ABSTRACT: The global reconstruction of the palm greenhouse at the Lednice state chateau, Czech Republic, was in progress during the years 1999 and 2003. The greenhouse at the Lednice chateau in the Czech Republic is part of the Lednice-Valtice complex, a UNESCO monument. The load carrying system is formed by 44 metal columns and arch ribs. The column marble block foundation is carried by the cell vault. The bearing ribs are anchored to the peripheral stone plinth. Ribs and columns are connected to the longitudinal roof truss girder on the top of the glass vault. The column behaviour with plaster and epoxide resin were calculated using finite element method in program ANSYS. The article also deals with the unique and complex reconstruction technology of the bearing system.

1 INTRODUCTION

1.1 History of greenhouse

The greenhouse at the Lednice chateau in the Czech Republic is part of the Lednice-Valtice complex, a UNESCO monument. The structure, which was built in 1845, was proposed by the architect Geore Wingelmüller on behalf of Alois Joseph II of Liechtenstein. It is one of the oldest and largest historical greenhouses on the European continent. The restoration was supervised by The Heritage institute in Brno. The company OK-DESIGN, Ltd. was both the provider of the design documentation and the general constructor, the authorized conservators were in charge of the actual reconstruction works.

The monument care process went in three phases. First - between the years 1995 and 1997 – came the analysis of the actual condition of the monument and conservators prospecting report. The preparation of the design documentation and conservators project followed. In the second stage (from 1997 to 2003) the monument care project was realized. The recovery of the greenhouse heating system was carried out in 1997 and in 1998, the structure of the greenhouse and its interior was reconstructed between 1999 and 2001. In 2002 and 2003 the exterior reconstruction was finished.
1.2 Steel bearing system

Forty-four load-carrying columns form the structure bearing system. The columns support the half-cylinder vault made from steel ribs. Both columns and steel ribs form the arch bearing system, the part of which is the glass tile cladding. The number of glass tiles is approx. 65000.

The bearing columns are located in the interior in two longitudinal rows, the longitudinal distance between them is 3900 mm, in the lateral direction 4300 mm, see figure 1.

As part of the conservator’s prospect, one column was extracted from the system and mechanically divided. The shape of the decorative bamboo tree was respected. This column (7072 mm high, octagonal shape footing) is bold anchored into the 600x600x400 mm marble block. The block is surrounded by brick deck with calcareous plaster, see figure 2.

The bearing column center is countersunk into the cast iron footing. The wrought iron center is of circular cross section, its diameter is 72 mm, and the upper end head serves as the connection with the vault, see figure 3.

The column head is hinge jointed to the longitude truss girders. The center is clad by six cast iron members imitating the bamboo tree shape. The bottom shaft part is covered by zinc banana tree foil; indentifiable foils and flowers cover the head. The space between the bearing center and the cladding was filled by gypsum.

Wrought iron ribbing made by smelting forms the half-cylinder vault bearing system. The distance between the double ribs is 3900 mm, see figure 4. These profiles are fixed into longitude girders. In the bottom side, they are anchored through the portal in the brick base. The single ribs are put between the doubled ribs in the distance of 250 mm. The ribs support cladding glass tiles by jigger and pin connection. The tiles prevent the ribs from lateral buckling. In the lateral direction, the upper longitude girders are joined by the timber cross member. This connection is made in the place of the double ribs. The timber greenhouse loft structure lies in this system. The participation of each member can be seen in figure 5.
1.3 The rehabilitation of the load bearing column

Primarily, the greenhouse was used as the orangery. The plants grew in containers and the columns stood freely in the air, not exposed to humidity and subsoil weight. When the orangery was converted into a greenhouse, the subsoil was spread in a layer of the height of up to 750 mm. Since the columns were not insulated from the subsoil humidity, the water crept up through gypsum the whole column height, creating - together with air humidity - conditions for the shaft and cladding corrosion.

After the columns were taken away from the greenhouse and replaced with temporary supports, the cladding had to be carefully removed from shaft. The steel pole was heated in a tempering furnace to loosen the rust and burn off the original filling material. Then, the sleeves were gripped, and using a hydraulic device, an attempt was made to strip them from the shaft. As the shaft and the sleeves were solidly bonded together by corrosion, this procedure failed. For this reason, a reverse procedure had to be used. The columns were submersed in a 10-15% bath of hydrochloric acid for 12 hours. Afterwards, they were sprayed with water under high pressure, and stabilized. In this way, the gypsum softened. Then the column was gripped and the bearing shaft was pushed out in a horizontal direction and the undamaged cast iron sleeves were freed. Against the primal theory, all shafts could be used without change. As the gypsum did not prove to be a suitable filling material, it was substituted by a two-element epoxy laminate resin Ebalta AH-110 with filler F-B (modified chalk). The resin has good mechanical characteristics. The adherent is designed to be removable – in case of need the resin is heated to the proper temperature and the sleeve is removed. After the corrosion was removed mechanically, the original coat was blasted, galvanized, and four times painted by Hempel colors. Originally, the material used to connect the sleeves was tin, now the sleeves were glued.

Figure 3: Column detail
Non-destructive experiments were applied on load carrying columns shafts in Královopolská strojírna in Brno. The testing was done by the magnetic dust method and by ultrasound. The magnetic dust method shows surface flaws, while ultrasound finds inner flaws in the material. The magnetic dust method is founded on the principle of the flow of the magnetic field through material. In the case of damage to the tested material, the flow of the magnetic flow is disrupted. The shape of the magnetic field in the tested material is found by magnetic suspension (in this case water was used as the support medium, and a concentrate as the electromagnetic material). The concentrate is colored with fluorescent dye. While the magnetic field is going through the tested sample, it is submerged in a magnetic suspension that copies the shape of the electromagnetic field, which is visible under ultraviolet light. The size of the disruption shown by the magnetic suspension corresponds exactly to the size of the disruption in the tested material. The electromagnetic field was introduced into the test sample by a horseshoe-shaped electromagnet – type TS 230 S TESTIMA running on alternating current of 220 V. The detection element in the magnetic suspension was type FLUOFUX (TIEDE).

