Fermilab

Particle Physics Division

Mechanical Department Engineering Note

Number: MD-ENG-547 Date: March 25, 2016

Project: NOvA

Project Internal Reference:

Title: NOvA SCINTILLATOR STORAGE TANK FOUNDATIONS

Author(s): R. J. Woods

Reviewer(s): RUSSELL RUCINSKI

Key Words:

Abstract/Summary:

The NOvA Surface Prototype Detector is being dismantled and the experimenters will be removing the existing scintillator oil that is contained in this detector. Saving this oil for future use makes economic sense due to the initial cost of the oil. Modifications to the underground Near Detector will not be included in this project.

Four, 3000 gallon polyethylene double walled tanks with secondary containment will provide the required storage capacity. Each tank will be supported on a concrete slab that is poured directly over an existing blacktop parking lot slab. Due to the existing slope of the blacktop, each tank support slab will be separate to avoid having the end slabs thicker than the middle slabs.

The slab reinforcing was designed by using two methods shown in *Slab on Grade Reinforcing Design* by D. Matthew Stuart, P.E., S.E., F.ASCE, F.SEI, EECB, MgtEng. A copy of this publication is included at the end of this note.

The first method's Design procedure considers the range of temperatures the slab will be subjected to, while the second method is based on the concrete to steel strength ratio. A minimum 8" thick slab was used for both procedures. The second method produced a result indicating the required reinforcing will be #6 bars spaced at 12" on center, placed 2" from the top of the slab, in both directions.

A six foot by six foot by six inch thick concrete slab was designed by using the 1984 *CRSI Handbook* chart for slabs on ground on page 13-61. A copy of this chart is also included at the end of this note. This slab will be for the pump and electrical hookup. A 6'-0" X 6'-0" x 6" thick slab reinforced with WWF 6 x 6 – W2.9 x W2.9 welded wire fabric located 2" from the top surface of the slab will be used for an allowable load of 400 to 500 psf.

See Drawing F10056447 for project location and Drawing F10056076 for slab details. Reduced size copies of these two drawings are included in this Engineering Note.

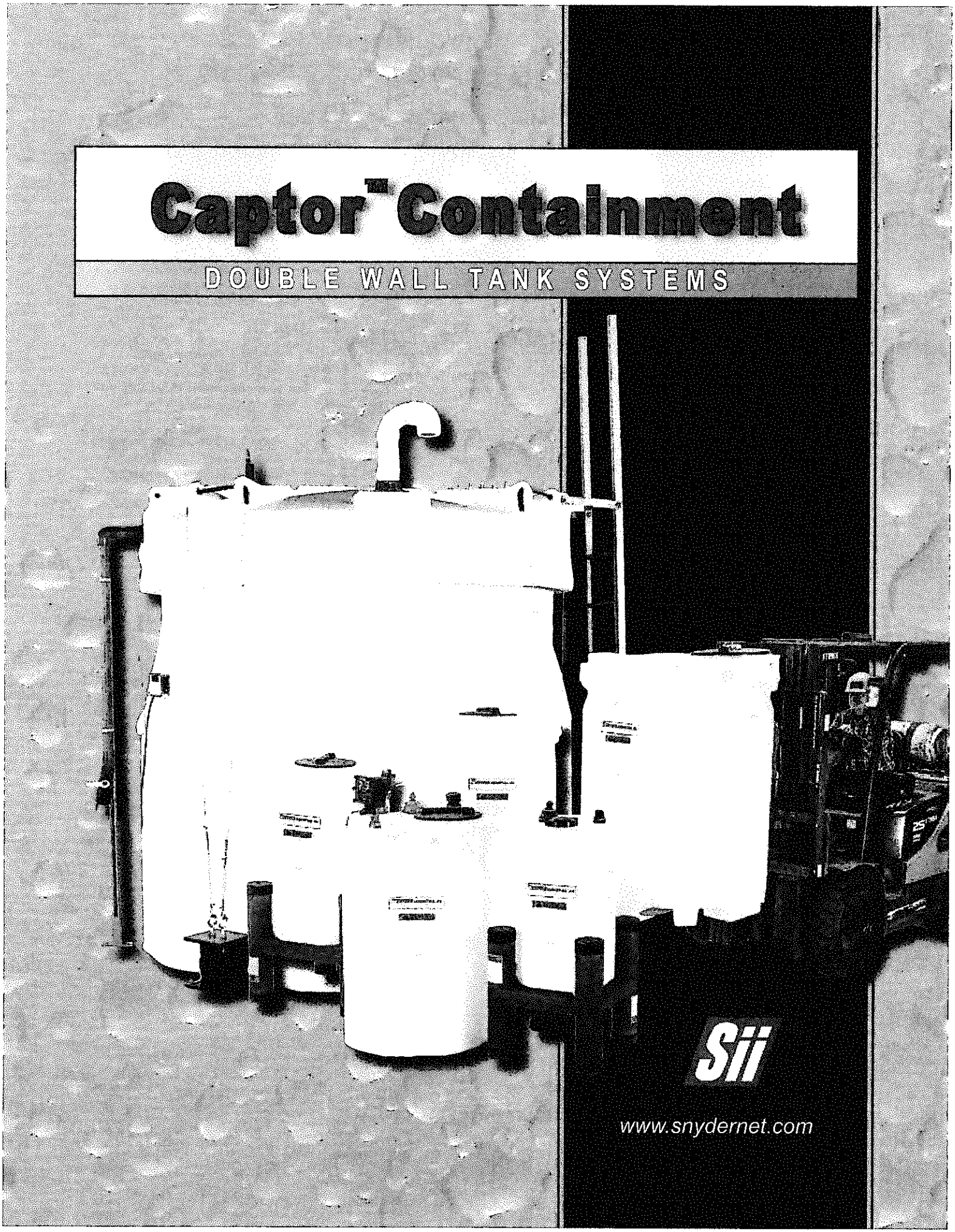
Applicable Codes:

Building Code Requirements for Structural Concrete, (ACI 318-02), American Concrete Institute, Farmington Hills, Michigan, January, 2002.

CRSI Handbook 1984, Concrete Reinforcing Steel Institute, Schaumburg, IL, First Edition, 1984.

Captor™ Containment

DOUBLE WALL TANK SYSTEMS



Sii

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Captor Containment System

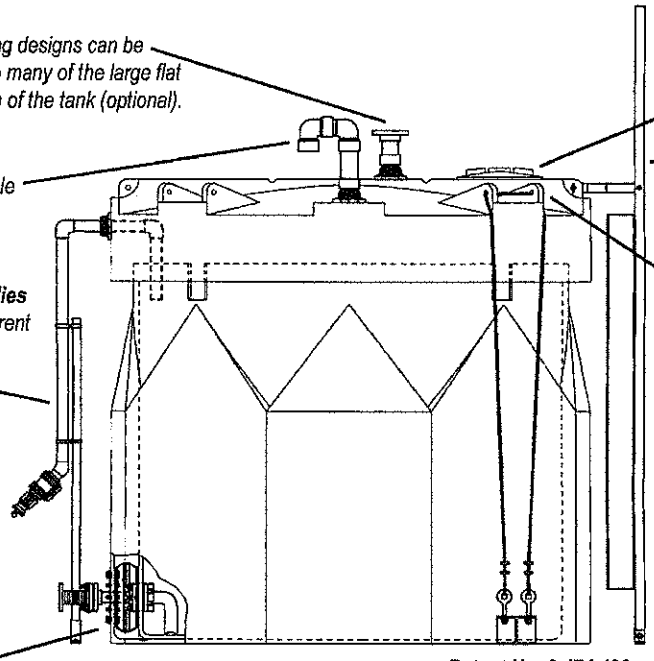
Protects Bulk Storage Profits
Without Jeopardizing Safety or the Environment

Flanged Outlets *and other fitting designs can be securely fastened and sealed to many of the large flat areas located on the top section of the tank (optional).*

