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STRUCTURAL ASSESSMENT AND STRENGTHENING OF ATATÜRK'S MAUSOLEUM, ANITKABİR

Saadet TOKER, Tuba KOCATÜRK and Ali İhsan ÜNAY

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INTRODUCTION

Anıtkabir is the mausoleum of Mustafa Kemal Atatürk, the commander of Turkish War of Independence and the founder of Republic of Turkey. Rather than a work of architecture, Anıtkabir has been a symbol and a focal center of Atatürk's principles, republican revolutions and modern Turkey.

The making of Anıtkabir marks also an important milestone in the architectural history of Republic of Turkey. It is a simple, elegant and aesthetic example of a counter-concept developed against foreign architectural trends in 1940-1950s. Turkish architects and sculptors introduced this work of art by creating modern figures that cover the components of all the past cultures in Anatolia (**Figure 1**).

As a consequence of the World War II, there had been a significant economic downfall in Turkey, especially between the years 1940-1950. In this era, resources had only been spared for strategically important projects. Difficulties in importing reinforcing steel limited the use of reinforced concrete and steel in Turkey as well as all around the world. New constructions started to be erected either by conventional masonry or composite construction techniques. In this period, there are only three prestigious buildings constructed of reinforced concrete in Turkey. These are the Atatürk Cultural Center, the Turkish Grand National Assembly Building, and Anıtkabir. The Atatürk Cultural Center was designed by Feridun Kip and Rüknettin Güney in 1946 and was built in Taksim, İstanbul. The Turkish Grand National Assembly Building was designed by Clemens Holtzmeister in 1938 as a competition project and was built in Ankara, the Capital. The project for Anıtkabir was also designed for a competition by Emin Onat and Orhan Arda in 1942. As for the financial restraints due to the World War II, constructions of all the three buildings were slowed down; moreover the construction of the Atatürk Cultural Center was stopped after the erection of skeletal frame. The project was renewed by Hayati Tabanlıoğlu in 1956 and the construction was

Figure 1. General view of Anıtkabir.

completed in 1969, 23 years after it was planned. The project of Anıtkabir was revised in 1951 by Onat and Arda upon the request of the government to decrease the cost. The construction took 9 years from 1944 to 1953. This could be seen as a success when compared to the construction duration of the other two buildings. The construction of the Turkish Grand National Assembly Building started in 1939 and the building was completed in 1961, after 32 years from the start, as majority of the resources were used for Anıtkabir (Tekeli, 2007).

Recently in Anıtkabir, the empty space in the basement underneath the mausoleum and the staircase approaching the mausoleum, was decided to be converted into a Turkish War of Independence Museum. A project conducted by the Middle East Technical University (METU) Department of Architecture aimed to assess the general structural capacity and seismic resistance of the mausoleum itself and the structural capacity of the load bearing system used in the staircase. Within the scope of the project, the structural system of Anıtkabir was re-identified, with detailed analytic models prepared for the mausoleum and the staircase separately. Structural analyses were carried out under all possible load cases.

Within the frame of the project, both the mausoleum and the staircase sections were analyzed independently under gravity loads. Then another set of analyses was performed to observe the behavior of the structure under probable earthquake loads. Results were evaluated to determine whether the structure is safe or not with its existing condition. Possible effects of modifications about the use of the structure were assessed, and suggestions made for possible modifications on the structural system to obtain a sound structural performance.

STRUCTURAL SYSTEM OF ANITKABİR

Anıtkabir is the most important reinforced concrete framed design of its time due to large beam spans and overall height. The main block of the

Figure 2. The gallery spanned by one-way joist beams in east-west direction.

mausoleum has a symmetrical and regular structural system. The overall height of the mausoleum section from the foundations to the top is 22.8 m.

The 18 m distance of the gallery is spanned by 1000 mm deep 500 mm wide one-way joist beams in east-west direction (**Figure 2**). This was a considerable span in those times when pre-stressing and post-tensioning were hardly ever applied to construction projects at such scale. As far as we understand, from the very limited information obtained from the Anıtkabir archives, the concrete used in the construction of Anıtkabir has a very low characteristic strength, which does not even comply with the current standards of the TS500 Requirements for design and construction of Reinforced Concrete Structures and Earthquake Codes.

The joists are the most striking structural members in the load bearing system, which are supported by column couples with 5.5 m distance in between. This column and beam arrangement forms the main frames running in the north-south direction. While the cross-sectional dimensions of the columns forming these frames are 800 mm × 800 mm, the beams with a 4.2 m clear span have a cross sectional dimensions of 500 mm × 1000 mm. As it is seen in **Figure 3**, the columns that support the 18 m gallery span should have great rigidity. This could only be achieved by means of columns with huge dimensions or shear walls. Use of slender columns in couples has been very appropriate decision to avoid any interruptions in space since the column couples have an equivalent rigidity with huge columns. The column couples in the basement were converted to shear walls with enormous cross-sectional dimensions.

