

## Review: Design of Post Tensioned Slab

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**ABSTRACT-** The objective of the present report is to summarize the experience available today in the field of post-tensioning in building construction and in particular to discuss the design and construction of post tensioned slab structures. A detailed explanation will be given of the checks to be carried out, the aspects to be considered in the design and the construction procedures and sequences of a post-tensioned slab. The execution of the design will be explained with reference to an example. In addition, already built structures will be described. In all the chapters, both bonded and unbonded post-tensioning will be dealt with.

Index Terms- **Post-tension slab, Prestressing, flexibility**

### 1. INTRODUCTION

Concrete is one of the most common building materials in civil engineering, due to its simple production, high compressive strength and versatility in form and application. However, concrete is a brittle material with a relatively low tensile strength, making it subjected to cracking. These problems are generally overcome by using reinforcement of various types; the most common is using regular reinforcement bars to carry tensile stresses where it is needed. Research has shown that labour on the construction site, such as preparation of formwork, placing of reinforcement bars and finishing of the concrete, can provide costs of the same magnitude as the material costs. Therefore, it is desirable to investigate new technologies that can contribute to saving labour time during construction and provide a more efficient solution.

**MAJOR HEADINGS**  
- Good crack behavior and therefore permanent protection of the steel against corrosion.

- Almost unchanged serviceability even after considerable overload, since temporary cracks close again after the overload has disappeared.

- High fatigue strength, since the amplitude of the stress changes in the prestressing steel under alternating loads are quite small.

### 2. LITERATURE REVIEW

Although some post-tensioned slab structures had been constructed in Europe quite early on, the real development took place in the USA and Australia. The first post tensioned slabs were erected in the USA in 1955, already

using unbounded post tensioning. Intensive research work, especially in Switzerland, the Netherlands and Denmark and more recently also in the Federal Republic of Germany have expanded the knowledge available on the behavior of such structures. These studies form the basis for standards, now in existence or in preparation in some countries. From purely empirical beginnings, a technically reliable and economical form of construction has arisen over the years as a result of the efforts of many participants. Intensive research work, especially in Switzerland, the Netherlands and Denmark and more recently also in the Federal Republic of Germany have expanded the knowledge available on the behavior of such structures. These studies form the basis for standards, now in existence or in preparation in some countries. From purely empirical beginnings, a technically reliable and economical form of construction has arisen over the years as a result of the efforts of many participants.

#### **2.1 Post-tensioning with or without bonding of tendons**

##### **2.1.1. Bonded post-tensioning**

As is well-known, in this method of post tensioning the prestressing steel is placed in ducts, and after stressing is bonded to the surrounding concrete by grouting with cement suspension. Round corrugated ducts are normally used. For the relatively thin floor slabs of buildings, the reduction in the possible eccentricity of the prestressing steel with this arrangement is, however, too large, in particular at cross-over points, and for this reason flat ducts have become common. They normally contain tendons comprising four strands of nominal diameter 13 mm, which

have proved to be logical for constructional reasons.

### 2.1.2 Typical applications of post-tensioned slabs

As already mentioned, this report is concerned exclusively with post-tensioned slab structures. Nevertheless, it may be pointed out here that post-tensioning can also be of economic interest in the following components of a multi-storey building:

- Foundation slabs.
- Cantilevered structures, such as overhanging buildings.
- Facade elements of large area; here light post-tensioning is a simple method of preventing cracks
- Main beams in the form of girders, lattice girders or north-light roofs.
- For spans of 7 to 12 m, and live loads up to approx. 5 KN/m<sup>2</sup>, flat slabs or slabs with shallow main beams running in one direction without column head drops or flares are usually selected.
- For larger spans and live loads, flat slabs with column head drops or flares, slabs with main beams in both directions and waffle are used.

## 3. FUNDAMENTALS OF THE DESIGN PROCESS

### 4.1. General

The objective of calculations and detailed design is to dimension a structure so that it will satisfactorily undertake the function for which it is intended in the service state, will possess the required safety against failure, and will be economical to construct and maintain. Recent specifications therefore demand a design for the ultimate and serviceability limit states.

