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Post-Tensioned Masonry

Maçonnerie précontrainte

Vorgespanntes Mauerwerk

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Hans Rudolf Ganz, born 1955, received his Civil Engineering diploma and doctorate at the Swiss Federal Institute of Technology, Zurich. He was involved in masonry research and in particular in the behaviour of shear walls. Now, he works as a project engineer in the design of post-tensioned structures.

SUMMARY

Masonry is an old construction material which combines excellent thermal and acoustic insulation properties with high durability and easy construction method. For lateral out-of-plane loading of the wall or shear and imposed deformations, unreinforced masonry shows, in general, an unfavourable behaviour regarding cracking and strength. Prestressing is an ideal method to improve the strength and in-service behaviour of masonry walls. This article describes a new post-tensioning system for masonry walls, presents some basic considerations for the design of post-tensioned masonry and illustrates a recent application.

RÉSUMÉ

La maçonnerie est un matériau de construction ancien, qui combine une excellente isolation thermique et acoustique avec une haute durabilité et une simple mise en place. Mais un mur en maçonnerie non renforcée se comporte de manière défavorable lorsqu'il est soumis à des charges latérales, à un effort tranchant ou à des déformations imposées. La précontrainte permet d'une manière simple et efficace d'améliorer sa charge admissible et son comportement à la fissuration. L'article décrit un nouveau système de précontrainte destiné à la maçonnerie et ses conditions d'emploi, présente quelques considérations au niveau du dimensionnement et une application récente fort réussie.

ZUSAMMENFASSUNG

Mauerwerk ist ein Baustoff, der gute thermische und akustische Eigenschaften mit grosser Dauerhaftigkeit und einfacher Baumethode kombiniert. Unter Belastungen quer zur Wand oder Schub und aufgezwungenen Verformungen zeigt unbewehrtes Mauerwerk jedoch ein relativ ungünstiges Verhalten bezüglich Rissen und Tragfähigkeit. Vorspannung ist ein ideales Verfahren, die Tragfähigkeit und das Rissverhalten von Mauerwerkswänden zu verbessern. Der Artikel stellt ein neues System zur Vorspannung von Mauerwerk vor, beschreibt seine Anwendung, gibt Hinweise zur Bemessung und zeigt eine erfolgreiche Anwendung des Systems in der Praxis.