The slender columns that frame the mausoleum section are probably the most remarkable members of the load bearing system of Anıtkabir. These cut-stone clad reinforced concrete columns frame the mausoleum in an arcade with a height of approximately16 m from the entrance level of the gallery to the roof (**Figure 4**). Based on the on-site measurements and as proved by the Anıtkabir Museum Archive documents, the outer cross-sectional dimensions of the columns were recorded as 1.4 m × 1.3 m.

Figure 3. The columns supporting the 18 m gallery should have great rigidity.

Figure 4. Slender columns that frame the mausoleum are the most remarkable members of the load bearing system of Anıtkabir.

Figure 5. The most vulnerable part of Anıtkabir in terms of structural safety is the staircases.

Figure 6. The three-dimensional reinforced concrete skeleton consisting of slender columns.

The dimensions of the inner column cores are identified as 0.9 m × 0.9 m. according to the documents and pictures taken during the construction.

The basement, which was rearranged as the Turkish War of Independence Museum, consists of reinforced concrete frames on a rectangular grid. Contrary to those in the main space of the mausoleum, the dimensions of the columns and beams at the basement provide the structural members with adequate rigidity.

The foundations of the mausoleum section had been the most controversial part of the construction as well as the most time-consuming part of the design stage. Initially, it was considered that the monument was going to be constructed by stone masonry construction. However, considering that the foundations of such a heavy building would be so expensive due to high soil pressure, it was decided to build the upper load-bearing system of the mausoleum as reinforced concrete and beam skeleton. It can be said that the foundations of Anıtkabir had been given more strength than required to prevent structural damages due to different settlements in different parts of the building. As for the foundation system, although it's not within the scope of this research and therefore haven't been examined in detail by the authors, the visual documents illustrate the use of a deep mat foundation system (Anıtkabir Tarihçesi, 1994).

Even without a detailed structural analysis, the most vulnerable part of Anıtkabir, structurally, can easily be identified as the staircase section approaching the mausoleum. The three dimensional reinforced concrete skeleton consisting of slender columns and inclined beams along the two sides of the staircase is constructed independently from the massive mat foundation of the mausoleum block (**Figure 5, 6**). Thus, the staircase section is supported by single footings at the bottom level of the deep foundation right beside.

BASIC PRINCIPLES OF NUMERICAL ANALYSIS AND ANALYTICAL MODELING OF STRUCTURES

Detailed analytical models were prepared for the mausoleum and staircase sections for structural assessment of Anıtkabir. First, both the mausoleum and the staircase sections were analyzed independently under gravity loads. Then another set of analyses were performed to observe the behavior of structure under the probable earthquake loads. General principles of our analysis and modeling are outlined in the following paragraphs to give a better understanding of our specific approach for Anıtkabir.

Structural analyses are generally performed for the design and dimensioning of load bearing members. Additionally, they are performed to determine stresses and internal forces in the structural members under various loads and environmental disturbances. These values are compared to the ultimate strength of the structural members. The stresses and internal forces obtained from the analyses that are carried out to determine the safety factors of existing buildings are compared to the load bearing values calculated for structural members (Lin and Stotesbry, 1981).

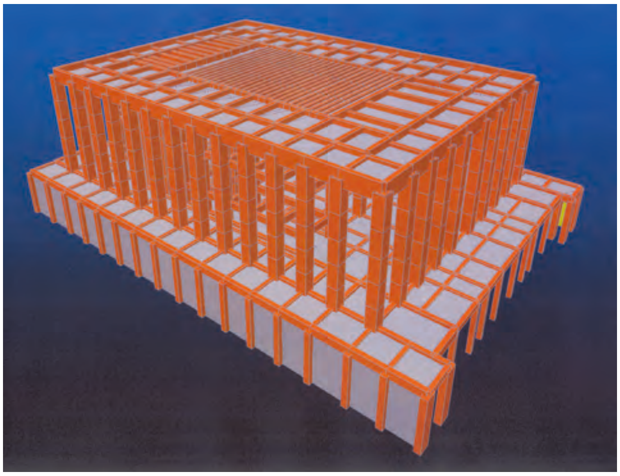
Structural analysis starts with developing an analytical (mathematical) model of a structural member or the overall structure. This process is called as the discretization of the structure. During discretization, the structure is divided into a number and form of elements proper to the scope of the analysis. The structural members may need to be identified by means of smaller elements. Identification of the structure considering the geometrical dimensions, degrees of freedom of the supports and elements, and the loads acting upon the structure is called as analytical modeling or mathematical modeling (Ünay, 2002).

The aim of analytical modeling is to observe the actual behavior of a structure or a structural member under various loads or external disturbances. The actual behavior of a structure is generally very sophisticated. This complexity requires simplifications to enable modeling of a structure. To obtain a simple and plain model, a proper identification of the actual construction materials that form the structure is required. The principles of analytical modeling are identified as follows:

- The simplest model gives the optimum results. Complex models that go beyond the aim and scope of the analysis are unnecessary.
- All the structural effects that are required for the analysis should be taken into consideration when determining the dimensions of the elements in the model. For instance, when the aim is to determine the deformation due to torsional moment in a beam, the element that define the beam in the model should be dimensioned in an appropriate way that it could give the values for axial forces (N), shear forces (V), bending moments (M) and torsional moments (T). Also, the cross-sectional characteristics should be identified in a way that they could display the outputs accordingly to these values.
- The model that is merely created by separating a particular part of the overall model is not sufficient to provide the behavior of the section or member in question. To obtain detailed behavior, models that accurately define the boundary conditions and connections are required (Cook, 1974).

