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COMPARATIVE DYNAMIC STABILITY STUDY OF A HIGH -RISE STRUCTURE EXPOSED TO SEISMIC AND WIND EFFECTS - CASE STUDY

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SUMMARY

The subject of this paper is comparative analysis of seismic and wind effects on dynamic stability of a structure and structural elements.

Presented briefly is the methodology and the performed dynamic analyses in the design of a specific high-rise structure. This structure represents a monument in the form of a cross composed of two dominant separate segments. The first segment represents the base of the cross constructed as a massive three-storey reinforced concrete structure, whereas the second segment represents a specially decorated 3-D steel structure with a cross outline. This impressive structure representing a cross extending to the height of 85.0 m, with arm width of 46.0 m is constructed on the top of a mountain rising to the altitude of 1068 m.

Due to the high seismicity of the region and the severe exposure of the structure to wind effects, there arose the need for consideration of these two types of effects upon the structure.

To get as realistic as possible insight into the behaviour of the structure under various effects, a three dimensional mathematical model involving all the elements of the steel structure and the integral RC base structure was formulated. Analyses of the dynamic response of the structure to the effect of earthquake excitations of different intensity as well as wind excitations were performed.

The results from the performed analyses showed that the above two effects are predominant and crucial for structural safety evaluation.

INTRODUCTION

On 27th September 2000, on the occasion of the 2000th anniversary of Christianity, the foundation stone of an imposing structure referred to as "Millenium Cross" was laid down marking the beginning of its construction. It is located on the top of Vodno mountain rising above the south part of Skopje.

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The architectonic design of the Cross was done by two architects, Dr. Jovan Stefanovski - Zan, and Oliver Petrovski based on accepted main parameters characterizing the structure.

The Investor of "Millenium Cross" allocated the responsible role of principal designer of the structural system of the Cross and main design reviewer of all design phases to the Institute of Earthquake Engineering and Engineering Seismology (IZIIS), Skopje. To support this unique project, the Institute of Earthquake Engineering and Engineering Seismology has realized its ample activities mostly as its own donation, which considerably contributed to the successful construction of the Cross. On 28th August 2002, the completion of the structural part of the Cross was marked by a special ceremony. Today, this structure attracts the attention of the citizens and the visitors of Skopje not only throughout the day but also during the night since the silhouette of the cross is illuminated (Fig. 1).

Fig. 1. View of the Cross: (a) in the course of day; (b) in the course of the night with its own illumination.

SELECTION OF LOCATION FOR THE CROSS

The Cross is located in the place called "Krstovar" on the top of Vodno Mountain overlooking Skopje, at an altitude of 1068 m. Based on available geological data, the wider area of this location is composed of Precambrian rock consisting of marble and cipolino as well as albitized philitomicashysts and green shysts.

To define the necessary parameters for foundation of the structure and the data necessary for static and dynamic stability of the structure under the effect of strong winds and seismic forces, geophysical and seismic investigations have been performed proving the existence of two geological media in the domain of the foundation soil that can be interpreted according to their physical mechanical characteristics. The first geological medium is located on the north side and is mainly composed of marble and cipolino that are compact in all lower levels below the surface level with depth of aproximately 3.0 m. In this medium, the seismic wave velocity is $V_p = 5000$ m/s and $V_s = 2750$ m/s.

The other geological medium is located on the south side and is mainly composed of albitized philitomicaschysts. This medium is characterized by lower velocity of seismic waves of Vp = 3450 m/s and Vs = 1550 m/s. The surface layers are disintegrated and loosened down to the depth of 10 m which points to the potential threat from sliding toward the south slope. Based on the final results from the performed geophysical investigations of the site and for the purpose of achieving uniform foundation conditions and improving the seismic stability of the structure, the foundation plan of the structure was dislocated for 3.0 m from the south to the north. In that way, it was enabled that the cross structure be completely founded in the compact marbles and cipolin, which represents a very important improvement of the conditions leading to satisfactory global stability of the integral structure.

MAIN CHARACTERISTICS OF THE STRUCTURAL SYSTEM

The integral structure of the Cross is composed of two dominant segments. The first segment represents the so called "pedestal of the Cross" which is constructed as a massive three story reinforced concrete round structure with foundation diameter of Dp = 24.00 m. The three-story structure of the pedestal is composed of three platforms. The first two platforms are constructed with the same diameter of 24.00 m and rest on 12 peripheral reinforced concrete columns with diameter Dps = 120 cm (symbolizing the 12 apostles) as well as on 4 central RC columns of a greater height and diameter, i.e., Dcs = 220 cm.

The four central columns are integrated with the third thick reinforced concrete slab - d = 100 cm at level + 7.00 m. On the top of the central reinforced concrete columns (at level + 10.00 m) a large steel structure segment in the form of big cross is installed and anchored.

