

Strengthening the Structure of St. Nicholas Church

Cracow, Poland

Submitted by Sika Corporation

St. Nicholas Church, located in Krakow (Cracow), Poland, is one of the oldest monuments in Cracow. It was designated as a parish church in 1327. Now the facility is under the local jurisdiction of the government agency Monument Preservation Office of Cracow.

The original building dates back to the second half of the 12th century. In 1456, the church was handed over to the University of Cracow in order to provide monks with an education. Thanks to the university's financial support, the church was extended in the first halves of the 15th and 16th centuries.

Unfortunately, the next turn of events brought about a run of bad luck for the chapel. The most dramatic point in the church's history was in the second half of the 17th century. In July of 1652, there was a heavy rainfall which caused the water level of Wisla (Vistula) River to rise and completely flood the church. Then, in 1656, Poland was attacked by Sweden during the so-called "Swedish Deluge" and the Swedish invaders burned the church down and destroyed its walls to prevent a besieged Polish army from launching artillery fire. After a series of wars in Poland in the mid-17th century, the church was in ruins. After the wars, the church was successively rebuilt and extended based on old foundations. The south nave, porch, and vestry were rebuilt at the beginning of the 20th century. Currently, the church is classified as a baroque and neo-baroque three-nave, three-bay basilica.

ORIGINAL CONSTRUCTION

The roof structure consists of a crown post truss over the main nave and chancel; a king post truss over the northern aisle; a queen post truss over the southern aisle, southern vestry, and porch; and another queen post truss with angle braces over the northern vestry and the chapel of Our Lady of Sorrows. The roofing is mainly ceramic tile, but has copper sheeting over the side chapel, vestry, and vestibule.

The current construction was built on the already-existing foundation from the structure destroyed in the past, much of which was done with local limestone. The stones used for the foundation and the limestone rock on which the church is located were subjected to washout and karst



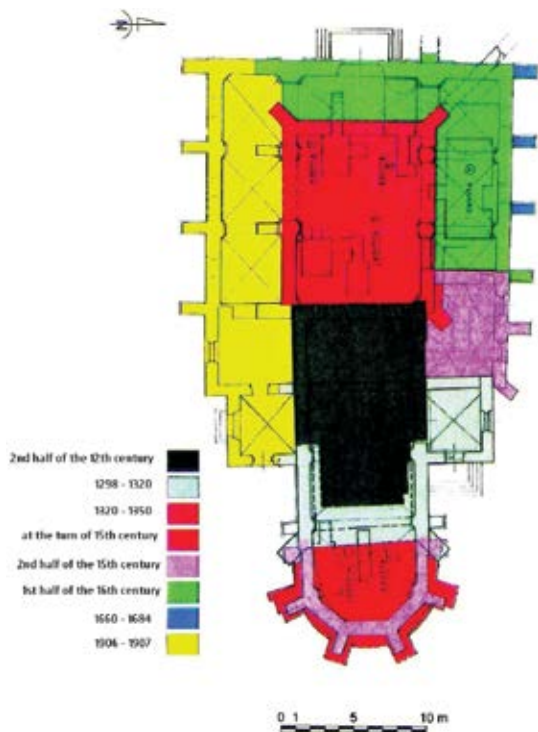
View of front façade

phenomenon over the centuries, leaving severe degradation within the foundation. Acid waters washout, as well as vibrations caused by increasing traffic—especially on the train track located just behind the church—were other causes of the severe deterioration of the foundation. This all led to the front wall deviating from vertical and falling away from the structural walls.

INITIAL TESTING

One of the most important actions to be taken before construction began was testing the strength of the church's wall substrate, which, in this case, was brick covered in plaster. Direct tensile pulls were required by the Monument Preservation Office to determine the quality and soundness of the substrates to be repaired.

Another test performed before construction began was a method of stratigraphy, used on this project to determine levels of karstic destruction (deterioration caused by areas of limestone consisting



Additions to the church since the 12th century. Spatial stratigraphy of the St. Nicholas church by H. Rojkowska and W. Niewalda

of sinkholes, underground streams, and ravines) within the existing substrate. The major prerequisite for any chosen repair technology was to minimize any interference with the original structure, making sure that there would not be any visible elements at the end of the strengthening process.

