

1973

## EC73-710 Technical Resource : Design Tables for Reinforced Concrete Manure Tanks, Slats, & Beams

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# TECHNICAL RESOURCE

Compiled by Agricultural Engineers of  
the Midwest Plan Service

TR

## Design Tables For REINFORCED CONCRETE MANURE TANKS, SLATS, & BEAMS

TR-3

This report is intended primarily for engineers with an understanding of reinforced concrete design. While it includes design criteria and adequate reinforcing for selected sections, many essential details are not included, such as foundations, corner reinforcing, design of necessary openings in walls or lids, etc.

The design loads used in developing the tables are from ASAE R345, Design of Farm Waste Storage Tanks. Refer to the Recommendation for additional information on location, safety features, etc.

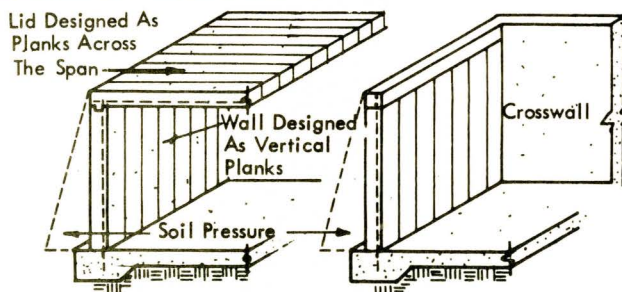
A plan based on this publication is available from the MWPS; enclose \$1.00 for Plan 74303, Liquid Manure Tanks.

Hydrogen sulphide,  $H_2S$ , is given off from anaerobic waste storages. Where a tank has air over the liquids and condensation on the underside of the lid,  $H_2S$  may lead to sulphuric acid,  $H_2SO_4$ . There is no general preventative to attack by the acid available to the farm tank designer or owner. Cement low in tri-calcium aluminate is naturally available in some areas, and has some sulphate resistance, as does Type II cement, which is apt to be available in areas with water supplies naturally high in sulphates. Specification of a high quality air-entrained concrete is perhaps the best solution available to the engineer.

Tables 1-4 list basic data for 3500 psi concrete, deformed billet steel reinforcing bars, and limiting steel placement dimensions.

Cover—Concrete protection over steel  
cover =  $1\frac{1}{2}$ " for #5 or smaller  
cover = 2" for #6 or larger

Table 5 (page 2) gives wall designs. Table 8 (page 4) lists top beam requirements. Tables 6 (page 3) and 7 (page 3) give lid designs. Table 9 (page 5-8) lists safe live loads for slats and beams.



Tank With Lid

Beam On Wall

Table 1. Properties of materials

Concrete				
strength	$f_c'$	3,500	psi	
bending $0.45f_c'$	$f_c$	1,575	psi	
shear $1.1f_c'^{1/2}$ beams	$v_c$	65	psi	
$2.0f_c'^{1/2}$ slabs		118.3	psi	
elasticity $(145^{1/2}) (33)f_c'^{1/2}$	$E_c$	$3.4 \times 10^6$	psi	
ratio $E_s/E_c$	$n$	8.5		
bond $4.8(f_c')^{1/2}/Diam$	$u$	284/Diam or 500 psi max		
Steel				
tension	$f_s$	20,000	psi	
elasticity	$E_s$	$29 \times 10^6$	psi	

Table 2. Reinforcing steel

No.	Area in. <sup>2</sup>	Diam. in.	Weight lb/ft	Peri- meter in.	Allow. Bond psi	Length for Full Bond
3	0.11	0.375	0.376	1.178	500.0	3.8
4	0.20	0.500	0.668	1.571	500.0	5.1
5	0.31	0.625	1.043	1.963	454.4	7.0
6	0.44	0.750	1.502	2.356	378.6	9.9
7	0.60	0.875	2.044	2.749	324.5	13.5
8	0.79	1.000	2.670	3.142	284.0	17.7
9	1.00	1.128	3.400	3.544	251.7	22.5
10	1.27	1.270	4.303	3.990	223.6	28.5
11	1.56	1.410	5.313	4.430	201.4	35.0

Table 3. Minimum steel in walls and slabs. Temperature and shrinkage steel = 0.002bt

Slab Thickness	4"	5"	6"	7"
Min. $A_s/ft$	0.096	0.120	0.144	0.168
Bar Size	#3	#3	#3	#3
Bar Spacing	13.8"	11"	9.2"	7.8"
OR				
Bar Size	#4	#4	#4	#4
Bar Spacing	25.0"	20.0"	16.7"	14.3"

Slab Thickness	8"	9"	10"	11"	12"
Min. $A_s/ft$	0.192	0.216	0.240	0.264	0.288
Bar Size	#3	#4	#4	#4	#4
Bar Spacing	6.9"	11.0"	10.0"	9.1"	8.3"
OR					
Bar Size	#4	#5	#5	#5	#5
Bar Spacing	12.5"	17.2"	15.5"	14.1"	12.9"

NOTE: Bar Spacing =  $\frac{(12) \times (\text{Bar area})}{(\text{Steel area req'd})}$

Table 4. Minimum member width, inches

Bar	Diameter	1 Bar	2 Bars	3 Bars
# 3	.375"	3.375"	4.750"	6.125"
4	.500	3.500	5.000	6.500
5	.625	3.625	5.250	6.875
6	.750	4.750	6.500	8.250
7	.875	4.875	6.750	8.625
8	1.000	5.000	7.000	9.000
9	1.128	5.128	7.384	9.640
10	1.270	5.270	7.810	10.350
11	1.410	5.410	8.230	11.050

Clear distance between bars not less than  
bar diameter, 1" nor  $1\frac{1}{3}$  times max  
course aggregate



## Tank Walls

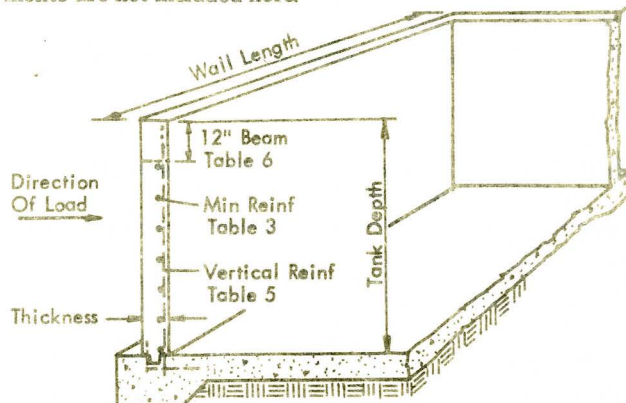
Tank walls are designed to support:

- 15 psf/ft inward for well-drained soil.
- 30 psf/ft inward for moderate drainage.
- 60 psf/ft inward for high water table, in both directions for partitions, and outward for walls above grade.

