Study on Continuously Supported Concrete Slab-on-Grade

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This is to certify that the thesis prepared by Tsige G/Hiwot, entitled: ***Study on Continuously Supported Concrete Slab-On-Grade*** and submitted in partial fulfillment of requirements for the degree of Degree of Masters of Science compiles with the regulations of the University and meets the accepted standards with respect to originality and quality.

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ABSTRACT

This thesis deals with the study of continuously supported slabs-on-grade for residential buildings supported by soil. If we consider our country, Ethiopia, due to mass construction of residential buildings, the thickness of slab and area of reinforcement of the ground floor slab is not from the result of detail structural design, as a result the slab thickness and reinforcement bars are not uniform for same kind of slab on grade. In effect, if detail design is carried out for each slab-on-grade, it can be minimized to optimum design, which will have a significant difference to the total cost of the building according to the project.

Therefore, this thesis will help to study a continuously supported concrete floor slab at grade. Concrete and reinforcement are the two primary expenses in cast-in-place concrete floor construction. Hence, by minimizing the thickness and area of reinforcement of the ground floor slab, the cost of construction can be significantly minimized. To emphasize and verify this study, a field test is conducted on four samples at Bole-Ayat Condominium Site. The result confirmed that by minimizing ground floor slab thickness and area of reinforcement, the cost of the construction can be significantly reduced.

1) INTRODUCTION

Ground-supported slabs, also called slabs-on-ground or slabs-on-grade, which bear directly on a compacted ground (grade) with organic top soil removed. Slabs are important load bearing structural elements in house-building, in industrial and high-rise buildings. A slab supported by ground, whose main purpose is to support the applied loads by bearing on the ground.

A very high percentage of the total volume of concrete used for the construction of buildings is used for the realization of slabs, see Table 1.

Consequently, as slabs have an important impact on the total cost of the construction, optimal design is necessary.

Table 1: Structural elements in buildings (WIGHT, 2009)

Structural element or load bearing member	Percentage of total volume of concrete
Foundation and ground supported member	22%
Bearing Walls	4%
Columns	5%
Slabs (Elevated or Framed slabs)	59%
Others	10%
Total	**100%**

In our country, the continuously support slabs on grade is designed only for temperature and shrinkage resistance. The assumption made to design such slab is, since the ground floor slab rests on the ground directly, no need of designing for flexure, which means, no structural design is required. Nevertheless, minimum reinforcement in both directions is provided to prevent shrinkage and temperature of the slab, stress due to temperature variation and crushing of slab due to concentrated loads. Stress in slabs-on-grade results from both imposed loads and volume changes of the concrete.

The magnitude of stress on slab depends upon factors such as:

- The degree of continuity,
- Method of construction,
- Quality of construction, and
- Sub-grade strength, and uniformity,
- Magnitude and position of the loads.

In most cases, the effects of these factors can only be evaluated by making simplifying assumptions with respect to material properties and soil-structure interaction.

This study will help to significantly reduce the traditional construction cost of slab on ground, especially for mass construction of buildings such as condominium housing, since condominium ground floor slabs are 100mm thick and the reinforcing bars are Ø8c/c 200.

Concrete and reinforcement are the two primary expenses in cast-in-place concrete floor construction to consider throughout the design process. By reducing the thickness and area of reinforcement of the ground floor slab, the cost of construction all over the project can be significantly reduced.

Therefore, this thesis will give a clue on a continuously supported concrete slab-on-grade, to advance understand how the design of residential differ according to soil type, support condition, loading type and function of the building. Moreover, it shows using sample tests how can minimize currently used thickness and reinforcement detail (spacing and area of reinforcement bar).

A slab, continuously supported by ground, whose total loading when uniformly distributed would impart a pressure to the grade or soil that is less than 50 percent of the allowable bearing capacity thereof. There are, of course, exceptions such as where the soil is highly compressible and allowable bearing pressures are extremely low.

A slab supported by ground, whose main purpose is to support the applied loads by bearing on the ground and may have uniform or variable thickness. The slab may be unreinforced or reinforced with none pre-stressed reinforcement, fibers or post-tensioned tendons. The reinforcement may be provided to limit crack width resulting from shrinkage and temperature restraint and the applied loads. Reinforcement or wire mesh may be provided to minimize cracking due to shrinkage and temperature restraint, resist the applied loads and accommodate movements due to expansive soil volume changes.

2) OBJECTIVE

The objective of this thesis is to show how 6cm thick slab on grade and Φ4 or lower bar size reinforcement can work without any expected failure; Cracking, Curling or warping, Scaling, Dusting, Spalling, Crazing and Plastic shrinkage by conducting 4 (four) sample tests with reinforcement bar and without reinforcement bar and modeling the slab on Safe Sofware to support the result gotten from the test.

The slab thickness & reinforcement bar used currently is without undertaking detail design & without having any ground data since the slab on grade of residential building differ according to soil type, support condition, loading type and function of the building, which means currently in most buildings, factories & residences, the slab thickness used is 10cm thick and Φ8 reinforcement bar with 200 center to center spacing.

Therefore, this thesis will show how one can minimize the slab thickness from 10cm to 6cm and re bar size with its spacing from Φ 8 to Φ4 bar size center to center 300mm because concrete and reinforcement are the two primary expenses in concrete floor construction to be considered throughout the design process.

3) LITERATURE REVIEW

Review of classical design theories— Design methods for slabs-on-grade are based on theories originally developed for airport and highway pavements. *Westergaard* developed one of the first rigorous theories of structural behavior of rigid pavement. This theory considers a homogeneous, isotropic, and elastic slab resting on an ideal Sub-grade that exerts, at all points, a vertical reactive pressure proportional to slab deflection; known as a *Wikler sub-grade*. The Sub-grade acts as a linear spring with a proportionality constant 'k' with units of pressure (KN/m) [KPa]) per unit deformation [m]. The units are commonly abbreviated as KN/m^3. This constant is defined as the modulus of Sub-grade reaction *(Wester gaard 1923, 1925, 1926).*

In the 1930s, the structural behaviors of concrete pavement slabs were investigated at the *Arlington Virginia* Experimental Farm and at the *Iowa* State Engineering Experiment Station. Good agreement occurred between experiential stresses and those computed by the *Westergaard's* theory, as long as the slab remained continuously supported by the sub-grade. Corrections were required only for the *Westergaard* corner formula to account for the effects of slab curling and loss of contact with the sub-grade. Although choosing the modulus of Sub-grade reaction was essential for good agreement with respect to stresses, here remained ambiguity in the methods used to determine the correction coefficient.

Westergaard developed one of the first rigorous theories of structural behavior of rigid pavement in the ACI and he recommended a minimum of 0.15 percent reinforcement without testing for expansion of the concrete.

Two characteristic constants — the modulus of soil deformation and Poisson's ratio are typically used to evaluate the deformation response of such solids. Based on the concept of the Sub-grade as an elastic and isotropic solid, and assuming that the slab is of infinite extent but of finite thickness, *Burmister* proposed the layered-solid theory of structural behavior for rigid pavements (*Burmister*, 1943). He suggested basing the design on a criterion of limited deformation under load. Design procedures for rigid pavements based on this theory are not sufficiently developed for use in engineering practice. The lack of analogous solutions for slabs of finite extent, for example, edge and corner cases, is a particular deficiency. Other approaches based on the assumption of a thin elastic slab of infinite extent resting on an elastic, isotropic solid have been developed. The preceding theories are limited to behavior in the linear range where deflections are proportional to applied loads. Lösberg (Lösberg, 1978; Pichumani 1973) later proposed a strength theory based on the yield - line concept for ground - supported slabs, but the use of ultimate strength for slab-on-ground design is not common.

In the major part of this work, the analysis of bending of slab-on-grade on an elastic foundation is developed on the assumption that the reaction forces of the foundation are proportional at every point to the deflection of the slab at that point.

Though the early investigators thought chiefly of soil as the supporting medium, it was later found that there are other fields where the conditions of *Wikler's* assumption are much more rigorously satisfied. While the theory of slab on grade on elastic foundation holds rigidly. Its application to soil foundations should be regarded only as a practical approximation. The physical properties of soils are obviously of a much more complicated nature than that which could be accurately represented by such a simple mathematical relationship as the one assumed by *Wikler*. There are, however, some important points which can be brought up in supporting the application of this theory to soil foundations. Under certain conditions the elasticity of soil is undeniable; it can propagate sound waves, for instance. Also, the second, and most debated part of *Wikler's* assumption, is that the foundation deforms only along the portion directly under loading. It has, since A. Föppl's classical experiment, often been found to be true on a large variety of soils.

Winkler (1867) assumed the soil medium as a system of identical but mutually independent, closely spaced, discrete and linearly elastic springs. The ratio between contact pressure (P) at any given point, and settlement (y) produced by load application at that point, is named the coefficient of subgrade reaction, *K*s:

$$\mathrm{ks} = \frac{p}{y} \qquad (1)$$

In fact, in this model subsoil is replaced by fictitious springs whose stiffness equals to Ks.

However, the simplifying assumptions, which this approach is based on, cause some approximations.

One of the basic limitations of it lies in the fact that the model cannot transmit the shear stresses, which are derived from the lack of spring coupling. Also, linear stress-strain behavior is assumed.

The coefficient of subgrade reaction, Ks, identifies the characteristics of foundation supporting and has a dimension of force per length cubed.

Based on the concept of the Sub-grade as an elastic and isotropic solid and assuming that the slab is of infinite extent but of finite thickness, *Burmister* in 1943 proposed the layered-solid theory of structural behavior for rigid. He suggested that the design should be based on a criterion of limited deformation under load. However, the design procedures for rigid pavements based on this theory were never developed enough for use in engineering practice. The lack of analogous solutions for slabs of finite extent (edge and corner cases) was a particular deficiency. Other approaches based on the assumption of a thin elastic slab of infinite extent resting on an elastic and isotropic solid have been developed.

The design of ground-floor slabs has traditionally been based on *Westergaard*'s solution for slabs on ground. The solutions are available for point loading situated at different critical locations (corner load, internal load and edge load). According to these solutions the slab's thickness can be determined using maximum allowable tensile stresses. Plastic methods are also available in which slab is designed as reinforced concrete section in ultimate limit state.

Normally only "hand calculation" based on theoretical solution of *Westergaard* are made. Design flow is such that in ultimate limit state the slab's thickness and reinforcement is determined and in service limit state concrete cracking is checked. Both of these analyses are made for point loading conditions. The stresses generated by environmental conditions (due to restraint to temperature and moisture change) are not clearly defined and design procedures for these indirect stresses are insufficient.

The Portland Cement Association suggests one-half the wire mesh crossing the construction joints should be cut accurately on the joint line. The warping effect will be aggravated if excess water is used in the concrete and it is forced to migrate in one direction to top or bottom of the slab, for example, when the slab has been cast on a vapor barrier or on a very dry sub-grade. For very long slabs, continuous reinforcement, approximately 0.006 times the gross area, is used to eliminate transverse joints in highway and airport pavement.

4) SCOPE OF WORK

4.1. BASICS OF SLAB ON GRADE

The slab-on-grade is dependent on

i. Slab type,

ii. Support condition (sub-grade Reaction),

iii. Loading type and

iv. Function of the building

4.1.1 Slab types

The six types of slabs-on-grade as per ACI identified are:

a) Unreinforced Plain concrete slab,

b) Slab reinforced for shrinkage and temperature only,

c) Shrinkage-compensating concrete with shrinkage reinforcement, Slabs reinforced to prevent cracking due to shrinkage and temperature restraint and applied loads,

d) Slab post-tensioned to offset shrinkage,

e) Slab post-tensioned and/or reinforced, with active pre-stress,

f) Slab reinforced for structural action, Structural slabs designed in accordance with ACI 318:

- Plain concrete and
- Reinforced concrete

Slab Types A through E are designed with the assumption that applied loadings will not crack the slab. For Type F the designer anticipates that the applied loadings may crack the slab. In our case, slab type A to C will be discussed.

Type A, Plain Concrete Slab

The design of this slab involves determining its thickness as a plain concrete slab without reinforcement; however, it may have due to loads on the slab surface. Plain concrete slabs do not contain any wire, wire fabric, plain or deformed bars, post-tensioning, or any other type of reinforcement. The effects of drying shrinkage and uniform sub-grade support on slab cracking are critical to the performance of these plain concrete slabs. To reduce drying shrinkage cracks, the spacing of contraction and/or construction joints is limited. A full uniform load over an entire area causes no bending moment if the boundaries of the area are simple construction joints.

Type B, slab Reinforced for Shrinkage and Temperature Only

Slab thickness design is the same as for plain concrete slabs, and the slab is assumed to remain un-cracked due to loads placed on its surface. Shrinkage cracking is controlled by a nominal or small amount of distributed reinforcement placed in the upper half of the slab, and therefore joint spacing can be greater than for Type A slabs.

Joint spacing can be computed using the sub-grade drag equation for a pre-selected amount of steel for shrinkage and temperature control; however, the amount of reinforcement area or steel stress is usually computed from a pre-determined joint spacing.

The primary purpose of the reinforcement in the Type B slab is to hold tightly closed any cracks that may form between the joints. The reinforcement must be stiff enough so that it can be accurately located in the top half of the slab. Reinforcement does not prevent the cracking, nor does it add significantly to the load-carrying capacity of a Type B slab. The best way to obtain increased flexural strength is to increase the thickness of the slab.

For plain wire fabric, the spacing should be not more than 350mm. longitudinally and 350mm. transversely, even though a wider spacing is easier for workers to step through. Deformed or un-deformed welded wire fabric can be spaced in the same manner as reinforcing bars. A gage or spacer can be inserted from the top of a slab during concrete placement to periodically check the location of the reinforcement.

