COMPDYN 2013
4th ECCOMAS Thematic Conference on
Computational Methods in Structural Dynamics and Earthquake Engineering
M. Papadrakakis, V. Papadopoulos, V. Plevris (eds.)
Kos Island, Greece, 12–14 June 2013

STRUCTURAL UPGRADING OF A 3-STOREY HERITAGE STRUCTURE OF 1925 IN THESSALONIKI

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Keywords: Reinforced Concrete Structure, Infilled Masonry, Upgrading, Jacketing.

Abstract. *The structural upgrading and rehabilitation procedure of a historic building representative of 1920s construction in Thessaloniki, Greece is presented. The case study building is a listed three-storey reinforced concrete flat-slab frame structure sited in Nikis Avenue in front of the old seaside of the city of Thessaloniki. Reinforced concrete columns and beams frames along with wide infilled masonry walls are the load-bearing elements of the structure. The building was designed in 1925 without Seismic Code requirements and constructed in 1926. The ground floor was used for many years as a cinema, whereas the upper floors are areas where people may congregate since they are used as assembly halls (dining halls, reading and conference rooms). Concrete core tests and in-situ non-destructive tests were first performed to evaluate the compressive strength of the concrete and to detect - determine the existing steel reinforcements of the reinforced concrete members. The concrete strength was low and the steel reinforcement of several columns of the ground floor and slabs of the upper floors was found to be corroded. Analytical evaluations of the original and the strengthened structure were carried out in order to identify the weak members of the structural system and to justify the decisions of the strengthening methods adopted. Comparisons between the capacity of the existing or/and the strengthened members with the design requirements derived from the initial and the strengthened structural system analyses are also presented. Special attention has been given in issues regarding the simulation of actual details encountered in mixed structural system. The upgrading methods used along with the uncovering of latent defects during the strengthening works and how these were managed are also commented in this paper.*

1 STRUCTURAL CHARACTERISTICS OF THE HERITAGE STRUCTURE

The building is sited in Thessaloniki, in Nikis Avenue in front of the old seaside of the city. It is a three-storey Reinforced Concrete (RC) flat-slab frame structure that was designed in 1925 and constructed in 1926. The ground floor was used for many years as a cinema, whereas the upper floors as assembly halls (dining halls, reading and conference rooms). The load-bearing elements of this structure consist of RC columns and beams frames along with wide infilled masonry walls.

This listed heritage structure has remarkable exterior decoration and noticeable architectural features as it can be observed in Figure 1. In this Figure the front façade of the building as it has been designed in a drawing of 1925 and as it is shown today in a recent photograph are presented. It should be mentioned that authorities responsible for potential preservations of heritage buildings do not allow interventions that may alter its front façade.