U-Vent Assemblies *are available in a variety of sizes to relieve vacuum pressures.*

Fill and/or Draw Pipe Assemblies *can be installed to facilitate different material loading or un-loading requirements. (optional).*

U.F.O. (Unified Fitting Outlet) *is uniquely designed to mechanically seal fitting outlet through both the inner and outer tank walls. Material unloading is easier and more cost effective than pumping contents from the top of the tank (optional).*



Patent No. 6,474,496

Bolted and Threaded Manways *are available in sizes up to 24". Standard size is an 18" threaded manway.*

OSHA Approved Ladders *are available with and without cages in fiberglass and steel construction.*

Molded in Tie-Down Lugs *interface with optional cable restraint system to meet seismic and 150 mph wind load requirements.*

Outer Containment Tank *provides 115-120% of inner tanks capacity for added safety factor. Complies with 40 CFR-264.193.*

Double Wall Tank Construction *encloses and interlocks outer and inner tank to prevent rain, snow, and debris from entering outer containment tank.*

Double Wall Tank System
Ideal for Mini-Bulk Chemical Delivery Programs

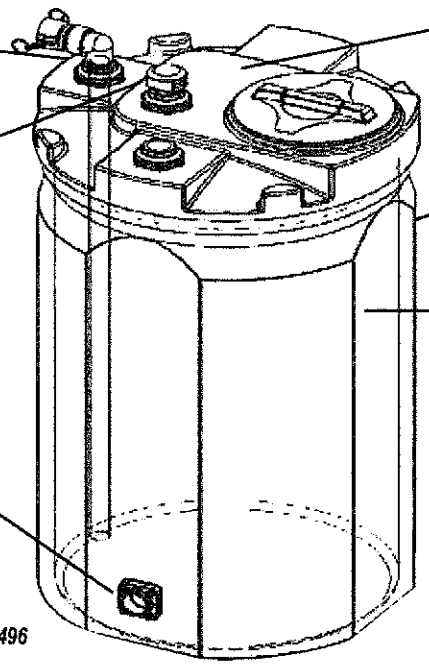
Top Draw-Tube Assembly *enables material contents to be safely dispensed from the top of the tank. (optional)*

2" Vent *provides pressure vacuum relief for interior tank. (optional)*

Available in XLPE and HDLPE *resin packages.*

Transition Fitting *allows sidewall safe installation and long-term sealing power through both walls of tank. (optional)*

Forklift Channels *are available on 275, 360 and 500 gallon sizes.*



Patent No. 6,474,496

Flat Surface Areas *provides ample space on top for a variety of fitting sizes and styles.*

Two Tanks within one *design provide double-wall protection.*

Narrow Diameter *provides location versatility in that it can fit through most any doorway on sizes up to 150 gallons.*

Secondary Containment Tank *provides 120% of inner tank's capacity. Complies with 40 CFR-264.193.*

All Other Snyder Industrial Product Fittings and accessories are available wherever applicable.

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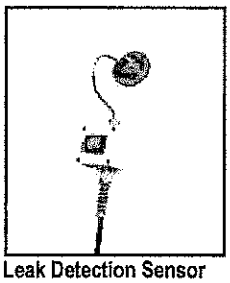
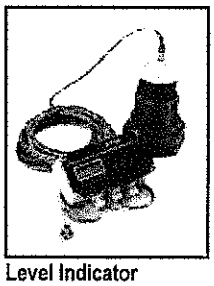
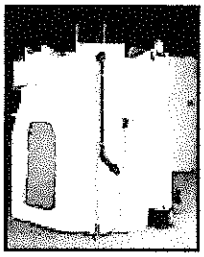
Captor Options/Accessories



Leak Detection Sensor
Capacitive proximity sensor detects and communicates the smallest of leaks with an easy to understand warning signal.

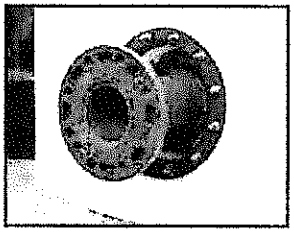


Level Indicator
Ultrasonic level indicator with digital display measures the inner tank's slightest liquid level changes.

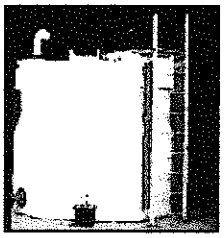


Modified to accommodate double wall construction and take advantage of our outer containment capability.

Other Options
Bolted and sealed manways, heat trace and insulation, and most other Snyder tank fittings and accessories.



Transition Fitting
U.F.O. (Unified Fitting Outlet) design allows side wall fittings to be installed and safely sealed through both walls of the Captor Containment System.

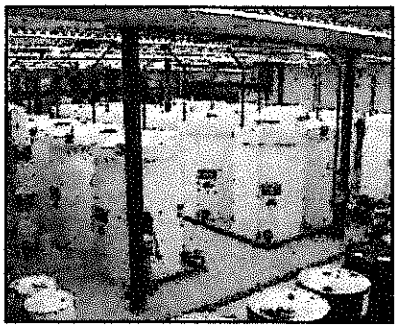


Seismic Restraints and Ladders
Molded-in tie-down lugs and cable tie-down system meet seismic and 150 mph wind load requirements. OSHA-approved ladders are also available.

Tank Material Options
High Density linear polyethylene (HDLPE) or cross-linked polyethylene (XLPE).

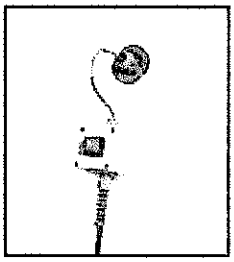
SPECIFICATIONS

Captor Containment System			
Part No.	**Gallons**	**Diameter**	**Height**
50400/50300	550	76"	65"
54700/54500	1,100	76"	104"
54900/54600	1,550	76"	136"
55700/55000	2,000	102"	103"
55800/55100	2,500	102"	122"
55900/55200	3,000	102"	142"
56000/55300	3,500	102"	158"
56100/55400	4,000	102"	178"
56200/55500	4,500	102"	197"
56300/55600	5,000	102"	216"
56600/56400	5,500	120"	172"
56700/56500	6,500	120"	199"
10064/10065	8,700	142"	197"
10066/10067	10,000	142"	226"
10311/10312	12,500	142"	274"

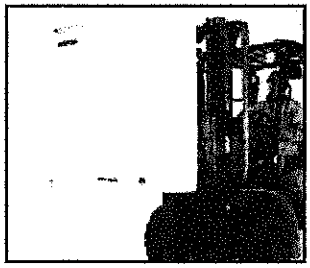


All Snyder specific gravity ratings meet or exceed ASTM D-1998. Consult your Snyder representatives on material construction recommendations for your company's particular application.

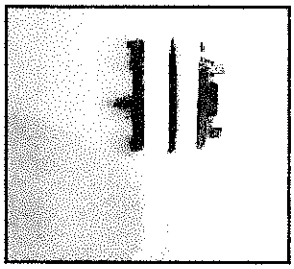
Mini-Captor Options/Accessories



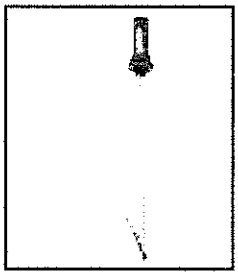
Leak Detection Sensor
Capacitive proximity sensor detects and communicates the smallest of leaks with an easy to understand warning signal.



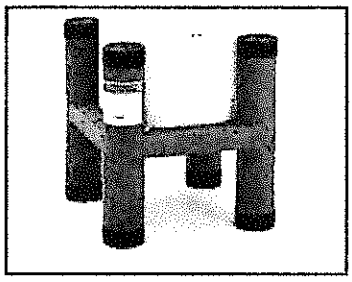
Forklift and Pallet Jack Accessible Design
Larger 275, 360 and 500 gallon sizes are equipped with forklift channels designed to help move the containers when full and empty.



