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Product Information Bulletin

BULLETIN NO.	1007
ISSUED:	August 10, 2017
REPLACES:	April 20, 2017

Influence of PlastiSpan Sub-Slab Insulation on Floor Slab Design

Review

PlastiSpan® insulation has provided designers and building owners with long-term thermal performance for over 45 years as a component in residential, commercial and industrial floor systems. The bulletin provides calculation examples to illustrate use of ***PlastiSpan*** insulation for structural floor slab applications.

Structural slab design is governed by the types and magnitude of loads on the concrete slab which may include wheel loads from forklifts or delivery vehicles, point loads from the legs of storage racks or distributed loads from product stored on the concrete slab. Often, selection of a sub-slab insulation product for structural slab-on-grade applications is based upon ability to sustain compressive loads transferred through the concrete slab, without full and accurate determination of the load distribution characteristics of the concrete slab.

In one design methodology, design calculations are based upon the assumption that loads distributed over a contact area on a concrete floor slab area can be "assumed" to be distributed by wheel contact area or base plate contact area through the concrete slab to a largely hypothetical bearing area on the top surface of the insulation. As illustrated in Table 1, the load exposure for the insulation (EPS compressive stress) calculated on this basis could dictate use of a high density, high compressive resistance insulation material increasing cost unnecessarily.

Table 1 – Calculation Examples: Typical Loads on Concrete Slabs

Example 1 - Forklift Wheel Load					Example 2 - Point Load (Storage Racks)				
Wheel Load - F	kN	35			Point Load - F	kN	45		
	lb_f	7,875				lb_f	10,125		
Wheel Contact Area	m	0.203	x	0.203	Base Plate Contact Area	m	0.152	x	0.152
	in	8.0		8.0		in	6.0		6.0
Stress Distribution Angle		45			Stress Distribution Angle		45		
Slab Thickness	m	0.152			Slab Thickness	m	0.152		
	in	6.0				in	6.0		
Loaded Area	m^2	0.26			Loaded Area	m^2	0.21		
	in^2	398				in^2	322		
EPS Compressive Load Exposure	kPa	136			EPS Compressive Load Exposure	kPa	240		
	psi	20				psi	31		

Another accepted design procedure to use for structural slab design with these types of loads is the theory of plates on elastic foundations. Using the theory of plates on elastic foundations design procedure, when a concrete slab is constructed over a compressible or elastic subgrade such as soil or rigid insulation, load distribution and transfer to the sub-slab insulation is controlled by the slab itself and its response to loads. Floor loads will cause concrete slab deflection as a function of both the concrete slab properties and the compressibility of the materials beneath it.

In order to use this method, designers use the insulation or subgrade response factor referred to as the modulus of subgrade reaction (k) or, in other cases, foundation modulus, k-modulus, k-value, etc. The use of k-values in the design of structural slabs as discussed in PCA Concrete Information[1] reflects the response of the insulation and subgrade under temporary (elastic) conditions when small deflections occur.

Disclaimer Regarding Example Calculations

This bulletin provides **examples of calculations** to illustrate applying the theory of plates on elastic foundations procedure to concrete slab design based upon a hypothetical wheel load with a defined wheel contact area or point load supported on a defined base plate contact area. It must be stressed that in all cases, design calculations and details for specific applications must be prepared by a registered design professional to verify compliance with applicable codes for the jurisdiction in which the project is to be constructed.

Limitations of Use:

1. It is not the intent of this bulletin to provide comprehensive design guidance. Concrete slab deflection for each application must be calculated by the design professional responsible for concrete slab design.
2. Design approaches expressed in this bulletin are related specifically to the distribution of floor loads to subgrade insulation. Final slab design is generally controlled by flexural stresses to which the slab is exposed under long term or short term rolling load conditions.
3. Relationships used to establish slab deflection assume load intensities on the subgrade insulation do not exceed the elastic limit of the insulation.
4. Such factors as the bearing capacity and compressibility of subsoil and/or subgrade slabs below the insulation must be considered in the design of slab/subgrade insulation composites.
5. These design considerations are applicable to concrete slabs-on-grade (insulation serving as grade) exposed to storage loads, storage rack post loads and vehicle axle or wheel loads causing limited slab deflection. High intensity column or wall loading on floor slabs requires further consideration.
6. Soils, concrete, steel and subgrade insulation exhibit creep or cold flow under long-term load exposures. Such long-term load exposures must be considered in slab design in order to prevent objectionable slab settlement.