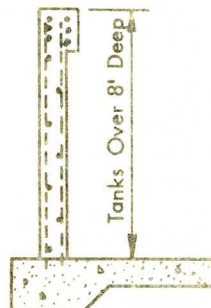
Note: In the tables "psf/ft" is abbreviated with its dimensional equivalent "pcf".

In addition, tanks over 8' deep constructed where the nature of the soil or the quality of backfilling may not provide solid lateral bearing for the walls, walls should be reinforced in the outside face to resist full lateral hydraulic pressure (60 psf/ft) from stored liquid in the tank.

ASAE R345 includes a design load of 110 psf/ft for saturated fine sand. This soil type requires major modification of designs to allow for flotation, a structural floor, serious drainage and settling problems, and possible restrictions by building or other public authorities. Design elements are not included here.



Tanks over 8' deep, reinforce both faces of the walls, and both faces of the top beams



## Tank Lids With No Vehicle Traffic

Table 8 gives designs for reinforced concrete lids for tanks. Recommended loads for lids are (in addition to dead weight):

- 40 psf for human or poultry traffic
- 150 psf for livestock traffic or up to 15" of soil cover.
- 40 psf + snow load on the ground for outdoor tanks with no vehicle traffic.

Tabulated steel is transverse; use Table 3 to select longitudinal temperature and shrinkage steel.

## Snow Zone Map

Snow Load on Ground, psf

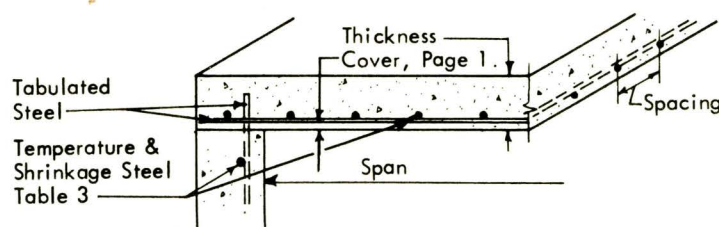


Table 5. Reinforced concrete tank walls; vertical reinforced design; bar size and spacing, inches

Tabulated reinforcing is vertical; minimum reinforcing (Table 3) is horizontal. See cover, page 1.

Wall Thickness	Load, pcf	Hydrastatic Load						Hydrastatic Load + psf Surcharge For Vehicle Load					
		Tank Depth						Tank Depth					
		6'	8'	10'	12'	14'	16'	6'	8'	10'	12'	14'	16'
6"	15	3, 9.2"	3, 9.2"	3, 9.2"	4, 9.4"	5, 8.9"	-	3, 9.2"	3, 7.0"	5, 10.7"	-	-	-
	30	"	"	4, 8.2"	7, 11.2"	-	-	"	4, 8.9"	-	-	-	-
	60	"	4, 8.0"	-	-	-	-	3, 7.0"	5, 8.6"	-	-	-	-
8"	15	3, 6.9"	3, 6.9"	3, 6.9"	3, 6.9"	4, 8.9"	5, 9.0"	3, 6.9"	3, 6.9"	4, 10.6"	5, 10.3"	5, 8.9"	8, 10.8"
	30	"	"	"	5, 10.6"	7, 11.3"	-	"	"	5, 11.2"	5, 8.8"	-	-
	60	"	"	5, 9.2"	8, 11.5"	-	-	"	4, 8.5"	6, 8.8"	-	-	-
10"	15	4, 10.0"	4, 10.0"	4, 10.0"	4, 10.0"	4, 10.0"	4, 7.9"	4, 10.0"	4, 10.0"	4, 10.0"	4, 9.0"	5, 9.3"	6, 8.7"
	30	"	"	"	4, 9.4"	5, 9.0"	7, 10.4"	"	"	4, 9.9"	5, 9.3"	7, 10.7"	9, 11.9"
	60	"	"	4, 8.1"	6, 9.3"	8, 10.0"	-	"	"	5, 9.3"	7, 9.8"	9, 10.1"	-
12"	15	4, 8.3"	4, 8.3"	4, 8.3"	4, 8.3"	4, 8.3"	4, 8.3"	4, 8.3"	4, 8.3"	4, 8.3"	4, 11.3"	5, 11.7"	5, 8.3"
	30	"	"	"	"	5, 11.2"	6, 9.9"	"	"	"	5, 11.6"	6, 10.2"	7, 9.5"
	60	"	"	"	5, 8.9"	7, 9.9"	9, 10.7"	"	"	5, 11.7"	6, 9.3"	8, 10.5"	10, 11.1"

## Tank Lids



### Tank Lids to Support Large Tractor or Manure Wagon

Table 6. Heavy tank lid designs for 2-5000 lb loads 4' o.c. plus deadweight of slabs

Span	Bar Size		Spacing, Inches		Slab Thickness						
	6"	7"	8"	9"	10"	11"	12"				
4'	#5, 11.7	#4, 9.5	#4, 11.3	#4, 11.0	#4, 10.0	#4, 9.1	#4, 8.3				
6'	6, 9.9	5, 10.2	4, 7.9	#4, 9.1	"	"	"				
8'	--	6, 9.5	5, 9.0	5, 10.3	#5, 11.6	#4, 8.3	"				
10'	--	7, 10.0	6, 8.9	6, 10.4	5, 8.9	5, 9.8	#5, 10.6				
12'	--	--	#7, 9.7	#7, 11.2	#6, 9.3	#6, 10.3	#5, 8.4				
14'	--	--	8, 10.3	8, 11.9	7, 10.3	7, 11.3	6, 9.1				
16'	--	--	--	8, 9.9	8, 11.1	7, 9.4	7, 10.2				
18'	--	--	--	9, 10.5	9, 11.8	8, 10.3	8, 11.2				
20'	--	--	--	--	#9, 10.1	#9, 11.1	#9, 12.0				
22'	--	--	--	--	10, 11.0	10, 12.0	9, 10.3				
24'	--	--	--	--	--	10, 10.5	10, 11.3				

Table 7. Reinforced concrete tank lids for NO vehicle traffic; one-way slab design adequate for load listed plus dead weight of slab; bar size and spacing, inches