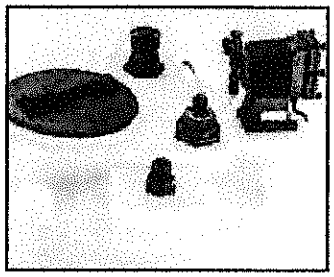
Transition Fitting
Allows safe sidewall installation and long-term sealing power through both walls of tank.



Level Gauge
Mechanical swing-arm type level gauge for visual level monitoring. All plastic with PVC bushing Kynar® rods and HDPE float.



Stands
Mini-Captor tank systems (35-275 gals.) can be mounted on elevation stands, creating more room for plumbing and other system requirements without utilizing additional floor space. ***Patent No. 7,059,575***



Other Fittings and Accessories
All applicable Snyder Industries fittings and accessories can be integrated to complete tank system.

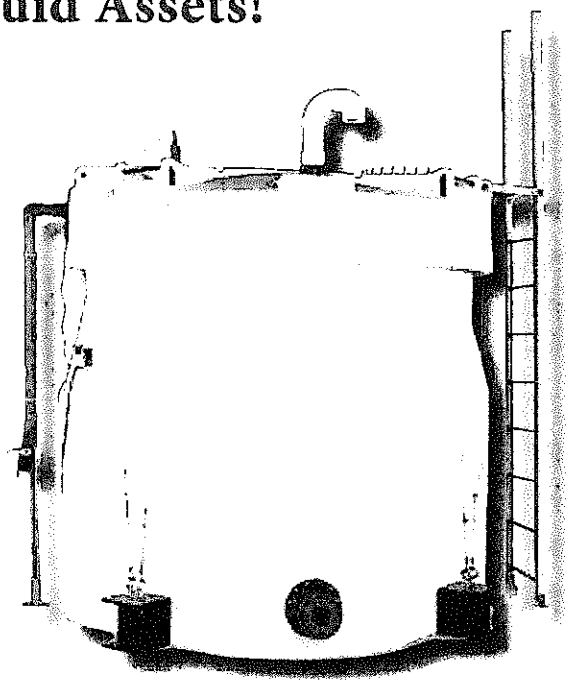
Tank Material Options
High-density linear polyethylene (HDLPE) or cross-linked polyethylene (XLPE).

SPECIFICATIONS

Mini-Captor Tank Systems				
Part No.	**Gallons**	**Diameter**	**Height**	**Lid**
1010002N--	15	23"	23"	8"
1010202N--	30	23"	35"	8"
1000112N--	35	22"	36"	6"
1010402N--	55	28"	36"	8"
5680002N--	60	26"	41"	14"
1010602N--	100	33"	44"	8"
5700102N--	120	34"	51"	14"
1010802N--	140	32X32"	48"	8"
5710102N--	150	34"	62"	14"
5740102N--	275	47"	63"	18"
5760102N--	360	53"	63"	18"
5780102N--	500	53"	81"	18"

Double Strength Protection

Protect Your Liquid Assets!



Regulation is becoming increasingly stringent in the formulation and enforcement of chemical containment legislation. Berm and tank-in-a-basin containment systems, thought to be modern, are now found to be inadequate and not compliant.

There is an answer. Snyder's polyethylene tanks with secondary containment systems can safely store a wide range of hazardous chemicals. Our double wall (tank-in-a-tank) designs are being increasingly utilized as a supplement or alternative to secondary containment requirements. The design features built into Snyder's Captor and Mini-Captor Tank Systems increase safety and protect the environment without jeopardizing your profits.

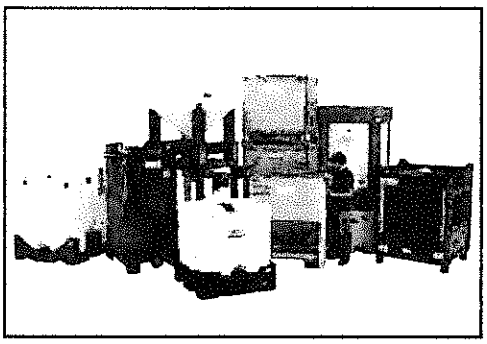
Consider the Benefits...

- Tank-in-a-tank design provides TOTAL containment protection in one space-saving unit.
- The system consists of a primary tank with a secondary outer containment tank with a capacity of 115%-120% of the inner tank's capacity, exceeding EPA standards.
- Double-wall construction is completely enclosed so that external matter such as rainwater, snow and debris is prevented from collecting in the outer containment tank making it ideal for outdoor chemical storage.
- Shipped fully-assembled on either a standard or wide-load flatbed trailer which reduces field assembly costs.
- Available in sizes ranging from 35 to 12,500 gallons.
- Available in High Density Linear Polyethylene (HDLPE) or Cross Link Polyethylene (XLPE) construction. Having a choice provides ultimate chemical compatibility and performance.
- Tanks designed with wall thickness equal to or greater than ASTM D-1998 standards.

Your Snyder Double Wall Tank can be customized with these options...

- Seismic restraint system (for 35-12,500 gallon sizes).
- 150 MPH wind load restraint system (for 35-12,500 gallon sizes).
- Ultrasonic level indicators.
- Leak detection sensors.
- Heat tracing and insulation.
- OSHA compliant ladders (for 550-12,500 gallon sizes).
- Variety of manway sizes and styles.
- Bottom sidewall outlets.
- Top inlet connections and vents.

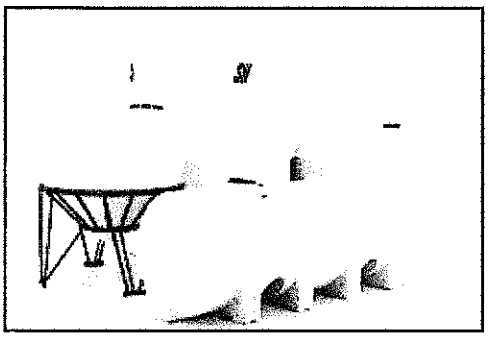
SOLUTIONS IN BULK HANDLING



Transportation containers hold from 60 to 550 gallons.

UN/DOT APPROVED IBCS

Snyder intermediate bulk containers (IBCs) are durable, corrosion-resistant and economical. These long-term, reusable containers are ideal for the transportation of both hazardous and non-hazardous liquid materials.



Stationary tanks store from 8 to 16,500 gallons.

BULK STORAGE & PROCESSING TANKS

For larger stationary applications, Snyder offers the industry's broadest range of tanks – from 8 to 16,500 gallons – in shapes that meet your specific needs. To match your special function requirements, we also market a complete line of accessories, such as stands, seismic tie-downs, ladders, fittings, gaskets, sight gauges, heat tracing and insulation.

Mini-bulk containers with containment.

MINI-BULK/CHEMICAL FEED STATIONS

Long lasting, corrosion-resistant tank and containment systems that provide the perfect solution for mini-bulk delivery programs. Complete and ready to use Chemical Feed Stations allow you to handle small amounts of liquids and other chemicals in a safer and more efficient manner than drums. The Chemical Feed Stations can be located close to your customer's use point, thereby eliminating th need for them to move and handle heavy drums and tote bins of hazardous materials, while at the same time eliminating the handling costs and inconvenient disposal of drums and one-way tote bins.

ONE SOURCE DOES IT ALL

Whether you are a manufacturer or distributor, Snyder Industries can help you improve the function, economics and performance of your company's bulk handling systems.

SNYDER INDUSTRIES, INC.

