Designing Concrete Slabs for Heavy Load Conditions

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Module 1: Introduction

Learning Objectives

By the end of this section, you will be able to:

- **Identify** the specific loading thresholds that differentiate light and heavy floor slab design.
- **Define** the core components of a design load, including moving, stationary, and wall load types.
- **Evaluate** the fundamental design considerations for concrete slabs on grade using the working stress concept.

Executive Summary: This module establishes the criteria and definitions for designing concrete floor slabs on grade subjected to heavy loads within military and industrial warehouse environments. The methodology relies on a working stress concept derived from empirical performance data, requiring engineers to determine slab thickness by analyzing moving live loads first, then verifying adequacy for stationary and wall loads.

Purpose of Slab Design

This course prescribes the criteria for designing concrete floor slabs on grade specifically for **heavy loads**. While applicable to all elements of military construction, these principles are standard for any high-capacity building, such as a warehouse. The primary load types addressed include:

- **Moving loads** (e.g., forklifts).
- **Stationary live loads** (e.g., pallet storage).
- **Wall loads** (e.g., partitions or structural walls).

Scope of Application

Designers must understand the theoretical concepts and practical applications that form the basis of design procedures for heavy loading scenarios. This includes the transition from basic soil mechanics to finalized slab geometry.

Design Definitions

To ensure consistency in application, the following technical definitions are adopted for this course:

General Slab Components

- **Slab on grade:** A concrete slab supported directly by foundation soil.
- **Nonreinforced slab:** A slab containing minimal distributed steel, typically **welded wire fabric (WWF)**, intended only to limit crack widths caused by shrinkage and temperature fluctuations.
- **Reinforced slab:** A slab containing steel reinforcement consisting of either WWF or **deformed reinforcing steel bars** to enhance structural capacity.

Load Classifications

- **Light loads:** Loads featuring a forklift axle load of **5 kips or less** and stationary live loads under **400 pounds per square foot (psf)**.
- **Heavy loads:** Any load exceeding one of the following thresholds:
    - Moving live loads > **5 kips** (forklift axle load).
    - Stationary live loads > **400 psf**.
    - Concentrated wall loads > **600 pounds per linear foot (plf)**.

Specific Load Types

- **Dead load:** The weight of all materials composing the permanent structure, including fixed equipment and permanent wall loads. **Note:** Dead loads of the floor slabs themselves are ignored in these calculations.
- **Live load:** Loads imposed by occupancy, further divided into:
    - **Moving live load:** Loads from vehicular traffic, primarily forklift trucks.
    - **Stationary live load:** Loads from movable items, such as stored materials.
- **Wall load:** Concentrated loads imposed by walls or partitions.
- **Vibratory loads:** Dynamic or oscillatory loading of a significant magnitude.
- **Design load:** The combined effects of stationary live, dead, wall, and moving live loads.

Subgrade Considerations

- **Special soils:** Soils that exhibit undesirable engineering properties, such as **high compressibility** or **swell potential**.

Design Fundamentals

Concrete floor slabs on grade must withstand various complex loading conditions. Engineers should follow this specific workflow:

1. **Determine** slab thickness based on **moving live loads**.
2. **Check** the adequacy of that thickness for **stationary live loads**.
3. **Determine** the required thickness for **wall loads** as a separate calculation.

💡 **Design Tip:** The entire procedure utilizes the **working stress concept**. Environmental effects, such as stresses induced by temperature gradients, are accounted for through the assignment of these working stresses. These values are not merely theoretical; they are established empirically from roadway and airfield pavement performance data.

Checkpoint Quiz

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1. **A project requires a slab to support a forklift with an 8-kip axle load and stationary storage of 350 psf. How should this loading be classified?**
   a) Light Load
   b) Heavy Load
   c) Special Soil Load
   d) Vibratory Load

Answer: (b). Although the stationary load is under the 400 psf threshold, the moving live load exceeds the 5-kip forklift axle load limit, which automatically classifies it as a heavy load.

