MULTILAYER CONCRETE INDUSTRIAL FLOORING SOLUTIONS ANALYSIS

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Abstract

The subject of the article is the presentation of European experience in the field of construction of industrial concrete floors. For the construction of the concrete slab floor to be prepared subsoil. Land stabilization can include mechanical stabilization, physical stabilization, and chemical stabilization.

The most commonly used stabilization is mechanical stabilization. In order to determine the efficiency and effectiveness of the process, the treatment depends on the soil moisture for the soil type, so attention is paid to this material feature. Accordingly, the recipes from the French experience for the concrete stabilization layer are presented.

For such prepared substrate the choice of material parameters and properties of concrete mixtures for concrete slabs for the concrete class in the strength of 10 to 35 MPa was presented.

Keywords

Industrial flooring, concrete floors, stabilization, concrete mixes, material properties.

Introduction

The paper analyzes the ways to determine industrial properties and technologies in floor construction. The requirements for the preparation of soil under the floor are discussed. The requirements to be met in the production, development and configuration of the concrete equipment are listed.

The industrial flooring needs to provide a surface ready to withstand loads and forces generated by vehicles. At the same time, the floor should provide safety and comfort. There are two typical structural concepts in industrial floorings: (a) concrete flooring and (b) resin flooring. They are shown in Figure 1.

Exposure of flooring material to the traffic generated load requires optimization of engineering features, thickness and mechanical properties of individual flooring layers. Industrial floorings shall be designed with consideration of soil properties and assumed loads. This brings about the following aspects to be explored during design of industrial floorings:

- specification of mechanical qualities of materials used to make individual layers and their thickness;
- selection of soil that does not deform as deformations can cause flooring damage.

The properly made industrial flooring should include the following layers:

- soil — homogeneous and densified,
- undercoat — bearing layer,
- processed concrete plate.

Proper and long-term functioning of flooring requires making three interacting layers. For low traffic, making a single layer coating is sufficient. In this case, the concrete surface is laid directly on the soil. Higher resistance floorings require using proper materials having elevated standards of undercoat layer bending resistance. In this case, it is necessary to make an undercoat layer of reinforced

DOI: 10.23968/2500-0055-2017-2-4-48-55

concrete having steel rods (OD 3–8 mm) with 20–30 cm spacing of rebars or mesh.

The industrial flooring type depends on the intended use of the facility designed or on the processing technology. The flooring thickness needs to be determined in the same manner as the road surface (Potrzebowski, 1998; Rajczyk, 2013; Rajczyk and Kosin, 2011; Wolski, 1996).

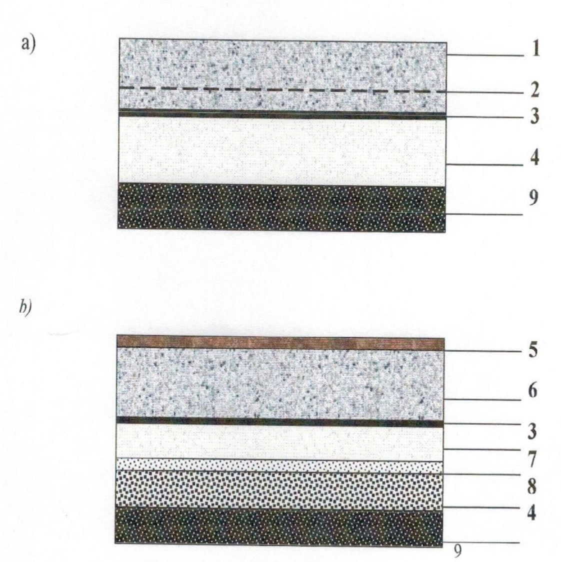

Figure 1. Typical structural concepts in industrial flooring: (a) concrete flooring, (b) resin flooring (Czarnecki and Rydz, 1995, 1998)

Structural concrete solutions in industrial floorings require considering several basic factors which influence resistivity, durability and safety. They include the following:

- the type and magnitude of load,
- the soil load bearing capacity,
- the properties of material to develop individual layers,
- the process chosen and its quality (Rajczyk, 2013; Rajczyk and Kosin, 2011; Rajczyk et al., 2016).

The thickness of the bearing layer can be calculated. The requirements depend on the actual load and the calculations are made using theoretical recommendations and equations of Hetenyi, Westergaard and Eisenmann. The recommendations on selecting concrete flooring are listed in Table 1.