Type C, shrinkage - compensating concrete slabs

The shrinkage compensating - concrete used in these slabs is produced either with a separate admixture or with ASTM C-845 Type K cement which contains the expansive admixture. This concrete does shrink, but first it expands an amount intended to be slightly greater than its drying shrinkage. Distributed reinforcement for temperature and shrinkage equal to 0.15 to 0.20 percent of the cross-sectional area is used in the upper half of the slab to limit the initial slab expansion and to restrain the slab's subsequent drying shrinkage.

Reinforcement must be stiff enough that it can be positively positioned in the upper half of the slab. The slab must be isolated from fixed portions of the structure, such as columns and perimeter foundations, with a compressible material that allows the slab to expand.

Type C slabs are designed to remain un-cracked due to loads applied to the slab surface. Thickness design is the same as for Type A and B slabs, but joints can be spaced farther apart than in those slabs.

4.1.2 Support Condition (Sub-Grade Conditions)

Importance of sub-grade conditions: The Sub-grade provides a foundation for supporting the floor slab. As a result, the required floor slab thickness and the performance obtained from the floor slab during its design life will depend in a large part, on the uniformity and bearing capacity of the sub-grade. It is desirable, if economically feasible, to thoroughly investigate the Sub-grade to assess the maximum support potential for the particular sub-grade.

Initial investigation: Preliminary investigations of Sub-grade conditions at the site of proposed construction should be performed to determine the engineering characteristics of the Sub-grade soils and the extent of any peculiarities of the proposed site. The general suitability of the Sub-grade soils is to be based on classification of the soil, moisture density relationships, expansive characteristics, susceptibility to pumping, and susceptibility to detrimental frost action. A careful study of the service history of existing floor slabs on similar Sub-grade materials in the locality of the proposed site should be made. Factors such as ground water, surface infiltration, soil capillarity, topography, rainfall, drainage conditions, and the seasonal change of such factors also may affect the support rendered by the sub-grade.

4.1.3 Soil – Structure Interaction

Successful application of the principles of structural engineering are directly linked to the ability of the engineer to model the structure and its support conditions in order to perform an accurate analysis and thereby a correct design.

Soil is a very complex material for the modeling. It is very difficult to model the soil-structure interaction problem and hence arriving at a realistic model is complicated in foundation analysis. In particular, concrete building slabs, supported directly by the soil medium, is a very common construction system. It is very important to be able to compute plate displacements and consequent stresses with an acceptable degree of accuracy in order to ensure a safe and economical design.

4.1.4 Soil Stiffness

Soil Stiffness is the relationship between changes of stress and changes of strain. The Sub-grade is assumed to act as a linear spring, with a proportionality constant ***'k'*** with units of pressure (KN/m^2) per unit deformation (in m). This is the constant now recognized as the coefficient of Sub-grade reaction, more commonly called the **modulus of soil reaction** or **modulus of sub-grade reaction**.

However, a proper choice of the modulus of Sub-grade reaction was found to be essential for good agreement with respect to stresses, there remained much ambiguity in the methods for experimental determination of that correction coefficient.

The most common and probably the safest correlation between bearing capacity and the modulus of subgrade reaction is that there both are the measurements of soil capacities and any of these two parameters can be used to design a regular foundation.

Again, the definition of Ks is the pressure per unit settlement. In other words, soil capacity to withstand pressure for a given displacement. It is also clear that even bearing capacity has an allowable settlement. It is therefore tempting to conclude that the modulus of subgrade reaction is the bearing capacity per unit settlement.

Even though the slab is intended to remain un-cracked under service loading, the reinforcement is used to aid in crack control; to permit use of longer joint spacing, thereby reducing the number of joints; to increase load transfer ability at joints; and to provide reserve strength after shrinkage or temperature cracking occurs.

Finally, this approach allows for the beneficial separation of the geotechnical design and the structural design, which greatly optimizes all aspects of the design phase. Geotechnical design consists in providing an equivalent soil profile. Structural design consists of calculating the bending moment distribution in the slab over the equivalent soil profile (classical calculation based on existing code of practice).

Also in the 193Os, considerable experimental information accumulated to indicate that the behavior of many sub-grades may be close to that of an elastic and isotropic solid. Two characteristic constants, typically the modulus of soil deformation and Poisson's ratio, are used to evaluate the deformation response of such solids.

The depth of compacted lifts varies with soil type and compaction equipment, but in most cases should be 150-225 mm. As stresses are increased or decreased a material body will tend to change size and shape as strains occur: The stiffness ***'k'*** is the gradient of the stress-strain curve. The three basic theories which are relevant to soil behavior are: elasticity, plasticity and viscous flow (often referred to as creep). In addition, the theories of elasticity and plasticity are combined into elasto-plasticity. If strains are zero, the behavior is rigid.

Table 2 The soil stiffness '*k*' for different soil type

Soil Type	**Typical '*k*'**
Un-weathered over consolidated clays	20 - 50 MPa
Boulder clay	10 - 20 MPa
Un-weathered	>150 MPa
moderately weathered	30 - 150 MPa
Weathered over consolidated clays	3 - 10 MPa
Organic alluvial clays and peats	0.1 - 0.6 MPa
Normally consolidated clays	0.2 - 4 MPa
Steel	205 MPa
Concrete	30 MPa

Table 3 Value of the coefficient of subgrade reaction

Soil	Type	$K_{0.3}$ (MN/m^3)
Sandy (dry or moist)	Loose	8-25
	Medium	25-125
	Dense	125-375
Sand (saturated)	Loose	10-15
	Medium	35-40
	Dense	130-150
Clay	Stiff (q=100-200kN/m^2)	12-15
	Very stiff (q=200-400kN/m^2)	25-50
	Hard (q>400kN/m^2)	>50

4.2. ANALYSIS AND DESIGN OF SLAB –ON-GRADE

Methods of analysis for slab-on-grade are similar to those developed for beams on elastic foundations. Usually the slab is assumed to be homogenous, the reaction of the Sub-grade is assumed to be only vertical and proportional to the defection. The numerical value of **'k'** varies widely for different soil types and degrees of consolidation and is generally based on experimental observation. The usual method of constructing a structural slab-on-grade is to use a thickened slab; at the edges of the slab, where most of the load will be carried, the slab is thickened, the thickened portion being cast integrally with the rest of the slab. For the analysis, uniform load is assumed.

There is a common theoretical basis that assumes highly idealized conditions but results are modified in recognition of test data and practical experience. Generally, the design is based on soil type, natural service loads and concrete stress that are compacted against specified limit.

In our country, the ground floor slab never undergoes any structural analysis and design. The designers just simply specify the thickness and reinforcement type and spacing. The practice is:

- Use Ø6 c/c 200mm in both directions with100mm thick slab
- Use Ø8 c/c 200mm in both directions with100mm thick slab
- Use Ø10 c/c 200mm in both directions with100mm thick slab

It is helpful that when the slab-on-ground design criteria are well established, that are shown on the detail engineering drawings of every building. This information is especially useful when future modifications are made to the slab or its use. Design issues, such as the slab contributing to wind or seismic resistance or building foundation uplift forces, would not be readily apparent unless noted on the drawings. Because it is not readily apparent when a slab is used as a horizontal diaphragm, it should be noted on the drawings. Removing or cutting a slab that is designed to resist uplift or horizontal forces could seriously impair the building's stability.

The following parameters must be taken in to consideration since they are the most significant factors to influence the design of slabs-on-grade.

1. Geotechnical soil properties and capacities:

a. Allowable Soil Bearing Pressure,

b. Standard Modulus of Sub-Grade Reaction,

c. Slab Stiffness,

d. Depth of Active Moisture Zone,

e. Shrink-Swell Potential,

f. Soil Surface Suction Change.

2. Compressive Strength of Concrete

3. Slab Length,

4. Uniform Storage and Imposed Loading,

The weather factors include the change of soil suction at the ground surface in the free field. Design of the slab-on-grade involves the interaction of the slab and the soil support system to resist moments and shears induced by the applied loads. Therefore, the properties of both the concrete and the soil are important.

Slab design will be appropriate to the bearing capacity of soils and will take into account any unusual loading conditions.

Slabs on grade are frequently designed as plain concrete slabs where reinforcement, if used in any form, serves in a manner other than providing strength to the un-cracked slab. The amounts of reinforcement used, as well as joint spacing are to control cracking and to prevent the cracks from gaping. If tests and design calculations are not used, then one may simply specify from some literatures' which recommends to use minimum of 0.15 percent reinforcement unless temperature conditions dictate otherwise. Steel reinforcements are used or placed mainly for crack control.

Use three or four continuous Φ4 reinforcement bar all around the perimeter of the slab turn-downed edge at a minimum, but final determination will depend upon local building codes. For slabs with light loads, as those for residences, include wire mesh 1/3 the thickness of the slab from top to reduce cracking.

A minimum ratio of reinforcement area to gross concrete area of 0.0015 should be used in each direction that shrinkage compensation is desired. This minimum ratio does not depend on the yield strength of the reinforcement. When procedures outlined I ACI 223 are followed, however a reinforcement ratio less than the aforementioned minimum may be used.

The location of the reinforcement is critical to both slab behavior and internal concrete stress. ACI 223 recommends that reinforcement be positioned 1/3 of the depth from the top. The function of the top reinforcement is to balance the restraint provided elastic restraint against expansion.

The purpose of the plain concrete slab-on-grade is to transmit loadings from their source to the Sub-grade with minimal distress. Design methods cited consider the strength of the concrete slab based on its un-cracked and unreinforced properties.

To determine the slab thickness, existing code of practice dedicated to slab-on-grades are only able to consider uniform soil conditions and the typical size of those structures forbid the modeling of the full extent of the slab.

Slabs on grade are designed and their thickness is selected to prevent cracking due to external loading. Slab thickness calculations are based on the assumption of an un-cracked and unreinforced slab. Steel reinforcement-commonly plain or deformed welded wire fabric, bar mats, or deformed reinforcing bars is sometimes used in slabs on grade to improve performance of the slab under certain conditions.

- Slabs on grade are, to a limited extent, the softer the supporting soil and/or the larger the load, the stronger and stiffer the slab must be to spread the load over more of the supporting soil (*See ACI 360R-06 1.4*)
- Slab stiffness is a function of slab thickness
- Slab cracking strength is a function of concrete strength and slab thickness

In concrete ground-floor slab, two types of indirect loading condition occur due to restraint to temperature and shrinkage movement.

- Firstly, change in length causes evenly distributed tensile stresses to the slab's cross-section, which magnitude depends on the amount of shrinkage and degree of the restraint and axial stiffness of the floor construction.

- Secondly, change in shape (warping/curling due to the thermal / moisture gradient) causes tensile stresses usually in upper surface of the slab because of differential shrinkage (moisture loss starts from upper surface).

Ideally, if contraction joints are working properly and are not placed too far apart and bonding to sub-base is prevented, the stresses from change in length produces very low tensile stresses to the slab. Curling due to differential shrinkage does induce tensile stresses to the upper surface. The magnitude of induced stresses depends on the spacing of the contraction joints and the magnitude of differential shrinkage.

Generally, this study will help to avoid the ambiguity and usage of unnecessary slab thickness and area of reinforcement.

Although slabs on grade seem to be simple structural elements, analysis is extremely complicated. The analysis depends on different factors:

- The soil factors include:
  - The soil modulus, Esoil,
  - The shrink-swell index, Iss (difference between the swell limit and the shrink limit), and
  - The field coefficient of unsaturated diffusivity,
- The slab factors include:
  - The slab length, L,
  - The slab bending stiffness EI, and
  - The loading *q* obviously,
- Reinforcing Steel:
  - Smaller bar sizes are better choices than large diameters
  - This steel “should be positioned one-third the slab thickness below the top surface *ACI 302.1R, pg 5*

- 2cm top clear cover for slabs protected from the weather, 1.4cm for #5 or smaller bars and 4cm for larger bars exposed to weather

In order to cover all the combinations of parameters, a very large number of simulation cases would have to be performed to develop a design procedure that addresses all these parameter effects.

In line of a precise analysis taking into account the following parameters:

- Live-load magnitude,
- Joint interval and detail,
- Concrete modulus of elasticity,
- The soil modulus, and
- Load patterns.

A quick solution to avoid uplift is to provide a slab sufficiently thick so that its weight is greater than one-fifth the live load. Such a slab may be unreinforced, if properly jointed, or reinforced for temperature and shrinkage stresses only. Alternatively, for very heavy loadings, an analysis and design may be performed for the use of reinforcement, top and bottom, to control uplift moments and cracking. *(Paul F. Rice, 1957),* solve the problem of soil-structure interaction and find out the maximum bending moment and deflection of the foundation slab. He performs an extensive parametric simulation study to find out what parameters are most important for the bending moment and the deflection.

In this model it is assumed that the displacement at any point on the surface of the foundation is directly, proportional to the foundation surface pressure, acting at that point and is independent of pressure applied at other locations.

As long as the soils deformations are low, there is negligible bending in the slab. Slabs on grade are deemed to be successful if there is little or no cracking.

