

## FOUNDATIONS ON EXPANSIVE SOILS

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### INTRODUCTION

It is a well known fact that expansive soils pose considerable problems in civil engineering constructions. Structures built on such soils show movements which are often detrimental and lead to structural damage. Damage from these soils is evidenced in many costly ways and is particularly obvious in buildings and pavements.

Several methods are suggested as solutions to prevent damage to buildings in expansive soil areas. Some of these have been used in this country over the last decade. The object of this paper is to familiarize the practicing engineer with those methods which have been tested under local conditions and find out to be most suitable and economical. The paper also attempts to present briefly the various solutions that exist to prevent building damage resulting from heave of expansive soils.

### CHARACTERISTIC OF EXPANSIVE SOILS

Expansive soils are clayey soils. As the name indicates, the main characteristic of an expansive soil is that it shrinks on drying and swells on wetting. The swelling potential of such a soil is measurable and is determined in the laboratory.

Different types of swelling tests are conducted in the laboratory. The most common ones are: the free swell, percentage swell, and swelling pressure tests. The free swell consists of placing a known volume of dry soil in water and noting the increase in volume. The difference between the final and initial volume, expressed as a percentage of initial volume, is the free swell. The free swell test is a very crude test and had been used in early days when refined testing methods

were not available. The percentage swell and swelling pressure tests, on the other hand, are more accurate methods and are conducted in the laboratory with undisturbed samples in one-dimensional consolidation test apparatus. Percentage swell is defined as the vertical expansion of a swelling soil expressed in percent of the initial height of the sample, whereas swelling pressure is the pressure required to keep the volume of a swelling soil sample constant. Table 1 gives limits of free swell, percentage swell, and swelling pressure for different degrees of expansiveness of swelling soils. Most expansive soils found in Addis Ababa have free swell and swelling pressure amounting to values of above 100% and 1.0 kp/cm<sup>2</sup> respectively.

From laboratory investigations, factors influencing the swelling potential of expansive soils have been found to be: initial moisture content, initial dry density, degree of saturation, thickness of soil stratum and the surcharge load. The percentage swell, or heave, is noted to decrease by increasing the initial moisture content and degree of saturation. This implies that prewetting on expansive soil, will reduce the amount of heave. Percentage swell is observed to decrease by increasing the surcharge load and decreasing the initial dry density of the soil. From this it can be concluded that by increasing the pressure under a foundation or pavement heaving will be reduced. Furthermore, the amount of heave decreases with the decrease in thickness of the swelling soil stratum. This again implies that removing part of the expansive soil or lowering the foundation deeper than normally needed for stable soils will reduce the amount of heave.

## SURVEY OF METHODS OF PREVENTING HEAVE DAMAGE

### Moisture Control

In this method attempt is made to prevent surface water which may seep into a building foundation by providing moisture barriers above and around the foundation soil, and adequate surface and subsurface drainage systems. Polythylene, concrete, asphalt and fine-grained soil layers are the most commonly used moisture barrier materials. The performance of this method is found effective in fuel station buildings where large area is covered with asphalt pavements. For ordinary buildings, however, it is less effective and requires high cost.

### Soil Stabilization

In this method effort is made to minimize the swelling potential of expansive soil by one or more of the following methods, namely: soil replacement, prewetting, compaction control and chemical treatment.

In soil replacement method, some or all of the swelling soil is removed and replaced with non-swelling fine-grained soil. This method is recommended for cases where the thickness of expansive soil is small, less than 2.5m.

In prewetting method, the soil is flooded to achieve swelling prior to commencement of construction. This, however, has a disadvantage in reducing bearing capacity of foundation soil and in inducing further swelling of lower soils long after completion of building. The performance of this method is found satisfactory with pavements and canal linings.

In compaction control method, the upper soil is scarified and recompacted to low soil density. This reduces the swelling property and heave of the expansive soil. The draw-back with this method is that the low density compaction will result in low bearing capacity of subgrade of foundation soil.

In the chemical treatment method, lime is injected into the expansive soil. Lime will reduce plasticity and hence the swelling potential of the soil. The performance of lime stabilization in highway and airport construction is encouraging, although the depth of treatment required and the results of treatment on a long term basis has not been evaluated. Use of lime stabilization for foundation soils is not advised.

