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The Golden Gate, Porta Aurea of Diocletian's Palace in Split, Outline of Historical Changes and Proposal for Reconstruction of Today's Condition

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ABSTRACT: Today's state of the Golden gate of Diocletian palace in Split is characterised by numerous damages of the wall structure and large horizontal deformations of the northern wall of St. Martin church in particular, which is incorporated in the former sentry corridor above the gate. Through monitoring of changes which occurred with time on the structure, and by analysing the consequences thereof on the same structure, basic assumptions of remediation methods were created. By using existing parts of the structure which comply with the context of the original structure, their spatial configuration, with minimum of interventions, it is possible to ensure necessary improvements in the transfer of loads.

1 INTRODUCTION

Changes on historical structures from the moment of erection to the present day change their spatial configuration, thereby implicating the changes in the structure. Knowing these changes and their consequences is of enormous significance when looking for causes of damage. Removal of that cause, to the extent possible, thus becomes a crucial factor in the entire remediation process.

Remediation proposal of the Golden gate of Diocletian palace in Split is based on thorough research of changes on the structure which took place during history. Presentation of this research and the proposal of remediation are subject of this paper.

2 REVIEW OF CHANGES ON THE STRUCTURAL SYSTEM

In the Diocletian palace Golden gates were the main land entrance, the spot where the road between the palace and ancient Salona ended. They are a part of northern defence wall which was protected by two lateral octagonal turrets. Bellow the large arch lintel was a horizontal stone beam, the so called "flat arch" which splits the gate opening into a lower rectangular and a higher semicircular part. The wall face was abundantly decorated with niches and blind arches which were supported by columns resting on stone cantilevers. Total wall thickness is 2,65 metres. Within this dimension above the gate was a sentry corridor for control and guarding of entrance gate. The south corridor wall is 0,4 m thick, and the northern 0,6 m. The corridor was covered in stone plates. (Fig. 1), (Marasović 1995).

The first adaptation performed above the entrance gate, in the existing corridor space was the construction of pre-roman church of St. Martin, only 1,65 m wide and about 7 m long, with a masonry semicircular barrel vault which caused the removal of nearly all stone cover plates. The south wall featured two pilasters of cross-section 0,3 x 0,5 m which were reinforcing the wall, stretching from corridor floor to the cover plates. These were removed to the height of 2,15 m above the floor, probably due to the church expansion. The assumed time period of this adaptation is between 9th and 11th century (Fig. 2).

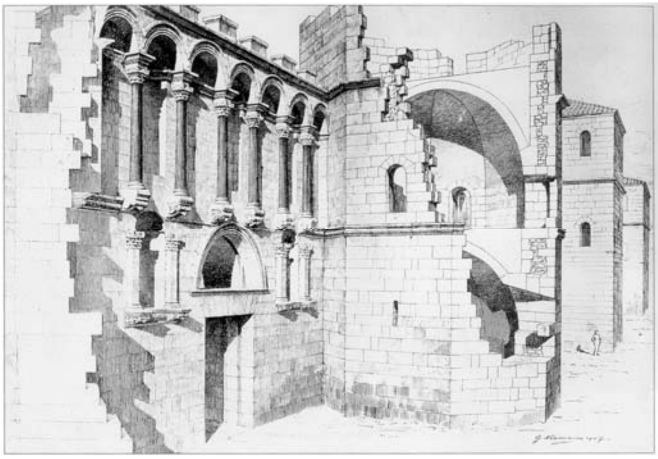


Figure 1 : Northern gate and turrets, according to G. Neimann.

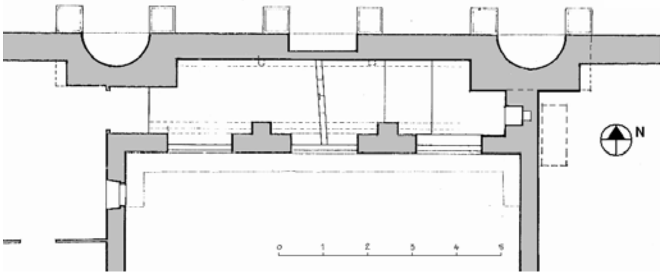


Figure 2 : Church layout.