Calculation Examples Using Theory of Plates on Elastic Foundation Procedure

The following calculation examples use the hypothetical loads for the two load types provided in Table 1 to illustrate the theory of plates on elastic foundation procedure. Floor slab deflection establishes magnitude of unit load transferred to the subgrade material, in this case thermal insulation, based on slab-on-grade design using the theory of plates on elastic foundations[2]. Slab deflection (W) is determined by load exposure, concrete slab strength and subgrade response (insulation and soil) to load transfer using the equation:

$$W = \frac{P}{8\sqrt{kD}}$$

where: W = slab deflection
P = applied load
k = modulus of subgrade reaction
D = $Eh^3/12(1-\mu^2)$ where: E = modulus of elasticity of concrete
h = slab thickness, in.
μ = Poisson's ratio of concrete

Based upon the theory of plates on elastic foundation procedure, slab deflection and insulation compressive load are calculated using elastic foundation design analysis based upon the combined characteristics of the insulation and a subgrade material.

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[1] Portland Cement Association, **Concrete Information,** Packard, Robert G., **Slab Thickness Design for Industrial Concrete Floors on Grade**, 1996.

[2] Timoshenko, S. and Woinowsky-Kreiger, S., ***Theory of Plates and Shells***, McGraw-Hill, 1959.

Assumptions for Calculation Examples: Theory of Plates on Elastic Foundation Calculations

1. Concrete strength (f_c') = 28 MPa (4000 psi)
2. Concrete thickness (h) as noted in table 1
3. Poisson's ratio for concrete = 0.15
4. Insulation thickness = 76 mm (3")
5. Subgrade k-value (k_s) = 100 MN/m^3 (368 pci)
6. k-value Insulation and soil = $1/k_T = 1/k_i + 1/k_s$

E-modulus of Concrete (E_c):
In SI units: $E_c = 4{,}700\sqrt{f_c'}$
$= 4{,}700 \times \sqrt{28} = 24{,}870$ MPa (3.605×10^6 psi)

Compressive resistance at 1% strain, the industry accepted allowable stress for live and dead loads, is provided in Table 2 for a variety of ***PlastiSpan*** insulation types.

Table 2 - *PlastiSpan* Insulation Compressive Resistance @ 1% Strain

Units	PlastiSpan HD Insulation	PlastiSpan 25 Insulation	PlastiSpan 30 Insulation	PlastiSpan 40 Insulation	PlastiSpan 60 Insulation
kPa	45	60	75	103	124
psi	6.50	8.7	10.9	15.0	18.0

Modulus of subgrade reaction values (**k_i**) expressed in units of MN/m^3 or lbs/in^3 (pci) for various PlastiSpan insulation types and thickness are provided in Table 3.

Table 3 - *PlastiSpan* Insulation Modulus of Subgrade Reaction (k)

PlastiSpan Insulation Types	Units	PlastiSpan Insulation Thickness - mm (in)			
		25 (1")	50 (2")	75 (3")	100 (4")
PlastiSpan HD Insulation	MN/m^3	176	147	111	92
	pci	650	540	410	340
PlastiSpan 25 Insulation	MN/m^3	255	212	160	133
	pci	940	780	590	490
PlastiSpan 30 Insulation	MN/m^3	299	247	187	157
	pci	1100	910	690	580
PlastiSpan 40 Insulation	MN/m^3	346	285	217	182
	pci	1275	1050	800	670
PlastiSpan 60 Insulation	MN/m^3	434	358	271	228
	pci	1600	1320	1000	840

Step 1: Calculate the modulus of subgrade reaction for 76 mm (3") *PlastiSpan* insulation plus subgrade material.
$1/k_T = 1/k_i + 1/k_s$

For floor slab designs incorporating multiple insulation layers and a subgrade material, k can be found by adding k values for each layer as follows: $1/k_T = 1/k_1 + 1/k_2 + \ldots 1/k_n$

Table 4 - PlastiSpan Insulation Plus Subgrade Modulus of Subgrade Reaction (k_T)

k_T	PlastiSpan HD Insulation	PlastiSpan 25 Insulation	PlastiSpan 30 Insulation	PlastiSpan 40 Insulation	PlastiSpan 60 Insulation
MN/m^3	53	62	65	68	73
pci	194	227	240	252	269

Step 2: Calculate slab deflection (W) due to load.