The lowest platform with diameter of Dp=24,00 m, at level ± 0.00 represents, at the same time, foundation slab with a total thickness of d = 120 cm in the central part and d = 50 cm at the end margins. The foundation slab is strengthened on the bottom side by foundation connecting beams of different proportions properly distributed: (1) along greater circle between 12 peripheral columns (diameter 2R = 20.0 m); (2) between the central columns spaced on the circle with diameter 2R = 6.00 m; and (3) foundation beams spaced radially between the central and the peripherial RC columns. The first free story height H = 210 cm, formed between the foundation RC slab and the next RC slab at level + 4.00 m (d = 20 cm) is used for creation of a strong and rigid supporting structure that possesses the necessary bearing capacity by which it is enabled that the "potential overturning point" of the entire structure be the peripheral edge of the foundation slab with diameter 2R = 24.0 m. This enables more uniform transfer of stresses at the contact between the foundation structure and the foundation soil, creating at the same time conditions for increasing the stability of the structure against global overturning under the effect of strong winds or seismic effects.

The created strong and rigid supporting structure in the form of space "tube" spaced completely in the domain of the first story height is formed by a system of vertical reinforced concrete walls (distributed partly in a circle and partly radially) between the first RC foundation slab and the upper RC slab at level + 4.00 m. The first vertical reinforced concrete wall forms a cylindrical structure characterised with wall thickness of d = 50 cm and by global cylinder diameter of Dp = 12.0 m. The remaining integrating walls are radially distributed and their thickness is d = 40 cm. The first series of eight radial walls (4 pairs) connect, in fact, eight peripheral columns with four central columns. The remaining four walls are also spaced radially between the peripheral columns and the formed round wall with thickness of 50 cm (Fig.2).Considering the central position of the cylindrical RC structure in respect to the four central columns, geometrically specific small -base- church is formed in the central part, with a four leaf-clover-like plan and two adequately adapted entries.

The next platform spaced at level + 4.00 m represents an attractive place with a view over all four sides. The highest (third) platform at the height of + 7.00 m has much larger thickness (d = 100 cm) possess important structural role since it integrate the central columns forming the needed space frame structural system. The extension of the central columns to the level of + 10.00 m has been used as convenient four supports system on which large steel cross-structure is placed and strongly anchored.

The designed appearance of the cross is represented in Fig. 1a, Fig. 1b and Fig. 3b. The integral cross-structure actually represents a nicely decorated spatial steel structure whose silhouette represents the Christian cross appearing above the city of Skopje as monumental, visually stable creative and attractive symbol structure. The actual distance between the four middle columns is 5.00 m forming square base support. Following the base shape, the vertical structure of the cross has also a square cross-section composed of two adequately interconnected spatial tube trusses (external and internal). The sides at the plan of the external truss are 6.00 m, while those at the internal one are 4.00 m. Considering that, in the corners of the vertical spatial trusses, there are formed strong vertical belts composed of four closed square profiles 200x200 x10 mm (in the lower part) and 200x200x6.3 (in the upper part) each, the axial distance of the center of gravity of the corner profiles is 5.0 m and coincides with the centers of the cross-sections of the middle columns.

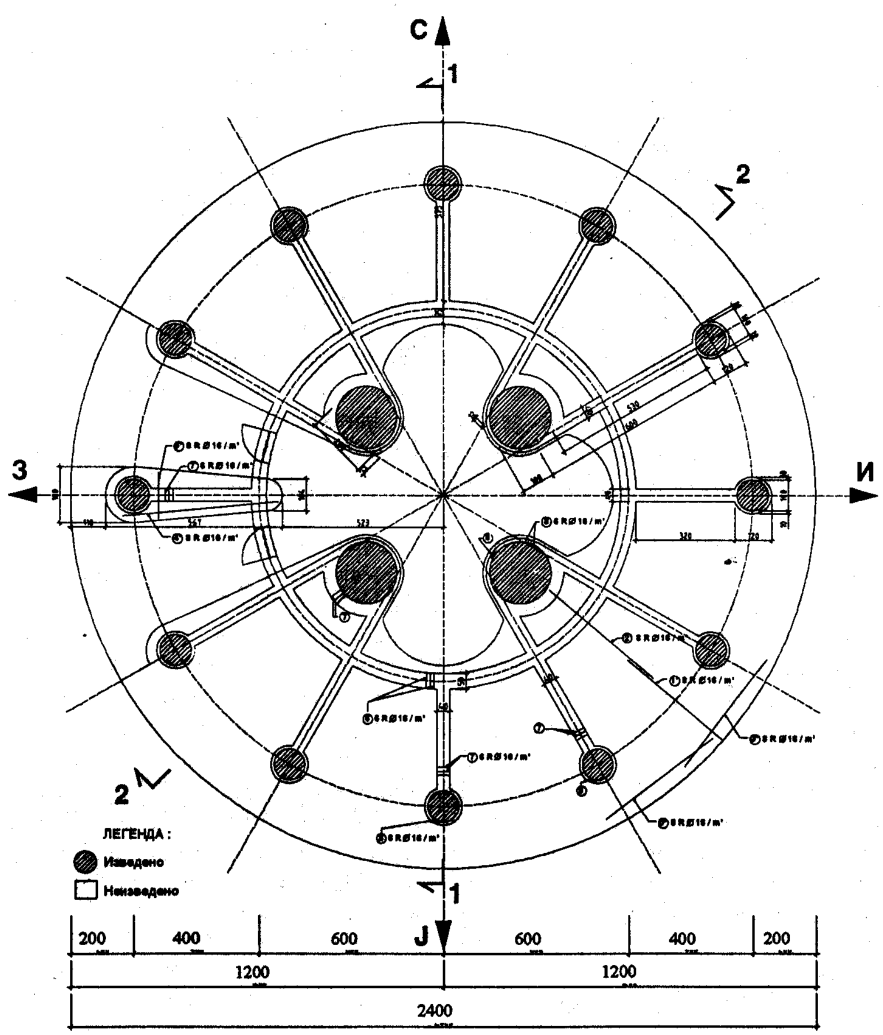


Fig. 2. Plan of the structure of the three-story RC pedestal of the Cross

In addition to the mentioned main belts, there are designed modular steel spatial elements by which is formed a stable spatial truss. The height of the principal vertical steel structure is 66.0 m. The horizontal steel structure of the cross has the same geometrical characteristics as the vertical one. The total length of the horizontal spatial steel truss structure is 46 m whereas the cantilever arms have identical length on both sides amounting to a total of 20.0 m each.