SOLUTIONS IN BULK HANDLING

P.O. Box 4583 • Lincoln, Nebraska 68504 • 402-467-5221 • FAX: 402-465-1220 • *www.snydernet.com* • *email: sales@snydernet.com*

Other manufacturing facilities: Marked Tree, Arkansas • Chowchilla, California • Philippi, West Virginia • Mancelona, Michigan

www.snydernet.com

Printed 8/2014

DESIGN SLAB ON GRADE FOR 4, 3000 GAL. TANKS:

DENSITY OF SCINTILLATOR = 1.05 g/cc = 8.763 #/GAL

∴ 3000 GAL = 26288 #

TANK DIAMETER = 102",
= 8.5'

AREA, BOTTOM OF TANK = $\pi(8.5)^2/4 = 56.75$ FT²
BEARING PRESSURE = 26288/56.75
= 463 #/FT²

FOR f'c = 4000 psi & Fy = 60,000 psi:
ALLOW. BRG. PRESSURE = $\phi(0.85 f'c)$ (ACI 10.17 P. 137)
= 0.70(0.85)(4000)
= 2380 psi

ACTUAL BRG. PRESSURE = (1.7)463/144 = 5.47 psi
< 2380 psi OK

ASSUME 8" THICK SLAB:
DESIGN METHOD 1:

$A_s = (f_r(12)t)/(2(f_s - T\alpha E_s))$
$= \frac{(190(12)(8))}{(2(45000 - 120(5\times10^{-6})(29\times10^{6}))}$
$= 0.33$ IN²/FT

MOR = $7.5\sqrt{4000}$
= 474
$f_r = 0.4$(MOR)
= 0.4(474)
= 190

f_s = ALLOW. WORKING STRESS OF REINF

T = TEMP. RANGE OF THE SLAB (F°)

$\alpha = 5\times10^{-6}$

$E_s = 29000000$ psi

DESIGN METHOD 2:

$A_s = (36\sqrt{f'c}\ t)/f_s$
$= (36(\sqrt{4000}\times8)/45000$
$= 0.41$ IN²/FT

USE #6@12" EA. WAY $A_s = 0.44$ IN²/FT

6" × 6'-0 × 6'-0 ELECTRICAL SLAB:

DESIGN TAKEN FROM CRSI HANDBOOK, 1984 PAGE 13-61 "SLABS ON GROUND"

6" SLAB W/ 1 LAYER 6×6 W2.9 × W2.9 WWF
PROVIDES 400-500 psf CAPACITY OK

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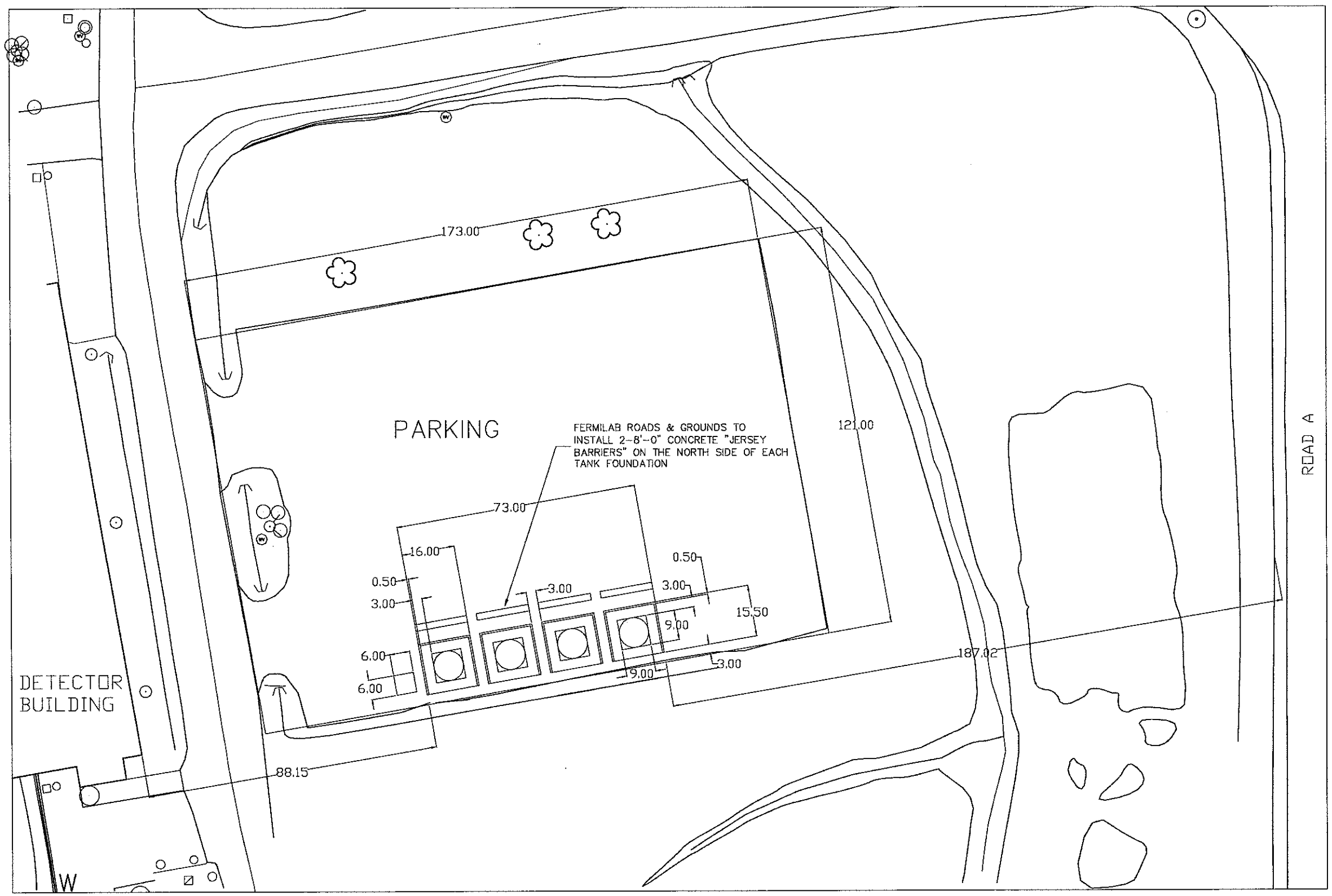


REV	REVISION CONTROL DOCUMENT	DATES	SIGNATURES
--	--	--	DRAWN --
			APPROVED --

UNLESS OTHERWISE SPECIFIED

X.X	X.XX	X.XXX	X/X	XX°
±.1	±.02	±.005	±1/16	±1°

BREAK ALL SHARP EDGES .010 MAX.
DO NOT SCALE DRAWING
DIMENSIONS BASED ON ASME Y14.5-2009
MAX. ALL MACH SURFACES 63
DRAWING UNITS INCHES

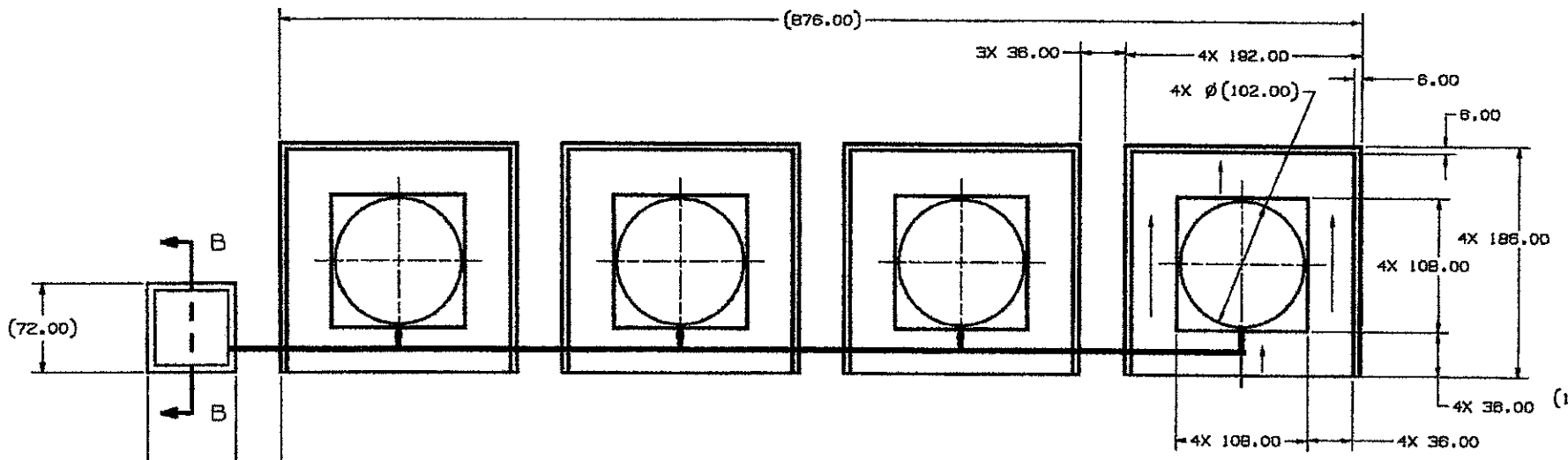
DRAWN	S.SCILLBERG	DATE	28-MAR-2016
CHECKED		DATE	
APPROVED		DATE	
USED ON			
MATERIAL			
GROUP	FPD/MECHANICAL SUPPORT	CAGE CODE	--