2. **In the design of concrete floor slabs on grade for heavy loads, which of the following is true regarding dead loads?**
   a) The dead load of the concrete slab itself must be added to the design load.
   b) Dead loads include only the weight of fixed equipment.
   c) Dead loads of the floor slabs on grade are ignored in the design calculation.
   d) Dead loads are only considered if the soil is classified as a "special soil."

Answer: (c). While the dead load of the permanent structure and fixed equipment is part of the design load, the self-weight of the slab on grade is specifically excluded.

3. **According to the standard design procedure, what is the first step in determining slab thickness?**
   a) Analyze stationary live loads.
   b) Evaluate the concentrated wall loads.
   c) Calculate thickness based on moving live loads.
   d) Determine the reinforcement ratio for WWF.

Answer: (c). The prescribed workflow requires determining thickness based on moving live loads first, followed by a check for stationary loads and a separate check for wall loads.

Module 2: Basis Of Floor Slab on Grade Design

Learning Objectives

By the end of this section, you will be able to:

- **Identify** the primary variables that control structural stresses in concrete floor slabs on grade.
- **Evaluate** the impact of positive and negative bending moments on allowable stationary live loads.
- **Select** the appropriate loading conditions for calculating required slab thicknesses under wall loads.

Executive Summary: The structural integrity of a concrete slab on grade is primarily governed by tensile stresses from moving live loads and, in specific cases, stationary and environmental factors. Design requirements are standardized against specific vehicle classifications and account for complex bending moments and subgrade reactions to ensure performance under both interior and edge loading conditions.

Structural Stresses

The design of a concrete floor slab on grade is primarily controlled by stresses from moving live loads and stationary loads.

Variables Influencing Vehicular Stress

Stresses resulting from vehicular loads are a function of the following parameters:

- **Slab Characteristics:** Floor slab thickness, modulus of elasticity, and Poisson's ratio of concrete.
- **Vehicle Configuration:** Total weight, weight distribution, and wheel or track configuration.
- **Support Conditions:** Modulus of subgrade reaction of the supporting material.

Traffic and Fatigue

- **Traffic Volume:** The total volume of traffic anticipated during the design life is critical for fatigue considerations.
- **Stress Limits:** The procedure focuses on limiting critical tensile stresses produced by vehicle loading.
- **Critical Loading Position:** Maximum tensile stresses generally occur when vehicle wheels are tangent to a **free edge**. Stresses at interior joints are typically less severe due to load transfer between tied slabs.

⚠️ **Safety Constraint:** Design assumptions for interior joint loading are invalidated if a wheel is placed at an edge at a doorway or near a free edge at a wall.

Vehicle-Imposed Loads

Military vehicles are divided into three general classifications to determine design requirements:

1. **Forklift trucks**.
2. **Other pneumatic and solid tired vehicles**.
3. **Tracked vehicles**.

Standardization Process

The relative severity of any given load is established by its relationship to a **standard loading**. All floor slab design requirements are then expressed in terms of this standard load.

Restraint and Environmental Stresses

- **Restraint Stresses:** Caused by thermal expansion and contraction of the concrete slab.
- **Warping Stresses:** Result from moisture and temperature gradients within the slab.
- **Safety Factors:** Because these stresses are cyclic and can add to live load stresses, they are accounted for by safety factors developed from full-scale accelerated traffic tests and observed performance.

Stationary Live Loads

The maximum allowable stationary live load is limited by two distinct stress types:

- **Positive Bending Moment:** Stress occurring directly under the load.
- **Negative Bending Moment:** Stress occurring at some distance from the load.

Stress Analysis

- **Positive Moments:** Computed using **Westergaard's analysis** of elastically supported plates. Safety factors are applied to account for environmentally imposed stresses.
- **Negative Moments:** More difficult to determine. A slab on an elastic subgrade deforms in a **damped sine curve**.
- **Critical Aisle Width:** If parallel loading areas are positioned such that their damped sine curves are in phase and additive, negative bending moment stresses become significant.

Purchase this course to see the remainder of the technical materials.