Performance based approaches to structural analysis of historical structures & a case study

K. Peker
ERDEMLI Engineering & Consulting Co.Ltd. / Istanbul - TURKEY

E.Togrol
Istanbul Technical University

ABSTRACT: There are a number of methods, that can be utilized in the structural analysis process of historical structures, which have great artistic and cultural importance. Performance based analysis procedures are utilized in this study in order to have well defined performance targets, against forcing conditions and specially the earthquake condition. A case study is given to define the framework of the methodology followed.

1. INTRODUCTION

Artistic and cultural importance of historical buildings has been recognized by people around the world, as among the more important values, which deserve respect and consideration.

In order to preserve such historical structures, they are either well protected from damage and deterioration or their lifetimes are extended by providing appropriate restoration. Sometimes they are converted into museums, and sometimes they are adapted for various other functions of the daily life so that they constitute a bridge between the past and the future, and, thus, are reborn thanks to their new utilization purposes.

The factor that lets the historical structures gain their so esteemed value is their age, but age is, at the same time, a destructive enemy for them that must be combated. In general, the deterioration of the construction materials, the insufficiency in strength of the original design concept, any structural damages attributable to any changes in their utilization purposes or any other damages occurred after great disasters of the past, as well as, any rough handlings and revisions which eventually led to some deteroiorations, are the most common problems of historical structures.

2. METHOD

With respect to their effects on the society and their social, artistic and cultural values, today, any and all historical structures have a different place and priority in terms of their protection and maintenance. This historical inheritance classified by specialists and specialized governmental institutions, is currently being protected officially under different priority ranges, so that all the existing historical structures are continuously checked by authorities under various performance criteria against destruction risks arising out of various reasons, such as wearing or deterioration of the construction materials, roughly handling or failure to maintenance and/or natural disasters.

The structural analysis of and inspection checks on historical structures when investigating their structural sufficiency and strength can be made within a scientific methodology by employing performance levels. The most important point here is, however, the proper definition of the expected performance of each type of historical buildings against various external impacts and any strains.

As the "performance based analysis of structural systems" has been introduced in recent years, the utilization of similar approaches for the structural analysis of historical buildings is still not very often accounted for, and also the scope and extend of available global knowledge and experience in this field is very limited. Below are given various "performance levels" and their definitions under commonly used terminology as taken from some very limited studies (such as Terenzi et al, 2002) carried out in this field:

Negligible Damage (ND): Occurrence of any negligible structural damage is allowed. The building should not lose its artistic value, and only small and negligible losses and damages should occur in both the structural members and the historical value of the building. Save for any special cases, this performance level is provided for the case of frequently occurring earthquakes (probability in 50 years 20-50% only).

Cultural Value Safety (CVS): Occurrence of repairable and small structural damage is allowed. Any repair works to be made should not necessitate any general security cautions. Local damages are acceptable, but no damages should occur that is distributing alongside the entire structure. Any limited losses and damages in the artistic or historical value of the building are acceptable, but not to such extent as it would lead to totally annihilation of such values. Such losses and damages should be of repairable nature, and the building should be able to be used-exhibited. Save for any special cases, this performance level is provided for the case of moderate frequently occurring earthquakes (probability in 50 years 10-20% only).

Collapse Prevention (CP): Occurrence of any general or local collapse of or in the building is not allowed. Any total losses and damages of and in the artistic or historical value of the building may occur, but the building should not collapse. Save for any special cases, this performance level is provided for the case of very rare occurring earthquakes (probability in 50 years 2-10% only).

For attaining to above-mentioned performance levels in structural analysis of building, and, if necessary, also in their restoration, the specifications and features of the relevant construction materials as well as any geotechnical characteristics must be known very well, and any rehabilitation works should be started after assessment of any weaknesses in the entire system of soil-structure in terms of both structural material and geotechnical soil conditions.

3. A CASE STUDY ON METHODOLOGY

For the detailed explanation of the above-mentioned "methodology for the performance based structural analysis of historical buildings", the design assumptions and details of the "Project for the Utilization Purpose Change and Conversing into Hotel of the Waterside Residence Atik Ali Paşa Yalısı on Bosphorus in Istanbul, Ortaköy", that is designed, planned and analyzed within the framework of this concept, are given below.

