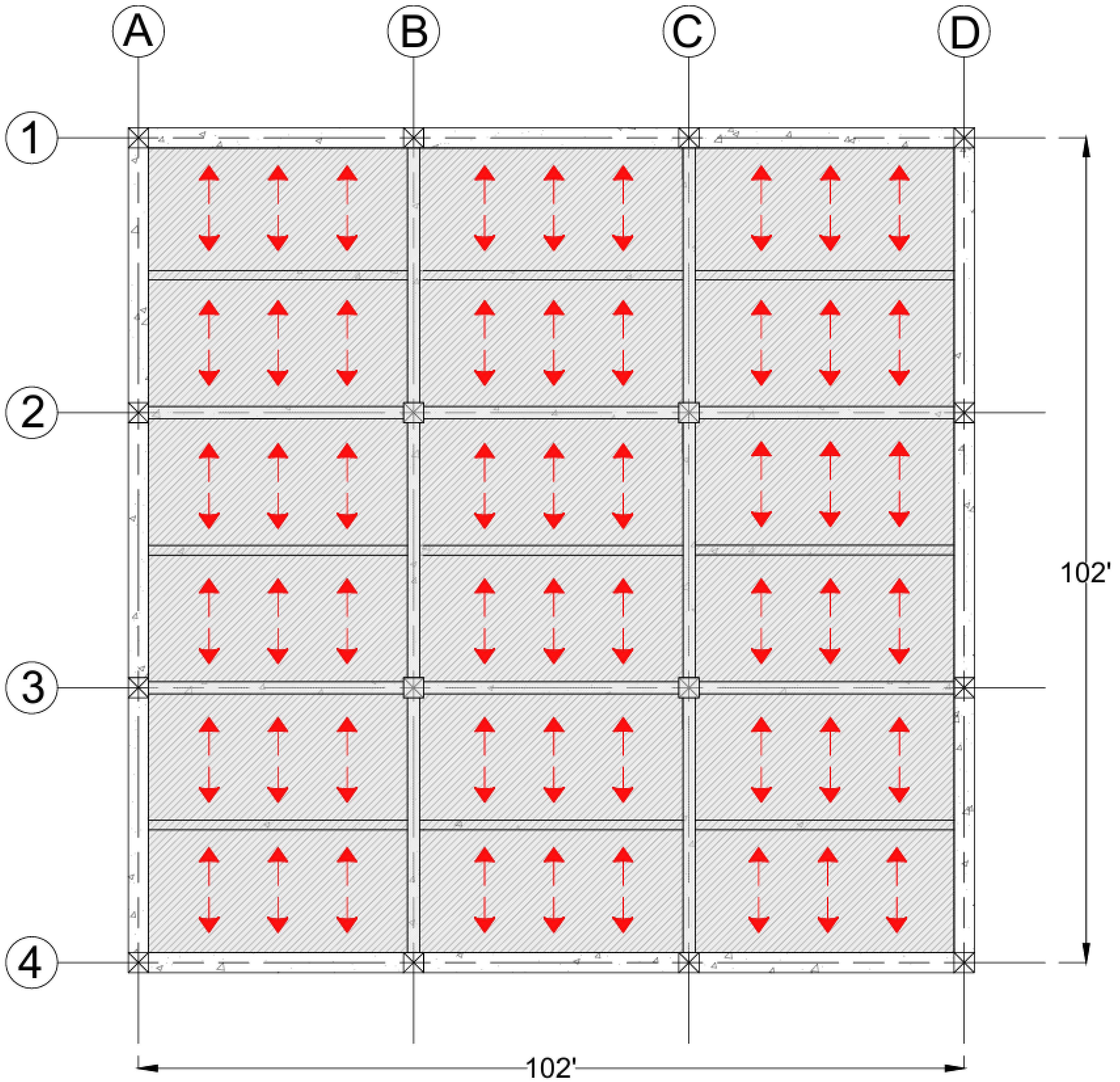
Introduction



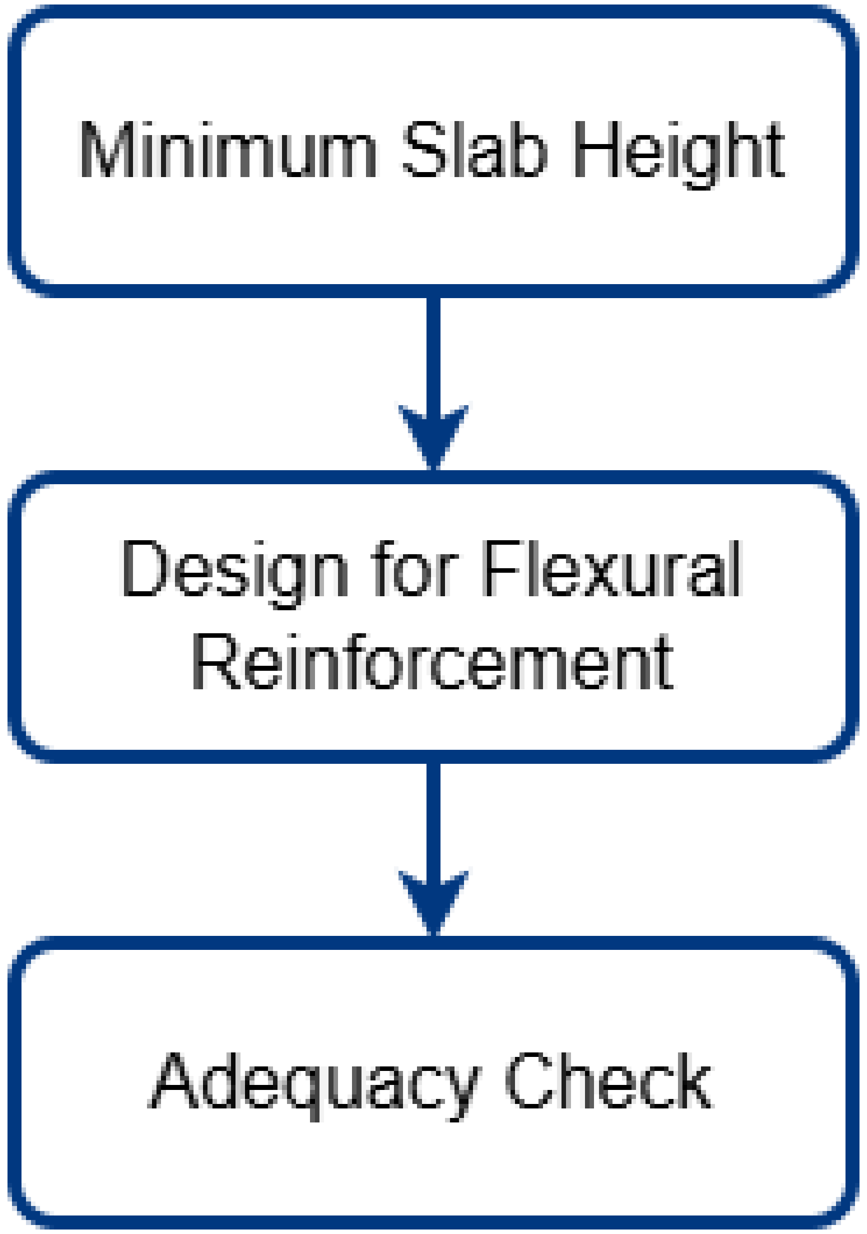
- Integrate sustainable practices in the structural design of a reinforced concrete water tank.
- Use of Glass Fiber Reinforced Polymer (GFRP) rebars instead of conventional steel
- Corrosion Resistance, High Tensile Strength, Lightweight.