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

NAME: SITE PLAN

SCALE	SIZE	DRAWING NUMBER	SHEET	REV
1:1	E	F10056447	1 OF 1	--

REV	REVISION CONTROL DOCUMENT	DATES	SIGNATURES
-	F10056076---RCD	DRAWN / APPROVED	



PLAN
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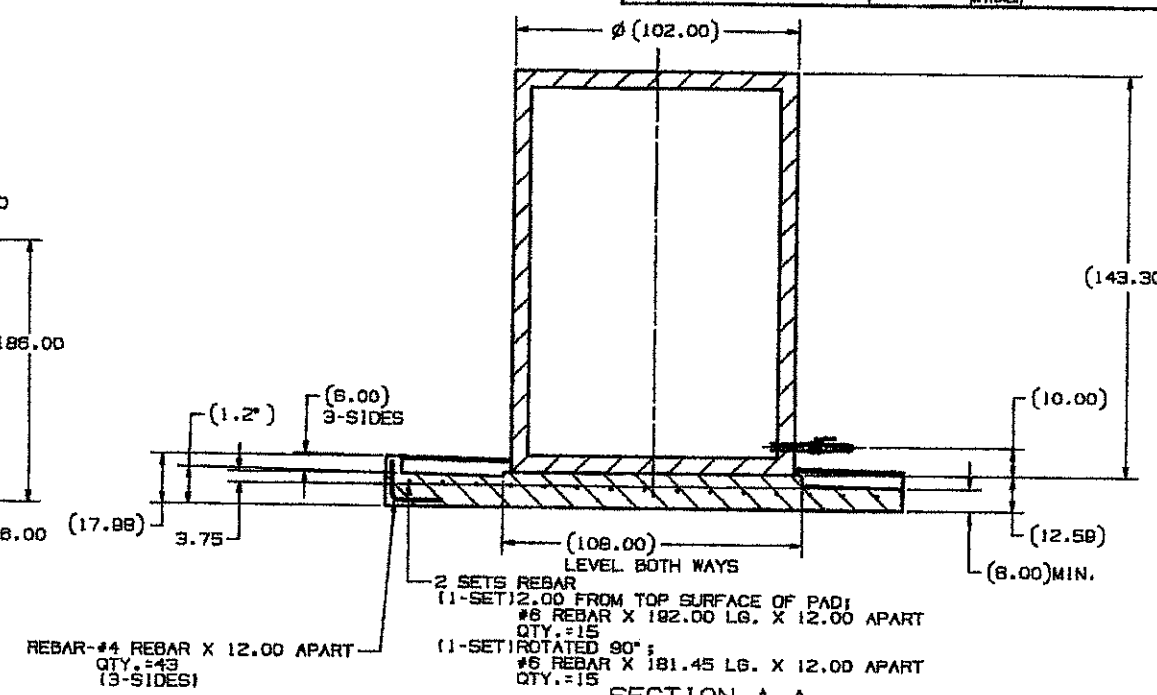
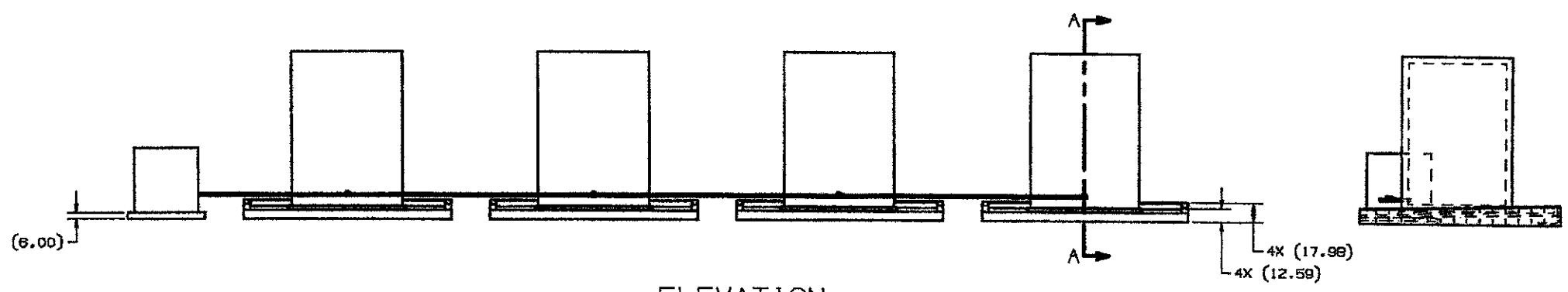
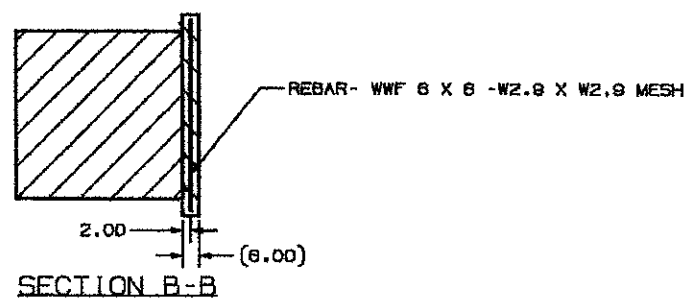


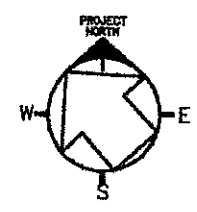
SECTION A-A
4-PLACES



ELEVATION
SCALE=1:64



SECTION B-B



GENERAL

1. THE SUBCONTRACTOR SHALL VERIFY ALL DIMENSIONS AND EXISTING CONDITIONS BEFORE STARTING WORK. IF CONDITIONS VARY FROM THOSE INDICATED ON THE DRAWINGS, THE FERMILAB CONSTRUCTION COORDINATOR SHALL BE NOTIFIED AND NO WORK SHALL BE DONE IN THE AREA WITHOUT HIS APPROVAL.
2. THE SUBCONTRACTOR SHALL COORDINATE WORK AND COOPERATE WITH SUBCONTRACTORS ON ADJACENT AND CONCURRENT WORK.
3. SCALE FOR THE DRAWINGS IS FOR GENERAL INFORMATION ONLY. LOCATIONS AND DIMENSIONS SHALL BE TAKEN AS SHOWN AND NOT SCALED.

EARTHWORK AND FOUNDATION NOTES

1. THE SOIL UNDER THE FOUNDATIONS SHALL HAVE A SAFE BEARING VALUE OF 2000 PSF.
2. DEWATERING OF EXCAVATIONS BY APPROPRIATE MEANS MAY BE NECESSARY TO PROVIDE A FIRM, DRY SUBBASE FOR CONSTRUCTION OR BACKFILL.
3. ALL EXCAVATIONS SHALL BE INSPECTED BY FERMILABCS CONSTRUCTION COORDINATE BEFORE PLACING FORMS OR REINFORCING.
4. NO CONCRETE SHALL BE PLACAED IN EXCAVATIONS CONTAINING FREE WATER OR FROZEN SOIL.
5. THE SUBCONTRACTOR SHALL TAKE EXTREME CARE WHEN WORKING AROUND EXISTING PIPES AND CONDUITS AND SHALL BEAR ANY EXPENSE WHICH MAY RESULT FROM DAMAGING SAID EQUIPMENT.

