Design of Heavy Duty Concrete Floor Slabs on Grade

An Online Continuing Education Course for Engineers

Course Number: C-3024

Credit: 3 Hours / 3 PDH / 3 CPD

Design of Heavy Duty Concrete Floor Slabs on Grade

Vincent D. Reynolds, P.E., M.B.A.

Chapter 1 – Introduction

1-1 Purpose

This course prescribes the criteria for the design of concrete floor slabs on grade for heavy loads in buildings such as warehouses include moving loads, stationary live loads, and wall loads.

1-2. Definitions

The following definitions have been adopted for this course:

a. Slab on grade. Concrete slab supported directly on foundation soil.
b. Light loads. Loads that consist of (comparable) forklift axle load of 5 kips or less and stationary live loads less than 400 pounds per square foot.
c. Heavy loads. Loads that consist of any one of the following: moving live loads exceeding a forklift axle load of 5 kips, stationary live loads exceeding 400 pounds per square foot, and concentrated wall loads exceeding 600 pounds per linear foot.
d. Wall load. Concentrated loads imposed by walls or partitions.
e. Dead load. All the materials composing the permanent structure, including permanent wall loads and all equipment that is fixed in position.
f. Live load—loads imposed by the use and occupancy of the structure.
    (1) Moving live load. Loads imposed by vehicular traffic such as forklift trucks.
    (2) Stationary live load. Loads imposed by movable items such as stored materials.
g. Vibratory loads. Dynamic and/or oscillatory loading of significant magnitude.
h. Design load. The effects of stationary live, dead, and wall loads and moving live loads. Dead loads of floor slabs on grade are ignored.
i. Special soils. Soils that exhibit undesirable properties for construction uses such as high compressibility or swell potential.
j. Non-reinforced slab. Concrete slab resting on grade containing minimal distributed steel, usually of welded wire fabric (WWF), to limit cracking width due to shrinkage and temperature change.
k. Reinforced slab. Concrete slab resting on grade containing steel reinforcement, which consists of either a welded wire fabric or deformed reinforcing steel bars.

1-3. Basic Considerations

Concrete floor slabs on grade are subjected to a variety of loads and loading conditions. The design procedure includes determining slab thickness based on moving live loads and then checking the adequacy of slab thickness for stationary live load. The design procedure separately includes determining the thickness of slab under wall load. The entire design procedure is based on a working stress concept. Stresses induced by temperature gradients and other environmental effects are considered by the assignment of working stresses. Working stresses have been established empirically over the years based on experience gained in roadway and airfield pavement performance data.

Chapter 2 - Basis of Floor Slab on Grade Design

2-1. Stresses

The structural design of a concrete floor slab on grade is primarily controlled by the stresses caused by moving live loads and, in some cases, the stationary loads. Stresses in floor slabs on grade resulting from vehicular loads are a function of floor slab thickness, vehicle weight, and weight distribution, vehicle wheel or track configuration, modulus of elasticity and Poisson's ratio of concrete, and modulus of subgrade reaction of supporting material. The volume of traffic during the design life is important for fatigue considerations. The floor slab design procedure presented herein is based on limiting the critical tensile stresses produced within the slab by the vehicle loading. Correlation studies between theory, small-scale model studies, and full-scale accelerated traffic tests have shown that maximum tensile stresses in floor slabs will occur when vehicle wheels are tangent to a free edge. Stresses for the condition of the vehicle wheels tangent to an interior joint, where the two slabs are tied together, are less severe than a free edge because of the load transfer across the two adjacent slabs. In the case of floor slabs, the design can be based on the control of stress at interior joints. Exceptions to this assumption for interior joint loading occur when a wheel is placed at the edge of a doorway or near a free edge at a wall.