The vertical translations of the soil '$\boldsymbol{q}$', at a point is assumed to depend only upon the contact pressure 'δ', acting at the point in the idealized elastic foundation and a proportionality constant, k.

$$\delta = kq$$

Modulus of sub grade reaction

The modulus of sub grade reaction is a relationship between soil pressure and deflection that is widely used in structural analysis of foundation members. The modulus of sub grade reaction is calculated from plate load test using following equation

$$k = q/\delta$$

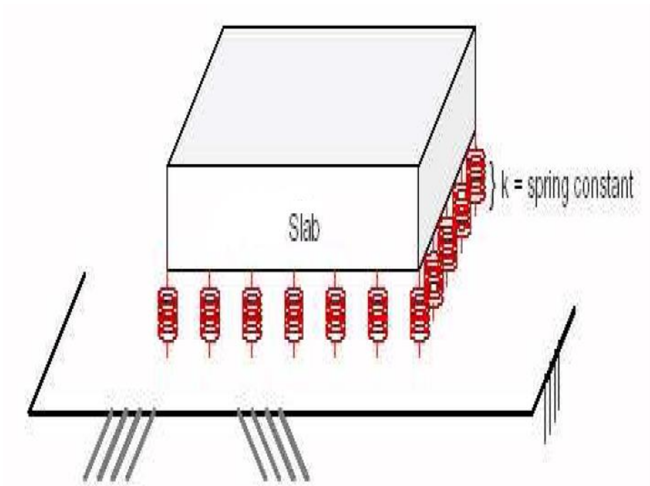


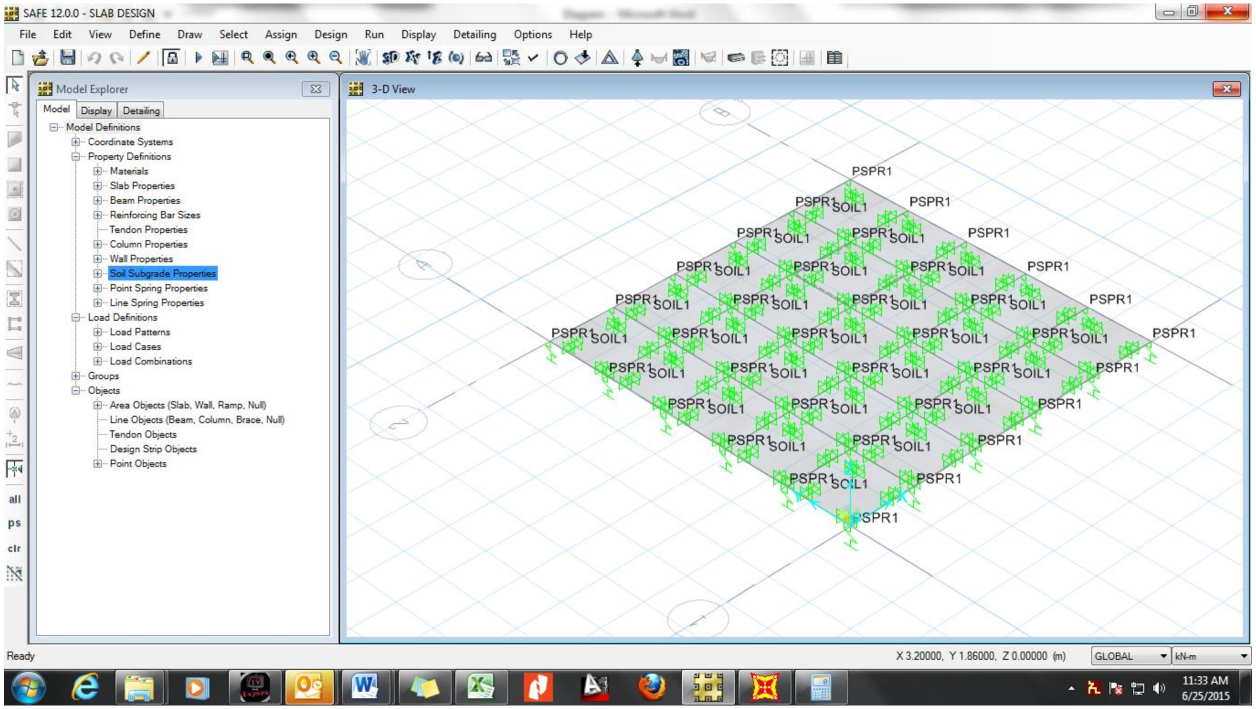
Figure 1 Modulus of Sub grade Reaction

The Slab Analysis by the Finite Element method software "SAFE" is used in this work for its simplicity. In the analysis, SAFE converts the object-based model created by the user into a finite element model, called the analysis model. The finite element mesh used in the analysis is a rectangular mesh based on a maximum acceptable element size.

Usually, the computer software transforms the problem of plates on elastic foundation into a computer-oriented procedure of structural analysis (Kame, 2008). The plate is idealized as a mesh of finite elements interconnected only at the nodes (corners), and the soil may be modeled as a set of isolated springs (Winkler foundation). The Finite element analysis adopted for plate is based on the classical theory of thick plates resting on *Winkler* foundation that accounts for the transverse shear deformation of the plate.

In the modeling of the slab on grade, the analysis of slab-on-grade on an elastic foundation is developed on the assumption that the reaction forces of the foundation are proportional at every point to the deflection of the slab at that point.

The pictorial view of 4m by 4m slab on grade model using safe is presented below.


SAFE 12.0.0 - SLAB DESIGN
File Edit View Define Draw Select Assign Design Run Display Detailing Options Help
Model Explorer
Model Display Detailing
Model Definitions
Coordinate Systems
Property Definitions
Materials
Slab Properties
Beam Properties
Reinforcing Bar Sizes
Tendon Properties
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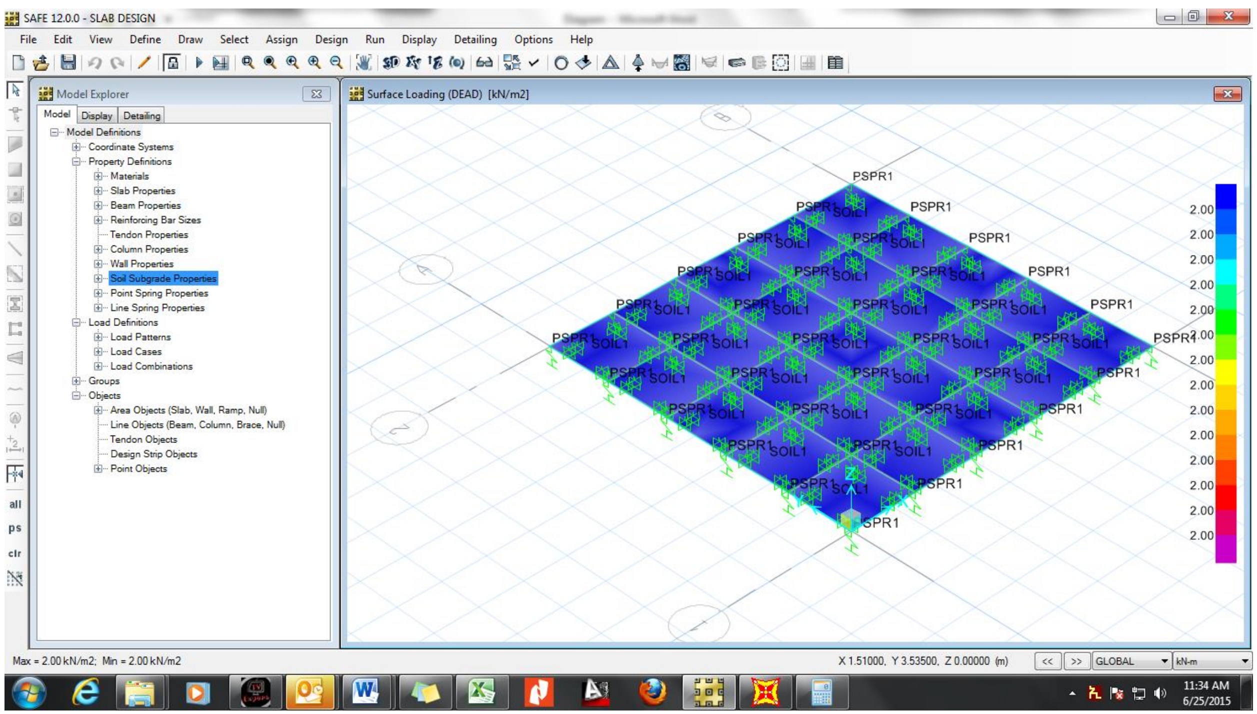
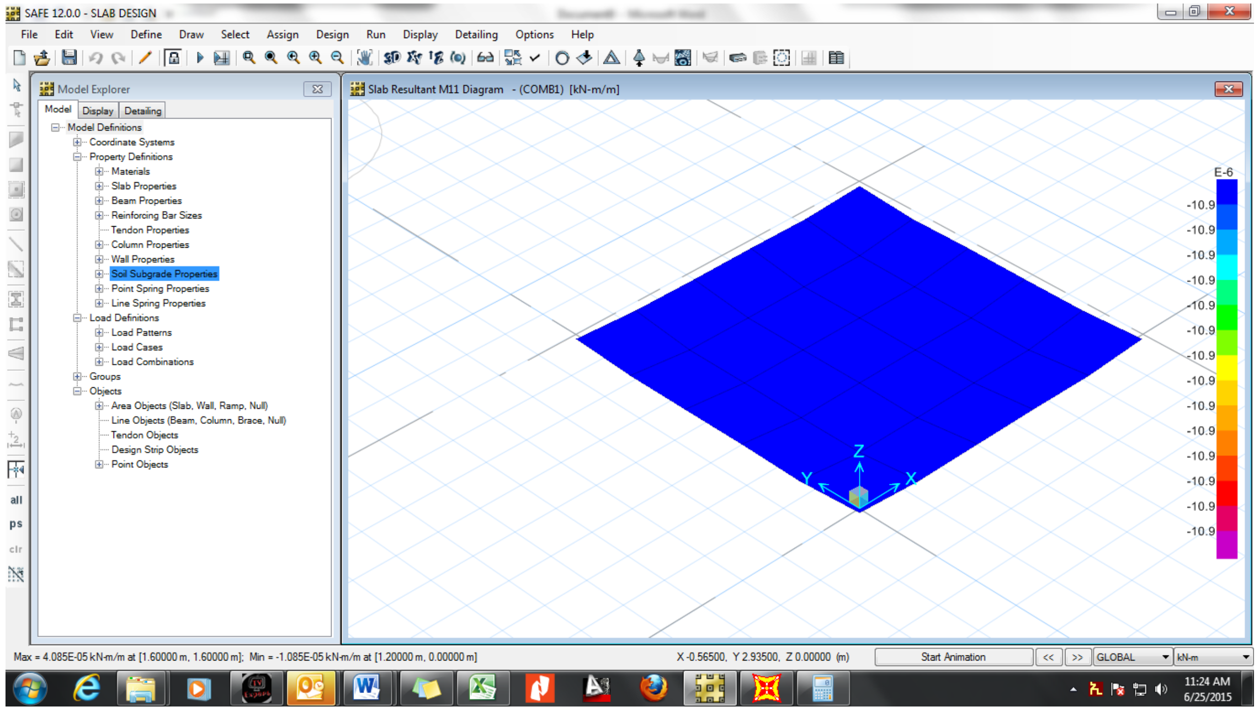
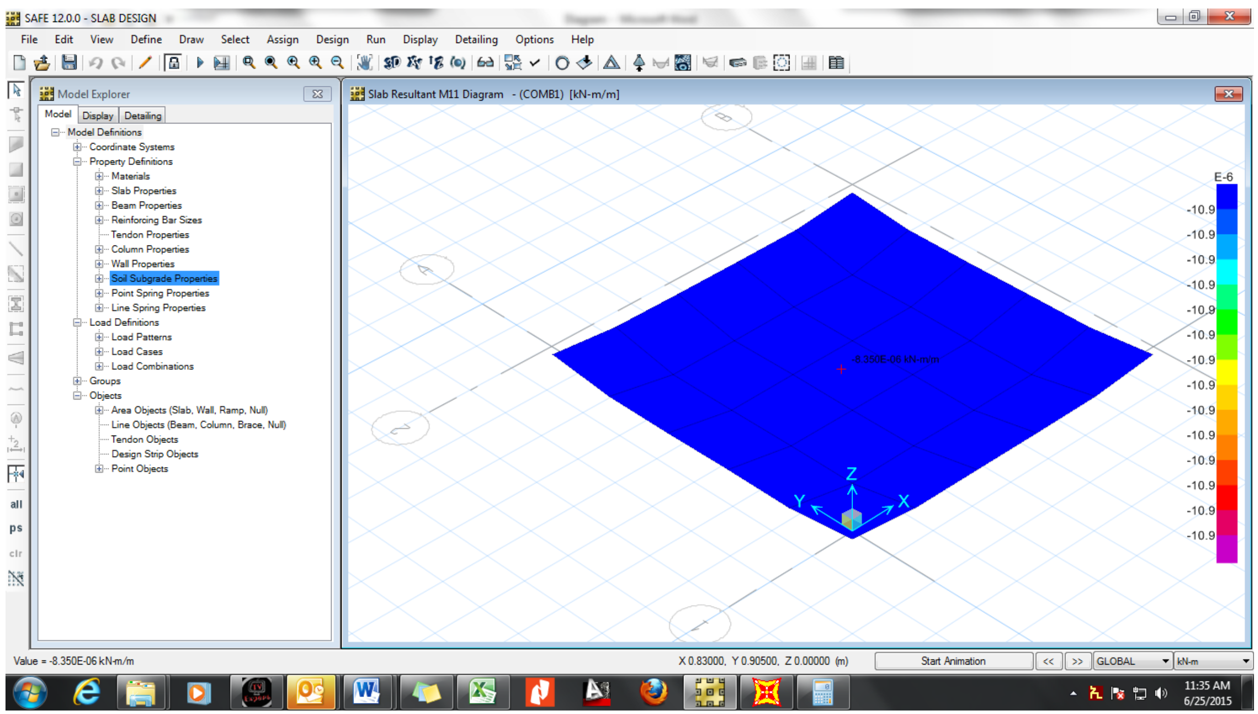
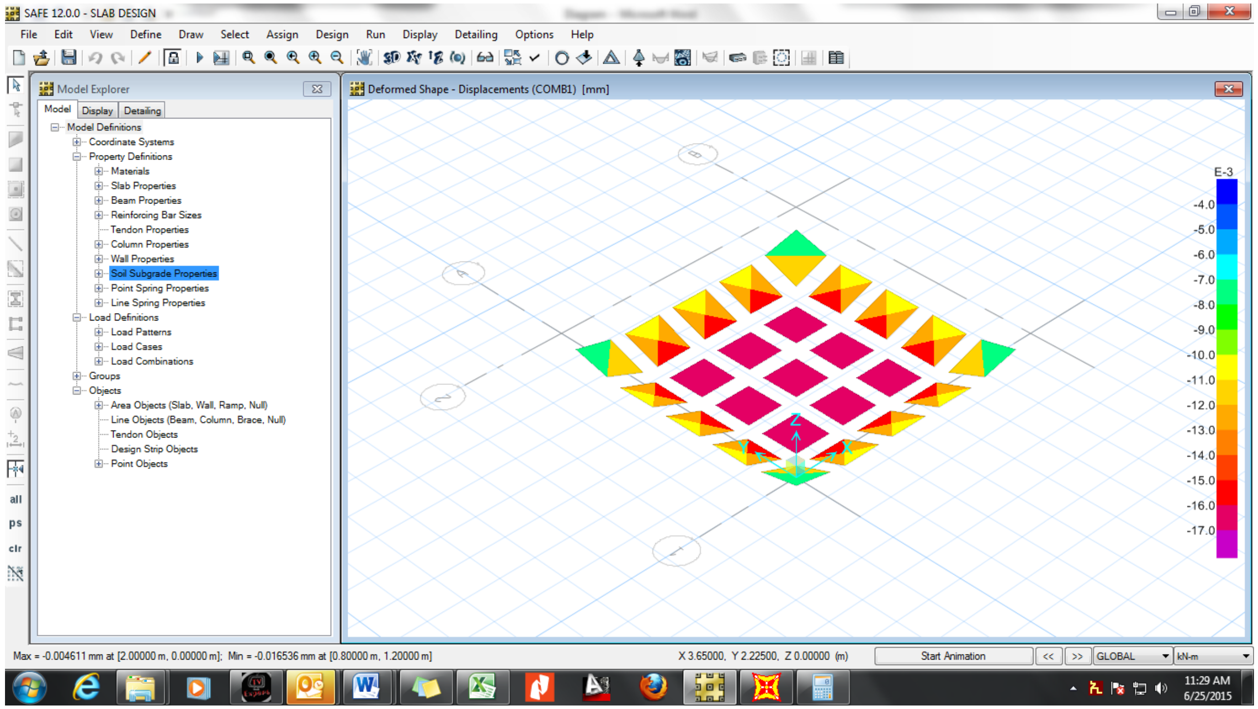
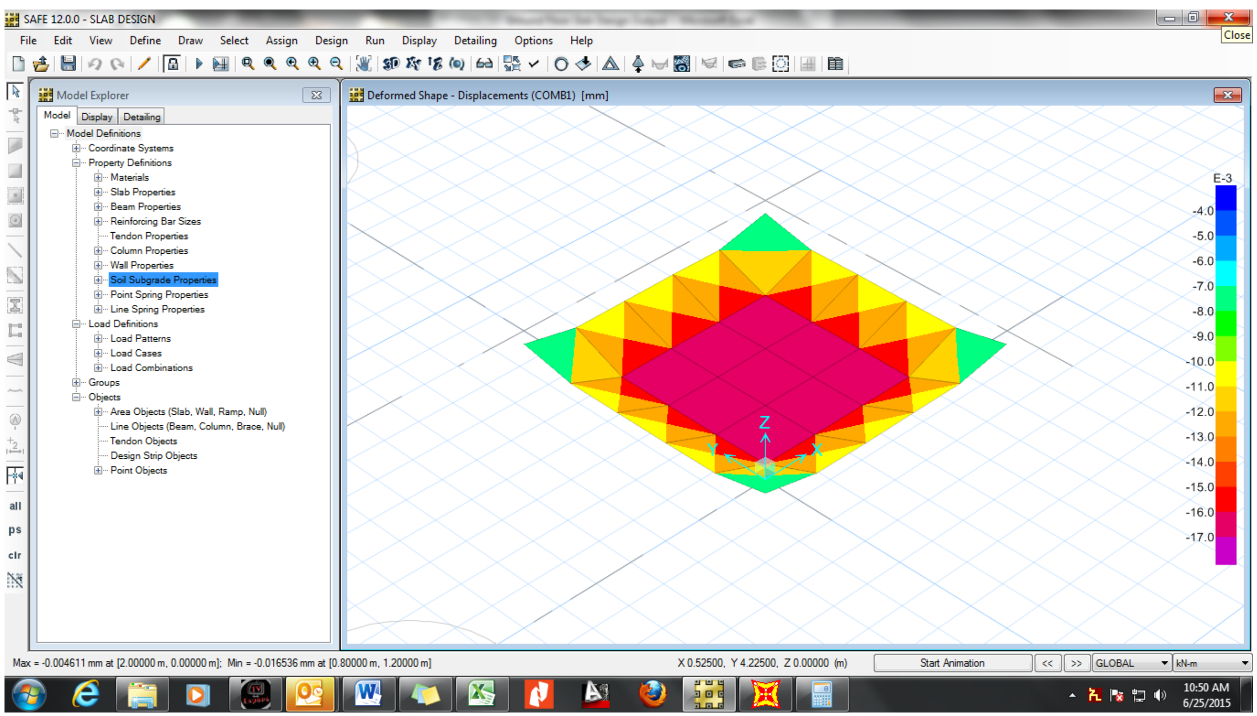
Load Definitions
Load Patterns
Load Cases
Load Combinations
Groups
Objects
Area Objects (Slab, Wall, Ramp, Null)
Line Objects (Beam, Column, Brace, Null)
Tendon Objects
Design Strip Objects
Point Objects
3-D View
PSPR1
SOIL1
Ready
X 3.20000, Y 1.86000, Z 0.00000 (m)
GLOBAL
kN-m
11:33 AM
6/25/2015