Modern industrial, storing and transporting technologies requirements (supermarket, production shop, warehouse) indicate that the potential flooring needs to meet the requirements depending on resistance to traffic, abrasion and impact. It also shall have high water-proof qualities, evenness and be easily cleaned. The modern surface needs to provide faultless performance without repairs and renovations within decades.

Undercoat and soil layer

The industrial surface structure, which needs to bear extremely high loads (forklifts of several dozens of tons of lifting capacity and similar concentrated loads) requires the undercoat and foundation.

Soil layer

The soil foundation consists of the original soil under the bearing structure. It can have both natural and improved surface; it can be located directly under the concrete surface, or underpin the undercoat. The soil layer needs to be properly densified.

Table 1. Recommendations on selecting concrete flooring regarding operational conditions (based on ACI — 302/89) (Rolla, 1983)

Operational conditions	Facility type	Concrete class	Flooring type	Flooring category
Low pedestrian traffic	Residential buildings	B20	Troweling	I
Intense pedestrian traffic	Public buildings	B22,5	Troweling + possible slip resistant layer	II
Intense pedestrian traffic + rubber wheel vehicles	Internal warehouses, access roads	B25	Superficial hardening (troweling)	III
Intense pedestrian traffic + rubber wheel vehicles + light vehicles	Internal warehouses, access roads	B28	Superficial hardening (troweling)	IV
Vehicles traffic including steel wheel vehicles	Industrial facilities, warehouses	B30	Superficial hardening, hard metallic or mineral fillings in the superficial layer	V
Vehicles traffic including steel wheel vehicles + impact load	Industrial facilities	B35 (undercoat B25)	According to the special project	VI
Pedestrian traffic + rubber wheel vehicles + light vehicles + vehicles including steel wheel vehicles	Cooling chambers/freezers, or flooring laid on the old undercoat	B35	According to the special project + min. thickness of 75 mm	VII

It is considered that the surface should rest on strong underlying soil. Only in this situation proper durability can be guaranteed. The soil needs to be protected against ingress of excessive humidity and from negative impact of frost.

General methods of soil stabilization can be divided into the following:

- mechanical stabilization involving application of optimized mixtures featuring no stabilizers, which is obtained through the following: densification (decreasing internal soil porosity), dehydration and maintenance of stable humidity, and mixing of several types of soil together,
- physical stabilization using stabilizers, such as: portland cement or cement emulsions,
- chemical stabilization involving ionization, polymerization or oxidation.

Designing heavily loaded industrial floorings needs to be preceded with geotechnical research in order to confirm the soil load bearing capacity. Unstable soils may need reinforcement. Basic soil parameters are determined under laboratory conditions. The Table below lists the values of *E* modules, internal angles friction *ϕ* and consistency *c* as functions of the soil humidity expressed in percentage of liquidity limit.

Prior to the development of an undercoat layer, it is important to ensure that the soil has proper stabilization. Most often the soil is stabilized through mechanical densification. Among the methods used, the most popular involve rolling, compacting and vibrating.

Under normal conditions, soil particles are loose featuring empty spaces filled with air or water. Densification involves compressing solid particles and maximum elimination of free space. The method chosen depends on the type of soil, its humidity and thicknesses of design layers. Each method (rolling, vibrating, compacting) requires specific equipment and machinery. Cohesive soils need to be vibrated and compacted, or vibrated and rolled. Loose soils (sand and gravel) require using the vibrating technique as the most efficient. Densification should be performed with vibrating plates (regular and/or trailing) and vibratory rollers.

Concrete bearing plate

The undercoat has a task to create a hard layer underneath the surface. The undercoat needs to form homogeneous support for the concrete plate. The undercoat thickness is defined accounting for the following factors:

- soil type,
- traffic intensity,
- material used.

The undercoat is required to:

- provide strong support under the concrete plate,
- improve soil bearing capacity,
- decrease plates cracking rate.

The undercoat can be composed of a mechanically stabilized aggregate, soil stabilized using cement or applying a lean concrete layer.

The 10-cm thick undercoat can be made of a mechanically stabilized aggregate, or soil stabilized with cement. In case operations involve applying extremely high loads it is recommended to develop a lean concrete undercoat.

