ELEVATED SLAB ANALYSIS BY JOHN M. CLARK, MS, PE

PRESENTED TO STRUCTURAL COMMITTEE OF FOUNDATION PERFORMANCE ASSOCIATION

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BACKGROUND

- RECENT FLOODING IN GREATER HOUSTON AREA HAS CAUSED OWNERS TO LIFT HOUSES OUT OF THE POSSIBLE FLOOD ELEVATION.

BACKGROUND

- MOST HOUSES ARE FOUNDED ON SLAB-ON-GRADE TYPE FOUNDATIONS.

BACKGROUND

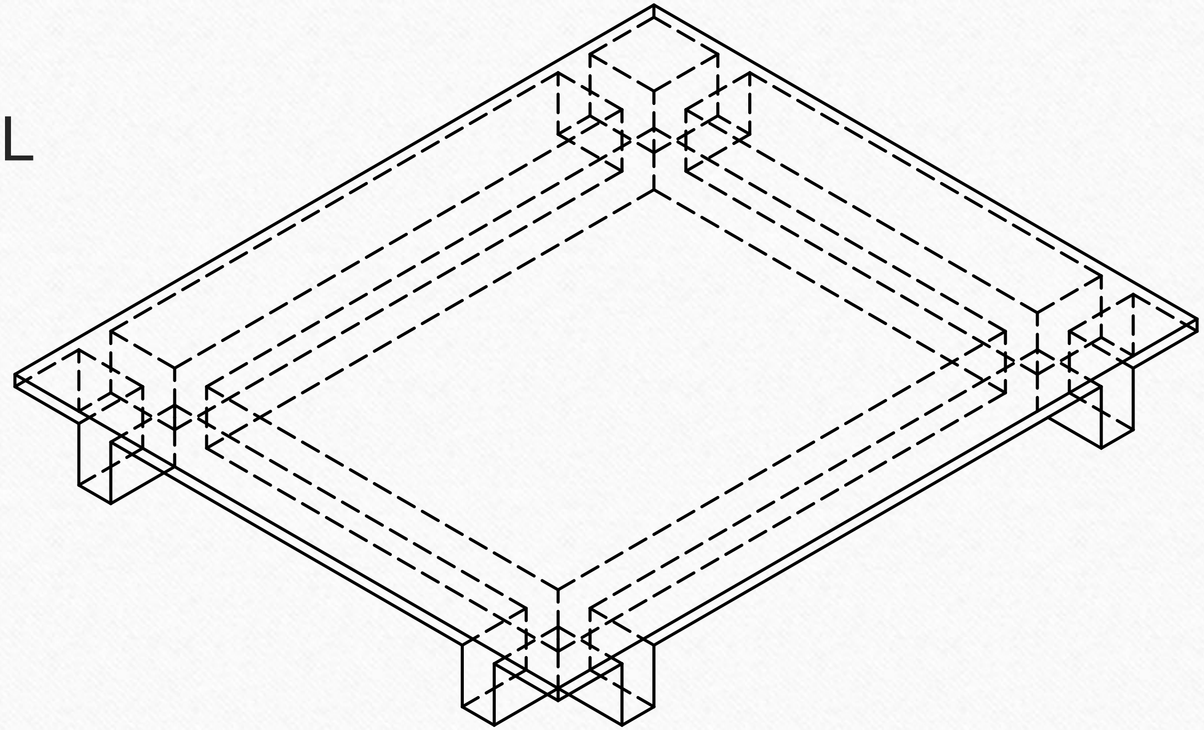
- THESE FOUNDATIONS ARE NOT DESIGNED FOR CLEAR SPAN CONDITIONS THAT RESULT WHEN THE FOUNDATION IS LIFTED.

BACKGROUND

- THE TYPE AND LOCATION OF SLAB REINFORCEMENT IN OLDER FOUNDATIONS IS GENERALLY NOT KNOWN.
- NOTE REINFORCING ON BOTTOM IN THIS PHOTO.

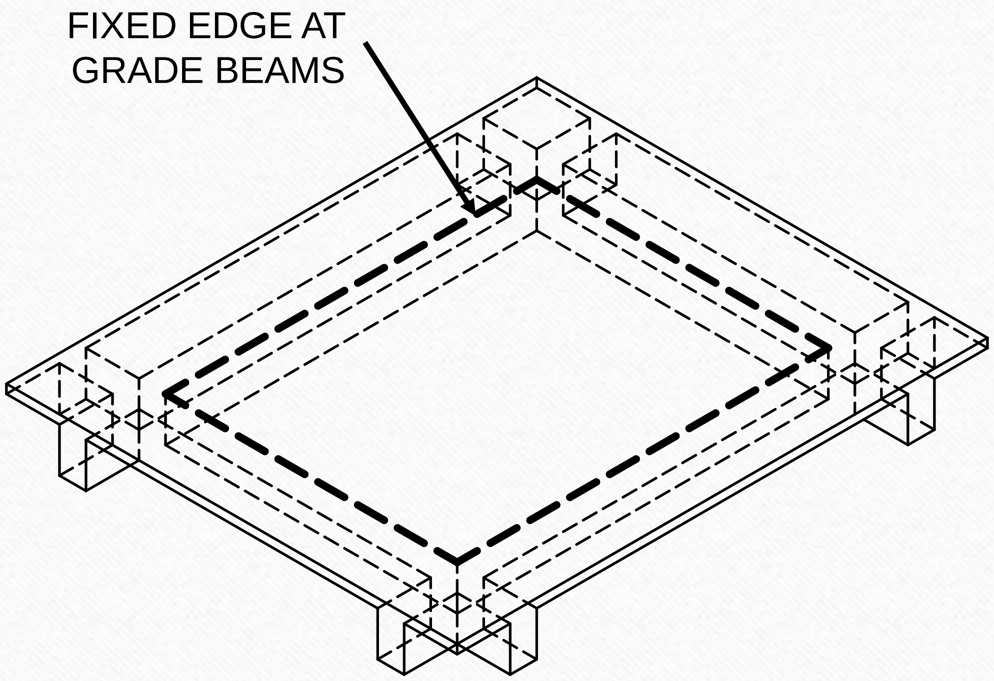
EXAMPLE PLATE

- FOR THIS PRESENTATION, FOR ALL EXAMPLES, PLATE SIZE IS 12 ft. x 15.33 ft.



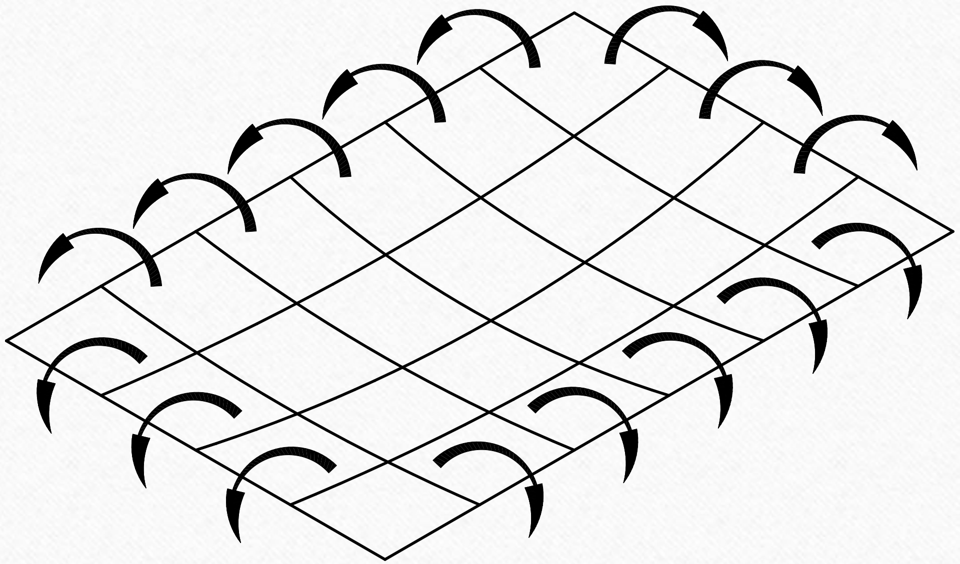
STRUCTURAL IMPLICATIONS

- FOR RECTANGULAR SLABS SUPPORTED BY GRADE BEAMS ON ALL FOUR SIDES THE EDGE CONDITION CAN BE CONSIDERED AS “FIXED”.
- I.E. THERE WILL BE NO CARRY-OVER MOMENTS FROM ADJACENT SPANS SINCE THE BEAM STIFFENERS AT THE EDGES ARE SUFFICIENT TO ABSORB THE EDGE MOMENTS FROM EACH ADJACENT FLAT PLATE PANEL.



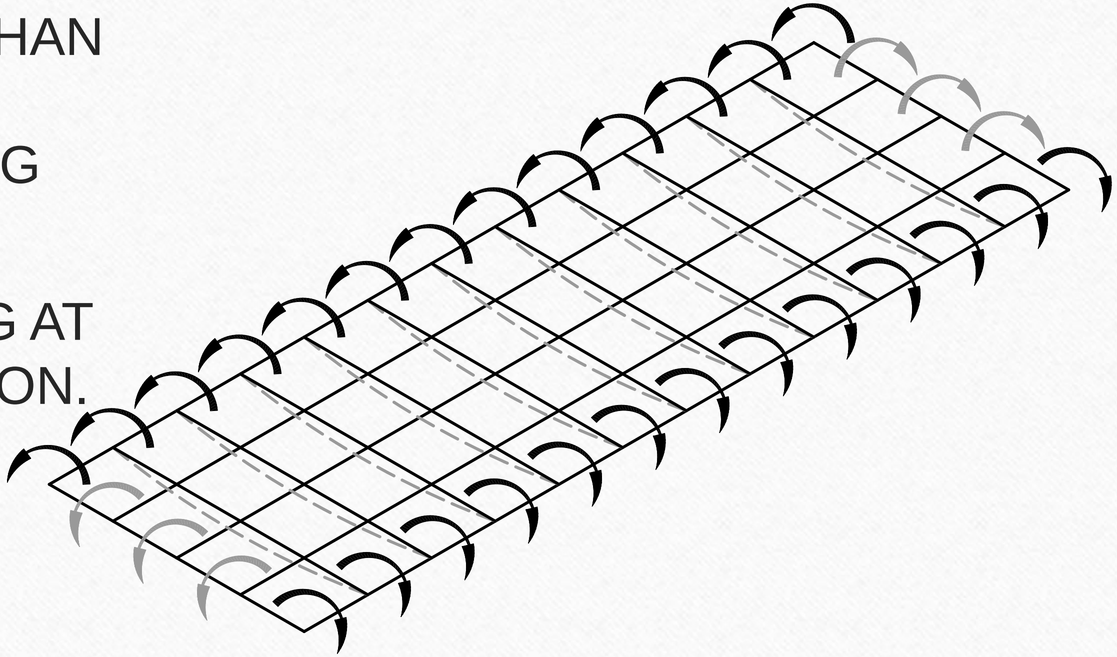
STRUCTURAL IMPLICATIONS

- ONCE A FOUNDATION SLAB IS LIFTED, THE SLAB BETWEEN THE GRADE BEAMS IS PLACED IN TWO-WAY BENDING.
- TWO WAY BENDING OCCURS FOR SLABS WHEN THE SIDES ARE EQUAL (a=b) UP TO ABOUT b=2a.



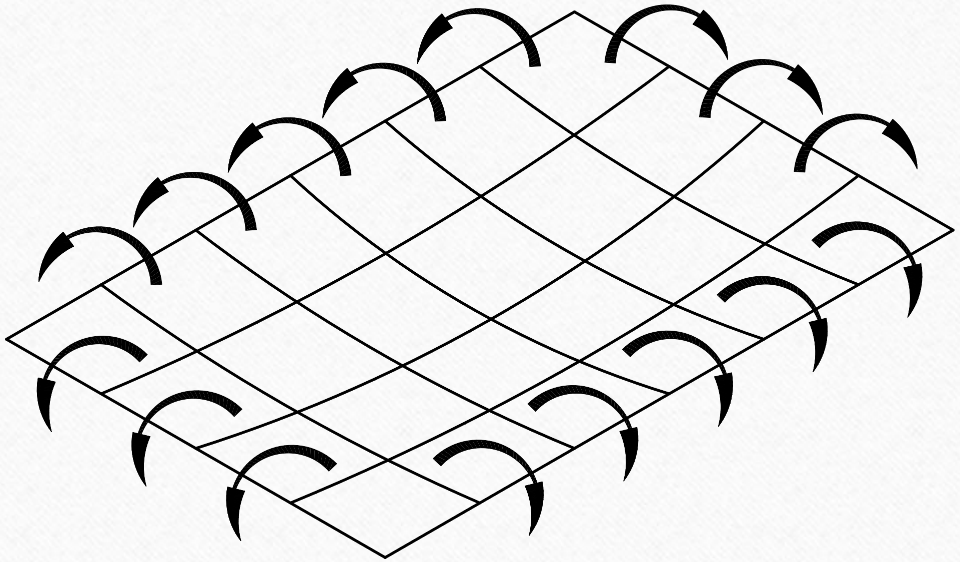
STRUCTURAL IMPLICATIONS

- IF LONGER SIDE IS GREATER THAN TWICE THE LENGTH OF THE SHORT SIDE, ONE WAY BENDING OCCURS.
- THERE WILL BE SOME BENDING AT SHORT ENDS IN LONG DIRECTION.



STRUCTURAL IMPLICATIONS

- THERE IS NO CLOSED FORM SOLUTION FOR TWO-WAY BENDING.



CODE REQUIRED LOADS

- LIVE LOAD = 40 psf FOR RESIDENTIAL FLOORS (PER ASCE 7-10)
  - OWNER OCCUPIED LIVE LOAD AVERAGE ≈12 psf
    - -ETHICAL ISSUE: WHAT SHOULD EOR USE FOR LIVE LOAD?
- TEMPERATURE REINFORCING
  - ACI 318 STATES THIS MUST BE SATISFIED, FOR A 4” THICK SLAB, A_{ST} = .0018 * 12” * 4” = 0.086 in^2/ft
  - WELDED WIRE MESH 6x6x1.4x1.4 SUPPLIES 0.028 in^2/ft
  - No. 3 (60ksi) BARS MUST BE SPACED AT 14 in. TO SUPPLY 0.086 in^2/ft

SLAB CRACKING

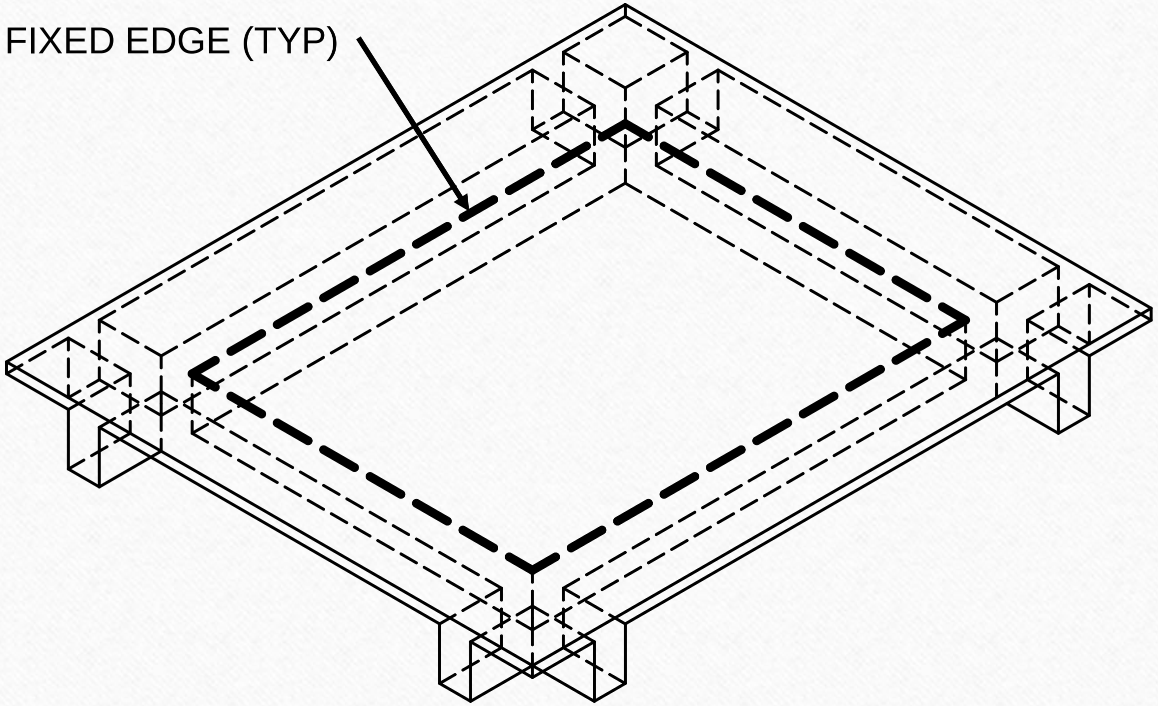
- MOST IF NOT ALL CONCRETE SLABS ON GRADE HAVE SHRINKAGE CRACKS.
- SHRINKAGE CRACKS TYPICALLY FORM AT ≈15’ TO 20’ SPACING.
- IF SLAB CRACKS, TENSILE STRESS IN EXISTING REINFORCING WILL LIKELY BE AT YIELD DUE TWO-WAY BENDING.
- ONCE STEEL STRESS REACHES YIELD, SLAB WILL START TO DEFLECT EXCESSIVELY AND HANG SIMILARLY TO A CHAIN (DEPENDING ON TOTAL LOAD APPLIED).

METHOD TO ANALYZE TWO-WAY BENDING

- TIMOSHENKO – “THEORY OF PLATES AND SHELLS, 2nd Ed.”, PROVIDES SERIES SOLUTIONS FOR PLATES WITH VARIOUS BOUNDARY CONDITIONS.
- ALSO SUPPLIED BY TIMOSHENKO IS AN APPROXIMATE METHOD WITH EQUAL SPANS

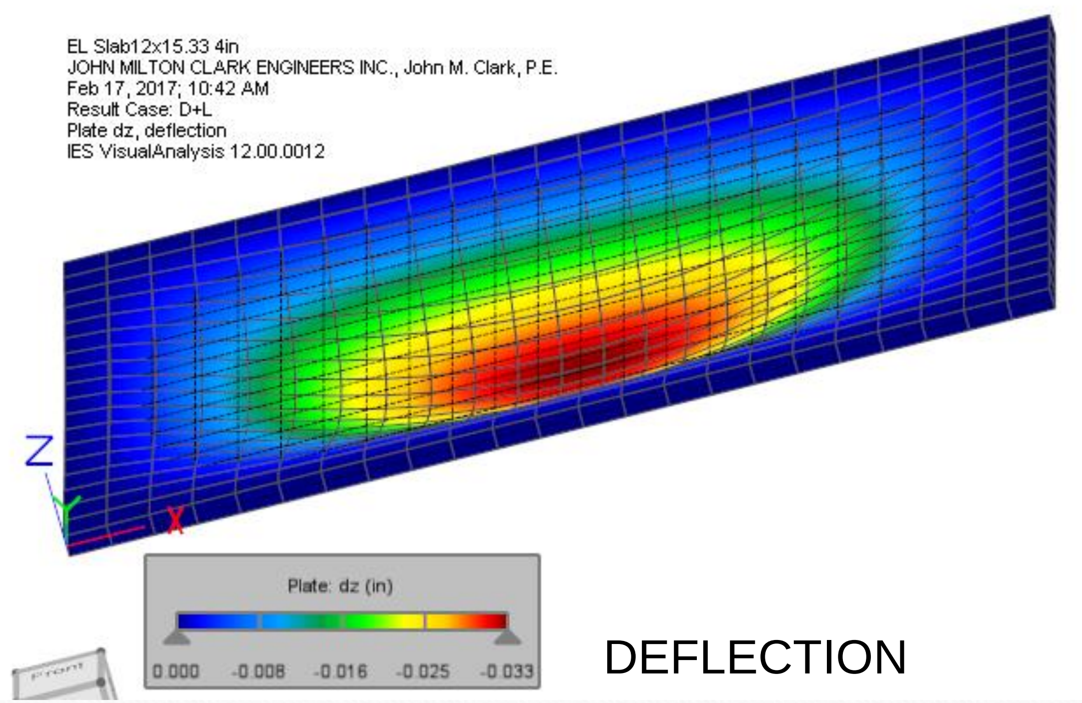
METHOD TO ANALYZE TWO WAY BENDING

- IN THIS CASE, A SLAB OF CONSTANT THICKNESS IS SUPPORTED BY A GRID OF GRADE BEAMS.



