Advanced Materials Research Vols. 133-134 (2010) pp 1155-1159

doi:10.4028/www.scientific.net/AMR.133-134.1155

Restoration of the Tsar-Bell Pedestal in the Moscow Kremlin

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Abstract The report contains brief historic and technical information about the Tsar-Bell as well as the structure of its pedestal and gives a detailed description of the instrumental inspection performed to assess structural state of the monument which included examination of the pedestal broad stone/brick masonry and metal fixing elements, check drilling and probing. The inspection results set up the basis for the restoration works.

The authors describe basic technical solutions for strengthening of the pedestal foundation and underlying soil providing structural stability and protection. Some of the solutions were tried out before to strengthen foundations of old historic buildings and cultural heritage monuments.

Restoration procedure of the pedestal superstructure is explained in detail including refurbishment of its metal elements, internal and external lining, special drainage systems installed under the pedestal.

It must be noted that the main idea of this interesting project was to choose appropriate technical solutions and materials which allowed not only to restore the monument but also to preserve its historic appearance.

Keywords: Restoration, strengthening, injections, hydro-active polyurethane foam, historic building

Introduction

The history of casting the so-called Russian giant-bells dates back to the beginning of the XVIIth century, after in 1532-1543 Italian architect Petrok Maly built a special belfry for big bells (later called Assumption Belfry) on to the famous "Ivan-the-Great" Bell-Tower in the Moscow Kremlin. First of these giant bells was cast under Boris Godunov reign (1598-1605) and weighed 17,4 tons. During one of the Kremlin fires it fell down and broke. Same story happened with the second giant bell cast in 1654 (it was heavier, 128 tons). The third one – the Tsar Bell (the biggest of all) was cast in 1735. Its dimensions were as follows: 202 tons; 6,14 m high; 6,6 m dia.

But it didn't escape the common lot: still down in the molding pit, it suffered from the Great fire of 1737 and cracked severely. It became clear that it couldn't be used as intended. Moreover, a huge piece of 11,5 tons broke off. Only a century later the bell was lifted up from the molding pit and placed on a stone pedestal by French architect Auguste Montferrant who always managed to find "customized" solutions which combined provision of necessary bearing capacity with elegance of style (Fig. 1).

Figure 1: General view of the Tsar-Bell

Pedestal Design

The octagon pedestal 1,4 m high 7,5 m dia. is an engineering masterpiece. Being relatively moderate in size, its shape resembles the shape of the Bell-Tower and forms a kind of an architectural ensemble. The rationality of its design is provided by creating of a load-bearing belt formed by three rows of broad stones (dense strong sandstone). Inside there is brick masonry lining to give additional support to the load-bearing belt and to add the whole structure enough thickness (equal to the thickness of the foundation). Metal ties connect broad stones with each other as well as with the brickwork and include cramps, pins and anchors. Such kind of interlocking is typical for massive structures of that time.

The pedestal foundation is put together from natural sandstone blocks and goes down to the depth of 2,5 m. It is supported by wooden piles (made of oak tree) 12-14 cm thick 1,0-1,2 m long rammed into the filled-up ground. It must be noted that the foundation of the “Ivan-the-Great” Bell-Tower has absolutely the same layout differing only in depth (6 m from the today’s ground level (4,3 m from the ground level at the time of construction back in 1505)). Most probably Montferrant decided – alongside with the octagonal shape of the Bell-Tower – to keep resemblance in the foundation design as well.

The necessity to accomplish thorough inspection of the pedestal with subsequent rehabilitation works was dictated by the actively propagating corrosion of both external and internal metal ties, surface deterioration of the brickwork and the material filling the joints between the stone blocks of the load-bearing belt. Traces of corrosion could be seen on the surface of the internal brickwork. Their repair could lead to cracking and deterioration of the external stonework. Besides, previous inspections showed that wooden piles under the foundation went rotten and in some parts became void and filled with soil (Fig. 2).

Figure 2: Pedestal prior to reconstruction

Instrumental Inspection of the Pedestal

Instrumental inspection included electromagnetic and acoustic probing, fiber-optic examination, and check drilling.

Electromagnetic probing allowed to locate the embedded metal ties as well as to define their depth and size; acoustic probing helped to assess brickwork homogeneity. To confirm the obtained results check drilling was used.

A special fiber-optic instrument was used to additionally examine the brickwork through the pre-drilled holes and the joints between the stones of the load-bearing belt.