FOUNDATION REPAIR WORK

The foundation was strengthened using the traditional method of shoring up the foundation with concrete blocks placed every 3.9 ft (1.2 m) and fixed in place with a mineral cement-based mortar. During the next step, all empty spaces were filled with concrete-based injections, section by section.

During the renovation and construction of the foundation, the contractors encountered the traces of burials from the previous centuries. Human remains were found under the church and in surrounding areas. The remains were secured and buried in a special, separate crypt on site.

STEEL REINFORCEMENT

Cracking was seen in the chancel vaults, the main nave, and the aisles, which resulted from a lack of rigid support receiving the strutting forces through the walls. The original timber framing was not enough to stabilize the structure, so steel framing and braces were installed throughout the attic of the church, hidden to normal visitors. This new reinforcement allowed even transfer of the strutting forces through the walls, and movement of the church was decreased significantly.



View of the southern façade



View of the vaults over the chancel



Preparation work on the substrate prior to applying the carbon fiber laminate strips and fabrics



Finishing the wall with the mortar in the places of carbon fiber laminate strips and fabrics

CARBON FIBER REINFORCEMENT

The next stage of repair consisted of placing carbon fiber laminate strips and fabrics, as well as cement grout pressure injection, into wall cracks. The carbon fiber-reinforced polymer (CFRP) laminates and fabrics were chosen because of their high strengths, small dimensions, and minimal interference into the structure, together with the fact that all strengthening jobs could be easily hidden under wall-covering plasters and façade coating. The injection material was specially formulated based on white cement and included additives that modified the rheological properties to increase the ease of injection. Once the cracks throughout the structure were stabilized by repairing the foundation and attic framing and through pressure injection, work could begin on repairing them.

The cracks to be repaired were grouped into two categories: those that were dynamic, and those that were static after stabilizing the foundation and attic. The static cracks were only on the surface of the façade and did not translate through the structure. Since these surface defects were not in motion, the repair consisted only of an on-site plaster mixture applied directly to the cracks to remain consistent with the current façade work.

The dynamic cracks were found mainly on the outside of the building and were repaired using the thin carbon fiber strips. For the transfer of the tensile forces accepted by the carbon fiber strips, it was recommended that the strips maintain a cross section of 2 x 48 in. (50 x 1219 mm) and that the strips were spaced every 20 in. (508 mm) with anchoring zones a minimum of 20 in. (508 mm) on each side of the crack. A special system epoxy adhesive was applied for leveling and fixing the carbon fiber strips.

The apses above the windows were repaired using carbon fiber strips, creating a kind of “wreath” above the window. The plaster was removed so the brick substrate was revealed, and the strips were fixed using a high-strength, high-modulus structural epoxy paste. The strips were fixed to the outside above the windows and along the inside of the nave walls. The inside was repaired in two levels, one above and one below the vaults, with one of the strips anchored to the front wall as well.

The vaults were strengthened using a unidirectional carbon fiber fabric which was fixed to the brick using a high-modulus, high-strength impregnating resin. The fabric was fixed perpendicular to the cracks and also adhered to a minimum anchoring distance of 20 in. (508 mm) beyond the end of the crack.

More carbon fiber reinforcement was used at the top and bottom of the cracks in the keystone vaults over the chancel and apse. The most severely cracked area, however, was over the lunettes in the chancel. The plaster was removed and the reinforcement strips were placed perpendicular to the crack.

FINISHING

Once the carbon reinforcement was cured, the areas were filled with a vertical repair mortar and finished with the same on-site, prepared, calcium-based plaster mixture used to fill the static cracks. After the completion of strengthening and plaster applications, all elevations were covered with a special silicate paint which completely hid all repaired zones. After the repairs were completed, the building was opened back up to the public in 2012. As required by the Cracow Monument Preservation Office, a yearly inspection is made on the entire structure to check for durability of the repair, and if any issues do arise, they can be addressed as quickly as possible.

St. Nicholas Church

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