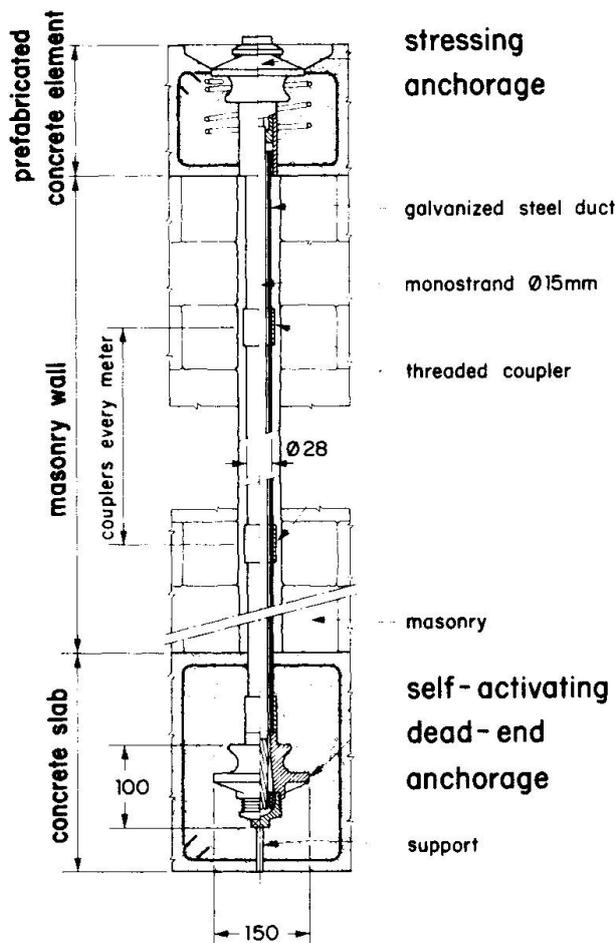
1. INTRODUCTION

Masonry has a relatively high compressive strength but only a low tensile strength. Therefore, masonry has been used so far primarily as an unreinforced construction material in buildings for vertical members subjected essentially to gravity loads. Apart from this principal action, however, lateral and shear loads from wind, earth pressure and earthquake as well as imposed deformations caused by rotations of floor slabs or volume changes of horizontal members may be applied to masonry walls. In many cases the gravity load is not large enough to provide the required strength and therefore, some standards allow to consider the tensile strength of masonry, [1, 2, 3]. Such a design procedure is rather unusual compared with the practice in reinforced and prestressed concrete and will fail for small axial loads and/or larger spans of the walls. Vertical post-tensioning of masonry walls is a simple and effective engineering solution to overcome the above disadvantages and improve strength, in-service behaviour and durability of masonry constructions.

Unreinforced masonry constructions can transfer loads only in compression. Thus, such structures require a direct load path from the point of load application into the foundation. On the other hand, alternative load paths may be developed in reinforced and prestressed structures by strut-and-tie action. Such alternative load paths are particularly desirable to avoid progressive collapse of parts of structures or entire structure.

2. NEW POST-TENSIONING SYSTEM FOR MASONRY

2.1 Tendon



A new post-tensioning system for masonry walls has recently been introduced in Switzerland, [4, 5]. For an optimum corrosion protection by grease and polyethylene sheathing as well as for constructibility an unbonded monostrand system has been used. A typical tendon for post-tensioned masonry is illustrated in Fig. 1.

At the lower end of the tendon a self-activating dead-end anchorage is placed in a cast-in-situ concrete element. The stressing anchorage is located at the upper end of the tendon. It may be placed either in a prefabricated concrete block laid on top of the masonry wall or in a cast-in-situ concrete element. Both anchorages are filled with a special grease for corrosion protection of the prestressing steel. Low relaxation 7-wire strands of diameter 15 mm (0.6") with a guaranteed ultimate strength of 258 kN are used. The strands with a double corrosion protection consisting of grease and polyethylene sheathing are placed in a galvanized steel duct. The duct is prepared in segments of 1 m length.

Fig. 1 : Tendon for post-tensioned masonry.

2.2 Masonry

For post-tensioned masonry the use of moderate to high strength bricks and cement mortar resulting in masonry compressive strengths of at least 8 N/mm² is recommended. The layout of the tendons in a masonry wall depends on the coring pattern of the bricks. For walls laid in a running bond the tendons can be placed in relatively large cores, say 50 mm diameter, along the center of the wall only.

2.3 Construction

First step in the construction of a post-tensioned masonry wall is the placement of the dead-end anchorages in the formwork of an in-situ concrete member. After the concrete has been poured wall construction can commence. Duct segments may be threaded to the anchorage or previously placed segments according to the progress of wall construction to allow an easy brick laying. When the final wall height is reached, the last duct segment is cut to the required length and the prefabricated concrete element with the stressing anchorage is placed on top of the wall. After the masonry has reached an adequate strength, typically after a minimum of seven days, the wall may be prestressed. Only now the monostrands are fed through the stressing anchorage and duct into the self-activating dead-end anchorage and can be stressed to a maximum of 75 % of their ultimate strength.

3. DESIGN CONSIDERATIONS

The influence of the prestressing force on the strength of masonry walls can easily be illustrated by interaction diagrams if the prestressing force, P , is considered similarly to an externally applied axial force, N .

