Traditional natural stones for the restoration of monuments

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Abstract: Most of the architectural heritage of European cities has been built from local natural stone. The range of traditional stone has, however, been depleted by both the rapid development of artificial building materials during the 20th century, particularly concrete, and massive imports of alien stones. The maintenance and restoration of monuments must, however, continue, resulting in a demand for traditional materials. The major question posed by restorers and architects to geologists is whether the supply of traditional material can be renewed or if stone of similar qualities can be supplied from another source.

This study focuses on the availability of traditional natural stones for the restoration of monuments. A possible solution is shown by the example of the Charles Bridge in Prague (Czech Republic) – a prestigious engineering work using Gothic architecture and one of the best known symbols of the Prague historic centre. The Charles Bridge suffered from poor maintenance after the 2nd World War. This inappropriate maintenance was partly caused by the closure of quarries that provided the original natural stone. The introduction of new types of sandstones during large repairs in the 1960s and 1970s did not improve the condition of the bridge. The idea of the re-opening of abandoned quarries and/or exploration for a new deposit were proposed during the preparation of new restoration plans in the current decade. The supply of traditional stone type would be beneficial not only during maintenance of the Charles Bridge but also for restoration of other monuments, dating back as far as the 12th century, where Carboniferous arkoses have been used.

Résumé: La plus grande partie de l'héritage architectural des villes européennes a été construit à partir de pierres naturelles locales. L'étendue des pierres traditionnelles a été néanmoins remplacée par un développement rapide de matériaux artificiels de construction pendant le XXe siècle; à savoir en béton et l'importation massive de pierres étrangères. La maintenance et la restauration de monuments doivent cependant être soutenues et nécessitent l'apparition de matériaux traditionnels. La plus grande question des restaurateurs et architectes aux géologues est si la réserve d'un matériau traditionnel peut être renouvelée ou si la pierre d'une qualité similaire peut être remplacée par une autre source.

Cette étude se concentre sur la disponibilité de pierres traditionnelles et naturelles pour la restauration de monuments. Une solution possible est démontrée sur l'exemple du pont Charles à Prague (République tchèque) : un travail prestigieux d'ingénierie d'une architecture gothique et l'un des symboles le plus connu du centre historique de Prague. Le pont Charles a subit de mauvais entretiens après la Seconde Guerre mondiale. La maintenance inappropriée a partiellement été causée par la fermeture de carrières fournissant de la pierre naturelle originale. L'introduction de nouveaux types de grès pendant les grandes réparations des années 1960 et 1970 n'a pas amélioré la condition du pont. L'idée de rouvrir les carrières abandonnées et/ou l'exploration d'un nouveau dépôt a été proposée pendant la préparation de nouveaux plans de restauration dans les années 2000. La fourniture du type de pierre traditionnelle serait bénéfique non seulement pour la maintenance du pont Charles mais aussi pour la restauration d'autres monuments où l'arkose carbonifère a été utilisée depuis environ le XIIe siècle.

Keywords: quarries, sandstone, monuments, building stone, historical bridge

INTRODUCTION

General

The availability of traditional building stone for the restoration of monuments has not been satisfactorily discussed in the scientific literature although it presents one of the crucial problems in the conservation of built heritage (Ashurst & Dimes 2004). The use of local natural stone is a characteristic feature of European architecture and sculpture. The tradition of natural stone utilisation dramatically declined after the 2nd World War when new, artificial materials and alien stone varieties were introduced. New materials such as concrete or imported stones are probably acceptable for new buildings but the restoration of monuments and historic city centres requires traditional materials. A common question that architects and restorers often ask geologists concerns the availability of the traditional stone. Even if the original stone can still be quarried, the quality and quantity of the remaining resource are crucial. In cases where the original stone is no longer available, the question is if a suitable alternative material can be used without changing the character of the monument.

Aims

This paper aims to discuss the availability of original natural stone for the restoration of important monuments. The Czech Republic can serve as a typical example of a country where most of the historically important building stones are not quarried at present. The non-availability of traditional stones may cause major problems in the restoration of monuments as shown by the example of the prominent Prague monument – the Charles Bridge.

NATURAL STONE TRADITION IN THE CZECH REPUBLIC

The Czech tradition of natural stone utilisation is influenced by the complex geological history of the Czech Republic territory. This area offers a wide range of rock types in a relatively small area that can provide blocks that meet specifications as to size (width, length, and thickness) and shape (dimension stone), although many deposits now have low reserves or low block sizes.

It is estimated that about 500 quarry sites provided more than 800 varieties of stone over the last 10 centuries (Přikryl, Svobodová & Siegl 2001, 2002, 2004). At present just 74 quarries are operated (2002 data) out of the 171 quarries registered by the Czech Geological Survey. The annual production of dimension stone is 300,000 cubic meters (750,000 tons) per year (Figure 1). Granites comprise two thirds of the production, followed by sandstones and marbles. Before the industrial production of stone, the majority of building stone was supplied from sandstone, marlstone and limestone quarries.