There are four basic phases to develop an analytical modeling of a structure:

1. Assumptions related to material behavior are determined according to the behavior of a very small part of the material, which is also known as differential element. The differential element constitutes the model of the material. Stress-strain characteristics of the material are considered in the material model.



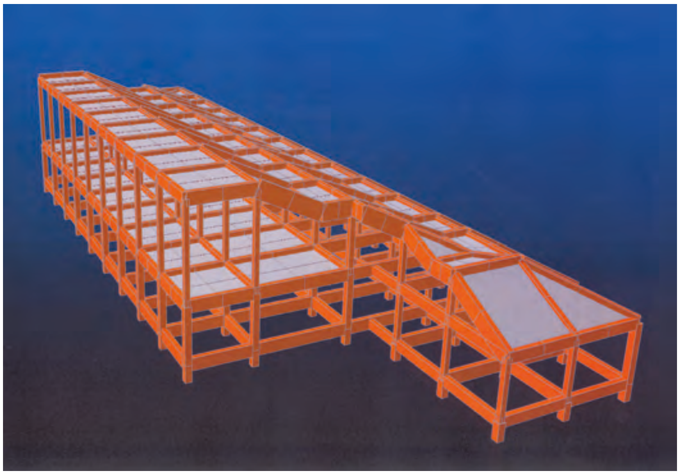


Figure 7. Analytical model of the mausoleum.

Figure 8. Analytical model of the staircases.

2. The differential elements are united to exhibit the behavior of elements that define the specific part of the building within the boundaries. These elements are also known as finite elements.
3. Finite elements are gathered to obtain a finite element model that is supposed to reflect the behavior of the overall structure.
4. The boundary conditions, degrees of freedom of supports and nodes, and the loads that would act upon the model are defined.

In finite element analysis, both the individual behavior of elements that constitute the model and the behavior of the overall analytical model have the utmost and equal importance. To obtain an excellent model, it is necessary to make a detailed study of material behavior and individual element behavior.

The history of the structure is very important in structural analysis. Ambiguity about the strength of construction materials, and/or the types of loads that acted upon the structure in its lifetime arouses suspicion about the validity and accuracy of the results related to the safety factor of the structure. Decisions based on the outputs of the analysis about the behavior of the structure are validated only if they comply with the damage, deformation, and cracks observed on the structure (Wen, 1990). Numerical analysis method is the most convenient method to analyze the existing structural condition of a building. Improvements in computer software have made it possible to perform static, dynamic, linear elastic and nonlinear elastic analyses for complex structures in a very limited time.

STRUCTURAL ANALYSIS OF ANITKABİR

The analyses of Anıtkabir under vertical loads (dead loads and live loads) and seismic loads were carried out by SAP2000 software. The analytical models that were prepared for the mausoleum and the staircase sections are given in the **Figure 7** and **Figure 8**. The analytical model of the mausoleum section consists of 1060 nodes, 1770 frame elements and 562 general shell elements.

Computer programs usually comprise of element libraries for the modeling of structural members. During the modeling of reinforced concrete framed structures, beams and columns are generally represented by frame

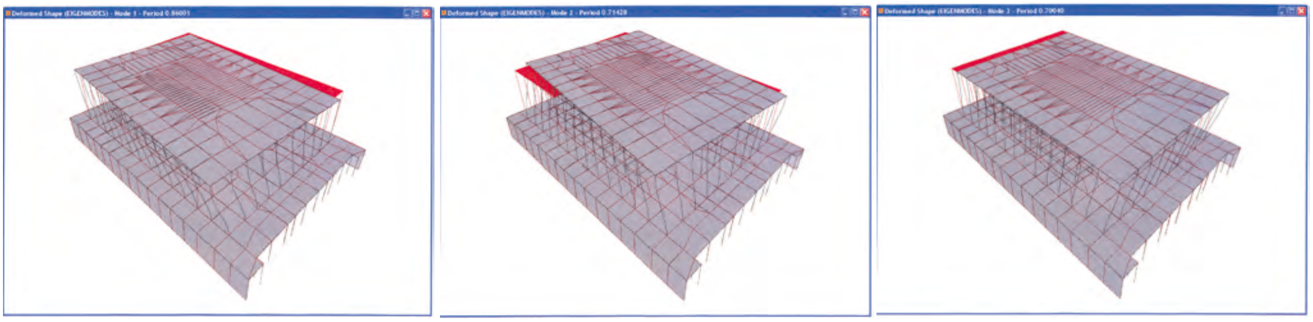


Figure 9. The first 3 modes derived from the 'response spectrum' analysis for the mausoleum.

elements whereas slabs and shear walls are represented by general shell elements.