## STRUCTURAL MEASURES

This is the most effective and widely used method. In this method one of the following measures is employed, namely: designing the building as a rigid unit, providing flexibility to buildings, and providing deep foundations.

A rigid building is one which is free from uneven displacement which might cause structural damage. Rigidity of a building can be achieved by providing adequate reinforcement to foundation, beams, slabs and walls in such a manner that all of these will result in a monolithic form of building (see Fig. 1); for example, stiffened hollow block wall construction on stiffened slab foundation (see Fig. 2). This method is recommended for light and compact buildings.

A flexible building is one which allows differential movement to occur between its members without itself being damaged. Flexibility can be achieved by dividing the building into small rigid compartments with flexible joints. This method is recommended for long buildings.

Where deep foundations, such as, piles are used, the pile should be placed in non-swelling stable zone (i.e., greater than 3.5m depth); bottom of piles should be enlarged (under-reamed) to increase bearing and anchoring capacities of the piles (see Fig. 3); piles should be protected from tension failure by either decreasing pile diameter or increasing loading on the pile as high as possible, or by reinforcing pile for tensile force due to soil heave, or by providing pile with sleeve (of weak spongy material) (see Fig. 4) in order to isolate pile shaft from soil.

## RECOMMENDED FOUNDATION DESIGN

The types of measures that could be taken to avoid damage to buildings in expansive soil areas have been discussed. The measure found most suitable and economical varies from country to country. For instance, in the United States and Australia, stiffened slab foundation is found to be economical for light residential buildings. In South Africa, the recommended practice is to use flexible type of construction. In India, under-reamed pile foundations are found cheaper and recommended for both single and multi-story buildings (Fig. 3). In Israel, for one and two storey buildings, best result is obtained by using short piles (with sleeve around the top two meters of the piles) and increasing the rigidity of the building (Fig. 1).