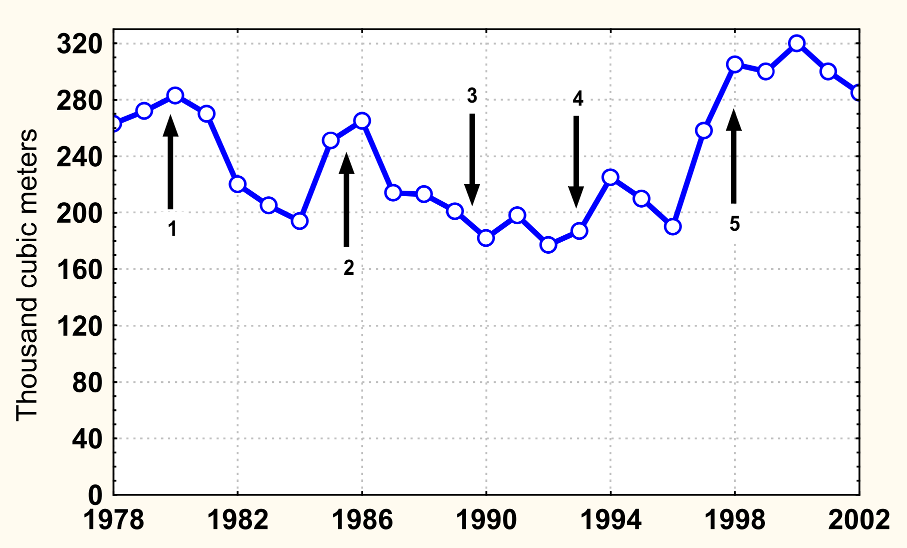

Figure 1. Dimension stone production in the Czech Republic (data from 1978 to 1992 are given for the Czech territory of the former Czechoslovakia). Data (after Czech Geological Survey) are shown in thousand cubic meters and expressed as bulk production. Explanation of the major trends: 1 – construction of underground (metro) A-line and Congress palace in Prague, 2 – construction of underground (metro) B-line in Prague, 3 – collapse of the communist regime in Czechoslovakia, 4 – split of Czechoslovakia, 5 – increasing export to the re-unified Germany (mainly paving cubes) (adopted from Přikryl, 2004a)

ATLAS OF HISTORICAL DIMENSION STONES

As shown in the previous section, most of the stone varieties that were quarried in the past (about 90 %) are not available at present. Information on these stone varieties and past quarries is partially provided by published stone inventories (Hanisch & Schmid 1901), general books on dimension stones (Rybařík 1994), and unpublished research reports archived by the Czech Geological Survey. Recent commercial lists of natural stone include only the current operating quarries.

Due to this incomplete information and to the lack of an archive of historical dimension stones (lithotheque), the project "Atlas of historical dimension stones of the Czech Republic" was initiated in mid 1990s (Přikryl, Svobodová & Siegl 2001, 2002, 2004). The project is focused on the sampling of the stones, their detailed characteristics (petrography, material, properties), and also on the possibility of reopening the most important quarries.

AVAILABILITY OF TRADITIONAL STONES FOR THE RESTORATION OF PRAGUE'S MONUMENTS – EXAMPLE OF THE CHARLES BRIDGE IN PRAGUE

Building stones of the Charles Bridge

The Charles Bridge, the oldest preserved bridge in Prague, was built during the period 1357 to 1402. The facing masonry was constructed using only local sandstones quarried in the area surrounding Prague. A minor part of the stone used was recycled from the antecedent Judita Bridge which was built in 1167 and collapsed after the 1342 floods. The extent of the original stonework cannot be determined at present because no written records on the source localities exist and also because the bridge has been widely reconstructed and repaired over the centuries, namely after severe floods (1432, 1784 and 1890) using sandstones from several localities.

Based on detailed petrographic research on stone samples from the bridge and on a geotechnical survey (Drozd & Přikryl 2003, Drozd, Přikryl & Votoček 2005), 7 quarry areas which provided two major rock types, Carboniferous arkoses and Cretaceous sandstones, can be traced (Table 1). Categorisation of the stones was facilitated by the lithotheque of historical dimension stones of the Czech Republic (Přikryl, Svobodová & Siegl 2001, 2002, 2004). The stone type of individual ashlar blocks was linked to petrographic type and source locality by both evaluation of macroscopic appearance (visual comparison of rock slabs from samples from individual localities to the face of the ashlar) and by microscopic analysis of rock thin sections, including quantitative analysis of microstructures.