#### Ultimate limit state:

This occurs when the ultimate load is reached; this load may be limited by yielding of the steel, compression failure of the concrete, instability of the structure or material fatigue. The ultimate load should be determined by calculation as accurately as possible, since the ultimate limit state is usually the determining criterion.

#### Serviceability limit state:

Here rules must be complied with, which limit cracking, deflections and vibrations so that the normal use of a structure is assured. The rules should also result in satisfactory fatigue strength.

## 3.2 Ultimate limit state

### 3.2.1. General principles of calculation

Bonded and unbonded post-tensioned slabs can be designed according to the known methods of the theories of elasticity and plasticity in an analogous manner to ordinarily reinforced slabs. A distinction is made between the following methods:

A. Calculation of moments and shear forces according to the theory of elasticity; the sections are designed for ultimate load.

B. Calculation and design according to the theory of plasticity.

#### Method A

In this method, still frequently chosen today, moments and shear forces resulting from applied loads are calculated according to the elastic theory for thin plates by the method of equivalent frames, by the beam method or by numerical methods (finite differences, finite elements). The prestress should not be considered as an applied load. It should intentionally be taken into account only in the determination of the ultimate strength. No moments and shear forces due to prestress and therefore also no secondary moments should be calculated. The moments and shear forces due to applied loads multiplied by the load factor must be smaller at every section than the ultimate strength divided by the cross-section factor

#### Method B

In practice, the theory of plasticity, is being increasingly used for calculation and design. The following explanations show how its application to flat slabs leads to a storable ultimate load calculation which will be easily understood by the reader. The mechanism to be chosen is that which leads to the lowest load. It illustrates mechanisms for an internal span. In flat slabs with usual column dimensions ( $\xi > 0.06$ ) the ultimate load can be determined to a high degree of accuracy by the line mechanisms. In the region of the column, a portion of the internal work is thereby neglected, which leads to the result that the load calculated in this way lies very close to

the ultimate load or below it. On the assumption of uniformly distributed top and bottom reinforcement, the ultimate design loads of the various mechanisms are compared. In post-tensioned flat slabs, the prestressing and the ordinary reinforcement are not uniformly distributed. In the approximation, however, both are assumed as uniformly distributed over the width  $l/2 + 12/2$ .

### 3.2.2 Deflections

Post-tensioning has a favorable influence upon the deflections of slabs under service loads. Since, however, post-tensioning also makes possible thinner slabs, a portion of this advantage is lost. As already mentioned the load-balancing method is very suitable for calculating deflections. Under permanent loads, which may with advantage be largely compensated by the transverse components from post-tensioning, the deflections can be determined on the assumption of uncracked concrete. Under live loads, however, the stiffness is reduced by the formation of cracks. In slabs with bonded post-tensioning, the maximum loss of stiffness can be estimated from the normal reinforced concrete theory. In slabs with unbonded post-tensioning, the reduction in stiffness, which is very large in a simple beam reinforced by unbonded post-tensioning, is kept within limits in edge spans by the ordinary reinforcement necessary for crack distribution, and in internal spans by the effect of the lateral restraint.

### 3.3 Post-tensioning force in the tendon

#### 3.3.1 Losses due to friction

For monostrands, the frictional losses are very small. Various experiments have demonstrated that the coefficients of friction  $\mu = 0.06$  and  $k = 0.0005/m$  can be assumed. It is therefore adequate for the design to adopt a lump sum figure of 2.5% prestressing force loss per 10 m length of strand. A constant force over the entire length becomes established in the course of time. For bonded cables, the frictional coefficients are higher and the force does not become uniformly distributed over the entire length. The calculation of the frictional losses is carried out by means of the well-known formula  $PX = P_0 \cdot e^{-(\mu a + kx)}$ . The force loss resulting from wedge drawing when the strands are locked off in the anchorage can usually be compensated by overstressing. It is

only in relatively short cables that the loss must be directly allowed.