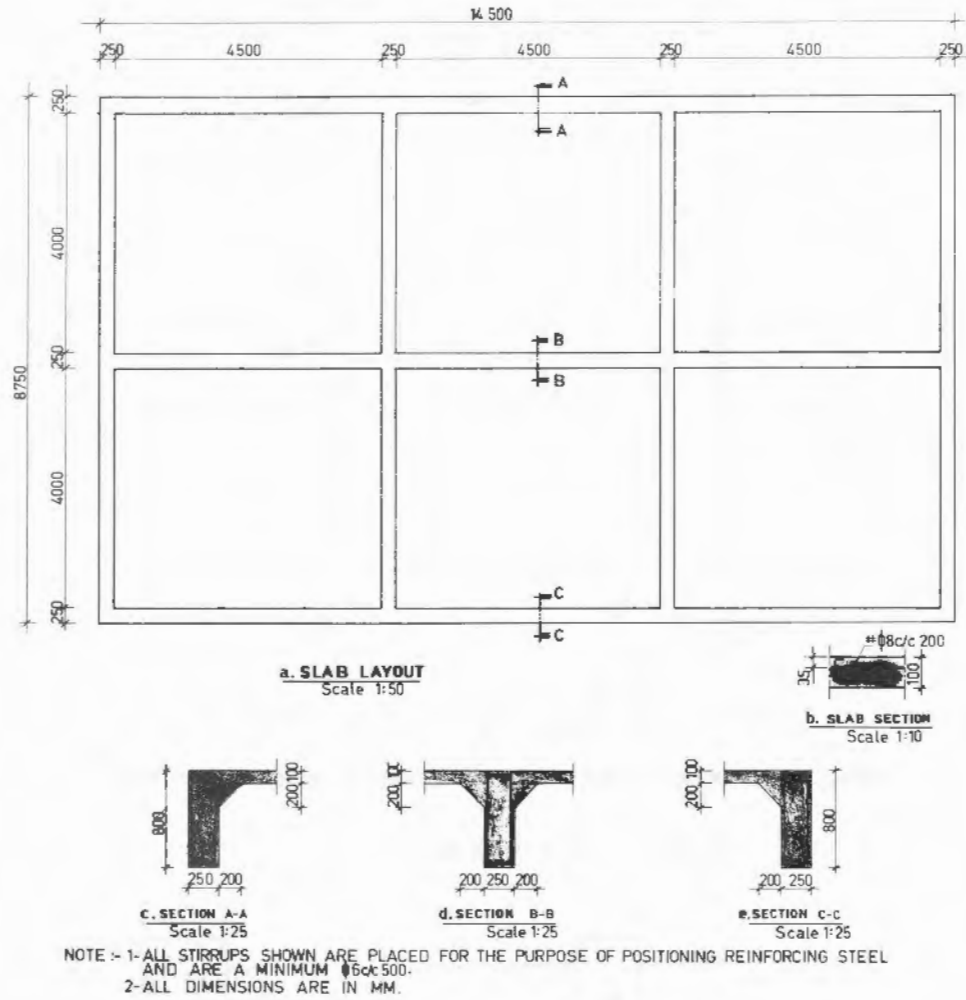


Fig. 1 Slab Layout and Reinforcement

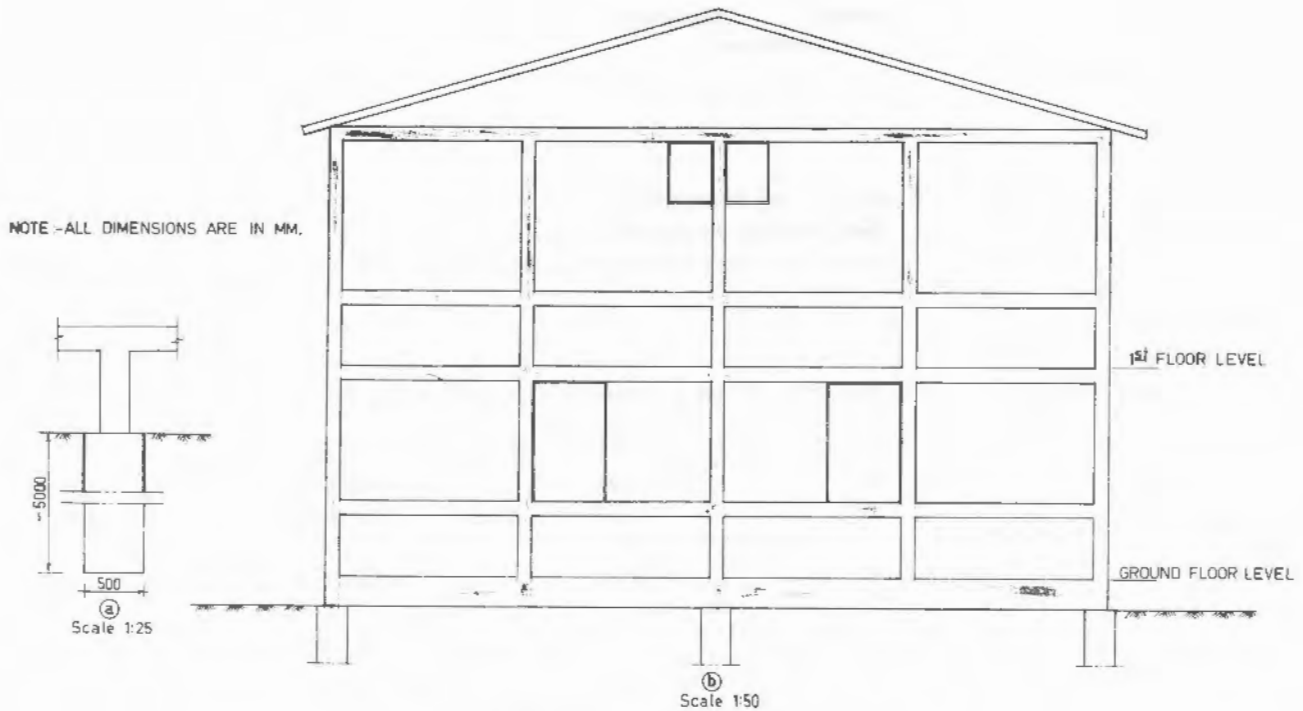


Fig. 2 Recommended Type of Construction

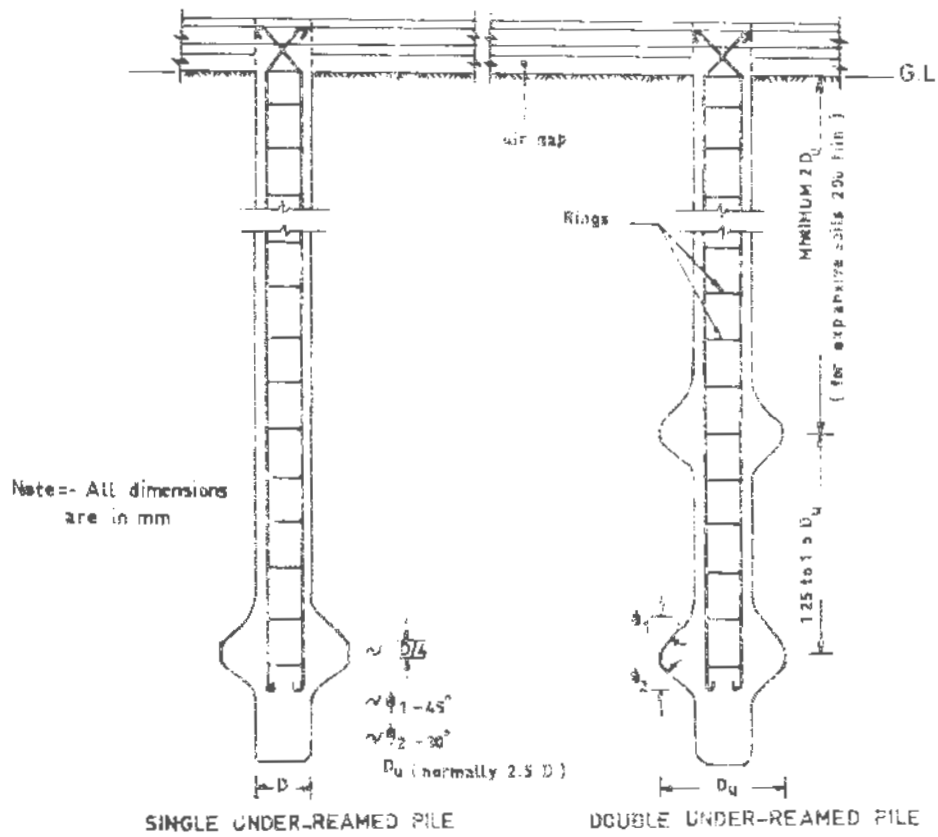


Fig. 3 Typical Details of Under-Reamed Piles

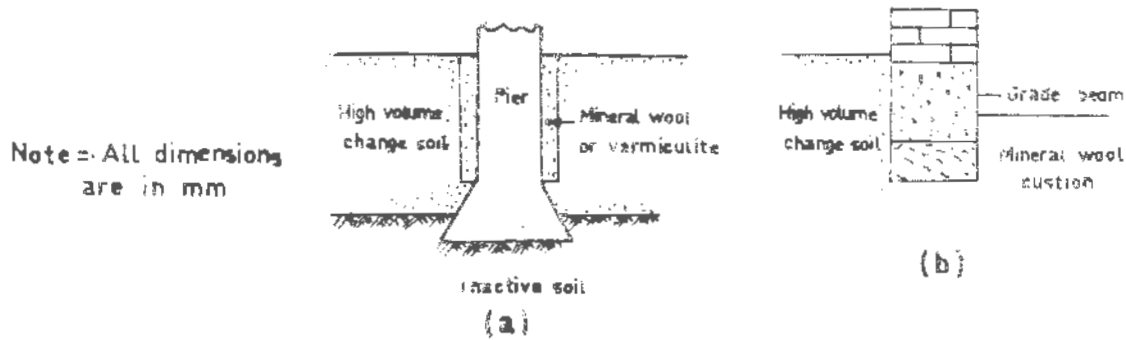


Fig. 4 Foundations for Heaving Soils  
 (a) Deep Pier with Insulation for Heave  
 (b) Grade Beam with Subfill of Compressible Material

Table 1. Limits of Swelling Potentials of Soils as Given by Different Swelling Tests

Degree of Expansiveness	Free Swell (%)	Percentage Swell (%)	Swelling Pressure (kp/cm <sup>2</sup> )
Low or none	Less than 50	Less than 1	Less than 0.2
Medium	50 to 100	1 to 5	0.2 to 1.0
High	Greater than 100	Greater than 5	Greater than 1.0

The above mentioned countries arrived at such conclusions and recommendations based on their local conditions, such as labour and material cost, and long term experience on the performance of buildings constructed in expansive soil areas. The latter, unfortunately, is missing in Ethiopia, and because of this it is difficult to adopt easily one of the measures employed elsewhere.