The Project includes, besides constructing new hotel buildings on the same site, the restoration and amendment of the utilization purpose of the existing waterside residence. The residence was constructed along Bosphorus between 1890 and 1900 and restored several times during the last century. The design works carried out for this Project aims at rehabilitation of the existing historical building and protection and restoration of its external façades of historical value. Therefore, the structural analysis has been performed in two different stages: "the construction stage" and "the operation stage".

Figure 1. Existing state of building.

Preparation of the detailed "as-built drawings" of the structure: By field studies, a full digital documentation of the historical façade and walls has been worked out. Any construction faults and geometric disorders have been ascertained, and all the geometric conditions on which the design model representing the existing building will be based, has been laid down in full extend and in a highly precise manner. Figure-1 shows the existing state of the building and Figure-2 a measured digital drawing of the façade.

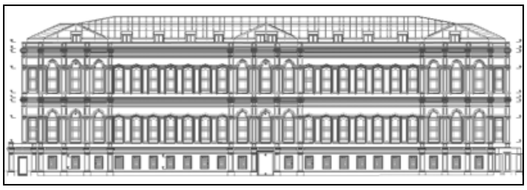

Figure 2. Façade digital drawing.

The thickness of the walls has been surveyed and any modifications made in and on the building during all the years have been ascertained step- by-step, and basing on these findings a detailed documentation of the existing structural system has been provided. Figure-3 outlines the wall-section and the overall structure of the foundation.

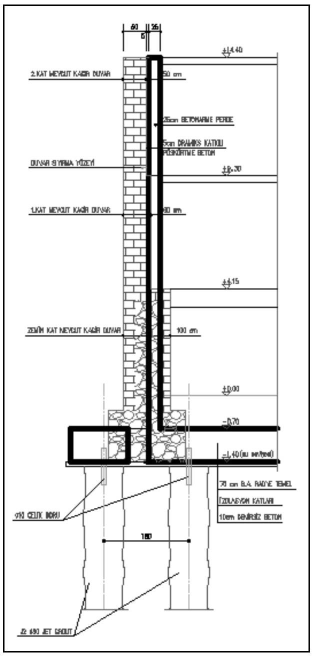

Figure 3. Historical wall section with the proposed strengthening system.

Changes in material and in construction methods, also construction and design faults made during the initial construction phase as well as any construction hypothesis assumed at that time have been examined systematically so that a very precise report could be provided on the current state of the original building. Places from where sampling of materials has been recovered are indicated.

<u>*Geotechnical and seismic investigations:*</u> Soil profile and soil properties have been investigated by exploratory borings, and test pits in several places at the site. The results of soil investigation are evaluated with respect to the existing structure.

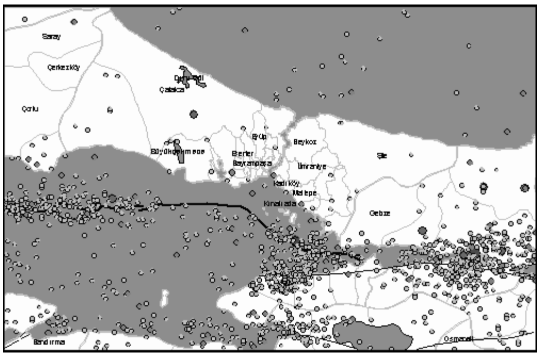

Figure 4. Seismic activity of the region.

The soil profile at the investigated site is overlain by 2.50 m to 4.50 m thick man made deposits. Below that man made layer shore deposits are encountered, composed of sediments that were eroded by waves, transported and deposited by shore currents. Shore deposits consisted of find sand with some gravel, sand with fine shells, and shells. Along the shoreline the thickness of shore deposits reached to 10.50 m. over the bedrock. Average value of SPT blow counts is N = 12 in that layer.

Bedrock belongs to Carboniferous. The shales and graywackes of the Carboniferous are occasionally interbedded by fine particled claystone and conglomeratic levels. The surface of the bedrock has a slope of 10 p.c. towards the sea.

The groundwater level observed at the time of the subsurface investigation was confirmed by observation of water level in the test pits. Water level is dominated by the sea level.

Earthquake risk is the most essential criterion for the design of structures to be built in Istanbul area. Turkish Earthquake Resistant Design Code recommends 0.40g and 0.30g values of spectral acceleration coefficients to be used in the first and second degree risk zones.

Nevertheless, detailed studies of recent earthquakes denoted that the recommended coefficients may be exceeded in the region studied.

Earthquake risk analysis is carried out under the consideration of the existing soil profile and the nearness of the building to the fault-lines in the neighborhood. Magnitudes for any frequently, moderate frequently or rarely occurring earthquakes in the region have been determined. Figure-4 shows the seismic activities in the region.