SITE CONCRETE NOTES

1. REINFORCING BARS SHALL CONFORM TO THE REQUIREMENTS OF ASTM A615, GRADE 60.
2. REINFORCING DETAILS SHALL CONFORM TO ACI STANDARD 315.
3. LAP SPLICES NOT SHOWN ON THE DRAWINGS SHALL CONFORM TO ACI CHAPTER 12 FOR CLASS B SPLICES.
4. MATERIAL AND WORKMANSHIP SHALL BE IN ACCORDANCE WITH THE REQUIREMENTS OF BUILDING CODE FOR REINFORCED CONCRETE ACI STANDARD 318.
5. MINIMUM 28 DAY STRENGTH FOR STRUCTURAL CONCRETE SHALL BE 4000 PSI.
6. CONCRETE COVER SHALL BE AS SHOWN ON THE DRAWINGS AND/OR REQUIRED BY THE LATEST EDITION OF ACI STANDARD 318.
7. SUBCONTRACTOR SHALL COORDINATE THE PLACING OF CONCRETE SO AS TO PROVIDE PROPER AND ADEQUATE CUTOUTS, SLEEVES, INSERTS AND OTHER BUILT-IN DEVICES FOR ELECTRICAL AND MECHANICAL EQUIPMENT AND PIPING AND ARCHITECTURAL DEVICES.
8. STRUCTURAL STEEL PLATES SHALL CONFORM TO ASTM A-36.

UNLESS OTHERWISE SPECIFIED

±.X	±.XX	±.XXX	±X/X	±X°
***	.05	***	***	1°

BREAK ALL SHARP EDGES .015 MAX.
DO NOT SCALE DRAWING
DIMENSIONS BASED ON ASME Y14.5-2009
MAX. ALL MACH SURFACES 125
DRAWING UNITS: INCHES

DRAWN	B.ELLISON	DATE	21-Mar-2016
CHECKED		DATE	
APPROVED		DATE	
USED ON			
MATERIAL			

GROUP: Parabolic Absorber Mechanical Support (CADE CODE) QUEBEC

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

NAME: SCINTILLATOR TANK FARM ASSEMBLY

SCALE	SIZE	DRAWING NUMBER	SHEET	REV
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PDHonline Course S132 (1 PDH)

Slab on Grade Reinforcing Design

Instructor: D. Matthew Stuart, P.E., S.E., F.ASCE, F.SEI, SECB, MgtEng

2013

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Materials:

The most common reinforcement associated with slabs-on-grade is welded wire fabric. However, this is not the only means of reinforcing slabs. In some cases deformed bars are used in order to assure that the reinforcement is placed at the correct depth within the slab and not damaged during placement. In either case when using deformed bars or welded wire fabric, it is essential that adequate support of the steel is provided.

Source: eHow.com

Welded Wire Fabric:

When using welded wire fabric, prefabricated sheets should be used in lieu of rolled fabric in order to help assure proper location of the steel within the concrete. In either case a minimum of one chair per 25 square feet of mesh should be used to adequately support the reinforcement above the sub-grade. The table provided in this slide lists common styles of welded wire fabric, including the "old" and "new" designations. Although the "new" designations are more than 20 years old, many engineers find this cross-reference helpful.

Common Styles of Welded Wire Fabric

Style Designation		Steel Area Sq. in. per ft.		Weight Lbs. per 100 SF
New Designation (by W-number)	Old Designation (by steel wire gauge)	Longitudinal	Transverse	
ROLLS				
6x6-W1.4xW1.4	6x6-10x10	.028	.028	21
6x6-W2.0xW2.0	6x6-8x8*	.040	.040	29
6x6-W2.9xW2.9	6x6-6x6	.058	.058	42
6x6-W4.0xW4.0	6x6-4x4	.080	.080	58
4x4-W1.4xW1.4	4x4-10x10	.042	.042	31
4x4-W2.0xW2.0	4x4-8x8*	.060	.060	43
4x4-W2.9xW2.9	4x4-6x6	.087	.087	62
4x4-W4.0xW4.0	4x4-4x4	.120	.120	85
SHEETS				
6x6-W2.9xW2.9	6x6-6x6	.058	.058	42
6x6-W4.0xW4.0	6x6-4x4	.080	.080	58
6x6-W5.5xW5.5	6x6-2x2**	.110	.110	80
4x4-W4.0xW4.0	4x4-4x4	.120	.120	85

* Exact W-Number size for 8 gauge is W2.1.
** Exact W-Number size for 2 gauge is W5.4

Deformed Bars:

The most common bar sizes encountered when using deformed reinforcement for typical lightly loaded slabs are #4 and #5 bars. However, it is recommended that #5 bars be used as a minimum as bars of smaller diameter are much more susceptible to damage due to foot traffic during the placing operation.

Source: John Rohrer Contracting Company

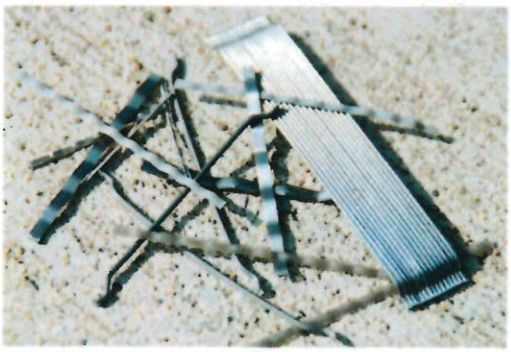
Post-Tensioning Tendons:

Post-tensioning is very popular for slab-on-grade construction in some areas of the country. This is especially true for super-flat industrial floors and areas susceptible to expansive soil. The most common post-tensioning material is half-inch diameter 270k prestressing strand. The strand is generally greased and encapsulated in an extruded plastic sheathing. Post-tensioning pre-compresses the concrete, which in turn helps to control shrinkage cracking allowing for greater distances between joints.

Source: Metzger Testing and Inspection

Fiber Reinforcement:

Synthetic fiberglass and steel fibers can also help to control plastic shrinkage cracking and limit the size of cracks when used according to the manufacturer's recommendations. However, currently there is no data indicating that the use of such fibers allows for an increase in joint spacing. In addition, currently ACI does not recognize fiber reinforcement as an acceptable substitute for conventional reinforcement. In addition, fiberglass fibers can sometimes protrude from the finish surface of the slab giving the concrete a "hairy" appearance.



Steel Fibers
Source: Concrete Construction

Subgrade Drag Procedure:

For most commercial and industrial floors, joint spacing is dictated by the location of columns or racks within the structure. This spacing may or may not coincide with the desired joint spacing of an unreinforced concrete slab. With some limitations, reinforcement for slabs can be sized using the Subgrade Drag Theory in order to increase the spacing of control or construction joints. The result is a lightly reinforced slab designed to offset the effects of temperature and shrinkage of the concrete.

ACI 360, "Design of Slabs-on-Grade", refers to this as a Type B slab. The Wire Reinforcing Institute recommends the use of the Subgrade Drag Theory for slabs up to 150 feet in length. However, with the relatively low percentage of steel provided by this method, it is recommended that only slabs whose joint spacing are within the range shown in Table 1 in the next slide should be reinforced using the Subgrade Drag Theory.

Longer strips of slabs than that indicated in the Table 1 can be placed, however, shrinkage cracks are more likely to occur. Additional reinforcing steel will help control the crack widths and supplement aggregate interlock, but random cracking is very likely to occur. Other calculation methods should be considered when determining reinforcing for joint spacing greater than that indicated in Table 1.