Table 1. Summary of natural stone types used for the construction and repair of the Charles Bridge in Prague

Rock type	Source area/locality	Period of use	Extent of use	Current availability
arkoses (medium to coarse grained, beige and yellow colour)	Carboniferous, limnic Kladno-Rakovník basin W and N from Prague, 4 major quarry areas (distance from 20 to 50 km)	undated, probably 14th - early 19th centuries	not measured on the whole bridge, 50-90% of test areas	recently not available, of great interest (quarry site must be investigated)
quartz sandstone with clay matrix (generally fine-grained, whitish to grey colour)	Upper Cretaceous, Cenomanian, mostly abandoned quarry areas NW, N a E from Prague (distance up to 30 km)	undated, probably 14th - early 19th centuries	not measured on the whole bridge, 20-45% of test areas	partly available, of no interest (low durability, uncertain period of use)
glauconitic quartz sandstone with clay matrix (extremely fine-grained, green-grey colour)	Upper Cretaceous, Cenomanian, abandoned quarry areas NW, N a E from Prague (distance up to 30 km)	undated, probably 14th - early 19th centuries or repairs till the end of 18th century	not measured on the whole bridge, up to 2% of test areas	not available, of no interest (minor use, low durability)
quartz sandstone with Fe-hydroxide cement (generally medium-grained, deep rusty brown colour)	Upper Cretaceous, basis of beds on Petřín hill (distance less than 1 km from the bridge)	undated, probably during construction in 14th century as a recycled material from the antecedent Judita Bridge	not measured on the whole bridge, up to 10% of test areas	not available, of potential interest (minor use)
quartz sandstone with clay matrix (fine-grained, yellow colour)	Upper Cretaceous, Cenomanian, active quarry area near Hořice E of Prague (distance 130 km)	after 1890 flood repair	not measured on the whole bridge, broad use on 3 collapsed arches	available, of no interest (extremely low durability)
glauconitic quartz sandstone with clay matrix (generally fine-grained, yellowish green-grey colour)	Upper Cretaceous, Cenomanian, active quarry area near Libná NE of Prague (distance 170 km)	1960-1970s repair	not measured on the whole bridge	partly available, of no interest (low durability, new repair stone only)
arkosic sandstone (generally medium-grained, light beige colour)	Upper Cretaceous, Turonian, active quarry area NE of Prague (distance 170 km)	1960-1970s repair, also for 2005 repair of pier nos. 8 and 9	not measured on the whole bridge	available, of no interest (low durability)

Plans for reconstruction/repair and stone availability

The Charles Bridge largely suffered from inappropriate maintenance during the 20th century. Major repairs were conducted after the damaging floods in 1890 (repairs continued until 1910) and then again in the 1960-1970s. Between and after these repairs, there was no routine maintenance of the facing masonry, partly caused by the non-availability of the original stone. Rapid recent deterioration of the facing masonry has been accelerated by the introduction of new types of stone that had not been used previously (see Table 1). These stones show pronounced granular disintegration by a salt weathering mechanism followed by loss of 1 cm thickness from the surface for Božanov arkosic sandstone after 30 years of service (rate 0.3 mm/year) and up to 3 cm loss for Hořice sandstone after 100 years of service.

Discussions of a new repair and maintenance plan opened the question of whether the dominant traditional natural stone (Carboniferous arkoses) could be used for replacement stonework (Přikryl 2004b). As the quarrying of such stone was stopped after the 2nd World War, exploration for a new deposit was initiated (Přikryl 2005). A desk study and field reconnaissance focused on four areas in the Prague environs where such stone had been quarried in the past. From 11 abandoned quarries, 2 were suggested for exploration and 2 others as possible targets of future exploration. The expected extent of reserves, stone appearance, its quality, and land availability were the main decision-making criteria for the selection of exploration areas.

JUSTIFICATION OF AUTHENTIC MATERIAL USE FOR THE REPAIR OF MONUMENTS

The supply of suitable natural stone material for monument reconstruction forms an important part of heritage policy. The use of the original stone is problematic if such material cannot be supplied due to the closure, renaturalisation or recultivation of the quarry, and/or if the reserves have been mined out. The long-term abandonment of a quarry does not necessarily mean that the stone cannot be made available, but other changes, such as conversion to agricultural land or use for waste deposition are irreversible. These, as well as mining out of the reserves, result in the need to find alternative sources of stone.

When large amounts of stone are needed for monument repair and authentic stone is not available due to the above-mentioned factors, three solutions exist:

- use of an alternative stone that is currently quarried and which has properties approaching the original material
- use of any available stone irrespective of its properties
- finding a replacement source of the original stone

The first possibility has been the most widely used, although it is not a very desirable solution. The ready availability of the stone may make this solution appear advantageous. However, properties differing from the original stone (appearance, colour of weathered stone, mechanical properties, durability) may result in dissimilar weathering patterns that may not occur not until many years later. This evidently happened on the Charles Bridge after the introduction of the Upper Cretaceous arkosic sandstone from Božanov instead of Carboniferous arkoses (compare Table 1).

The second possibility – application of any available stone type – presents an extemporary solution that is not acceptable in most cases. The Charles Bridge can also provide an example of such an unsuitable approach. After the 1890 floods that caused collapse of three arches, the non-original Cretaceous sandstone from the Hořice area was used for repairs (see Table 1). This fine-grained soft sandstone is highly susceptible to weathering and is absolutely unsuitable for highly exposed structures.

The third possibility – reopening of the abandoned quarry supplying original material – is the most acceptable solution. If the original quarry is unknown or cannot be reopened, an alternative new locality in the same geological formation can be explored. The possible use of original stone has been also suggested for the Charles Bridge (Přikryl 2004b, 2005). The highest mechanical performance and mostly acceptable resistance to weathering present the main advantages of this approach. The recent non-availability of the stone can be solved by re-opening one of the abandoned quarries.

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