FINITE ELEMENT METHOD

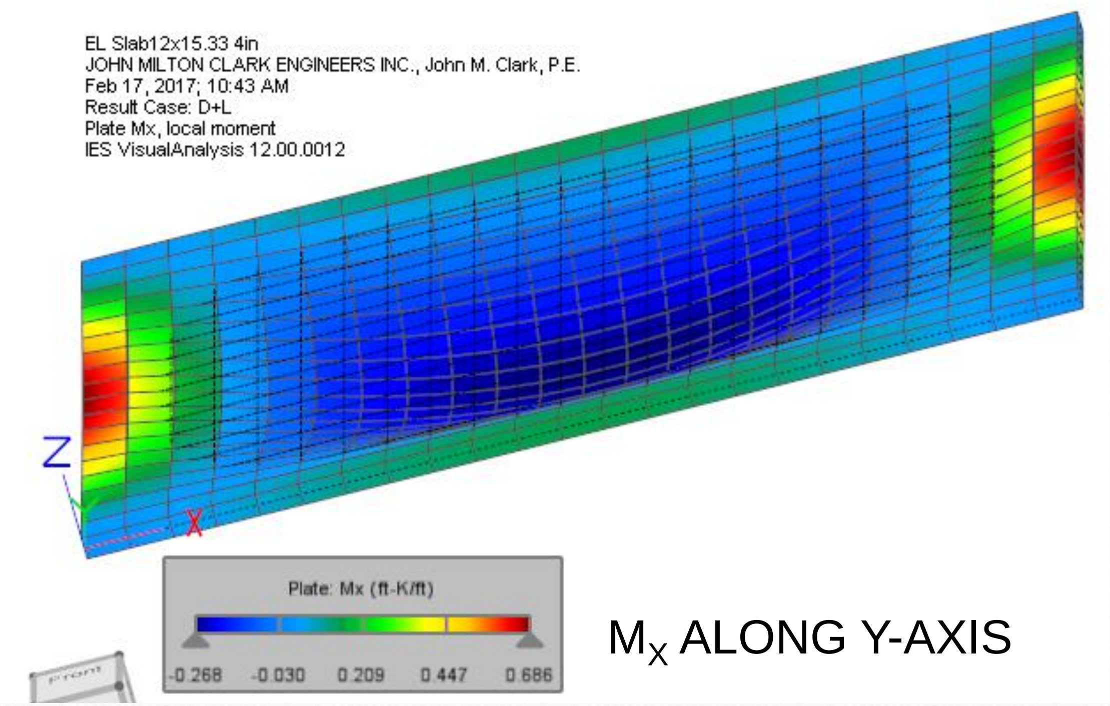
- WITH ADVENT OF POWERFUL DESKTOP COMPUTERS AND POWERFUL FINITE ELEMENT PROGRAMS, PLATE ANALYSIS HAS BECOME GREATLY SIMPLIFIED.



DEFLECTION

FINITE ELEMENT METHOD

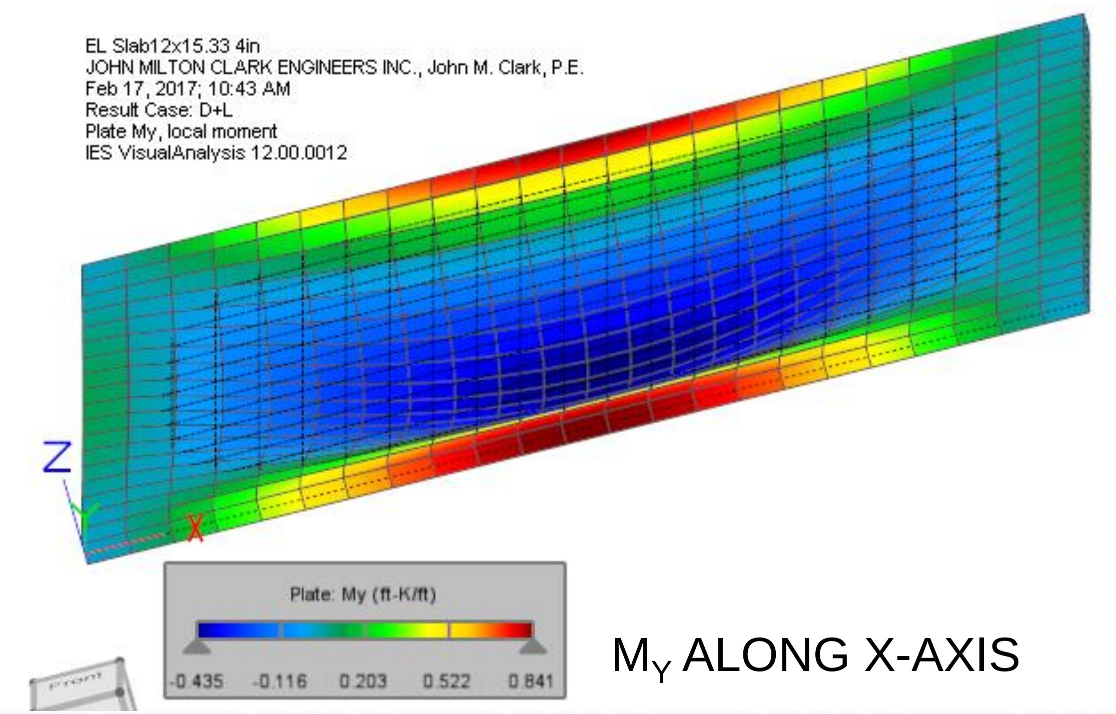
- EACH UNIQUE SIZE AND BOUNDARY CONDITIONS FOR A GIVEN LOAD MUST BE MODELED.
- CAN BE TIME CONSUMING.
- ALSO, INTERIOR PIER SUPPORTS MUST BE CAREFULLY MODELED.



M_X ALONG Y-AXIS

FINITE ELEMENT METHOD

- AND YOU NEED TO HAVE A STRUCTURAL ANALYSIS PROGRAM SUCH AS *VISUAL ANALYSIS*, *SAPP* etc. WHICH CAN BE COSTLY, ESPECIALLY IF THERE IS NO OTHER NEED FOR THIS TYPE OF PROGRAM.



M_Y ALONG X-AXIS

MOMENT AND SHEAR COEFFICIENTS DEVELOPED FROM FINITE DIFFERENCE METHOD

- **ANOTHER METHOD** TO SOLVE PLATE ANALYSIS IS BY USE OF THE **FINITE DIFFERENT METHOD**. SEE e.g. GERALD, APPLIED NUMERICAL ANALYSIS.
- IN 1960 US DEPT. OF INTERIOR, BUREAU OF RECLAMATION PUBLISHED ENGINEERING MONOGRAPH NO. 27, “MOMENTS AND REACTIONS FOR RECTANGULAR PLATES. DEVELOPED BY FINITE DIFFERENCE METHOD.

MOMENT AND SHEAR COEFFICIENTS DEVELOPED FROM FINITE DIFFERENCE METHOD

https://www.usbr.gov/tsc/techreferences/hydraulics_lab/pubs/EM/EM27.pdf

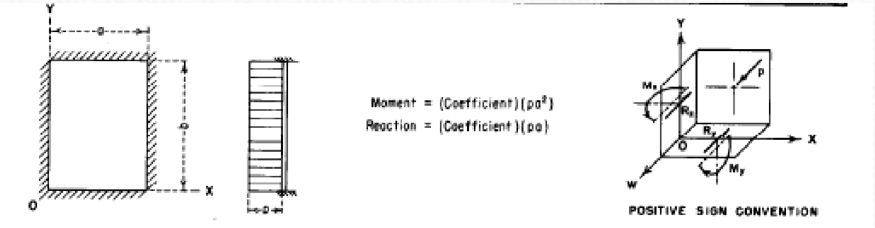
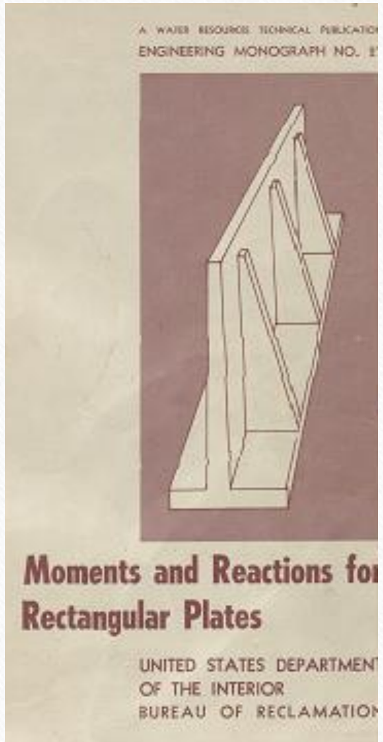


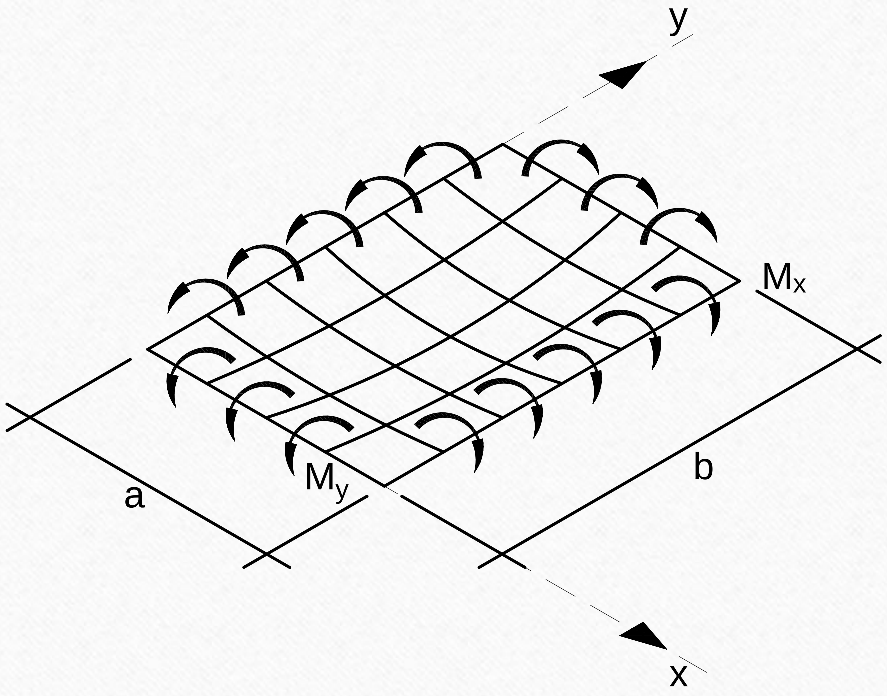
FIGURE 34.—*Plate fixed along four edges, moment and reaction coefficients, Load I, uniform load.*



			M_x							M_y						
	y/b	R_x \ x/a	0	0.05	0.1	0.2	0.3	0.4	0.5	0	0.05	0.1	0.2	0.3	0.4	0.5
a/b = 3/8	0.5	+.5055	+.0830	+.0590	+.0376	+.0024	-.0226	-.0375	-.0424	+.0166	+.0113	+.0074	+.0002	-.0050	-.0082	-.0093
	0.4	+.5068	+.0825	+.0585	+.0371	+.0022	-.0225	-.0372	-.0420	+.0165	+.0117	+.0073	-.0001	-.0055	-.0088	-.0099
	0.3	+.5060	+.0796	+.0558	+.0348	+.0013	-.0219	-.0355	-.0400	+.0159	+.0110	+.0065	-.0013	-.0071	-.0108	-.0120
	0.2	+.4778	+.0690	+.0470	+.0282	-.0004	-.0192	-.0299	-.0334	+.0138	+.0091	+.0046	-.0034	-.0095	-.0132	-.0145
	0.1	+.3316	+.0400	+.0254	+.0139	.0017	.0108	-.0155	-.0170	+.0080	+.0047	+.0017	-.0033	-.0066	-.0084	-.0090
	0.05	+.1331	+.0170	+.0108	+.0060	+.0001	-.0026	-.0037	-.0039	+.0034	+.0026	+.0026	+.0044	+.0071	+.0094	+.0102
	0	-.0513	0	+.0005	+.0016	+.0047	+.0076	+.0096	+.0103	0	+.0024	+.0078	+.0234	+.0381	+.0481	+.0516
		R_x \ R_y	-.0513	-.0797	+.0291	+.2203	+.3559	+.4352	+.4612							
a/b = 1/2	0.5	+.5142	+.0815	+.0573	+.0359	+.0015	-.0224	-.0365	-.0411	+.0163	+.0113	+.0068	-.0012	-.0071	-.0108	-.0121
	0.4	+.5111	+.0797	+.0557	+.0346	+.0011	-.0220	-.0355	-.0399	+.0159	+.0110	+.0064	-.0017	-.0078	-.0116	-.0129
	0.3	+.4928	+.0728	+.0499	+.0303	-.0000	-.0203	-.0319	-.0356	+.0146	+.0097	+.0051	-.0031	-.0093	-.0132	-.0145
	0.2	+.4260	+.0568	+.0375	+.0217	-.0014	-.0159	-.0238	-.0263	+.0114	+.0071	+.0030	-.0042	-.0096	-.0128	-.0139
	0.1	+.2350	+.0270	+.0168	+.0090	.0011	.0066	-.0092	-.0100	+.0054	+.0032	+.0014	-.0006	-.0013	-.0015	-.0012
	0.05	+.0591	+.0099	+.0066	+.0039	+.0011	+.0003	+.0003	+.0003	+.0020	+.0022	+.0034	+.0082	+.0135	+.0174	+.0188
	0	-.0496	0	+.0005	+.0016	+.0049	+.0080	+.0100	+.0108	0	+.0025	+.0082	+.0247	+.0399	+.0502	+.0538
		R_x \ R_y	-.0496	-.0651	+.0571	+.2253	+.3598	+.4382	+.4638							
a/b = 5/8	0.5	+.5143	+.0765	+.0526	+.0319	-.0001	-.0214	-.0336	-.0376	+.0153	+.0102	+.0054	-.0033	-.0101	-.0144	-.0159
	0.4	+.5045	+.0736	+.0502	+.0302	-.0004	-.0207	-.0321	-.0358	+.0147	+.0097	+.0050	-.0037	-.0104	-.0147	-.0161
	0.3	+.4660	+.0642	+.0429	+.0251	-.0012	-.0181	-.0274	-.0304	+.0126	+.0082	+.0037	-.0045	-.0107	-.0146	-.0159
	0.2	+.3697	+.0462	+.0297	+.0166	-.0017	-.0127	-.0186	-.0204	+.0092	+.0055	+.0020	-.0039	-.0082	-.0106	-.0114
	0.1	+.1635	+.0191	+.0119	+.0065	-.0004	-.0037	.0052	.0056	+.0038	+.0025	+.0018	+.0022	+.0036	+.0050	+.0056
	0.05	+.0150	+.0063	+.0046	+.0030	+.0018	+.0020	+.0025	+.0028	+.0013	+.0021	+.0042	+.0110	+.0180	+.0231	+.0249
	0	-.0454	0	+.0005	+.0017	+.0050	+.0082	+.0102	+.0109	0	+.0025	+.0083	+.0252	+.0408	+.0511	+.0547
		R_x \ R_y	-.0454	-.0527	+.0410	+.2277	+.3616	+.4394	+.4648							
a/b = 3/4	0.5	+.4999	+.0686	+.0457	+.0265	-.0017	-.0196	-.0293	-.0324	+.0137	+.0087	+.0037	-.0055	-.0128	-.0175	-.0191
	0.4	+.4845	+.0653	+.0432	+.0248	-.0019	-.0186	-.0277	-.0306	+.0131	+.0082	+.0034	-.0056	-.0126	-.0171	-.0186
	0.3	+.4311	+.0550	+.0357	+.0200	-.0022	-.0156	-.0227	-.0249	+.0110	+.0066	+.0024	-.0054	-.0113	-.0150	-.0162
	0.2	+.3179	+.0374	+.0235	+.0126	-.0019	-.0101	-.0142	-.0155	+.0075	+.0043	+.0014	-.0033	-.0064	-.0081	-.0086
	0.1	+.1133	+.0140	+.0089	+.0049	+.0001	-.0018	-.0025	-.0026	+.0028	+.0021	+.0023	+.0045	+.0074	+.0098	+.0107
	0.05	-.0109	+.0043	+.0034	+.0024	+.0022	+.0031	+.0039	+.0043	+.0009	+.0021	+.0048	+.0129	+.0210	+.0268	+.0288
	0	-.0412	0	+.0005	+.0017	+.0051	+.0082	+.0102	+.0109	0	+.0024	+.0083	+.0254	+.0409	+.0511	+.0546
		R_x \ R_y	-.0412	-.0457	+.0445	+.2305	+.3626	+.4384	+.4629							
a/b = 7/8	0.5	+.4730	+.0592	+.0380	+.0208	-.0031	-.0172	-.0245	-.0267	+.0118	+.0070	+.0021	-.0072	-.0146	-.0193	-.0209
	0.4	+.4542	+.0560	+.0356	+.0193	-.0031	-.0162	-.0229	-.0250	+.0112	+.0065	+.0018	-.0070	-.0139	-.0183	-.0198
	0.3	+.3928	+.0462	+.0288	+.0153	-.0029	-.0131	-.0183	-.0198	+.0092	+.0052	+.0012	-.0059	-.0113	-.0146	-.0157
	0.2	+.2736	+.0302	+.0184	+.0094	-.0020	-.0079	-.0107	-.0114	+.0060	+.0033	+.0010	-.0026	-.0047	-.0057	-.0061
	0.1	+.0798	+.0106	+.0068	+.0037	+.0005	.0005	-.0006	-.0008	+.0021	+.0019	+.0027	+.0060	+.0099	+.0129	+.0139
	0.05	-.0250	+.0031	+.0026	+.0021	+.0025	+.0037	+.0047	+.0051	+.0006	+.0021	+.0051	+.0140	+.0226	+.0285	+.0306
	0	-.0377	0	+.0005	+.0017	+.0050	+.0080	+.0099	+.0106	0	+.0024	+.0083	+.0251	+.0400	+.0497	+.0530
		R_x \ R_y	-.0377	-.0391	+.0503	+.2341	+.3608	+.4319	+.4546							
a/b = 1	0.5	+.4389	+.0500	+.0306	+.0156	-.0040	-.0147	-.0198	-.0213	+.0100	+.0054	+.0007	-.0082	-.0153	-.0197	-.0213
	0.4	+.4189	+.0470	+.0286	+.0144	-.0039	-.0137	-.0184	-.0197	+.0094	+.0050	+.0006	-.0078	-.0143	-.0184	-.0198
	0.3	+.3551	+.0382	+.0229	+.0112	-.0033	-.0109	-.0143	-.0153	+.0076	+.0040	+.0003	-.0061	-.0109	-.0137	-.0147
	0.2	+.2373	+.0244	+.0143	+.0068	-.0020	-.0061	-.0078	-.0082	+.0049	+.0026	+.0007	-.0020	-.0033	-.0039	-.0040
	0.1	+.0585	+.0082	+.0052	+.0028	+.0007	+.0003	+.0006	+.0007	+.0016	+.0018	+.0028	+.0068	+.0112	+.0144	+.0156
	0.05	-.0316	+.0024	+.0021	+.0018	+.0026	+.0040	+.0050	+.0054	+.0005	+.0021	+.0052	+.0143	+.0229	+.0286	+.0306
	0	-.0351	0	+.0005	+.0016	+.0049	+.0076	+.0094	+.0100	0	+.0024	+.0082	+.0244	+.0382	+.0470	+.0500
		R_x \ R_y	-.0351	-.0316	+.0585	+.2373	+.3551	+.4189	+.4389							

MOMENT AND SHEAR COEFFICIENTS DEVELOPED FROM FINITE DIFFERENCE METHOD

- TABLES OF MOMENT COEFFICIENTS FOR MX AND MY ARE PROVIDED FOR a/b RATIOS OF ⅜, ½, ⅝, ¾, ⅞, & 1 WHERE a IS THE SHORTER SIDE AND b IS THE LONGER SIDE.