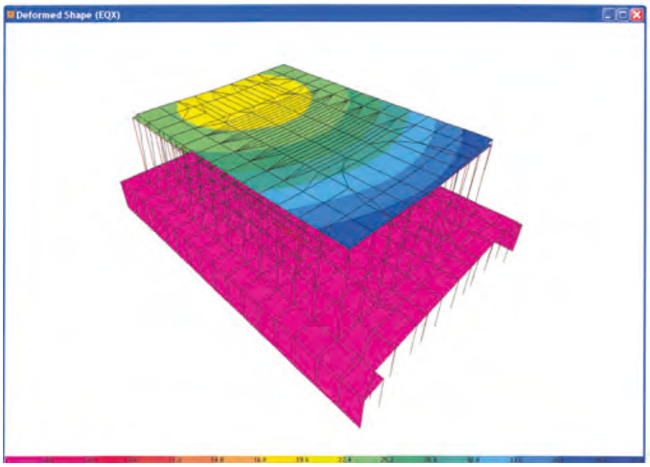
The analytical model of the staircase section consists of 668 nodes, 834 frame elements, and 452 general shell elements. The inclined reinforced concrete plates that support the steps of the staircase and the slabs at the mezzanine level were modeled by general shell elements. These general shell elements were used to transfer the loads accurately to the beams and columns. Additionally, general shell elements help obtain the accurate behavior of a structure under horizontal and vertical loads especially in seismic analysis. A separate detailed model was developed and analyzed to determine the strengths of slabs and staircase plates.

An analysis under the vertical loads (including the maximum possible live loads) was performed for the mausoleum and staircase sections in the first instance. Following this, a response spectrum analysis was performed considering the first 30 modes according to the earthquake spectrum specified by the Turkish Earthquake Code for Ankara in EQx and EQy directions. While interpreting the analyses results, two separate loading combinations were created to represent gravity loads and earthquake loads in X direction (G+EQx) and gravity loads and earthquake loads in Y direction (G+EQy).

The steps to follow for structural assessment of buildings are as follows:

- The periods of the building are determined for all the modes
- Total weight of the building under vertical loads are calculated
- Base shear values are obtained from the seismic analysis
- Maximum displacements in vulnerable structural members are determined
- Maximum displacements are determined from lateral load analysis
- Internal forces in selected major structural members are calculated

The results of analysis that cover the steps above for Anıtkabir are summarized according to related graphical outputs as follows. The values for the first 3 modes derived from the 'response spectrum' analysis are: T1=86 sec., T2=71 sec., T3=70 sec. respectively as shown in **Figure 9**. Due to the earthquake loads in X direction, the greatest displacement in X direction is 36 mm (Δ_x=36 mm), where the earthquake loads in Y direction leads to a 23 mm displacement in Y direction (Δ_y=23 mm) (**Figure 10** and **Figure 11**). The total weight of the Mausoleum is 238679 kN. The total base shear values are 17697 kN and 25285 kN due to earthquake loads in X and Y direction, respectively. According to these results, the base shear value in



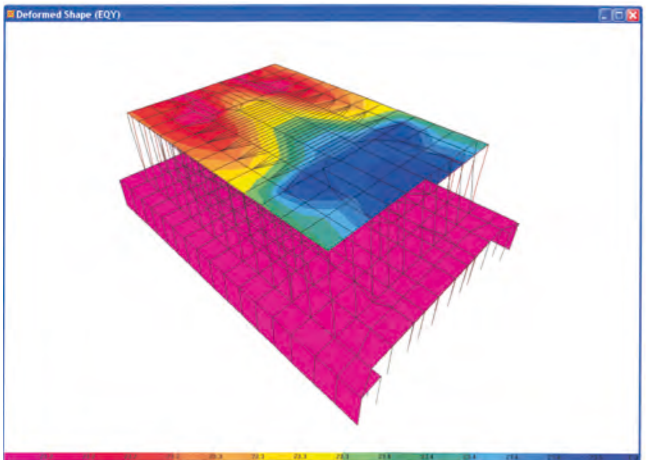


Figure 10. Maximum displacements due to the earthquake loads in X direction.

Figure 11. Maximum displacements due to earthquake loads in Y direction.

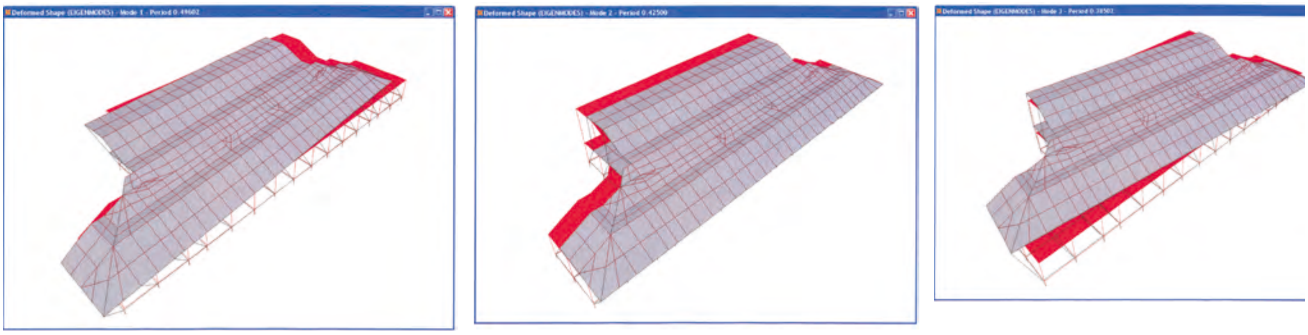
X direction corresponds to the 7% of the total weight of the structure in X direction and 11% of the total weight of the structure in Y direction. These results show that the loads due to an earthquake that could potentially occur in Ankara would not exceed the ultimate limit values in the Mausoleum section.