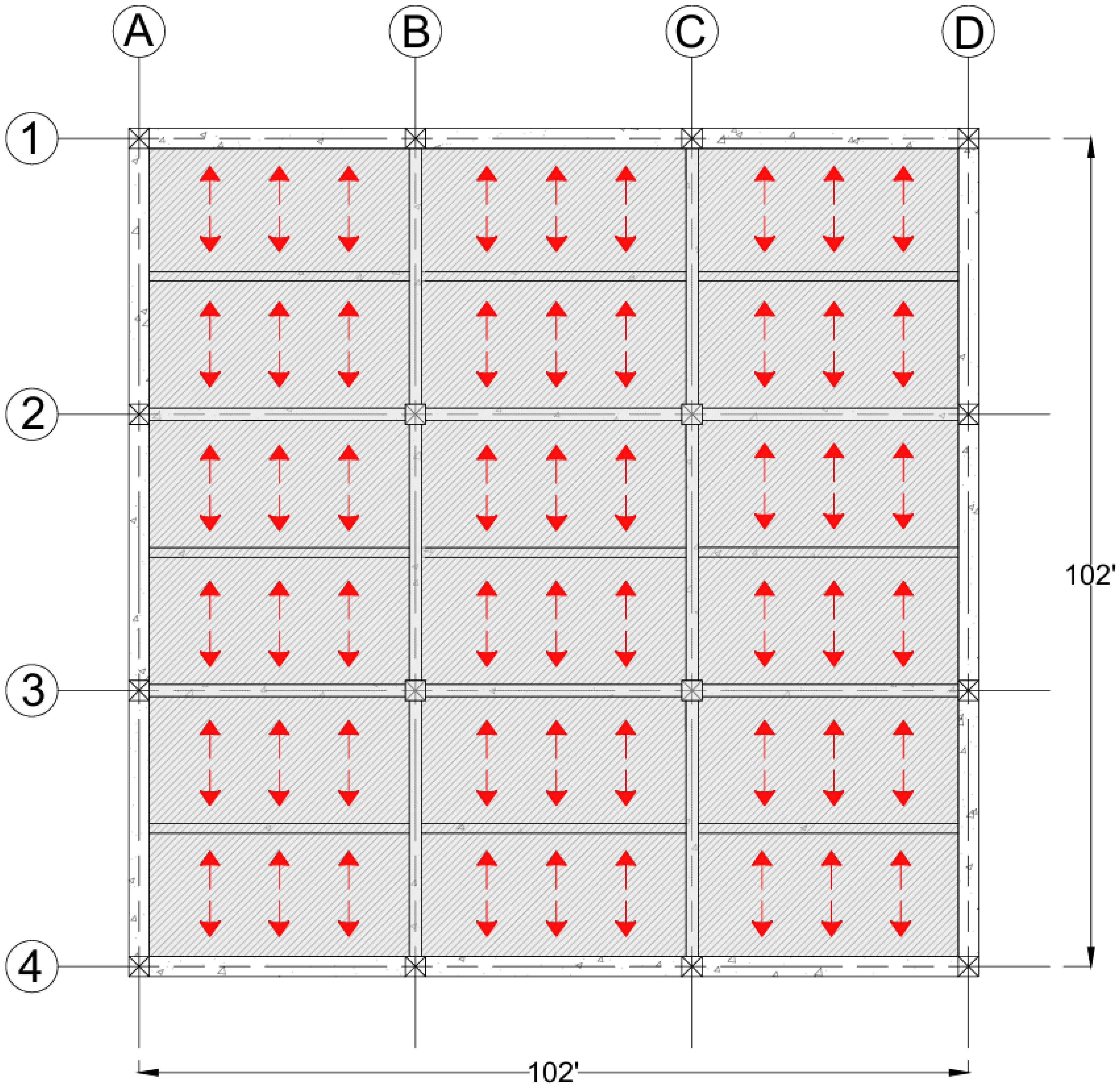
GFRP Reinforced Slab Design Parameters

GFRP One-Way Slab Design Parameters	
Guaranteed Tensile Strength of GFRP, f^*_{fu}	80 ksi
Environmental Reduction Factor	0.7
Tensile Strength of GFRP, f_{fu}	56 ksi
Strength of Concrete, f'_c	5 ksi
Modulus of Elasticity, E_f	6,000 ksi
Ultimate GFRP Strain at Failure	0.0093
Ultimate Concrete Strain at Failure	0.003