Recent earthquake events which took place within this region during the time interval of 1901-2001 are examined with respect to their magnitudes, epicentral coordinates , and depths of the hypocenters. After the specification of earthquake sources, the probability distributions of these earthquakes are calculated by recurrence relations for magnitudes and their frequencies of each source. A suitable attenuation relation for Istanbul is selected to determine the variation of magnitude, distance and the acceleration for an expected earthquake. For a structure with an importance factor of I=1, the Code recommends a risk of exceedance of R=10% to be taken. The results of the seismic analysis indicates that such a structure should be designed resisting an acceleration of Y=55 cm/sec^2. The design of such a building with an assumed economic life of 50 years should be realized resisting an earthquake of accelerartion 0.382g.

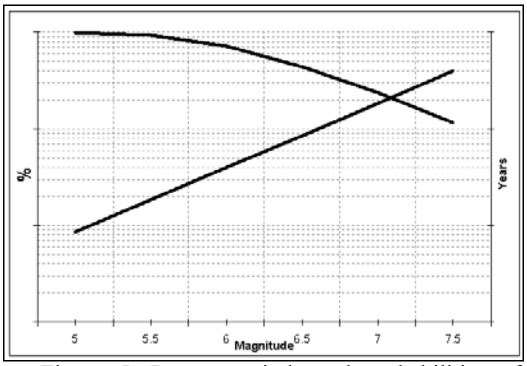

Figure 5. Return periods and probabilities of earthquakes around the site.

Defined probability rates as well fixed seismic magnitudes are shown in Figure-5. Local acceleration spectrums to be used in structural analysis under consideration of the local soil conditions have been obtained as indicated in Figure-6.

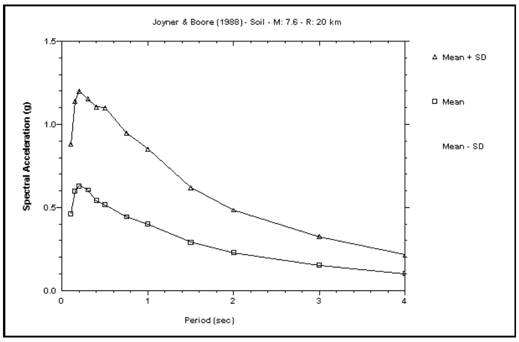

Figure 6. Site design response acc. Spectra.

The strength and adequacy of the existing foundation system as well as the potential of the soil to liquefy under the impact of the above-mentioned strong seismic shocks has been investigated, and thus, the bearing capacity of the soil under ultimate load has been calculated. As our investigations and calculations showed that the soil under and around the historical building is exposed to liquefaction risk, it has been decided to improve soil properties by installing jet-grout columns. Jet-grout columns are also used in underpinning the foundations of the old building (Figure-7) .

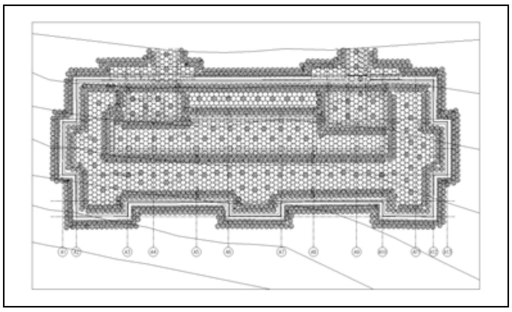

Figure 7. Soil-improvement with jet-grouting under the historical walls and the new structure.

Material tests:

The material samples having been recovered from all those points and places as specified previously have been duly investigated and tested so that any and all the characteristic mechanical strength values and deformation features of all components of the brick-walls could be clearly laid down, and by applying EC-

6 method any results and values obtained from these investigations and tests have been converted into material models being able to be used for the modeling process. The EC-6 method has also been applied for the ascertainment of the necessary characteristic material values to be used for the formation of the wall model by using the macro-modeling technique. The material model used is shown in Figure-8.

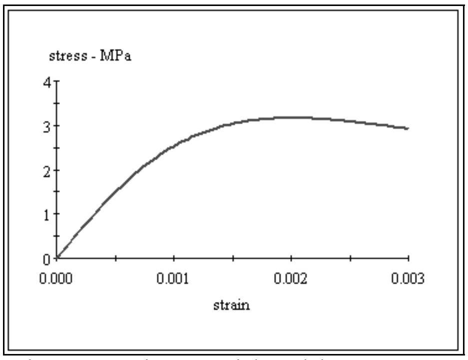

Figure 8. Design material model.