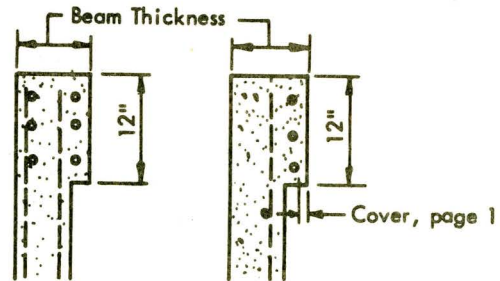
Lid Thickness		Lid Span*					Bar Size and Spacing, Inches		Lid Span					
		6'	8'	10'	12'	14'	Lid Thickness	14'	16'	18'	20'	22'	24'	
PSF							PSF							
4"	40	3,11.9"	4,11.5"	5,10.9"	-	-	8"	40	5,10.6"	6,10.3"	7,10.8"	8,11.2"	-	-
	50	3,10.7"	4,10.3"	-	-	-	50	5, 9.9"	6, 9.6"	7,10.1"	8,10.5"	-	-	
	60	3, 9.7"	4, 9.4"	-	-	-	60	5, 9.3"	6, 9.0"	7, 9.4"	-	-	-	
	70	3, 8.9"	4, 8.6"	-	-	-	70	5, 8.7"	7,11.2"	8,11.4"	-	-	-	
	80	3, 8.2"	5,11.7"	-	-	-	80	6,10.4"	7,10.6"	8,10.7"	-	-	-	
	90	3, 7.6"	5,10.8"	-	-	-	90	6, 9.8"	7,10.0"	8,10.1"	-	-	-	
	110	3, 7.1"	5,10.1"	-	-	-	100	6, 9.3"	7, 9.5"	9,11.9"	-	-	-	
110	4,11.4"	-	-	-	-	110	6, 8.9"	8,11.6"	-	-	-	-		
150	4, 9.1"	-	-	-	-	150	7, 9.9"	-	-	-	-	-		
5"	40	3,11.0"	3, 8.5"	4, 9.5"	5, 9.8"	-	10"	40	4, 7.9"	5, 9.2"	6, 9.5"	7,10.3"	8,10.9"	9,11.4"
	50	"	3, 7.7"	4, 8.7"	5, 9.0"	-	50	5,11.3"	5, 8.7"	6, 8.9"	7, 9.7"	8,10.3"	9,10.7"	
	60	"	3, 7.1"	5,11.8"	-	-	60	5,10.7"	6,10.7"	7,11.3"	8,11.8"	8, 9.7"	9,10.1"	
	70	"	4,11.4"	5,10.9"	-	-	70	5,10.2"	6,10.1"	7,10.7"	8,11.1"	9,11.4"	10,11.9"	
	80	3,10.8"	4,10.6"	5,10.1"	-	-	80	5, 9.6"	6, 9.6"	7,10.1"	8,10.6"	9,10.9"	10,11.3"	
	90	3,10.1"	4, 9.9"	5, 9.5"	-	-	90	5, 9.2"	6, 9.2"	7, 9.7"	8,10.1"	9,10.3"	-	
	100	3, 9.5"	4, 9.3"	5, 8.9"	-	-	100	5, 8.8"	6, 8.7"	7, 9.2"	9,11.9"	9, 9.9"	-	
110	3, 8.9"	4, 8.7"	-	-	-	110	5, 8.4"	7,11.2"	8,11.4"	9,11.4"	10,11.7"	-		
150	3, 7.2"	5,10.6"	-	-	-	150	6, 9.3"	7, 9.5"	8, 9.7"	9, 9.7"	-	-		
6"	40	3, 9.2"	-	4,11.2"	5,11.7"	5, 8.6"	12"	40	4, 8.3"	5,10.1"	6,10.5"	7,11.4"	7, 9.4"	8,10.2"
	50	"	3, 9.2"	4,10.3"	5,10.7"	6, 9.5"	50	4, 8.2"	5, 9.5"	6,10.0"	7,10.8"	8,11.6"	8, 9.7"	
	60	"	3, 8.5"	4, 9.5"	5, 9.9"	-	60	4, 7.8"	5, 9.1"	6, 9.5"	7,10.3"	8,11.0"	9,11.5"	
	70	"	3, 7.9"	4, 8.9"	5, 9.2"	-	70	5,11.3"	5, 8.6"	6, 9.0"	7, 9.8"	8,10.5"	9,10.9"	
	80	"	3, 7.4"	4, 8.3"	5, 8.6"	-	80	5,10.8"	6,10.9"	7,11.6"	7, 9.4"	8,10.0"	9,10.5"	
	90	"	3, 6.9"	5,11.6"	6, 9.7"	-	90	5,10.3"	6,10.5"	7,11.1"	8,11.6"	9,11.9"	9,10.0"	
	100	"	4,11.4"	5,11.0"	6, 9.1"	-	100	5, 9.9"	6,10.0"	7,10.6"	8,11.1"	9,11.4"	10,11.9"	
110	"	4,10.8"	5,10.4"	7,11.4"	-	110	5, 9.5"	6, 9.6"	7,10.2"	8,10.7"	9,11.0"	10,11.5"		
150	3, 8.9"	4, 8.8"	5, 8.5"	-	-	150	6,10.9"	7,11.2"	8,11.4"	9,11.5"	10,11.8"	10, 9.9"		
8" 150	3, 6.9"	4,11.9"	5,11.5"	6,10.1"	7, 9.9"									

\* All 4' wide covers require only minimum reinforcing, except 4" thickness, 150 psf = #3, 11.9".



**Table 8. Beams at top of tank walls**

The designs assume continuous lateral support at the top and bottom of the walls. The upper 12" of the wall may be reinforced as given in Table 8, to carry wall loads to a pilaster, partition, or endwall. See Cover, page 1.



Entries in the table are the maximum wall length, in feet.