The research showed that the western church section had a bell-tower situated on top of the barrel vault. The construction period is assumed between 12th and 13th century. The bell-tower was torn down in the 14th century. It was one of several very similar bell-towers erected in the palace, one of which still exists today.

The next enterprise was demolition of both octagonal turrets. Exact data about that does not exist but it is assumed it could have occurred in 16th century.

From six stone columns which were supporting the blind arches prior to 1782, three were torn down. This can be concluded from a painting by L.F. Cassas from the same year which displays the three remaining columns. The same painting shows that the gate was immured considerably. At the end of 18th century or at the start of 19th century the remaining three columns were torn down, see Fig. 3 (Marasović 1995).

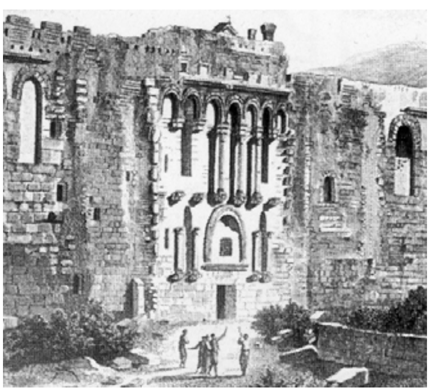


Figure 3 : Northern façade according to L.F. Cassas, 1782.

3 REVIEW OF TODAY'S STATE

Today's state of the gate and the northern wall section directly around it, in the sense of structural system, corresponds to that after demolition of three remaining columns (Fig. 4).

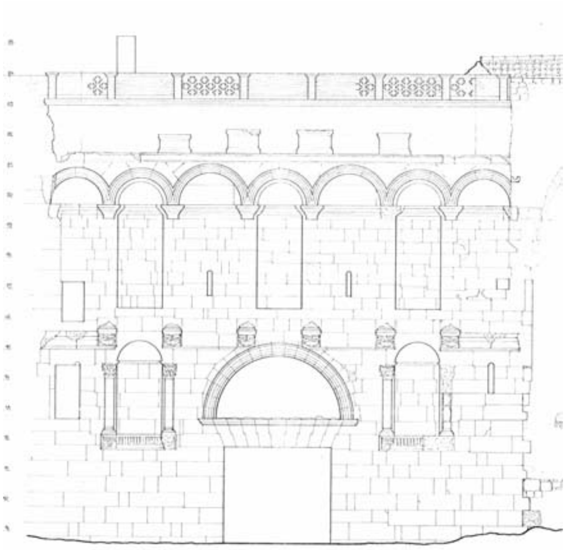


Figure 4 : View of northern wall section around the gate.

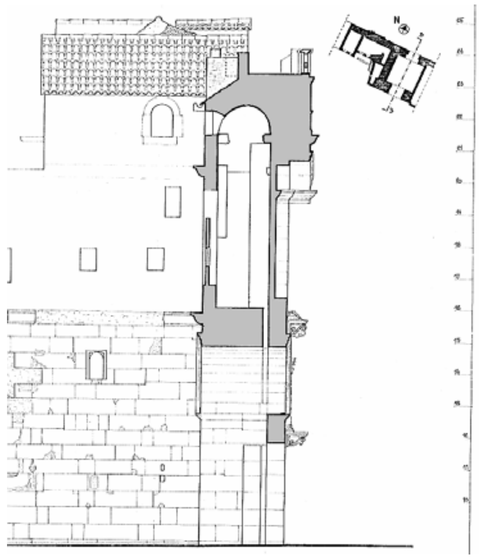


Figure 5 : Transversal cross-section of the church.

Above the blind arches and the barrel vault there is a significant amount of loose material which was deposited there because of forming of roof terrace. Vertical loads and horizontal load from vault thrust act very unfavourably on the southern and northern church wall (Fig. 5).

Considerable deformations and damage are visible on the barrel vault, and most dominantly on the northern wall. On the vault crown there is a longitudinal crack several centimetres wide, which stretches along the entire vault. In some places it branches creating parallel cracks (Fig. 6).