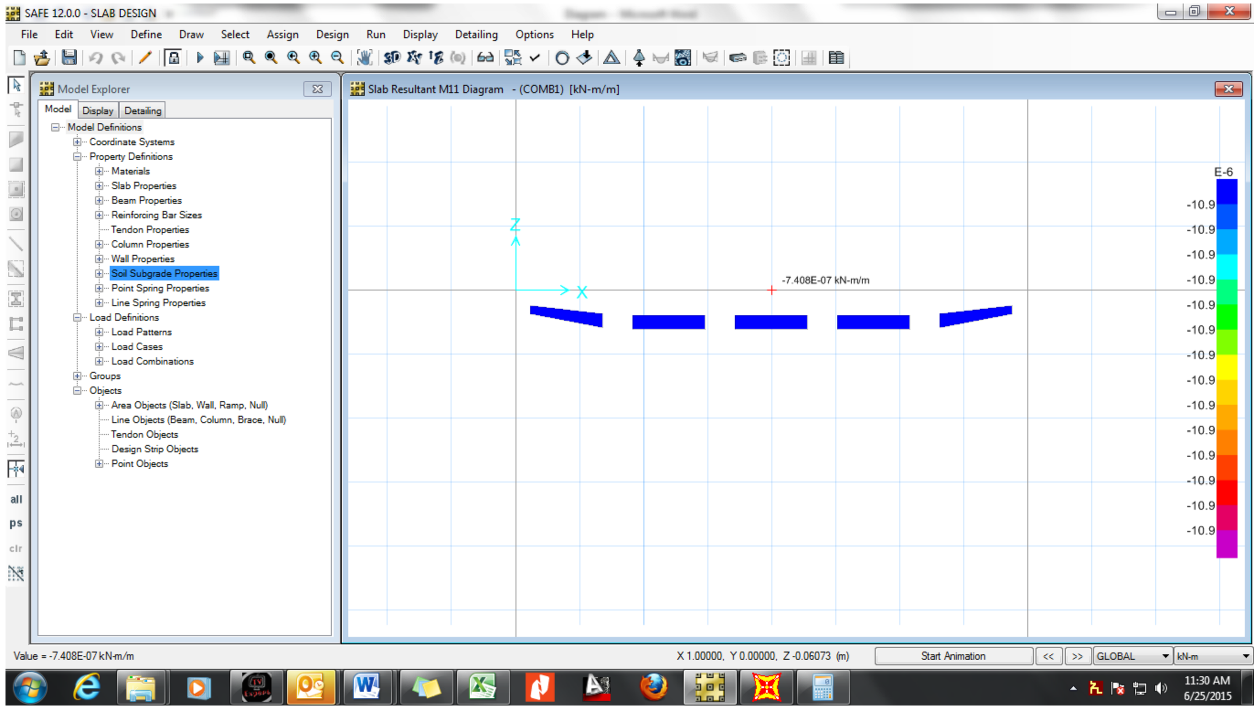

SAFE 12.0.0 - SLAB DESIGN
File Edit View Define Draw Select Assign Design Run Display Detailing Options Help
Model Explorer
Model Display Detailing
Model Definitions
Coordinate Systems
Property Definitions
Materials
Slab Properties
Beam Properties
Reinforcing Bar Sizes
Tendon Properties
Column Properties
Wall Properties
Soil Subgrade Properties
Point Spring Properties
Line Spring Properties
Load Definitions
Load Patterns
Load Cases
Load Combinations
Groups
Objects
Area Objects (Slab, Wall, Ramp, Null)
Line Objects (Beam, Column, Brace, Null)
Tendon Objects
Design Strip Objects
Point Objects
Surface Loading (DEAD) [kN/m2]
PSPR1
SOIL1
2.00
Max = 2.00 kN/m2; Min = 2.00 kN/m2
X 1.51000, Y 3.53500, Z 0.00000 (m)
GLOBAL
kN-m
11:34 AM
6/25/2015

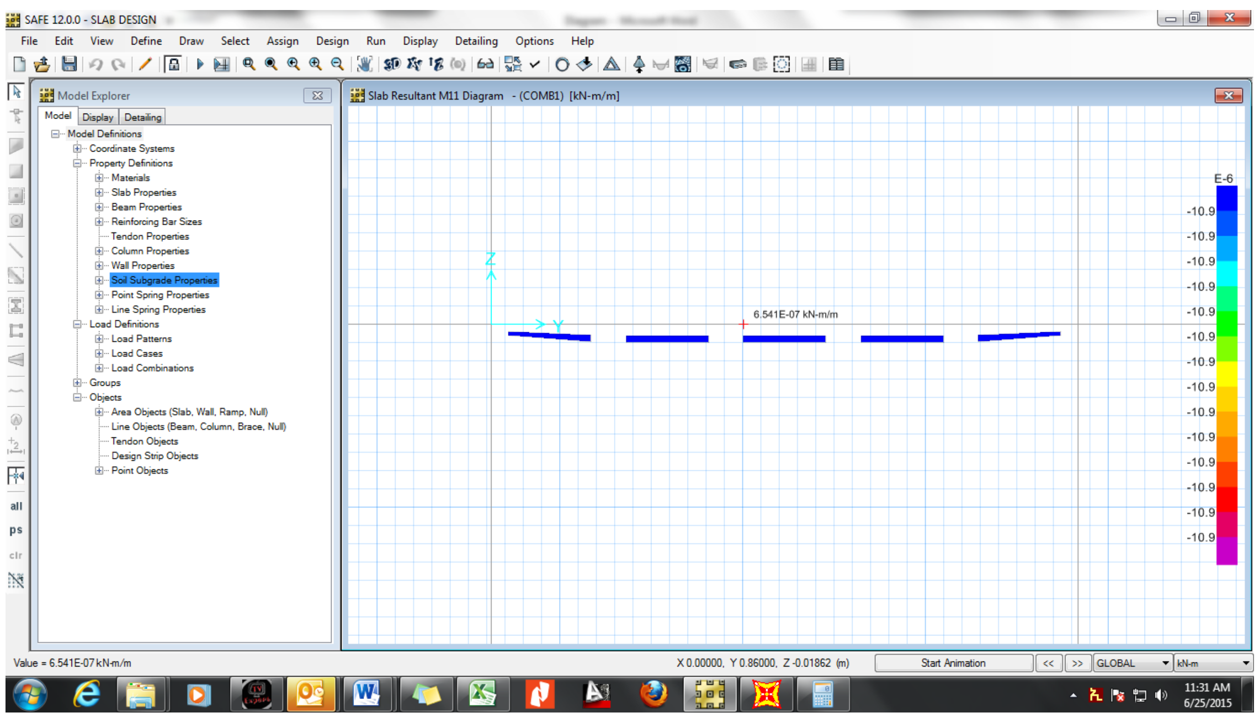

SAFE 12.0.0 - SLAB DESIGN
File Edit View Define Draw Select Assign Design Run Display Detailing Options Help
Model Explorer
Slab Resultant M11 Diagram - (COMB1) [kN-m/m]
Max = 4.085E-05 kN-m/m at [1.60000 m, 1.60000 m]; Min = -1.085E-05 kN-m/m at [1.20000 m, 0.00000 m]
X -0.56500, Y 2.93500, Z 0.00000 (m)
Start Animation
GLOBAL
11:24 AM
6/25/2015


SAFE 12.0.0 - SLAB DESIGN
File Edit View Define Draw Select Assign Design Run Display Detailing Options Help
Model Explorer
Slab Resultant M11 Diagram - (COMB1) [kN-m/m]
Value = -8.350E-06 kN-m/m
X 0.83000, Y 0.90500, Z 0.00000 (m)
Start Animation
GLOBAL
11:35 AM
6/25/2015


SAFE 12.0.0 - SLAB DESIGN
File Edit View Define Draw Select Assign Design Run Display Detailing Options Help
Model Explorer
Deformed Shape - Displacements (COMB1) [mm]
Max = -0.004611 mm at [2.00000 m, 0.00000 m]; Min = -0.016536 mm at [0.80000 m, 1.20000 m]
X 3.65000, Y 2.22500, Z 0.00000 (m)
Start Animation
GLOBAL
kN-m


