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VSL REPORT SERIES

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# POST-TENSIONED SLABS

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**Fundamentals of the design process**

**Ultimate limit state**

**Serviceability limit state**

**Detailed design aspects**

**Construction Procedures**

**Preliminary Design**

**Execution of the calculations**

**Completed structures**

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## Foreword

With the publication of this technical report, VSL INTERNATIONAL LTD is pleased to make a contribution to the development of Civil Engineering.

The research work carried out throughout the world in the field of post-tensioned slab structures and the associated practical experience have been reviewed and analysed in order to establish the recommendations and guidelines set out in this report. The document is intended primarily for design engineers, but we shall be very pleased if it is also of use to contractors and clients. Through our

representatives we offer to interested parties throughout the world our assistance and support in the planning, design and construction of post-tensioned buildings in general and post-tensioned slabs in particular.

I would like to thank the authors and all those who in some way have made a contribution to the realization of this report for their excellent work. My special thanks are due to Professor Dr B. Thürlimann of the Swiss Federal Institute of Technology (ETH) Zürich and his colleagues, who were good enough to read through and critically appraise the manuscript.



Hans Georg Elsaesser  
Chairman of the Board and President  
of VSLINTERNATIONALLTD

Berne, January 1985

## Table of contents

	Page		Page		Page
<b>1. Introduction</b>	<b>2</b>	<b>5. Detail design aspects</b>	<b>13</b>	9.5. Doubletree Inn, Monterey, California, USA	30
1.1. General	2	5.1. Arrangement of tendons	13	9.6. Shopping Centre, Burwood, Australia	30
1.2. Historical review	2	5.2. Joints		9.7. Municipal Construction Office Building, Leiden, Netherlands	31
1.3. Post-tensioning with or without bonding of tendons	3	<b>6. Construction procedures</b>	<b>16</b>	9.8. Underground garage for ÖVA Brunswick, FR Germany	32
1.4. Typical applications of post-tensioned slabs	4	6.1. General	16	9.9. Shopping Centre, Oberes Muri-feld/Wittigkooen, Berne, Switzerland	33
<b>2. Fundamentals of the design process</b>	<b>6</b>	6.2. Fabrication of the tendons	16	9.10. Underground garage Oed XII, Lure, Austria	35
2.1. General	6	6.3. Construction procedure for bonded post-tensioning	16	9.11. Multi-storey car park, Seas-Fee, Switzerland	35
2.2. Research	6	6.4. Construction procedure for unbonded post-tensioning	17	9.12. Summary	37
2.3. Standards	6	<b>7. Preliminary design</b>	<b>19</b>	<b>10. Bibliography</b>	<b>38</b>
<b>3. Ultimate limit state</b>	<b>6</b>	<b>8. Execution of the calculations</b>	<b>20</b>	<b>Appendix 1: Symbols/ Definitions/ Dimensional units/ Signs</b>	<b>39</b>
3.1 Flexure	6	8.1. Flow diagram	20	<b>Appendix 2: Summary of various standards for unbonded post-tensioning</b>	<b>41</b>
3.2 Punching shear	9	8.2. Calculation example	20		<b>1</b>
<b>4. Serviceability limit state</b>	<b>11</b>	<b>9. Completed structures</b>	<b>26</b>		
4.1 Crack limitation	11	9.1. Introduction	26		
4.2. Deflections	12	9.2. Orchard Towers, Singapore	26		
4.3 Post-tensioning force in the tendon	12	9.3. Headquarters of the Ilford Group, Basildon, Great Britain	28		
4.4 Vibrations	13	9.4. Centro Empresarial, São Paulo, Brazil	28		
4.5 Fire resistance	13				
4.6 Corrosion protection	13				

# 1. Introduction

## 1.1. General

Post-tensioned construction has for many years occupied a very important position, especially in the construction of bridges and storage tanks. The reason for this lies in its decisive technical and economical advantages.

The most important advantages offered by post-tensioning may be briefly recalled here:

- By comparison with reinforced concrete, a considerable saving in concrete and steel since, due to the working of the entire concrete cross-section more slender designs are possible.
- Smaller deflections than with steel and reinforced concrete.
- Good crack behaviour 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.

For the above reasons post-tensioned construction has also come to be used in many situations in buildings (see Fig 1).