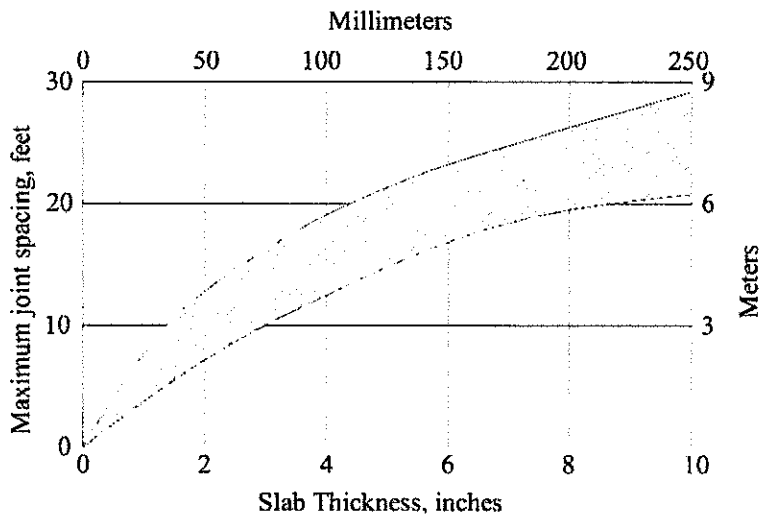


Table 1

The Subgrade Drag equation is frequently used to determine the amount of non-prestressed reinforcement required within the joint spacing distance L. This method does not apply to prestressing or the use of fibers.

The Subgrade Drag equation is as follows:

$$A_s = (FLW)/(2f_s)$$

Where: A_s = cross-sectional area in square inches of steel per lineal foot of slab width

F = friction factor

L = distance in feet between joints

(the distance between the free ends of the slab that can move due to shrinkage contraction or thermal expansion).

W = dead weight of the slab (psf).

f_s = allowable working stress of the reinforcement (psi).

The 2 in the denominator is not a safety factor. It is based on the theory that the slab panel will move an equal distance from each end toward the center. This may not always be the situation (see the definition of L). F, the friction factor, can vary from 0.5 or greater. A value of 1.5 should be used as an average when accurate information is not available

Alternative Design Procedures:

There are two other rational procedures for selecting steel percentages for slabs-on-grade. One is based on temperature, and the other is based on the concrete-to-steel strength ratio. Both of these procedures will often produce slightly higher values than the Subgrade Drag procedure, however, these alternate methods do assure superior crack control. The Temperature method for determining reinforcement is:

$$A_s = (f_t(12)t) / (2(f_s - T\alpha E_s))$$

Where:
- A_s = cross-sectional area in square inches of steel per lineal foot of slab width
- t = thickness of slab in inches
- f_t = tensile strength of concrete (psi) = 0.4 x Modulus of Rupture
- f_s = allowable working stress of the reinforcement (psi)
- T = range of temperature the slab is expected to be subjected to (F°)
- α = thermal coefficient of concrete (in/in F°)
- E_s = modulus of elasticity of steel (psi)

The normal range of the coefficient of thermal expansion of concrete (α) is 5 to 7 x 10^{-6}. The modulus of elasticity (E_s) of reinforcing bars is generally taken as 29 x 10^6 psi. Interior floor slabs are usually not subjected to the same severe temperature gradients experienced by outside pavements. Therefore it is reasonable to design for the maximum temperature range that the slab will experience during its service life. However, even interior climate controlled spaces can experience temperature ranges of 40° to 60°F.

The second alternate procedure for determining reinforcement is the computation of the percent of steel necessary to complement the tensile strength of the concrete. The steel is calculated based on a value of 75% of the yield strength of the reinforcing, and the value of the tensile strength of the concrete, which is taken as 0.4 times the modulus of rupture (MOR). This method produces a significantly higher percentage of steel than the other two methods described. The modulus of rupture of concrete can be realistically taken as $7.5\sqrt{f'_c}$. This results in the following formula:

$$A_s = (36\sqrt{f'_c}\,t) / f_s$$

Where:
- A_s = cross-sectional area in square inches of steel per lineal foot of slab width
- t = thickness of slab in inches
- f'_c = strength of concrete (psi)
- f_s = allowable working stress of the reinforcement (psi)

It is recommended that the merits of using the methods which require greater percentages of steel than that determined by the Subgrade Drag formula be considered, particularly for industrial floor applications where the control of random cracking is critical.

Steel Placement:

When the Subgrade Drag formula is used for steel design, the recommendation for concrete cover above the reinforcing is two inches below the top of the slab. However, it is reasonable to allow for an envelope of steel placement ranging from two inches below the top of the slab to the center of the slab. Placing the steel any lower than this limit could, however, adversely affect the performance of the slab.

For most conventional slab-on-grade design, the steel does not have to be discontinuous at the contraction or sawn control joints. However, in cold storage facilities it is recommended that the reinforcing be discontinuous at all control joints. In industrial facilities in areas subjected to random and repeated heavy forktruck wheel traffic it is also recommended that dowel baskets be used at the sawn control joint locations to help supplement the load transfer capability of the controlled crack location. This is particularly true if the slab is unreinforced and only capable of transferring vertical loads across the control joint via aggregate interlock.

Dowel Basket
Source: Illinois DOT

Post-Tensioned Industrial Floors:

The advantages of post-tensioning for industrial floors are:

1. Less concrete, i.e. reduced slab thickness.
2. Reduction or elimination of random cracks.
3. Substantial reduction in joints, i.e. increased spacing of joints.

Post-tensioning is an active rather than passive form of reinforcing. In other words, post-tensioning pre-compresses the concrete to help prevent cracking from occurring rather than holding cracks together mechanically after they have already formed as conventional reinforcing does.

Source: VSL

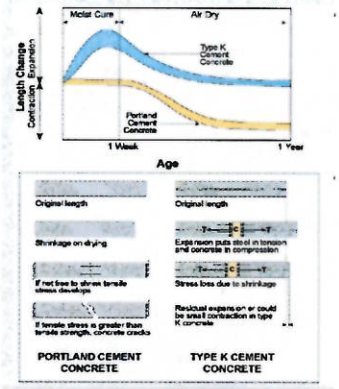
Post-tensioned slabs are generally designed to have a residual pre-compression stress of 50 psi to 150 psi. This generally results in half-inch diameter 270k tendons spaced between 24 inches to 48 inches on center. Tendons are typically placed at the center of the slab to avoid any stresses that might be induced by the eccentricity of the strands relative to the concrete cross section. Post-tensioning tendons are usually seven-wire strand, with a cross-sectional area of 0.153 square inches. It is recommended that a continuous slip-sheet beneath the bottom of the slab and the subgrade be used to reduce drag as a result of movement of the slab due to the pre-compression induced by the post-tensioning force. Coefficients of friction can be kept at or below 0.5 with the use of either a single or double layer polyethylene slip-sheet membrane. When designing the thickness of a post-tensioned slab, it is recommended that standard PCA and WRI methods be used.

Source: JVK Inspections

Shrinkage Compensating Concrete Slabs:

Shrinkage-compensating concrete (Type K cement) undergoes an early age expansion and then undergoes drying shrinkage similar to conventional concrete. However, the net result is the apparent lack of any shrinkage of the concrete once the material has cured. Bonded reinforcement is essential for this type of slab. The reinforcement is placed in tension during the initial concrete expansion. The tension is then relieved due to drying shrinkage and long term creep of the concrete.

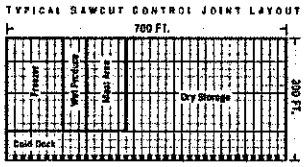
Expansive Cements

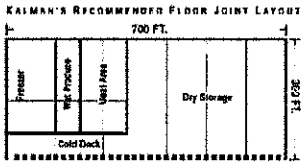


Source: University of Berkeley, CA

The purpose of shrinkage-compensating concrete is to limit cracking and minimize joint spacing. Shrinkage compensating concrete permits slab panel sizes up to 15,000 square feet. More manageable sizes such as 50 x 50 feet (2,500 square feet) are more commonplace. Reinforcing steel for shrinkage compensating concrete ranges from 0.15 percent to 0.6 percent of the gross cross-sectional area of concrete, however, lower values have been known to perform successfully. In either case, the reinforcing should be placed in the upper third of the slab.

