Rehabilitation of 150 m ENO Nováky chimney

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INTRODUCTION

This contribution deals with the issue of maintaining and reinforcing a 150 m high chimney at ENO Nováky. The chimney was put into operation in 1963. This is a reinforced concrete construction built with sliding formwork technology. A common mark of cylindrical constructions such as tanks, silos, chimneys and cooling towers is the large ratio between the area exposed to the surrounding environment and the dimensions of the cross-section. In light of the character and usage of such constructions, their reliability is endangered by volume changes from the effects of temperature and corrosion of the concrete and reinforcements. In the case of older constructions, mainly tanks, we often meet with under-dimensioned walls. The stated effects are often the cause of the emergence and progression of vertical cracks which may result in the partial or complete loss of the ability of the construction to fulfill its required function. Reinforcement by external non-adhesive prestressing combined with the repair of the cracks and surfaces of these constructions is more effective than their replacement.

Keywords: concrete, chimney, rehabilitation

REASONS FOR THE DEGRADATION OF REINFORCED CONCRETE CHIMNEYS

Chimneys, as cooling towers, belong among those constructions that are loaded primarily by their own weight, by wind, by seismic factors and the effects of temperature changes In contrast to cooling towers, in chimneys there is a greater variance of temperature. This fact is accounted for by the high temperature of waste gases (to 300 °C). Even though the concrete construction is protected on its inner surface by a protective lining, in the majority of concrete chimneys it is possible to observe a small amount of vertical cracks of great length. The reason for the occurrance of such cracks is the horizontally acting of bend and tension on the concrete shaft of the chimney as a result of the differences in temperatures of the inner and outer surface. In the winter season, when the internal temperature, during the operation of the chimney, is greater than the exterior, vertical cracks appear on the outer surface (Fig. 1A). If the chimney is not in operation, during sunny weather an opposite temperature difference occurs, producing tension on the interior side of the shell, which is often not reinforced, thus leading to the occurrence of a smaller amount of wide cracks. (Fig. 1B)

It is difficult to avoid the appearance of these cracks. If their width and stresses in the reinforcement does not exceed a given limit value, for the most part the safety and serviceability of the chimney are not threatened. In any case, they have an unfavorable influence on the structure's life span. A reinforced concrete chimney shaft belongs to the category where a maximum width of cracks of 0,2 or 0,3 mm is allowed for constructions exposed to a usual environment on free space. It is possible to reduce the width of cracks and the extent of reinforcement stress by the type, amount, diameter and shape of the surface of horizontal cylindrical reinforcement.

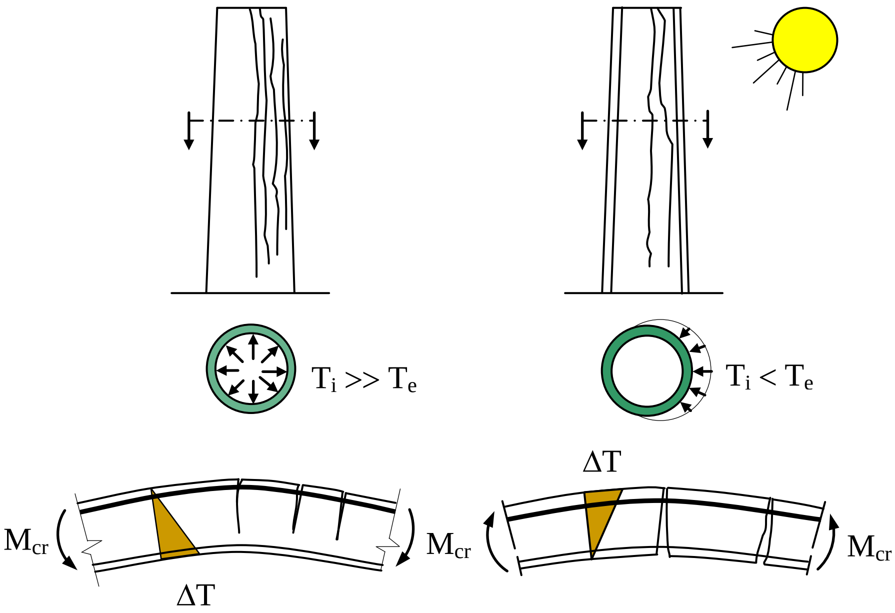

Fig. 1. Appearance of vertical cracks in chimney shaft due to temperature gradient

In situations of insufficient reinforcement of the chimney shaft by horizontal reinforcement on the outside surface and the frequent absence of reinforcing on the interior surface, wide vertical cracks appear. If the stress on the horizontal reinforcement is greater than the yield value of the steel used, a plastic behavior occurs in the reinforcement in the crack, along with an increase in the width of the cracks. If at the same time we take into account the continuing corrosion of the reinforcement in the crack, it is quite likely that in the course of several years there an increasing width of the cracks will take place, leading to a division of the cylindrical cross-section of the chimney shaft into a number of more or less independently acting segments. The cross-section has an essentially unfavorable division of the vertical stresses if the cracks are spread throughout the whole thickness of the shaft, and the deflection of the chimney will increase due to the effects of the horizontal load.