**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, especially post-tensioned flat slabs\*. A detailed explanation will be given of the checksto 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.**

In addition to the already mentioned general features of post-tensioned construction, the following advantages of post-tensioned slabs over reinforced concrete slabs may be listed:

- More economical structures resulting from the use of prestressing steels with a very high tensile strength instead of normal reinforcing steels.
- larger spans and greater slenderness (see Fig. 2). The latter results in reduced dead load, which also has a beneficial effect upon the columns and foundations and reduces the overall height of buildings or enables additional floors to be incorporated in buildings of a given height.
- Under permanent load, very good behavior in respect of deflections and cracking.
- Higher punching shear strength obtainable by appropriate layout of tendons
- Considerable reduction in construction time as a result of earlier striking of formwork real slabs.

\* For definitions and symbols refer to appendix 1.

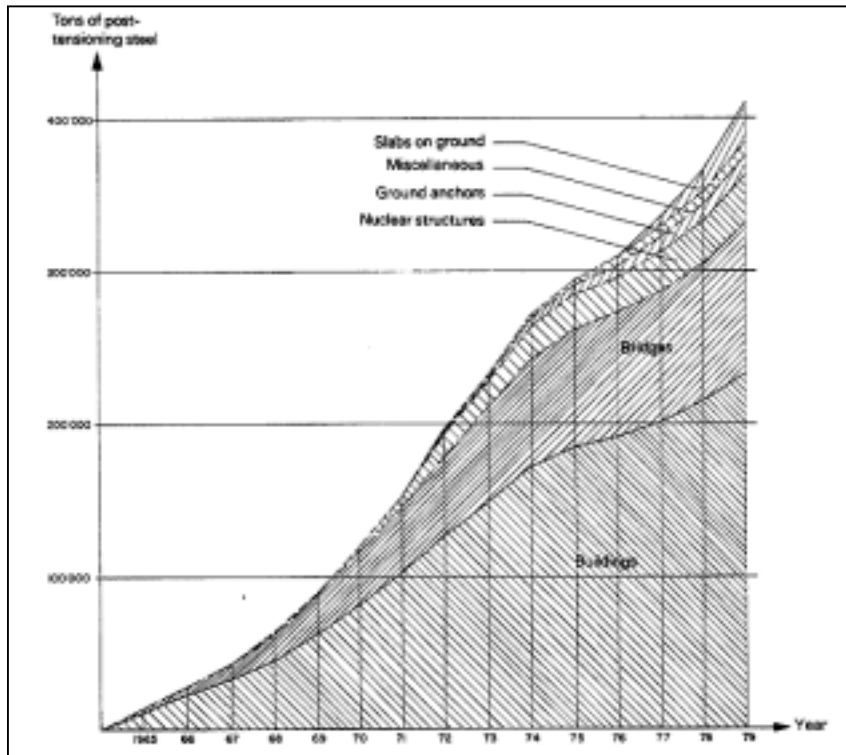


Figure 1. Consumption of prestressing steel in the USA (cumulative curves)

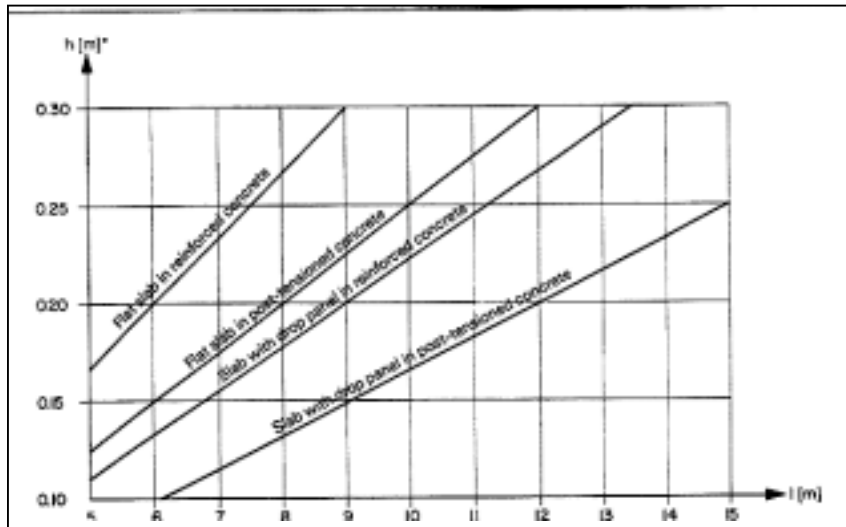


Figure 2: Slab thicknesses as a function of span lengths (recommended limits slenderness)

## 1.2. Historical 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 unbonded post-tensioning. In the succeeding years numerous post-tensioned slabs were designed and constructed in connection with the lift slab method. Post-tensioning enabled the lifting weight to be reduced and the deflection and cracking performance to be improved. Attempts were made to improve knowledge in depth by theoretical studies and

experiments on post-tensioned plates (see Chapter 2.2). Joint efforts by researchers, design engineers and prestressing firms resulted in corresponding standards and recommendations and assisted in promoting the widespread use of this form of construction in the USA and Australia. To date, in the USA alone, more than 50 million m<sup>2</sup> of slabs have been post tensioned. In Europe, renewed interest in this form of construction was again exhibited in the early seventies. Some constructions were completed at that time in Great Britain, the Netherlands and Switzerland.

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 behaviour 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. Thus the method is now also fully recognized in Europe and has already found considerable spreading various countries (in the Netherlands, in Great Britain and in Switzerland for example).

### 1.3. Post-tensioning with or without bonding of tendons

#### 1.3.1. 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 (see also Fig. 6). They normally contain tendons comprising four strands of nominal diameter 13 mm (0.5"), which have proved to be logical for constructional reasons.

#### 1.3.2. Unbonded post-tensioning

In the early stages of development of post-tensioned concrete in Europe, post-tensioning without bond was also used to some extent (for example in 1936/37 in a bridge constructed in Aue/Saxony [D] according to the Dischinger patent or in 1948 for the Meuse, Bridge at Sclayn [B] designed by Magnel). After a period without any substantial applications, some important structures have again been built with unbonded post-tensioning in recent years. In the first applications in building work in the USA, the prestressing steel was grased and wrapped in wrapping paper, to facilitate its longitudinal movement during stressing. During the last few years, however, the method described below for producing the sheathing has generally become common. The strand is first given a continuous film of permanent corrosion preventing grease in a continuous operation, either at the manufacturer's works or at the prestressing firm. A plastics tube of polyethylene or polypropylene of at least 1 mm wall thickness is then extruded over this (Fig. 3 and 4). The plastics tube forms the primary and the grease the secondary corrosion protection.

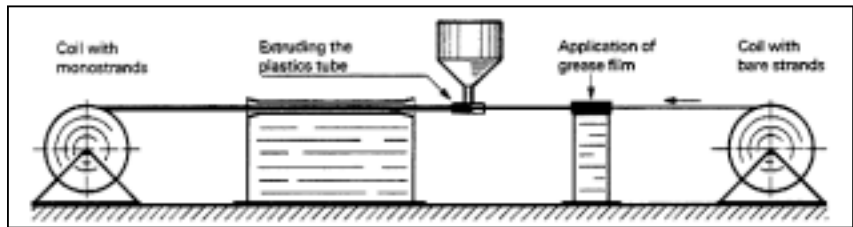


Figure 3: Diagrammatic illustration of the extrusion process

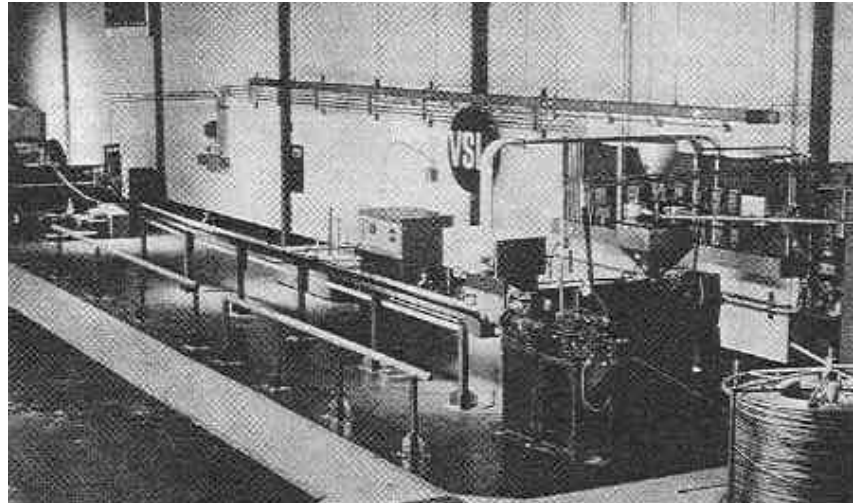


Figure 4: Extrusion plant

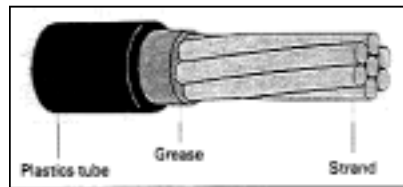


Figure 5: Structure of a plastics-sheathed, greased strand (monostrand)

Strands sheathed in this manner are known as monostrands (Fig. 5). The nominal diameter of the strands used is 13 mm (0.5") and 15 mm (0.6"); the latter have come to be used more often in recent years.

#### 1.3.3. Bonded or unbonded?

This question was and still is frequently the subject of serious discussions. The subject will not be discussed in detail here, but instead only the most important arguments far and against will be listed:

#### Arguments in favour of post-tensioning without bonding:

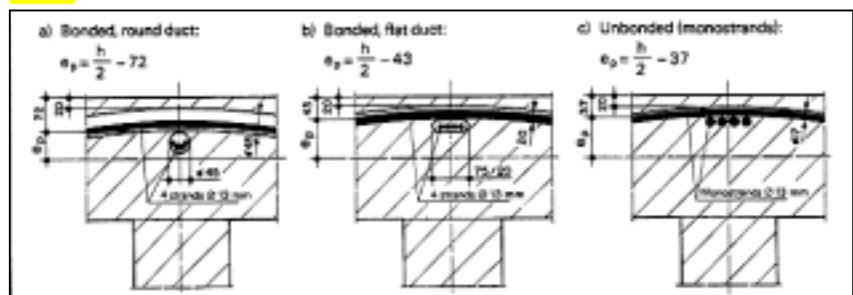
- Maximum possible tendon eccentricities, since tendon diameters are minimal; of special importance in thin slabs (see Fig 6).
- Prestressing steel protected against corrosion ex works.
- Simple and rapid placing of tendons.
- Very low losses of prestressing force due to friction.
- Grouting operation is eliminated.
- In general more economical.

#### Arguments for post-tensioning with bonding:

- Larger ultimate moment.
- Local failure of a tendon (due to fire, explosion, earthquakes etc.) has only limited effects

Whereas in the USA post-tensioning without bonding is used almost exclusively, bonding is deliberately employed in Australia.

Figure 6 Comparison between the eccentricities that can be attained with various types of tendon



Among the arguments for bonded post-tensioning, the better performance of the slabs in the failure condition is frequently emphasized. It has, however, been demonstrated that equally good structures can be achieved in unbonded post-tensioning by suitable design and detailing. It is not the intention of the present report to express a preference for one type of post-tensioning or the other. It is always possible that local circumstances or limiting engineering conditions (such as standards) may become the decisive factor in the choice. Since, however, there are reasons for assuming that the reader will be less familiar with undonded post-tensioning, this form of construction is dealt with somewhat more thoroughly below.

#### 1.4. 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 (Fig 7).
- Cantilevered structures, such as overhanging buildings (Fig 8).
- Facade elements of large area; here light post-tensioning is a simple method of preventing cracks (Fig. 9).
- Main beams in the form of girders, lattice girders or north-light roofs (Fig. 10 and 11).

Typical applications for post-tensioned slabs may be found in the frames or skeletons for office buildings, mule-storey car parks, schools, warehouses etc. and also in multi-storey flats where, for reasons of internal space, frame construction has been selected (Fig. 12 to 15).

What are the types of slab system used?

- For spans of 7 to 12 m, and live loads up to approx.  $5 \text{ kN/m}^2$ , flat slabs (Fig. 16) or slabs with shallow main beams running in one direction (Fig. 17) without column head drops or flares are usually selected.
- For larger spans and live loads, flat slabs with column head drops or flares (Fig 18), slabs with main beams in both directions (Fig 19) or waffle slabs (Fig 20) are used.

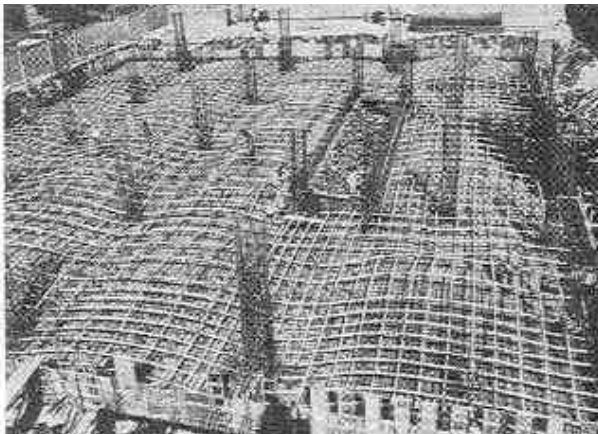


Figure 7: Post-tensioned foundation slab

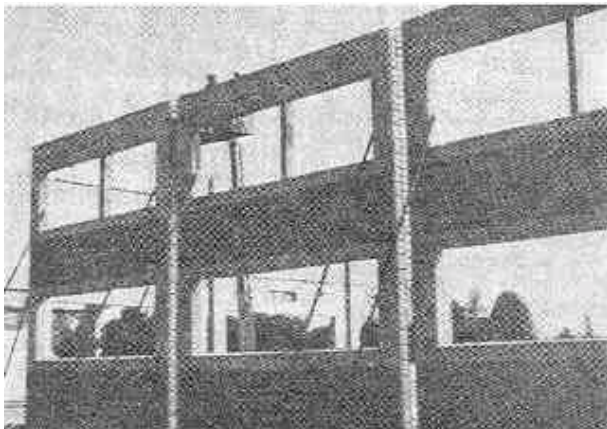


Figure 9: Post-tensioned facade elements



Figure 10: Post-tensioned main beams

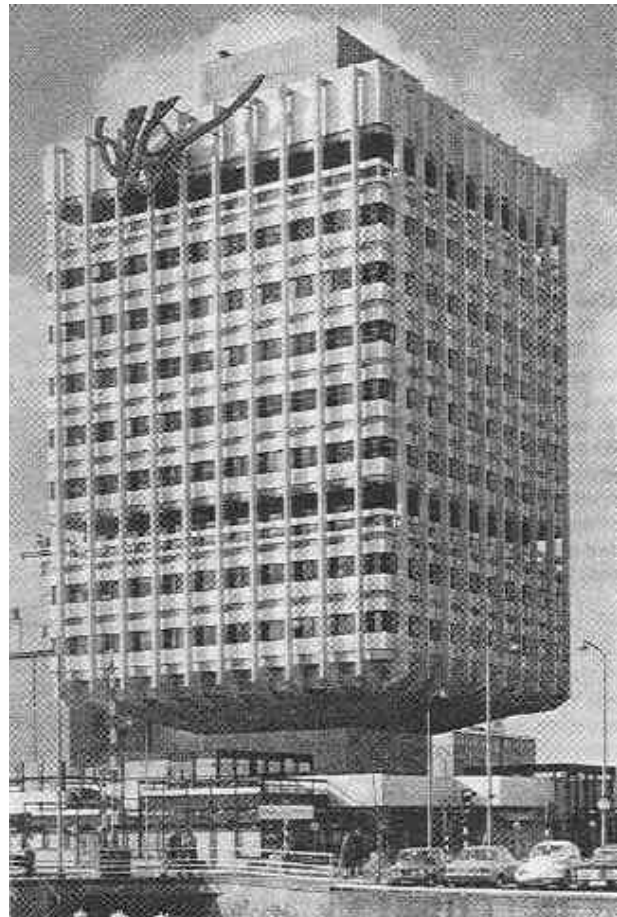


Figure 8: Post-tensioned cantilevered building



Figure 11: Post-tensioned north-light roofs

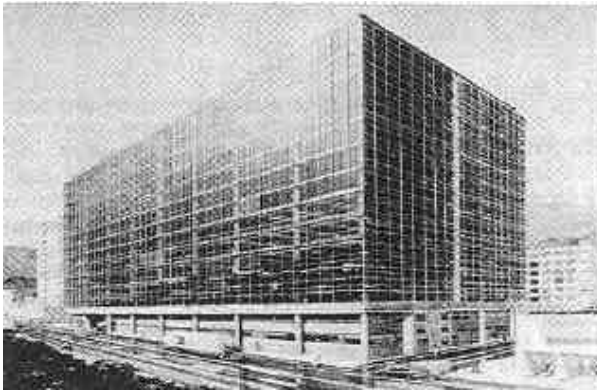


Figure 12: Office and factory building



Figure 13: Multi-storey car park



Figure 14: School