In Ethiopia, stiffened slab foundation, under-reamed pile foundation, flexible type of construction and conventional types of foundations with provisions, such as soil replacement and improved drained systems have been used during the last decade. As there has been no agency interested in following up the behaviour of such buildings, it is difficult to give definite recommendations. However, based on the author's experiences some recommendations are presented hereunder. The proposals given are based on the types of buildings and degree of expansiveness of the soils (see Table 2). The proposals are expected to provide minimum cost for the tolerable amount of building damage, and they should not be considered as absolute solutions to all expansive soil problems.

Currently, thousands of compact light-weight residential buildings are being constructed in Addis Ababa and other major towns of our country. Because of the existing housing shortages more buildings are envisaged to be constructed in the future. As some of this buildings are to be located on the expansive soil areas (at least in Addis Ababa) it seems proper for the author to present a detailed design procedure for the stiffened mat (or slab) foundation (see Appendix A).

The design procedure is adopted from Ref. 3. The author has proposed modification in some of the design parameters, such as support index and allowable steel stress in order to reduce the amount of reinforcement in the beams. By changing the value of the support index,  $C$ , from 0.6 to 0.8 and the value of allowable steel stress from 1400 to about 1800  $\text{kp}/\text{cm}^2$ , the amount of steel reinforcement can be reduced by half. The author has witnessed the satisfactory performance of buildings designed with the incorporation of the above modification over the past five years.

Table 2. Recommended Foundations on Expansive Soils

Type of Building	Degree of Expansiveness	Recommended Foundation
Long store, workshop and similar buildings	Moderate to High	3.0m deep isolated footing foundation with 1.0m thick soil replacement under the ground slab and improved drainage systems
Compact: light residential and single storey office buildings	Moderate	3.0m deep isolated footing foundation with 1.0m thick soil replacement under the ground slab and improved drainage systems
Compact: light residential and single storey office buildings	High	Stiffened slab foundations, with split or flexible type of construction if the building is longer than 15m. Improved drainage system is essential
Multi-storey and movement sensitive factory or other buildings	Moderate to High	Under-reamed pile foundation with suspended floor slabs and grade beams, and increased rigidity of the building

To give some idea to the reader the following design values are given hereunder.

#### Assumed.

An ordinary residential building; size 8m by 12m, constructed with brick-walls, and corrugated iron sheet roofing.

#### Design values.

- (a) Number of beams in long direction = 3
- (b) Number of beams in short direction = 4
- (c) Sizes of beams in both direction.
  - width = 25cm
  - depth = 75cm
- (d) Reinforcement in long beams
  - top = 4  $\phi$  16
  - bottom = 4  $\phi$  18
- (e) Reinforcement in short beams
  - top = 3  $\phi$  16
  - bottom = 3  $\phi$  16
- (f) Thickness of slab = 10cm
- (g) Reinforcement in slab =  $\phi$  8 center-to-center 20 cm in both direction; slab reinforcement placed at 1/3 slab thickness from upper surface of the slab.

### APPENDIX A — DESIGN PROCEDURE FOR STIFFENED MAT FOUNDATION ON EXPANSIVE SOIL

#### Step 1

Estimate the total average dead and live load on the slab.

- (a) Estimate the per-square-meter load ( $W_d$ ) of the slab itself from the empirical formula:

$$W_d = (32.5L + 145) \text{ in } \text{kp/m}^2 \quad (\text{A-1})$$

where,

$L$  = the long side of the rectangular slab in meter.