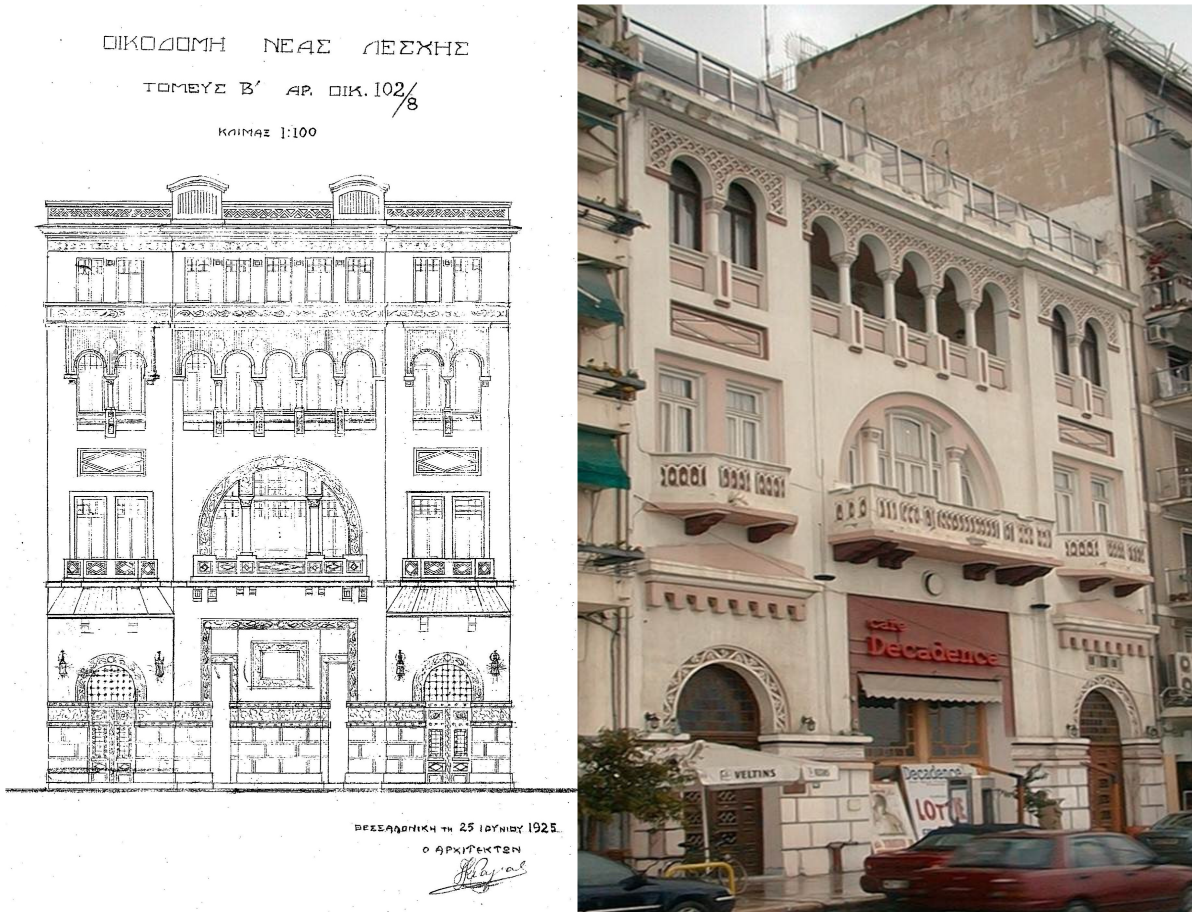
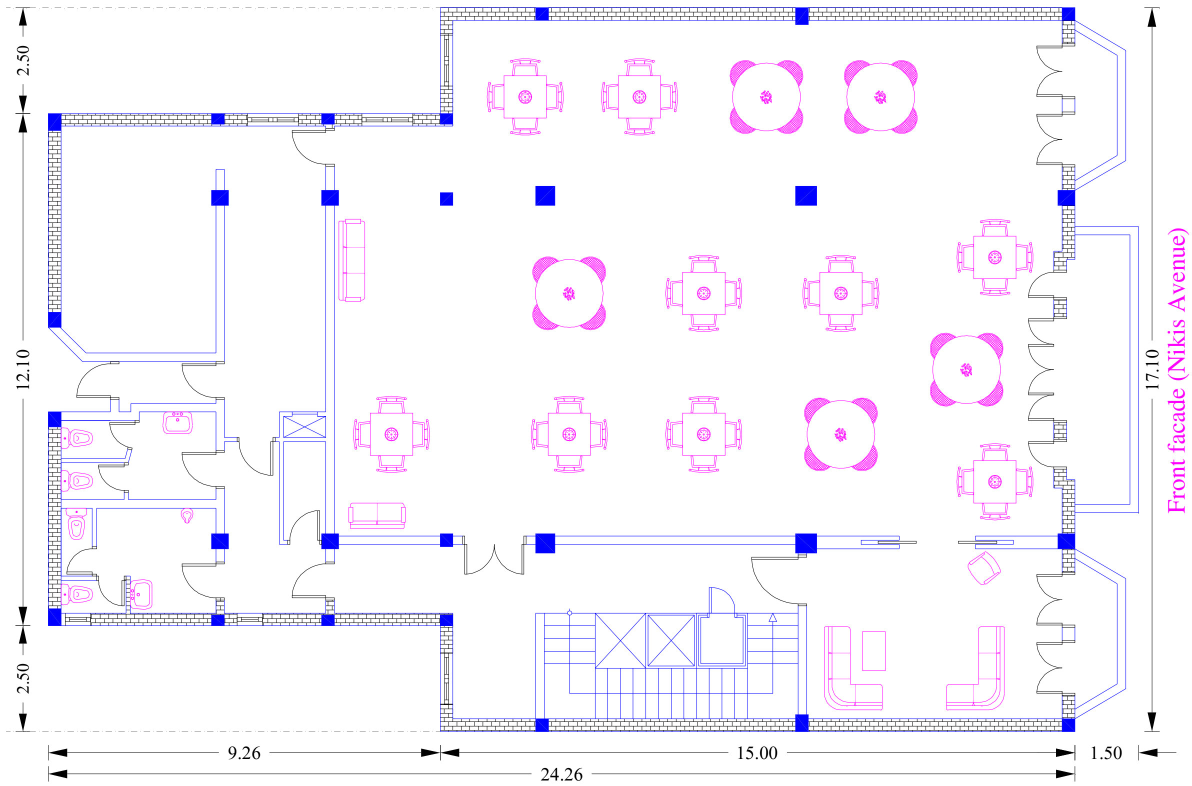