All the steel profiles and all the structural elements of the RC pedestal are proportioned to provide an appropriate level of static and dynamic stability of the integral structure. All the steel elements are designed as precast, while the connections are realized through "hatching", using individual nodal sheets and by local strengthening of profiles, where necessary. Anticipated in the central part of the vertical structure is an elevator for transport from level +4.00 to the level of the horizontal structure, i.e., + 51.00 m (the floor of the horizontal structure) for visitors who want to see the interior of the cross and nice open panorama view all arround.

Around the central elevator, accessory safety steel spiral staircase is designed to enable communication without direct use of the elevator. To enable visibility of the cross silhouette, illumination of the structure is done by a total of two thousand lights and special reflectors reflecting light toward the sky and located on the tips of all the 12 peripheral columns. The steel structure of the cross is well anchored at four central columns by application of an adequately designed anchorage system.

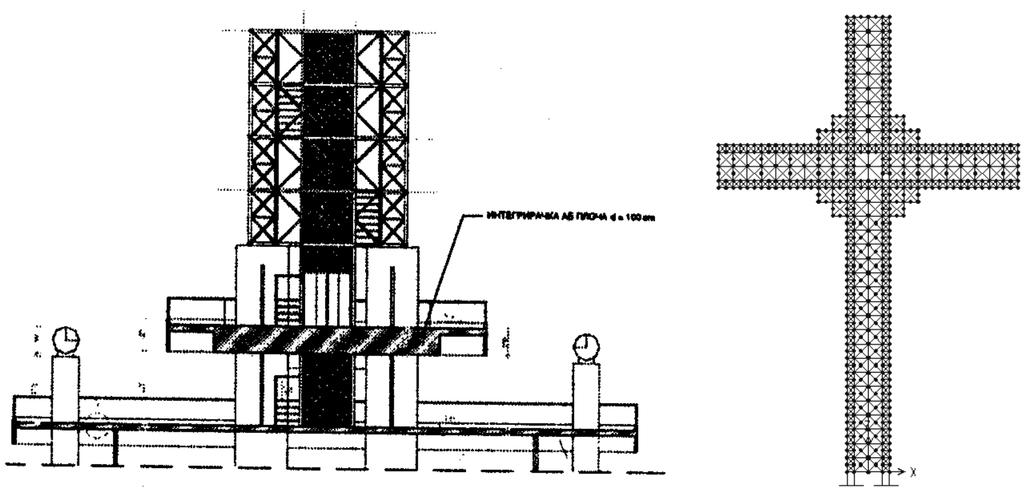


Fig. 3. Vertical cross-section of the three-story RC pedestal (a) and steel structure (b) of the Cross

ANALYSIS OF THE STATIC STABILITY OF THE STRUCTURE

Presented briefly in the following text are the main elements of the formulated mathematical model of the structure, the concept of the performed analyses, the treatment of the competent load combinations as well as the main results from the static analyses.

Three-dimensional mathematical models of the structure

For the purpose of getting as realistic as possible insight into the actual behaviour of the integral structural system under the effect of different design loads and their combinations, a complete three-dimensional mathematical model indicated as Model-M1 (Fig. 7 and Fig. 8) was formulated in the first study phase. Mathematical model M1 includes, in fact, in much details, all the profiles of the steel structure of the cross (in order to provide conditions for their final proportioning), while the pedestal structure is included in this model in a simplified way through its global equivalent stiffness characteristics simulated by a corresponding (smaller) number of equivalent finite elements.

Such a formulation of the mathematical model M1 has proved very successful since in that way, the behavior of the complete structural system under the effect of individual (both static and dynamic loads) is successfully solved. This mathematical model is three-dimensional, with an extraordinarily great number of finite elements (about 12.000) since it contains all the steel elements of the three-dimensional cross structure. Part of the three-dimensional mathematical model of the steel structure of the cross is presented in Fig. 5. An imposing number of finite elements included in model M1 is also evident in Fig. 8. The simplified treatment of the pedestal structure has proved to be a very successfully chosen alternative since realistic behavior of the integral structure has been simulated with an emphasis on the details of the steel cross structure.

To enable going into much detail as to the analytical treatment of the pedestal structure, an additional refined three-dimensional mathematical model referred to as Model - M2 was formulated. Part of the three-dimensional mathematical model of the RC pedestal structure composed of beam finite elements and spatial shell elements is presented in Fig. 4.