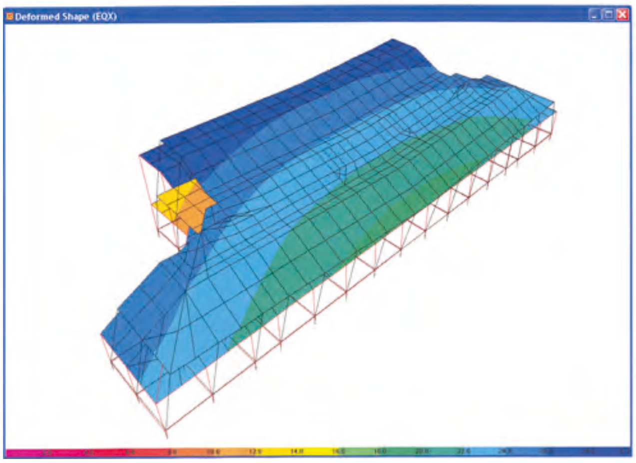
As shown in **Figure 12**, the values for the first 3 modes derived from the 'response spectrum' analysis for the stairs section on Anıtkabir are: T1=88 sec., T2=72 sec. and T3=70 sec. The earthquake loads in X direction cause 27 mm displacement in X direction (Δ_x=27 mm), where the maximum displacement in Y direction is 18 mm (Δ_y=18 mm) due to the earthquake loads in Y direction (**Figure 13** and **Figure 14**). The total weight of the stairs section is 28360 kN. The total base shear values are 10460 kN and 12295 kN due to earthquake loads in X and Y direction, respectively. Thus, the base shear value in X direction corresponds to the 37% of the total weight of the structure in X direction and 43% of the total weight of the structure in Y direction. These results point out that the stairs section of Anıtkabir is subject to earthquake forces well beyond the ultimate limit values.

STRUCTURAL ASSESSMENT OF ANITKABİR

The biggest Bending Moment (M), Shear Force (V) and Axial Force (N) values are obtained from the calculations for vertical loads and earthquake loads. These values are used in the analyses for column and beam cross-sections. Assuming the construction material used for the structural members and the stairs section is of standard strength, the Bending

Figure 12. The first 3 modes derived from the response spectrum analysis for the staircases.





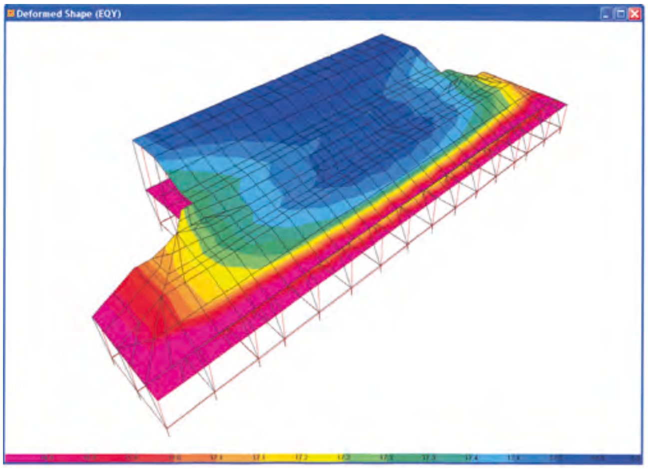


Figure 13. Maximum displacements due to earthquake loads in X direction.

Figure 14. Maximum displacements due to earthquake loads in Y direction.

Moment (M), Shear Force (V) and Axial Force (N) values are seen to cause no risk to the overall stability of the structure.

Confirming with the coring tests, the nondestructive tests performed for the beams and the columns of the mausoleum and the stairs sections, the strength values of concrete are identified between 17 MPa and 23 MPa.

The reinforcement zones within the slender members of especially the stairs section, are identified by means of nondestructive tests. This method provides only an estimation of stirrup locations and the amount of reinforcing bars. The most unfavorable values are considered during the cross-sectional capacity analyses in terms of amount and placement of stirrups.

After the vulnerable beams and columns are specified according to the large internal forces, their capacities are determined by means of axial force-bending moment (N-M) interaction diagrams. The axial force and bending moment capacities of the selected beams and columns are determined by considering the lowest amount of reinforcement, which is well below the values specified in the Turkish Codes. The best means to observe the behavior of columns under Moment (M) and Axial Force (N) is the N-M Interaction Diagram.

The detailed analyses are performed to determine not only the current behavior of the structural members of the mausoleum and the stairs section but also the effects of the proposed arrangements and repair process on these sections. Also, the current codes and regulations were used to specify the probable earthquakes that are likely to occur in Ankara. This was particularly done to determine the effects of earthquake loads on the structure. When results of the analyses and the codes are assessed together, it could be said that neither the current situation nor the modified condition of the load bearing system of the mausoleum and the stairs section would be in danger due to earthquakes.