It has been observed that the material values do generally not change within the structure on the whole, but that at two problematic points some material deterioration has been occurred due to lack of water insulation. Therefore, in modeling studies, a separate material model has been taken for these problematic points.

Structural analysis and performance checks:

The plan geometry of the building has been laid down in the light of the existing digital data of the building. Considering the necessity to reflect any eventual weaknesses in the façade geometry, and aiming to simplify the numerical analysis, a detailed 3D-model of the building has been created by using the macro-modeling technique. Figure-9 shows a structural analysis model of the building for the construction stage.

After preparation of the defined material models and calculation of the seismic parameters and soil spring coefficients, the performance of the building under these circumstances has been laid down by (i) checking the limit values defined on basis of displacements (d_{lim}) for the performance levels ND and CVS, and (ii) using the maximum moment value (M_u) method for the performance level CP, and thereafter the relevant capacity checks have been performed.

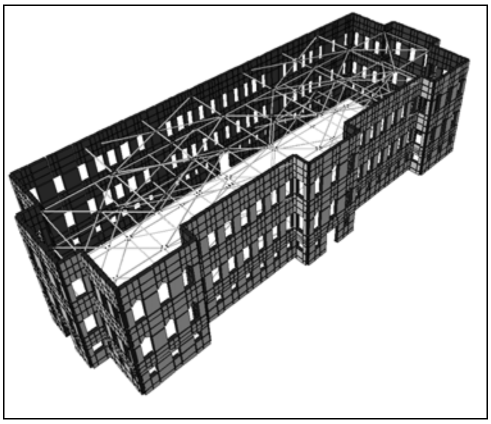
Figure 9. Construction stage structural model.

The limitations taken for the displacement limits (d/h) have been adopted from international publications (literature) and chosen for the performance levels ND and CVS as 0.005 and 0.001 respectively. For the performance level CP, the moment bearing capacity value that had been initially calculated by using the maximum moment value (M_u) method as mentioned above, has been checked and verified by using a much more developed calculation method in order to get an idea about the non-linear deformations and sectional ductility. Figure-10 gives the distribution of the M_u value for the construction stage.

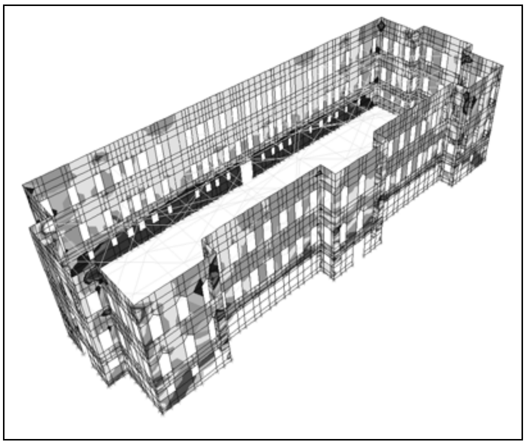
Figure 10. Damage distribution under design loads

By checking the M_u value under various loading cases, any eventual damaging zones have been ascertained and, accordingly, the relevant strengthening has been proposed.

4. CONCLUSIONS

Performance based analysis methodology is a fast and reliable way of maintaining good results under various forcing conditions. Requirements for higher level of engineering, coordination of disciplines and risk management, bring in development and gain to global knowledge on behavior of historical structures.

5. REFERENCES

Sorace, S., Terenzi, G. (2002). Seismic Evaluation and Retrofit of Historical Churches, SEI Volume4-12, 283-288

FEMA-356 (2000) Pre-standard and Commentary for the Seismic Rehabilitation of Buildings

Mola, F., Vitaliani, R. (1997). Analysis, Diagnose and Preservation of Ancient Monuments, Structural Analysis of Historical Construction, Barcelona 1998

Conference Report, Structural Analysis of Historical Constructions II, Barcelona, 1998

Conference Report, Structural Analysis of Historical Constructions I, Barcelona, 1995

Report/UCB/EERC-95/04, Earthquake Hazard Reduction In Historical Buildings Using Seismic Isolation, 1995

EUROCODE-6 Design of masonry structures

http://www.sayisalgrafik.com/deprem/index.html Depremler, Türkiye’nin depremselliği ve haritalar

XTRACT, User manual

SHAKE2000, User manual