### 3.4 Detail design aspects

#### 3.4.1 Bonded post-tensioning

The corrosion protection of grouted tendons is assured by the cement suspension injected after stressing. If the grouting operations are carefully carried out no problems arise in regard to protection. The anchorage block-outs are filled with low shrinkage mortar.

## 4 METHODOLOGY

### 4.1 One-way Slabs

This section covers the following topics.

- Introduction
- Analysis and Design

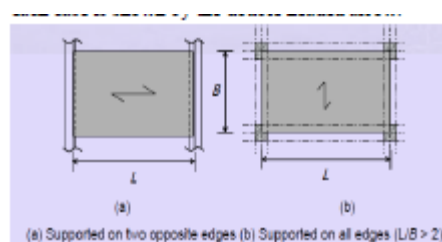
#### 4.1.1 Introduction

Slabs are an important structural component where prestressing is applied. With increase in the demand for fast track, economical and efficient construction, prestressed slabs are becoming popular. The slabs are presented in two groups:

**one-way slabs** and **two-way slabs**. Rectangular slabs can be divided into the two groups based on the support conditions and length-to-breadth ratios. The one-way slabs are identified as follows.

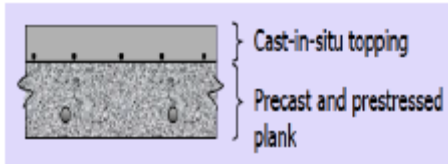
- 1) When a rectangular slab is supported only on two opposite edges, it is a one-way slab spanning in the direction perpendicular to the edges. Precast planks fall in this group.
- 2) When a rectangular slab is supported on all the four edges and the length-to-breadth ( $L/B$ ) ratio is equal to or greater than two, the slab is considered to be a one-way slab. The slab spans predominantly in the direction parallel to the shorter edge.

The following sketches show the plans of the two cases of one-way slabs. The spanning direction in each case is shown by the double headed arrow.



**Fig – One way slab**

Slabs can be composite for the benefits of reduction in form work, cost and time of construction and quality control. A precast plank can be prestressed and placed in the final location. A topping slab is overlaid on the precast plank. The grades of concrete in the two portions can be different. The following sketches show the sections of some one-way slabs.



## 4.2 Two-way Slabs

This section covers the following topics.

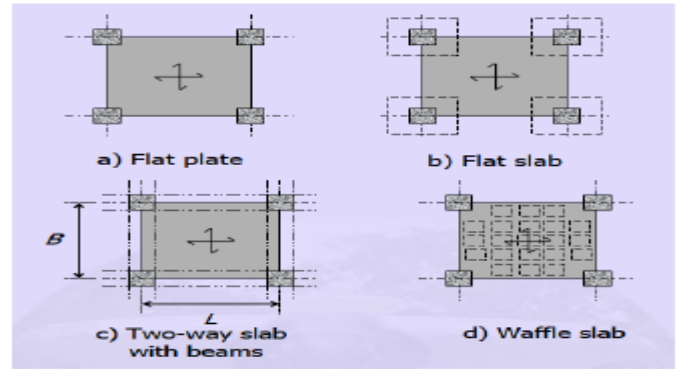
- Introduction
- Analysis and Design
- Features in Modeling and Analysis
- Distribution of Moments to Strips

### 4.2.1 Introduction

A rectangular slab is supported on all the sides and the length-to-breadth ratio is less than two, it is considered to be a two-way slab. The slab spans in both the orthogonal directions. A circular slab is a two-way slab. In general, a slab which is not falling in the category of one-way slab, is considered to be a two-way slab. -Rectangular two-way slabs can be divided into the following types.

- 1) Flat plates: These slabs do not have beams between the columns, drop panels or column capitals. Usually, there are spandrel beams at the edges.
- 2) Flat slabs: These slabs do not have beams but have drop panels or column capitals.
- 3) Two-way slabs with beams: There are beams between the columns. If the beams are wide and shallow, they are termed as band beams.