SAFE 12.0.0 - SLAB DESIGN
File Edit View Define Draw Select Assign Design Run Display Detailing Options Help
Model Explorer
Deformed Shape - Displacements (COMB1) [mm]
Max = -0.004611 mm at [2.00000 m, 0.00000 m]; Min = -0.016536 mm at [0.80000 m, 1.20000 m]
X 0.52500, Y 4.22500, Z 0.00000 (m)
Start Animation
GLOBAL
kN-m


SAFE 12.0.0 - SLAB DESIGN
File Edit View Define Draw Select Assign Design Run Display Detailing Options Help
Model Explorer
Slab Resultant M11 Diagram - (COMB1) [kN-m/m]
-7.408E-07 kN-m/m
E-6
Value = -7.408E-07 kN-m/m
X 1.00000, Y 0.00000, Z -0.06073 (m)
Start Animation
GLOBAL
11:30 AM
6/25/2015


SAFE 12.0.0 - SLAB DESIGN
File Edit View Define Draw Select Assign Design Run Display Detailing Options Help
Model Explorer
Slab Resultant M11 Diagram - (COMB1) [kN-m/m]
6.541E-07 kN-m/m
E-6
Value = 6.541E-07 kN-m/m
X 0.00000, Y 0.86000, Z -0.01862 (m)
Start Animation
GLOBAL
11:31 AM
6/25/2015

4.1.5 Safe Analysis and Design input Data

ProgramName	Version	CurrUnits	MergeTol	ModelDatum	StHtAbove	StHtBelow	ConcCode
Text	Text	Text	Text	Text	Text	Text	Text
SAFE	12.0.0	kN-m	1	0	3	3	Eurocode 2-2004

TABLE: Grid Lines								
CoordSys	**AxisDir**	**GridID**	**Ordinate**	**Visible**	**BubbleLoc**	**GridColor**	**BubbleSize**	**HideAll**
Text	Text	Text	m	Yes/No	Text	Text	mm	Yes/No
GLOBAL	X	A	0	Yes	End	10461087	1250	No
GLOBAL	X	B	4	Yes	End			
GLOBAL	Y	1	0	Yes	Start			
GLOBAL	Y	2	4	Yes	Start			

TABLE: Material Properties 01 - General			
Material	**Type**	**Color**	**Notes**
Text	Text	Text	Text
SOG	Concrete	Magenta	Normalweight C20 added 4/11/2015 10:35:20 AM

TABLE: Load Cases 01 - General			
LoadCase	**Type**	**DesignOpt**	**DesignType**
Text	Text	Text	Text
DEAD	LinStatic	Auto	DEAD
LIVE	LinStatic	Auto	LIVE

TABLE: Point Spring Assignments	
Point	**Spring**
Text	Text
1	PSPR1

TABLE: Load Patterns		
LoadPat	**Type**	**SelfWtMult**
Text	Text	Unitless
DEAD	DEAD	1
LIVE	LIVE	0

TABLE: Load Assignments - Surface Loads						
Area	**LoadPat**	**UnifLoad**	**CoordSys**	**A**	**B**	**C**
Text	Text	kN/m2	Text	kN/m3	kN/m3	kN/m2
1	DEAD	2	GLOBAL	0	0	0
2	LIVE	2	GLOBAL	0	0	0

TABLE: Load Combinations			
Combo	**Load**	**SF**	**Type**
Text	Text	Unitless	Text
COMB1	DEAD	1.3	Linear Add
COMB1	LIVE	1.6	

TABLE: Design Preferences 01 - Resistance Factors								
Country	**ComboSet**	**Theta**	**GammaSteel**	**GammaConc**	**AlphaCC**	**AlphaCT**	**AlphaCCLW**	**AlphaCTLW**
Text	Text	Unitless	Unitless	Unitless	Unitless	Unitless	Unitless	Unitless
CEN	Eq. 6.10	0.005	1.15	1.5	1	1	0.85	0.85

TABLE: Design Preferences 02 - Rebar Cover - Slabs			
CoverTop	**CoverBot**	**BarSize**	**SlabType**
mm	mm	Text	Text
15	15	6	Two Way

TABLE: Soil Properties		
Soil	**Subgrade**	**Color**
Text	kN/m3	Text
SOIL1	30000	Magenta

TABLE: Spring Properties - Point								
Spring	**Ux**	**Uy**	**Uz**	**Rx**	**Ry**	**Rz**	**NonlinOpt**	**Color**
Text	kN/mm	kN/mm	kN/mm	kN-mm/rad	kN-mm/rad	kN-mm/rad	Text	Text
PSPR1	0	0	30	0	0	0	None (Linear)	Cyan

TABLE: Cracking Analysis Reinforcement	
ReinfOpt	**MinReinf**
Text	Unitless
FE Design	0.0018

4.1.6 Safe Analysis Result / Output Data

TABLE: Nodal Displacements									
Node	**Point**	**OutputCase**	**CaseType**	**Ux**	**Uy**	**Uz**	**Rx**	**Ry**	**Rz**
Text	Text	Text	Text	mm	mm	mm	Radians	Radians	Radians
1	1	COMB1	Combination	0	0	-0.009836	0.000024	0.000024	0
2	2	COMB1	Combination	0	0	-0.009836	0.000024	-0.000024	0
3	3	COMB1	Combination	0	0	-0.009836	-0.000024	-0.000024	0
4	4	COMB1	Combination	0	0	-0.009836	-0.000024	0.000024	0
5	6	COMB1	Combination	0	0	-0.018946	-0.000051	0.000014	0
6	7	COMB1	Combination	0	0	-0.035261	-0.000018	0.000018	0
7	8	COMB1	Combination	0	0	-0.018946	-0.000014	0.000051	0
8	9	COMB1	Combination	0	0	-0.035273	0.000004985	0.000019	0
9	10	COMB1	Combination	0	0	-0.018946	0.000002017	0.000052	0
10	11	COMB1	Combination	0	0	-0.035267	-0.000001412	0.000019	0
11	12	COMB1	Combination	0	0	-0.018946	2.413E-07	0.000051	0
12	13	COMB1	Combination	0	0	-0.03527	4.445E-07	0.000019	0
13	14	COMB1	Combination	0	0	-0.018945	-3.227E-07	0.000051	0
14	15	COMB1	Combination	0	0	-0.035268	3.16E-09	0.000019	0
15	16	COMB1	Combination	0	0	-0.018946	-4.182E-10	0.000051	0
16	17	COMB1	Combination	0	0	-0.03527	-4.346E-07	0.000019	0
17	18	COMB1	Combination	0	0	-0.018945	3.268E-07	0.000051	0
18	19	COMB1	Combination	0	0	-0.035267	0.00000142	0.000019	0
19	20	COMB1	Combination	0	0	-0.018946	-0.000000237	0.000051	0
20	21	COMB1	Combination	0	0	-0.035273	-0.000004973	0.000019	0
21	22	COMB1	Combination	0	0	-0.018946	-0.000002013	0.000052	0
22	23	COMB1	Combination	0	0	-0.035261	0.000018	0.000018	0
23	24	COMB1	Combination	0	0	-0.018946	0.000014	0.000051	0
24	25	COMB1	Combination	0	0	-0.018946	0.000051	0.000014	0
25	26	COMB1	Combination	0	0	-0.018946	-0.000052	-0.00000201	0
26	27	COMB1	Combination	0	0	-0.035273	-0.000019	-0.000004972	0

Node	Point	OutputCase	CaseType	Ux	Uy	Uz	Rx	Ry	Rz
Text	Text	Text	Text	mm	mm	mm	Radians	Radians	Radians
27	28	COMB1	Combination	0	0	-0.035281	0.000004971	-0.000004978	0
28	29	COMB1	Combination	0	0	-0.035276	-0.000001392	-0.000004828	0
29	30	COMB1	Combination	0	0	-0.035277	0.000000359	-0.000004907	0
30	31	COMB1	Combination	0	0	-0.035277	-1.321E-09	-0.000004793	0
31	32	COMB1	Combination	0	0	-0.035277	-3.674E-07	-0.000004908	0
32	33	COMB1	Combination	0	0	-0.035276	0.000001391	-0.000004832	0
33	34	COMB1	Combination	0	0	-0.035281	-0.000004987	-0.000004973	0
34	35	COMB1	Combination	0	0	-0.035273	0.000019	-0.000004977	0
35	36	COMB1	Combination	0	0	-0.018946	0.000052	-0.000002021	0
36	37	COMB1	Combination	0	0	-0.018946	-0.000051	-2.392E-07	0
37	38	COMB1	Combination	0	0	-0.035267	-0.000019	0.000001412	0
38	39	COMB1	Combination	0	0	-0.035276	0.000004835	0.000001396	0
39	40	COMB1	Combination	0	0	-0.035272	-0.000001241	0.00000124	0
40	41	COMB1	Combination	0	0	-0.035273	2.875E-07	0.000001244	0
41	42	COMB1	Combination	0	0	-0.035273	3.04E-10	0.000001198	0
42	43	COMB1	Combination	0	0	-0.035273	-2.888E-07	0.000001243	0
43	44	COMB1	Combination	0	0	-0.035272	0.000001242	0.000001243	0
44	45	COMB1	Combination	0	0	-0.035276	-0.000004831	0.000001387	0
45	46	COMB1	Combination	0	0	-0.035267	0.000019	0.000001418	0
46	47	COMB1	Combination	0	0	-0.018946	0.000051	-2.322E-07	0
47	48	COMB1	Combination	0	0	-0.018945	-0.000051	3.214E-07	0
48	49	COMB1	Combination	0	0	-0.03527	-0.000019	-4.316E-07	0
49	50	COMB1	Combination	0	0	-0.035277	0.000004916	-3.656E-07	0
50	51	COMB1	Combination	0	0	-0.035273	-0.000001249	-2.874E-07	0
51	52	COMB1	Combination	0	0	-0.035274	3.034E-07	-3.014E-07	0
52	53	COMB1	Combination	0	0	-0.035274	-3.871E-09	-2.706E-07	0
53	54	COMB1	Combination	0	0	-0.035274	-2.989E-07	-3.019E-07	0
54	55	COMB1	Combination	0	0	-0.035273	0.000001239	-2.902E-07	0
55	56	COMB1	Combination	0	0	-0.035277	-0.000004902	-3.647E-07	0

Node	Point	OutputCase	CaseType	Ux	Uy	Uz	Rx	Ry	Rz
Text	Text	Text	Text	mm	mm	mm	Radians	Radians	Radians
56	57	COMB1	Combination	0	0	-0.03527	0.000019	-4.372E-07	0
57	58	COMB1	Combination	0	0	-0.018945	0.000051	3.253E-07	0
58	59	COMB1	Combination	0	0	-0.018946	-0.000051	1.202E-09	0
59	60	COMB1	Combination	0	0	-0.035268	-0.000019	4.174E-09	0
60	61	COMB1	Combination	0	0	-0.035277	0.000004789	-2.76E-10	0
61	62	COMB1	Combination	0	0	-0.035273	-0.000001198	9.57E-11	0
62	63	COMB1	Combination	0	0	-0.035274	2.692E-07	-1.455E-10	0
63	64	COMB1	Combination	0	0	-0.035273	2.166E-09	-2.039E-09	0
64	65	COMB1	Combination	0	0	-0.035274	-2.759E-07	9.704E-10	0
65	66	COMB1	Combination	0	0	-0.035273	0.000001203	6.028E-10	0
66	67	COMB1	Combination	0	0	-0.035277	-0.000004799	-2.559E-09	0
67	68	COMB1	Combination	0	0	-0.035268	0.000019	2.055E-10	0
68	69	COMB1	Combination	0	0	-0.018946	0.000051	1.821E-09	0
69	70	COMB1	Combination	0	0	-0.018945	-0.000051	-3.305E-07	0
70	71	COMB1	Combination	0	0	-0.03527	-0.000019	4.469E-07	0
71	72	COMB1	Combination	0	0	-0.035277	0.000004912	3.616E-07	0
72	73	COMB1	Combination	0	0	-0.035273	-0.000001248	2.847E-07	0
73	74	COMB1	Combination	0	0	-0.035274	3.015E-07	2.992E-07	0
74	75	COMB1	Combination	0	0	-0.035274	-1.857E-09	2.725E-07	0
75	76	COMB1	Combination	0	0	-0.035274	-3.009E-07	2.979E-07	0
76	77	COMB1	Combination	0	0	-0.035273	0.000001242	2.861E-07	0
77	78	COMB1	Combination	0	0	-0.035277	-0.000004911	3.567E-07	0
78	79	COMB1	Combination	0	0	-0.03527	0.000019	0.000000445	0
80	81	COMB1	Combination	0	0	-0.018946	-0.000051	0.000000237	0
81	82	COMB1	Combination	0	0	-0.035267	-0.000019	-0.000001411	0
82	83	COMB1	Combination	0	0	-0.035276	0.000004828	-0.000001396	0
83	84	COMB1	Combination	0	0	-0.035272	-0.000001243	-0.000001236	0
84	85	COMB1	Combination	0	0	-0.035273	2.873E-07	-0.000001243	0
85	86	COMB1	Combination	0	0	-0.035273	-3.075E-10	-0.0000012	0