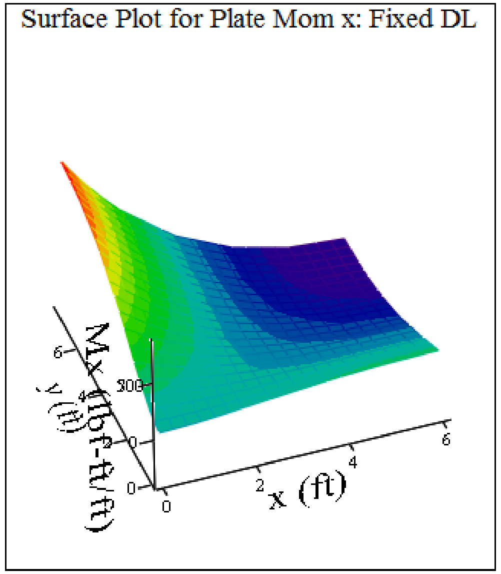


MATHCAD METHOD

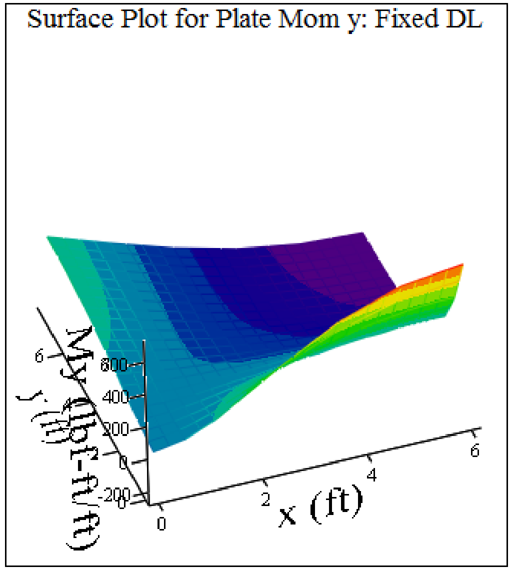
- **CLARK ENGINEERS** HAS DEVELOPED A MATHCAD TEMPLATE USING THE TABLES ON PG. 40, FIG. 34 FOR FIXED EDGES WITH UNIFORM LOAD. BOTH DEAD LOAD AND TOTAL LOAD ARE CONSIDERED.
- LIVE LOAD MAY BE FACTORED BY PERCENT TO STUDY EFFECT OF VARIOUS CONDITIONS.
- THE SHEET USES SURFACE POLYNOMIALS FOR EACH SET OF COEFFICIENTS FOR SPECIFIC a/b RATIO, THEN USES THE INTERPOLATION FUNCTION TO COMPUTE COEFFICIENTS FOR A CURRENT RATIO OF a'/b'.

MATHCAD METHOD - SURFACE PLOTS FOR MOMENT COEFFICIENTS

Moment Plots for Total Load $\frac{a}{b} = 0.783$



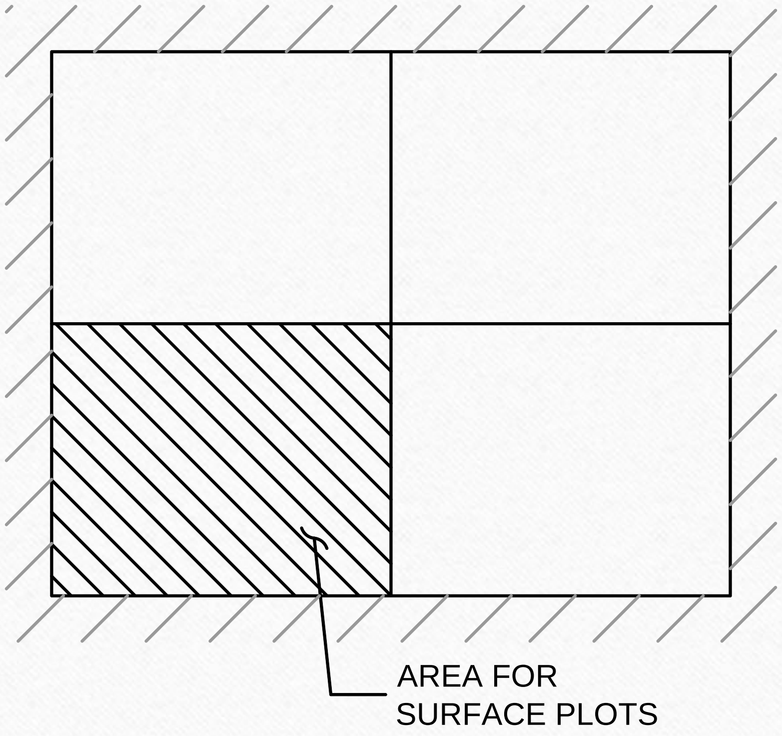
$\left(\frac{x}{ft}, \frac{y}{ft}, \frac{M_{x\_TL}}{lbf}\right)$



$\left(\frac{x}{ft}, \frac{y}{ft}, \frac{M_{y\_TL}}{lbf}\right)$

TABLE VALUES: SYMMETRY

- PLOTS ARE FOR BOTTOM LEFT QUADRANT OF THE PLATE, VALUES ARE QUADRI-SYMMETRIC FOR A PLATE WITH UNIFORM PRESSURE.
- FOR ANALYSIS RESULTS, THE FULL PLATE SOLUTION IS PROVIDED BY APPROPRIATE REFLECTION ABOUT CENTER AXIS.



COMPARE FEA TO MATHCAD

- MAXIMUM EDGE MOMENTS OCCUR AT MID LENGTH OF THE SIDES.
- REACTION COEFFICIENTS ARE COMPUTED BY LINEAR INTERPOLATION FOR CURRENT RATIO a'/b'.
- RESULTS OF THE MATHCAD TEMPLATE WERE COMPARED TO FEA RESULTS OF A PLATE OF DIMENSIONS 12 FT.X15.33 FT. WITH AN 8 INCH GRID.
- THE MCAD TEMPLATE HAD MAXIMUM MOMENTS THAT WERE ABOUT 12-14% HIGHER THAN THE FEA RESULTS FROM VA MODEL SO MATHCAD TEMPLATE IS MORE CONSERVATIVE. BOTH RESULTS ARE CONSIDERED REASONABLE.

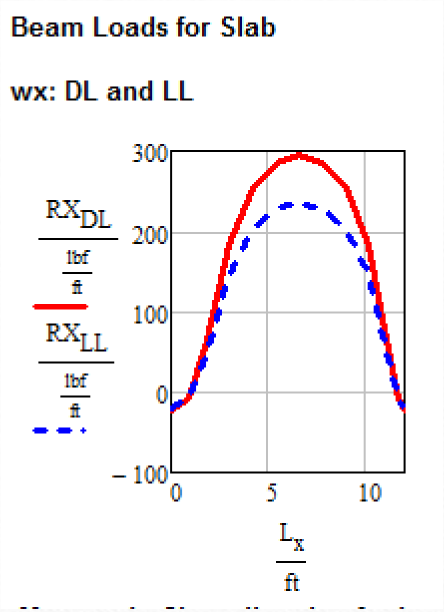
COMPARE FEA TO MCAD RESULTS FOR 12 ft. x 15.33 ft.

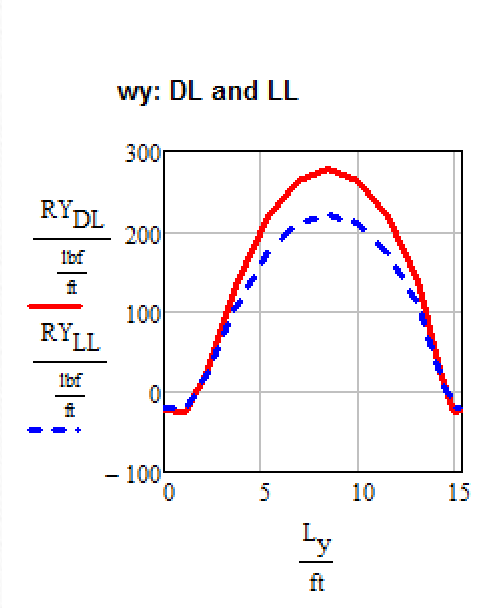
	MAXIMUM MOMENT (lbs. ft. /ft.)		
	FEA	MCAD	%DIFF.
MX	757	859	12%
MY	617	703	14%
DEFLECTION+ (in)	0.033	.079+	same order of magnitude

+ USING METHOD IN ROARK'S FORMULAS FOR STRESS AND STRAIN 6th Ed., TABLE 26, CASE 8a.

EDGE REACTIONS
(FOR CURRENT a & b)

- REACTIONS ARE PLOTTED FOR EACH PLATE AXIS x and y.
- MOMENTS ARE COMPUTED AT THE CENTER SPAN FOR A SIMPLE BEAM (FOR USE IF USING INTERMEDIATE BEAM SUPPORTS AFTER SLAB IS LIFTED)





SHEAR CHECK

Check Slab for Edge Shear

$R_{uX\_max} = 733 \frac{lbf}{ft}$ $R_{uY\_max} = 686 \frac{lbf}{ft}$ $\phi_v := 0.85$

$d_{reinf\_x} = 2.07 \cdot in$ $d_{reinf\_y} = 1.93 \cdot in$

$v_{cx} := \frac{R_{uX\_max}}{d_{reinf\_x}}$ $v_{cy} := \frac{R_{uY\_max}}{d_{reinf\_y}}$

$v_{cx} = 30\, psi$ $v_{cx} = 30\, psi$

Ultimate Shear Strength is one half of ultimate for no shear reinforcing

$v_u := \phi_v \cdot 2 \sqrt{\frac{f_c}{psi}} \cdot psi \div 2$ $v_u = 47\, psi$

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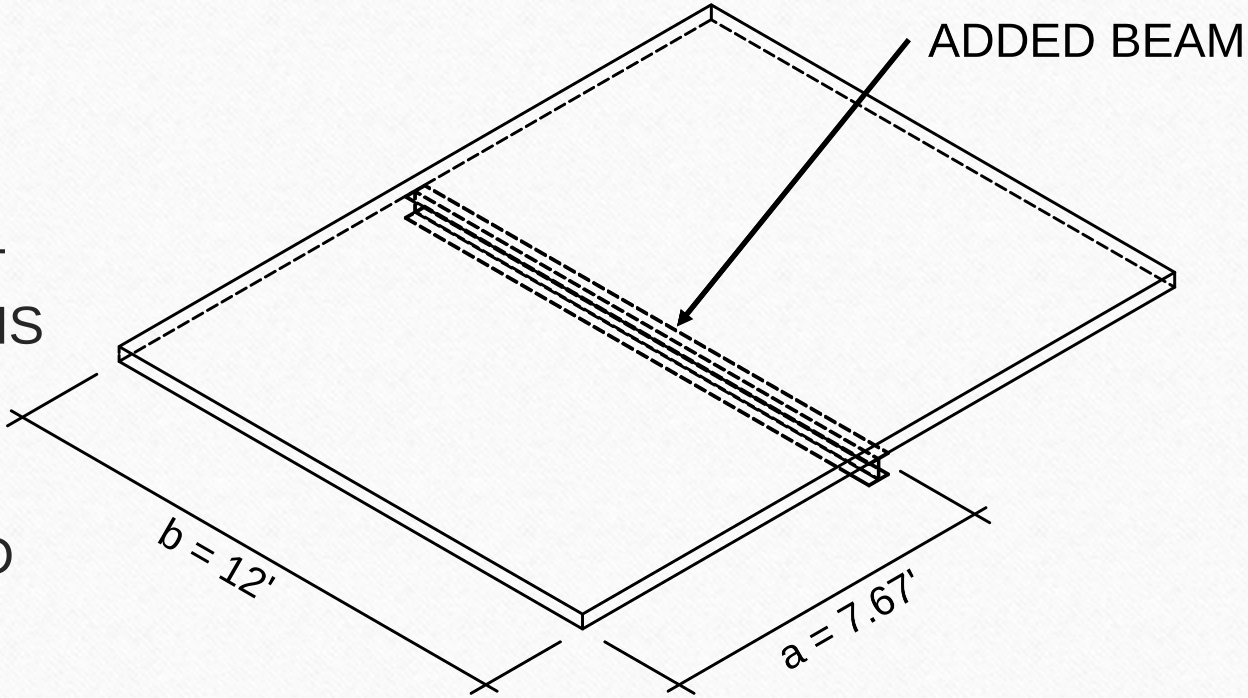
MOMENTS AND SHEARS FOR AN INTERMEDIATE STEEL BEAM

- VALUES SHOWN ARE FOR CURRENT VALUES OF a & b.
- a = 12’, b = 15.33’
- TO ADD ONE BEAM IN SHORT DIRECTION, NEW DIMENSIONS ARE:

  a = 7.67’, b = 12’
- LOAD IS DOUBLED FOR LOAD FROM BOTH SIDES.



INTERMEDIATE STEEL BEAM

Moment in Short direction for intermediate steel beam

$V_{X\_DL} = 1.4 \cdot kip$ $V_{X\_LL} = 1.1 \cdot kip$ $V_{X\_tot} = 2.5 \cdot kip$ $b = 15 \cdot ft$

$M_{X\_DL} = 3.6 \cdot kip \cdot ft$ $M_{X\_LL} = 2.8 \cdot kip \cdot ft$ $M_{X\_tot} = 6.4 \cdot kip \cdot ft$

Moment in Long direction for intermediate steel beam

$V_{Y\_DL} = 1.1 \cdot kip$ $V_{Y\_LL} = 0.9 \cdot kip$ $V_{Y\_tot} = 1.9 \cdot kip$

$M_{Y\_DL} = 2.2 \cdot kip \cdot ft$ $M_{Y\_LL} = 1.8 \cdot kip \cdot ft$ $M_{Y\_tot} = 4 \cdot kip \cdot ft$ $a = 12 \cdot ft$

$f_{all} := 30ksi$ $S_{req} := \frac{2M_{X\_tot}}{f_{all}}$

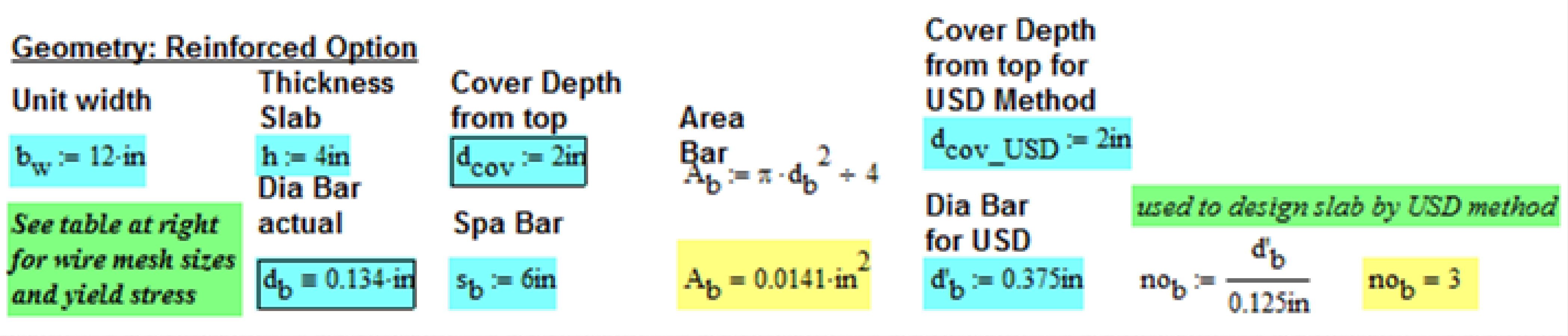
Double Section Modulus for load for both sides

$S_{req} = 5.121 \cdot in^3$

The user must exorcize care when using this method based on how many subdivisions a particular flat plate has.

INPUTS FOR MATHCAD SHEET

- GEOMETRY
- CLEAR SPANS a & b (TYPICALLY FEET., ANY UNIT SYSTEM IS OK)
- SLAB THICKNESS (TYPICALLY INCHES, ANY UNIT IS OK)



INPUTS FOR MATHCAD SHEET

- ENTER LIVE LOAD, PERCENT OF LIVE LOAD, AND LOAD FACTORS FOR USD.

Loads

Unit wt Concrete	Dead Load	Live Load by Code	Percent of LL to Considered	Load Factors for DL and LL	
$\gamma_{conc} \equiv 150pcf$	$q_{DL} \equiv \gamma_{conc} \cdot t_{slab}$	$q'_{LL} \equiv 40psf$	$\%_{LL} \equiv 100\%$	$LFD := 1.2$	$LFL := 1.6$
	$q_{DL} = 50 \cdot psf$	Live Load Considered	Live Load Considered	$\phi_b := 0.9$	$\phi_T := 0.0018 \cdot \frac{60ksi}{F_{y\_USD}}$
		$q_{LL} \equiv \%_{LL} \cdot q'_{LL}$	$q_{LL} = 40 \cdot psf$	$F_{y\_USD} \equiv 60ksi$	$\phi_T = 0.0018$

INPUTS FOR MATHCAD SHEET

- A CHECK FOR VALID DIMENSIONS IS PROVIDED, b MUST BE GREATER THAN OR EQUAL TO a.

Check for Valid Method

$$Check_{method} \equiv \text{if}\left(a'_b \leq 1 \wedge a'_b \geq \frac{3}{8}, \text{"Valid"}, \text{"Not Valid"}\right)$$

$$Check_{method} = \text{"Valid"}$$

SHEET GIVES ERROR IF a > b.

INPUTS FOR MATHCAD SHEET

Post Tensioned Option (slab only)

Post Tensioned Cables	No. cables per plate lengths a & b	Cable Force
$spa_{cable\_X} \equiv 5.0ft$	$No_X = 3.07$	$P_{PT} := 26.7kip$
$spa_{cable\_Y} \equiv 5.0ft$	$No_Y = 2.4$	

Section Modulus

$$S_s := \frac{t_{slab}^2}{6} \qquad S_s = 32.0 \cdot \frac{in^3}{ft}$$

Note: to compute effective presstress including beam, use Added Prestress Section at right. Enter cable dist for top, usually $t_{slab}/2$

INPUTS FOR MATHCAD SHEET

NA for Tee beam in X and Y directions

$NA_{t\_x} = 4.81 \cdot in$ $NA_{t\_y} = 5.33 \cdot in$

Prestressed Reinforcing Option (slab and beam

Beam width	Beam Depth	Cable Force	No. Beam Cables
$b_{bm} \equiv 12in$	$d_{bm} \equiv 24in$	$P_{PS} := 26.7kip$	$N_{bcx} := 2$
$spa_{ps\_X} \equiv 5.0ft$	$No_{Xps} = 3.07$	Cover PT in beam	$N_{bcy} := 2$
$spa_{ps\_Y} \equiv 5.0ft$	$No_{Yps} = 2.4$	$cov_{ps} \equiv 3in$	

Prestress Cable Location from Top

Refer to NAts dimensions below for top strand location

$y_{pstx} := 6in$ $y_{psty} := 7in$

Typ slab strand position for PT option

$\frac{t_{slab}}{2} = 2in$

INPUTS FOR MATHCAD SHEET

Material Properties

Yield Strength	Modulus Steel	Concrete Strength	Modular Ratio	Allowable Tension in concrete	
$F_y \equiv 65 \cdot ksi$	$E_{steel} \equiv 29000 \cdot ksi$	$f'_c \equiv 3 \cdot ksi$	$n_r := 9$	$f_{t\_all} := -\left(6 \cdot \sqrt{\frac{f'_c}{psi}} \cdot psi\right)$	$f_{t\_all} = -329 \cdot psi$

REINFORCING

AREA OF STEEL FURNISHED FOR WELDED WIRE MESH (WWM)

TABLE 1
(Revised)

Common [3] Styles of Metric Welded Wire Reinforcement (WWR)
With Equivalent US Customary Units

	Equivalent US Customary Style	A (in^2/ft)	Wt (lbs/CSF)	A (mm^2/m)	Metric System (MW = Plain wire)[1]	Wt. (kg/m^2)
A[1&4]	4x4 – W1.4xW1.4	.042	31	88.9	102x102 – MW9xMW9	1.51
	4x4 – W2.0xW2.0	.060	44	127.0	102x102 – MW13xMW13	2.15
	4x4 – W2.9xW2.9	.087	62	184.2	102x102 – MW19xMW19	3.03
	4x4 – W4.0xW4.0	.120	88	254.0	102x102 – MW26xMW26	4.30
	6x6 – W1.4xW1.4	.028	21	59.3	152x152 – MW9xMW9	1.03
	6x6 – W2.0xW2.0	.040	30	84.7	152x152 – MW13xMW13	1.46
	6x6 – W2.9xW2.9	.058	42	122.8	152x152 – MW19xMW19	2.05
	6x6 – W4.0xW4.0	.080	58	169.4	152x152 – MW26xMW26	2.83
B[1]	4x4 – W3.1xW3.1	.093	65	196.9	102x102 – MW20xMW20	3.17
	6x6 – W4.7xW4.7	.094	68	199.0	152x152- MW30xMW30	3.32
	12x12 – W9.4xW9.4	.094	71	199.0	305x305 – MW61xMW61	3.47
	12x12 – W17.1xW17.1	.171	128	362.0	305x305 – MW110xMW110	6.25
C[1]	6x6 – W8.1xW8.1	.162	116	342.9	102x102 – MW52xMW52	5.66
	6x6 –W8.3xW8.3	.166	119	351.4	152x152 - MW54xMW54	5.81
	12x12 – W9.1xW9.1	.091	69	192.6	305x305 – MW59xMW59	8.25
	12x12 – W16.6xW16.6	.166	125	351.4	305x305 – MW107xMW107	9.72
D[1]	6x6 – W4.4xW4.4	.088	63	186.3	102x102 – MW28xMW28	3.22
	6x6 –W8xW8	.160	115	338.7	152x152 - MW52xMW52	5.61
	12x12 – W8.8xW8.8	.088	66	186.3	305x305 – MW57xMW75	3.22
	12x12 – W16xW16	.160	120	338.7	305x305 – MW103xMW103	5.61
E[1]	6x6 – W4.2xW4.2	.084	60	177.8	102x102 – MW27xMW27	3.08
	6x6 –W7.5xW7.5	.150	108	317.5	152x152 - MW48xMW48	5.52
	12x12 – W8.3xW8.3	.083	63	175.7	305x305 – MW54xMW54	3.08
	12x12 – W15xW15	.150	113	317.5	305x305 – MW97xMW97	5.52

1 Group A – Compares areas of WWR at a minimum f_y = 65,000 psi
Group B – Compares areas of WWR at a minimum f_y = 70,000 psi
Group C – Compares areas of WWR at a minimum f_y = 72,500 psi
Group D – Compares areas of WWR at a minimum f_y = 75,000 psi
Group E – Compares areas of WWR at a minimum f_y = 80,000 psi

2 Wires may also be deformed, use prefix MD or D, except where only MW or W is required by building codes (usually less than a ..MW26 or W4). Also wire sizes can be specified in 1 mm^2 (metric) or .001 in (US Customary) increments.