2-2 Vehicle-Imposed Loads

For determining floor slab design requirements, vehicles have been divided into three general classifications: forklift trucks, other pneumatic, and solid tired vehicles, and tracked vehicles. The relative severity of any given load within any of the three classifications is determined by establishing a relationship between the load in question and a standard loading. Floor slab design requirements are then established in terms of the standard load. Other stresses, such as restraint stresses resulting from thermal expansion and contraction of the concrete slab, and warping stresses resulting from moisture and temperature gradients within the slab, due to their cyclic nature, will, at times, be added to the moving live load stresses. Provision for these stresses that are not induced by wheel loads is made by safety factors developed empirically from full- scale accelerated traffic tests and from the observed performance of pavements under actual service conditions.

2-3. Stationary Live Loads

The maximum allowable stationary live load is limited by both the positive bending moment stress under the load and the negative bending moment stresses occurring at some distance from the load.

a. Positive bending moments. Stresses due to positive bending moments are relatively simple to compute by using Westergaard's analysis[1] of elastically supported plates. An appropriate safety factor is applied to determine allowable stresses due to these loads because environmentally imposed stresses must also be accounted for when considering stationary loads.
b. Negative bending moments. The effect of negative bending stress is somewhat more difficult to determine. A slab on an elastic subgrade will deform under loading somewhat like a damped sine curve where the amplitude, or deformation, of successive cycles at a distance from the loading position decreases asymptotically to zero. Thus, there exists some critical aisle width where the damped sine curves from parallel loading areas are in phase and additive. In this situation, the negative bending moment stresses will become significant and must be considered. Therefore, allowable stationary live loads were established to include the effects of negative moment bending stresses. These calculations are reflected in the tabulated values of allowable stationary live loads.

2-4. Wall Loads

There are situations where a wall is placed on a new thickened slab or on an existing concrete floor slab on grade. Walls weigh from several hundred to several thousand pounds per linear foot. The design table used for determining thicknesses required under walls is developed by Staab (see Biblio) and is based on the theory of a beam on a liquid foundation subjected to concentrated loads. Three loading conditions are considered: loads at the center of the slab, loads at a joint, and loads at the edge of the slab. The widths of thickened slabs are developed together with the recommended transitions.

---

[1] Westergaards analysis is actually for plates on a liquid foundation, sometimes called a Winkler foundation. There is a distinct difference between the structural behavior of plates on a liquid and on an elastic foundation. In many textbooks, the term "beam on elastic foundation" Is actually "beam on liquid foundation."

Chapter 3 - Determination of Floor Slab Requirements

3-1. Vehicular Loads

- The following traffic data are required to determine the floor slab thickness requirements:
- Types of vehicles
- Traffic volume by vehicle type
- Wheel loads, including the maximum single-axle and tandem-axle loading for trucks, forklift trucks, and tracked vehicles
- The average daily volume of traffic (ADV), which, in turn, determines the total traffic volume anticipated during the design life of the floor slab.

For floor slabs, the magnitude of the axle load is of far greater importance than the gross weight. Axle spacings generally are large enough so that there is little or no interaction between axles. Forklift truck traffic is expressed in terms of maximum axle load. Under maximum load conditions, weight carried by the drive axle of a forklift truck is normally 87 to 94 percent of the total gross weight of the loaded vehicle.

For tracked vehicles, the gross weight is evenly divided between two tracks, and the severity of the load can easily be expressed in terms of gross weight. For moving live loads, axle loading is far more important than the number of load repetitions. Full-scale experiments have shown that changes as little as 10 percent in the magnitude of axle loading are equivalent to changes of 300 to 400 percent in the number of load repetitions.

3-2. Traffic Distribution

To aid in evaluating traffic for the purposes of floor slab design, typical forklift trucks can be divided into six categories as follows:

Forklift Truck Category	Forklift Truck Maximum Axle Load, kips	Maximum Load Capacity, kips
I	5 to 10	2 to 4
II	10 to 15	4 to 6
III	15 to 25	6 to 10
IV	25 to 36	10 to 16
V	36 to 43	16 to 20
VI	43 to 120	20 to 52

Vehicles other than forklift trucks, such as conventional trucks, can be evaluated by considering each axle as one forklift truck axle of approximate weight. For example, a three-axle truck with axle loads of 6, 14, and 14 kips will be considered as three forklift truck axles, one in Category I and two in Category II. (Note that design of lightly loaded slabs for vehicles with axle loads less than 5 kips is outside the scope of this course.)