**6" Beam Thickness**

TANK DEPTH	LOAD pcf	EXTRA 1-#3	REINFORCING 1-#4	IN TOP FOOT 1-#5	1-#6	2-#5
4'	15	12'	16'	20'	22'	24'
	30	8	10	14	16	-
	60	6	8	10	-	12
6'	15	8'	10'	12'	14'	16'
	30	4	6	8	-	10
	60	4	-	6	-	8
8'	15	6'	8'	10'	-	12'
	30	4	-	6	8'	-
	60	-	4	-	-	6
10'	15	4'	6'	8'	-	-
12'	15	4'	-	6'	-	8'

**10" Beam Thickness**

TANK DEPTH	LOAD pcf	EXTRA 1-#5	REINFORCING 1-#6	IN TOP FOOT 2-#5	2-#6	2-#7
4'	15	24'	-	-	-	-
	30	20	22'	24'	-	-
	60	14	16	18	20'	24'
6'	15	18'	22'	24'	-	-
	30	12	14	16	20'	24'
	60	8	10	12	14	16
8'	15	14'	16'	18'	22'	24'
	30	10	-	12	14	18
	60	6	8	10	-	12
10'	15	10'	12'	14'	16'	18'
	30	8	-	10	12	14
	60	4	6	-	8	10
12'	15	8'	10'	12'	14'	16'
	30	6	-	8	10	12
	60	4	-	6	-	8
14'	15	8'	-	10'	12'	14'
	30	4	6'	-	8'	10'

**8" Beam Thickness**

TANK DEPTH	LOAD pcf	EXTRA 1-#4	REINFORCING 1-#5	IN TOP FOOT 1-#6	2-#5	2-#6	2-#7
4'	15	20'	24'	-	-	-	-
	30	14	16	20'	22'	24'	-
	60	10	12	14	16	18	20'
6'	15	12'	16'	18'	20'	24'	-
	30	8	10	12	14	16	18'
	60	6	8	-	10	12	-
8'	15	10'	12'	14'	16'	18'	20'
	30	6	8	10	-	12	-
	60	4	6	-	8	-	10
10'	15	8'	-	10'	12'	14'	16'
	30	4	6'	8	-	10	-
	60	4	-	-	6	-	8
12'	15	6'	8'	-	10'	12'	-
	30	4	-	6'	-	8	-
14'	15	4'	6'	8'	-	10'	-
16'	15	4'	6'	-	8'	-	10'

**12" Beam Thickness**

TANK DEPTH	LOAD pcf	EXTRA 1-#5	REINFORCING 1-#6	IN TOP FOOT 2-#5	2-#6	2-#7	2-#8	3-#7
4'	15	24'	-	-	-	-	-	-
	30	22	24'	-	-	-	-	-
	60	14	18	20'	24'	-	-	-
6'	15	20'	-	22'	24'	-	-	-
	30	14	16'	20	22	24'	-	-
	60	10	12	14	16	18	20'	24'
8'	15	14'	18'	20'	24'	-	-	-
	30	10	12	14	16	20'	22'	-
	60	6	8	10	12	14	16	-
10'	15	12'	14'	16'	20'	22'	24'	-
	30	8	10	12	14	16	18	-
	60	6	-	8	10	-	12	-
12'	15	10'	12'	14'	16'	18'	20'	22'
	30	6	8	10	-	12	14	-
	60	4	6	-	8	-	10	-
14'	15	8'	10'	12'	14'	16'	18'	-
	30	6	-	8	10	-	12	-
16'	15	6'	8'	10'	12'	14'	16'	-
	30	4	6	-	8	10	-	-

Table 9 lists the safe superimposable load on concrete slats and beams.

Slats up to 6" x 7.5" and 16' long are reinforced with one bar. Beams are reinforced with 2 or with 3 bars.