3 For other available styles or wire sizes, consult other WRI publications or discuss with WWR manufacturers.

4 Styles may be obtained in roll form. Note: It is recommended that rolls be flattened and cut to size before placement.

REINFORCING

- COMPUTE BAR DIAMETER OF WELDED WIRE MESH FROM A_S PER FOOT IN WELDED WIRE MESH.

For Wire Mesh

Area per foot = 0.028 in^2 for 6 x 6 1.4 x 1.4. Thus the area of one bar is 0.028*6in/12in = 0.014in^2

The diameter of othe bar is then

Dia Bar = $\sqrt{\frac{0.014in^2 \cdot 4}{\pi}} = 0.134 \cdot in$ for 6 x 6 1.4 x 1.4

The yield Strength for this bar is 65 ksi for Group 1.

STRUCTURAL PLAIN CONCRETE (SPC)

22.2.1 — Use of structural plain concrete shall be limited to (a), (b), or (c):

(a) Members that are continuously supported by soil or supported by other structural members capable of providing continuous vertical support;

(b) Members for which arch action provides compression under all conditions of loading;

(c) Walls and pedestals. See 22.6 and 22.8.

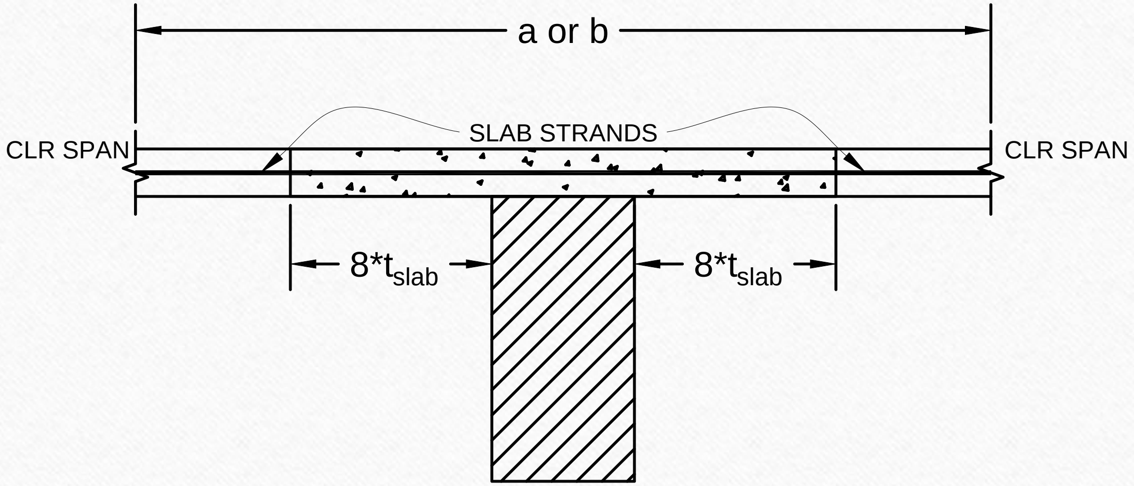
The use of structural plain concrete columns shall not be permitted.

22.2.2 — This chapter shall not govern design and installation of cast-in-place concrete piles and piers embedded in ground.

- FROM ACI 318
- ELEVATED SLABS ARE NOT INCLUDED IN SPC.

POST TENSIONED REINFORCING

- FOR TEE BEAMS, EFFECTIVE WIDTH EACH SIDE & BEAM IS TAKEN AS $8*t_{SLAB}$. SO, PAST THE EFFECTIVE WIDTH OF TEE, SLAB BENDS ABOUT IT’S OWN NEUTRAL AXIS.



POST TENSIONED REINFORCING

- THUS ONLY SLAB STRANDS ARE CONSIDERED IN COMPUTING SLAB STRESS.
- TO CONSIDER EFFECT OF BEAM USE ADDED PRESTRESS IN NEXT SECTION.

Post Tensioned Option (slab only)

Post Tensioned Cables	No. cables per plate lengths a & b	Cable Force
$spa_{cable\_X} \equiv 5.0ft$	$No_X = 3.07$	$P_{PT} := 26.7kip$
$spa_{cable\_Y} \equiv 5.0ft$	$No_Y = 2.4$	

Section Modulus

$S_s := \frac{t_{slab}^2}{6}$ $\quad S_s = 32.0 \cdot \frac{in^3}{ft}$

Note: to compute effective presstress including beam, use Added Prestress Section at right. Enter cable dist for top, usually $t_{slab}/2$

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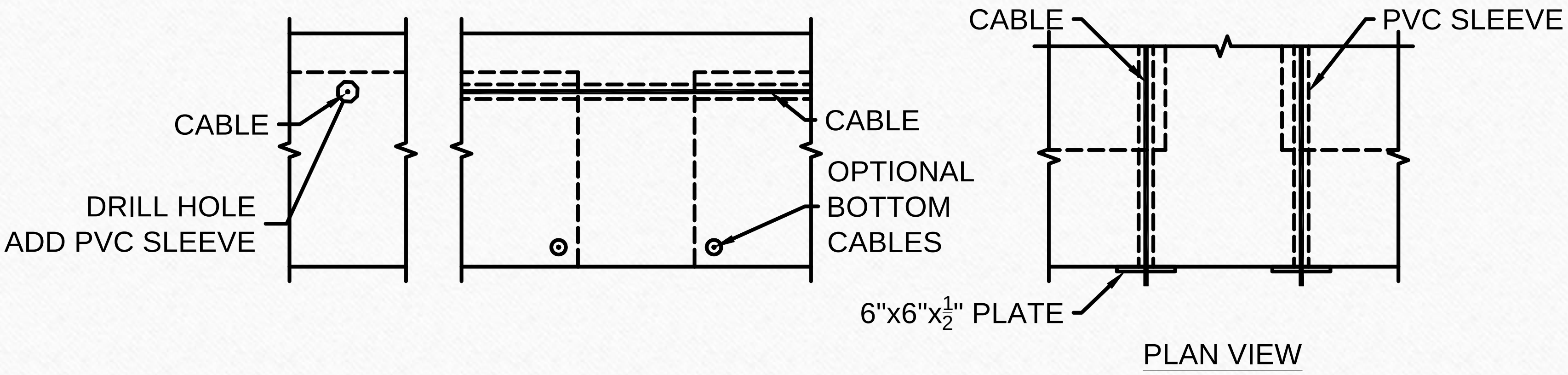
PRE-STRESSED OPTION

- SINCE NEW CABLES CAN BE ADDED THE TEE BEAM IS CONSIDERED EFFECTIVE.



PRESTRESSED OPTION

- IF POSSIBLE KEEP SLAB CABLES ABOVE NEUTRAL AXIS (NA) OF COMBINED NEUTRAL AXIS OR AS CLOSE TO NEUTRAL AXIS AS POSSIBLE.

Prestressed Reinforcing Option (slab and beam

Beam width	Beam Depth	Cable Force	No. Beam Cables
$b_{bm} \equiv 12in$	$d_{bm} \equiv 24in$	$P_{PS} := 26.7kip$	$N_{bcx} := 2$
$spa_{ps\_X} \equiv 5.0ft$	$No_{Xps} = 3.07$	Cover PT in beam	$N_{bcy} := 2$
$spa_{ps\_Y} \equiv 5.0ft$	$No_{Yps} = 2.4$	$cov_{ps} \equiv 3in$	

Prestress Cable Location from Top

Refer to NAts dimensions below for top strand location

$y_{pstx} := 6in$ $y_{psty} := 7in$

Typ slab strand position for PT option

$\frac{t_{slab}}{2} = 2in$

NA for Tee beam in X and Y directions

$NA_{t\_x} = 4.81 \cdot in$ $NA_{t\_y} = 5.33 \cdot in$

RESULTS

ANALYSIS RESULTS ARE SUPPLIED FOR DEAD LOAD AND TOTAL LOAD FOR:

1. RESULTANT MOMENTS ACROSS THE SLAB (LIVE LOAD MAY BE FACTORED UP OR DOWN).
2. CONCRETE STRESS USING FULL UNCRACKED SECTION
   - SHOWN FOR REFERENCE ONLY.
3. STRESS IN EXISTING REINFORCING (WSD) FOR CRACKED SECTION.
4. POST TENSIONED STRESS IN EXISTING REINFORCING FOR CRACKED SECTION (STRESS IN TOP OF SLAB).

WSD: WORKING STRESS DESIGN

RESULTS

RESULTS ARE SUPPLIED FOR DEAD LOAD AND TOTAL LOAD FOR:

5. ADDED PRESTRESSING STRESS IN CONCRETE (STRESS IN TOP OF SLAB).
6. ULTIMATE STRENGTH DESIGN – A_S REQUIRED AND BAR SPACING (FOR SPECIFIED BAR DIAMETER).
7. RESULTS FOR INTERMEDIATE PIER (EXAMPLE).

APPLIED MOMENTS

- SHADING IS USED TO DIFFERENTIATE POSITIVE AND NEGATIVE MOMENTS.
- DEAD LOAD

DL Moment X Direction (lbf ft/ft)

Green Shade: Negative Moment;
Orange Shade: Positive Moment

	0.0'	0.8'	1.5'	3.1'	4.6'	6.1'	7.7'	9.2'	10.7'	12.3'	13.8'	14.6'	15.3'
0.0'	0	-28	-94	-255	-379	-453	-477	-453	-379	-255	-94	-28	0
0.6'	-4	-23	-60	-159	-243	-297	-315	-297	-243	-159	-60	-23	-4
1.2'	-12	-17	-33	-84	-135	-168	-180	-168	-135	-84	-33	-17	-12
2.4'	-36	-17	-2	14	17	16	15	16	17	14	-2	-17	-36
3.6'	-59	-24	10	68	108	130	137	130	108	68	10	-24	-59
4.8'	-73	-30	14	95	155	190	202	190	155	95	14	-30	-73
6.0'	-78	-33	15	103	169	210	223	210	169	103	15	-33	-78
7.2'	-73	-30	14	95	155	190	202	190	155	95	14	-30	-73
8.4'	-59	-24	10	68	108	130	137	130	108	68	10	-24	-59
9.6'	-36	-17	-2	14	17	16	15	16	17	14	-2	-17	-36
10.8'	-12	-17	-33	-84	-135	-168	-180	-168	-135	-84	-33	-17	-12
11.4'	-4	-23	-60	-159	-243	-297	-315	-297	-243	-159	-60	-23	-4
12.0'	0	-28	-94	-255	-379	-453	-477	-453	-379	-255	-94	-28	0

DL Moment Y Direction (lbf ft/ft)

Green Shade: Negative Moment;
Orange Shade: Positive Moment

	0.0'	0.8'	1.5'	3.1'	4.6'	6.1'	7.7'	9.2'	10.7'	12.3'	13.8'	14.6'	15.3'
0.0'	0	-6	-19	-51	-76	-91	-95	-91	-76	-51	-19	-6	0
0.6'	-17	-15	-15	-29	-45	-56	-59	-56	-45	-29	-15	-15	-17
1.2'	-60	-35	-18	-9	-15	-21	-24	-21	-15	-9	-18	-35	-60
2.4'	-182	-96	-36	22	40	43	43	43	40	22	-36	-96	-182
3.6'	-293	-155	-59	43	82	94	96	94	82	43	-59	-155	-293
4.8'	-366	-197	-78	53	108	121	130	121	108	53	-78	-197	-366
6.0'	-391	-212	-84	57	116	137	142	137	116	57	-84	-212	-391
7.2'	-366	-197	-78	53	108	121	130	121	108	53	-78	-197	-366
8.4'	-293	-155	-59	43	82	94	96	94	82	43	-59	-155	-293
9.6'	-182	-96	-36	22	40	43	43	43	40	22	-36	-96	-182
10.8'	-60	-35	-18	-9	-15	-21	-24	-21	-15	-9	-18	-35	-60
11.4'	-17	-15	-15	-29	-45	-56	-59	-56	-45	-29	-15	-15	-17
12.0'	0	-6	-19	-51	-76	-91	-95	-91	-76	-51	-19	-6	0

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APPLIED MOMENTS

- TOTAL LOAD

Total Load Moment X Direction (lbf ft/ft)

Green Shade: Negative Moment;
Orange Shade: Positive Moment

	0.0'	0.8'	1.5'	3.1'	4.6'	6.1'	7.7'	9.2'	10.7'	12.3'	13.8'	14.6'	15.3'
0.0'	0	-51	-169	-458	-682	-815	-858	-815	-682	-458	-169	-51	0
0.6'	-6	-41	-108	-286	-438	-534	-567	-534	-438	-286	-108	-41	-6
1.2'	-22	-30	-59	-151	-242	-303	-324	-303	-242	-151	-59	-30	-22
2.4'	-66	-30	-3	25	31	29	27	29	31	25	-3	-30	-66
3.6'	-106	-42	18	123	194	233	246	233	194	123	18	-42	-106
4.8'	-131	-54	25	171	279	343	364	343	279	171	25	-54	-131
6.0'	-140	-59	26	186	305	378	401	378	305	186	26	-59	-140
7.2'	-131	-54	25	171	279	343	364	343	279	171	25	-54	-131
8.4'	-106	-42	18	123	194	233	246	233	194	123	18	-42	-106
9.6'	-66	-30	-3	25	31	29	27	29	31	25	-3	-30	-66
10.8'	-22	-30	-59	-151	-242	-303	-324	-303	-242	-151	-59	-30	-22
11.4'	-6	-41	-108	-286	-438	-534	-567	-534	-438	-286	-108	-41	-6
12.0'	0	-51	-169	-458	-682	-815	-858	-815	-682	-458	-169	-51	0

Total Load Moment Y Direction (lbf ft/ft)

Green Shade: Negative Moment;
Orange Shade: Positive Moment

	0.0'	0.8'	1.5'	3.1'	4.6'	6.1'	7.7'	9.2'	10.7'	12.3'	13.8'	14.6'	15.3'
0.0'	0	-89	-292	-794	-1182	-1413	-1488	-1413	-1182	-794	-292	-89	0
0.6'	-31	-84	-190	-492	-755	-921	-978	-921	-755	-492	-190	-84	-31
1.2'	-107	-91	-116	-253	-406	-510	-547	-510	-406	-253	-116	-91	-107
2.4'	-324	-162	-48	66	98	99	96	99	98	66	-48	-162	-324
3.6'	-521	-254	-42	247	408	486	510	486	408	247	-42	-254	-521
4.8'	-649	-323	-53	338	575	693	739	693	575	338	-53	-323	-649
6.0'	-694	-349	-59	365	627	769	812	769	627	365	-59	-349	-694
7.2'	-649	-323	-53	338	575	693	739	693	575	338	-53	-323	-649
8.4'	-521	-254	-42	247	408	486	510	486	408	247	-42	-254	-521
9.6'	-324	-162	-48	66	98	99	96	99	98	66	-48	-162	-324
10.8'	-107	-91	-116	-253	-406	-510	-547	-510	-406	-253	-116	-91	-107
11.4'	-31	-84	-190	-492	-755	-921	-978	-921	-755	-492	-190	-84	-31
12.0'	0	-89	-292	-794	-1182	-1413	-1488	-1413	-1182	-794	-292	-89	0

UNCRACKED SECTION CONCRETE STRESS (TOP)

(STRUCTURAL PLAIN CONCRETE (SPC) – REFERENCE ONLY)

Allowable Tensile Stress $f_{t\_all} = -329\ psi$

Unreinforced Structural Concrete

Percent of Tensile Strength of Concrete

Dead Load

b = 15.33 ft

a = 12 ft

	0.0'	0.8'	1.5'	3.1'	4.6'	6.1'	7.7'	9.2'	10.7'	12.3'	13.8'	14.6'	15.3'
0.0'	0%	3%	11%	29%	43%	52%	54%	52%	43%	29%	11%	3%	0%
0.6'	2%	3%	7%	18%	28%	34%	36%	34%	28%	18%	7%	3%	2%
1.2'	7%	4%	4%	10%	15%	19%	21%	19%	15%	10%	4%	4%	7%
2.4'	21%	11%	4%	3%	5%	5%	5%	5%	5%	3%	4%	11%	21%
3.6'	33%	18%	7%	8%	12%	15%	16%	15%	12%	8%	7%	18%	33%
4.8'	42%	23%	9%	11%	18%	22%	23%	22%	18%	11%	9%	23%	42%
6.0'	45%	24%	10%	12%	19%	24%	25%	24%	19%	12%	10%	24%	45%
7.2'	42%	23%	9%	11%	18%	22%	23%	22%	18%	11%	9%	23%	42%
8.4'	33%	18%	7%	8%	12%	15%	16%	15%	12%	8%	7%	18%	33%
9.6'	21%	11%	4%	3%	5%	5%	5%	5%	5%	3%	4%	11%	21%
10.8'	7%	4%	4%	10%	15%	19%	21%	19%	15%	10%	4%	4%	7%
11.4'	2%	3%	7%	18%	28%	34%	36%	34%	28%	18%	7%	3%	2%
12.0'	0%	3%	11%	29%	43%	52%	54%	52%	43%	29%	11%	3%	0%