Table 2. Properties of soil as a function of its humidity (Rolla, 1985)

Soil type	Soil properties	Relative humidity (w/w1)						
		0.6	0.65	0.7	0.75	0.8	0.85	0.9
Thick sand, sand and gravel mix	*E* [MPa] *ϕ* [degrees]	130 43	130 43	130 43	130 43	130 43	130 43	130 43
Medium-thick sand	*E* [MPa] *ϕ* [degrees]	120 40	120 40	120 40	120 40	120 40	120 40	120 40
Fine sand	*E* [MPa] *ϕ* [degrees]	100 38	100 38	100 38	100 38	100 38	100 38	100 38
Dusty sand	*E* [MPa] *ϕ* [degrees]	50 36	50 36	50 36	50 36	50 36	50 36	50 36
Clay and thick sand	*E* [MPa] *ϕ* [degrees]	60 40	60 40	60 40	60 40	60 40	60 40	60 40
Clay sand	*E* [MPa] *ϕ* [degrees] *C* [kPa]	45 35 12	42 35 11	39 34 10	37 34 9	35 33 8	- - -	- - -
Dust, clay, loam	*E* [MPa] *ϕ* [degrees] *C* [kPa]	60 24 32	42 21 26	34 18 19	28 15 15	24 13 10	21 11 7	20 10 5

DOI: 10.23968/2500-0055-2017-2-4-48-55

Table 3. Examples of lean concrete types used at French construction sites (Rolla, 1983)

Ingredient	Unit	Construction site		
		I	II	III
Aggregate				
0–2.5 mm	kg	-	305	-
0–5 mm	kg	786	545	770
0–20 mm	kg	632	655	640
0–40 mm	kg	632	505	640
Cement 325 or 400	kg	160	160	160
Fly-ash	kg	70	50	70
Water	l	160	165	190
Plasticizer (% cement)	%	0.5	0.5	0.5
Aerator (% cement)	%	0.075	0.15	0.075

Lean concrete composition should be selected with regard to high resistance standards and low shrinkage. The disadvantage of such solution is that undercoat cracks can propagate to the main plate. In order to prevent developing these defects, it is necessary to extend the time of response of the undercoat and plate to mechanical deformation paying major attention to make the undercoat smooth and levelled promptly responding to shrinkage joints of the plate.

Examples of lean concrete used at French construction sites are shown in Table 3.

Shrinkage joints do not appear when the undercoat is made upon the sand surface stabilized with cement or an aggregate with cement. The cement content in the aggregate undercoat is 3.5% and the aggregate content is dependent on the surface load; low content is used in natural gravel and sand mixes; high content is used in the full aggregate.

The influence of cement on stabilized sand resistance is shown in Figure 2.

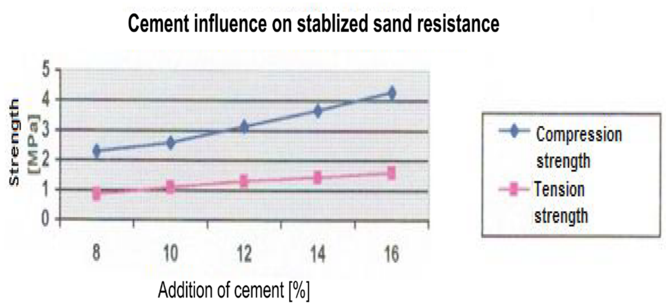

Figure 2. Cement influence on stabilized sand resistance (Stypulkowski, 1981)

Requirements to concrete mixes used to develop concrete surfaces (Polish experience): concrete composition.

Concrete, as a main ingredient, is an artificial stone having the resistance depending on numerous factors. The quality and composition of ingredients (cement, aggregate, water) are the most vital ones that influence performance and processing quality. The concrete resistance also depends on humidity and temperature, as well as on chemically invasive factors.

The mix composition involves cement, aggregate, water and additives in order to obtain design properties. The criteria for industrial concrete floorings are as follows:

- resistance — to comply with project assumptions,
- consistency — to ensure suitability of the selected application method,
- durability — depends on conditions of use.

The concrete composition should be established accounting for its functions. It involves aggregate granulation, selecting cement and individual ingredients in the required quantity, ensuring workability and consistence.

According to PN-88/B-06256, the minimum class of abrasion resistivity of concrete should be B25; the Boehme disc abrasiveness evaluated using electrolytically produced corundum powder B80 should not exceed the following values:

- 0.40 cm for the concrete grade selected for intense traffic,
- 0.50 cm for the concrete grade selected for abrasive movements.

The thickness of layers exposed to direct abrasion should be at least:

- 4 cm when laid on a concrete mix before hardening,
- 6 cm when laid on hardened concrete.