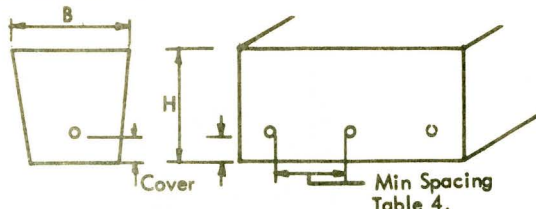


Table 9. Superimposable load in pounds per foot on slats and beams

1 Bar per beam

Table 9. Superimposable load in pounds per foot on sills and beams																					
1 Bar per beam																					
SPAN B H	NO. 3							NO. 4							NO. 5						
	4	6	8	10	12	14	16	4	6	8	10	12	14	16	4	6	8	10	12	14	16
4	3.0	73	26	9	1	0	0	80	29	11	2	0	0	0	80	29	11	2	0	0	0
3.5	130	33	22	9	2	0	0	152	59	27	12	4	0	0	159	63	29	13	5	0	0
4.0	170	66	30	13	4	0	0	240	97	46	24	12	4	0	258	106	52	27	14	6	1
4.5	211	83	39	18	7	0	0	339	142	72	39	22	11	4	331	156	80	44	25	14	6
5.0	252	100	48	23	10	2	0	402	188	97	55	32	18	9	394	214	111	64	38	23	12
5.5	293	118	56	28	13	3	0	466	220	114	65	38	22	12	457	278	147	86	53	33	20
6.0	334	135	65	33	15	5	0	529	253	131	75	45	26	14	521	339	186	110	69	44	28
6.5	375	152	74	38	18	6	0	592	285	149	86	51	31	17	584	380	228	136	86	57	37
7.0	417	169	83	43	21	8	0	655	318	166	96	58	35	20	647	422	263	158	101	67	44
7.5	459	187	92	48	24	9	0	718	350	184	107	65	39	23	710	463	290	175	112	74	50
5	3.0	85	29	10	1	0	0	94	32	12	2	0	0	0	95	32	12	2	0	0	0
3.5	128	29	19	5	0	0	0	177	69	31	13	4	0	0	188	74	34	15	5	0	0
4.0	168	63	27	10	0	0	0	279	113	42	27	13	4	0	303	123	60	31	15	6	0
4.5	209	80	35	14	3	0	0	376	154	77	41	21	10	2	414	182	92	51	28	15	6
5.0	249	97	43	18	5	0	0	450	186	93	51	27	13	4	493	249	129	73	43	25	13
5.5	290	113	52	23	7	0	0	525	218	110	61	33	17	7	572	323	170	99	60	37	21
6.0	331	130	60	27	10	0	0	600	250	127	70	40	21	9	651	388	205	120	74	46	28
6.5	372	147	68	32	12	0	0	676	282	144	80	46	25	11	730	438	232	137	85	53	33
7.0	414	164	77	36	14	1	0	752	314	161	90	52	29	14	808	489	259	153	96	61	38
7.5	455	181	85	41	17	2	0	828	347	178	101	58	33	16	887	539	287	170	106	68	43
6	3.0	86	28	8	0	0	0	106	29	13	1	0	0	0	109	29	13	2	0	0	0
3.5	126	44	15	2	0	0	0	201	26	34	14	3	0	0	215	83	38	16	5	0	0
4.0	166	60	23	6	0	0	0	302	120	38	28	12	2	0	345	140	38	35	17	6	0
4.5	206	76	31	10	0	0	0	375	152	73	37	17	5	0	497	206	104	51	31	15	5
5.0	246	93	39	14	0	0	0	450	183	90	46	23	9	0	592	281	145	48	47	27	13
5.5	287	109	47	18	2	0	0	525	215	106	56	29	12	1	686	336	174	99	59	34	18
6.0	328	125	55	22	4	0	0	600	246	123	65	34	15	3	781	386	201	116	69	41	23
6.5	369	142	63	26	6	0	0	675	278	139	75	40	19	5	876	436	228	132	79	48	27
7.0	410	158	71	30	8	0	0	751	310	156	84	46	22	7	970	486	255	148	90	55	32
7.5	451	175	79	34	10	0	0	827	342	173	94	51	26	9	1065	537	282	164	100	62	36
5	3.0	16	1	0	0	0	0	15	0	0	0	0	0	0	10	0	0	0	0	0	0
3.5	90	29	9	0	0	0	0	84	27	7	0	0	0	0	76	24	6	0	0	0	0
4.0	188	72	32	13	3	0	0	186	71	31	13	2	0	0	181	69	30	12	2	0	0
4.5	314	127	61	31	14	4	0	313	129	62	32	15	5	0	302	128	62	32	15	5	0
5.0	402	191	96	53	29	14	5	391	198	100	55	30	16	6	381	201	102	56	31	16	6
5.5	480	265	137	78	45	26	13	470	279	144	82	49	28	15	460	287	149	85	51	30	16
6.0	559	348	183	106	64	39	23	549	356	194	113	69	43	26	539	349	202	119	73	46	28
6.5	638	414	233	137	85	54	33	628	408	249	148	93	59	38	618	401	262	156	98	63	41
7.0	717	466	287	171	108	70	45	707	459	310	185	118	77	51	697	453	327	196	126	83	55
7.5	796	518	346	208	133	87	58	786	511	374	226	145	97	65	775	504	369	241	156	104	71
6	3.0	13	0	0	0	0	0	13	0	0	0	0	0	0	11	0	0	0	0	0	0
3.5	103	26	10	0	0	0	0	97	26	8	0	0	0	0	89	26	6	0	0	0	0
4.0	216	83	36	14	2	0	0	215	82	35	14	2	0	0	210	80	34	13	2	0	0
4.5	359	144	69	34	15	4	0	367	148	71	36	16	5	0	363	148	71	36	16	5	0
5.0	482	217	109	48	31	15	4	470	227	114	62	34	17	6	458	232	117	64	35	18	6
5.5	577	301	155	87	50	28	14	564	318	164	93	54	31	16	552	329	170	97	57	33	17
6.0	671	395	206	119	58	43	24	659	421	221	128	78	47	28	647	419	231	135	82	51	30
6.5	766	497	262	154	95	59	36	754	489	283	167	104	66	41	741	481	299	177	111	71	45
7.0	860	559	324	192	120	68	49	848	551	351	209	132	86	56	836	543	372	223	142	93	61
7.5	955	622	364	216	136	88	57	943	613	424	255	163	108	72	931	605	443	273	176	117	79
6	3.0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.5	79	23	4	0	0	0	0	67	18	1	0	0	0	0	55	13	0	0	0	0	0
4.0	200	75	32	11	0	0	0	186	69	28	9	0	0	0	171	62	24	7	0	0	0
4.5	350	145	70	35	16	4	0	337	140	67	33	14	3	0	323	133	63	30	13	2	0
5.0	445	232	117	64	35	18	6	431	229	116	63	34	17	6	418	223	112	61	33	16	5
5.5	540	334	173	99	58	34	18	526	335	174	99	59	34	18	512	330	172	98	58	34	18
6.0	634	411	237	139	85	53	32	620	401	241	141	87	54	33	607	392	241	141	87	54	33
6.5	729	473	309	183	115	74	48	715	464	316	188	119	77	49	701	454	319	190	120	78	50
7.0	824	535	387	233	149	98	65	810	526	384	240	154	102	68	796	517	377	244	157	104	70
7.5	918	597	436	286	185	124	84	904	588	429	297	192	129	88	891	579	423	304	197	133	90