GFRP Reinforced Slab Design Process



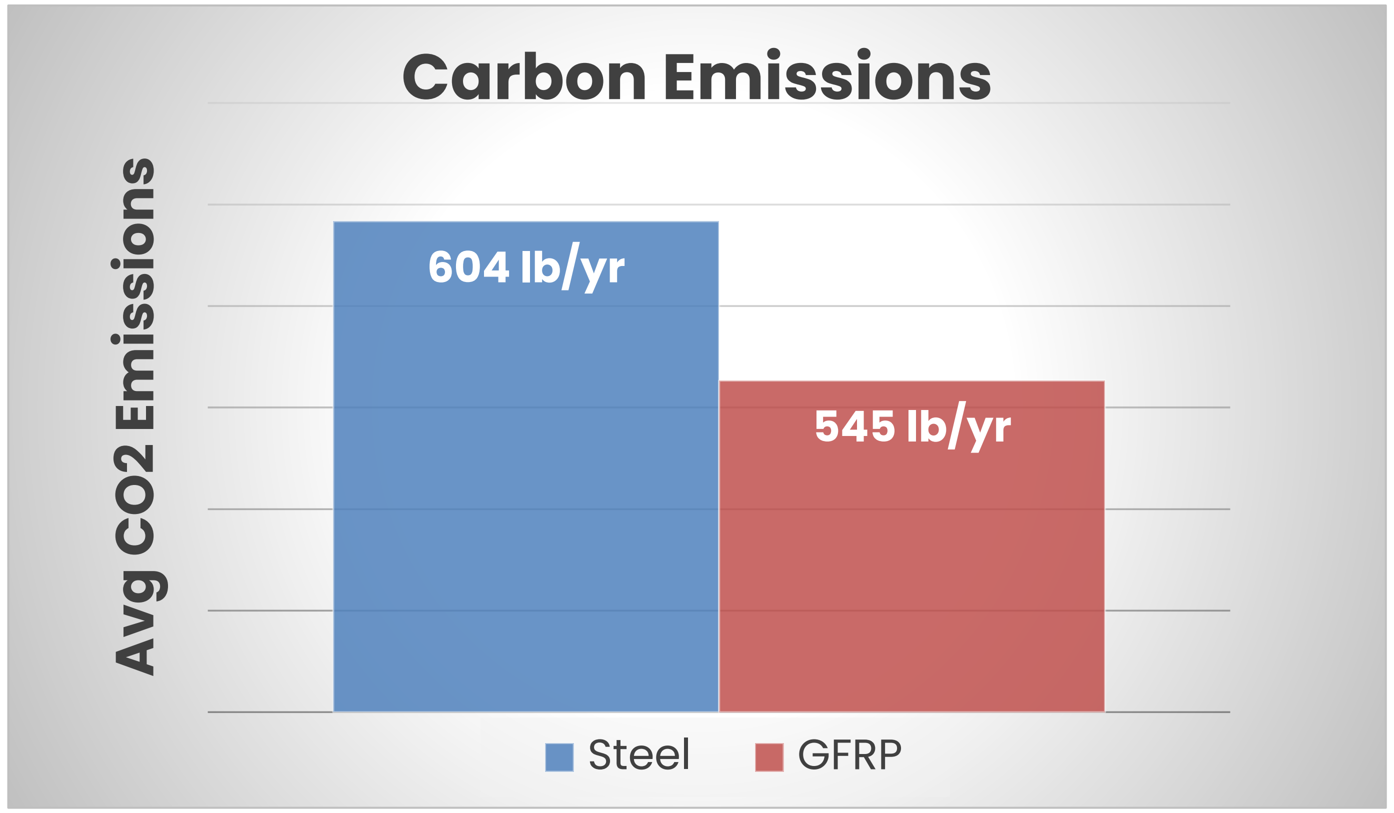


GFRP Reinforced Roof Slab Final Design

GFRP & Steel Design Summary and Comparison		
Description	Steel	GFRP
Geometry		
Thickness of slab	10.5 in.	10.5 in.
Flexural Design Details		
Flexural Reinforcement	#5 @ 10" O.C.	#9 @ 8" O.C.
Maximum Bending Design, M_u	7.37 k-ft	7.37 k-ft
Design Bending Moment Capacity, ΦM_n	14.10 k-ft	29.29 k-ft
Demand/Capacity	0.52	0.25