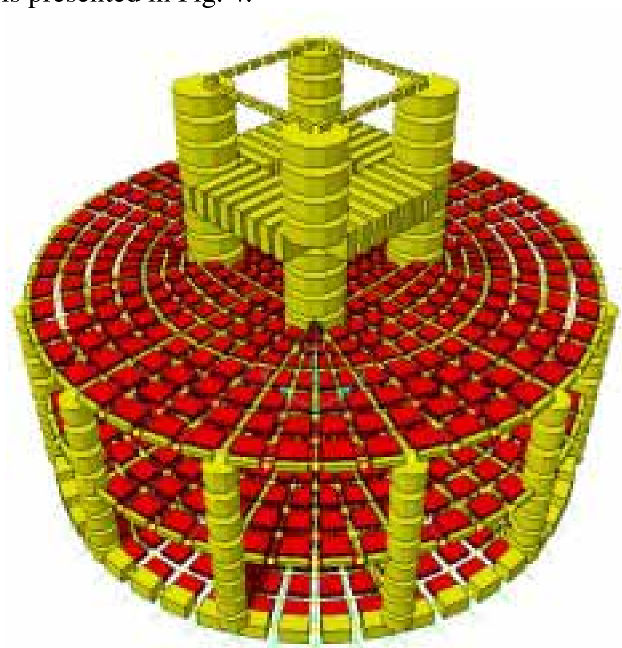


Fig. 4. Part of the three-dimensional mathematical model of the RC pedestal structure composed of 3D beam and shell finite elements.

Mathematical model M2 successfully served for detailed proportioning of all components of the reinforced concrete pedestal structure, proving the stability of the structure against overturning and determination of actual distribution of stresses imposed by the foundation structure to the foundation soil. This additional mathematical model M2 represented an excellent modelling option since its application enabled very detailed treatment of the three-dimensional behavior of the integral RC pedestal structure. Realistic stress-strain state of the RC pedestal structure was enabled through adequate simulation of the effect of loads from the steel cross structure for many considered individual load sets and all competent load combinations needed for the final design purposes.

Competent load combinations

In the first phase, using the formulated three-dimensional mathematical model M1, all the necessary analytical options covering the main design phase of the steel cross structure were performed. Within this basic design phase, a total number of 18 competent load combinations were treated in order to cover all potentially critical loading options. These load combinations arose from the adopted options of individual loads as follows: (1) case-1 (DL): dead weight, (2) case-2 (LL1): symmetric live load on the horizontal structure of the cross ($q = 3.0$ kN/m^2), (3) case-3 (LL2) live load only on one half of the horizontal structure of the cross ($q = 3.0$kN/m^2); (4) case-4 (WLX): wind effect in x-x direction of the cross with intensity of 2.0 kN/m^2, and (5) case-5 (WLY): wind effect in y-y direction of the cross with intensity of 2.0 kN/m^2. The mentioned five and additional 13 load combinations represented a total of 18 main loading states. However, the individual load cases in respective load combinations have been multiplied by respective factors determined in compliance with the design criteria given in the Eurocode.

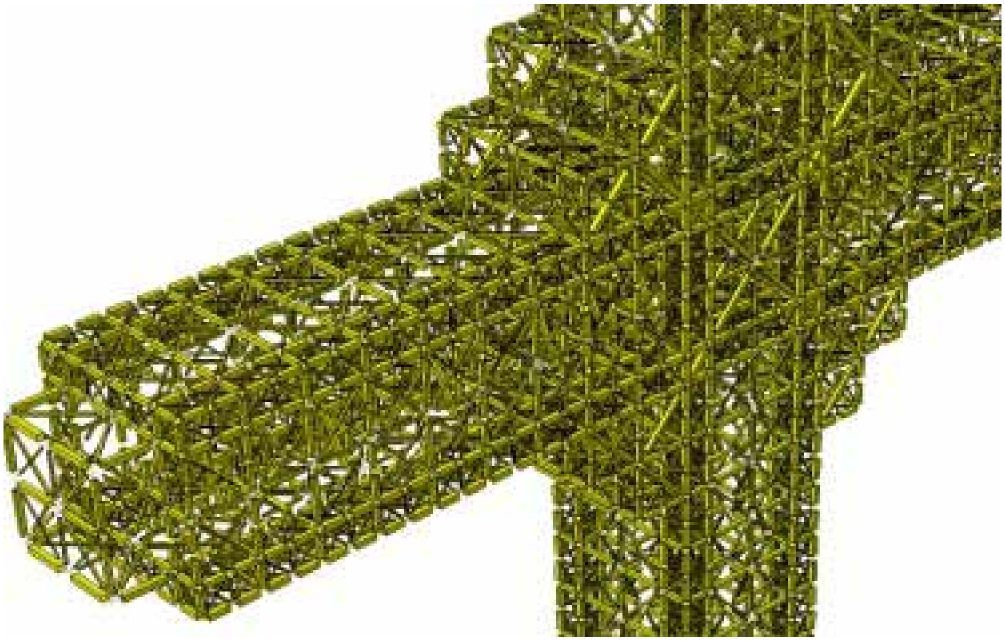


Fig. 5. Part of the three-dimensional mathematical model of steel cross structure composed of about 12000 spatial beam finite elements.

Using an additional three-dimensional model of the RC pedestal (Model-M2) in the second phase (Fig. 4), design analyses were performed for the same cases of individual loads and for 18 competent design load combinations.