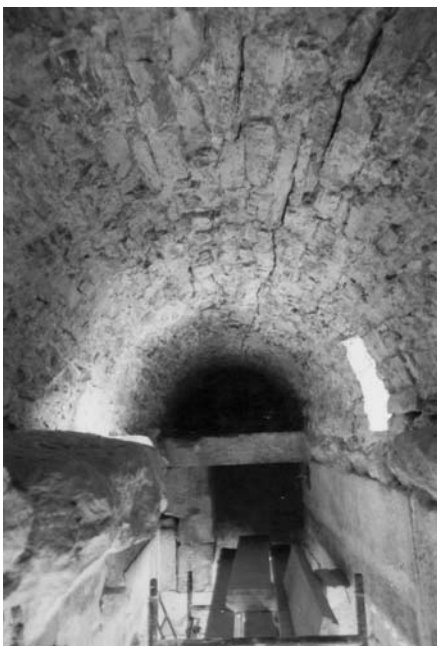


Figure 6 : Longitudinal crack in the vault crown.

Figure 7 : Stone plate removed from its resting place on the northern wall

Northern church wall is inclined towards north by 16,5 cm at the vault foot level, whereas the southern wall is inclined also towards north by 5,5 cm.

The only remaining stone plate which once covered the sentry corridor got pulled out of its resting position and stands like a cantilever clamped in the wall. This detail precisely illustrates the shift of the northern wall relative to the southern wall (Fig. 7).

One of the reasons for considerable damage of edge sections is the way the lateral turrets were demolished. The connecting blocks of turret and wall were torn down without proper precautions. Thus, from old turret walls remained only the projecting blocks of irregular shapes, the mass of which caused local damages on the surrounding sections of the structural system. Here, the end supports of the blind arches must be mentioned which are so reduced that this part of the structural system transfers loads with the minimum of safety reserves.

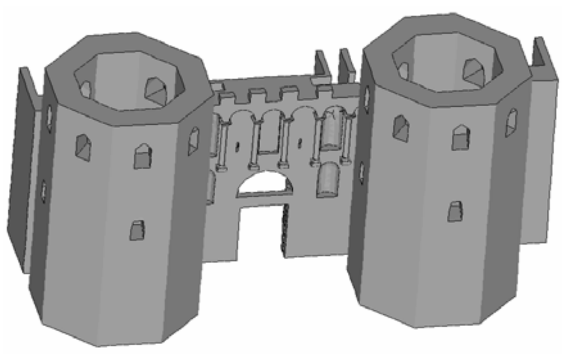
Stone boulders of semicircular arch lintel took heavy damage as well. The same can be said about the "flat arch". Inclination of wall lead to the increase of edge stresses and inherently to stone damage, especially on the pilasters. The masonry in the blind arches is degraded by atmospheric influence and by weed growth, which created hollow spaces in a wall that was once homogenous.

4 ANALYSIS OF PARTICULAR PHASES OF STRUCTURAL SYSTEM

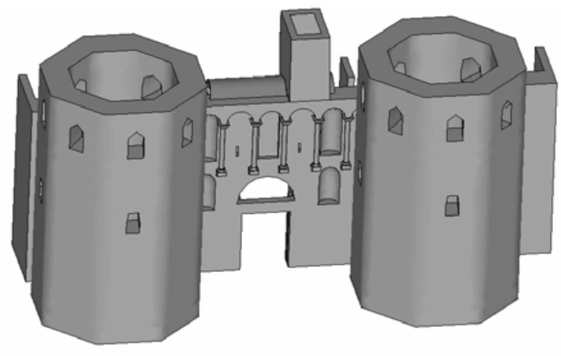
The historical sequence of events concerning the structural system of the Golden gate which can be reliably reconstructed enabled the determination of several phases which were significant in the sense of changes in the structural system (load transfer path).

Comparative analysis was conducted for vertical loads on five different models of structural system (Fig. 8):

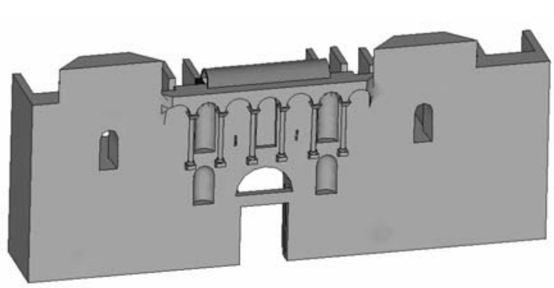
1. Original state after palace erection
2. Erection of small church, removal of stone cover plates and erection of barrel vault, with additional load of the dome by the bell-tower
3. Demolition of octagonal turrets, without the bell-tower which was torn down earlier
4. Demolition of columns
5. Today's state with all recorded deformations