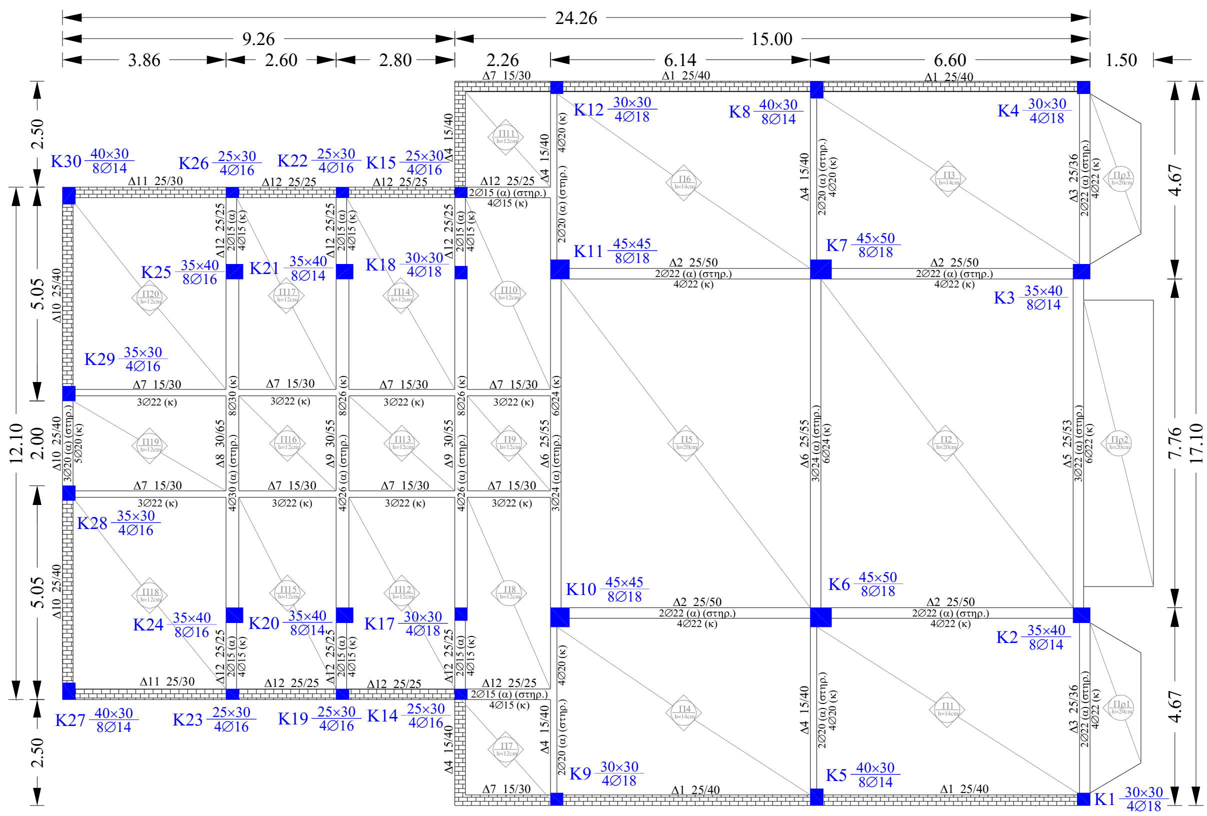