Based on detailed results from the analyses performed by using mathematical model M1, proportioning of all the steel elements of the steel cross structure and all its precast joints was performed. Particular attention was paid to unification of cross-sections of the closed steel profiles for the purpose of not disturbing the architectural appearance of the cross. Therefore, unified global dimensions were conditionally adopted, while the necessary changes were included through the changes of the wall thickness of steel profiles.

Based on detailed results from the analyses performed by using mathematical Model-M2, all the reinforced concrete elements of the integral RC structure of the pedestal were completely proportioned. Particular attention was paid to cover successfully (by reinforcement and concrete) all critical stress states in all critical structural elements resulting from all competent design load combinations.

Results from performed static analyses

Taking into account the great volume of obtained results from performed analyses, in this paper only selected representative results are presented. However, in all the individual load cases as well as in the cases of competent load combinations, the computed local and global deformations are within the limits of the allowable ones. Presented herewith are only a few data in order to provide a general insight into the structural response under selected design loads.

For example, the vertical deformations due to dead weight are: $\delta 1 = 0.48$ cm (at the top) and $\delta 2 = 0.82$ cm (at the ends of the horizontal cantilevers). The vertical deformations due the symmetric life load (LL1) are: $\delta 1 = 0.15$ cm (at the top) and $\delta 2 = 0.47$ cm (at the ends of the cantilever).

The deformations due to life load (LL2), load on one cantilever only are: $\delta^z{}_1 = 0.39$ cm and $\delta^x{}_1 = 7.11$ cm (at the top), $\delta^z{}_2 = 3.70$ cm and $\delta^x{}_2 = 3.19$ cm (at the end of the loaded cantilever).

The horizontal deformations due to wind in x direction (smaller effective surfaces) are: $\delta^x{}_1 = 10.37$ cm (at the top) and $\delta^x{}_2 = 5.53$ cm (at the visitors' platform of the horizontal structure).

The horizontal deformations due to wind in y direction (greater effective surface) are: $\delta^y{}_1 = 20.85$ cm (at the top) and $\delta^y{}_2 = 11.18$ cm (at the visitors' platform of the horizontal structure).

From the listed deformations, it can be stated that the deformability of the integral structure is brought into the allowable limits and the bearing capacity of all the structural components is successfully designed providing well controlled structural response.

ANALYSIS OF DYNAMIC STABILITY OF THE STRUCTURE

To analyze the dynamic stability of the structure, the three-dimensional mathematical model-M1 providing a realistic simulation of the dynamic behavior of the integral structural system was formulated and used.

Main dynamic characteristics of the structural system

In the first part of analysis of the dynamic stability of the integral system, the dynamic characteristics of the structure were analyzed. Taking into account that the structure is quite specific and tall and the fact that a three-dimensional model of the integral structure was applied, quite unique successive modes of free vibrations in 3D space were obtained. To get a more detailed insight into the dynamic characteristics of the integral structure, a total of nine vibration modes were computed. Fig. 6 shows the projections of the first two modes of free vibrations that are dominant in x-x direction. Presented in Fig. 7 are the projections of the first two modes of free vibrations that are dominant in analytical y-y direction. However, to provide a thorough insight into the actual dynamic characteristics of the integral structure, Fig. 8 displays a three-dimensional graphic presentation of the first nine mode shapes of free vibrations. It is very characteristic to observe the order of successive modes. The first mode is in the x-direction, the second in the y-direction, the third mode characterizes torsion, the fourth mode is again in x-direction, the fifth mode is again in y-direction, the sixth mode dominates in the vertical direction, the seventh mode is again torsion, the eighth mode is again in x-direction and finally the ninth mode represents a complicated form of torsion.

The results are unique and have a great significance from the view point of structural engineering. Generally, it is evident from the calculated value of the fundamental mode of vibration of $Tx1 = 1.32$ s that the structure of the Millenium cross is not much flexible. In fact, the objective was to achieve this structural property because the structure was planned to be used as an attraction for tourists (by the visiting space in the horizontal structured part) and hence it was necessary to reduce the unfavorable vibrations that might arouse fear among the visitors.

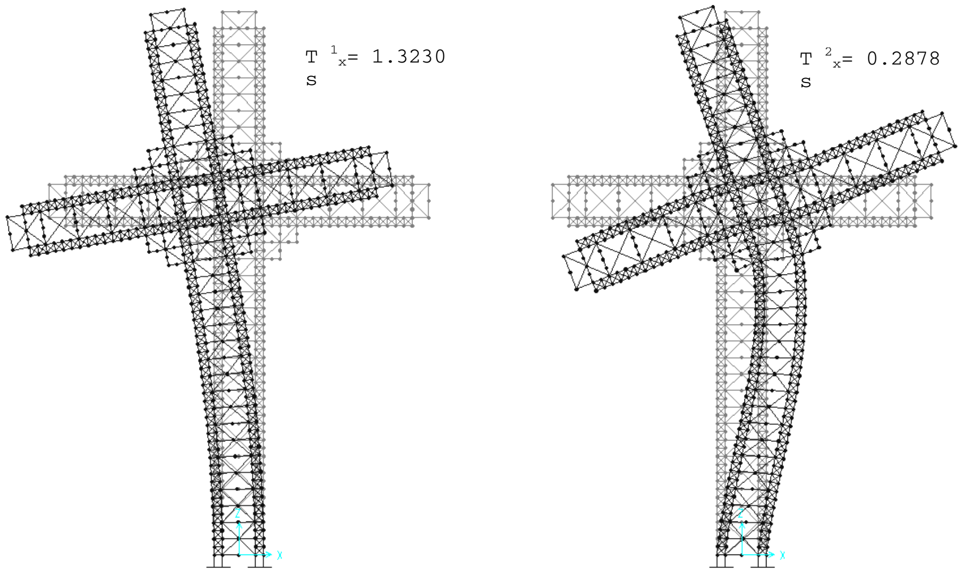


Fig. 6. The shape of the first two modes of free vibrations in the analytical x-x direction