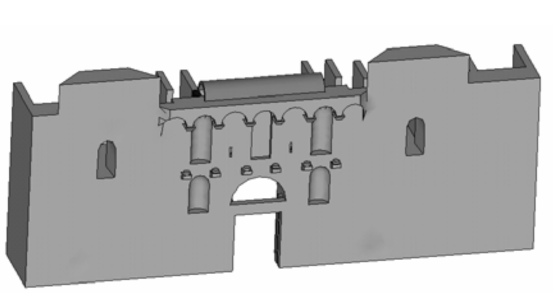
Phase one



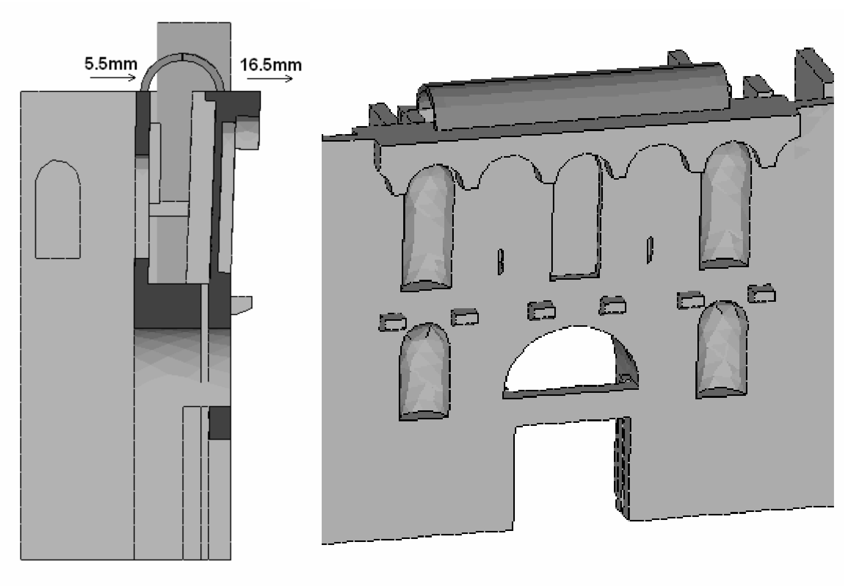
Phase two



Phase three



Phase four



Phase five

Figure 8 : Model display of all 5 phases.

Model assumptions of particular phases were done based on research of changes that appeared and the time period in which they appeared. Model behaviour analysis showed the progression of weak spots at every change. In the research it was difficult to include the changes within in the walls into the model. They are a consequence of the duration of structure and hence of exposure to long term loads, but also of all other influences which occurred with time. One of the most important influences is the deterioration of binding mortar between stone blocks, weed growth that seriously worsens the overall condition by shifting blocks and by destroying the binding mortar with root spreading. When such a process goes on for centuries accompanied by undertaken alterations which are in their nature unfavourable for structural condition, current state is a logical consequence of mentioned causes.

Analysis of the initial state of structural system of the Golden gate revealed the asymmetrics in mass distribution in the cross-section. It exists due to abundant profiling and sectionalized entrance façade of the emperor's palace. The means for it are blind arches, niches and columns resting on cantilevers which support the blind arches. One should not forget the fact that raising of entrance gate lead to penetration through the barrel vault. Because of this penetration, the 0,6 m thick northern wall at it's bottom rests on a stone arch of same thickness instead on a vault in full breadth of 2,65 m.

4.1 Analysis and comparison of particular phases models

Numerical analysis was done on the three-dimensional models of all phases for all prescribed vertical loads. The obtained results were too extensive, so only most important data were shown in tables along with the textual explanation. The program package 'ALGOR' was used for FEM analysis.

Changes of stresses and deformations were compared for particular phases. The deformation scale obtained for each model of changed state is small. However, it is necessary to mention that each of them was obtained without superposing with the previous state, with the exception of last model in which the initial state was set with all measured deformations.