Figure 1: The front façade of the building as it was first designed (drawing of 1925) and as it is today (recent photograph).

The total length of the building is 24.26 m, while the width of its front façade is 17.10 m. This width remains the same for a length equal to 15.00 m and then it is reduced symmetrically to 12.10 m (see also the plan view of Figure 2a). The area of a typical floor is approximately 370 m^2 and the total height of this three-storey structure is 17.40 m. The examined heritage structure stands between two adjacent multi-storey modern apartment buildings, as shown in the photograph of Figure 1.



(a) Plan view



(b) Formworks plan

Figure 2: Drawings of the first floor (typical floor) of the initial status of the building.

Figure 3: Corrosion of the steel reinforcement of the RC columns K17, K21, K24, K28 and K29 (ground floor).

Figure 4: Extensive corrosion of the steel reinforcement of the RC slabs.

There are 30 RC columns in the ground floor and 28 in the upper two floors. These columns and the infilled masonry walls at the perimeter of the structure consist of the vertical load-bearing elements, whereas RC beams and slabs are the horizontal elements, as shown in the formworks plan of Figure 2b.

The building has been constructed very close to the coast line where the soil's characteristics are not safe due to the presence of underground water. For this reason, the foundation of the building consists of a rigid RC raft foundation system with RC ribs that connect the existing RC columns.

The main damages of the building come from the aging of concrete and the extensive corrosion of the reinforcing steel, as shown in the photographs of Figures 3 and 4. Limited and rather expecting cracking has also been observed in the RC beams and slabs of the structure with rather large spans. The condition of the masonry walls could be characterized as satisfactory since no severe cracks or damages in the bricks or the mortars have been observed.

2 METHODOLOGY

First, extensive in situ non-destructive tests have been performed in order to determine the present status of the building, to estimate the concrete strength and to record the dimensions and the steel reinforcement arrangements (bars and stirrups) of the RC elements, mainly of the columns and the beams. The concrete strength has also been evaluated by core tests of concrete cylindrical core samples that have been taken from five columns and three foundation beams of the building. These tests showed that the mean compressive concrete cylinder strength is today 15.9 MPa with standard deviation 4.6 MPa. Thus, the concrete strength class is very low (C8/10) with characteristic strength 8 MPa.

Plain round mild steel bars and stirrups have been used for the reinforcement of the concrete elements of the building. The characteristic strength of the mild steel used is 220 MPa. Further, in situ observations and half-cell potential measurements highlighted the problem of corrosion in the steel reinforcement of many RC elements (see also Figures 3 and 4).

The vulnerability of the building was mainly originated from the following aspects: (i) The low quality of the building materials (concrete and steel), (ii) the significant corrosion of steel reinforcement, (iii) the lack of seismic design and consequently its inadequate seismic resistance, (iv) the minor cross-sectional dimensions and the low reinforcement ratio of several RC columns and (v) the lack of adequate ductility.

It is known that the strengthening of heritage structures located in seismic areas is a very complex problem due to the wide variety of involved aspects, such as the quality of the materials (concrete, steel and masonry), the building structural assemblages and, apparently, the economical implications. Further, the analysis of the seismic response of such buildings needs a proper knowledge of the traditional constructive techniques, the identification of the damage and collapse mechanisms activated by the earthquake and the check of the effectiveness of the most applied retrofitting techniques [1-3].

Experimental tests of RC beam-column joints and frames with or without infilled masonry sub-assemblages [4-7] have shown that the excessive damage or failure of joints, in particular exterior joints, can lead to the global collapse of a building [8, 9]. The poor joint behavior of older construction can be attributed to the inadequate shear reinforcement in joint region, the poor bond properties of plain round bars reinforcement and the deficient anchorage details into the joint region [10, 11]. Various retrofit or seismic rehabilitation schemes have been previously proposed and implemented for RC beam-column joints and frames [12]. The majority of these methods involve either the strengthening of the joint only or both the joint and column in order to induce plastic hinging in the beams.

Jacketing is one of the most favorable and well-known strengthening method of poor detailed or deficient members and structures. It has long been recognized that RC jackets do provide increased strength, stiffness and overall enhancement of the structural performance. Jackets constructed by conventional cast-in-place concrete [13], premixed, non-shrink, flowable, rapid and high-strength cement-based mortar [14], shotcrete [15], self-compacting concrete [16] and FRP sheets [17, 18] have been examined as rehabilitation methods in existing inadequate or damaged RC members.

The upgrading scheme selected for the examined heritage structure is presented in Figure 5. Most of the existing RC columns have been strengthened using RC jacketing. The checking and design procedure of the existing and the strengthened columns, respectively, is presented and briefly described in Figures 6-10 for four representative columns of the building.