It is recommended that designers using this product familiarize themselves with ACI 223 "Standard Practice for the Use of Shrinkage-Compensating Concrete." It is also advisable to seek the assistance of a shrinkage compensating cement supplier and contractor familiar with this type of product prior to designing and detailing a project using Type Kcement.





Source: Kalman Floor Company

Structurally Reinforced Slabs:

One additional use of reinforcing in slab-on-grades is to allow for a reduced slab thickness, even though as it is expected in the following example, hairline cracks due to loading will occur. The following example is taken from "Designing Floor Slabs-on-Grade," Boyd C. Ringo, Robert B. Anderson (Aberdeen Group, 1992).

Example:

Provide a maximum slab thickness of 8 inches. Strength will be provided with reinforcing steel selected to provide a safety factor of two.

- Actual moment = 5,700 ft. lb. per foot of slab width
- Concrete compressive strength - 4,000 psi
- MOR = 570
- Cracking moment; $M_{cr} = ((bd^2)/6) \times (MOR/12)$
- M_{cr} = 6,080 ft.-lb. per foot of slab width
- Moment required for a safety factor of 2; 5,700 x 2 = 11,400 ft.-lb. per foot of slab width.
- One possible solution is the use of one layer of #6 bars. Table 2 provided in the next slide shows that the moment capacity per foot of width is 7.13 ft.-kips if the #6 bars are spaced at 12 inches. It is necessary to adjust this to a closer spacing since the 12-inch spacing does not provide enough moment capacity.
- Spacing = 12 (7.13/11.4) = 7.505 inches
- Use one layer of number six bars at 7½inches one center

Slab Moment Capacities for One or Two Layers of Rebar at 12-Inch Spacing

Slab Thickness		8-in						10-in					
		#3	#4	#5	#6	#7	#8	#3	#4	#5	#6	#7	#8
Number of Layers	A_s (in^2)	0.11	0.20	0.31	0.44	0.60	0.79	0.11	0.20	0.31	0.44	0.60	0.79
	d_b (in)	0.38	0.50	0.63	0.75	0.88	1.00	0.38	0.50	0.63	0.75	0.88	1.00
	d (in)	4.00	4.00	4.00	4.00	4.00	4.00	5.00	5.00	5.00	5.00	5.00	5.00
ONE	resulting cover (in.)	3.63	3.50	3.38	3.25	3.13	3.00	4.63	4.50	4.38	4.25	4.13	4.00
	M_u (ft-k/ft)	1.78	3.24	5.02	7.13	9.72	12.80	2.23	4.05	6.28	8.91	12.15	16.00
	P(%)	0.11	0.21	0.32	0.46	0.62	0.82	0.09	0.17	0.26	0.37	0.50	0.66
	wgt (psf)	0.75	1.37	2.12	3.01	4.10	5.40	0.75	1.37	2.12	3.01	4.10	5.40
TWO	d (in)	6.38	6.25	6.13	6.00	5.88	5.75	8.38	8.25	8.13	8.00	7.88	7.75
	M_u (ft-k/ft)	2.84	5.06	7.69	10.69	14.28	18.40	3.73	6.68	10.20	14.26	19.14	24.80
	P(%)	0.23	0.42	0.65	0.92	1.25	1.65	0.16	0.33	0.52	0.73	1.00	1.32
	wgt (psf)	1.50	2.73	4.24	6.01	8.20	10.79	1.50	2.73	4.24	6.01	8.20	10.79

Notes:

1. f'c = 400 psi, cover=1.25 in, b=12in, Φ=0.90
2. Design Assumptions made in Table

	One Layer	Two Layers
d	t/2	t"(cover+d_b)
$J_u d$	0.9d	
M_u	$\Phi A_s f_y (J_u d)$	

3. Percentage of Reinforcement based on gross section b x t
4. Slab moment capacities (resistance) in foot-kips per foot of slab width, using either one or two layers of reinforcing bars.

TABLE 2

Unreinforced Slabs:

Unreinforced, plain concrete slabs (i.e. slabs without distributed steel or structural reinforcement) offer advantages of economy as well as ease and speed of construction. There are many similarities between an unreinforced road pavement and a plain concrete floor slab. As in pavement design, the factors involved in determining the required floor thickness of an unreinforced slab include:

1. Sub-grade and sub-base bearing support.
2. Strength of concrete.
3. Slab edge condition.
4. Location and frequency of imposed loads.
5. Magnitude of load.

Table 3 provided below is the suggested spacing for control joints in plain unreinforced slab-on-grade recommended by "Concrete Floors on Ground" published by the PCA (The Portland Cement Association).

Slab Thickness	Spacing (ft.)		
	< ¾" Aggregate	> ¾" Aggregate	Slump < 4"
5"	10	13	15
6"	12	15	18
7"	14	18	21
8"	16	20	24
9"	18	23	27
10"	20	25	30

TABLE 3

SLABS ON GROUND

For any slab on the ground, adequate preparation of subgrade for drainage and compaction is of prime importance. Dowelled expansion joints and weakened plane contraction joints should be carefully located, including expansion joints at all walls, columns, open pits, etc.

The design of slabs on the ground to distribute concentrated or uniform loads involves the elastic properties of the subsoil and the slab itself.* An analysis can be made but is quite involved. Slabs for the very lightest occupancy should be not less than 4″ thick, and slabs for other occupancies may be empirically selected, the following being about minimum and sometimes less than required (ACI 10.5.3) for supported slabs:—

Occupancy **	Min. Slab Thickness	Reinforcement ‡
Sub-slabs under other slabs	2″	None
Domestic or light commercial (loaded less than 100 psf)	4″	One layer 6 x 6 10/10 welded wire fabric, minimum for ideal conditions; 6 x 6 8/8 for average conditions.
Commercial—institutional—barns (loaded 100-200 psf)	5″	One layer 6 x 6 8/8 welded wire fabric or one layer 6 x 6 6/6.
Industrial (loaded not over 400-500 psf) and pavements for industrial plants, gas stations, and garages	6″	One layer 6 x 6 6/6 welded wire fabric or one layer 6 x 6 4/4.
Industrial (loaded 600-800 psf) and heavy pavements for industrial plants, gas stations, and garages	7″	Two layers 6 x 6 6/6 welded wire fabric or two layers 6 x 6 4/4
Industrial (loaded 1500 psf) †	8″	Two mats of bars (one top, one bottom), each of #4 bars @ 12″ c/c, each way
Industrial (loaded 2500 psf) †	9″	Two mats of bars (one top, one bottom), each of #5 bars @ 12″ c/c, each way
Industrial (loaded 3000-3500 psf) †	10″	Two mats of bars (one top, one bottom), each of #5 bars @ 8″ to 12″ c/c, each way

* "Concrete Floors on Ground" and "Concrete Airport Pavement," Portland Cement Association, 1952; "Design of Concrete Floors on Ground for Warehouse Loadings," ACI Jour., Aug. 1957; "Design, Construction, and Performance of Slabs-on-Grade for an Industry," ACI Jour., Nov. 1978; and "Pavements and Slabs-on-Grade with Structurally Active Reinforcement," ACI Jour., Dec. 1978.

** For loads in excess of, say, 500 psf, use at least 3000 psi quality controlled concrete, and investigate subsoil conditions with extra care. Fill material and compaction should be equivalent to ordinary highway practice. If laboratory control of compaction is available, the load capacities can be increased in the ratio of the actual compaction coefficient, k, to 100.

† For loads in excess of, say, 1500 psf the subsoil conditions should be investigated with extra care and subbase should provide $k \geq 200$.