It is known that above thickness values can be decreased by 1.0…1.5 cm through adding steel fibers in the amount of 0.8…1.2 %.

The maximum amount of water allowed penetrating the abrasion resistant concrete is as follows:

- 5% of weight for the concrete exposed to constant or periodical humidity and intense traffic,

- 6% of weight for the concrete exposed to constant or periodical humidity and traffic of low and/or medium intensity.

The selection of ingredients for industrial flooring concrete requires paying attention to the following aspects:

- low shrinkage,
- B25 minimum class,
- water/concrete (w/c) lower than 0.5,
- proper workability.

According to PN-88/B-06250, concrete mix control implies estimation of the concentrated load strength distribution in each batch of concrete.

Cement grades are listed in Table 4 in relation to the concrete class. Table 5 shows the concrete classes and respective guaranteed resistance.

Table 4. Portland cement grade and concrete classes (Rowinski et al., 1980)

Cement grade	Concrete class	
	Structure	
	Monolithic	Prefabricated
250	Up to B10 inclusive	Up to B15 inclusive
350	B10–B15	B15–B35
400 and 450	B15–B35	B25–B40
500	B25	B35

Table 5. Concrete classes and the corresponding strength guaranteed by PN-88/B-06250 (Wolski, 1996)

Concrete class	R^G_b	
B7.5	7.5	11
B10	10	14
B15	15	20
B20	20	25
B25	25	32.5
B30	30	40
B35	35	45
B40	40	50
B50	50	60

Aggregate granulation

Aggregate makes approximately 75% of concrete, which means it influences considerably the concrete quality. Selection of aggregate has a great impact on cement consumption, workability, resistance and durability of concrete. Each specific concrete class requires different type and kind of aggregate. Granulation provides the mix impermeability and consistence. Relations between aggregate and concrete classes are shown in Table 6.

B30 concrete needs to be based on natural aggregate with max. 16 mm granulation (up to 8mm is recommended) compliant with PN-83/B-06712.

Resistant concrete is based on thick aggregate described in Table 7.

Table 6. Aggregate type and its influence on the concrete class

Concrete class	Type and kind of aggregate
Higher than B25	Crushed stones, natural fine aggregate, natural thick aggregate, natural thick aggregate in the volume not exceeding 30% of the general quantity over 2 mm
Lower than B25	Natural thick aggregate, 20 grade gravel, natural fine aggregate
Lower than B15	As above but grade 10
Lower than B10	Sand and gravel mixes, natural fine aggregate

Thick natural aggregate is made of crushed volcanic or metamorphic rocks, compliant with PN-83/B-06712 for crushed fieldstone grade 30 having the following parameters:

- abrasion resistance — min. 120 MPa
- water absorption — below 1%,
- Boehme disc abrasiveness — max. 0.35 cm (corundum B80),
- granulation — according to the Table.

Table 7. Thick aggregate selection criteria to make abrasion-resistant concrete (Potrzebowski, 1998)

no.	Abrasive layer thickness [mm]	Largest approved granulation [mm]	Thick aggregate fraction	
			Fraction [mm]	Content in thick aggregate [%]
1	<10	4	2–4	100
2	10 to 20	8	4–8	100
3	20 to 30	16	4–16	100
4	>30	16	2–4	25
			4–16	75

The granulation given by S. Rolla (1983, 1985) applied to regular types of concrete for concrete undercoat and lean concrete is presented in charts. Aggregate granulation can vary within the curves. The curve contained in this area can be a kinked one indicating the presence of certain intermediate fractions.

Forming conditions: mix workability and consistence

Consistence and workability are the features which define concrete mix properties and ability to fill the molds and keep the shape after the molds are disassembled.

The concrete mix consistence is examined using the Ve-Be or cone slump method. The first one is recommended for plastic and dense mixes, the second one works better with liquid mixes.

Both methods have been standardized and described in PN-88/B-06250.

Recommendations on workability and consistence are given in Table 8.