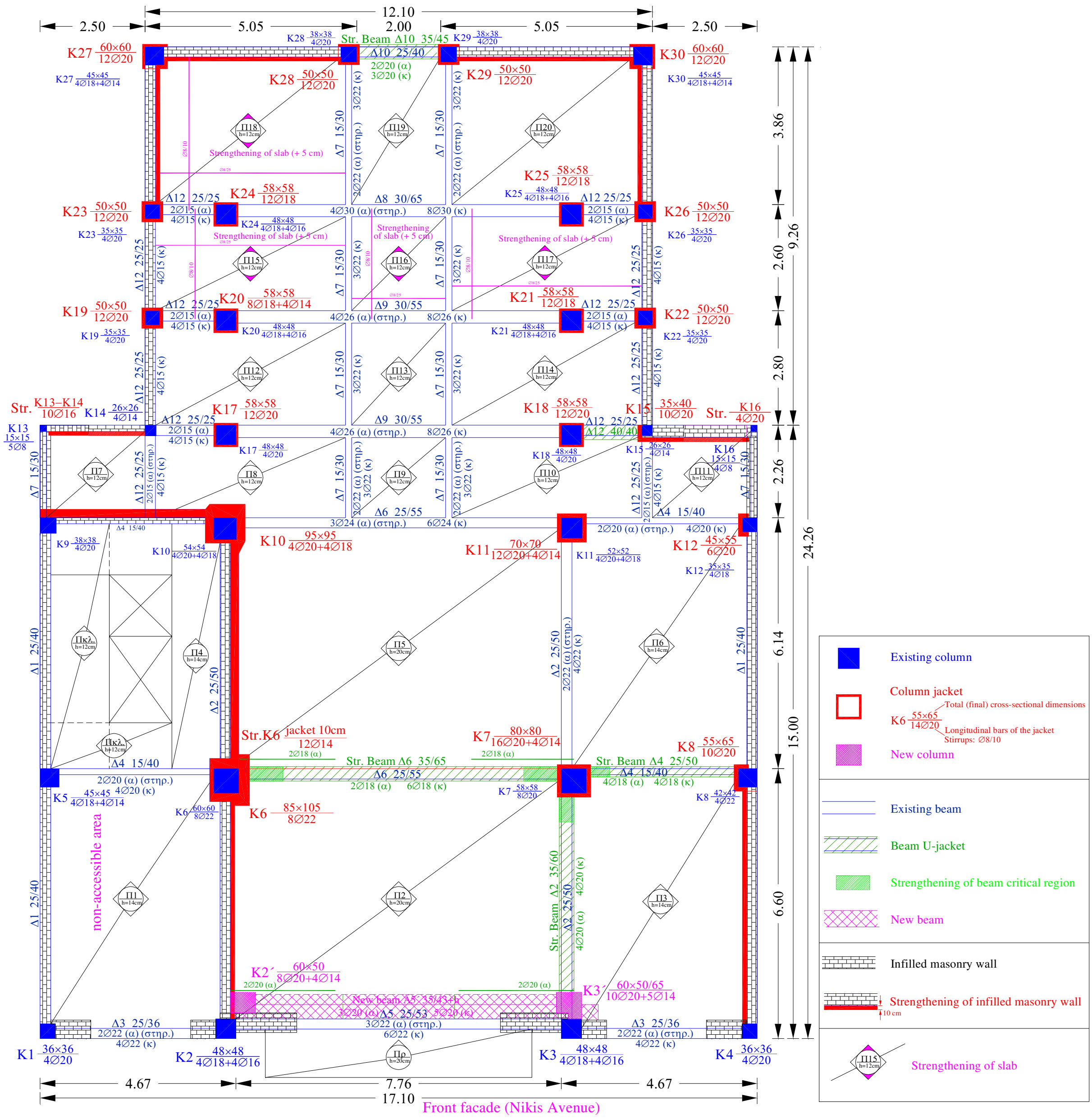
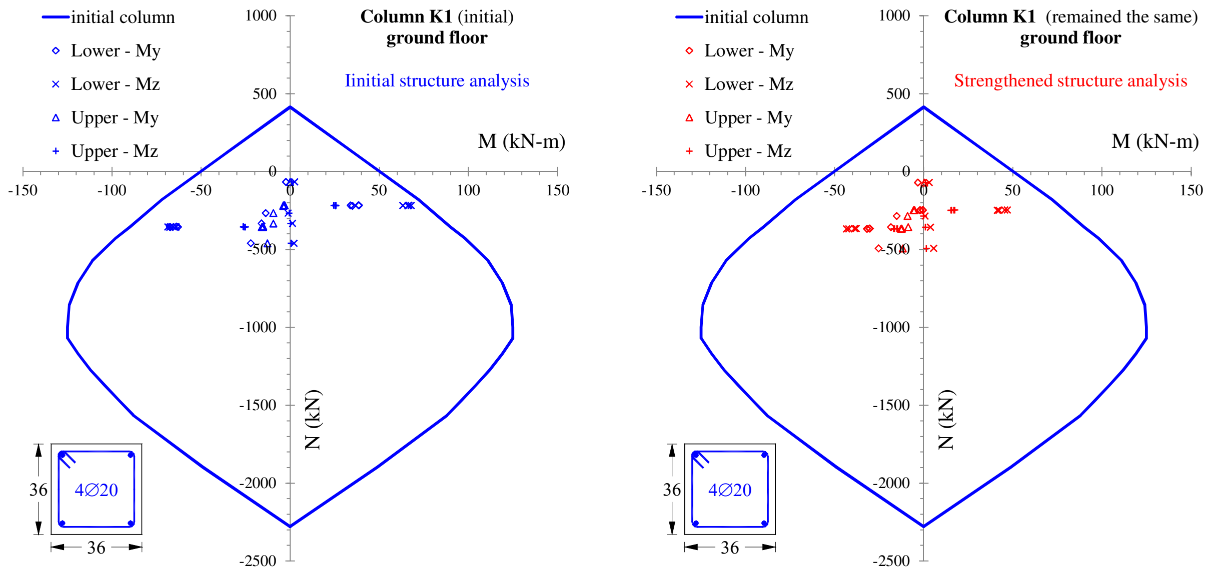