Degradations in the ENO chimney

The reinforced concrete shaft of the ENO chimney has a diameter of 10,95 m and a thickness of 585 mm in its lower part, on the upper edge a diameter of 6,84 m and a thickness of 180 mm. The actual degree of the shell reinforcement by horizontal cylindrical reinforcement on the outside surface, ascertained by a Proceq SA profometer, along the height of the chimney ranged around 0,1% to 0,21 %. According to the projecting documentation, the inner surface is without reinforcement. The temperature in the chimney of non-desulphurised waste gases was 175 ± 15°C.
In 1994, vertical cracks reaching a length of several meters and up to ten meters were recorded on the shaft, with widths from 0,2 to 1,8 mm. By long-term tracking of the dynamic of the width of these cracks it was found that the width of the cracks was progressively increasing. As the calculations showed, this state is the result of the plastic yielding of the reinforcement at the crack places due to under-dimensioning of the horizontal reinforcement of the chimney shaft, which is stressed over the yield point. After inspection in 2001, on the shell were recorded vertical cracks of widths of 0,3 to 3,0 mm (Fig. 2, 3). On the basis of these facts, the owner was advised to strengthen the chimney shaft, which would stabilize the width of the existing, and prevent the formation of new cracks [1].

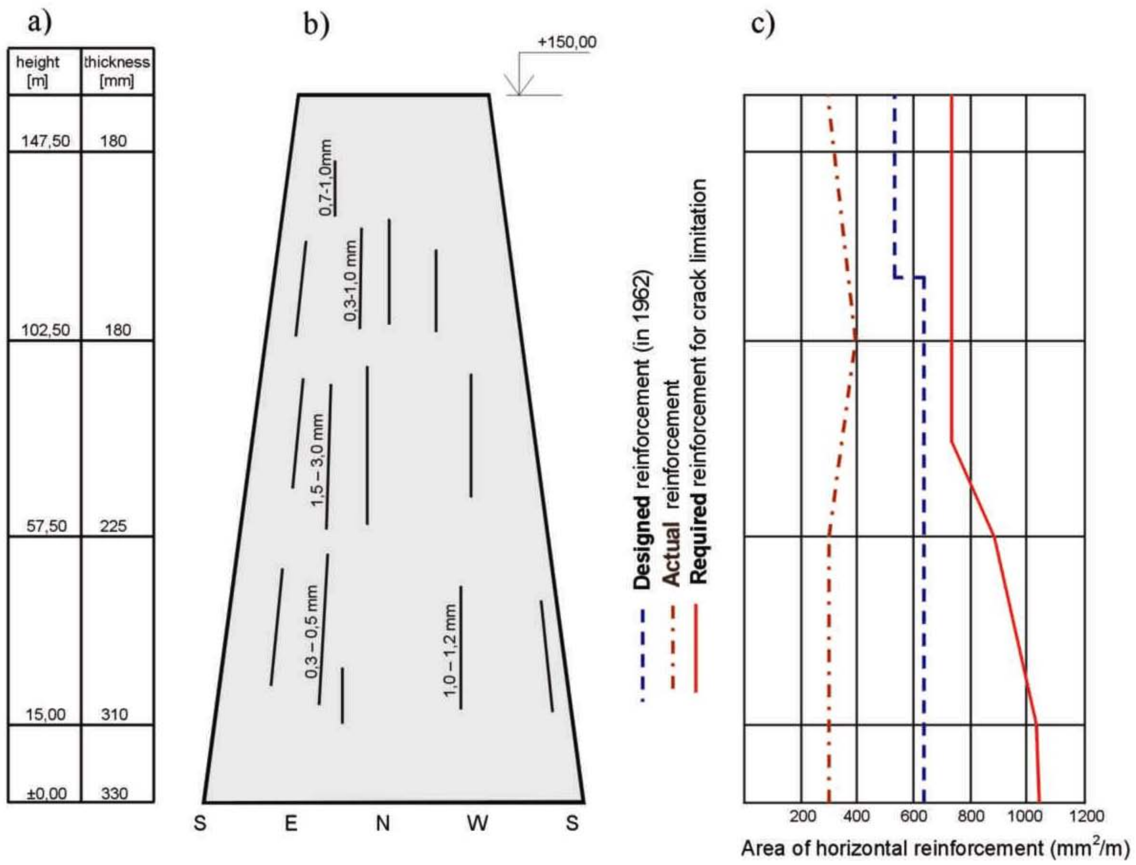

Fig. 2 Pattern and width of cracks on the developed surface of the chimney shaft, comparison of the actual, projected and required area of horizontal reinforcement