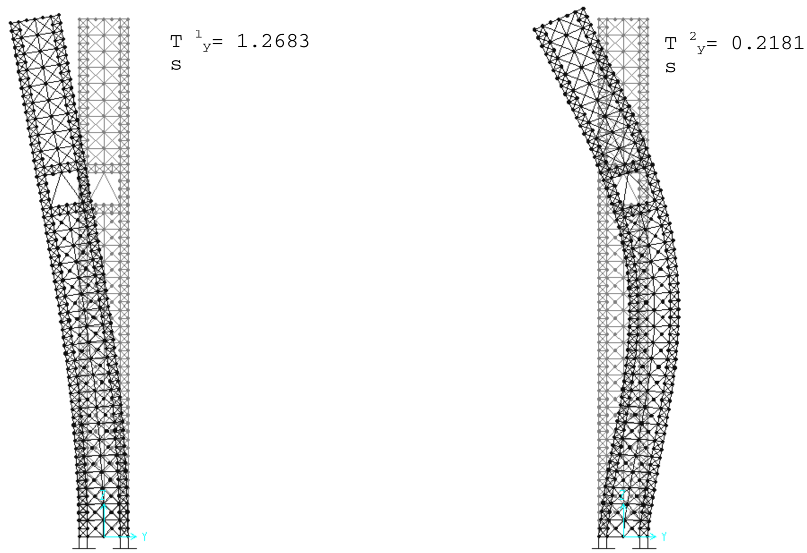
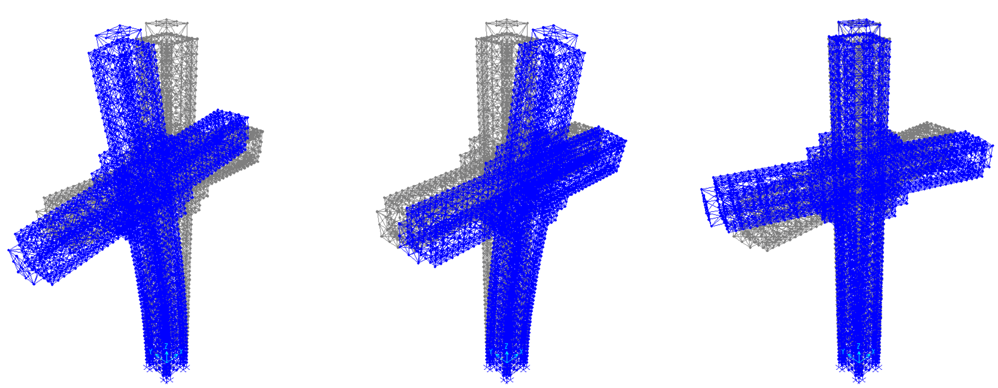


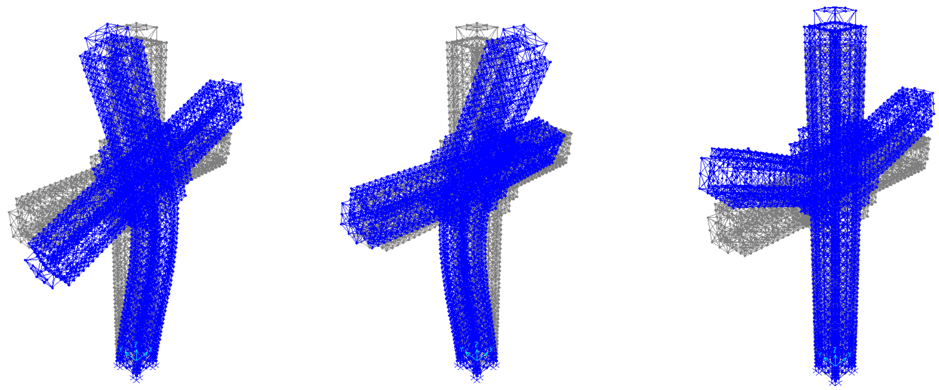
Fig. 7. The shape of the first two modes of free vibrations in the analytical y-y direction