Forklift Truck Category	Tracked Vehicles Maximum Gross Weight, kips
I	less than 40
II	40 to 60
III	60 to 90
IV	90 to 120

Categories for tracked vehicles may be substituted for the same category for forklift trucks.

3-3. Stationary Live Loads

Floor slabs on grade should have adequate structural live loads. Since floor slabs are designed for moving live loads, the design should be checked for stationary live loading conditions. Table 3-1 lists values for maximum stationary live loads on floor slabs. For very heavy stationary live loads, the floor slab thicknesses listed in table 3-1 will control the design. Table 3-1 was prepared using the equation

$$w = 257.876s\sqrt{\frac{kh}{E}}$$

(eq 3-1)

where:

w = the maximum allowable distributed stationary live load, pounds per square foot

s = the allowable extreme fiber stress in tension excluding shrinkage stress and is assumed to be equal to one-half the normal 28-day concrete flexural strength, pounds per square inch

k = the modulus of subgrade reaction, pounds per cubic inch

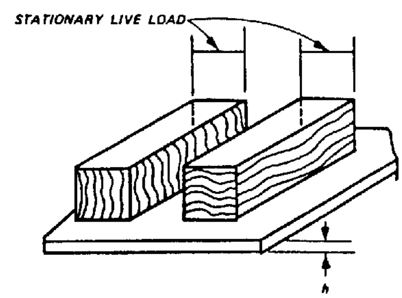
h = the slab thickness, inches

E= the modulus of elasticity for the slab (assumed to equal 4.0 x 106 pounds per square inch)

The above equation may be used to find allowable loads for combinations of values of s, h, and knot given in table 3-1. Further safety may be obtained by reducing allowable extreme fiber stress to a smaller percentage of the concrete flexural strength, as have been presented by Grieb and Werner, Waddell, and Hammitt (see Biblio). The selection of the modulus of subgrade reaction for use in table 3-1 is discussed in later in the course. The design should be examined for the possibility of differential settlements, which could result from non-uniform subgrade support. Also, consideration of the effects of overall long-term settlement for stationary live loads may be necessary for compressible soils.

Table 3-1. Maximum allowable stationary live load

Slab Thickness		Stationary Live Load w in lb./ft^2 for These Flexural Strengths of Concrete		
Inches	550 lb.	600 lb.	650 lb.	700 lb.
h	in2	in2	in2	in2
6	868	947	1,026	1,105
7	938	1,023	1,109	1,194
8	1,003	1,094	1,185	1,276
9	1,064	1,160	1,257	1,354
10	1,121	1,223	1,325	1,427
11	1,176	1,283	1,390	1,497
12	1,228	1,340	1,452	1,563
14	1,326	1,447	1,568	1,689
16	1,418	1,547	1,676	1,805
18	1,504	1,641	1,778	1,915
20	1,586	1,730	1,874	2,018



NOTE: Stationary live loads tabulated above are based on a modulus of subgrade reaction (k) of 100 lb./in^3. Maximum allowable stationary live loads for other moduli of subgrade reaction will be computed by multiplying the above —tabulated loads by a constant factor. Constants for other subgrade moduli are tabulated below:

Modulus of Subgrade reacti	...0	200	300
Constant factor	...)	1.4	1.7

For other modulus o... y be found from the expression:

3-4. Wall Loads

Floor slabs on grade sh... ables 3-2 and 3-3 show the minimum thic... he equations used to compute these values ar... uired for wall loads exceeds that required fo... will be thickened in accordance with figure 3... was considered by using a reduced allowable tensile stress o... which was computed using the equation: