POST-TENSIONED IN BUILDINGS

General Objectives in Building Design
Applications of Post-Tensioning
in Building Structures
The VSL Hardware for Use in Buildings
Details and Layouts Improving the
Constructability
Preliminary Sizing
of Post-Tensioned Floors
Examples

4.1

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Preface

The development of reliable prestressing techniques has certainly been the most important innovation in the field of structural concrete. It enabled concrete construction to compete successfully within areas that had previously been dominated by steel construction, including long-span bridges, high-rise buildings, pressure vessels and offshore structures. Today, prestressing and, in particular, post-tensioning is a mature technology, providing efficient, economic and elegant structural solutions for a wide range of applications.

Surveys indicate vast differences in the use of post-tensioning among different countries. While the wide spread can largely be explained by differences in local needs, standards, education and habits it appears that the potential offered by post-tensioning is far from being exploited, especially in building structures. Too many building structures, for which post-tensioning would provide a clearly superior solution, are conceived, designed and built as non -prestressed. For too long, non-prestressed and prestressed concrete have been treated as completely seperate entities and hence, prestressing is not yet regarded as a familiar and desirable construction option by many developers, architects, engineers and contractors.

Post-tensioning in buildings is not limited to floor slabs. Post-tensioning of foundations, transfer beams and plates, post-tensioned masonry and the combination of precast elements with cast-in-place concrete by means of post-tensioning offer other interesting opportunities. Developers, architects, engineers, contractors, educators and students will find the present report to be most informative in this regard. It describes the application of post-tensioning within the overall context of building construction and it yields a sufficient basis for corresponding preliminary designs; special information required for the final dimensioning and detailing will be given in a companion report.

VSL should be commended for continuing their tradition to disseminate state-of-the art information on post-tensioning and it is hoped that through this and related efforts an increasing number of companies and individuals will benefit from the use of posttensioning in buildings.

Zurich, 30th April 1992

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1. Introduction

It is no secret that the key to the successful construction of new buildings is successful planning. Successful planning starts from the very beginning with good communication and close cooperation between all parties involved in the project, in particular the owner, the architect and the engineer. As soon as a contractor has been nominated he too should be included in the planning team. In this way one of the key aspects of successful planning, the constructability of the building, can be addressed properly as part of the evaluation process of various concepts. This is of paramount importance for the success of the project since constructability most markedly affects the time to completion of a turn-key project and thus the final cost to the owner. Because the major part of the total cost of large developments is financing cost rather than actual construction cost, the completion time is often a more important consideration than material consumption. With this in mind it follows that successful planning means to always maintain an overall perspective of the project, that is to consider the building as a whole rather than looking at individual parts in isolation. Since the various parts of a building strongly influence oneanother, in particular in the way they are constructed, optimization of one part may well be detrimental to another.

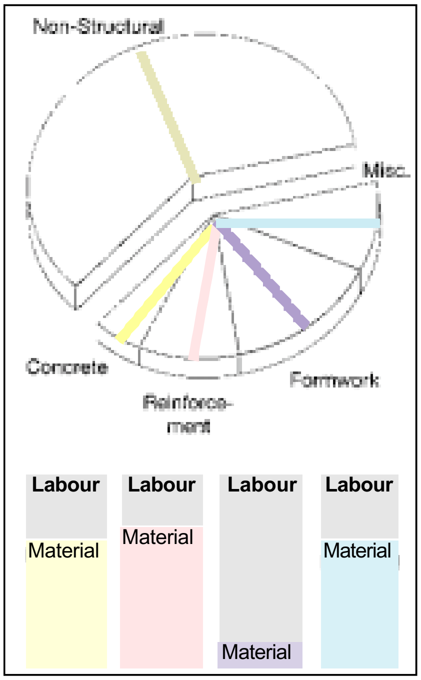


Fig. 1.1: Split-up of Total Cost for Buildings

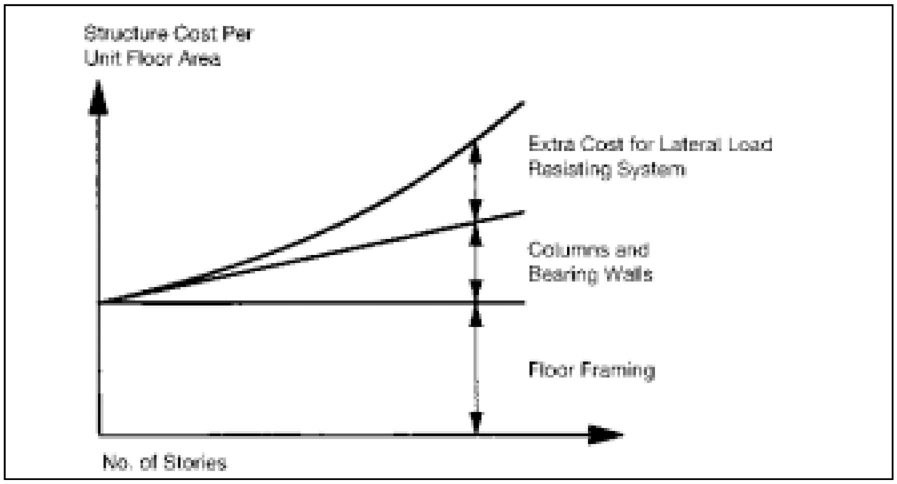


Fig. 1.2: Contribution of Floor Framing to Total Structural Cost [1]

another, in particular in the way they are constructed, optimization of one part may well be detrimental to another.

Even when considering only the construction costs (Fig. 1.1), it is evident that optimization of structural material consumption alone will result in relatively modest overall savings since on one hand the structural cost makes only about 30 to 50% of the total construction cost and on the other hand more than half of the structural cost is labour cost, related mainly to formwork.

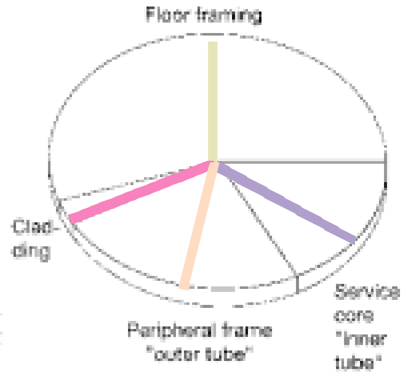
Any significant saving in construction cost can therefore only be achieved by means that also affect the labour cost and the non-structural cost for cladding, electrical and mechanical services, lifts, fit-out, etc.

The most cost significant structural element of a building is the floor framing. Fig. 1.2 demonstrates the relative contribution of the floor framing to the total structural cost per unit floor area. While for low-rise buildings this contribution is almost 100 %, the cost for columns and walls including their foundations, and for the lateral load resisting system becomes increasingly significant for taller buildings. The floor framing system affects the cost in two ways:

First it has a direct influence on the rest of the structure in that its weight determines the size of columns, walls and foundations, and its structural depth determines the total building height and thereby the quantity of cladding and vertical trunk lines. In seismic areas the floor weight also determines the member sizes of the lateral load resisting system. Fig. 1.3 shows the split-up of the total structural weight of a 49-storey building. While the floor framing accounts for just over 50 of the total, any reduction of floor weight would cause a corresponding weight reduction also for the peripheral frames and the service core and would thus affect almost the entire structural weight.

The second way the floor framing system affects the cost of the building relates to the total construction time: Both the time required to construct one floor and the time lag between the structural completion of the floor and the commencement of fit-out work such as electrical and mechanical services, suspended ceilings and decorating, are major factors influencing the time to completion of the building. These considerations demonstrate that the optimization of the floor framing with regard to weight, structural depth and constructability goes a long way towards successful planning. However, one should not make the mistake of comparing the cost of one floor system against the cost of another without considering the arryover effects on other parts of the structure, including the non-structural parts, and on financing cost.

In some countries, including the U.S.,Australia, South Africa and Thailand, a great number of large buildings have been successfully constructed using posttensioned floors. One of the main reasons for this success is the improved constructability of post-tensioned slabs: less material to bo handled and placed, simpler and less congested reinforcement, earlier stripping of formwork and often simpler formwork. Apart from shorter overall construction time and savings in material and labour cost, post-tensioning allows more architectural freedom: Larger columnfree spaces providing more flexibility in the subdivision of commercial and office floors, wide-spanning or boldly cantilevering floors that leave generous space for lobbies or public areas, slender elegant roofs for show rooms or exhibition halls, to name a few examples.



Note: Saving weight of floor framing results in significant savings in core and outer tube, particulary so in seismic area

Fig. 1.3: Split-up of Total Structural Weight for a 49 Storey Office Building of the "Tube-in-Tube" Type (adopted from [2]

In addition, the reduction of structural height and weight as outlined above, and the improved deflection and cracking behaviour contribute to the success of post-tensioned floors.

Fig. 1.4 shows the total post-tensioning consumption and the percentage used in buildings in various countries in the year 1990. It is evident that there are huge differences. While in the U.S. and Australia more than 75 % of the total posttensioning was built into building structures, this market made less than 10 % in most European countries. The objective of this report is to encourage the use of post-tensioning in buildings, particularly in countries where this idea is not yet widely accepted, by demonstrating its advantages and benefits. The report is intended to provide useful background information to owners, architects, engineers and contractors, and to relate to them the positive experience made in areas where the use of post-tensioning in buildings is commonplace.

Specifically, Chapter 2 summarises the major design objectives, including suggestions how thesb objectives can be met. This should help the reader to rationally select an efficient overall structural concept for a building. Then, in Chapter 3 a wide range of post-tensioning applications are illustrated, including foundations, structural walls and service cores, moment-resisting frames, transfer beams and plates, and masonry walls. In recognition of their key role in building structures, floor framing systems are discussed in greater depth. These illustrations demonstrate that post-tensioning can make a significant contribution to the success of building designs. After a brief review of the VSL post-tensioning hardware in Chapter 4, Chapter 5 presents some background information to enable the reader to determine preliminary sizes of floor framing members, and to estimate approximate reinforcing and prestressing steel quantities. The content is not intended to serve as a design aid to engineers. Technical design issues will be the subject of the second volume of this report. Tendon arrangements, connection and anchorage details for post-tensioned floors are discussed in Chapter 6. Finally, Chapter 7 presents two examples that reiterate the contents of Chapters 3, 5 and 6. While post-tensioning is a very attractive repair and strengthening method, this report is limited to applications in new construction.

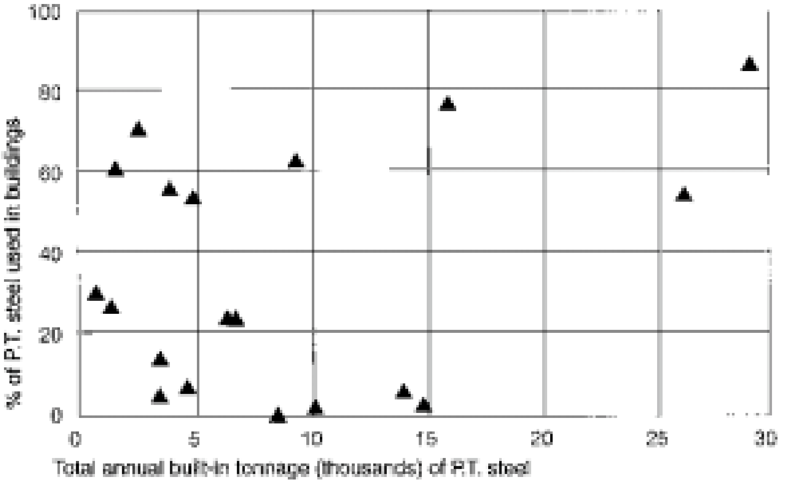


Fig. 1.4: Total Annual Post-Tensioning Consumption and Percentage Used in Building Structures in Various Countries (1990 Figures)

2. General Objectives in the Design of Building Structures

Buildings can be classified in many different ways. They can be distinguished by their use or occupancy, by the construction materials, by their owners (public / private), or by their height (low-rise / high-rise). Here two representative building types, distinguished primarily by the predominant direction in which the construction progresses, are used to demonstrate some general objectives to be considered in the conceptual design.

Fig. 2.1: Typical High-Rise Building under Construction

Fig. 2.2: Typical Low-Rise Building under construction

For typical medium to high-rise office or multi-purpose buildings similar to the example shown in Fig. 2.1, the construction progresses vertically, floor by floor. The high repetition rate of identical floors and the floor-by-floor construction sequence imply a number of design objectives typical for this type of building. Table 2.1 summarises some of these objectives and how the project benefits if the objectives are met. For instance, in order to minimise the overall construction time, one of the prime design objectives must be to achieve a fast floor cycle, that is to minimise the time required to complete a floor. In order to minimise the size of vertical members and foundations the floor weight must be kept as low as possible. In order to save on cladding, vertical structural members and vertical service trunk lines, the storey height and therefore the structural height of the floor framing must be minimised. In order to maximise rentable space and flexibility of occupancy the floor framing is usually required to have relatively long spans, which is in conflict with the objective to minimise structural floor height and weight.

For typical large area, low to medium-rise buildings similar to the one shown in Fig. 2.2, the predominant direction of construction progression is horizontal, with some simultaneous vertical progression. The completion of an entire floor is therefore not on the critical path to the same extent as for high-rise buildings. Also, the repetition rate of identical floors, and the total number of floors is usually relatively small so that the structural height and the weight of the floor framing do not normally play as significant a role as they do in the design of high-rise buildings. Table 2.2 summarises some of the design objectives for this type of building and the corresponding benefits for the project. While the design objectives related to the constructability are similar to those listed for high-rise buildings, the different usage of low-rise buildings, e.g. industrial, retail, parking, often implies some specific requirements such as strict cracking and deflection limitations or avoidance of expansion joints.

Tables 2.1 and 2.2 also include suggestions as to how each design objective can be met. These suggestions include the use of simple and efficient formwork, post-tensioning, pre-fabrication of reinforcing assemblages, complete or partial pre-fabrication of entire concrete elements, the choice of a suitable floor framing system, simple details, high degree of standardization, and the use of high early strength concrete.

Post-tensioning helps to meet each single one of the design objectives. The reasons for this are different in each case and are listed as foot notes under the tables. The most prominent ones are that post-tensioning allows the floor framing to be more slender, solving the problem of the conflicting needs for long spans and small structural depth, and that it replaces a significant amount of reinforcement, thus reducing steel quantities and allowing standardization and simplification of the reinforcement. Further reasons why post-tensioning helps to improve the design are that usually the concrete quantities are reduced and that the