Figure 5: Formworks plan of the ground floor of the strengthened building.

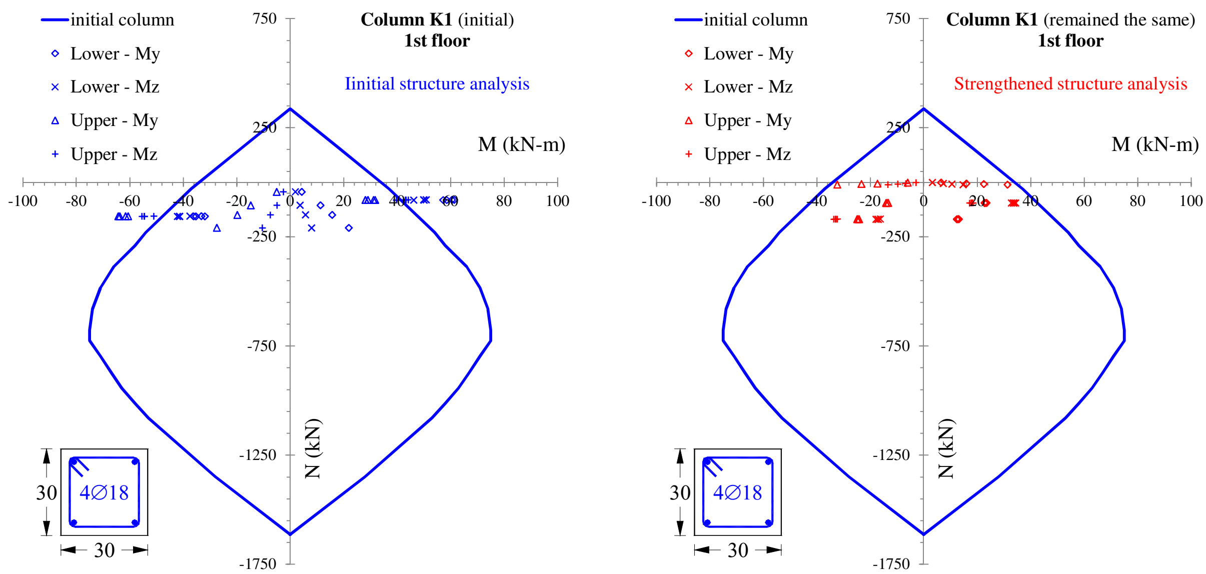
Further, selected infilled masonry walls along with the deficient beams and slabs due to corroded steel reinforcement have also been strengthened using new steel reinforcement and shotcrete, as shown in Figure 5. Moreover, since the front façade of the upgrading heritage building should be remained intact, a new two columns - beam RC frame has been constructed in the interior of the structure. This frame is in contact and connected with the structural RC elements of the front façade.

The new and the strengthened RC elements are designed according to the specifications of the Greek Code for Concrete Structures [19] and the Greek Seismic Code [20] for concrete strength class C20/25, steel reinforcement class S500s, design ground acceleration 0.16g, ground type C, importance factor 1.00, behavior factor 1.5 for the initial structure and 3.5 for the strengthened structure and live loads 5 kN/m^2. Eight seismic combinations were examined: G+0.30Q±E_x±0.3E_y and G+0.30Q±0.3E_x±E_y, where G and Q are the dead and live loads respectively, and E_x and E_y are the seismic loads along the x and y axes, respectively.



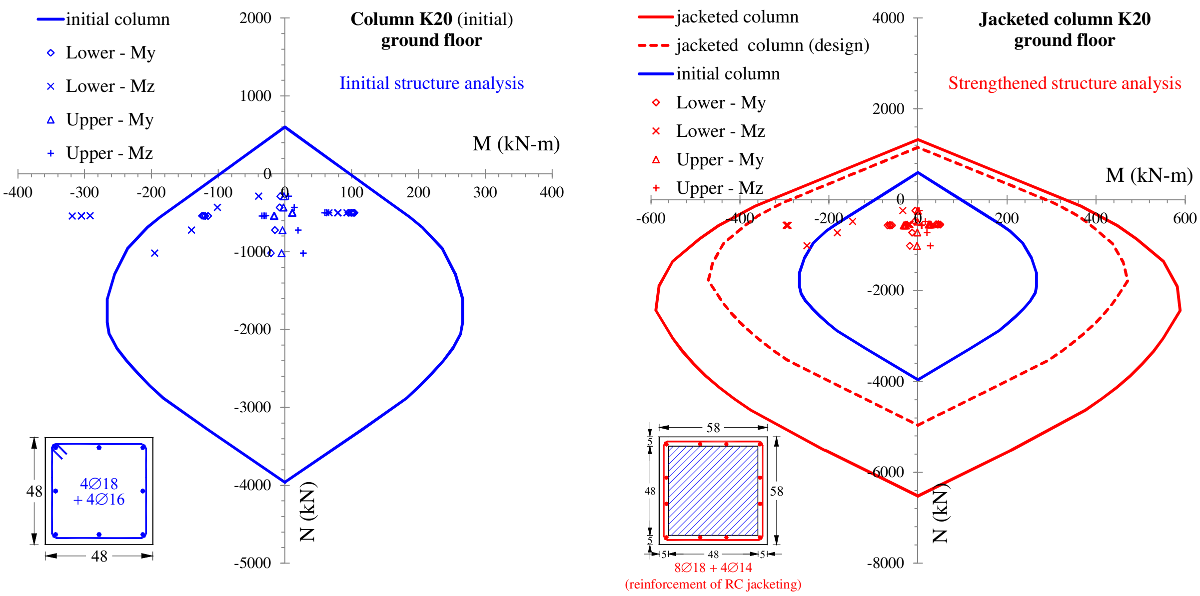
(a) Initial structure (b) Strengthened structure

Figure 6: Bending moment (M) versus axial force (N) interaction curves for the column K1 of the ground floor. The data points (M, N) represent the design values of the applied M and N derived from the seismic analyses of the (a) initial and (b) strengthened structural system. It is concluded that there is no need column K1 of the ground floor to be strengthened since its strength satisfy the design requirements in all cases.