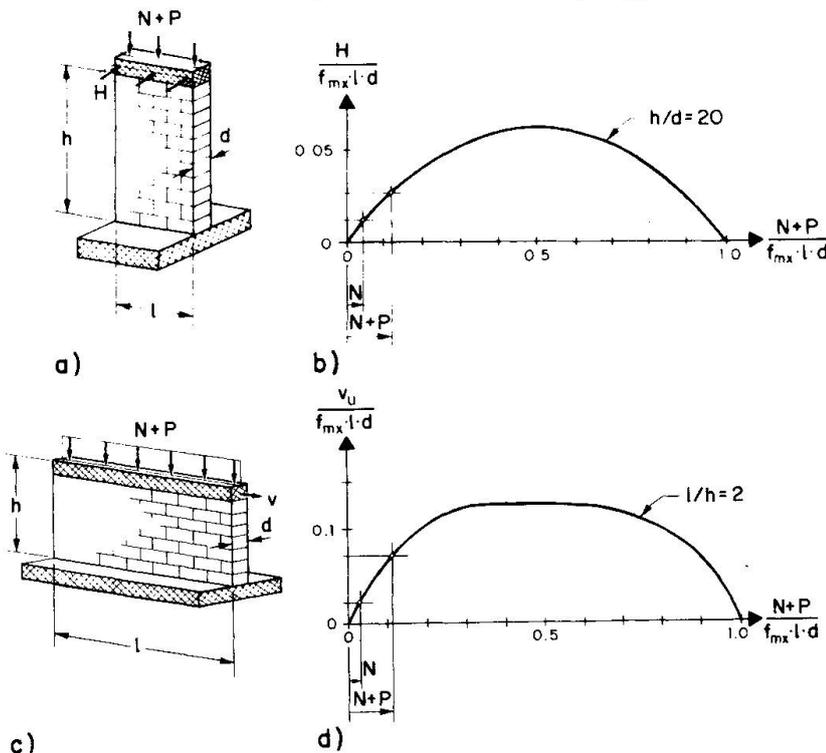


Fig. 2 : Influence of prestressing on the strength of masonry walls:

- a) Laterally loaded wall
- b) Interaction diagram for laterally loaded wall
- c) Shear wall
- d) Interaction diagram for shear wall



Fig. 2 shows the increase in strength due to prestress of a cantilever wall loaded by out-of-plane lateral load and a shear wall, respectively. The interaction diagrams are presented in a non-dimensional form with f_{mx} = uniaxial compressive strength of masonry for loadings perpendicular to the bed joints. Second order effects due to wall deformations have not been considered.

Paying due attention to the anisotropic material properties of masonry, post-tensioned masonry walls can be designed similarly to post-tensioned concrete. The design for ultimate and for serviceability requirements will determine the minimum amount of prestress or for a given tendon force the maximum tendon spacing. Detailing requirements may provide further limitations to the tendon spacing.

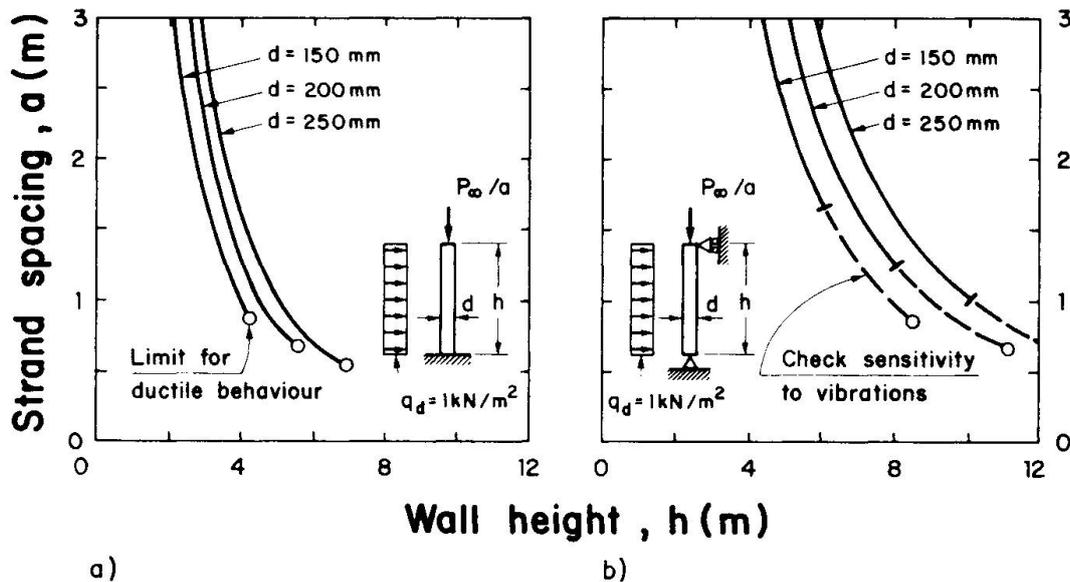


Fig. 3 : Diagrams for the preliminary design of laterally loaded walls:

