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Cost effect of earthquake region and soil type for office buildings in Turkey

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Abstract

In this study, the change in the load-bearing system cost of a reinforced concrete office building has been investigated in relation to the earthquake regions and soil types. Three different office projects each with five stories were investigated. The structural design calculations have been made according to four different soil types and four different earthquake regions. According to each combination, concrete, steel and formwork adopted approximations were calculated to reach the rough cost of each office building. The changes in the cost of projects according to the soil type and earthquake region were examined with multiple regression analysis and analysis of variance. In general, the change in cost has been observed around 22% between first and fourth soil type and 14% between first and fourth earthquake region.

Keywords: Office buildings; Cost analysis; Multiple regression; Earthquake region; Soil type

1. Introduction

First aspect on structural design is to prevent loss of life during earthquakes. For small earthquakes, the building should suffer no or minimal damage, for medium earthquakes the building load-bearing system must not get any damage and for intense earthquakes, the load-bearing system must survive. The literature on various fields of earthquake engineering indicates that the reasons for unexpected damages due to earthquakes can be listed as missing or incomplete soil reports, insufficient building geometry and load-bearing system.

The expected earthquake load to be acting on the building highly depends on soil type, earthquake zone and building types. On the other hand, the overall performance of a building can be achieved by quality control of production. Engineering provides the optimum level of durability, aesthetics and economy.

Previous studies by Muratoglu and Ozkan [1,2] showed some basic relations in cost differences for different earthquake zones and soil types. This study goes one step further and correlates the cost effect on these two variables by introducing a multiple regression analysis and two-way ANOVA which would quantitatively analyze the situation. The two-way ANOVA is a procedure that examines the effects of two independent variables concurrently. It also, and often much more importantly, allows the user to determine whether the two independent variables interact with respect to their effect on the dependent variable.

It is a known fact that the earthquake load would affect the building load-bearing system dimensions. The soil type would also affect the expected earthquake load and affect the system dimensions indirectly. The effect of soil type with respect to distance from epicenter can be seen in Fig. 1. The figure also shows the variation in the velocity and the acceleration values for the same earthquake load.

In this study, for three different office projects, the effect of change in earthquake zones and soil types on cost of building load-bearing system was analyzed statistically. The cost of systems was defined by concrete, steel and

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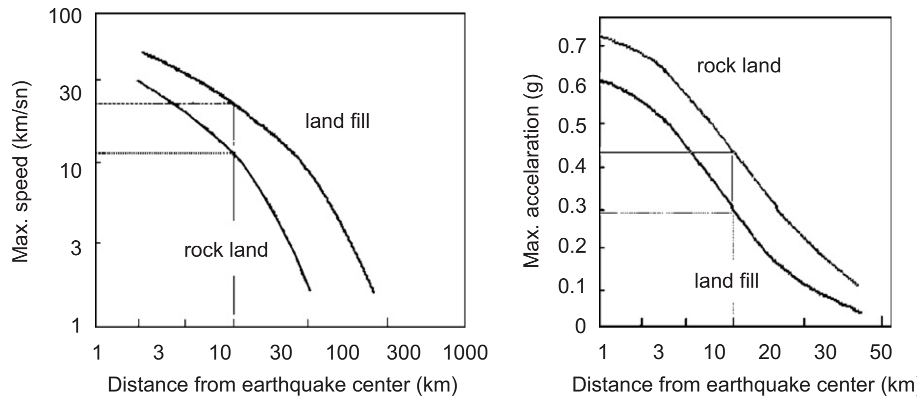

Fig. 1. Effect of distance and soil type.

formwork unit prices. The structural design and unit costs were implemented by taking into account the Turkish practice and codes.

2. Research methodology

The structural analysis for three different project types was analyzed by the help of commercial software. This software takes into account the necessary codes and regulations required by the Government.

All projects have five stories and different dimensions with respect to structural members and room sizes. The plans for the projects can be seen in Fig. 2. The earthquake and soil constants required for structural design are listed in Table 1. In this table, A_0 is the ground acceleration coefficient, 'I' is the building importance factor, ASP is the allowable soil pressure, and T_a and T_b are the spectrum characteristic periods. Structural, dimensional and distributive elements are all responsible for great differences in cost for each zone and for each soil type.

After the structural design is carried out by the software, the quantity adopted approximation for concrete, steel and forms was performed. The unit prices for each cost item are then obtained from Turkish Ministry of Housing and Urban Development. The multiple regression analysis and two-way ANOVA were then carried out for random variables, earthquake zone and soil type.

3. Research outcomes

3.1. Project outcomes

After the quantity adopted approximation was calculated, the unit prices published yearly by the Turkish Ministry of Housing and Urban Development were implemented for year 2005 to calculate the total cost of the building load-bearing system. The total costs can be seen in Table 2.

It can be seen from the tables that the average cost difference between first and fourth earthquake zone is around 14%. The cost difference between second and third earthquake zones is not more than 6%. When cost differences for soil types are investigated the percentage values are 5%, 18% and 22% for first and second, first and third, and first and fourth soil types, respectively. One should note that the percentages quoted are restricted to single cases. For example '14%' is average value for only for soil type ST1, since it lowers to 8% for soil type ST4, independent of the project type on average. Furthermore, '5%, 18% and 22%' are valid only for Zone-1 independently of the project type. However, they can change up to 8%, 24% and 30% in Zone 4 on average.

It is seen that there are significant differences in terms of cost for different earthquake zones and soil types. In Turkey, typical projects designed for first earthquake region are usually utilized in public sector, whatever the real zone is. According to this study, this will cause a 14% additional cost in the load-bearing system, which would be a very huge number concerning the national economy. The same problem would also happen in soil types. The cost effect of these two factors can be seen in Fig. 3.

3.2. Multiple regression analysis

The relation between building costs and earthquake zone and soil types were statistically analyzed by commercial software. The dependent variable, which was the building cost, was regressed on earthquake zone and soil type on a multiple regression analysis. In regression analysis, the value of a dependent response variable is predicted based on the value of independent variables. The model is

$$Y = b_0 + b_1X_1 + b_2X_2 + \cdots + b_kX_k + e, \tag{1}$$

where Y is the independent variable (building cost), b_0, b_1 and b_k are the regression constants, X_1, X_2 and X_k (earthquake zones and soil types) are the dependent variables and e is the error.

Multiple regression can establish that a set of dependent variables explains a proportion of the variance in an independent variable at a significant level (through a significance test of R^2), and can establish the relative predictive importance of the dependent variables. In our