This conclusion is based on the condition that the coring results reflect the true strength of the structural members. It is important to note that although there could be some local incompetence; the redistribution characteristic of reinforced concrete would immediately compensate this incompatibility. On the other hand, considering the significance of Anıtkabir for the Turkish Nation, although there seemed to be no significant structural problems for the load bearing system of the stairs

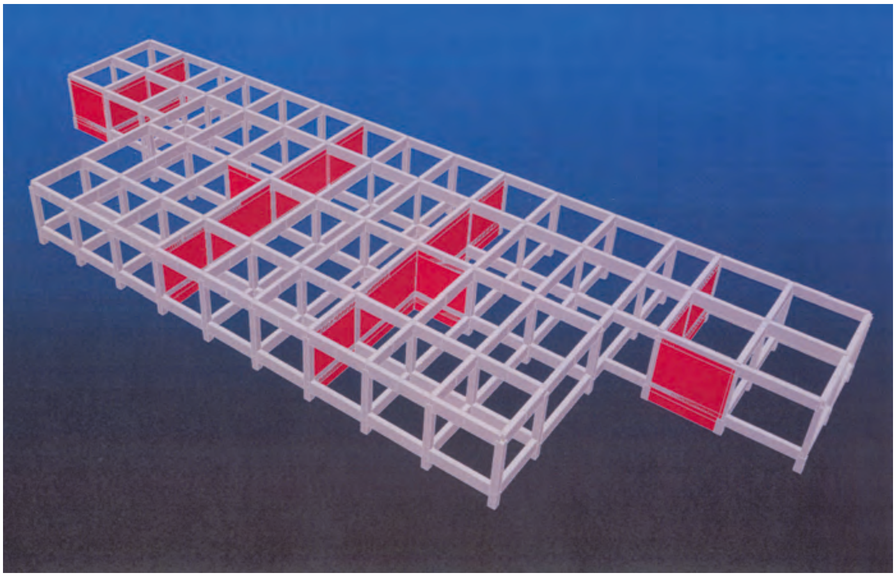


Figure 15. Strengthening of staircases by in-fill shear walls.

section (under gravity and seismic loads), an extra precaution is taken to provide the maximum safety in case of an unforeseen failure.

As seen in the **Figure 15**, in the stairs section, the columns are turned into shear walls in some frames. In other words, the span between the two columns is filled to obtain shear force behavior. Holes are drilled on the surfaces of both the columns and the beams; and reinforcing bars are replaced through these holes. Reinforcing bars make it possible to have the beam, column and the filling shear wall act together, as if they were united. The analyses were performed again, this time with the shear wall fillings. **Figure 16** shows the dramatic change in the seismic behavior of the stairs section in terms of time periods, T1=26 sec., T2=14 sec., T3=13 sec. As it can be seen in **Figure 17** and **Figure 18**, the overall displacement of the structure decreased about 27 %. Δ_{max}=7.2 mm while it was mentioned to be 27 mm originally. All internal forces and stresses are also decreased to safe levels.

CONCLUSIONS

Anıtkabir is the unique symbol of freedom, independence, laicism and modernity for the Turkish nation. It should be well-protected and preserved. This study explains the structural assessment and strengthening proposals regarding the attempts to turn the lower floor of the mausoleum into the Turkish War of Independence Museum. Important findings

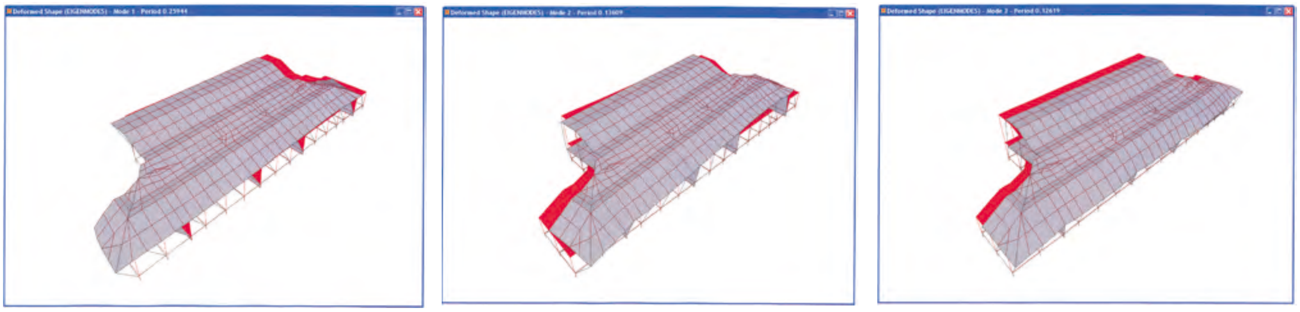
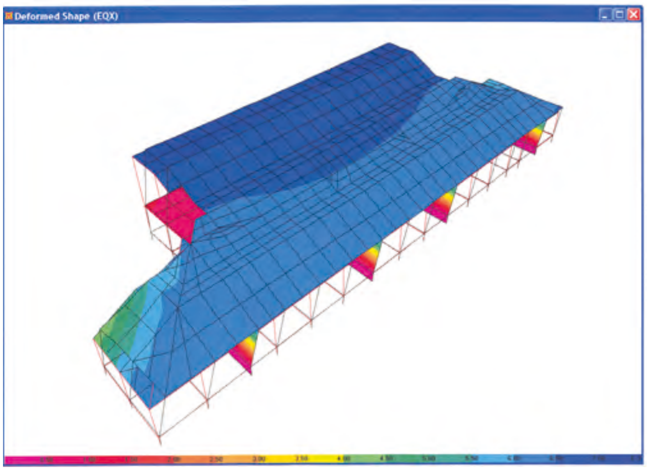