Percent of Tensile Strength of Concrete

Total Load

b = 15.33 ft

a = 12 ft

	0.0'	0.8'	1.5'	3.1'	4.6'	6.1'	7.7'	9.2'	10.7'	12.3'	13.8'	14.6'	15.3'
0.0'	0%	6%	19%	52%	78%	93%	98%	93%	78%	52%	19%	6%	0%
0.6'	4%	5%	12%	33%	50%	61%	65%	61%	50%	33%	12%	5%	4%
1.2'	12%	7%	7%	17%	28%	35%	37%	35%	28%	17%	7%	7%	12%
2.4'	37%	20%	7%	5%	8%	9%	9%	9%	8%	5%	7%	20%	37%
3.6'	60%	32%	12%	14%	22%	27%	28%	27%	22%	14%	12%	32%	60%
4.8'	75%	41%	16%	20%	32%	39%	42%	39%	32%	20%	16%	41%	75%
6.0'	80%	44%	17%	21%	35%	43%	46%	43%	35%	21%	17%	44%	80%
7.2'	75%	41%	16%	20%	32%	39%	42%	39%	32%	20%	16%	41%	75%
8.4'	60%	32%	12%	14%	22%	27%	28%	27%	22%	14%	12%	32%	60%
9.6'	37%	20%	7%	5%	8%	9%	9%	9%	8%	5%	7%	20%	37%
10.8'	12%	7%	7%	17%	28%	35%	37%	35%	28%	17%	7%	7%	12%
11.4'	4%	5%	12%	33%	50%	61%	65%	61%	50%	33%	12%	5%	4%
12.0'	0%	6%	19%	52%	78%	93%	98%	93%	78%	52%	19%	6%	0%

NOTE: STRESS VERY CLOSE TO TENSILE STRENGTH

CHECK TENSILE STRESS IN REINFORCING – CRACKED SECTION

- CRACKED SECTION:
  - PRIOR TO CRACKING ALL STRESS IS TAKEN BY THE CONCRETE.
  - ONCE THE CONCRETE CRACKS THE TENSILE REINFORCING BECOMES EFFECTIVE IN RESISTING BENDING.
- SHADING OF RESULTS SHOWN:
  - RED FONT/PINK SHADE FOR f_s = >F_y
  - BROWN FONT/ YELLOW SHADE FOR $f_s > F_{all}$
  - BLACK FONT/ NO SHADE FOR $f_s \leq F_{all}$

CHECK TENSILE STRESS IN REINFORCING – CRACKED SECTION

(MAX STRESS IN REINFORCING FOR M_X OR M_Y IS REPORTED FOR WWM)

Dead Load

Stress in ksi

b = 15.33-ft

a = 12-ft

	0.0	0.8	1.5	3.1	4.6	6.1	7.7	9.2	10.7	12.3	13.8	14.6	15.3
0.0'	0	6	20	55	65	65	65	65	65	55	20	6	0
0.6'	4	5	13	34	52	64	65	64	52	34	13	5	4
1.2'	14	8	7	18	29	36	39	36	29	18	7	8	14
2.4'	42	22	8	5	9	9	9	9	9	5	8	22	42
3.6'	65	36	14	16	25	30	32	30	25	16	14	36	65
4.8'	65	46	18	22	36	44	47	44	36	22	18	46	65
6.0'	65	49	19	24	39	48	51	48	39	24	19	49	65
7.2'	65	46	18	22	36	44	47	44	36	22	18	46	65
8.4'	65	36	14	16	25	30	32	30	25	16	14	36	65
9.6'	42	22	8	5	9	9	9	9	9	5	8	22	42
10.8'	14	8	7	18	29	36	39	36	29	18	7	8	14
11.4'	4	5	13	34	52	64	65	64	52	34	13	5	4
12.0'	0	6	20	55	65	65	65	65	65	55	20	6	0

Total Load

Stress in ksi

b = 15.33-ft

a = 12-ft

	0.0'	0.8'	1.5'	3.1'	4.6'	6.1'	7.7'	9.2'	10.7'	12.3'	13.8'	14.6'	15.3'
0.0'	0	11	36	65	65	65	65	65	65	65	36	11	0
0.6'	7	9	23	62	65	65	65	65	65	62	23	9	7
1.2'	25	15	13	33	52	65	65	65	52	33	13	15	25
2.4'	65	40	15	9	16	17	17	17	16	9	15	40	65
3.6'	65	64	24	28	45	54	57	54	45	28	24	64	65
4.8'	65	65	32	40	64	65	65	65	64	40	32	65	65
6.0'	65	65	35	43	65	65	65	65	65	43	35	65	65
7.2'	65	65	32	40	64	65	65	65	64	40	32	65	65
8.4'	65	64	24	28	45	54	57	54	45	28	24	64	65
9.6'	65	40	15	9	16	17	17	17	16	9	15	40	65
10.8'	25	15	13	33	52	65	65	65	52	33	13	15	25
11.4'	7	9	23	62	65	65	65	65	65	62	23	9	7
12.0'	0	11	36	65	65	65	65	65	65	65	36	11	0

POST TENSIONED RESULTS

- RESULTS ARE PROVIDED FOR TOP STRESS IN SLAB.
- STRESS IS CHECKED AGAINST ALLOWABLE CONCRETE TENSILE STRESS.
- BOTTOM OF SLAB STRESS CAN BE REPORTED.

POST-TENSIONED RESULTS STRESS IN TOP OF SLAB

(MAXIMUM NEGATIVE TENSION IS SHOWN FOR EACH DIRECTION x OR y)

Dead Load

Concrete stress in top of slab (psi)

b = 15.33-ft

a = 12-ft

	0.0'	0.8'	1.5'	3.1'	4.6'	6.1'	7.7'	9.2'	10.7'	12.3'	13.8'	14.6'	15.3'
0.0'	87	85	76	16	-31	-59	-68	-59	-31	16	76	85	87
0.6'	81	81	82	52	20	0	-7	0	20	52	82	81	81
1.2'	65	74	81	80	61	48	44	48	61	80	81	74	65
2.4'	19	51	74	95	102	103	103	103	102	95	74	51	19
3.6'	-23	29	65	103	118	122	123	122	118	103	65	29	-23
4.8'	-50	13	58	107	127	132	136	132	127	107	58	13	-50
6.0'	-59	8	55	108	131	138	140	138	131	108	55	8	-59
7.2'	-50	13	58	107	127	132	136	132	127	107	58	13	-50
8.4'	-23	29	65	103	118	122	123	122	118	103	65	29	-23
9.6'	19	51	74	95	102	103	103	103	102	95	74	51	19
10.8'	65	74	81	80	61	48	44	48	61	80	81	74	65
11.4'	81	81	82	52	20	0	-7	0	20	52	82	81	81
12.0'	87	85	76	16	-31	-59	-68	-59	-31	16	76	85	87

Total Load

b = 15.33-ft

a = 12-ft

	0.0'	0.8'	1.5'	3.1'	4.6'	6.1'	7.7'	9.2'	10.7'	12.3'	13.8'	14.6'	15.3'
0.0'	87	83	48	-61	-145	-194	-211	-194	-145	-61	48	83	87
0.6'	75	77	71	4	-53	-89	-101	-89	-53	4	71	77	75
1.2'	47	63	75	54	20	-2	-10	-2	20	54	75	63	47
2.4'	-36	23	63	102	114	116	116	116	114	102	63	23	-36
3.6'	-111	-18	47	116	142	150	152	150	142	116	47	-18	-111
4.8'	-160	-46	35	123	160	169	175	169	160	123	35	-46	-160
6.0'	-177	-56	30	125	166	180	183	180	166	125	30	-56	-177
7.2'	-160	-46	35	123	160	169	175	169	160	123	35	-46	-160
8.4'	-111	-18	47	116	142	150	152	150	142	116	47	-18	-111
9.6'	-36	23	63	102	114	116	116	116	114	102	63	23	-36
10.8'	47	63	75	54	20	-2	-10	-2	20	54	75	63	47
11.4'	75	77	71	4	-53	-89	-101	-89	-53	4	71	77	75
12.0'	87	83	48	-61	-145	-194	-211	-194	-145	-61	48	83	87

MIN. PT STRESS = 100psi FOR TEMPERATURE REINFORCING AND 125psi FOR TWO WAY SLABS.

ADDED PRESTRESSING RESULTS

- RESULTS ARE PROVIDED FOR TOP STRESS IN SLAB. STRESS IS CHECKED AGAINST ALLOWABLE TENSILE STRESS.
- BOTTOM OF SLAB STRESS IS CALCULATED AND CAN BE REPORTED IF NEEDED.

ADDED PRESTRESSING RESULTS IN TOP OF SLAB

(MAXIMUM NEGATIVE TENSION IS SHOWN FOR EACH DIRECTION x OR y)

Dead Load

Concrete stress in top of slab

b = 15.33-ft

a = 12-ft

	0.0'	0.8'	1.5'	3.1'	4.6'	6.1'	7.7'	9.2'	10.7'	12.3'	13.8'	14.6'	15.3'
0.0'	60	62	67	79	88	94	95	94	88	79	67	62	60
0.6'	66	65	65	70	77	81	82	81	77	70	65	65	66
1.2'	71	73	66	63	65	68	69	68	65	63	66	73	71
2.4'	80	73	67	51	45	43	44	43	45	51	67	73	80
3.6'	89	76	63	41	26	18	15	18	26	41	63	76	89
4.8'	94	78	62	31	9	-5	-9	-5	9	31	62	78	94
6.0'	96	79	61	28	3	-12	-17	-12	3	28	61	79	96
7.2'	94	78	62	31	9	-5	-9	-5	9	31	62	78	94
8.4'	89	76	63	41	26	18	15	18	26	41	63	76	89
9.6'	80	73	67	51	45	43	44	43	45	51	67	73	80
10.8'	71	73	66	63	65	68	69	68	65	63	66	73	71
11.4'	66	65	65	70	77	81	82	81	77	70	65	65	66
12.0'	60	62	67	79	88	94	95	94	88	79	67	62	60

Total Load

b = 15.33-ft

a = 12-ft

	0.0'	0.8'	1.5'	3.1'	4.6'	6.1'	7.7'	9.2'	10.7'	12.3'	13.8'	14.6'	15.3'
0.0'	60	64	72	94	111	121	124	121	111	94	72	64	60
0.6'	69	70	70	79	90	97	100	97	90	79	70	70	69
1.2'	75	78	72	66	70	74	76	74	70	66	72	78	75
2.4'	91	78	68	45	33	30	31	30	33	45	68	78	91
3.6'	106	83	60	21	-6	-21	-26	-21	-6	21	60	83	106
4.8'	116	87	57	3	-38	-62	-70	-62	-38	3	57	87	116
6.0'	119	89	57	-3	-48	-75	-84	-75	-48	-3	57	89	119
7.2'	116	87	57	3	-38	-62	-70	-62	-38	3	57	87	116
8.4'	106	83	60	21	-6	-21	-26	-21	-6	21	60	83	106
9.6'	91	78	68	45	33	30	31	30	33	45	68	78	91
10.8'	75	78	72	66	70	74	76	74	70	66	72	78	75
11.4'	69	70	70	79	90	97	100	97	90	79	70	70	69
12.0'	60	64	72	94	111	121	124	121	111	94	72	64	60

MIN. PT STRESS = 100psi FOR TEMPERATURE REINFORCING AND 125psi FOR TWO WAY SLABS.

DESIGN OF REINFORCING USING USD METHOD

- AS A CHECK, THE REINFORCING IS DESIGNED USING USD METHOD.
- LOAD FACTORS
  - LF_{DL} = 1.2 LF_{LL} = 1.6
  - $Ø_b$ = 0.9
  - $Ø_T$ = .00188(60/F_y)
- AREA REINFORCING REQUIRED INCLUDES TEMPERATURE REINFORCING.
- USD CHECK HAS SEPARATE BAR COVER DEPTH INPUT.
- USD % ULTIMATE STRENGTH DESIGN.

USD RESULTS

Design by Ultiumate Strength Method

Temperature Reinf $A_{s\_T} = 0.086 \cdot in^2$ Area of Steel Existing $A_{s\_s} = 0.028 \cdot in^2$

Required Area of Steel per foot

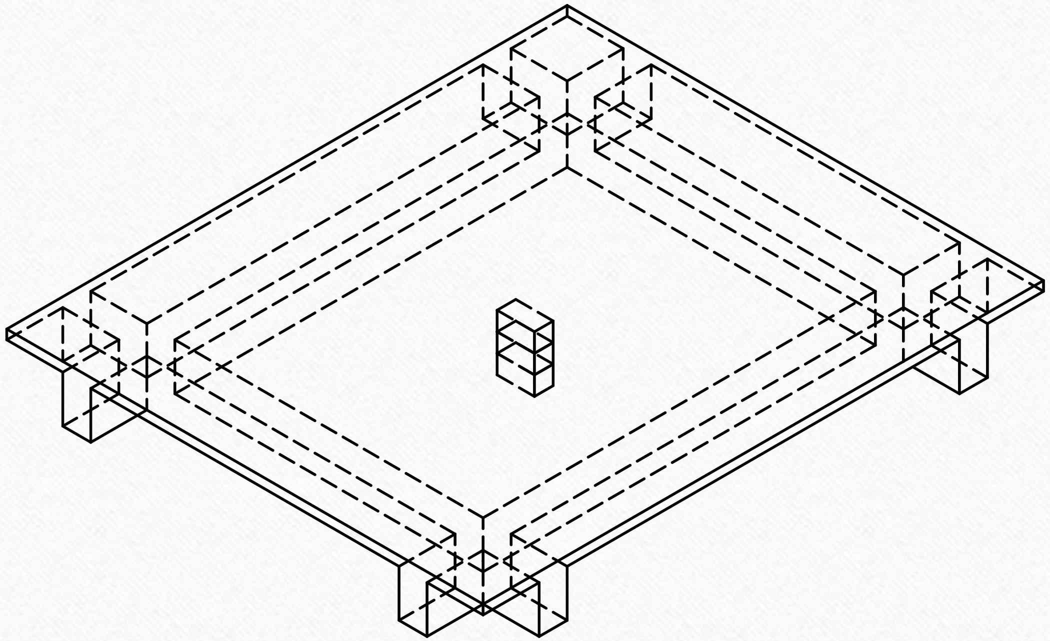
	0.0'	0.8'	1.5'	3.1'	4.6'	6.1'	7.7'	9.2'	10.7'	12.3'	13.8'	14.6'	15.3'
0.0'	0.086	0.086	0.086	0.102	0.157	0.191	0.202	0.191	0.157	0.102	0.086	0.086	0.086
0.6'	0.086	0.086	0.086	0.086	0.098	0.121	0.129	0.121	0.098	0.086	0.086	0.086	0.086
1.2'	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086
2.4'	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086
3.6'	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086
4.8'	0.086	0.086	0.086	0.086	0.086	0.086	0.089	0.086	0.086	0.086	0.086	0.086	0.086
6.0'	0.086	0.086	0.086	0.086	0.086	0.092	0.098	0.092	0.086	0.086	0.086	0.086	0.086
7.2'	0.086	0.086	0.086	0.086	0.086	0.086	0.089	0.086	0.086	0.086	0.086	0.086	0.086
8.4'	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086
9.6'	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086
10.8'	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086
11.4'	0.086	0.086	0.086	0.086	0.098	0.121	0.129	0.121	0.098	0.086	0.086	0.086	0.086
12.0'	0.086	0.086	0.086	0.102	0.157	0.191	0.202	0.191	0.157	0.102	0.086	0.086	0.086

Required Bar Spacing for $no_b = 3$ bar $d'_b = 0.375 \cdot in$

	0.0'	0.8'	1.5'	3.1'	4.6'	6.1'	7.7'	9.2'	10.7'	12.3'	13.8'	14.6'	15.3'
0.0'	15.3	15.3	15.3	12.9	8.4	6.9	6.5	6.9	8.4	12.9	15.3	15.3	15.3
0.6'	15.3	15.3	15.3	15.3	13.6	11.0	10.3	11.0	13.6	15.3	15.3	15.3	15.3
1.2'	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3
2.4'	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3
3.6'	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3
4.8'	15.3	15.3	15.3	15.3	15.3	15.3	14.9	15.3	15.3	15.3	15.3	15.3	15.3
6.0'	15.3	15.3	15.3	15.3	15.3	14.4	13.5	14.4	15.3	15.3	15.3	15.3	15.3
7.2'	15.3	15.3	15.3	15.3	15.3	15.3	14.9	15.3	15.3	15.3	15.3	15.3	15.3
8.4'	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3
9.6'	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3
10.8'	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3
11.4'	15.3	15.3	15.3	15.3	13.6	11.0	10.3	11.0	13.6	15.3	15.3	15.3	15.3
12.0'	15.3	15.3	15.3	12.9	8.4	6.9	6.5	6.9	8.4	12.9	15.3	15.3	15.3

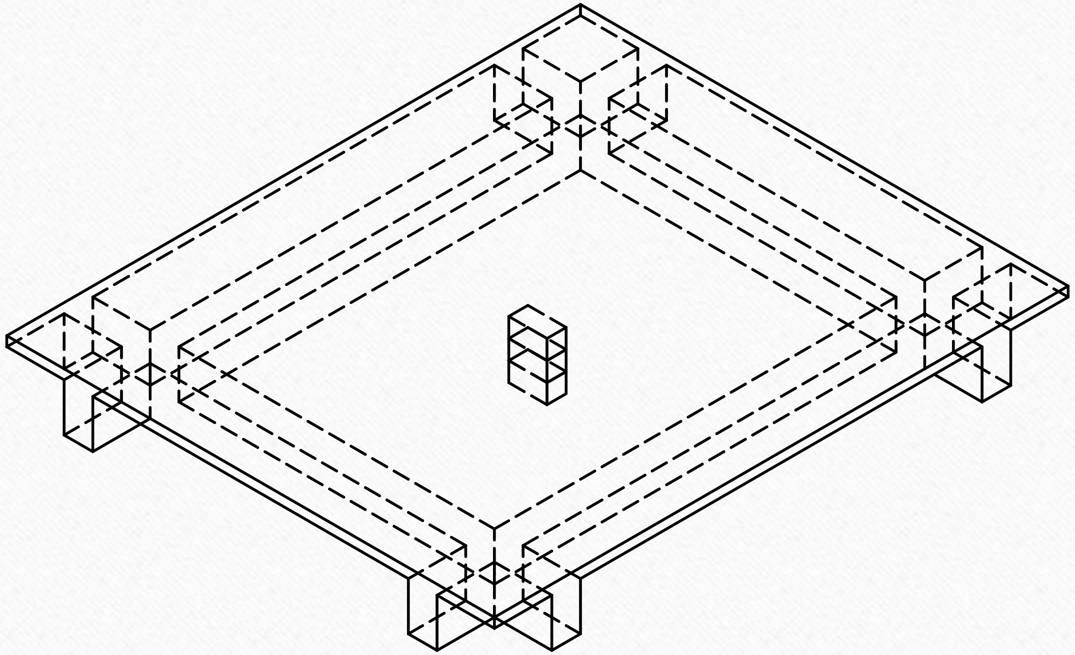
INTERMEDIATE PIER ANALYSIS

- INTERMEDIATE PIERS
  - THERE ARE NO PUBLISHED NUMERICAL METHODS FOR INTERMEDIATE PIERS FOR PLATES WITH FIXED EDGES.