Displacements on each model can be taken as initial. Their increase is expected due to deteriorated condition within the structural system in the sense of load transfer change, but also due to material yielding caused by long term loads. Since the changes occurred after long time periods, structural deterioration should be superposed with constant erosion of walls (Roca 2004).

Today's condition of the structural system is a consequence on one hand of changes in it that occurred from palace erection until today, and on the other of simultaneous deterioration of material substance the structure is built from. These are two parallel processes, first of which can be concretely simulated by changes on the structural system models, while the second can be interpreted relying on today's condition of walls as a result of an ongoing long lasting degradation process (Fig. 9).

Table 1 : Comparison of maximum horizontal deformations and maximum stress values in longitudinal direction at central position of the upper edge.

	Horizontal displacement mm	Longitudinal stresses kN/m^2
phase 1	0.435	21.7
phase 2	1.214	133.6
phase 3	1.475	107.9
phase 4	1.516	118.2
phase 5	6.326	527.7

Stress reduction in the third phase relative to second phase is the consequence of bell-tower removal which considerably contributed to stress increase. However, demolition of turrets as well as the church barrel vault is an obvious degradation with respect to first phase.

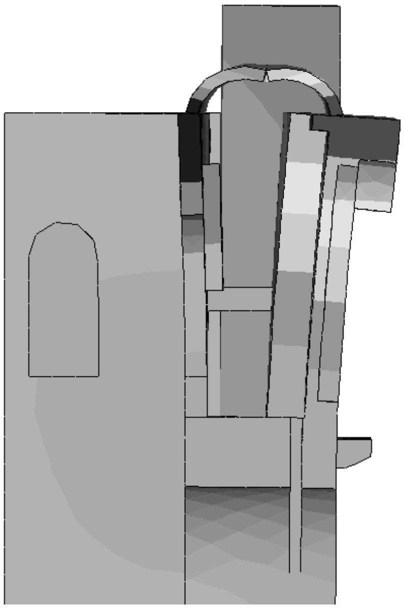


Figure 9 : Horizontal deformation of model of phase 5.

Table 2 : Force comparison in stone columns and tension stresses of stone cantilevers.

	Total force on all columns (6 columns) kN	Max. force on one column kN	Tension stresses in cantilevers kN/m^2
phase 1	122.4	24.0	199.9
phase 2	225.4	51.1	389.7
phase 3	203.9	37.8	319.8

The magnitudes of compression forces, tension stresses in stone cantilevers can be interpreted in the same way as deformation and stress changes in the upper edge of structural system.

5 PROPOSAL OF STRUCTURAL SYSTEM REMEDIATION

The remediation proposal is based on two measures:

One is supposed to restore the lost structural capacity of walls by remedying all damages and weakenings which occurred with time, filling all cavities, remedying of cracks on stone blocks, anchoring of projecting blocks that remained after demolition of octagonal turrets, strengthening of end supports of blind arches and by replacing of now cracked blocks of semicircular arch below the northern wall by new ones.

The other measure should make up the good features that structural system has lost by removing the stone cover plates, turrets and columns, and remove the bad features it received by erection of barrel vault.

G. Ciribini says in his essay «Short notes about design methods in architecture»: «The expression preservation designates changes which are inseparable from a structure, that do not take the structure out of it's limitations, but only create elements which always belong to the structure and which preserve it's laws» (Ciribini 1968).

Therefore the installation of transversal steel ties in the former positions of stone plates, which should take over the horizontal thrust of the vault, is recomended. It is also recomended that northern and southern wall be held by steel ties in the planes of eastern and western wall of defence garden behind the gate, as a substitute for former leaning against octogonal turrets (Fig. 10).