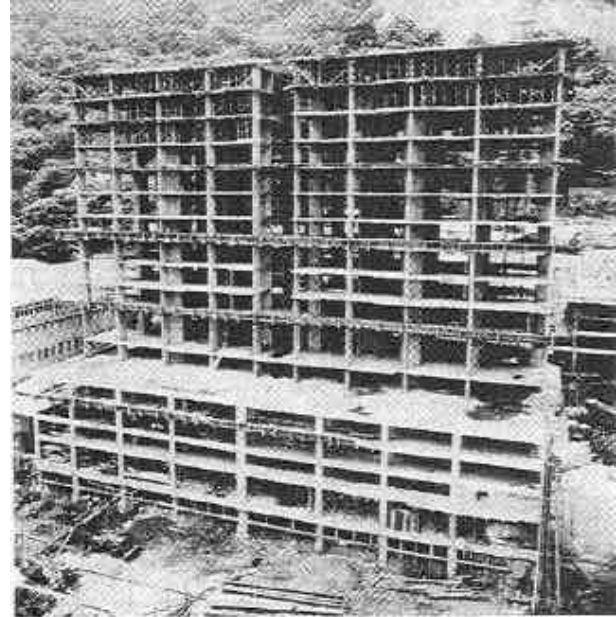


Figure 15: Multi-storey flats

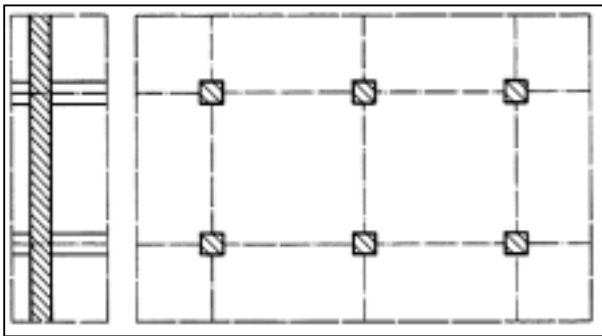


Figure 16: Flat Slab

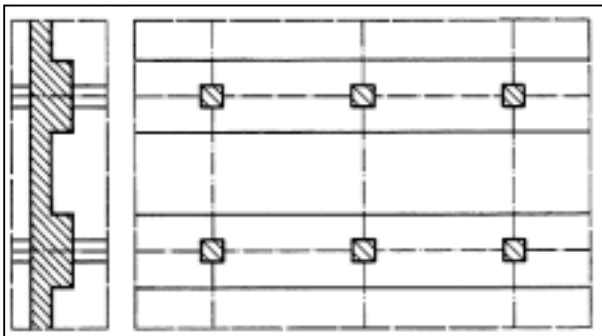


Figure 17: Slab with main beams in one direction

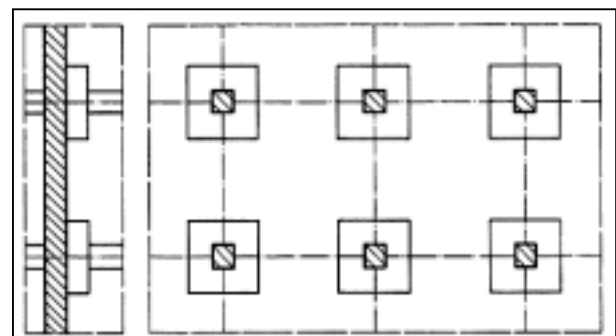


Figure 18: Flat slab with column head drops

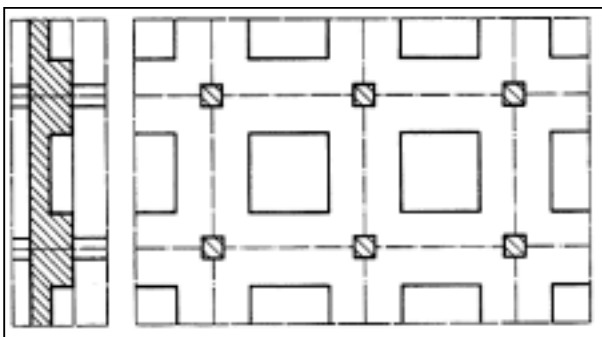


Figure 19: Slab with main beams in both directions

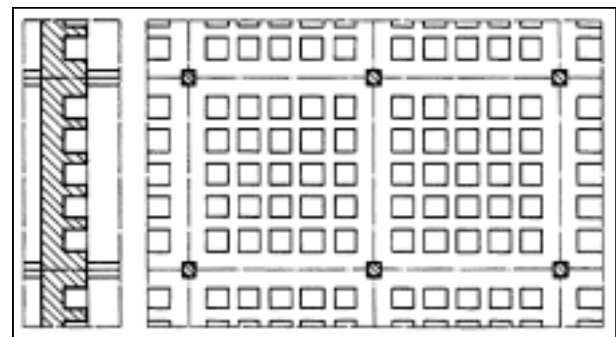


Figure 20: Waffle slab