- a) Cantilever
- b) Simply supported wall ends

Fig. 3 shows graphs for the preliminary design of non-load bearing walls, $N = 0$, under out-of-plane lateral loading. The graphs have been developed based on the new Swiss Standard SIA 177/2, [6], for a design lateral load of $q_d = 1 \text{ kN/m}^2$, an effective tendon force of $P_\infty = 160 \text{ kN}$ and a masonry strength of 8 N/mm^2 . The graphs give the maximum tendon spacing, a , for various wall systems, wall heights and wall thicknesses. As Fig. 3 shows, tendon spacing are typically in the order of 1 to 2 m for design loads of 1 kN/m^2 . The tendon spacing is proportional to the factor P_∞/q_d and therefore, different tendon forces and design loads can easily be considered.

Strut-and-tie models may be used to investigate the increase of shear strength of masonry walls due to prestressing, [7].

In Fig. 4 a prestressed wall loaded by axial force, shear and bending is considered. In a non-prestressed wall a single diagonal compression strut will develop under the eccentric axial force which can carry a shear force of $V_d = N_d \times \tan \alpha$. In a prestressed wall additional diagonal struts can develop beneath the tendon anchorage and thus, increase its shear strength.

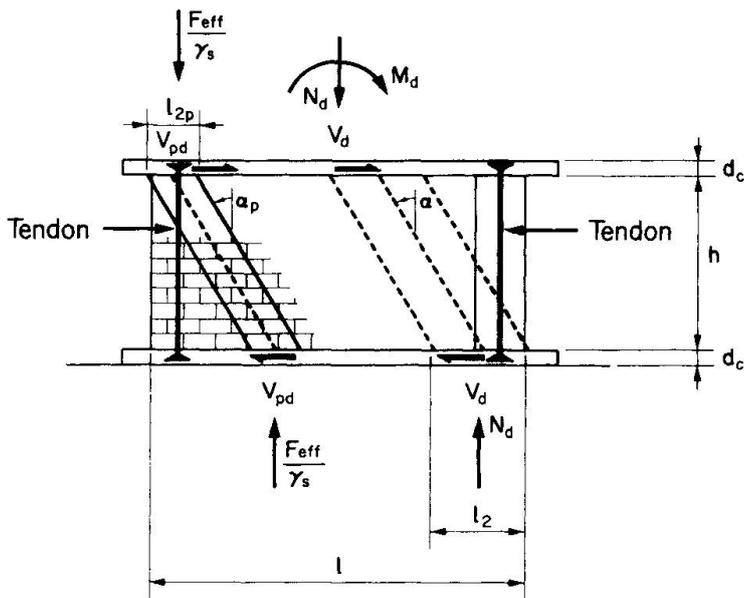


Fig. 4 : Design of prestressed masonry shear wall.

A brittle behaviour of masonry walls is undesirable and may be avoided by a proper limitation of the maximum amount of prestressing. In [6] walls with axial design forces not exceeding 25 % of their axial design capacity are considered to behave ductile. This limitation has been introduced in Fig. 3 to determine the minimum tendon spacing which is in the order of 0.9 and 0.5 m for 150 mm and 250 mm thick walls, respectively. For very slender walls, say $h/d > 40$, sensitivity to vibrations should be checked.

Squat walls with low normal forces and imposed deformations are particularly susceptible to large crack widths. Prestressing offers two major advantages regarding cracking. First, crack initiation is delayed due to the prestressing force. Second, the imposed deformation will be distributed to several joints rather than being localized at a single joint. Thus, smaller average crack widths will be obtained in a prestressed wall compared with a non-prestressed wall for an identical imposed deformation. This fact is illustrated in Fig. 5 for a wall with imposed end rotation.