Fig.3 Cracks on the chimney exterior shaft after water jet cleaning

PROPOSAL FOR REHABILITATION OF CRACKS AND STRENGTHENING OF THE CHIMNEY

The criterion for the reinforcement necessary for strengthening the chimney was the achievement of such a state of stress at which the width of the cracks from temperature loading would not exceed a width of 0,3 mm, and the stress in the concrete reinforcement a standard yield value of 400 MPa (Toros 10 492 reinforcement).
The strengthening proposal was presented in two alternatives:
1. reinforcement by Sika CarboDur M 614 carbon laminas
2. reinforcement by external prestressing by non-adhesive MONOSTRAND tendons

After consideration of both alternatives, reinforcement of the chimney shaft by external prestressing tendons was recommended unequivocally.

Rehabilitation of cracks and surface protection of the shell coat

For the removal of the old paint coats and the degraded concrete layers a directed water jet with up to 120 MPa pressure was used. After the cleaning of the outer chimney shaft there followed repair of the cracks, with the main goal of sealing them to prevent the penetration of water and aggressive materials to the inner concrete and to the reinforcement. Due to the various widths of the cracks three methods for the crack repair were proposed and carried out:

- Cracks up to 0,5 mm wide were covered and sealed by a flexible coating system, SIKAGARD 552W, which was used for the secondary protection of the outer chimney surface. This is capable of covering changes in the crack width of up to 0,3 mm.
- Cracks of width from 0,5 to 1,0 mm were sealed by an injection of flexible injection material on a base of polyurethane resin.
- Cracks of width greater than 1,0 mm were cut by a carbon grinder with a diamond disc for gaps of depth 20 mm and width 10 mm. After cleaning the gaps, PE cord with a diameter of 10 mm was pressed into the gaps. Following this, the wall gaps were penetrated with PRIMER SIKA 3 coating paint, and finally the gaps were permanently sealed with SIKAFLEX PRO 3 WF flexible putty. (Fig. 4).

The contractor for the above-stated maintenance work was the Energoterm, a.s. firm, Bratislava.

Fig.4 Rehabilitation of large cracks

Strengthening of chimney shaft by external prestressing

For strengthening of the ENO chimney shaft was used the certified technology for the external pre-stressing of cylindrical constructions of the PROJSTAR company, which was used successfully in the strengthening of the reinforced concrete tanks in Petržalka and Nitra [2].

External prestressing was used from a height of +17,5 m to height +132,5 m. In total 310 cylinders of Monostrand tendons were proposed along the height of the chimney divided as follows: 50 x 300 mm + 44 x 340 mm + 175 x 400 mm. The upper part of the chimney, in a length of 14,0 m, was strengthened by steel bands at a distance of 1,0 m. The prestressing tendons were alternately anchored in steel ribs no. 1,2 by PROJSTAR single-cable anchors (Fig. 5). Monostrand was manufactured such that it resisted the increased loading from local unevenness of the chimney surface and the sun's rays. The thickness of the UV stabilized HDPE polyethylene is 2 mm. The colouring of the polyethylene corresponds to the colour tones of the chimney. The basic shade of the polyethylene is silver-grey. In warning-band places, red-coloured polyethylene was used. The closed cylinders of the pre-stressing reinforcement are anchored in one of a pair of opposed ribs. The anchored ribs are manufactured from U-profile rolled steel of a height of 140 mm. In the area of anchoring of the tendon, the U-profile is reinforced by steel reinforcements of a thickness of 8 mm. An HDPE guard runs through holes in the rib, thus increasing the protection of the Monostrand against damage by notched pressure. The ribs are anchored to the chimney shell by steel anchors of width Ø12 mm. The anchoring ribs were manufactured in previously established lengths and their surface was treated with heat galvanizing. The Monostrand tendons are anchored in the ribs by a pair of PROJSTAR CH-1/VK single-cable anchors (Fig. 6). The anchor is treated by a zinc coating, and is treated so that leaking of the anchoring casing does not occur. Permanent plastic bitumen putty was used to seal the connector and the protective cover, and the interior space of the anchoring was filled with lubricant.