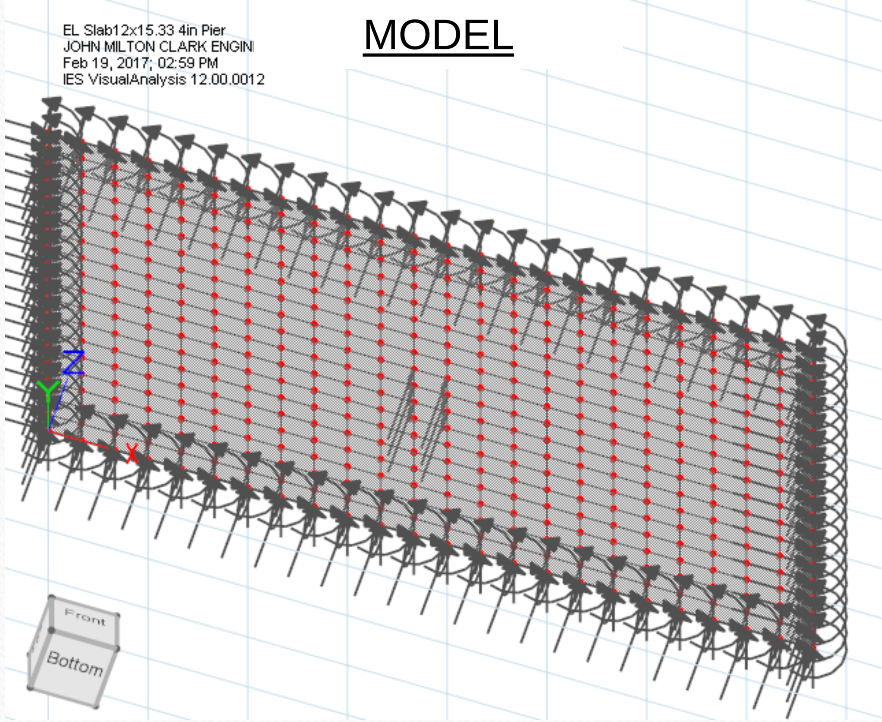
INTERMEDIATE PIER ANALYSIS

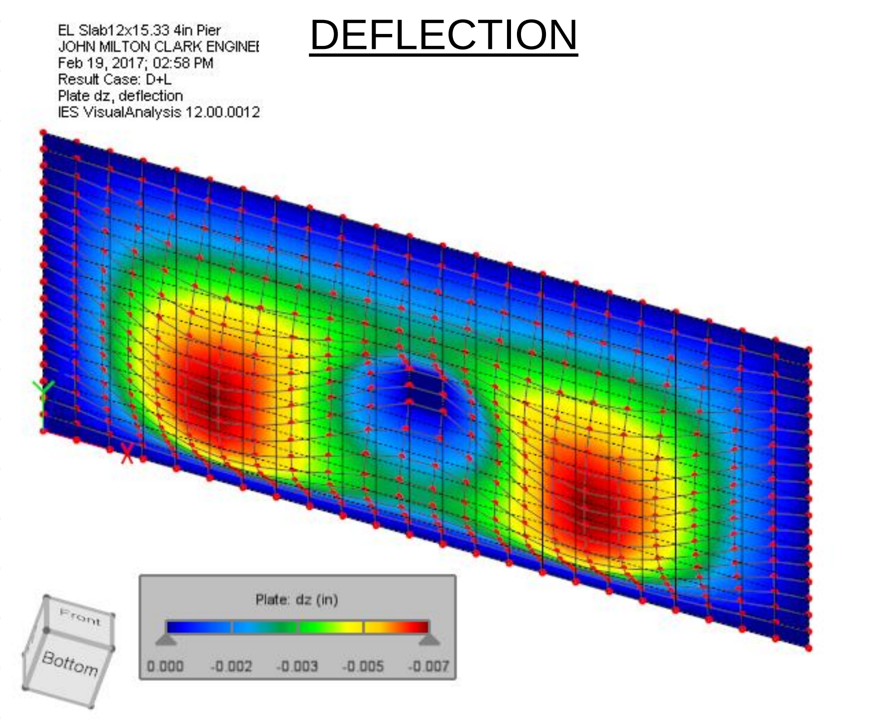
- INTERMEDIATE PIERS ON SLABS WITHOUT BEAMS.
  - MUST USE FEA OR SIMPLIFIED METHOD TO ANALYZE (???).
  - EXISTING REINFORCING WILL IN GENERAL NOT BE SUFFICIENT FOR INTERMEDIATE PIERS.



INTERMEDIATE PIER ANALYSIS

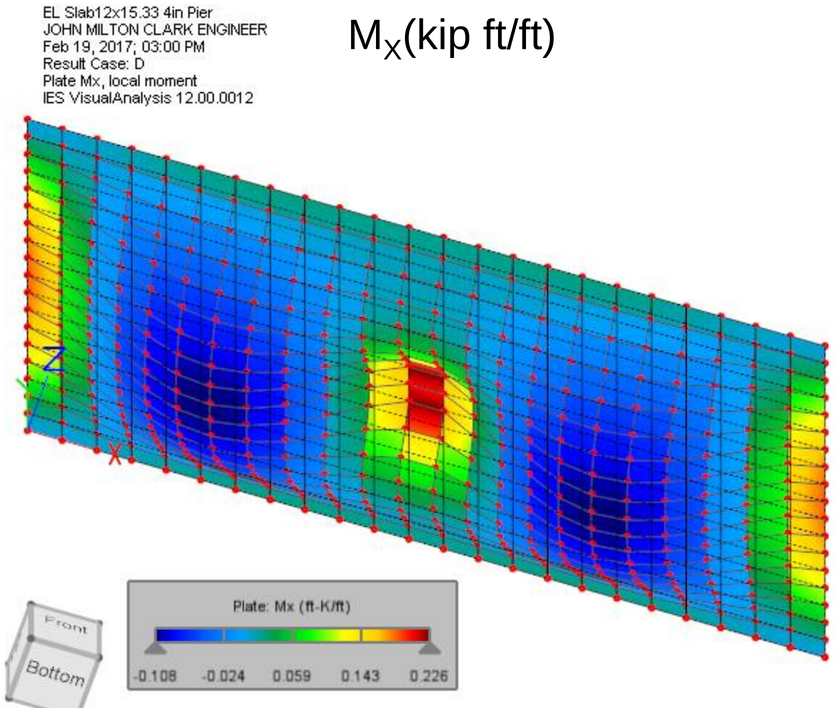
FEA EXAMPLE: a = 12' b = 15.33' PIER IN CENTER



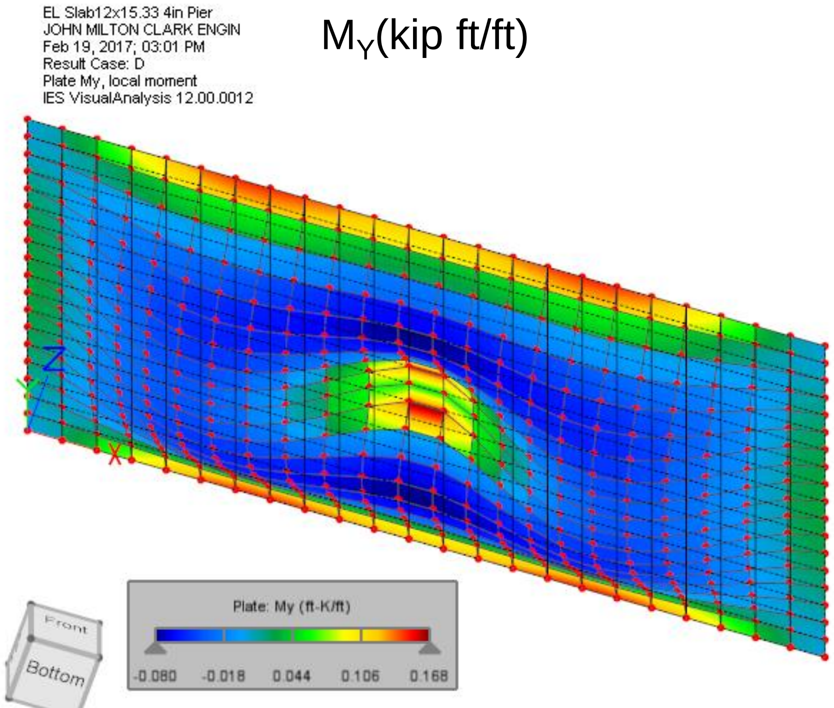


INTERMEDIATE PIER ANALYSIS

M_X(kip ft/ft)

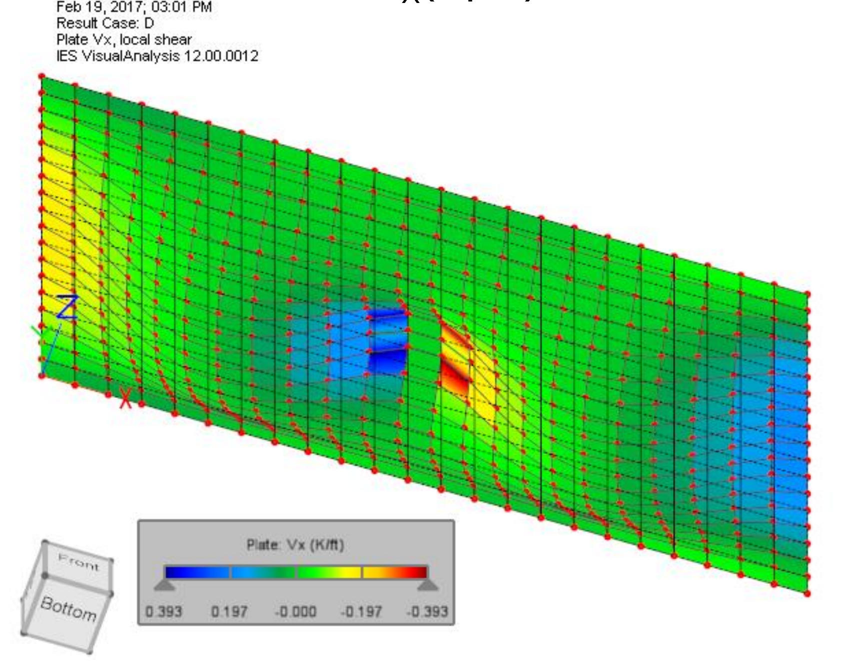


M_Y(kip ft/ft)

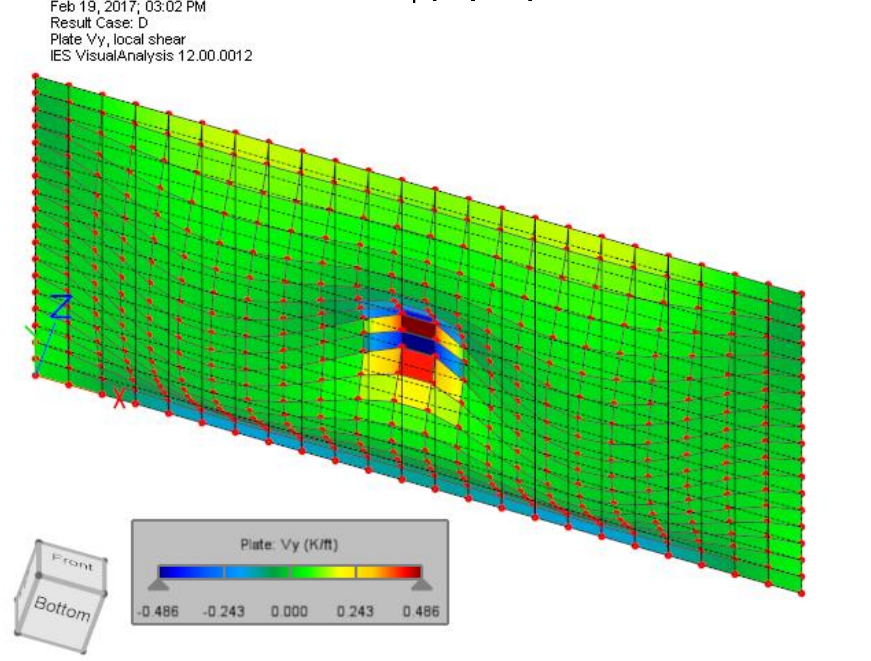


INTERMEDIATE PIER ANALYSIS

V_X(kip/ft)



V_Y(kip/ft)



INTERMEDIATE PIER ANALYSIS

UNCRACKED STRESS RESULTS

Stress Results for FEA with 8 x 16 pier at center Example

Uncracked Section

Moment		**Bending Stress**		**% Use**
$M_{xp} := \frac{0.453 kip \cdot ft}{ft}$	$f_{bx\_pier} := \frac{M_{xp}}{S_{slab}}$	$f_{bx\_pier} = 170 \cdot psi$	$\%_{tenx} := \left\| \frac{f_{bx\_pier}}{(f_{t\_all})} \right\|$	$\%_{tenx} = 52 \cdot \%$
$M_{yp} := \frac{0.336 kip \cdot ft}{ft}$	$f_{by\_pier} := \frac{M_{yp}}{S_{slab}}$	$f_{by\_pier} = 126 \cdot psi$	$\%_{teny} := \left\| \frac{f_{by\_pier}}{(f_{t\_all})} \right\|$	$\%_{teny} = 38 \cdot \%$

INTERMEDIATE PIER ANALYSIS

Back Calculated Moment Coefficients for Pier

$\beta_{px} = 0.2097$ $\beta_{py} = 0.0953$

Let spans be 1/2 of plate dimensions

$a_p = 6\,ft$ $b_p = 7.665\,ft$

$M'_{xp} := w_{TL} \cdot a_p^{\,2} \cdot \frac{\beta_{px}}{ft}$ $M'_{yp} := w_{TL} \cdot b_p^{\,2} \cdot \frac{\beta_{py}}{ft}$

$M'_{xp} = 0.453\,\frac{kip \cdot ft}{ft}$ $M'_{yp} = 0.336\,\frac{kip \cdot ft}{ft}$

- CAN ONLY BE USED FOR a/b = .783
- OTHER GEOMETRIES WILL HAVE SIMILAR VALUES

INTERMEDIATE PIER ANALYSIS

Punching Shear

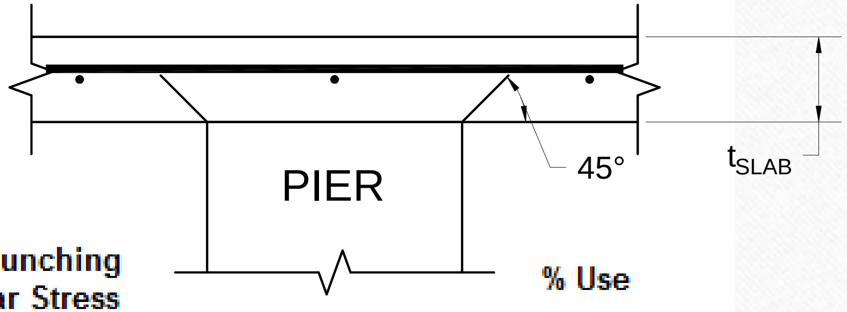
t.slab

$h = 4\,in$

Reinforcing Depth

$\left|d'_{reinf\_x}\right| = 1.81\,in$

$\left|d'_{reinf\_y}\right| = 2.19\,in$



Shear

$V_x := 0.786\,\frac{kip}{ft}$

$V_y := 0.971\,\frac{kip}{ft}$

Shear Stress

$v_{cx} := \frac{V_x \cdot \sin(45deg)}{h \cdot d'_{reinf\_x}}$ $\quad v_{cx} = 87 \cdot \frac{psi}{ft}$

$v_{cy} := \frac{V_y \cdot \sin(45deg)}{h \cdot d'_{reinf\_y}}$ $\quad v_{cy} = 89 \cdot \frac{psi}{ft}$

Ult Punching Shear Stress

$v_p := 4 \cdot \sqrt{\frac{f'_c}{psi}} \cdot psi$

$v_p = 219 \cdot psi$

% Use

$\%_{vpx} := \frac{v_{cx} \cdot ft}{v_p}$ $\quad \%_{vpx} = 40\,\%$

$\%_{vpy} := \frac{v_{cy} \cdot ft}{v_p}$ $\quad \%_{vpy} = 41\,\%$

INTERMEDIATE PIER ANALYSIS

- CAN ONLY BE USED FOR a/b = .783
- OTHER GEOMETRIES WILL HAVE SIMILAR VALUES

Back Calculated Shear Coefficients for Pier

$\alpha_x = 2.1833$ $\qquad$ $\alpha_y = 2.1113$

$V'_{xp} := \alpha_x \cdot w_{TL} \cdot a_p$ $\qquad$ $V'_{xp} = 0.786\,kip$

$V'_{yp} := \alpha_y \cdot w_{TL} \cdot b_p$ $\qquad$ $V'_{yp} = 0.971\,kip$

INTERMEDIATE PIER ANALYSIS

WSD CHECK

Check Steel Working Stress at Pier $F_y = 65 \cdot ksi$ $f_{all} = 26 \cdot ksi$

Compression in concrete

$Cp_{TLx} := \text{if}\left(M_{xp} \geq 0, \frac{M_{xp}}{arm_x} \cdot ft, \left|\frac{M_{xp}}{arm'_x}\right| \cdot ft\right)$ $Cp_{TLx} = 2.75\,kip$ $Cp_{TLy} := \text{if}\left(M_{yp} \geq 0, \frac{M_{xp}}{arm_y} \cdot ft, \left|\frac{M_{xp}}{arm'_y}\right| \cdot ft\right)$ $Cp_{TLy} = 2.95\,kip$

$arm_x = 1.975\,in$ $arm'_x = 1.844\,in$ $arm_y = 1.844\,in$ $arm'_y = 1.975\,in$

For equilibruinm tension in steel equals compression in concrete

Stess in Steel $A_{s\_s} = 0.028\,in^2$

$f''_{spx} := \frac{Cp_{TLx}}{A_{s\_s}}$ $f''_{spx} = 98\,ksi$ $f''_{spy} := \frac{Cp_{TLy}}{A_{s\_s}}$ $f''_{spy} = 104\,ksi$

- EXCEEDS YIELD STRESS

INTERMEDIATE PIER ANALYSIS

Set Stress equal to Yield if exceeds Yield

$f'_{spx} := \text{if}\left(f''_{spx} > F_y, F_y \cdot 1.001, f''_{spx}\right)$

$f'_{spx} = 65\ \text{ksi}$

$f'_{spy} := \text{if}\left(f''_{spx} > F_y, F_y \cdot 1.001, f''_{spy}\right)$

$f'_{spx} = 65\ \text{ksi}$

$f'_{spxx} := \text{if}\left(f'_{spx} > F_y, \text{"at or Exceeds yld"}, \text{if}\left(f'_{spx} < -f_{all} \vee f'_{spx} > f_{all}, \text{"Exceeds Allowable"}, \text{"OK"}\right)\right)$

$f'_{spyy} := \text{if}\left(f'_{spy} > F_y, \text{"at or Exceeds yld"}, \text{if}\left(f'_{spy} < -f_{all} \vee f'_{spy} > f_{all}, \text{"Exceeds Allowable"}, \text{"OK"}\right)\right)$

$f'_{spxx} = \text{"at or Exceeds yld"}$

$f'_{spyy} = \text{"at or Exceeds yld"}$

INTERMEDIATE PIER ANALYSIS

USD CHECK

Ultimate Moment Supplied at pier

$$M_{upf} := \frac{\phi_b \cdot A_{s\_s} \cdot F_y \cdot \left(d_{reinf} - 0.59 \cdot \frac{A_{s\_s} \cdot F_y}{f'_c \cdot b}\right)}{ft}$$

Ultimate Moment Furnished

$$M_{upf} = \begin{pmatrix} 0.275 \\ 0.301 \end{pmatrix} \frac{kip \cdot ft}{ft}$$

Ultimate Moment Required

$$M_{up} = \begin{pmatrix} 0.62 \\ 0.46 \end{pmatrix} \frac{kip \cdot ft}{ft}$$

Percent of required Moment Supplied

$$\%M_{p\_supld} := \overrightarrow{\left(\frac{M_{upf}}{M_{up}}\right)}$$

$$\%M_{p\_supld} = \begin{pmatrix} 44 \\ 65 \end{pmatrix} \%$$

RECOMMENDATIONS

- ACCURATELY DETERMINE SIZE, SPACING, AND DEPTH OF SLAB REINFORCING – e.g. GPR AS WELL AS SLAB THICKNESS AND LOCATION OF GRADE BEAMS
- ITERATE ON SLAB SIZE (a & b), CHECK – BY SUBDIVIDING PLATE UNTIL ALLOWABLE TENSILE STRESS IS SATISFIED.

GPR: GROUND PENETRATING RADAR

EXAMPLES OF ADDING INTERMEDIATE BEAMS

BAR STRESS FOR INITIAL PLATE SIZE

Total Load

Stress in ksi

b = 15.33-ft

a = 12-ft

	0.0'	0.8'	1.5'	3.1'	4.6'	6.1'	7.7'	9.2'	10.7'	12.3'	13.8'	14.6'	15.3'
0.0'	0	11	36	65	65	65	65	65	65	65	36	11	0
0.6'	7	9	23	62	65	65	65	65	65	62	23	9	7
1.2'	25	15	13	33	52	65	65	65	52	33	13	15	25
2.4'	65	40	15	9	16	17	17	17	16	9	15	40	65
3.6'	65	64	24	28	45	54	57	54	45	28	24	64	65
4.8'	65	65	32	40	64	65	65	65	64	40	32	65	65
6.0'	65	65	35	43	65	65	65	65	65	43	35	65	65
7.2'	65	65	32	40	64	65	65	65	64	40	32	65	65
8.4'	65	64	24	28	45	54	57	54	45	28	24	64	65
9.6'	65	40	15	9	16	17	17	17	16	9	15	40	65
10.8'	25	15	13	33	52	65	65	65	52	33	13	15	25
11.4'	7	9	23	62	65	65	65	65	65	62	23	9	7
12.0'	0	11	36	65	65	65	65	65	65	65	36	11	0

All cells must be white to comply with ACI.