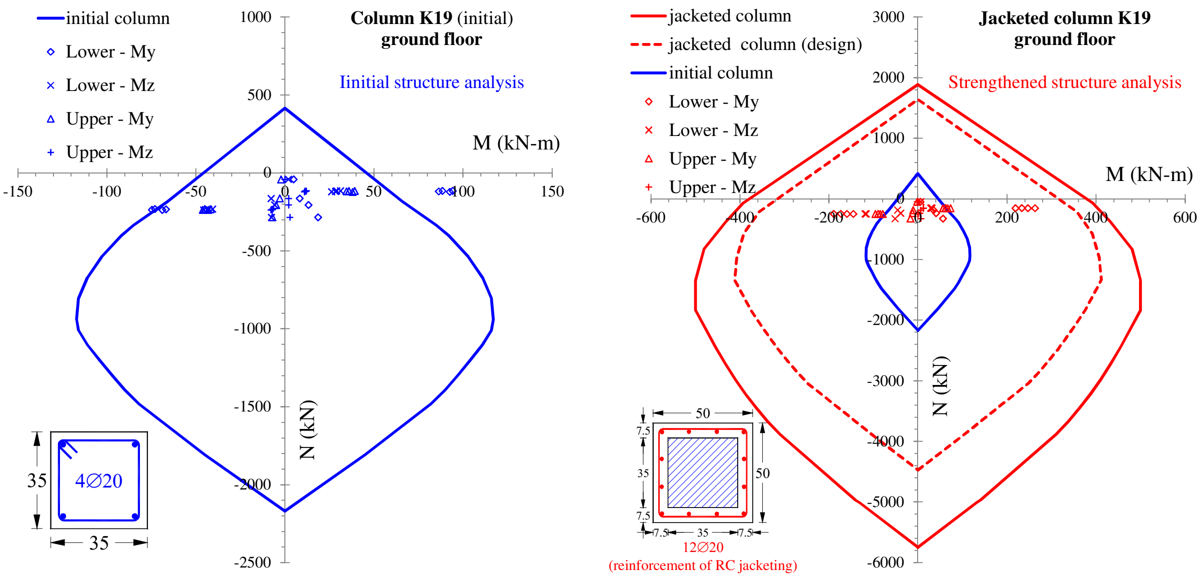
(a) Initial structure (b) Strengthened structure

Figure 7: Bending moment (M) versus axial force (N) interaction curves for the column K1 of the first floor. The data points (M, N) represent the design values of the applied M and N derived from the seismic analyses of the (a) initial and (b) strengthened structural system. It is concluded that although the strength of the existing column does not satisfy the design requirements of the initial structure analysis in all cases, the design requirements of the strengthened structure analysis become lower and henceforth proved to be satisfied. Thus, there is no need column K1 of the first floor to be strengthened.



(a) Initial structure (b) Strengthened structure

Figure 8: Bending moment (M) versus axial force (N) interaction curves for the column K20 of the ground floor. The data points (M, N) represent the design values of the applied M and N derived from the seismic analyses of the (a) initial and (b) strengthened structural system. The strength of the existing column does not satisfy the design requirements of both analyses (initial and strengthened). Thus, column K20 of the ground floor is strengthened by applied RC jacket.



(a) Initial structure (b) Strengthened structure

Figure 9: Bending moment (M) versus axial force (N) interaction curves for the column K19 of the ground floor. The data points (M, N) represent the design values of the applied M and N derived from the seismic analyses of the (a) initial and (b) strengthened structural system. The strength of the existing column does not satisfy the design requirements of both analyses (initial and strengthened). Thus, column K19 of the ground floor is strengthened by applied RC jacket.

3 STRENGTHENING WORKS

Selected strengthening works applied in the examined heritage building are presented in the photographs of Figure10.

(a) Masonry walls and columns of the ground floor

(b) Connection with the infilled masonry wall

(c) Jacketing of the ground floor columns

(d) U-jacketing of a beam with large span

(e) Slab strengthening of the second floor

(f) Shotcrete application

Figure 10: Reinforcement arrangement and shotcrete application of the jacketing - strengthening works in the existing RC elements of the building

4 CONCLUSIONS

This study presents the upgrading procedure of a three-storey historic building with mixed structural system. Reinforced concrete slabs and beam-column frames along with wide infilled masonry walls are the load-bearing elements of the structure. The building was designed in 1925 without seismic design provisions. In situ non-destructive and core tests have been performed in order to evaluate the concrete strength and to record the present status of the building. The compressive concrete cylinder characteristic strength found to be 8 MPa. The steel reinforcement in several columns of the ground floor and in some slabs of the upper floors was found to be substantially corroded. Analyses of the initial and the strengthened structural system were carried out and comparisons between the capacity of the existing or/and the strengthened members with the design requirements are presented and discussed. Most of the existing RC columns have been jacketed, whereas selected infilled masonry walls and deficient beams and slabs have been strengthened using new steel reinforcement and shotcrete. During the strengthening works, covered problems such as extended steel reinforcement corrosion and severe cracking in beams with long spans have been revealed and supplementary interventions were carried out. In this case study, an integrated upgrading procedure is presented as a contribution in the field of structural upgrading of historic buildings with mixed structural system.

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