Node	Point	OutputCase	CaseType	Ux	Uy	Uz	Rx	Ry	Rz
Text	Text	Text	Text	mm	mm	mm	Radians	Radians	Radians
86	87	COMB1	Combination	0	0	-0.035273	-2.868E-07	-0.000001241	0
87	88	COMB1	Combination	0	0	-0.035272	0.000001238	-0.000001238	0
88	89	COMB1	Combination	0	0	-0.035276	-0.00000483	-0.000001396	0
89	90	COMB1	Combination	0	0	-0.035267	0.000019	-0.000001414	0
90	91	COMB1	Combination	0	0	-0.018946	0.000051	2.349E-07	0
91	92	COMB1	Combination	0	0	-0.018946	-0.000052	0.000002009	0
92	93	COMB1	Combination	0	0	-0.035273	-0.000019	0.000004976	0
93	94	COMB1	Combination	0	0	-0.035281	0.000004974	0.000004979	0
94	95	COMB1	Combination	0	0	-0.035276	-0.000001396	0.000004818	0
95	96	COMB1	Combination	0	0	-0.035277	3.601E-07	0.000004912	0
96	97	COMB1	Combination	0	0	-0.035277	-2.272E-09	0.000004792	0
97	98	COMB1	Combination	0	0	-0.035277	-3.648E-07	0.000004902	0
98	99	COMB1	Combination	0	0	-0.035276	0.000001387	0.000004823	0
99	100	COMB1	Combination	0	0	-0.035281	-0.000004977	0.000004971	0
100	101	COMB1	Combination	0	0	-0.035273	0.000019	0.000004979	0
101	102	COMB1	Combination	0	0	-0.018946	0.000052	0.000002023	0
102	103	COMB1	Combination	0	0	-0.018946	-0.000051	-0.000014	0
103	104	COMB1	Combination	0	0	-0.035261	-0.000018	-0.000018	0
104	105	COMB1	Combination	0	0	-0.035273	0.000004964	-0.000019	0
105	106	COMB1	Combination	0	0	-0.035267	-0.000001411	-0.000019	0
106	107	COMB1	Combination	0	0	-0.03527	4.416E-07	-0.000019	0
107	108	COMB1	Combination	0	0	-0.035268	2.769E-09	-0.000019	0
108	109	COMB1	Combination	0	0	-0.03527	-4.363E-07	-0.000019	0
109	110	COMB1	Combination	0	0	-0.035267	0.000001419	-0.000019	0
110	111	COMB1	Combination	0	0	-0.035273	-0.000004964	-0.000019	0
111	112	COMB1	Combination	0	0	-0.035261	0.000018	-0.000018	0
112	113	COMB1	Combination	0	0	-0.018946	0.000051	-0.000014	0
113	114	COMB1	Combination	0	0	-0.018946	-0.000014	-0.000051	0
114	115	COMB1	Combination	0	0	-0.018946	0.000001998	-0.000052	0

Node	Point	OutputCase	CaseType	Ux	Uy	Uz	Rx	Ry	Rz
Text	Text	Text	Text	mm	mm	mm	Radians	Radians	Radians
115	116	COMB1	Combination	0	0	-0.018946	2.463E-07	-0.000051	0
116	117	COMB1	Combination	0	0	-0.018945	-3.291E-07	-0.000051	0
117	118	COMB1	Combination	0	0	-0.018946	-3.857E-09	-0.000051	0
118	119	COMB1	Combination	0	0	-0.018945	3.235E-07	-0.000051	0
119	120	COMB1	Combination	0	0	-0.018946	-2.413E-07	-0.000051	0
120	121	COMB1	Combination	0	0	-0.018946	-0.00000201	-0.000052	0
121	122	COMB1	Combination	0	0	-0.018946	0.000014	-0.000051	0

TABLE: Nodal Displacements - Summary

Panel	Node	OutputCase	CaseType	Ux	Uy	Uz	Rx	Ry	Rz	MaxUzRel	GlobalX	GlobalY
Text	Text	Text	Text	mm	mm	mm	Radians	Radians	Radians	mm	m	m
1	93	COMB1	Combination	0	0	-0.035281	0	0	0	0.025445	3.2	0.8

TABLE: Sum Of Reactions

OutputCase	CaseType	GlobalFX	GlobalFY	GlobalFZ	GlobalMX	GlobalMY	GlobalMZ	GlobalX	GlobalY	GlobalZ
Text	Text	kN	kN	kN	kN-m	kN-m	kN-m	m	m	m
COMB1	Combination	0	0	12.2752	24.5504	-24.5504	0	0	0	0

TABLE: Nodal Reactions									
Node	**Point**	**OutputCase**	**CaseType**	**Fx**	**Fy**	**Fz**	**Mx**	**My**	**Mz**
Text	Text	Text	Text	kN	kN	kN	kN-m	kN-m	kN-m
1	1	COMB1	Combination	0	0	0.307	0	0	0
2	2	COMB1	Combination	0	0	0.307	0	0	0
3	3	COMB1	Combination	0	0	0.307	0	0	0
4	4	COMB1	Combination	0	0	0.307	0	0	0
5	6	COMB1	Combination	0	0	0.614	0	0	0
6	7	COMB1	Combination	0	0	1.227	0	0	0
7	8	COMB1	Combination	0	0	0.614	0	0	0
8	9	COMB1	Combination	0	0	1.227	0	0	0
9	10	COMB1	Combination	0	0	0.614	0	0	0
10	11	COMB1	Combination	0	0	1.227	0	0	0
11	12	COMB1	Combination	0	0	0.614	0	0	0
12	13	COMB1	Combination	0	0	1.227	0	0	0
13	14	COMB1	Combination	0	0	0.614	0	0	0
14	15	COMB1	Combination	0	0	1.227	0	0	0
15	16	COMB1	Combination	0	0	0.614	0	0	0
16	17	COMB1	Combination	0	0	1.227	0	0	0
17	18	COMB1	Combination	0	0	0.614	0	0	0
18	19	COMB1	Combination	0	0	1.227	0	0	0
19	20	COMB1	Combination	0	0	0.614	0	0	0
20	21	COMB1	Combination	0	0	1.227	0	0	0
21	22	COMB1	Combination	0	0	0.614	0	0	0
22	23	COMB1	Combination	0	0	1.227	0	0	0
23	24	COMB1	Combination	0	0	0.614	0	0	0
24	25	COMB1	Combination	0	0	0.614	0	0	0
25	26	COMB1	Combination	0	0	0.614	0	0	0
26	27	COMB1	Combination	0	0	1.227	0	0	0
27	28	COMB1	Combination	0	0	1.228	0	0	0
28	29	COMB1	Combination	0	0	1.228	0	0	0
29	30	COMB1	Combination	0	0	1.228	0	0	0

Node	Point	OutputCase	CaseType	Fx	Fy	Fz	Mx	My	Mz
Text	Text	Text	Text	kN	kN	kN	kN-m	kN-m	kN-m
30	31	COMB1	Combination	0	0	1.228	0	0	0
31	32	COMB1	Combination	0	0	1.228	0	0	0
32	33	COMB1	Combination	0	0	1.228	0	0	0
33	34	COMB1	Combination	0	0	1.228	0	0	0
34	35	COMB1	Combination	0	0	1.227	0	0	0
35	36	COMB1	Combination	0	0	0.614	0	0	0
36	37	COMB1	Combination	0	0	0.614	0	0	0
37	38	COMB1	Combination	0	0	1.227	0	0	0
38	39	COMB1	Combination	0	0	1.228	0	0	0
39	40	COMB1	Combination	0	0	1.227	0	0	0
40	41	COMB1	Combination	0	0	1.227	0	0	0
41	42	COMB1	Combination	0	0	1.227	0	0	0
42	43	COMB1	Combination	0	0	1.227	0	0	0
43	44	COMB1	Combination	0	0	1.227	0	0	0
44	45	COMB1	Combination	0	0	1.228	0	0	0
45	46	COMB1	Combination	0	0	1.227	0	0	0
46	47	COMB1	Combination	0	0	0.614	0	0	0
47	48	COMB1	Combination	0	0	0.614	0	0	0
48	49	COMB1	Combination	0	0	1.227	0	0	0
49	50	COMB1	Combination	0	0	1.228	0	0	0
50	51	COMB1	Combination	0	0	1.227	0	0	0
51	52	COMB1	Combination	0	0	1.228	0	0	0
52	53	COMB1	Combination	0	0	1.228	0	0	0
53	54	COMB1	Combination	0	0	1.228	0	0	0
54	55	COMB1	Combination	0	0	1.227	0	0	0
55	56	COMB1	Combination	0	0	1.228	0	0	0
56	57	COMB1	Combination	0	0	1.227	0	0	0
57	58	COMB1	Combination	0	0	0.614	0	0	0
58	59	COMB1	Combination	0	0	0.614	0	0	0
59	60	COMB1	Combination	0	0	1.227	0	0	0

Node	Point	OutputCase	CaseType	Fx	Fy	Fz	Mx	My	Mz
Text	Text	Text	Text	kN	kN	kN	kN-m	kN-m	kN-m
60	61	COMB1	Combination	0	0	1.228	0	0	0
61	62	COMB1	Combination	0	0	1.227	0	0	0
62	63	COMB1	Combination	0	0	1.228	0	0	0
63	64	COMB1	Combination	0	0	1.228	0	0	0
64	65	COMB1	Combination	0	0	1.228	0	0	0
65	66	COMB1	Combination	0	0	1.227	0	0	0
66	67	COMB1	Combination	0	0	1.228	0	0	0
67	68	COMB1	Combination	0	0	1.227	0	0	0
68	69	COMB1	Combination	0	0	0.614	0	0	0
69	70	COMB1	Combination	0	0	0.614	0	0	0
70	71	COMB1	Combination	0	0	1.227	0	0	0
71	72	COMB1	Combination	0	0	1.228	0	0	0
72	73	COMB1	Combination	0	0	1.227	0	0	0
73	74	COMB1	Combination	0	0	1.228	0	0	0
74	75	COMB1	Combination	0	0	1.228	0	0	0
75	76	COMB1	Combination	0	0	1.228	0	0	0
76	77	COMB1	Combination	0	0	1.227	0	0	0
77	78	COMB1	Combination	0	0	1.228	0	0	0
78	79	COMB1	Combination	0	0	1.227	0	0	0
79	80	COMB1	Combination	0	0	0.614	0	0	0
80	81	COMB1	Combination	0	0	0.614	0	0	0
81	82	COMB1	Combination	0	0	1.227	0	0	0
82	83	COMB1	Combination	0	0	1.228	0	0	0
83	84	COMB1	Combination	0	0	1.227	0	0	0
84	85	COMB1	Combination	0	0	1.227	0	0	0
85	86	COMB1	Combination	0	0	1.227	0	0	0
86	87	COMB1	Combination	0	0	1.227	0	0	0
87	88	COMB1	Combination	0	0	1.227	0	0	0
88	89	COMB1	Combination	0	0	1.228	0	0	0
89	90	COMB1	Combination	0	0	1.227	0	0	0

Node	Point	OutputCase	CaseType	Fx	Fy	Fz	Mx	My	Mz
Text	Text	Text	Text	kN	kN	kN	kN-m	kN-m	kN-m
90	91	COMB1	Combination	0	0	0.614	0	0	0
91	92	COMB1	Combination	0	0	0.614	0	0	0
92	93	COMB1	Combination	0	0	1.227	0	0	0
93	94	COMB1	Combination	0	0	1.228	0	0	0
94	95	COMB1	Combination	0	0	1.228	0	0	0
95	96	COMB1	Combination	0	0	1.228	0	0	0
96	97	COMB1	Combination	0	0	1.228	0	0	0
97	98	COMB1	Combination	0	0	1.228	0	0	0
98	99	COMB1	Combination	0	0	1.228	0	0	0
99	100	COMB1	Combination	0	0	1.228	0	0	0
100	101	COMB1	Combination	0	0	1.227	0	0	0
101	102	COMB1	Combination	0	0	0.614	0	0	0
102	103	COMB1	Combination	0	0	0.614	0	0	0
103	104	COMB1	Combination	0	0	1.227	0	0	0
104	105	COMB1	Combination	0	0	1.227	0	0	0
105	106	COMB1	Combination	0	0	1.227	0	0	0
106	107	COMB1	Combination	0	0	1.227	0	0	0
107	108	COMB1	Combination	0	0	1.227	0	0	0
108	109	COMB1	Combination	0	0	1.227	0	0	0
109	110	COMB1	Combination	0	0	1.227	0	0	0
110	111	COMB1	Combination	0	0	1.227	0	0	0
111	112	COMB1	Combination	0	0	1.227	0	0	0
112	113	COMB1	Combination	0	0	0.614	0	0	0
113	114	COMB1	Combination	0	0	0.614	0	0	0
114	115	COMB1	Combination	0	0	0.614	0	0	0
115	116	COMB1	Combination	0	0	0.614	0	0	0
116	117	COMB1	Combination	0	0	0.614	0	0	0
117	118	COMB1	Combination	0	0	0.614	0	0	0
118	119	COMB1	Combination	0	0	0.614	0	0	0
119	120	COMB1	Combination	0	0	0.614	0	0	0