Table 5 - Slab Deflection (W)

Insulation Type	PlastiSpan HD Insulation	PlastiSpan 25 Insulation	PlastiSpan 30 Insulation	PlastiSpan 40 Insulation	PlastiSpan 60 Insulation
Example 1 – 152 mm (6") Concrete Slab Deflection (W) Under Wheel Load					
mm	0.22033	0.20381	0.19806	0.19326	0.18707
in.	0.00867	0.00802	0.00780	0.00761	0.00737
Example 2 – 152 mm (6") Concrete Slab Deflection (W) Under Point Load					
mm	0.28328	0.26204	0.25464	0.24848	0.24052
in.	0.01115	0.01032	0.01003	0.00978	0.00947

Step 3: Check compressive stress (F) in 76 mm (3") thick EPS insulation.
The above slab deflection (W) will transfer load to the insulation material at intensity directly related to the insulation k-value from Table 3: $F = K_i W$.

Table 6 - EPS Compressive Stress (F)

PlastiSpan Insulation Types	Example 1 - Wheel Load		Example 2 - Point Load	
	152 mm (6”) Slab		152 mm (6”) Slab	
	kPa	psi	kPa	psi
PlastiSpan HD Insulation	25	3.56	32	4.57
PlastiSpan 25 Insulation	33	4.73	42	6.09
PlastiSpan 30 Insulation	37	5.38	48	6.92
PlastiSpan 40 Insulation	42	6.09	54	7.83
PlastiSpan 60 Insulation	41	5.89	52	7.58

Based upon the above calculation examples, the compressive load transferred to the ***PlastiSpan*** insulation is within the allowable stress range provided in Table 2 for all insulation types.

Step 4: Check concrete slab bending stress (f_b).

$$f_b = 0.316 \frac{P}{h^2}\left[\log h^3 - 4 \log \left(\sqrt{1.6a^2 + h^2} - 0.675\, h\right) - \log k + 6.48\right]$$

Where f_b = Concrete bending stress, h = slab thickness and a = radius of load contact

$a = \sqrt{\frac{A_c}{\pi}}$; where A_c = load contact area

Table 7 - Concrete Bending Stress (f_b)

Design Loads	Wheel Load – Load Factor =1.5		Point load – Load Factor =1.25	
	kN	lb_f	kN	lb_f
	35	7,875	45	10,125
Radius of Contact (a)	115 mm (4.5”)		86 mm (3.4”)	
PlastiSpan Insulation Type	152 mm (6”) Slab		152 mm (6”) Slab	
	MPa	psi	MPa	psi
PlastiSpan HD Insulation	2.88	417	3.70	494
PlastiSpan 25 Insulation	2.83	410	3.35	486
PlastiSpan 30 Insulation	2.81	407	3.33	484
PlastiSpan 40 Insulation	2.79	405	3.32	481
PlastiSpan 60 Insulation	2.77	402	3.30	478

Concrete Tensile Strength (f_r):

MPa in SI Units: $f_r = 0.62\sqrt{f'_c}$

Bending stress should not exceed the concrete tensile strength = 3.41 MPa (495 psi).

Selection of the ***PlastiSpan*** insulation type based upon concrete slab design using the theory of plates on elastic foundation would result in:

- Based upon the hypothetical wheel load for calculation example 1 from Table 1, ***PlastiSpan HD*** insulation would satisfy the design requirements.
- Based upon the hypothetical point load for calculation example 2 from table 1, ***PlastiSpan 25*** insulation would satisfy the design requirements.

Calculation Example Summary:

1. Under "assumed" or hypothetical load distribution patterns, the EPS compressive resistance requirement for the load exposure from the two load types typical for structural slabs would dictate use of a high strength thermal insulation.
2. Using elastic foundation design theory, a much lower compressive load would be transferred to the sub-slab insulation based upon slab deflection under the two hypothetical load types allowing the use of a more cost-effective ***PlastiSpan*** insulation alternative.