Table 9. (continued) Superimposable load in pounds per foot on slats and beams

## 2 Bars per beam

SPAN B H	4	6	8	10	12	14	16	4	6	8	10	12	14	16	4	6	8	10	12	14	16
6				NO. 3						NO. 4							NO. 5				
6.0	671	278	140	77	42	21	8	793	509	270	160	100	64	40	781	509	306	183	116	75	49
7.0	838	349	178	98	55	29	13	982	640	341	203	128	83	53	970	633	452	274	177	119	81
8.0	1005	420	215	120	69	38	17	1172	765	412	247	156	102	67	1159	757	555	378	248	169	118
9.0	1173	491	252	142	82	46	22	1361	889	484	290	185	121	80	1349	881	647	463	305	210	148
10.0	1342	563	290	164	95	54	27	1550	1013	556	334	214	141	94	1538	1005	739	533	352	242	171
11.0	1511	635	328	186	109	62	32	1739	1137	629	378	242	161	107	1727	1129	830	604	399	276	195
12.0	1681	707	366	208	122	71	37	1929	1262	701	423	271	180	121	1916	1253	922	675	446	309	219
13.0	1851	779	404	230	136	79	42	2118	1386	774	467	301	200	135	2106	1378	1014	746	494	342	244
14.0	2021	851	442	252	149	87	47	2307	1510	847	512	330	220	148	2295	1502	1105	817	542	376	268
15.0	2192	924	480	275	163	96	52	2496	1634	921	557	359	240	162	2484	1626	1197	889	590	409	292
7																					
6.0	670	274	136	72	37	16	2	926	508	267	156	95	59	35	911	593	340	202	128	82	53
7.0	837	344	172	92	49	23	6	1146	638	337	198	122	77	47	1132	738	501	303	195	130	88
8.0	1004	415	209	113	61	30	10	1367	769	408	241	150	95	60	1353	883	640	389	253	171	118
9.0	1172	485	245	134	74	37	14	1588	901	479	284	178	114	72	1574	1028	752	458	299	203	140
10.0	1340	556	282	155	86	45	18	1809	1034	551	327	206	132	85	1794	1173	862	528	345	235	163
11.0	1509	628	319	176	99	52	22	2029	1167	622	370	234	151	97	2015	1318	969	598	392	267	186
12.0	1678	699	356	198	111	59	26	2250	1300	694	414	262	170	110	2236	1462	1076	668	438	300	210
13.0	1848	770	393	219	124	67	30	2471	1434	767	458	290	189	123	2457	1607	1183	739	485	332	233
14.0	2017	842	430	240	137	74	34	2692	1568	839	502	318	208	136	2677	1752	1289	810	532	365	256
15.0	2188	914	468	261	149	82	38	2912	1703	912	545	347	227	149	2898	1897	1396	881	579	398	280
8																					
6.0	668	270	131	66	31	10	0	1058	506	263	151	90	53	29	1042	678	372	220	138	62	57
7.0	834	339	166	86	42	16	0	1310	636	333	193	117	71	41	1294	844	526	316	202	134	69
8.0	1001	409	202	106	54	22	2	1562	767	403	235	143	88	52	1546	1009	637	384	247	165	111
9.0	1168	479	238	126	65	29	5	1815	898	473	277	170	106	64	1798	1175	749	453	292	196	133
10.0	1336	549	274	146	77	35	8	2067	1030	544	319	197	124	76	2051	1340	861	522	338	227	155
11.0	1505	620	310	166	89	42	11	2319	1163	615	362	224	141	87	2303	1506	974	592	384	258	177
12.0	1673	690	346	187	100	48	14	2572	1296	687	405	252	159	99	2555	1671	1087	661	430	290	199
13.0	1842	761	382	207	112	54	17	2824	1429	758	448	279	177	111	2808	1837	1201	731	476	322	222
14.0	2012	832	419	227	124	61	20	3076	1563	830	491	306	195	123	3060	2002	1315	801	522	354	244
15.0	2181	902	455	248	135	67	23	3329	1696	901	534	334	213	135	3312	2168	1429	871	568	386	267
9																					
6.0	666	266	126	61	26	4	0	1190	503	259	146	85	48	24	1172	756	401	237	148	56	59
7.0	831	334	160	80	36	10	0	1474	633	328	187	111	64	34	1456	949	523	312	197	128	83
8.0	998	403	195	99	46	15	0	1758	763	398	228	136	81	45	1739	1135	633	379	241	158	104
9.0	1165	472	230	118	57	20	0	2042	894	467	270	162	98	56	2023	1322	745	447	286	188	125
10.0	1332	542	265	137	68	26	0	2325	1026	537	311	189	115	66	2307	1508	857	516	330	219	146
11.0	1500	611	300	156	78	31	0	2609	1158	608	353	215	131	77	2591	1694	969	584	375	249	168
12.0	1668	681	336	176	89	36	3	2893	1290	678	395	241	148	88	2875	1880	1082	653	420	280	189
13.0	1836	751	371	195	100	42	5	3177	1423	749	437	268	165	99	3159	2067	1195	722	466	311	211
14.0	2005	821	406	214	110	47	7	3461	1556	820	479	294	182	110	3443	2253	1308	792	511	342	232
15.0	2173	891	442	234	121	53	9	3745	1689	891	521	321	200	121	3726	2439	1422	861	557	373	254
10																					
6.0	663	261	120	55	20	0	0	1201	500	255	141	80	43	18	1302	776	410	240	149	50	57
7.0	828	329	154	73	29	3	0	1504	629	323	181	104	58	28	1617	978	519	307	192	122	77
8.0	994	397	188	91	39	7	0	1808	759	392	222	129	74	38	1933	1181	629	374	235	151	97
9.0	1160	465	222	110	48	12	0	2114	889	461	262	154	89	47	2248	1386	740	441	279	181	117
10.0	1326	534	256	128	58	16	0	2421	1020	530	303	180	105	57	2564	1591	851	509	322	210	137
11.0	1494	602	291	146	68	20	0	2729	1152	599	344	205	121	67	2879	1798	963	577	367	240	158
12.0	1661	671	325	165	77	25	0	3038	1283	669	385	230	137	77	3194	2005	1075	645	411	270	178
13.0	1829	740	359	183	87	29	0	3348	1415	739	426	256	153	87	3510	2213	1188	713	455	300	199
14.0	1997	809	394	201	97	34	0	3658	1548	809	467	282	170	97	3825	2421	1300	782	500	330	220
15.0	2165	878	428	220	107	38	0	3968	1680	879	508	307	186	107	4141	2630	1413	850	545	360	240
7				NO. 6						NO. 7							NO. 8				
6.0	783	508	286	168	103	65	40	769	498	300	177	110	69	43	755	489	309	183	114	72	45
7.0	1004	653	452	271	173	114	76	990	643	470	290	186	124	83	975	634	463	304	196	131	88
8.0	1225	798	584	392	255	173	119	1210	788	577	423	277	188	131	1196	779	570	445	293	201	140
9.0	1445	942	691	530	349	239	168	1431	933	684	534	380	262	186	1417	923	677	529	406	281	200
10.0	1666	1087	798	624	452	314	224	1652	1078	791	619	495	345	248	1638	1068	784	613	499	372	268
11.0	1887	1232	905	708	534	372	267	1873	1223	898	703	573	436	316	1859	1213	891	697	568	472	343
12.0	2108	1377	1012	792	602	420	302	2094	1368	1005	787	642	535	390	2079	1358	997	781	637	534	425
13.0	2329	1522	1119	877	671	468	337	2314	1512	1111	871	710	596	470	2300	1503	1104	865	706	592	506
14.0	2549	1667	1225	961	739	517	373	2535	1657	1218	955	779	654	530	2521	1648	1211	949	775	650	556
15.0	2770	1812	1332	1045	808	566	408	2756	1802	1325	1039	848	712	580	2742	1793	1318	1033	844	708	606
8																					
6.0	895	581	314	183	113	62	42	879	570	331	195	120	76	46	863	559	343	202	125	79	49
7.0	1147	746	495	297	189	124	81	1131	735	530	319	204	135	90	1115	724	529	335	215	143	96
8.0	1400	912	668	429	278																



Table 3. (continued) Superimposable load in pounds per foot on slats and beams

## 2 Bars per beam

SPAN	4	6	8	10	12	14	16	4	6	8	10	12	14	16	4	6	8	10	12	14	16	
B H																						
	NO. 6							NO. 7							NO. 8							
10	6.0	1119	697	366	212	129	50	46	1099	712	389	227	139	50	52	1078	699	405	238	146	92	56
	7.0	1434	933	575	343	217	140	55	1414	919	620	371	236	155	102	1354	906	654	393	252	166	111
	8.0	1750	1140	813	492	317	211	143	1729	1126	824	540	351	236	162	1709	1113	814	577	376	255	176
	9.0	2065	1347	972	589	382	256	175	2045	1333	977	732	481	329	231	2024	1319	967	755	519	357	252
	10.0	2381	1554	1132	688	447	302	208	2360	1540	1130	884	625	433	303	2340	1526	1120	876	678	471	337
	11.0	2696	1760	1292	787	513	348	240	2676	1747	1283	1004	719	499	356	2655	1733	1272	996	811	597	431
	12.0	3011	1967	1445	887	579	393	273	2991	1954	1435	1124	812	564	404	2971	1940	1425	1116	910	733	533
	13.0	3327	2174	1598	987	645	440	306	3306	2161	1588	1244	905	630	452	3286	2147	1578	1236	1008	846	620
	14.0	3642	2381	1751	1087	712	486	339	3622	2368	1741	1364	998	696	500	3601	2354	1730	1356	1107	929	686
	15.0	3957	2588	1903	1188	779	532	372	3937	2575	1893	1485	1092	762	548	3917	2561	1883	1476	1205	1012	752