TABLE: Concrete Slab On Grade Design 01 - Flexural Data															
Strip	**Station**	**Conc Width**	**Conc Width**	**Ftop Combo**	**Ftop Moment**	**Ftop Area**	**Fbot Combo**	**Fbot Moment**	**Fbot Area**	**Fbot AMin**	**Status**	**GlobalX**	**GlobalY**	**Re-BarΦ4**	**Spacing**
Text	m	m	m	Text	kN-m	mm2	Text	kN-m	mm2	mm2	Text	m	m	mm2	mm
CSA	0.0	2	4	COMB1	-3.15	77.08	COMB1	0.00	12.51	0	OK	-1	0	12.566	163.02
CSA	0.4	2	4	COMB1	-3.47	83.85	COMB1	0.00	19.54	0	OK	-0.8	0	12.566	149.87
CSA	1.2	2	4	COMB1	-2.61	65.44	COMB1	0.00	0.00	0	OK	-0.4	0	12.566	192.03
CSA	1.4	1.4	2.8	COMB1	-2.00	47.48	COMB1	5.96	1.23	0	OK	-0.3	0	12.566	264.66
CSA	1.52	1.4	2.8	COMB1	-1.56	37.84	COMB1	0.00	0.00	0	OK	-0.24	0	12.566	332.11
CSA	1.64	1.4	2.8	COMB1	-1.40	33.12	COMB1	0.00	0.00	0	OK	-0.18	0	12.566	379.40
CSA	1.76	1.4	2.8	COMB1	-1.29	30.17	COMB1	0.00	0.00	0	OK	-0.12	0	12.566	416.49
CSA	1.88	1.4	2.8	COMB1	-1.20	27.71	COMB1	0.00	0.00	0	OK	-0.06	0	12.566	453.54
CSA	2.00	1.4	2.8	COMB1	-1.10	25.15	COMB1	0.00	0.00	0	OK	0	0	12.566	499.62
CSA	2.12	1.4	2.8	COMB1	-1.20	27.71	COMB1	0.00	0.00	0	OK	0.06	0	12.566	453.53
CSA	2.24	1.4	2.8	COMB1	-1.29	30.17	COMB1	0.00	0.00	0	OK	0.12	0	12.566	416.48
CSA	2.36	1.4	2.8	COMB1	-1.40	33.12	COMB1	0.00	0.00	0	OK	0.18	0	12.566	379.39
CSA	2.48	1.4	2.8	COMB1	-1.56	37.84	COMB1	0.00	0.00	0	OK	0.24	0	12.566	332.11
CSA	2.6	1.4	2.8	COMB1	-2.00	47.48	COMB1	5.96	1.23	0	OK	0.3	0	12.566	264.66
CSA	2.8	2	4	COMB1	-2.61	65.44	COMB1	0.00	0.00	0	OK	0.4	0	12.566	192.03
CSA	3.6	2	4	COMB1	-3.47	83.85	COMB1	0.00	19.54	0	OK	0.8	0	12.566	149.87
CSA	4.0	2	4	COMB1	-3.15	77.08	COMB1	0.00	12.51	0	OK	1	0	12.566	163.02
CSB1	0.0	2	4	COMB1	-3.15	79.88	COMB1	0.00	17.77	0	OK	0	-1	12.566	157.32
CSB1	0.4	2	4	COMB1	-3.47	87.18	COMB1	0.00	25.36	0	OK	0	-0.8	12.566	144.15
CSB1	1.2	2	4	COMB1	-2.61	67.32	COMB1	0.00	4.71	0	OK	0	-0.4	12.566	186.67
CSB1	1.4	1.4	2.8	COMB1	-2.00	49.84	COMB1	5.96	1.28	0	OK	0	-0.3	12.566	252.13
CSB1	1.52	1.4	2.8	COMB1	-1.56	39.83	COMB1	0.00	0.00	0	OK	0	-0.24	12.566	315.50
CSB1	1.64	1.4	2.8	COMB1	-1.40	34.77	COMB1	0.00	0.00	0	OK	0	-0.18	12.566	361.42

Strip	Station	Conc Width	Conc Width	Ftop Combo	Ftop Moment	Ftop Area	Fbot Combo	Fbot Moment	Fbot Area	Fbot AMin	Status	GlobalX	GlobalY	Re-BarΦ4	Spacing
Text	m	m	m	Text	kN-m	mm2	Text	kN-m	mm2	mm2	Text	m	m	mm2	mm
CSB1	1.76	1.4	2.8	COMB1	-1.29	31.62	COMB1	0.00	0.00	0	OK	0	-0.12	12.566	397.38
CSB1	1.88	1.4	2.8	COMB1	-1.20	29.00	COMB1	0.00	0.00	0	OK	0	-0.06	12.566	433.27
CSB1	2.00	1.4	2.8	COMB1	-1.10	26.30	COMB1	0.00	0.00	0	OK	0	0	12.566	477.77
CSB1	2.12	1.4	2.8	COMB1	-1.20	29.01	COMB1	0.00	0.00	0	OK	0	0.06	12.566	433.17
CSB1	2.24	1.4	2.8	COMB1	-1.29	31.63	COMB1	0.00	0.00	0	OK	0	0.12	12.566	397.30
CSB1	2.36	1.4	2.8	COMB1	-1.40	34.78	COMB1	0.00	0.00	0	OK	0	0.18	12.566	361.35
CSB1	2.48	1.4	2.8	COMB1	-1.56	39.84	COMB1	0.00	0.00	0	OK	0	0.24	12.566	315.44
CSB1	2.6	1.4	2.8	COMB1	-2.00	49.86	COMB1	5.96	1.28	0	OK	0	0.3	12.566	252.05
CSB1	2.8	2	4	COMB1	-2.61	67.32	COMB1	0.00	4.71	0	OK	0	0.4	12.566	186.66
CSB1	3.6	2	4	COMB1	-3.47	87.17	COMB1	0.00	25.35	0	OK	0	0.8	12.566	144.15
CSB1	4.00	2	4	COMB1	-3.15	79.88	COMB1	0.00	17.77	0	OK	0	1	12.566	157.32

4.3. EXPECTED FAILURE OF GROUND SUPPORTED SLABS

Failures of concrete slabs on ground are frequent. Unequal settlement or overloading may cause cracking, as well as restrained shrinkage as volume changes occur. Failures are not spectacular and do not involve collapse in the usual sense. They may even pass unnoticed for a considerable period of time. Nevertheless, the function of the structure is often impaired and repairs are both embarrassing. It is the slab which is loaded uniformly over its entire areas and is supported by an absolutely uniform, sub-grade; stresses will be due solely to restrained volumetric changes. However, foundation materials are not uniform in their properties. However, most slabs of residential buildings are subjected to uniform loading.

As said, failure of ground-supported slabs is all too common. Unequal settlement, overloading and restrained shrinkage and thermal displacement all tends to produce cracking. Slab Failure, when they occur is not spectacular and does not results in collapse in the usual scene, but the usefulness of slab may be gladly simpered, and repairs may be costly.

An area of the floor system that is crucially important is the sub-grade. The most important item is proper compaction; many floors settle and have structural cracks. Of course, organic material can't be properly compacted and must never be in the sub-grade. It is a simple fact that the floor system rests on the grade and if the Sub-grade settles, the floor settles. As a result, a common failure of slab on grade results from uplift of the sub-grade so the slabs causing negative moment on (top) causing cracking.

List of concrete floor problems

- Cracking – Structural, many fine hairline cracks in a new slab which resemble a road map
- Curling or warping - Top of slab shrinks more than bottom and slab edge lifts and Out – of - plane deformation of the corners, edges, and surface of a slab panel from its original shape
- Scaling - Hardened concrete breaking away from slab top in sheets 3mm to 6mm thick
- Dusting - Appearance of powdery material at slab surface
- Spalling - Disintegration of concrete at joint edges

- Crazing - the result of differential shrinkage of the surface zone of a concrete slab relative to the bulk and is a common feature of power-finished floors.
- Plastic shrinkage - rapid drying of the exposed concrete surface. If the rate of evaporation from the surface exceeds the rate at which bleed water rises to the surface, net shrinkage will occur (with the possibility of subsequent cracking).
- Plastic cracking - one of the worse problems that occur. Plastic shrinkage cracks form before the concrete hardness and are caused by hot, dry, and /or windy conditions. The cracks resemble the shrinkage cracks seen in clay soils during very dry weather.

Types of Cracks

- Structural
    - Structural cracks are the result of sub-grade settlement and/or stiffness discontinuity
    - Often occur when a slab is over loaded
- Shrinkage
    - Shrinkage cracks occur soon after a floor slab DRIES and will not increase in length, width or number after the drying process is completed.
- Causes of Structural Cracking
    - Virtually all structural cracks are the result of sub-grade failure (See ACI 360R-06 3)

Causes of Shrinkage Cracking

- Shrinkage cracking occurs due to the normal volumetric changes associated with drying
- Normal concrete can only stretch about 0.0167cm per meter without rupturing
- Normal shrinkage is about 0.05 cm per meter

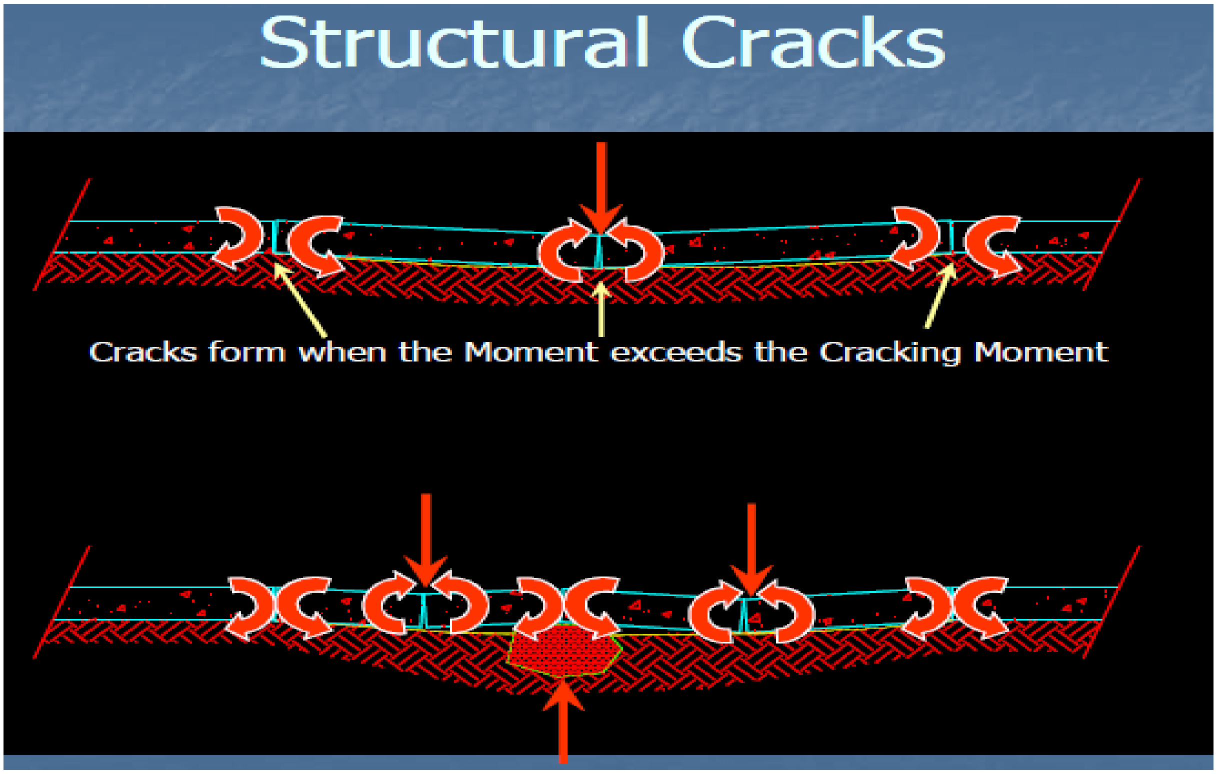


Figure 2 Structural Cracks

- If the slab is restrained against movement then cracking is inevitable or expected

Cause for cracking is due to the differential shrinkage when the top of the slab dries faster than the bottom of the slab. In addition, the differential shrinkage causes also upward edge curling, this can be problematic near walls and when considering flatness of slab surface.

Shrinkage and temperature change in slabs on ground can combine effects adversely to create warping, uplift and top crackling failures with no load. Closely spaced joint intervals, alternate-panel casting sequence, and controlled curing will avoid these failures. The bending of the foundation is due to the shrinking and swelling of the soil during the dry and wet seasons under the edges of the structure. Somewhat longer joint spacing can be specified if reinforcement with an area of about 0.0015 times the gross section area of slab is provided in perpendicular directions. With such reinforcement, warping will usually be negligible if the slab is casted in alternate lanes 350 to 450cm wide, and provided with contraction joints at 600 to 900cm spacing in the direction of casting.

Of course no matter how well designed and constructed the slab-on-grade is for light structures on shrink-swell soils, some poor practices may be very detrimental to the structure including trees too close to the structure and poor drainage.

Several generic types of shrinkage are of concern. They are:

i. Drying shrinkage
ii. Early thermal contraction
iii. Crazing
iv. Plastic shrinkage.

Crazing

Crazing is the result of differential shrinkage of the surface zone of a concrete slab relative to the bulk, and is a common feature of power-finished floors. Experience suggests that despite its appearance, crazing generally has no effect on the performance of a floor surface.

Plastic Shrinkage

The main cause of plastic shrinkage is rapid drying of the exposed concrete surface. If the rate of evaporation from the surface exceeds the rate at which bleed water rises to the surface, net shrinkage will occur (with the possibility of subsequent cracking). This is a phenomenon commonly associated with floor slabs and large mass foundations. Any early age cracks in large mass foundations are more likely to be plastic settlement which can be fixed by minimizing bleed and re-vibration.

4.4. CAUSE OF FAILURE & CONTROLLING MECHANISM

Reinforcement serves to restrain the shrinkage, effectively subdividing the slab and hence distributing the crack area more evenly. This produces smaller and more numerous cracks than would occur in an unreinforced slab of the same dimensions. The actual crack area remains essentially the same.

All concrete shrinks as the water in the concrete evaporates to the atmosphere, though the shrinkage mechanism is not fully understood. The key to minimize the drying shrinkage of concrete is to keep the water content as low as possible.

Reducing restraint on the slab

- Shrinkage cracking can be controlled by encouraging cracks to appear at predetermined locations
- Use reinforcement bar

Minimizing Shrinkage Cracking

- Shrinkage cracking can be minimized reducing the shrinkage characteristics of the concrete mix

Concrete slab will crack if tensile stresses due to applied loading or indirect loading (restraint stresses) exceeds the tensile strength of the concrete. The severity of cracking can be reduced by reinforcement. At a crack tensile force is carried by reinforcement. The effective way to reduce crack width is to use closely spaced a small diameter bars at minimum concrete cover.