DOI: 10.23968/2500-0055-2017-2-4-48-55

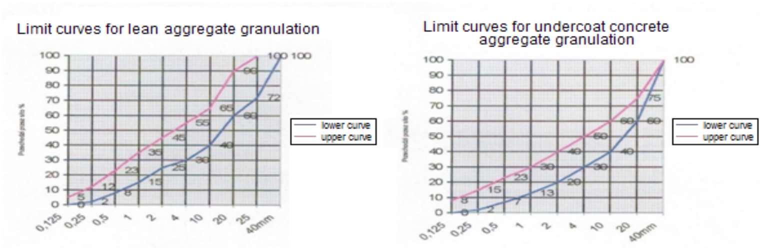

Figure 3. Limit curves for lean and undercoat concrete aggregate granulation

Table 8. Mix consistence recommendations according to PN-88/B-06250 (Rowinski, 1978)

Concrete mix consistence	Consistence symbol	Consistence indicator	
		Ve-Be [s]	Cone slump [cm]
Humid	K-1	Exceeding 30	N/A
Dense/plastic	K-2	16–30	N/A
Plastic	K-3	8–16	2–8
Semi-liquid	K-4	5–8 not recommended	8–12
Liquid	K-5	N/A	Exceeding 12

Table 9. Concrete mix consistence regarding the structure and densification method. PN-88/B-06250 (Rowinski, 1978)

Consistence	Type of construction and method of compacting
Humid	Prefabricates subject to vibration densification at frequency 100 Hz. Prefabricates subject to vibration compaction. Manually applied non-construction concretes
Dense/plastic	Concrete and reinforced concrete, mechanically densified. Concrete and reinforced concrete construction, prefabricated construction, surface vibration densification or with simple vibration probes. Manually densified non-construction concretes
Plastic	Regular concrete and reinforced concrete structures, densified with vibration probes or attached vibrators. Concrete and reinforced concrete structures, densified with vibration probes or attached vibrators and shaped in thin vertical walls
Liquid and semi-liquid	Construction concretes, manually densified, or self-densified.

Concrete consistence provides a great impact on cement consumption, so it needs to be limited by the densest concrete mixes having plasticizers.

Influence of fibers on concrete workability

In terms of workability, introduction of fibers reduces the quality of concrete by one class. Therefore, achieving K3/K4 requires using a plasticizer and achieving K4/K5 requires using a superplasticizer.

K3/K4 consistence is recommended when the fibers are added into the concrete delivered in trucks. This corresponds to the Abrams cone slump of 4–6 cm after the fibers are added; the maximum value of 10 cm can be reached before adding the fibers.

If the concrete is pumped to the work area, it should have consistence of K4/K5 which corresponds to the Abrams cone slump of 8–10 cm after the fibers are added and 12–14 cm before the fibers are introduced.

Cement volume and w/c ratio

Concrete composition involves such basic indicator as cement-water (c/w) which constitutes a cement to water weight ratio. The lower the water content (above a certain level), the more resistant the concrete is.

The relation between conditions of application and concrete mix is expressed through the smallest acceptable cement volume as shown in PN-88/B-06250. The parameters are listed in Table 10.

Table 10. Minimum cement volume with regard to conditions of application [PN-88/B-06250] (Rowinski, 1978)

Structures and operating conditions	Minimum cement volume kg/m^3 for:	
	Structures	
	Reinforced	Regular
Structures not exposed to weather conditions	0.4z	0.35z
Structures exposed to weather conditions	0.5z	0.45z
Structures exposed to constant water penetration and frost	0.5z	0.50z

The highest cement volume in kg/m3 should not exceed:

550 — for medium compression resistant concretes — higher or equal to 40 MPa,

450 — for other types of concrete.

In road concrete, it should not exceed:

400 — for the surface concrete,

250 — for the undercoat concrete,

150 — for lean undercoat concrete.

Frost resistance

The concrete exposed to humidity and frost should feature the following:

- average resistance: minimum 15 MPa,
- frost resistance expressed with maximum 5% erosion (shown in samples),
- frost resistance defined with compression resistance decrease: max 20 %.

Moreover, the concrete exposed to direct influence of liquids needs to be water-proof with pressure of at least 0.7 MPa in at least four samples.

Conclusion

The article discusses recommendations for selecting processes and materials used depending on the floor category and the application purpose. For the purpose of constructing industrial concrete floors based on the experience of Polish construction companies, recommendations are made for developing substructures under the industrial surface in line with characteristics of seven types of soil, showing the influence of the cement stabilizer on the mechanical properties of sand. Solution examples to make concrete mixes for concrete foundation using the French experience are given. Selection of grading aggregate for concrete depending on the class of concrete is presented on the basis of Polish experience guidelines. General terms of producing and molding concrete mixes to develop industrial concrete floors are discussed.

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