- (b) Compute the total super-structure load ( $W_s$ ) allowing for a live load of 150 kp/m<sup>2</sup> of floor area and 50 kp/m<sup>2</sup> of roof area and introducing all super-structure load with their true value.

- (c) Set average total load

$$W = W_d + W_s \quad (\text{A-2})$$

#### Step 2

Use support index  $C = 0.6$  for expansive soil. Support index  $C$  depends on criterion for soil sensitivity and climatic rating. (The support index  $C$  may assume a value up to 0.8.)

#### Step 3

Obtain the maximum allowable deflection ratio  $\frac{\Delta}{L}$  for the contemplated type of super-structure. The following may be used:

$$\frac{\Delta}{L} = 1/200 \text{ for wooden wall}$$

$$\frac{\Delta}{L} = 1/300 \text{ for unplastered or gypsum wall board}$$

$$\frac{\Delta}{L} = 1/360 \text{ for stucco or plastered wall.}$$

#### Step 4

Divide the slab of irregular shape into overlapping rectangles in such a fashion that the resulting boundary provides complete congruence with the slab perimeter.

#### Step 5

Determine the effective load, ( $\bar{W}$ ), along the long ( $L$ ) and short ( $L'$ ) dimensions of the slab. i.e.,

$$\text{for long dimension } \bar{W}_L = W(1 - C) \quad (\text{A-3})$$

$$\text{for short dimension } \bar{W}_s = W\alpha(1 - C) \quad (\text{A-4})$$

where  $\alpha$  is the reduction factor and is equal to 0.5 or  $1.4 - 0.4(L/L')$ , whichever is greater.

#### Step 6

Select a layout for the stiffening beams. The beams should be spaced equidistant along each slab side not to exceed a 4.5m clear spacing, and, preferably a spacing between corresponding beams of overlapping rectangles of irregularly shaped slabs should coincide, eventhough some variation in spacing may result. In any event, the spacing of beams along any side should be kept as nearly equal as possible.

#### Step 7

Select the basic dimensions. In cases where  $L/L'$  exceeds 2, the beams along the short dimension can be designed with smaller depth than in the long dimension, provided