## 3 Bars per beam

SPAN	4	6	8	10	12	14	16	4	6	8	10	12	14	16	4	6	8	10	12	14	16	
B H	NO. 3							NO. 4							NO. 5							
7	6.0	940	423	220	125	74	43	23	926	603	346	206	130	68	55	911	593	386	231	148	97	65
	7.0	1161	530	277	159	95	57	32	1146	748	506	306	198	132	76	1132	738	541	347	226	153	106
	8.0	1381	638	334	194	117	71	41	1367	893	626	380	247	166	114	1353	883	648	480	316	217	153
	9.0	1602	747	392	228	139	85	50	1588	1037	734	447	291	197	136	1574	1028	755	591	418	290	207
	10.0	1823	855	450	263	161	100	60	1809	1182	843	514	336	228	158	1794	1173	862	675	529	370	267
	11.0	2044	964	509	298	183	114	69	2029	1327	953	582	381	259	180	2015	1318	969	760	611	429	310
	12.0	2264	1074	567	332	205	128	78	2250	1472	1063	650	426	290	202	2236	1462	1076	844	684	480	348
	13.0	2485	1184	626	368	227	143	88	2471	1617	1174	718	471	322	225	2457	1607	1183	928	756	531	385
	14.0	2706	1294	685	403	250	157	97	2692	1762	1284	787	516	353	247	2677	1752	1289	1012	827	583	423
	15.0	2927	1404	743	438	272	172	107	2912	1906	1395	855	562	385	270	2898	1897	1396	1096	896	635	461
8	6.0	1007	421	215	120	69	38	17	1058	689	378	224	141	62	58	1042	678	424	254	161	106	70
	7.0	1257	527	272	154	89	51	26	1310	855	515	309	198	130	86	1294	844	619	380	247	166	114
	8.0	1508	634	329	187	110	64	34	1562	1020	623	375	241	160	107	1546	1009	741	525	345	236	166
	9.0	1750	742	386	221	131	77	42	1815	1186	731	442	285	190	128	1798	1175	863	676	455	315	224
	10.0	2014	850	443	255	152	90	50	2067	1351	840	508	328	220	150	2051	1340	985	772	534	371	265
	11.0	2268	959	501	289	173	104	59	2319	1517	949	575	372	250	171	2303	1506	1107	868	605	421	302
	12.0	2523	1068	558	323	195	117	67	2572	1682	1058	643	417	281	192	2555	1671	1229	964	677	472	339
	13.0	2778	1177	616	357	216	131	76	2824	1848	1168	710	461	311	214	2808	1837	1352	1060	749	523	376
	14.0	3034	1286	674	391	237	144	84	3076	2013	1278	778	506	342	235	3060	2003	1474	1157	822	574	413
	15.0	3291	1396	732	425	259	158	93	3329	2179	1389	846	550	372	257	3312	2168	1596	1253	894	625	450
9	6.0	1007	417	211	115	63	32	12	1190	764	406	240	150	56	61	1172	763	460	275	174	113	71
	7.0	1257	523	267	148	83	44	19	1474	960	512	305	192	124	80	1456	949	678	411	266	179	122
	8.0	1508	630	323	180	103	57	26	1758	1148	619	370	235	153	100	1739	1135	833	567	372	254	177
	9.0	1760	737	379	213	123	69	34	2042	1334	727	436	278	182	121	2023	1322	971	695	458	315	222
	10.0	2013	845	435	246	143	81	41	2325	1520	835	502	321	212	141	2307	1508	1108	800	528	364	257
	11.0	2267	952	492	279	163	94	48	2609	1706	943	568	364	241	161	2591	1694	1246	906	599	414	293
	12.0	2522	1061	549	312	184	106	56	2893	1893	1052	634	407	271	182	2875	1880	1383	1012	670	463	329
	13.0	2777	1169	606	346	204	119	63	3177	2079	1162	701	451	300	202	3159	2067	1521	1119	741	513	366
	14.0	3032	1277	663	379	224	131	71	3461	2265	1271	768	495	330	223	3443	2253	1658	1226	813	564	402
	15.0	3288	1386	720	412	245	144	78	3745	2451	1381	835	539	360	244	3726	2439	1795	1334	885	614	438
10	6.0	1006	414	206	110	58	27	6	1322	763	403	236	145	50	55	1302	848	494	294	186	121	65
	7.0	1256	519	261	142	77	38	12	1638	958	508	300	187	118	74	1617	1055	728	440	284	190	129
	8.0	1507	625	316	173	96	49	19	1953	1155	615	364	228	146	93	1933	1262	926	586	382	260	180
	9.0	1759	731	372	205	115	60	25	2269	1353	722	429	270	175	113	2248	1469	1079	690	452	308	214
	10.0	2011	836	427	237	134	72	31	2584	1552	829	495	313	203	132	2564	1676	1232	795	521	356	249
	11.0	2265	945	483	270	153	83	38	2899	1752	937	560	355	232	151	2879	1882	1384	900	592	405	284
	12.0	2519	1053	539	302	173	95	44	3215	1953	1046	626	398	260	171	3194	2089	1537	1006	662	454	320
	13.0	2774	1160	596	334	192	107	51	3530	2153	1154	692	440	289	191	3510	2296	1690	1112	723	504	355
	14.0	3029	1268	652	367	212	118	58	3845	2355	1263	758	483	318	210	3825	2503	1842	1219	804	553	391
	15.0	3284	1376	708	399	231	130	64	4161	2557	1372	824	526	347	230	4141	2710	1995	1326	875	603	426
9	NO. 6							NO. 7							NO. 8							
	6.0	1007	653	384	226	140	89	55	989	641	401	237	148	94	59	970	629	411	243	152	98	62
	7.0	1291	839	608	366	235	156	104	1273	827	605	389	251	168	113	1254	815	595	406	262	176	120
	8.0	1575	1026	751	531	346	235	163	1556	1013	742	569	373	255	178	1538	1001	733	572	394	270	190
	9.0	1859	1212	889	695	473	326	230	1840	1200	879	687	513	355	253	1822	1187	870	680	545	379	271
	10.0	2142	1398	1026	803	614	427	306	2124	1386	1017	795	648	468	337	2106	1374	1008	788	642	501	362
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	7.0	1434	933	655	394	252	166	111	1414	919	672	420	270	180	121	1394	906	662	439	284	190	129
	8.0	1750	1140	835	570	371	251	174	1729	1126	824	614	402	274	191	1709	1113	814	635	425	291	204
	9.0	2065	1247	987	770	507	348	245	2045	1333	977	764	552	381	271	2025	1319	967	755	588	408	291
	10.0	2381	1534	1140	892	658	456	326	2360	1540	1130	884	719	502	361	2340	1526	1120	876	713	539	389
	11.0	2696	1760	1293	1012	804	562	404	2676	1747	1283	1004	818	634	460	2655	1733	1272	996	811	680	498
	12.0	3011	1967	1445	1132	907	634	457	2991	1954	1435	1124	917	768	568	2971	1940	1425	1116	910	763	617
	13.0	3327	2174	1598	1252	1010	707	511	3306	2161	1588	1244	1015	851	684	3286	2147	1578	1236	1008	846	724
	14.0	3642	2381	1751	1373	1113	780	565	3622	2368	1741	1364	1114	934	799	3601	2354	1730	1356	1107	929	795
	15.0	3957	2588	1903	1493	1217	854	618	3937	2575	1893	1485	1212	1017	871	3917	2561	1883	1476	1205	1012	866