Figure 16. The first 3 modes derived from the response spectrum analysis for the staircases after strengthening.



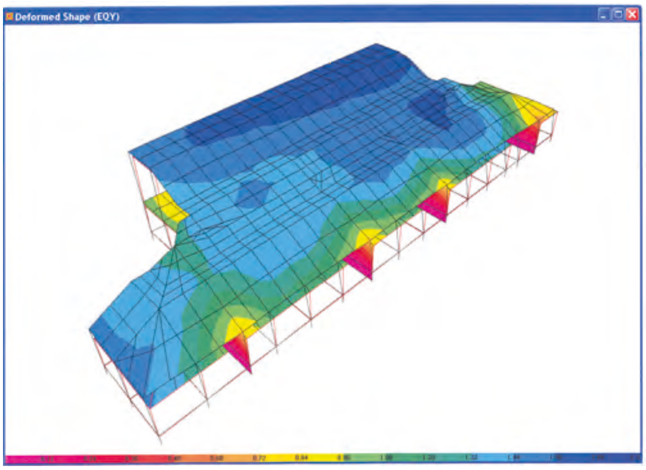


Figure 17. Maximum displacements due to the earthquake loads in X direction after strengthening.

Figure 18. Maximum displacements due to the earthquake loads in Y direction after strengthening.

are obtained about exploring the structural problems of buildings with historical value, specifying the current structural performance of buildings by means of computer based structural analysis techniques, and assessment of various strengthening methods on buildings.

Anıtkabir is invaluable for Turkish Nation. It stands for independence of the Republic. Thus, structural performance of Anıtkabir is a concern beyond safety. Every condition that the structure could experience was taken into consideration for these sets of analyses and the results were interpreted with utmost attention.

Based on the observations, surveys and analyses, it is seen that the Mausoleum section, which is the main part of Anıtkabir, has no structural problems in its present condition. Additionally, the analysis showed that the main structural elements would not sustain important damage in case of an earthquake, as foreseen by the current Earthquake Codes, in Ankara.

Figure 19. Staircases are exposed to excessive live loads due to ceremonial crowds in national events.

Based on the experience obtained from similar structures, the columns at the stairs section ascending to the Mausoleum have relatively smaller dimensions than required. As shown in **Figure 19**, considering the fact that the stairs section is exposed to excessive live loads due to ceremonial crowds in national events, these slender columns are observed to have the risk to reach their ultimate capacity. Therefore, some frames are strengthened by means of in-filled shear walls. The computer analyses show that the strengthening process provides a significant increase in the overall strength and the capacity of the vulnerable structural members. The strengthening process shows a considerable increase in the structural performance of the stairs section.

This study once more verifies the importance and benefit of finite element analyses using appropriate modeling techniques. These modeling techniques greatly help reflect the actual behavior of structures as well as determine the effects of any strengthening method without the need for destructive tests.

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Anahtar Sözcükler: Anıtkabir; yapısal analiz; güçlendirme, Sonlu Elemanlar Analizi; deprem dayanımı.

ANITKABİR'İN YAPISAL DEĞERLENDİRMESİ VE GÜÇLENDİRİLMESİ

Anıtkabir, Türk Kurtuluş Savaşı'nın önderi, Türkiye Cumhuriyeti'nin kurucusu Mustafa Kemal Atatürk'ün anıt mezarıdır. Simgelediği değerlerden ötürü Anıtkabir'in Türk Milleti ve Türkiye Cumhuriyeti için önemi çok büyüktür. Anıtkabir'in Atatürk İlkeleri'nin, Cumhuriyet Devrimleri'nin ve Modern Türkiye'nin sembolü olarak ele alınması çok doğru bir yaklaşım olacaktır.

Bu çalışma, Anıtkabir'in strüktürel kapasitesinin belirlenmesi, merdiven bloğunun ve mozole bloğunun depreme karşı dayanımının saptanması, ve gerektiği takdirde yapının kritik bölümlerinin güçlendirilmesi için, ODTÜ Mimarlık Bölümü tarafından yürütülen projenin sonuçlarını kapsamaktadır. Proje kapsamında, Anıtkabir'in taşıyıcı sistemi yeniden tanımlanmış, mozole ve merdiven blokları için ayrıntılı analitik modeller hazırlanmış, olası çeşitli yükler altında yapısal analizler gerçekleştirilmiştir. Çalışmanın sonucunda tarihi niteliğe sahip yapıların strüktürel sorunlarının araştırılması, bilgisayara dayali yapısal analiz teknikleriyle yapıların varolan strüktürel durumlarının saptanması ve çeşitli güçlendirme yöntemlerinin yapıya kazandırdığı dayanım konularında önemli bulgular elde edilmiştir.