BAR STRESS WITH 2 INTERMEDIATE BEAMS

a = 5.11 ft, b = 12 ft

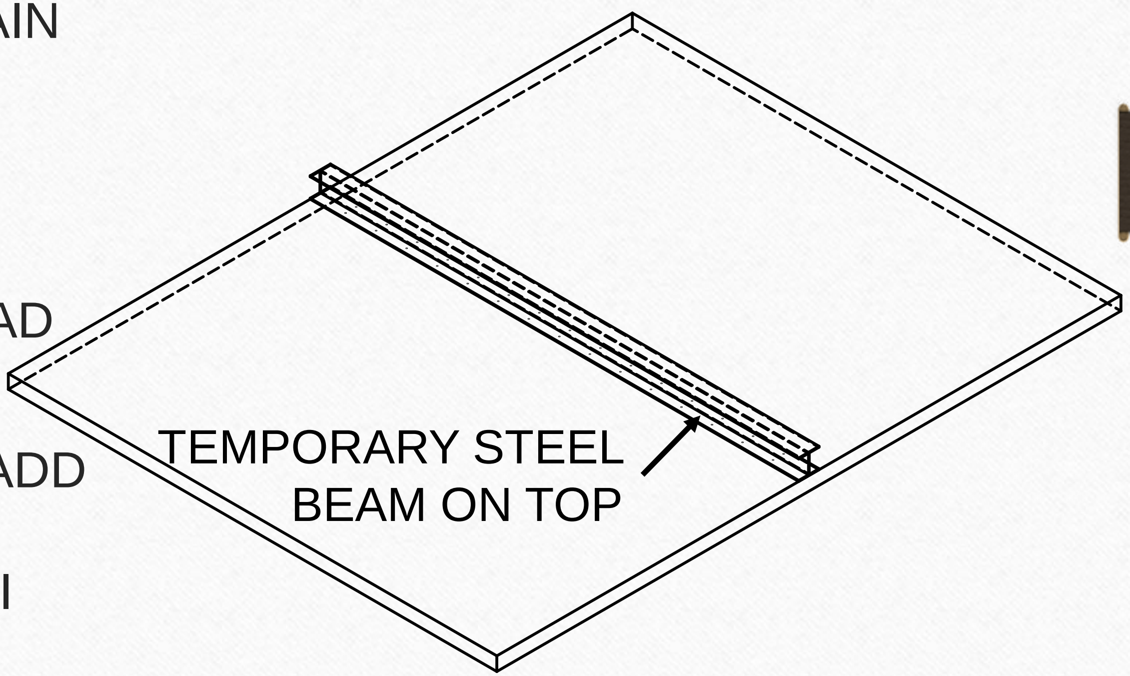
0	1	4	13	21	27	29	27	21	13	4	1	0
7	4	3	3	5	7	8	7	5	3	3	4	7
17	11	6	1	5	7	7	7	5	1	6	11	17
32	22	13	2	10	15	16	15	10	2	13	22	32
39	27	17	1	12	19	21	19	12	1	17	27	39
41	29	18	1	12	20	22	20	12	1	18	29	41
42	30	19	1	12	20	23	20	12	1	19	30	42
41	29	18	1	12	20	22	20	12	1	18	29	41
39	27	17	1	12	19	21	19	12	1	17	27	39
32	22	13	2	10	15	16	15	10	2	13	22	32
17	11	6	1	5	7	7	7	5	1	6	11	17
7	4	3	3	5	7	8	7	5	3	3	4	7
0	1	4	13	21	27	29	27	21	13	4	1	0

0	1	4	13	21	27	29	27	21	13	4	1	0
7	4	3	3	5	7	8	7	5	3	3	4	7
17	11	6	1	5	7	7	7	5	1	6	11	17
32	22	13	2	10	15	16	15	10	2	13	22	32
39	27	17	1	12	19	21	19	12	1	17	27	39
41	29	18	1	12	20	22	20	12	1	18	29	41
42	30	19	1	12	20	23	20	12	1	19	30	42
41	29	18	1	12	20	22	20	12	1	18	29	41
39	27	17	1	12	19	21	19	12	1	17	27	39
32	22	13	2	10	15	16	15	10	2	13	22	32
17	11	6	1	5	7	7	7	5	1	6	11	17
7	4	3	3	5	7	8	7	5	3	3	4	7
0	1	4	13	21	27	29	27	21	13	4	1	0

0	1	4	13	21	27	29	27	21	13	4	1	0
7	4	3	3	5	7	8	7	5	3	3	4	7
17	11	6	1	5	7	7	7	5	1	6	11	17
32	22	13	2	10	15	16	15	10	2	13	22	32
39	27	17	1	12	19	21	19	12	1	17	27	39
41	29	18	1	12	20	22	20	12	1	18	29	41
42	30	19	1	12	20	23	20	12	1	19	30	42
41	29	18	1	12	20	22	20	12	1	18	29	41
39	27	17	1	12	19	21	19	12	1	17	27	39
32	22	13	2	10	15	16	15	10	2	13	22	32
17	11	6	1	5	7	7	7	5	1	6	11	17
7	4	3	3	5	7	8	7	5	3	3	4	7
0	1	4	13	21	27	29	27	21	13	4	1	0

RECOMMENDATIONS

- DO <u>NOT</u> DESIGN FOR STRUCTURAL PLAIN CONCRETE (SPC) PER ACI 318 22.2.1
- OK TO CONSIDER SPC FOR LIFTING CONDITIONS.
- DESIGN FOR CODE SPECIFIED LIVE LOAD OF 40 psf.
- IF SLAB WILL CRACK DURING LIFTING. ADD TEMPORARY REINFORCING ON TOP OF SLAB. BOLT BEAM TO FLOOR WITH HILTI ANCHOR BOLTS (S).



RECOMMENDATIONS

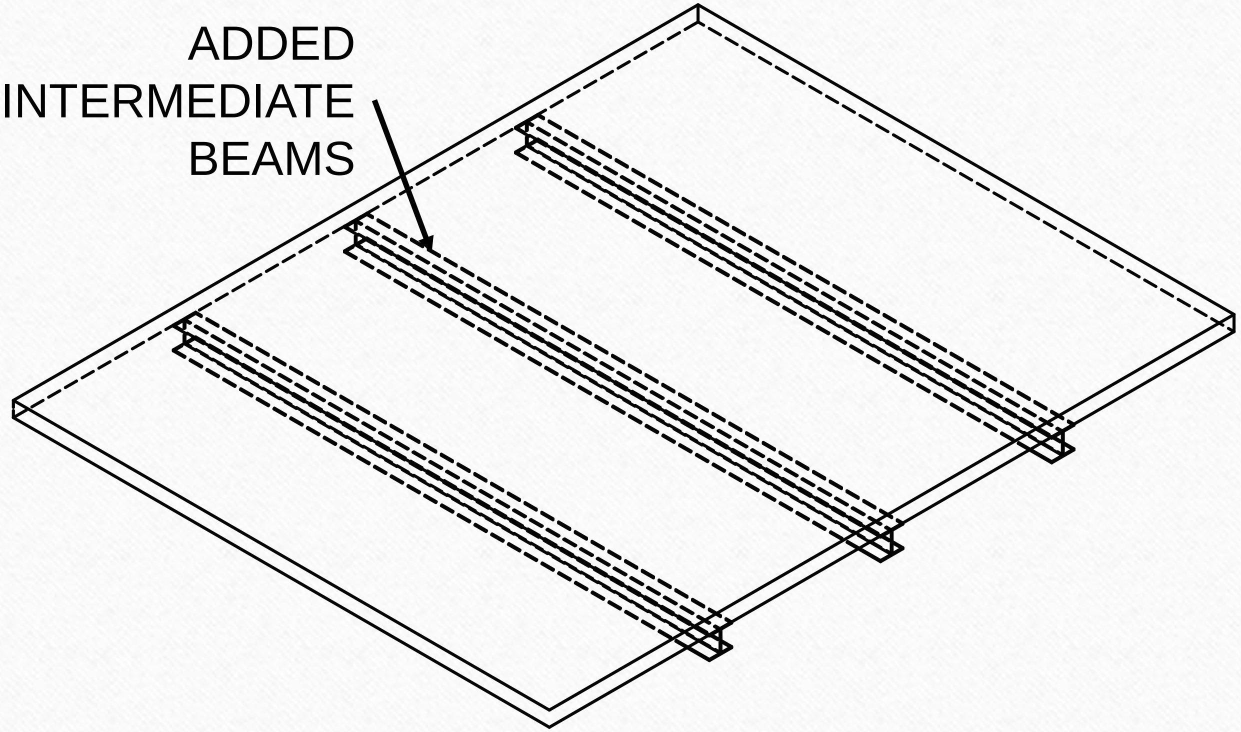
- INTERMEDIATE BEAMS MAY NOT SATISFY TEMPERATURE REINFORCING.

LESSONS LEARNED

- EOR IS RESPONSIBLE TO PROVIDE APPROPRIATE DETAILS FOR TEMPERATURE REINFORCING.
- ULTIMATE STRENGTH DESIGN (USD)
  - MINIMUM REINFORCING FOR GIVEN SPANS a AND b CAN EASILY BE DETERMINED BY USD METHOD FOR SPECIFIED BAR DIAMETER AND SPACING IS SUPPLIED.

RECOMMENDATIONS

- FOR SLABS THAT DO NOT HAVE ADEQUATE REINFORCING TO SATISFY TOTAL LOAD, ADD INTERMEDIATE BEAMS AT APPROPRIATE SPACING.
- BOLT BEAM ENDS TO GRADE BEAMS, ENSURE UNIFORM CONTACT TO BOTTOM OF SLAB.
- VERIFY TEMPERATURE REINFORCING AND DETAILS.



SOME LESSONS LEARNED

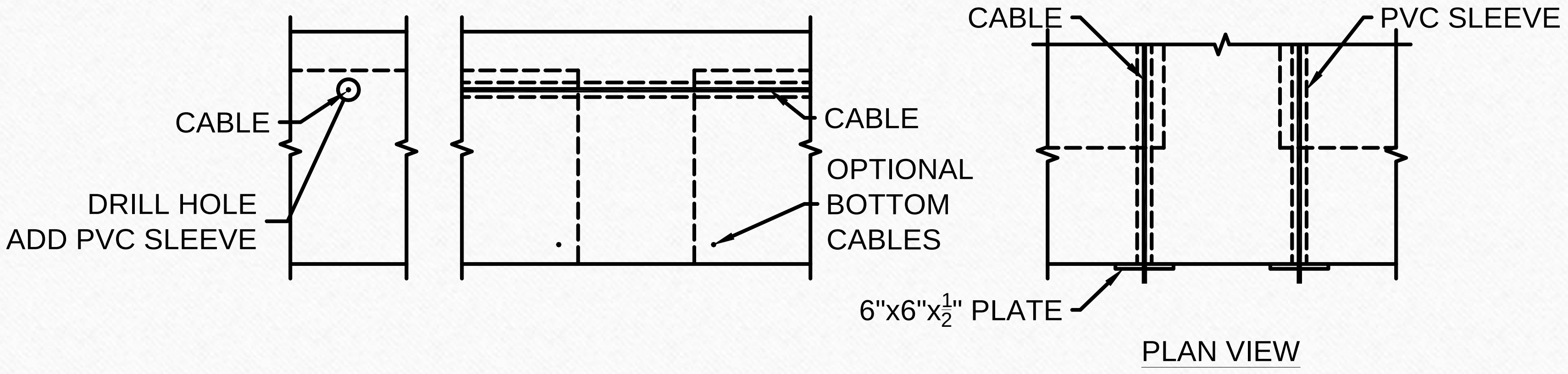
- POST TENSIONED
  - IT IS POSSIBLE THAT EXISTING POST TENSIONED SLABS WILL HAVE ADEQUATE REINFORCING FOR CLEAR SPANS DEPENDING ON SLAB SPANS.
  - CHECK TO SATISFY 100psi PRESTRESS AFTER LOSSES FOR TEMPERATURE.
  - CHECK TENSILE STRESS LESS THAN CRACKING STRESS.
  - ACI SPECIFIES THAT TWO-WAY SLABS SHALL HAVE 125psi EFFECTIVE PRESTRESS (ACI 318 8.6.2.1).
  - ADDED PRESTRESS CABLES MAY BE REQUIRED TO SATISFY MIN. PRESTRESS.

SOME LESSONS LEARNED

- PRESTRESS REINFORCING
  - IT IS POSSIBLE TO ADD PRESTRESS REINFORCING INSTEAD OF INTERMEDIATE BEAMS.
  - FEASIBILITY WILL BE BASED ON COST COMPARISON BETWEEN TWO OPTIONS.
  - CHECK TO SATISFY 125psi MIN. PRESTRESS.

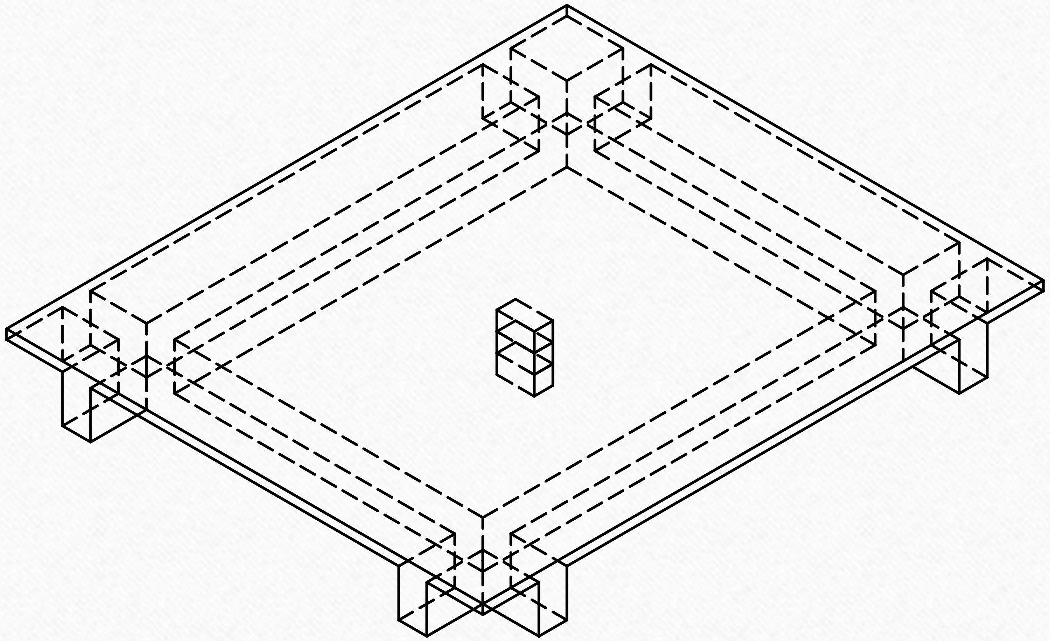
SOME LESSONS LEARNED

- PRESTRESS REINFORCING DETAILS AND SKETCHES.
  - CHECK TENSILE STRESS LESS THAN CRACKING STRESS.
  - NEW CABLES SHOULD BE PLACED IN PVC TUBES, GROUT IF POSSIBLE.



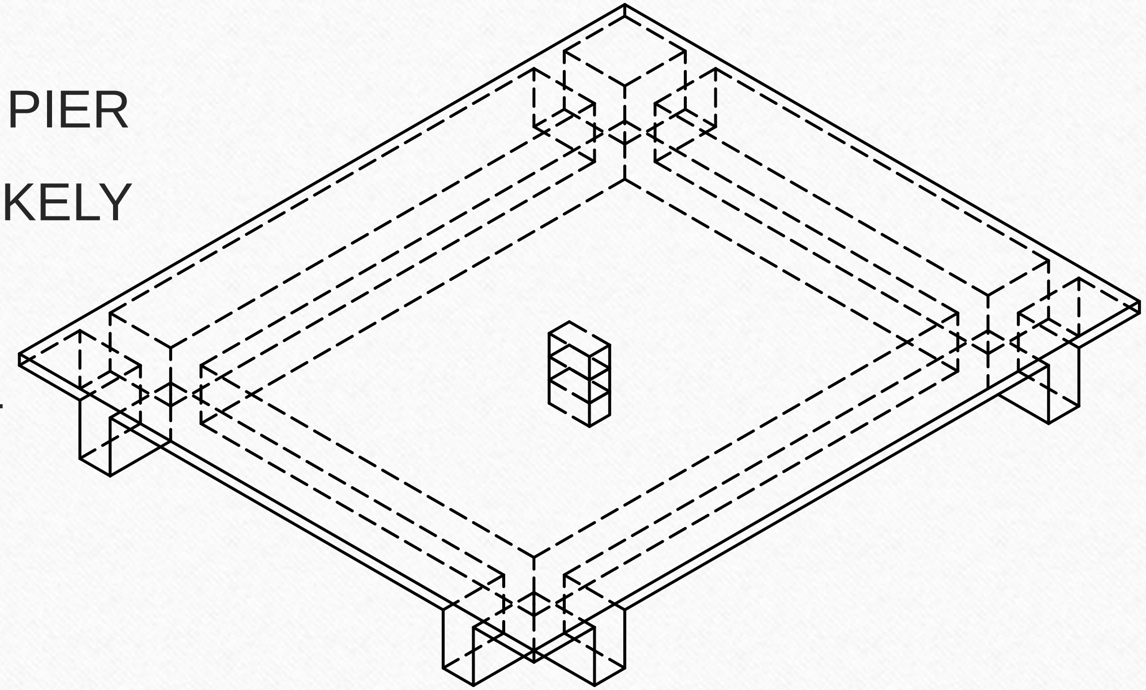
SOME LESSONS LEARNED

- INTERMEDIATE PIERS ON SLABS WITHOUT BEAMS.
  - MUST USE FEA OR SIMPLIFIED METHOD TO ANALYZE (???).
  - EXISTING REINFORCING WILL IN GENERAL NOT BE SUFFICIENT FOR INTERMEDIATE PIERS.



SOME LESSONS LEARNED

- UNCRACKED SECTIONS WILL PROBABLY NOT CRACK WITH PIER
- PUNCHING SHEAR STRESS LIKELY WILL BE ADEQUATE
- INTERMEDIATE PIERS WILL PROBABLY WORK WITH POST TENSIONED AND ADDED PRESTRESSED OPTIONS.



SOME LESSONS LEARNED

- UNCRACKED SECTION MAY BE OK FOR LIFTING.
- UNCRACKED SECTION WILL LIKELY BE CLOSE TO MAXIMUM TENSILE STRESS AT TOTAL LOAD (FOR REFERENCE ONLY).
- MOST IF NOT ALL REINFORCED CONCRETE SLABS HAVE SHRINKAGE CRACKS.
- SHRINKAGE CRACKS TYPICALLY FORM AT ≈15’ TO 20’ SPACING.

SOME LESSONS LEARNED

- IF SLAB CRACKS, TENSILE STRESS IN EXISTING REINFORCING WILL LIKELY BE AT YIELD IN TWO WAY BENDING.
- ONCE STEEL STRESS REACHES YIELD, SLAB WILL START TO DEFLECT EXCESSIVELY AND HANG SIMILARLY TO A CHAIN UNDER TOTAL LOAD
- YIELDING MAY NOT OCCUR UNDER NORMAL LIVE LOAD (≈12 psf).

SOME LESSONS LEARNED

- IF SLAB IS UNCRACKED, CAN SPAN ABOUT (±) 15 ft IN TWO WAY BENDING.
- IF SLAB IS CRACKED, EXISTING REINFORCING WILL GENERALLY NOT BE ADEQUATE.
- WELDED WIRE MESH (WWM) WILL GENERALLY NOT BE ADEQUATE FOR SPANS OVER ABOUT 4 ft. SHORT SPAN (WWM AT MID DEPTH).
- LOCATION AND SIZE OF REINFORCING IS GENERALLY NOT KNOWN AND SHOULD BE VERIFIED BY GROUND PENETRATING RADAR (GPR) OR OTHER APPROPRIATE METHODS, e.g. TAKE CORE SAMPLES.

SOME LESSONS LEARNED

- EDGE SHEAR WILL GENERALLY NOT CONTROL DESIGNS OF TWO WAY SLABS.
- POST-TENSIONED SLABS WILL MOST LIKELY BE OK FOR LIFTING FOR SPANS UP TO ABOUT 15 FT. OR SO.