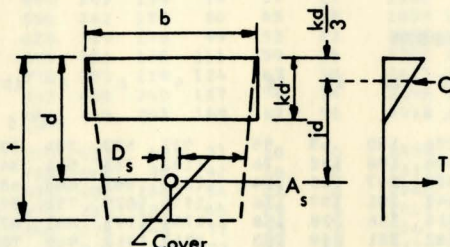
## Supplement

The following material summarizes the procedure and assumptions used to develop the tables, and is included for those wishing to evaluate the designs.

### Designing Slats and Beams

Safe superimposable loads, plf, were computed for several sizes and spans of reinforced concrete beams with one, two, and three tension bars. The design procedure selected the size, span and reinforcing, and then determined the load-carrying capacity as the least of bending, shear, bond, and deflection.

Criteria were selected from ACI-318-63, WSD Part IV A. Taper in slats was ignored.



#### Procedure

##### Select beam.

Dead weight =  $t \times b \times 145 \text{pcf} / 144 \text{ in}^2 / \text{ft}^2$  rounded to  $t \times b$ .

$d = t - \text{cover} - D_s / 2$

$k = 1/2(-C + (C^2 + 4C)^{1/2})$

where  $C = (\text{number of bars}) (2nA_s / bd)$

$I = b(kd)^3 / 3 + nA_s(d - kd)^2$

$j = 1 - k / 3$

$M_c = f_c b k j d^2 / 2 = \text{compression couple}$

$M_s = f_s j d A_s = \text{tension couple}$

$M = \text{the smaller of } M_s / 12 \text{ or } M_c / 12, \text{ ft lb}$

$P = 8M / \text{Span}^2 = \text{total load/ft}$

Maximum load/ft is

Bending =  $P - \text{deadweight}$

= 0 if beam won't hold deadweight

Shear =  $2bdf_v / \text{Span} - \text{deadweight}$

Bond =  $2u\phi j d / \text{Span} - \text{deadweight}$

Deflection =  $384 E_c I / 180 \text{ Span}^3 \times 5 \times 1728 - \text{deadweight}$

Only designs of beams wide enough for at least minimum side cover and bar spacing (table 4) are tabulated.

### Designing Waste Storage Tanks

Safe designs were computed for walls and covers of liquid storage tanks. The procedure determined reinforcing required (bar size, inches spacing) for various wall and lid thicknesses, spans, and loads.

#### Procedure (wall design, hydrastatic load)

##### First Approximation (balanced design)

$k = 1 / (1 + f_s / n f_c) = 0.4012$

$j = 1 - k / 3 = 0.8663$

$W = \text{Psf} \times \text{Span}^2 / 2 = \text{wall load, lb}$

$M = 1.5396W \times \text{Span, in-lb}$

$\text{RBOT} = 2W / 3 = \text{reaction in bottom of wall}$

$d = t - 2'' \text{ cover}$

$A_s = M / f_s j d$ , balanced design

Both cover and  $d$  are functions of bar diameter; convert  $A_s$  to a bar number;

$A_s = 6.65 \text{ max, \#11 @ 1.25'' clearance.}$

$A_s \text{ less than } 0.20$ , bar = #3.

$A_s \text{ from } 0.20 \text{ to } 6.65$ :

Bar # =  $-2.164A_s^2 + 8.784A_s + 2.454$

The equation assigns a given bar number between its own area (#4 = 0.20) and the next larger (#5 = 0.31). Bar spacing is therefore no larger than 12''.

#### Second Approximation:

$d = t - D_s / 2 - \text{cover}$

cover =  $1\frac{1}{2}''$  to #5, 2'' for larger bars.

$k = 1/2(-C + (C^2 + 4C)^{1/2})$

where  $C = 2nA_s / bd$

$A_s = M / f_s j d$

Return to equation for bar size; recompute bar number using the new  $A_s$ .

Compute stresses and compare with allowable;

$f_c = 2M / 12j d k d$ ,  $b = 12''$

$f_s = M / A_s j d$

Bond =  $\text{RBOT} / \phi j d$

Shear =  $\text{RBOT} / bd$

$I = b(kd)^3 / 3 + nA_s(d - kd)^2$

Defl =  $0.013044 W (1728 \text{ Span}^3) / E_c I$

Bar Spacing =  $12(\text{Area of one bar}) / A_s$

#### Procedure (Lid Design)

Lids for uniform loads were designed the same as tank walls, with coefficients adjusted for uniform instead of triangular load.

Lids for tractor or wagon loads (2 - 5000 lb loads 4' apart) were designed using the bridge design equation from AASHO:

$$M = \left( \frac{\text{Span} + 2}{32} \right) (\text{load}) + w l^2 / 8, \text{ deadload}$$

In AASHO, load = wheel load, and wheels are 6' apart on axles 14' apart. Tractors and tank wagons may be shorter and narrower than trucks. Therefore designs are based on load = axle load.

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