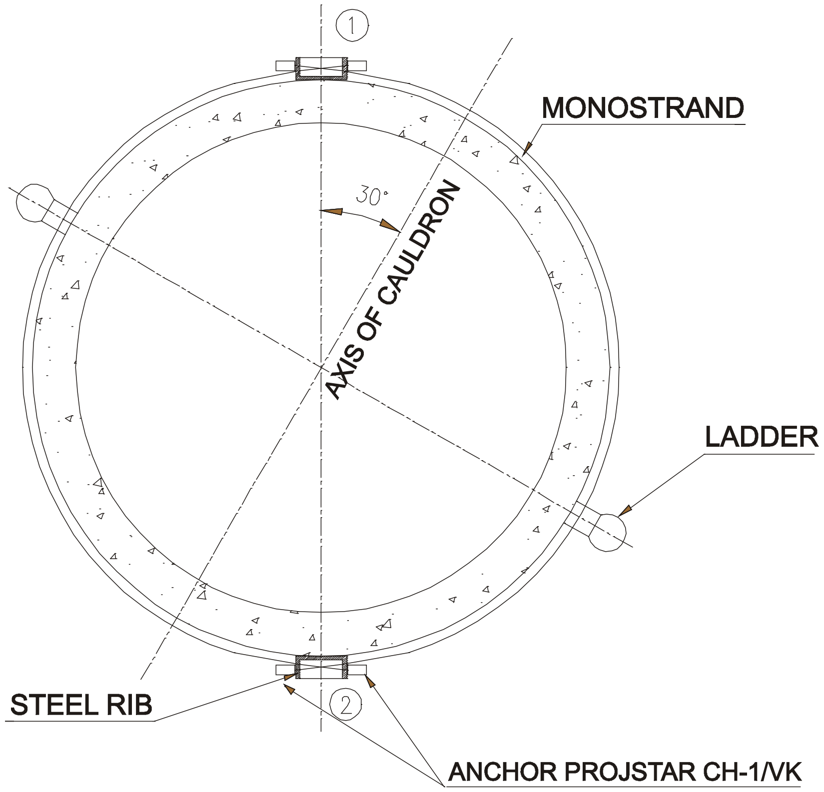

Fig. 5 Scheme of external prestressing of the chimney

Fig. 6 Anchoring of the Monostrand tendon

Since the chimney already had a defined surface treatment, it was necessary to minimize the interventions into the surface of the chimney's protective coat. For the stated reasons, the further stabilizing of the ring track by vertical steel strips was rejected. After the marking of the verticals, the anchored ribs were assembled from the bottom and their height was continuously monitored.
The assembly was carried out from two scaffolds which moved along the vertical lines of the anchoring. For the assembly of the prestressing tendons the scaffolds were augmented by additional scaffolds (Fig. 7), from which it was possible to progressively place the tendon and stabilize its course by simple determiners of the tendon position. After the fixing of the anchors, the tendon was stressed to the calculated force of 65,5 kN. The speed of assembly of the tendons was limited mainly by the relocation of the additional scaffold. In 3 daily lintels of the scaffolding it was possible to assemble 20 tendons.
The stressing of the tendons to 180 kN was performed after the completion of the assembly of all the tendons. The stressing process was carried out so as to avoid the bending of the ribs on one side. For the prestressing were used two PAUL TENSA SM200 kN sets with special press extensions, which angled the press from the chimney wall.
After the completion of the tensing of the tendons were carried out a final setting of the anchoring, the cutting off of the strands, anti-corrosion treatment of the anchoring, the placement of the protective caps, and the sealing of the anchoring elements.
The manufacture of the strengthening components and prestressing of the tendons was executed by the Projstar-PK s.r.o. company. Employees of the Energoterm,a.s. company assisted in the assembly of the pre-stressing tendons [3].

Fig. 7 Installation of prestressing tendons

Fig. 8 The view of finished chimney

CONCLUSIONS

Strengthening of the 150 m ENO chimney is by its character specific in that Monostrand tendons are not covered with a concrete layer as is usual in the majority of cylindrical concrete structures destabilized by the climate. The usage of an open system was dictated by the bearing capacity of the foundations, which did not allow potentially further loading of the chimney and of the foundations by protection by a concrete layer. The more than seven years of experience with the application of this system for strengthening of tanks was also put to good use for strengthening chimneys.

In the choice of an appropriate system for the repair of cracks, a starting point was the implementation of materials and processes of the SIKA firm in the rehabilitation of a number of chimneys in Germany.

The rehabilitation work on the chimney started in September 2002 and was completed in May 2003. The winter season made necessary the interruption of the work for 4 months. During its execution, greater stress was placed on quality, which was overseen by two independent organizations. Part of the project includes ongoing monitoring of the finished work. A view of the rehabilitated chimney is found in Fig.8.

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