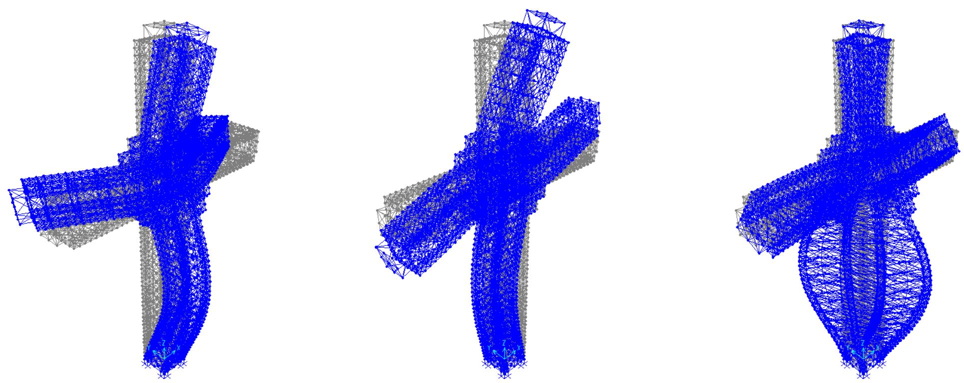
Ton-1: $T1_x$=1.3230 s

Ton-2: $T2_y$=1.2683 s

Ton-3: $T3_T$=1.0247 s



Ton-4: $T4_x$=0.2878 s Ton-5: $T5_y$=0.2181 s Ton-6: $T6_z$=0.1353 s



Ton-7: $T7_y$=0.1171 s Ton-8: $T8_x$=0.1058 s Ton-9: $T9_T$=0.0948 s

Fig.8. Three-dimensional presentation of the first nine mode shapes of free vibrations

Analysis of the seismic stability of the structure

Analysis of the seismic stability of the structure has been done by application of the formulated complete three-dimensional mathematical model M1. The analysis itself consisted of definition of the dynamic response of the structure to the effect of a set of accelerogrammes with spectral characteristics encompassing the domain of the dynamic characteristics of the structure compatible to the response spectra recommended in Eurocode 8. Because of lack of detailed engineering-seismological investigations in the immediate location, the main intensity of the applied accelerogrammes has been designed as equivalent to a seismic zone with intensity of 9 degrees according to MCS, i.e., maximum horizontal acceleration amax = 0.4 g (based on available seismological evidence from respective studies conducted up to date).

With the performed seismic analysis of the structure under the effect of earthquakes in both directions (x and y), the following characteristic results have been obtained:

Earthquake in x - direction:

- At the top of the structure (level ρ_1):
  maximum deformation of $\delta_1 = 0.12$ m to $\delta_1 = 0.17$ m
- At the platform level - the arms (level ρ_2):
  maximum deformation of $\delta_2 = 0.07$ to $\delta_2 = 0.10$ m.

Earthquake in y-direction

- At the top of the structure (level ρ_1):
  maximum deformation of $\delta_1 = 0.22$ m to $\delta_1 = 0.25$ m
- At the platform level - the arms (level ρ_2):
  maximum deformation of $\delta_2 = 0.14$ to $\delta_2 = 0.15$ m.

It should however be noted that the presented results refer to considered earthquakes with an extraordinary high intensity representing the maximum design earthquake. Based on the obtained results, it was concluded that, for the case of considered maximum design earthquake, the behaviour of the structure is within the acceptable limits.

Analysis of dynamic wind effect

To evaluate the dynamic wind effect, representing a dominant effect upon the structure, in addition to the analysis with equivalent horizontal static wind load, an analysis by consideration of the dynamic wind effects has also been performed. A wind excitation defined by harmonic variation of the wind speed (Vd) in respect to the average wind speed (Vsr) has been applied. The average speed (Vsr) has been defined as equivalent to the wind load WL = 1200 N/m2, anticipated with the existing regulations. An evaluated wind speed of Vsr = 155 km/h corresponds to this load. A harmonic variation of the wind speed of around Vsr with amplitude Vd, which is assumed to be Vd = $\pm ((1.5)^{1/2} - 1)$Vsr, i.e., Vd = ±35 km/h has been assumed. The period of the harmonic variation of the speed with amplitude V_d around Vsr has been assumed equal to the period of the first fundamental mode of natural vibrations of the structure. This assumption is the possible most unfavourable one since it is used to define the resonant harmonic excitation.

From the analyses performed with the previously assumed dynamic wind excitation, the following characteristic results were obtained:

- Maximum horizontal deformations due to wind in x - direction
  $\delta_x = 6.22 \pm 7.8 = 14.02$ cm (at the top)
  $\delta_x = 3.32 \pm 4.1 = 7.42$ cm (on the visitors' platform along the arms)
- Maximum horizontal deformations due to wind in y - direction
  $\delta_y = 12.51 \pm 11.6 = 24.11$ cm (at the top)
  $\delta_y = 6.71 \pm 6.12 = 12.83$ cm (on the visitors' platform along the arms)

From the presented results, it can be said that the deformability of the structure is within the allowable limits. The comparison with the equivalent static wind effect from Chapter 4.3 points to compatibility of results, which, in the case of applied dynamic wind effect, as the maximum value, are negligibly greater than those obtained under the equivalent static effect.

TECHNOLOGY OF LONG-TERM PROTECTION OF THE STRUCTURE

To achieve long-term protection of the structure, particularly the steel structure, the technology of complete galvanization of all the metal structural elements was applied on both the exterior and interior surfaces (Fig. 10). The galvanization was done in the factory of EMO-Ohrid in Kichevo. Over the galvanized surfaces, other two layers of protective colour of adequate characteristics was applied. Finally, a finishing layer of golden yellow colour is applied to provide the final appearance to the structure.

To create conditions for galvanization of all the elements and taking into account the geometrical characteristics of the galvanization baths, the proportions of all the elements were successfully adapted to enable their galvanization. This process resulted in a high quality of long-term protection of the steel structure.