Yapının varolan strüktürel durumunu belirlemek amacıyla yapılan analizler için en elverişli olanı sonlu elemanlar analizi yöntemidir. Bilgisayar yazılımlarındaki gelişmeler, çok kısa bir sürede oldukça kapsamlı analiz modellerinin bile statik, dinamik, doğrusal elastik ve doğrusal elastik olamayan analizlerinin yapılmasını sağlamaktadır.

İlk olarak, mozole bölümü ve merdiven bölümleri için olası hareketli yüklerin göz önüne alındığı düşey yükler altında bir analiz yapılmıştır. Daha sonra, yürürlükteki Türkiye Deprem Şartnamesi'nin Ankara için öngördüğü deprem spektrumu için, ilk 30 mod dikkate alınarak, doğu-batı (EQx) ve kuzey-güney (EQy) doğrultularında tepki spektrumu analizi yapılmıştır. Analiz sonuçlarının değerlendirilmesinde düşey yükler ile x yönünde deprem yükleri (G+EQx) ve düşey yükler ile y yönündeki deprem yükleri (G+EQy) için iki ayrı yük birleşimi oluşturulmuştur.

Düşey yükler ve deprem yükleri için gerçekleştirilen hesaplar sonucunda elde edilen en büyük Moment (M), Kesme Kuvveti (V) ve Eksenel Kuvvetler (N) dikkate alınarak kolon ve kiriş kesit analizleri yapılmıştır. Bu analizler, merdiven bölümünü ve mozole bölümünü oluşturan taşıyıcı elemanların durumunda taşıma kapasitesi bakımından herhangi bir tehlike olmadığını göstermiştir.

Ayrıca, hem malzeme dayanımının belirlenmesi hem de özellikle merdiven bölümünde bulunan narin kolon ve kiriş elemanları üzerindeki donatı bölgelerinin belirlenmesi amacıyla, merdiven bölümü ve mozole bölümündeki birçok kolon ve kiriş için tahribatsız yöntemlerle testler yapılmıştır. Bu yöntemle ancak tahmini olarak etriye aralıkları ve donatı miktarları belirlenebilmiştir. Kesit kapasite analizleri sırasında bu tahmini değerlerin en olumsuz olanları dikkate alınmıştır.

Yapılan ayrıntılı hesaplar, Anıtkabir'in mozole ve merdiven taşıyıcı sisteminin gerek şimdiki durumuyla, gerekse önerilen düzenlemelerle, Ankara için olası bir deprem sırasında ortaya çıkabilecek ve diğer yükler altında herhangi bir tehlike oluşturmadığını göstermektedir. Ancak, Mozole'ye çıkış merdivenlerinin bulunduğu bölümde yer alan narin kolonların muhtemel bir deprem sırasında limit kapasitelerine ulaşma riski görülmüştür. Anıtkabir'in çok önemli bir yapı olduğu ve merdiven bölümünün törenlerde insan kalabalığından dolayı aşırı bir hareketli yük yığılmasına maruz kalabileceği gerçekleri göz önüne alınarak, ek bir önlem alınmış, bazı çerçevelerde kolonların arasına betonarme perde duvar şeklinde dolgu yapılmıştır. Eklenen perde duvarlar dikkate alınarak yapılan yeni analizler, güçlendirme işleminin yapının genel dayanımında ve kritik elemanlarının kapasitelerinde artış sağlandığını göstermiştir.

SAADET TOKER, B. Arch, M. Sc., Ph.D.
Received B.Arch., M.Sc. in Building Science and Ph.D. in Building Science (1997), at METU. Extended her training in Civil and Architectural Engineering in University of Wyoming as a post doctoral research fellow. Currently employed as assistant professor in Architecture et the University of Texas at San Antonio. Fields of interest are structural analysis and design, earthquake resistant building design, structures in architectural education.

TUBA KOCATÜRK, B. Arch, M. Sc., Ph.D.
Received a B.Arch. and M.Sc. in Building Science at METU; a Ph.D. in Building Technology at Delft University of Technology. Currently employed as Lecturer in Architectural Design and Technology of the School of the Built Environment at the University of Salford. Is the Coordinator of M.Sc. Course Development in Digital Design. Fields of interest are digital design / engineering and CAD/CAM processes, collaborative design knowledge modelling, information and communication technologies in design education, free-form design processes, and cognitive processes in design education and practice.

ALİ İHSAN ÜNAY, B.CE, M. Sc., Ph.D.
Received B.CE.(1985), M.Sc. in Building Science (1988) and Ph.D. in Building Science (1997), at METU. Has been teaching at the Department of Architecture at METU since 1986. Currently employed in the Department of Architecture in Gazi University as professor. Fields of interest are structural design, structural analysis of historic buildings, morphological analysis of structures, and earthquake resistant building design.