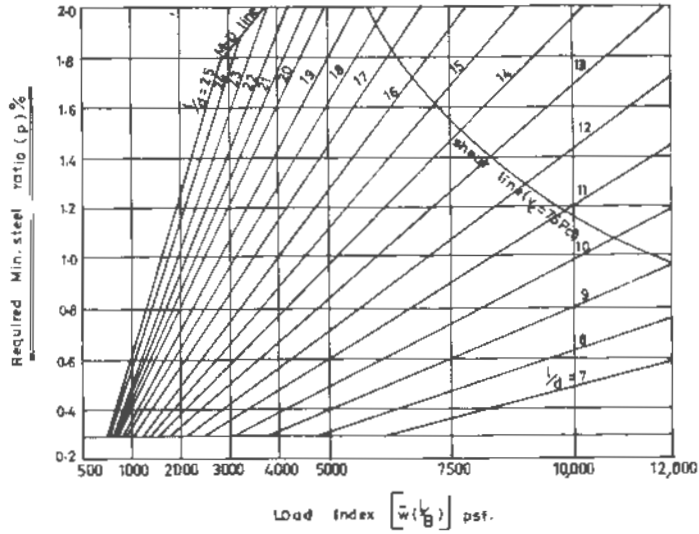


Fig. A-1 Steel Ratio for  $\Delta/L = 1/200$

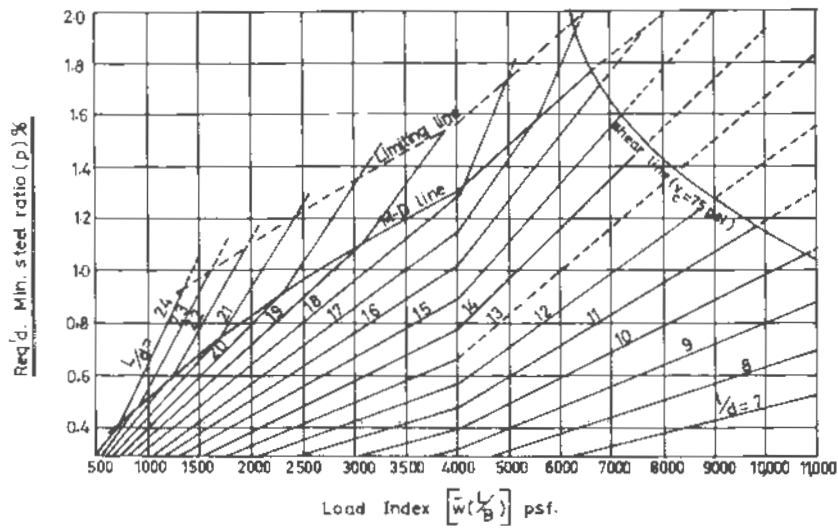


Fig. A-2 Steel Ratio for  $\Delta/L = 1/300$

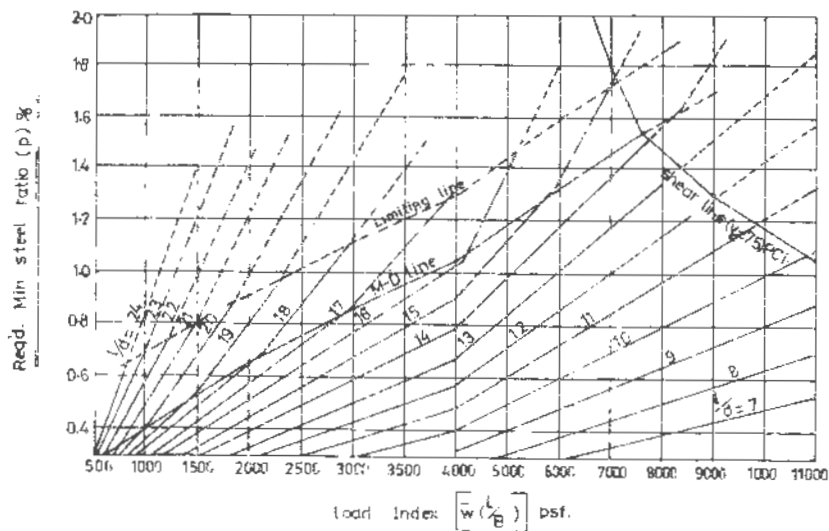


Fig. A-3 Steel Ratio for  $\Delta/L = 1/360$

there are definite cost or construction advantages and design computations have been adjusted properly. Select a trial ratio ( $L/d$ ) using the following rule-of-thumb values:

- (i)  $L/d > 20$  for  $\bar{W}_L < 120 \text{ kp/m}^2$
- (ii)  $L/d = 18 \text{ to } 20$  for  $\bar{W}_L = 120 \text{ to } 240 \text{ kp/m}^2$
- (iii)  $L/d = 14 \text{ to } 18$  for  $\bar{W}_L = 240 \text{ to } 720 \text{ kp/m}^2$

Select tentative design values for beam widths:

$B$  and  $B'$  (for  $L$  and  $L'$ , respectively)

$B = N_L b$ , where  $N_L$  = number of beams in long direction

$B = N_S b$ , where  $N_S$  = number of beams in short direction

preferably  $b$  should not be less than 20 cm and more than 35 cm.

#### Step 8

Compute the load index

$$W_s(L/B')$$
 in  $\text{kp/m}^2$  in short direction.

#### Step 9

Calculate  $L/d$  ratio

$L/d$  for long beam

$L'/d$  for short beam.

#### Step 10

Determine the steel ratio using the charts given in Figs. A1, A2 and A3 and the values obtained from Steps 8 and 9.

$$\text{Long beam : } L/V_s \bar{W}_L (L'/B) = p$$

$$\text{Short beam : } L'/d V_s \bar{W}_s (L/B') = p'$$

#### Step 11

Calculate reinforcement

$$\text{Long beam (bottom) : } A_s = pbd$$

$$\text{(top) : } A_s' = A_s - 4.0 \text{ cm}^2$$

$$\text{Short beam (bottom) : } A_s = p'bd$$

$$\text{(top) : } A_s' = A_s - 4.0 \text{ cm}^2$$

$A_s$  and  $A_s'$  values may be reduced by using higher allowable steel stress and using a correcting factor of 0.8.

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