TECHNOLOGY OF CONSTRUCTION

The Cross was constructed by two construction firms. The structure of the reinforced concrete pedestal was constructed by "Beton" company from Shtip, whereas the structure of the steel cross was constructed by the "EMO" company from Ohrid. Both firms achieved a high quality of construction. The details of the constructed structure of RC pedestal are shown in Fig. 9, Fig. 11 and Fig. 12. In all the phases of construction, starting from reinforcement to the final concrete works, there was compliance with all the prescribed standards which is of a particular importance for this unique structure. The construction of the RC pedestal was done by casting in situ of the reinforced concrete elements.

Fig. 9.Characteristic detail of construction of the RC structure of the pedestal

Fig. 10. Works on construction of the precast steel elements: (a) galvanization process, (b) process of trial assembling

Fig. 11. Details of the construction of the RC pedestal structure: (a) entry into the small church within the base of the cross and (b) view of the constructed three-story pedestal structure.

The steel structure of the cross is constructed as completely prefabricated. This mode of construction was adopted because of the need of galvanization of the elements and simplification of the construction conditions considering the height of the location and the effect of strong winds and their high frequency of occurrence in the course of construction. The technology of construction of the steel cross involved two phases. In phase-1, all the structural elements and joints were manufactured, including also their galvanization, painting and trial assemblage. In phase-2, all the structural elements were assembled by "hatching" whereat almost ideal level of technological harmonization of the progress of the works was achieved.

Fig. 12. Details of constructed parts of the structure

For the assemblage, only one telescope crane was used. With its bearing capacity, it enabled successful assemblage of all the structural elements. It is particularly noteworthy to mention the high professional skill of the operators and their supervisors which enabled very high quality of the performed works on the metal cross structure. Details of the constructed metal structure of the cross are given in Fig. 12, Fig. 13 and Fig. 14.

Fig. 13. Construction details: (a) resting of the corner of the vertical structure on the base and (b) joints of steel elements.

Fig. 14. Characteristic joints of precast steel elements

The last figure (Fig.15) shows a photo of the constructed structure of the Cross, which represents in fact, the present phase of construction of the cross. After this phase, there will follow the performance of all the next phases, the installation of the elevator, the finishing of the pedestal, the finalization of the illumination, the finalization of the visitors' platform and the accompanying structures, etc. The Investor is continuing activities in order to finalize all the anticipated works.

PLANNED EXPERIMENTAL DYNAMIC INVESTIGATIONS

The Institute of Earthquake Engineering and Engineering Seismology, i.e., the authors of this paper are planning to perform dynamic test on the full scale structure. To that effect, two types of tests are anticipated. The first tests shall be based on the ambient vibration method. The other tests shall represent forced vibration tests. Both methods of testing will provide data on the actual dynamic characteristics of the constructed structural system of the Cross. From structural engineering aspects, these investigations could be of a great significance.

CONCLUSIONS

It is not so often that the structural engineers are given the opportunity to participate in realization of unique structural projects. This specific project that involves design of the structural system of such a unique symbol as is the Millenium cross, was a special professional challenge for the authors both as scientific applicative project and specific structural project. Therefore, all the activities realized within this project were aimed at making the Millenium Cross a long lasting structure with a high level of static and dynamic stability. We believe that the set goals have successfully been realized.

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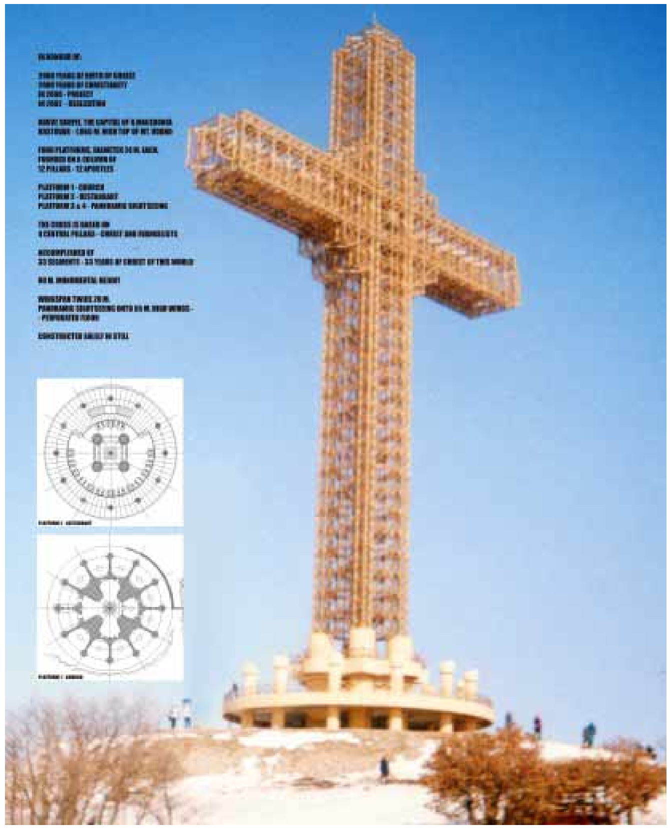

Fig. 15. Photo of the constructed structure of the "Millenium Cross" (present state - works are to be resumed).

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