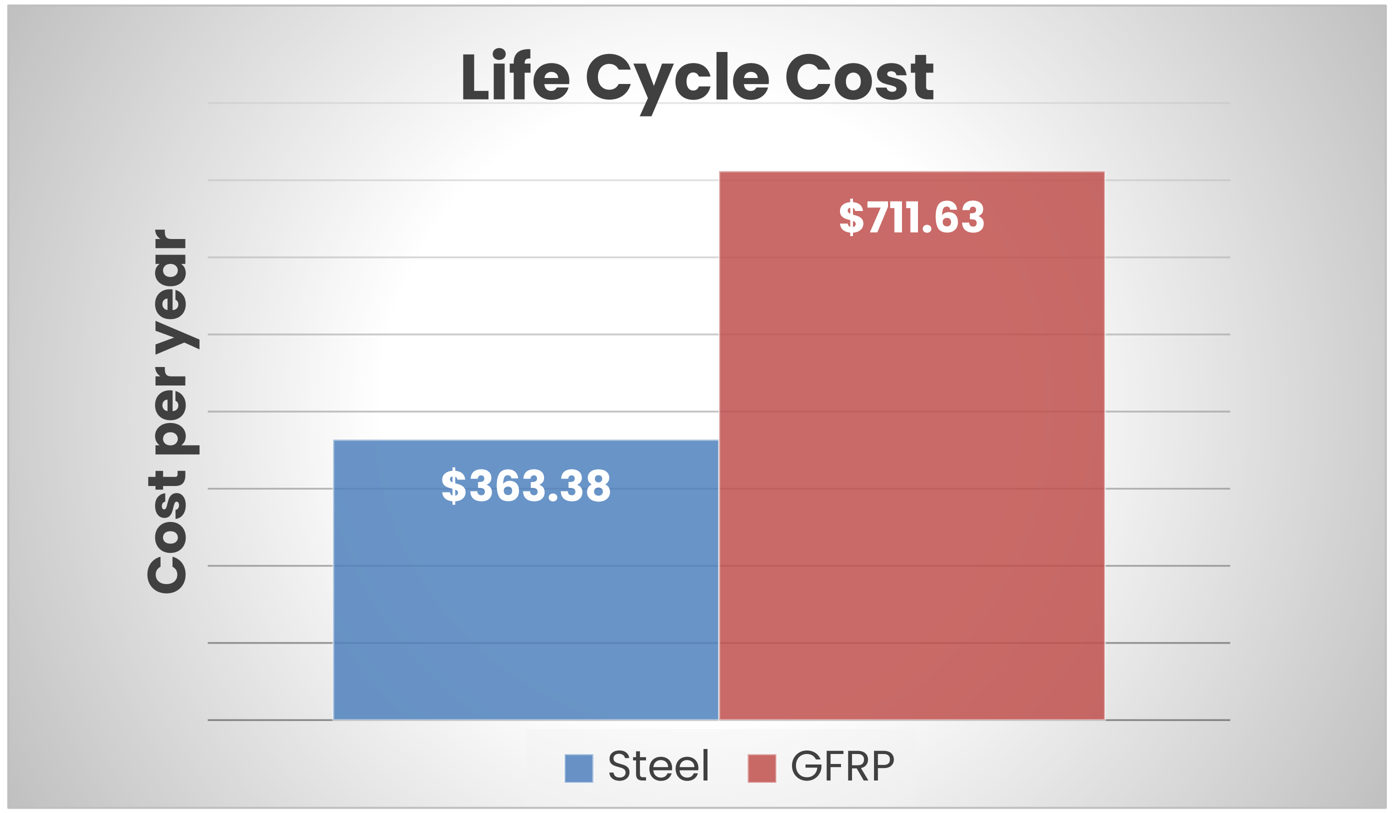
GFRP Reinforced Roof Slab

Average CO_2 Emissions		
Item Description	Steel Rebar	GFRP
Total CO_2 Emission	36,264.39 lbs	32,672.11 lbs
Service Life	50 - 75 Years	50 - 100 Years
Average Emissions per Service Year	604.4 lbs	544.53 lbs



Cost Analysis in Roof Slab Design		
Item Description	Steel Rebar	GFRP
Total weight of Flexural Reinforcement	6.59 ton	6.43 ton
Unit Cost	$5,520.15/ton	$11,067.39/ton
Total Cost	$36,377.79	$71,163.36

RSMeans data from GORDIAN®



Advantages of GFRP over Steel

Comparison of GFRP vs. STEEL Roof Slab Design	
STEEL	GFRP
ϕMn=14.10 k-ft	ϕMn=29.29 k-ft
Higher Carbon Emission	Less Carbon Emission
50-75 Year Service Life	50-100 Year Service Life
High Density	Lightweight
Higher Modulus of Elasticity	Lower Modulus of Elasticity
Low Cost	Higher Cost

Conclusion and Future Works

Conclusion

- Designed a rectangular reinforced concrete water tank in compliance with codes and standards
- Implemented permanent BMPs in compliance with local regulations
- Identified design risks and proposed mitigation strategies
- Implemented sustainable designs

Future Work

- Incorporate hydrodynamic loads into our structural analysis and design
- Utilize ETABS to design an integrated structural system
- Conduct GFRP experiments and apply findings to design development

Acknowledgements

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Myla Perito,
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Aaron Sutton, P.E.
GHD

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Thank you!
Any Questions?

QR Repository:
- PowerPoint
- References