SOME LESSONS LEARNED

- CHECK EXISTING POST TENSIONED SLAB
- DESIGN ADDED PRESTRESSED REINFORCING AS APPROPRIATE.
- DESIGN INTERMEDIATE BEAMS.
- MCAD TEMPLATES ARE AN EXCELLENT TOOL FOR FAST PRELIMINARY DESIGN AND FOR COST ESTIMATES.
- FINAL DESIGN IS RESPONSIBILITY OF EOR.

CAUTION:
SOME FINAL THOUGHTS

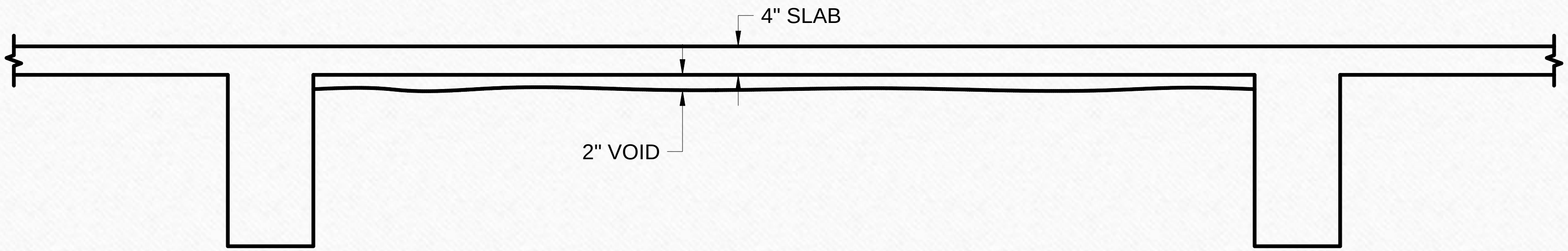
- RAISED SLABS THAT ARE CHECKED USING STRUCTURAL PLAIN CONCRETE (SPC) MAY BE OPERATING CLOSE TO FAILURE.
- THIS DOES NOT COMPLY WITH ACI CODE AND MOST LIKELY DOES NOT COMPLY WITH IBC OR SPECIFIED LIVE LOAD OF 40 psf (ASCE 7-10).
- AN OWNER MAY ADD A VERY HEAVY LOAD SUCH AS A GRAND PIANO OR POOL TABLE THAT CAUSES A RAISED SLAB TO FAIL IF NOT ADEQUATELY REINFORCED.
- A RAISED SLAB THAT FAILS WHICH IS NOT DESIGNED ACCORDING TO IBC AND ACI WILL **CAUSE** EOR AND CONTRACTOR A SIGNIFICANT AMOUNT OF GRIEF.

CAUTION:
SOME FINAL THOUGHTS

- SLABS WITH WWM WILL MOST LIKELY NOT HAVE ADEQUATE TEMPERATURE REINFORCING.
- A RAISED SLAB IS MORE SUSCEPTIBLE TO TEMPERATURE CHANGE THAN A SLAB ON GRADE.
- EXISTING REINFORCING SUCH AS #3s @ 12” EACH WAY WILL NOT BE ADEQUATE FOR TYPICAL GRADE BEAM SPACING, SO INTERMEDIATE BEAMS ARE REQUIRED.

HISTORICAL COMMENTS

- SOME FOUNDATION REPAIR CONTRACTORS HAVE RAISED DOZENS OF SLABS ON GRADE.
- THEY REPORT THAT OFTEN THE SLABS HAVE CONTINUOUS VOIDS BETWEEN GRADE BEAMS WITH OUT CRACKS.
- WHY DO THESE SLABS WORK?



HISTORICAL COMMENTS

- DESIGN LIVE LOAD IS 40 psf
- OWNER OCCUPIED LIVE LOAD ≈12 psf FROM ASCE 7-10
  TABLE C4-2, pg. 414
- LIVE LOAD = 6.0 psf CONSTANT +6.0 psf TRANSIENT

HISTORICAL COMMENTS

- TWO CASES ARE SHOWN BELOW FOR STRUCTURAL PLAIN CONCRETE (SPC) BENDING STRESS 40 psf LIVE LOAD AND 12 psf LIVE LOAD.

Percent of Tensile Strength of Concrete

<u>Total Load</u>

q_{LL} = 40 psf

b = 15.33-ft, a = 12-ft

	0.0'	0.8'	1.5'	3.1'	4.6'	6.1'	7.7'	9.2'	10.7'	12.3'	13.8'	14.6'	15.3'
0.0'	0%	6%	19%	52%	78%	93%	98%	93%	78%	52%	19%	6%	0%
0.6'	4%	5%	12%	33%	50%	61%	65%	61%	50%	33%	12%	5%	4%
1.2'	12%	7%	7%	17%	28%	35%	37%	35%	28%	17%	7%	7%	12%
2.4'	37%	20%	7%	5%	8%	9%	9%	9%	8%	5%	7%	20%	37%
3.6'	60%	32%	12%	14%	22%	27%	28%	27%	22%	14%	12%	32%	60%
4.8'	75%	41%	16%	20%	32%	39%	42%	39%	32%	20%	16%	41%	75%
6.0'	80%	44%	17%	21%	35%	43%	46%	43%	35%	21%	17%	44%	80%
7.2'	75%	41%	16%	20%	32%	39%	42%	39%	32%	20%	16%	41%	75%
8.4'	60%	32%	12%	14%	22%	27%	28%	27%	22%	14%	12%	32%	60%
9.6'	37%	20%	7%	5%	8%	9%	9%	9%	8%	5%	7%	20%	37%
10.8'	12%	7%	7%	17%	28%	35%	37%	35%	28%	17%	7%	7%	12%
11.4'	4%	5%	12%	33%	50%	61%	65%	61%	50%	33%	12%	5%	4%
12.0'	0%	6%	19%	52%	78%	93%	98%	93%	78%	52%	19%	6%	0%

Percent of Tensile Strength of Concrete

<u>Total Load</u>

q_{LL} = 12 psf

b = 15.33-ft, a = 12-ft

	0.0'	0.8'	1.5'	3.1'	4.6'	6.1'	7.7'	9.2'	10.7'	12.3'	13.8'	14.6'	15.3'
0.0'	0%	4%	13%	36%	54%	64%	67%	64%	54%	36%	13%	4%	0%
0.6'	2%	3%	8%	22%	34%	42%	45%	42%	34%	22%	8%	3%	2%
1.2'	8%	5%	5%	12%	19%	24%	25%	24%	19%	12%	5%	5%	8%
2.4'	26%	14%	5%	3%	6%	6%	6%	6%	6%	3%	5%	14%	26%
3.6'	42%	22%	8%	10%	15%	18%	19%	18%	15%	10%	8%	22%	42%
4.8'	52%	28%	11%	13%	22%	27%	29%	27%	22%	13%	11%	28%	52%
6.0'	55%	30%	12%	15%	24%	30%	32%	30%	24%	15%	12%	30%	55%
7.2'	52%	28%	11%	13%	22%	27%	29%	27%	22%	13%	11%	28%	52%
8.4'	42%	22%	8%	10%	15%	18%	19%	18%	15%	10%	8%	22%	42%
9.6'	26%	14%	5%	3%	6%	6%	6%	6%	6%	3%	5%	14%	26%
10.8'	8%	5%	5%	12%	19%	24%	25%	24%	19%	12%	5%	5%	8%
11.4'	2%	3%	8%	22%	34%	42%	45%	42%	34%	22%	8%	3%	2%
12.0'	0%	4%	13%	36%	54%	64%	67%	64%	54%	36%	13%	4%	0%

HISTORICAL COMMENTS

- MAX STRESS IS 98% OF CRACKING AT 40 psf AND JUST 67% AT 12 psf.

Percent of Tensile Strength of Concrete

Total Load

q_{LL} = 40 psf

b = 15.33-ft, a = 12-ft

	0.0'	0.8'	1.5'	3.1'	4.6'	6.1'	7.7'	9.2'	10.7'	12.3'	13.8'	14.6'	15.3'
0.0'	0%	6%	19%	52%	78%	93%	98%	93%	78%	52%	19%	6%	0%
0.6'	4%	5%	12%	33%	50%	61%	65%	61%	50%	33%	12%	5%	4%
1.2'	12%	7%	7%	17%	28%	35%	37%	35%	28%	17%	7%	7%	12%
2.4'	37%	20%	7%	5%	8%	9%	9%	9%	8%	5%	7%	20%	37%
3.6'	60%	32%	12%	14%	22%	27%	28%	27%	22%	14%	12%	32%	60%
4.8'	75%	41%	16%	20%	32%	39%	42%	39%	32%	20%	16%	41%	75%
6.0'	80%	44%	17%	21%	35%	43%	46%	43%	35%	21%	17%	44%	80%
7.2'	75%	41%	16%	20%	32%	39%	42%	39%	32%	20%	16%	41%	75%
8.4'	60%	32%	12%	14%	22%	27%	28%	27%	22%	14%	12%	32%	60%
9.6'	37%	20%	7%	5%	8%	9%	9%	9%	8%	5%	7%	20%	37%
10.8'	12%	7%	7%	17%	28%	35%	37%	35%	28%	17%	7%	7%	12%
11.4'	4%	5%	12%	33%	50%	61%	65%	61%	50%	33%	12%	5%	4%
12.0'	0%	6%	19%	52%	78%	93%	98%	93%	78%	52%	19%	6%	0%

Percent of Tensile Strength of Concrete

Total Load

q_{LL} = 12 psf

b = 15.33-ft, a = 12-ft

	0.0'	0.8'	1.5'	3.1'	4.6'	6.1'	7.7'	9.2'	10.7'	12.3'	13.8'	14.6'	15.3'
0.0'	0%	4%	13%	36%	54%	64%	67%	64%	54%	36%	13%	4%	0%
0.6'	2%	3%	8%	22%	34%	42%	45%	42%	34%	22%	8%	3%	2%
1.2'	8%	5%	5%	12%	19%	24%	25%	24%	19%	12%	5%	5%	8%
2.4'	26%	14%	5%	3%	6%	6%	6%	6%	6%	3%	5%	14%	26%
3.6'	42%	22%	8%	10%	15%	18%	19%	18%	15%	10%	8%	22%	42%
4.8'	52%	28%	11%	13%	22%	27%	29%	27%	22%	13%	11%	28%	52%
6.0'	55%	30%	12%	15%	24%	30%	32%	30%	24%	15%	12%	30%	55%
7.2'	52%	28%	11%	13%	22%	27%	29%	27%	22%	13%	11%	28%	52%
8.4'	42%	22%	8%	10%	15%	18%	19%	18%	15%	10%	8%	22%	42%
9.6'	26%	14%	5%	3%	6%	6%	6%	6%	6%	3%	5%	14%	26%
10.8'	8%	5%	5%	12%	19%	24%	25%	24%	19%	12%	5%	5%	8%
11.4'	2%	3%	8%	22%	34%	42%	45%	42%	34%	22%	8%	3%	2%
12.0'	0%	4%	13%	36%	54%	64%	67%	64%	54%	36%	13%	4%	0%

HISTORICAL COMMENTS

- ONCE THE CONCRETE CRACKS THE REINFORCING WILL IMMEDIATELY BE STRESSED.
- THE STRESSES ARE SHOWN BELOW FOR WWM, WITH REINFORCEMENT AT MID DEPTH OF SLAB FOR 40 psf AND 12 psf.

HISTORICAL COMMENTS

- IN BOTH CASES THE WWM YIELDS WHEN CRACKING OCCURS.

Total Load

Stress in ksi

b = 15.33-ft

a = 12-ft

	0.0'	0.8'	1.5'	3.1'	4.6'	6.1'	7.7'	9.2'	10.7'	12.3'	13.8'	14.6'	15.3'
0.0'	0	11	36	65	65	65	65	65	65	65	36	11	0
0.6'	7	9	23	62	65	65	65	65	65	62	23	9	7
1.2'	25	15	13	33	52	65	65	65	52	33	13	15	25
2.4'	65	40	15	9	16	17	17	17	16	9	15	40	65
3.6'	65	64	24	28	45	54	57	54	45	28	24	64	65
4.8'	65	65	32	40	64	65	65	65	64	40	32	65	65
6.0'	65	65	35	43	65	65	65	65	65	43	35	65	65
7.2'	65	65	32	40	64	65	65	65	64	40	32	65	65
8.4'	65	64	24	28	45	54	57	54	45	28	24	64	65
9.6'	65	40	15	9	16	17	17	17	16	9	15	40	65
10.8'	25	15	13	33	52	65	65	65	52	33	13	15	25
11.4'	7	9	23	62	65	65	65	65	65	62	23	9	7
12.0'	0	11	36	65	65	65	65	65	65	65	36	11	0

Total Load (12psf LL)

Stress in ksi

b = 15.33-ft

a = 12-ft

	0.0'	0.8'	1.5'	3.1'	4.6'	6.1'	7.7'	9.2'	10.7'	12.3'	13.8'	14.6'	15.3'
0.0'	0	8	25	65	65	65	65	65	65	65	25	8	0
0.6'	5	6	16	42	65	65	65	65	65	42	16	6	5
1.2'	17	10	9	22	36	45	48	45	36	22	9	10	17
2.4'	52	27	10	6	11	12	12	12	11	6	10	27	52
3.6'	65	44	17	19	31	37	39	37	31	19	17	44	65
4.8'	65	56	22	27	44	54	58	54	44	27	22	56	65
6.0'	65	61	24	30	48	60	64	60	48	30	24	61	65
7.2'	65	56	22	27	44	54	58	54	44	27	22	56	65
8.4'	65	44	17	19	31	37	39	37	31	19	17	44	65
9.6'	52	27	10	6	11	12	12	12	11	6	10	27	52
10.8'	17	10	9	22	36	45	48	45	36	22	9	10	17
11.4'	5	6	16	42	65	65	65	65	65	42	16	6	5
12.0'	0	8	25	65	65	65	65	65	65	65	25	8	0

HISTORICAL COMMENTS

- CALCULATIONS ARE BASED ON:
  1. 4 INCH THICK (VARIES FOR SLABS ON GRADE).
  2. STEEL REINFORCING IS NOT DEVELOPED IN AN UNCRACKED SECTION.
  3. CONCRETE HAS 3000 psi COMPRESSIVE STRENGTH (VARIES). e.g. OLDER SLABS MAY BE 2500 psi.
  4. THESE EXACT DIMENSIONS (a=12 ft, b=15.33ft), FOR DIFFERENT SLAB DIMENSIONS, STRESSES WILL BE DIFFERENT.

HISTORICAL COMMENTS

- THERE IS NOT ENOUGH LIVE LOAD TO CAUSE CRACKING AT 12 PSF, EVEN WITH LARGER CLEAR SPANS.
- *THIS IS WHY THERE ARE NO OBSERVED PROBLEMS IN THE DOZENS OF SLABS THAT HAVE BEEN LIFTED.*
- WITH FULL LIVE LOAD AS SPECIFIED BY CODE, PREDICTED STRESSES ARE VERY CLOSE TO FAILURE FOR 12'x15.33' RECTANGULAR SLAB.
- A GARAGE WITH 20 TO 30 psf FOR CARS IS STILL WELL WITHIN THE ALLOWABLE CRACKING LIMIT.
- ONCE A SLAB CRACKS, THE STEEL REINFORCING IS ACTIVATED AND WILL QUICKLY REACH YIELD STRESS.

HISTORICAL COMMENTS

- FOR AN UNDER-REINFORCED SLAB (WWM) RAISED SLAB DOES NOT HAVE ADEQUATE FACTOR OF SAFETY AND IS CONSIDERED TO BE A ***LIFE SAFETY ISSUE***.
- SPC IS NOT PERMITTED FOR ELEVATED SLABS PER ACI 318-14 22.2.1
- SLABS WITH WELDED WIRE MESH (WWM) WILL FAIL ALMOST IMMEDIATELY ONCE THE SLAB CRACKS.
- SLABS WITH REBAR (e.g. #3s @ 12”) WILL TAKE LONGER TO FAIL.
- SLABS WITH WWM WILL NOT HAVE SUFFICIENT TEMPERATURE REINFORCING AS REQUIRED BY CODE.

HISTORICAL COMMENTS

- A **PHILOSOPHICAL** QUESTION TO CONSIDER IS: *WHAT ARE HOME OWNERS REASONABLY EXPECTING FOR COMPLETED REPAIRS?*
  a) IT WORKS AND THIS ALL I CARE ABOUT; OR
  b) I EXPECT THIS REPAIR TO COMPLY WITH THE GOVERNING BUILDING CODE WITH APPROPRIATE FACTOR OF SAFETY.
- ENGINEERS MUST DESIGN TO THE CODE SPECIFIED LOAD OF 40 psf REGARDLESS OF WHAT A LOWER OR NORMALLY EXPECTED LOAD THAT IS ACTUALLY PLACED ON A STRUCTURE.

HISTORICAL COMMENTS

- IF A NEW OWNER PLACES A HEAVY PIANO, A POOL TABLE OR HEAVILY LOADED BOOK CASES ON THE ELEVATED SLAB AS SOME PRACTICAL EXAMPLES, THIS TYPE OF LOAD COULD BE ENOUGH TO CAUSE THE SLAB TO CRACK.
- ELEVATED FOUNDATION SLABS MUST BE DESIGNED FOR 40 PSF LIVE LOAD PER METHODS SPECIFIED IN ASCE 7-10, ACI 318 AND IBC 12 (OR SEE LATEST HOUSTON BUILDING CODE).
- THIS INCLUDES SUFFICIENT REINFORCING FOR BOTH GRAVITY STRUCTURAL LOADS AND TEMPERATURE LOADS.

CONCLUSIONS

- FOR SLABS WITH WWM REINFORCING, BEST STRUCTURAL OPTION TO SATISFY IBC AND ACI 318 MAY BE TO ADD PRESTRESSING.
- FOR SLABS WITH #3s AT e.g. 12 INCH SPACING FOR TEMPERATURE, BEST OPTION APPEARS TO BE ADDING INTERMEDIATE BEAMS OR ADDING PRESTRESSING.
- FOR POST TENSIONED SLABS BEST OPTION APPEARS TO BE ADDING ADDITIONAL PRESTRESSING TO SATISFY IBC AND ACI.
- IT APPEARS THAT ADDING INTERMEDIATE BEAMS IS A BETTER SCHEME THAN ADDING INTERMEDIATE PIERS AND ITS MUCH EASIER TO ANALYZE.

MATHCAD DESIGN TOOL FOR ELEVATED CONCRETE SLABS BY CLARK ENGINEERS

- EXCELLENT FOR PRELIMINARY DESIGN FOR COST ESTIMATES.
- MAKES DESIGN CHECKS FAST AND EASY.
- EASILY CHECK EXISTING REINFORCING.
- EASILY SIZE INTERMEDIATE BEAMS.
- EASILY DESIGN ADDED PRESTRESSING.
- MCAD SHEET IS NOT A SUBSTITUTE FOR SOUND ENGINEERING JUDGEMENT.
- THE <u>EOR</u> IS RESPONSIBLE FOR THE FINAL DESIGN.

MCAD DESIGN TOOL BY CLARK ENGINEERS

- CONTACT CLARK ENGINEERS FOR QUICK PRELIMINARY DESIGN CHECKS AND TO HELP IN COSTING.
- CONTACT CLARK ENGINEERS FOR PRICING ON MCAD TEMPLATES.

OTHER DESIGN TOOLS AVAILABLE

Structural Analysis
MCAD

MathCAD Sheets written
By Engineers For Engineers

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http://structuralanalysismcad.com/
info@structuralanalysismcad.com

Design Tools

- Structural Analysis and Design
  - 2D Matrix Structural Analysis
  - Bulkhead / Laterally Loaded Pier Design
  - Reinforced Concrete Beam
  - Reinforced Concrete Column
  - Steel Base Plate Design w/ multiple rows
  - Anchor Bolt Design
  - Beam on Elastic Foundation
  - Wind Load on a Pole / Stack / Sign
  - PTI Foundation Design (Post Tension)
- FRP Tanks and Equipment
  - Chem Tank Design
  - Horizontal Chem Tank Design
  - Elevated Tanks
  - FRP Stack and Base Design
  - RTP-1 Laminate Property Calculator
  - **Custom Design and Costing Sheets**

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