Two-way slabs are also present as mat (raft) foundation. The following sketches show the plan of various cases of two-way slabs. The spanning directions in each case are shown by the double headed arrows.



**Fig:- Design Two Way Slab**

The absence of beams in flat plates and flat slabs lead to the following advantages.

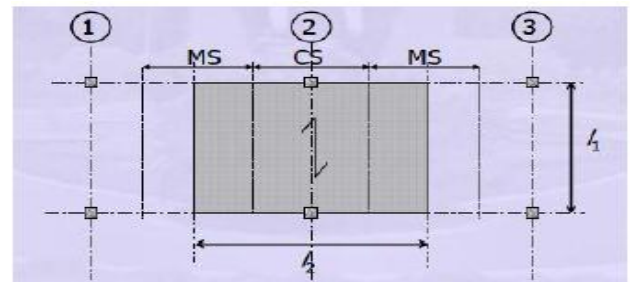
- 1) Formwork is simpler
- 2) Reduced obstruction to service conduits
- 3) More flexibility in interior layout and future refurbishment.

### 4.2.2 Analysis and Design

#### 4.2.2.1 Analysis

The analysis of two-way slabs is given in **Section 31, IS:456 - 2000**, under “Flat Slabs”. The analysis is applicable to flat plates, flat slabs and two-way slabs with deflecting beams. For two-way slabs with beams, if the beams are sufficiently stiff, then the method (based on moment coefficients) given in Annex D, **IS:456 – 2000**, is applicable.

The direct design method of analyzing a two-way slab is not recommended for prestressed slabs. The equivalent frame method is recommended by **ACI 318-02**. It is given in **Subsection 31.5, IS:456 - 2000**. This method is briefly covered in this section for flat plates and flat slabs. The following figure shows the division in to strips along one direction. The direction under investigation is shown by the double headed arrow.



**Fig:- c/s of slab**

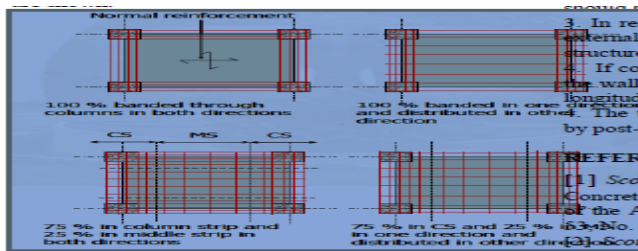
In the above figure,

$l_1$  = span of the equivalent frame in a bay

$l/2$  = width of the equivalent frame. This is the tributary width for calculating the loads.

#### 4.2.2.2 Design

Once the design moments per unit width of the CS and MS are known, the steps of design for prestressing steel are same as that for one-way slab. The profile of the tendons is selected similar to that for continuous beams. The flexural capacity of prestressed slab is controlled by total amount of prestressing steel and prestress rather than by tendon distribution. But the tendon distribution effects the load balancing. Some examples of tendon distribution are shown.



Maximum spacing of tendons or groups of tendons should be limited to  $8h$  or 1.5 m, whichever is less. Here,  $h$  is the thickness of the slab. A minimum of two tendons shall be provided in each direction through the critical section for punching shear around a column. The ducts for placing the individual strands are oval shaped to maintain the eccentricity, reduce frictional losses and convenient placement of crossing ducts. The ducts are not commonly grouted as the use of unbonded tendon is not detrimental in buildings.

The following photo shows the ducts for the prestressing tendons and the non-prestressed reinforcement in a two-way slab.



## 5. CONCLUSIONS

1. In slabs of more than 30 m length, a uniform, homogeneous deformation behavior of the slabs and walls in the longitudinal direction should be aimed at.

2. In closed buildings with concrete walls or columns, a homogeneous behavior for shrinkage and creep should be achieved.
3. In respect of temperature, however, the concreted external walls behave differently from the internal structure.
4. If cooling down occurs, tensile stresses develop in the wall. Distribution of the cracks can be ensured by longitudinal reinforcement.
5. The tensile stresses may also be compensated for by post-tensioning the wall.

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