Preservation of structural monuments: Charles Bridge

Preservation of Structural Monuments – Charles Bridge

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Summary

Degradation and corrosive processes of structures cannot be generally prevented. They are manifested by the structures' ageing. Experimental monitoring and investigation of Charles Bridge has shown exceptional importance of non-force impacts and effects acting on structures. These impacts and effects due to namely physical, chemical and microbial processes are a major cause of gradual deterioration and ageing of structures. From the point of view of preservation of prominent structural and cultural monuments, it is necessary to study these processes, their causes and mutual connections.

Keywords: physical degradation, recrystallisation cycles, microbial corrosion, biodegradation, non-force impacts, chemical and microbial processes, structural damage, cyclic temperature and moisture impacts, long-term impacts

1. Historical introduction

On 9th July 1357, Charles IV laid the foundation of a new stone bridge with a level line by 4 m higher than that of Judith's Bridge, with 16 compartments with a clear span of 16.62 m to 23.38 m. The overall bridge length is 515.76 m and it is 9.4 m wide. Its plan is slightly elongated, goosenecked, curved in shape. The dimensions of massive stone piers at the vault impost range between 8.5 m to 10.84 m x 24.0 m to 25.0 m. Pier heads have been "sharpened" against the water stream at an angle of 65°. The bridge construction, entrusted to Petr Parléř's stone works, was completed in 1406.

2. Physical, chemical, microbial and mechanical impacts

Among the most frequent causes of primary physical degradation of stone masonry there is migration and crystallisation of salts, combined with moisture penetration inside stone and with frost cycles. The samples taken from sandstone blocks of Charles Bridge were subjected to frost and recrystallisation cycles. The achieved partial results have proved that frost cycles do not represent extreme danger for the stability of sandstone blocks of Charles Bridge. The stone degradation is only of surface character. Deeper changes have not been recorded. The impact of salts contained in considerable amounts in sandstone blocks is much more noticeable. In order to achieve moisture balance between the inside and outside environment during stone moistening, due to their hydroscopic properties salts either absorb or release water. Thus hydration and crystallisation pressures arise which may affect the development of fine expansion joints or microcracks in stone. This was also confirmed by experimental results. As early as after the first cycle, fine cracks (arkose) appeared which gradually grew wider. It is probable that the old stone blocks of Charles Bridge in particular will be very much susceptible to hydration or recrystallisation pressures exerted namely by sulphate, chloride and nitrate salts, which is necessarily manifested by accelerated development of cracks on the stone surface. Due to variable chemism of solutions migrating in the pores of building stone, cyclic growth and, simultaneously, dissolution of salts occur (formation of two generations of plaster stone was proved). The ageing of Charles Bridge building stone is highly affected by deposits and crusts formed by minerals with high contents of molecular water. At the crusts' contact with the building stone surface, the crusts are dissolved and the solutions creep through the rock pores into the centre of the stone; this leads to salt crystallisation in the rock pores. The analysed samples proved that maximum concentration of crystallised salts occurred in the zone approximately 11mm below the stone facing. Integral part of sandstone weathering is microbial corrosion which is manifested by coloured stains and patina, efflorescence, pulverisation or organic material deposits on the stone. Sandstone bridge block biodegradation, however, does not represent just a cosmetic problem. It is a synergistic action combining both physical and climatic effects, as well as biological impacts.

Long-term measurements (1984-1988) show that in the course of an annual cycle vertical movements arise in the vault crown - crown rise and flattening (ranging within approximately 1/7500 - 1/2500 of the vault span) - while the character of the vertical deformations pattern corresponds to the outside temperature pattern in keeping with the season. The value showing the difference of measured vertical deformations given by the difference of the highest positive (rise) and the lowest negative (fall, flattening) value lies in the interval of 2 mm - 10 mm. The value of the permanent component of vertical deformation of crown sections growing in time (approximately 0.4 to 0.7 $mm.year^{-1}$) testifies to a gradual disintegration of the bridge vault masonry. The impacts of temperature and moisture cause horizontal deformations of namely the crown cross sections of the bridge structure whose permanent component grows in time (approximately 1.5 to 12 $mm.year^{-1}$). The deformations caused by non-constant temperature and moisture patterns along the bridge structure section are characterised, above all, by changes in the shape of the crown cross section, by the appearance of tensile transversal normal stresses, shear stresses between individual cross sections of the bridge structure and by the bridge body stratification due to shear forces. The temperature and structural analysis of a section of the Charles Bridge structure has shown that the values of maximum deformations of the bridge structure cross section range within 0.6 mm to 2.4 mm for a temperature load characterised by a 10 °C to 17 °C difference between the surface and core temperature. Maximum values of tensile normal stresses amount up to +770 kPa, while maximum values of compressive normal stresses reach -773 kPa (bottom section) for the given temperature load.

3. Conclusion

Degradation and corrosive processes of structures cannot be generally prevented. They are manifested by the structures' ageing. An integral part of any structural design and its implementation, or reconstruction has to include, apart from meeting the relevant demands, also the necessary reliability that guarantees the function of individual elements and the structure as a whole in time, or during the time of their presumed service life. This requires such solution that limits the intensity and kinetics of degradation and corrosive processes to the lowest practically achievable level.