Water as a support medium was used because of its relatively harmless effect on the test sample. The purpose of the test was to show that the test sample did not reveal linear cross indicators (faults) of more than 3 mm in length. The ultrasound waves were introduced into the test sample by means of a B 2 SN probe, with a frequency of 2 MHz. The readings were taken on a USM 2 MT (KRAUTKRAMER) instrument, the range of which was set at 100 mm. The purpose of the test was to show that the tested sample did not reveal internal indicators (flaws) longer than 7 mm.
As a part of the project documentation “Monument care of the greenhouse” the static analysis of a stand-alone shaft was made. Since the slenderness of this member (of the length of 7072 mm) is too high, it was necessary to consider the participation of both the iron shaft and the sleeve. In this way, the slenderness ratio is 200. We assumed that the shaft is loaded by the axis force of 28.9 kN and that the cladding prevents the column from buckling. The shaft damaged during the conservators project was replaced by the stainless pipe 73/7.1.
The load carrying capacity was recalculated by the ANSYS program system. The detailed model where the participation of each member of the column (shaft, sleeve, epoxy laminate) was exactly defined. The anchoring and the connection by the longitude girder were also taken into account. This control calculation approves the statical reliability of the columns in the greenhouse at the Lednice chateau.
Among the numerous analysis methods, the finite element method (FEM) is no doubt a powerful one and has been used extensively in recent researches. However, because of the complexity of the deformation, some simplifications had to be made in the analyses. In this paper we develop a 3D elastic–plastic finite element model of slender column. The global as well as the local deformation shape, the stress and strain distribution are simulated based on the model.

In recent years much attention has been paid to studies of strength characteristics and behavior of different types of steel structures. The investigations are primarily focused on standard beams framing into columns. The carrying system of the column used on Greenhouse is realized by full circle shaft, transferring pressure force. Regarding high slenderness is this shaft protected against loosing of stability by cast iron cladding. Cladding is created by segment spanning on. Transmission of stabilizing forces from shaft to the cladding is realized by the help of resin, which fill annulus in column.

In case of historical structure experimental research, the tests consisted of full-scale column was not possible to realize. The finite element method is alternative method to analyze the behavior of complex behavior of this type of column under various loading conditions.

The linear methods of analysis have been widely used because of its simplicity and of their conservative results. Also the effect of connection of the column with other parts (footing, transverse beam) was considered. It is necessary to take into account the behavior of the joint region and introduce the corresponding model with contact capabilities.

![Figure 10: Column bottom part – shaft and cladding](image)

ANSYS finite element code was used in three-dimensional modeling. Assumptions and simplifications were made in order to avoid detailed modeling and reduce the computational effort. Symmetry about a plane passing through the beam axis was utilized and only one-half of the column was analyzed and symmetric displacement boundary conditions was defined for the nodes along in the vertical plane. However, column members were modeled and meshed along their full length. During the meshing operation, care was taken also for contact regions between the column and footing and also between shaft and cladding material to prevent any conver-
gence difficulties. Resin material was replaced by contact elements with adequate characteristic in concentrated stress conditions. An adequate mesh density was required for regions undergoing plastic deformations to allow contact stresses to be distributed in a smooth fashion. Brick elements, as called Solid45 in ANSYS, were used in three-dimensional modeling of column shaft, cladding and epoxy sections. The use of these elements provides the same number of integration point density as the higher-order elements but requires much less computational power. The element is defined by eight nodes and each having three degrees of freedom with orthotropic material properties. The contact surfaces on footing and high shear contact on epoxy-steel contact surface was defined and paired during the mesh operation including areas anticipated to be contact. These contact surfaces were meshed with contact element (Conta 174) and target segment elements (Targe 170).

The column symmetrical half geometry was defined by 23 686 solid45 elements located by 24312 nodes and 2330 conta174 elements.

Contact stiffness and penetration tolerances were properly modified during the load steps since the plastic deformation on contact surfaces generally leads to convergence difficulties. Conta174 provides an option for defining a maximum equivalent shear stress so that, regardless of the magnitude of the contact pressure, a sliding will occur when the magnitude of the equivalent shear stress reaches its maximum. Since it was expected that the friction would be a dominant parameter of stiffness at the initial stage of loading, the connection were compared with different friction coefficient for 0.2 and 0.5 to predict the effect of friction on the response of the connection. When the friction coefficient value of 0.2 is used instead of 0.5, the general stress and strain distribution obtained from finite element analysis. The coefficient of friction between steel contact surfaces was assumed as 0.2.

3 CONCLUSIONS

The priority of the monument care of the bearing steel structure in the greenhouse at the Lednice chateau was to protect the greenhouse vegetation. For this reason, the special and complicated technologies were chosen. The timing of the works respected the health of the vegetation. The process of the monument care can be seen in the following figures. The restoration of the Lednice greenhouse was awarded by GRAND PRIX 2003 prize of architectural associations.

REFERENCES

Bajer, M., Kala, J. (2004) Care of the greenhouse bearing system at the Lednice chateau, Slovak Journal of Civil Engineering, pp. 16-20, Vol. XI, ISSN 1210-3896