Wall cross section

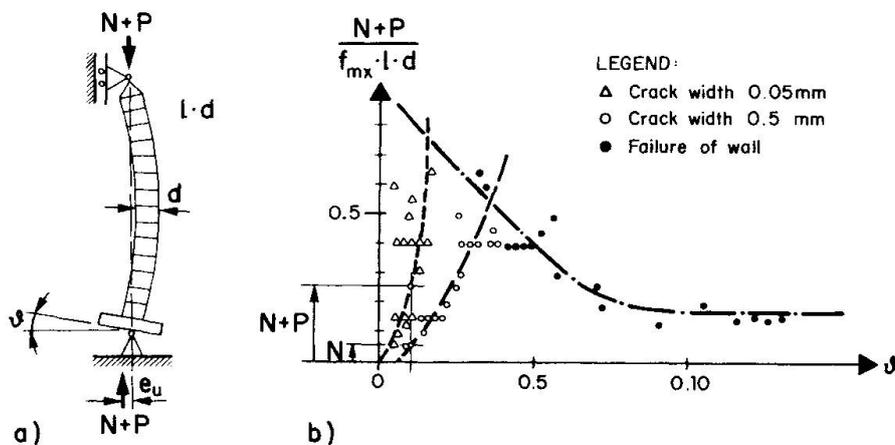


Fig. 5 : Influence of prestressing on crack width in masonry walls:

- a) Test set-up
- b) Test results, [8]



4. APPLICATIONS

The new system for post-tensioned masonry has been used in two recent applications, [4], one of them is described in the following. It is a fire-proof wall in a factory near Zurich. The wall consists of a single leaf of calcium-silicate bricks, 250 mm thick, Fig. 6.

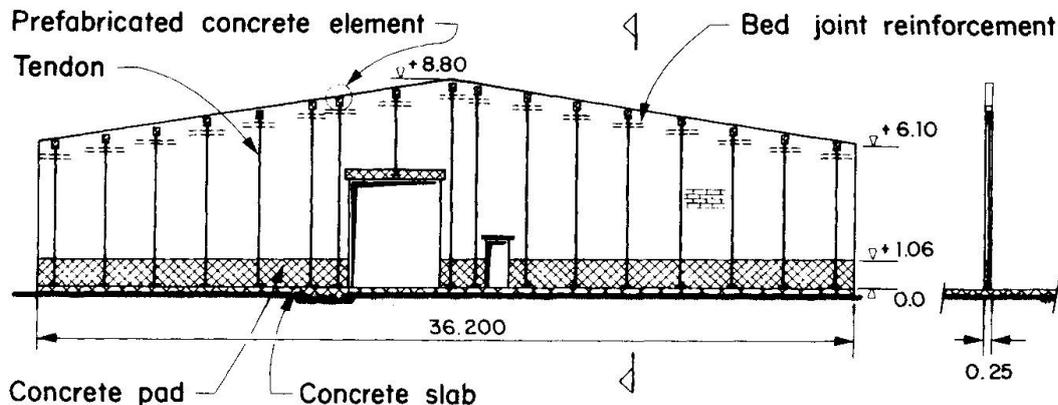


Fig. 6 : Post-tensioned masonry wall in factory.

The wall is 36.2 m long and up to 8.8 m high. The dead-end anchorages of the tendons were cast into a 1 m high in-situ concrete pad beneath the masonry wall which is anchored into an existing concrete floor slab. The masonry wall was prestressed by 17 tendons at an average spacing of approximately 2.0 m. The stressing anchorages were placed in prefabricated concrete cubes, 250 mm long, on top of the wall. Because the wall could not be connected to the roof it was designed to withstand lateral wind load in case of fire as a cantilever.

Post-tensioning offers a new potential to innovative engineers for the revival of masonry as a structural material. Plenty of types of applications such as in residential, hotel and office buildings, for infilled frames in industrial building, are feasible for in-place constructions as well as for pre-fabrication.

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