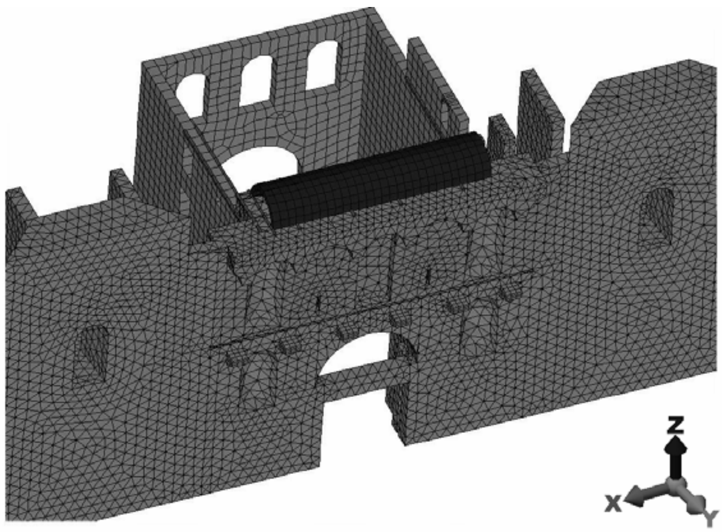


Figure 10 : FEM model of today's state with built-in ties.

Table 3 : Comparison of maximum horizontal displacements and maximum stress values in longitudinal direction in the central part of upper edge. (Fig. 11A & 11B)

	Horizontal displacement mm	Stresses in longitudinal direction kN/m^2
phase 5	6.326	527.7
remediation	2.013	145.1

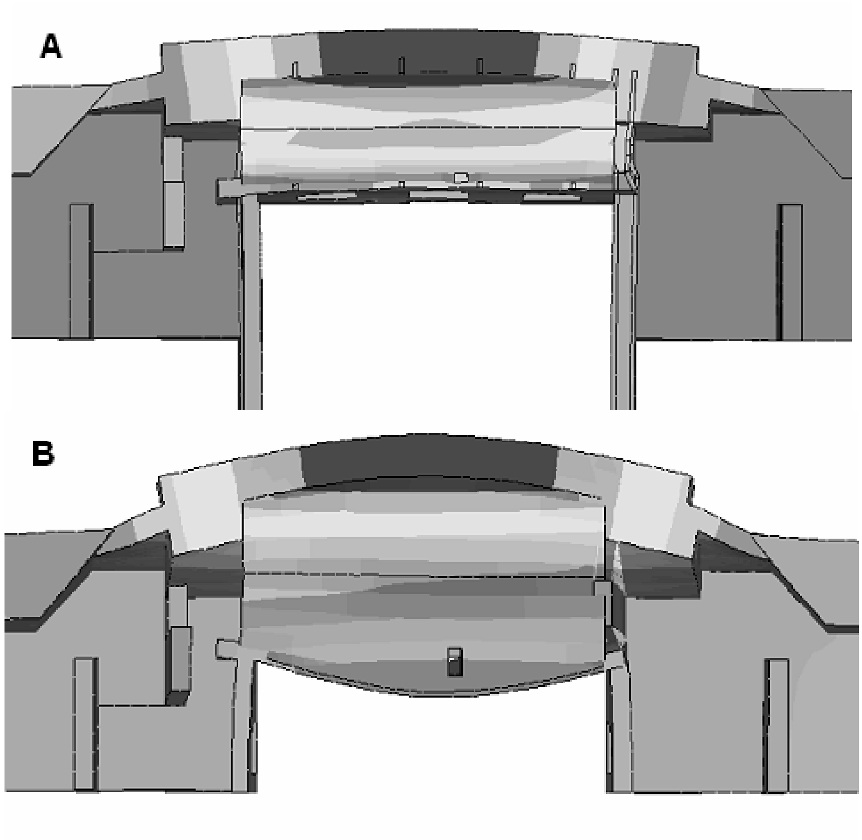


Figure 11 : Horizontal displacement A) remediation, B) phase 5.

6 CONCLUSIONS

Considerable damage of the Golden gate and of parts of northern wall around it demands remediation that should put a stop to a destructive process which has been going on for centuries or at least slow it down notably.

By comparative analysis of several models of structural system as results of changes which took place on that part of northern wall, assumption concerning deterioration caused by those very changes was asserted. Destruction of walls notably contributes to further progression of damages.

Although all of the changes are irreversible, the idea was contemplated of possible reconstruction of some structural parts that were removed, primarily columns, but it was dropped eventually.

The proposed reinforcements of structural system are in the context of behaviour of some removed parts of structure. Steel ties instead of stone cover plates and lateral restraining of northern and southern wall instead of turrets.

Checks on the model of proposed reinforcements shows considerable improvement of displacements and stresses.

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