Reducing Shrinkage Characteristics of the Concrete Mix

- Reduce the volume of water in the mix
- The challenge is to limit the amount of water in the mix while maintaining workability and finish-ability without excessive use of water reducers
- Use the largest sized aggregate permitted by design

When specifying low shrinkage concrete:

- Do not specify a higher strength than necessary.
- Do not exceed a water/cement ratio of 0.55.
- Consider water-reducing (super plasticizing) admixtures.
- Consider shrinkage-reducing admixtures.
- Specify the largest appropriate aggregate volume for the mix and large sized coarse aggregate can assist in this.
- Do not specify high minimum cement content.

Reducing Settlement of Soil and Slab

When potential settlement of the slab is a problem, an efficient and cost-effective solution consists of reinforcing the soil with a dense grid of vertical rigid or semi-rigid inclusions. In this scenario, a granular Load Transfer Platform is installed between the slab and the rigid inclusions.

The reduction of settlement provided by the reinforcement induces a significant reduction of the bending moment in the slab. However, the non-uniform distribution of stress reaction in a reinforced soil creates an additional stress in the slab on a different pattern from the stress reaction distribution of the loads and of the joints.

In order to avoid the mentioned problems, all the details of a concrete slab, from design to curing, must be performed appropriately. Due to the importance of the floor, a step-by-step procedure for obtaining an acceptable concrete slab-on-grade is crucial.

Position of Reinforcement bar along the slab cross section

A concrete slab with centric reinforcement is not working effectively for crack control. The centric reinforcement is so far away from cracked surface that it has practically no influence to cracking. In order to control cracking, reinforcement should be placed as close as possible to the top of slab, since the upper half of the slab has the greatest drying shrinkage. Reinforcing in the bottom half of slab is therefore not needed for indirect loading cases, but applied loading cause tensile stresses to the bottom of the slab, and thus bottom reinforcing is needed for bearing capacity. Therefore, in order to control cracking of a slab, reinforcing steel in top half of the slab is needed, and in order to increase the loading capacity of the slab, reinforcing steel in bottom of the slab is needed.

Concrete slabs on ground having requirements for crack widths, water permeability or surface coatings should be design and construct using both top and bottom reinforcing. Crack control is possible with top reinforcement and loading capacity is ensured with bottom reinforcement.

4.5. FIELD TEST AND INVESTIGATION

4.5.1. Sample slab tests

To emphasize and disprove the concrete thickness and the reinforcement used in our country, which is assumed to be over designed, a field test is conducted on four samples. The samples are 2m by 2m area at Bole – Ayat Condominium site with different concrete thickness and reinforcement bar. The concrete quality used for the samples is C-20.

The samples are:

1. Sample 1 – Concert thickness 6cm and ϕ4 wire mesh
2. Sample 2 – Concert thickness 6cm and ϕ2.5 wire mesh
3. Sample 3 – Concert thickness 6cm with no wire mesh
4. Sample 4 – Concert thickness 8cm and no wire mesh

Method of construction

The first step in the process is the concrete design mix. Rarely does low quality concrete produce a high quality floor. A C-25 concrete is recommended instead of a C-20 concrete mix due to the higher cement content and improved wear resistance. The Portland Cement Association recommends that a commercial or industrial concrete floor use a concrete with a three-day compressive strength of C-20. This requirement provides early protection from construction traffic. Water-cement ratio is also critical for concrete slabs-on-grade in order to minimize shrinkage cracking. A manual was prepared which addresses common construction problems associated with structural slab-on-grade construction. It does not address issues related to their structural design.

By compacting the soil one can minimize the chance that the soil will move in the future and that is a source of cracking known as movement cracks or heaving. Once the sub-grade is compacted, you can place stone to act as a cushion and to help keep water from migrating up through the slab.

Forming of concrete floors is reasonably straight forward. One must remember that loose or warped edge forms cause for uneven floors. Therefore, care is taken with the edge form setting to be proportional to final fitness of the floor.

To conduct sample tests of slab-on-grade the following steps and proper way is followed:

- All organic material is removed: topsoil, leaves, trees, roots, etc. Clearing to a depth of 200 mm is done
- Level the subsoil, paying particular attention to maintaining undisturbed soil beneath the building
- Undertake earth compaction
- Moisten the earth before placing concrete
- Place 25cm hard core below the slab
- Ensure that water cement ratios do not exceed 0.55

The field test pictures before concrete casting, during concrete casting and after 28 days of curing are shown in the Figure 2 to 14.

This thesis will help to study a continuously supported concrete floors at grade, to advance understand how the design of residential differ according to soil type, support condition, loading type and function of the building and to prepare optimized design which will minimize currently used thickness and reinforcement detail (spacing and area of reinforcement bar).

Drying of concrete slab on ground takes place mainly from its upper surface. Drying downward direction is negligible because of the higher moisture content of the sub-base. Moisture gradient will be thus introduced and the slab is subjected to differential shrinkage due to the drying shrinkage. This produces upward curling of the slab and tensile stresses in the upper surface.

Depending on the magnitude of drying shrinkage and degree of the restraining the tensile stresses can be greater than tensile strength of concrete causing cracking to the slab. Cracking of slab can be controlled using adequate reinforcement close to top surface mostly 1/3 from the top surface. The maximum crack width shall be less than 0.1mm and crack length shall be less than 500 mm.

Plain bar reinforcement is generally used if necessary, although in continuous slabs bottom bars are sometimes bent up to serve as negative reinforcement over the supports. Welded wire reinforcement can be employed for slabs on ground.

4.5.2. Site Sample Pictures

Figure 3 Sample #1,

Figure 4 Preparing sample #2

Figure 5 Preparing sample #3

Figure 6 Preparing sample #4

Figure 7 Fresh Concrete Cast of Sample #1*(6cm thick concrete and ϕ4 wire mesh)*

Figure 8 Fresh Concrete Cast of Sample #2 *(6cm thick concrete and ϕ 2.5 wire mesh)*

Figure 9 Fresh Concrete Cast of Sample #3 (*8cm concrete thickness with no wire mesh)*

Figure 10 Fresh Concrete Cast of Sample #4 (*6cm concrete thickness with no wire mesh)*

Figure 11 Fresh Concrete Caste of All Sample #1 - #4

Figure 12 28 days Concrete Sample #1 ***(6cm thick concrete and ϕ4 wire mesh)***

Figure 13 28 days Concrete Sample #2 ***(6cm thick concrete and ϕ 2.5 wire mesh)***

Figure 14 28 days Concrete Sample #3 (*8cm concrete thickness with no wire mesh)*

Figure 15 28 days Concrete Sample #4 (*6cm concrete thickness with no wire mesh)*

Figure 16 Applying Load to Samples

Figure 17 Applying Load to Samples

4.5.3. Limitation on the study

Some limitations were observed during the thesis study, such as;

- The Ethiopian Building Code Standard (EBCS) doesn't allow to use re-bar size less than 6cm diameter for any structure but in this thesis we provide a 4cm diameter
- Even though, the test is conducted on 2014, there is not any type of major failure on the slab.
- For resident houses with light weight load, there is no enough references or studies on slab on grade

4.6. COST IMPLICATION

On projects where the slab performance is not critical, engineering judgment should be exercised to reduce costs. A prime prerequisite for the proper design of a slab support system is soils identification. Without this knowledge, the modulus of Sub-grade reaction is unknown and potential volume change cannot be determined. With knowledge of soil classification, the engineer can select an appropriate '***k'*** value and design for the specific soil conditions.

For small projects, it may be advantageous to assume a low '***k'*** factor and add a selected thickness of crushed stone to enhance the safety factor rather than performing an expensive soil analysis. Risk of slab failure at an earlier age increases as the design is rationalized but there are occasions where the simplified design approach is justified. These decisions are a matter of engineering judgment and economics.

Our country, Ethiopia, the mega project Housing Development Project constructs 6,671 blocks since 2003 G.C to date.

From the four samples tests, which are 2m by 2m and C-20 concrete quality, we can specify the slab on ground thickness and reinforcement detail like **sample-1** and **sample-2**, which are 6cm thick concert with **ϕ4 and ϕ2.5-wire mesh**.

In the table below the cost saving between the 10cm thick slab with **ϕ8c/c 200** and 6cm thick concert with **ϕ4** c/c 200 **and ϕ2.5** c/c 200 **wire is shown in detail.**

Table 4 Cost of concrete used to be casted

Slab-On-Grade with 10 cm thick concrete and Φ6 reinforcement bar		
	Amount of Concrete	**Amount of Reinforcement**
For 1 Block	41,693.98	12,839.61
For 6,671 Blocks	278,140,550.78	85,653,066.33

Table 5 Comparison with Cost of sample 1

Slab-On-Grade with 6 cm thick concrete and Φ4 reinforcement bar		
	Amount of Concrete	**Amount of Reinforcement**
For 1 Block	25,016.39	6,897.77
For 6,671 Blocks	166,884,330.47	46,015,010.99
Difference from concrete only	-	111,256,220.31
Difference from reinforcement bar only	-	39,638,055.33
Total difference from concert and Reinforcement	-	150,894,275.64

Table 6 Comparison with Cost of sample 2

Slab-On-Grade with 6 cm thick concrete and Φ2.5 reinforcement bar		
	Amount of Concrete	**Amount of Reinforcement**
For 1 Block	25,016.39	2,633.94
For 6,671 Blocks	166,884,330.47	17,571,036.10
Difference from concrete only	-	111,256,220.31
Difference from reinforcement bar only	-	68,082,030.23
Total difference from concert and Reinforcement	-	179,338,250.54

Table 7 Comparison with Cost of sample 3

Slab-On-Grade with 6 cm thick concrete and no reinforcement bar		
	Amount of Concrete	**Amount of Reinforcement**
For 1 Block	25,016.39	
For 6,671 Blocks	166,884,330.47	
Difference from concrete only	-	111,256,220.31
Difference from reinforcement bar only	-	85,653,066.33
Total difference from concert and Reinforcement	-	196,909,286.64

Table 8 Comparison with Cost of sample 4

Slab-On-Grade with 8 cm thick concrete and no reinforcement bar		
	Amount of Concrete	**Amount of Reinforcement**
For 1 Block	33,355.19	
For 6,671 Blocks	222,512,440.62	
Difference from concrete only	-	55,628,110.16
Difference from reinforcement bar only	-	85,653,066.33
Total difference from concert and Reinforcement	-	141,281,176.48

5) CONCLUSION

Based on this thesis; from sample test results and from the safe analysis output, one can reduce slab thickness from 10cm to 6cm and reinforcement bar size including its spacing from Φ8 to Φ4 bar size center to center 30cm because concrete and reinforcement are the two primary expenses in concrete floor construction to be considered throughout the design process.

From the four sample tests result, none of the samples show any type of failure on the slab on grade such as

- Cracking – Structural, Many fine hairline cracks more than 0.1mm
- Curling or warping - Top of slab shrinks more than bottom and slab edge lifts and Out – of - plane deformation of the corners, edges, and surface of a slab panel from its original shape
- Scaling - Hardened concrete breaking away from slab top in sheets 3mm to 6mm thick
- Dusting - Appearance of powdery material at slab surface
- Spalling - Disintegration of concrete at joint edges
- Crazing - the result of differential shrinkage of the surface zone of a concrete slab relative to the bulk and is a common feature of power-finished floors.
- Plastic shrinkage - rapid drying of the exposed concrete surface. If the rate of evaporation from the surface exceeds the rate at which bleed water rises to the surface, net shrinkage will occur (with the possibility of subsequent cracking).
- Plastic cracking - one of the worse problems that occur. Plastic shrinkage cracks form before the concrete hardness and are caused by hot, dry, and /or windy conditions. The cracks resemble the shrinkage cracks seen in clay soils during very dry weather.

Since, the expected failures are not seen in the sample slabs one can say

- 6 cm thick concrete slab-on-grade with Φ4 reinforcement bar can work
- 6 cm thick concrete slab-on-grade with Φ2.5 reinforcement bar can work
- Show 6 cm thick plain concrete slab-on-grade can work

- Show 8 cm thick plain concrete slab-on-grade can work

Besides, for every building special for mass construction such as condominium buildings, the slab on grade has to designed as per the parameters to design and construct slab on grade such as

- Geotechnical soil properties and Capacities:
    - Soil type,
    - Allowable Soil Bearing Pressure,
    - Standard Modulus of Sub-Grade Reaction,
    - Slab Stiffness,
    - Depth of Active Moisture Zone,
    - Shrink-Swell Potential,
    - Soil Surface Suction Change.
- Support condition,
- Compressive Strength of Concrete,
- Slab Length,
- Uniform Storage and Imposed Loading,

On the other hand, to be safe enough, a 6cm thick concrete slab-on-grade is better with Φ4 wire mesh. The Φ4 wire mesh is important to limit crack widths due to shrinkage and temperature restraint and applied loads because severity of cracks can be reduced by reinforcement. if there is a probability of sever cracks occurrence, closely spaced small diameter bars at minimum concrete cover will be effective.

Above and beyond, on top of the 6cm thick slab, from our country's experience for finishing purpose 5cm cement screed and different type of finished tiles like ceramics, granite, wooden material or plastic (PVC) material is used above the slab, where the finishing material thickness ranges from 10mm to 25mm. Therefore, the total thickness of the slab will be more than 6cm and the total thickness will adequate to withstand the influence of sub grade reaction.

6) REFERENCE

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I declare that ‘‘this thesis is my original work and has not been presented for a degree in any other university, and that all sources of material used for the thesis have been duly acknowledged’’.

____________________________ ____________________________

Student Signature Supervisor/Advisor Signature