The inspection results showed:

- fixing pattern between the load-bearing belt stones and the brickwork was typical for massive supported structures of that time. Cramps, pins, and anchors provide structural rigidity of the pedestal. These elements were caulked into the stonework with the help of lead (poured in a melted state into the pre-cut grooves) and couldn't be taken out. Corrosion protection of the anchors inside the brickwork was done with lime mortar;

- standard fixing pattern was enhanced by Γ-shape cramps which was not typical for similar structures of that period. The cramps fastening the brickwork and the upper row of the load-bearing belt stones served primarily to give support to the bell as well as transfer the load to the stonework and further to the foundation. This function (support) was needed also for positioning of the bell when placing it onto the pedestal;

- non-homogeneity of the brickwork could be explained mainly by cyclic wetting-drying of the lime mortar in the joints till its complete softening at the contact with the load-bearing belt stones. The wetting action was aggravated by the absence of any kind of sealing between the bell edge and the pedestal surface which could eliminate water seepage through the masonry joints and accumulation of precipitation inside the pedestal as well as by the absence of a peripheral drainage system (Fig. 3).

Figure 3: Instrumental inspection (acoustic probing)

Basic Rehabilitation Solutions

The results of our visual and instrumental inspections as well as the results of the previous inspections made it clear that actually the complex of rehabilitation works should include two stages: consolidation of soils under the pedestal foundation and strengthening of the foundation and the pedestal body (stonework and brickwork). Taking into consideration non-uniformity of the soil it was decided to make micro-piles under the foundation.

When choosing a particular technological scheme, we decided in favour of injections of hydro-active polyurethane foams which we used successfully for rehabilitation of other historical buildings and architectural monuments.

To reduce the possible influence of the works on the Tsar-Bell itself, we chose small-size drill-rigs designated for slim-hole drilling (20, 40, and 76mm).

Boreholes were drilled both from inside the pedestal and from the outside. In the area of each side of the pedestal (8 sides altogether) we drilled six vertical boreholes 6,5 m deep as well as 16 inclined ones (fan pattern, 4 rows of 4 boreholes) crossing the foundation and going into the soil to the depth of 2,5-6,5 m.

For injections we used TAM (tubes a machette) 25 mm dia. and a screw pump. Vertical boreholes were injected with cement grout with 10-15% of hydro-active polyurethane foam. Inclined boreholes were injected with pure polyurethane of different grades: PU forming rigid foam was used for the soil; PU forming elastic foam was used for the foundation.

Aboveground brickwork part of the pedestal was strengthened with elastic PU foam through the boreholes of 20 mm dia. from inside the structure. There were four rows of 3 boreholes at each side of the pedestal. We did it not only to strengthen the brickwork, but also to make an elastic seal at the interface with the stones of the load-bearing belt. The elastic seal was needed to provide a joint work of different structural parts in taking up deformations caused by seasonal temperature fluctuations.

To eliminate moisture entrance and to stop its negative influence on structural deterioration gaps between the stones of the load-bearing belt were sealed to full depth from the outside by injecting an elastic hydro-active polyurethane foam. Prior to injecting the inner part of the joints were sealed with polymer-modified cement mortar similar in properties to the sandstone of the load-bearing belt blocks. The same mortar was used to fill the gap between the Tsar-Bell and the load-bearing belt.

The brickwork inside the pedestal was mended with bricks from the Kremlin store-rooms and lime mortar.

Visible metal ties (both inside and outside the pedestal) had to be cleaned from corrosion traces (rust, etc.) and covered with corrosion-inhibiting coating. Some of the ties required additional anchoring into the stonework with molten lead.

As mentioned above, accumulation of precipitation inside the pedestal as well as absence of external water drainage system leads to excessive wetting of the structure. To eliminate negative consequences we proposed a horizontal drainage system with a filtering pit located under the sandstone floor plates. Outside the pedestal drainage pipes were laid under the external stone pavement with the outflow into the existing storm water sewer.

Brickwork surface inside the pedestal was finished with a breathable waterproofing coating to substitute the former cement-based rendering which had been almost completely deteriorated. The external surface of the load-bearing belt was sandblasted, bringing back its original appearance.

Conclusion

Thus, we can summarize as follows. Since 1836 the pedestal was subject to constant loading of 200 t (the approximate weight of the Tsar-Bell). Besides, both the pedestal structure and its foundation suffered from gradual wear and destruction of their constituent materials (metal ties, stone- and brickwork, wooden piles). The results of the inspection performed by our diagnostics department allowed to evaluate the actual degree of damage and based on this to work out the program of structural preservation and strengthening.

We do hope that all the works done successfully will extend the service life of the monument and new generations of tourists who visit the Moscow Kremlin will be able to admire it many long years.