EFFECT OF ASEISMIC DESIGN ON BUILDING COST IN EGYPT

Yasser EL-HAKEM[1] And Mohamed SOBAIH[2]

SUMMARY

In developing countries it is very common that engineers and owners believe that considering earthquake forces in the design of residential buildings will lead to excessive increase in cost . This leads to ignoring these forces . This paper deals with estimating the effect of aseismic design on cost of residential buildings in various areas in Egypt . This is achieved by evaluating seismic risk of buildings with different economic levels of finishing . First a review of similar previous works in other countries is presented . A proposed method is presented for calculating the additional cost of aseismic design for various areas in Egypt . It has been proved that the expected cost of damage due to expected earthquakes that may occur during the life-time of residential buildings are higher than the additional cost of aseismic design. This means that the earthquake resistant design of buildings in Egypt is profitable

REVIEW OF PREVIOUS STUDIES

Some of previous studies in different countries on the cost of aseismic design are summarized here-in-after . In 1978, a study was done in Italy [Petrini,1978] and examined in particular the influence of the structural type of building. To do this, two buildings were compared, one is a residential block in reinforced concrete taken to be the standard building , the other, made of steel, for housing the plant of a heavy industry. The percentage of the extra cost of aseismic design is about 10 % for the residential building and about 7 % for the industrial building in the worst case .

In Turkey, a study was done [Altan and Gulay,1990] according to the Turkish code on a residential building of three-stories in two regions of different seismicity. The increase in the total cost for the building in region I is only 1.9 % higher than the building in region II .

[El-Haddad,1992] estimated the additional cost of aseismic design for different types of buildings (residential, offices, industrial and commercial buildings) .The additional cost of aseismic design is about 0.7 % of the total cost of the project for normal residential buildings (not more than five-stories) and the average of the additional cost for the other types of buildings which were included in the study is only 1.6 % of the total cost of the project.

For Yugoslavia a study was done [Fajfar et al.,1978] to estimate the additional cost of earthquake-resistant shear wall structures. A plan-layout very popular in Yugoslavia is considered. The number of stories is varied and structures with and without coupling beams are studied. If Yugoslav code coefficients and Yugoslav prices are used, the cost increase is lower than 1% of the building total cost in the worst case. Even in the case of relatively high seismic activity .

Another study was done in USA [Sassi et al.,1997] to estimate the cost of seismic retrofit for two "historic" buildings in Southern California that were subjected to the 1994, Northridge Earthquake. The cost of repair and

[1] *Structural Engineer, Misr Consulting Engineers, Giza, Egypt Email: elhakem@yahoo.com*
[2] *Email: msobaih@hotmail.com*

retrofit is considered very high compared with the cost of replacement. The cost of repair is about 80 % of the cost of the replacement for the first building and it is about 44 % of the cost of the replacement for the second building .

SEISMIC ACTIVITY IN EGYPT

Since the beginning of this century about 500 earthquakes have been recorded within the territory of Egypt. During this century Cairo had not been seriously affected by an earthquake such as the one occurred on October 12, 1992 which caused the destruction to thousands of buildings and thousands of casualties and injuries . Seismic hazard maps have been recently proposed [Sobaih,1992a] . These maps provide indispensable tool to study the problem under consideration .

PROPOSED METHOD FOR CALCULATION OF THE COST OF ASEISMIC DESIGN

In order to minimize the collapse of buildings and the loss of lives during earthquakes, the earthquake load effects must be considered as well as vertical loads and the minimum requirements for the structural members to resist earthquakes must be taken into consideration. These considerations lead to an increase in the cost of buildings. A proposed method for calculation of the cost of aseismic design in Egypt compared with the cost of damage due to expected earthquakes is presented in this study .

Calculation of Loads

Dead loads, live loads and earthquake loads must be calculated and taken into consideration according to the following rules :

Dead and live loads

In the computation of dead loads and live loads , the rules given in the Egyptian Code of Practice for the Design and Construction of Reinforced Concrete Structures [RCHBP,1995] and in the Egyptian Code of Practice for Calculation of Loads and Forces in the Constructions and Buildings [RCHBP,1993] are followed .

Earthquake loads

The earthquake loads are calculated following the rules which given in the Regulations for Earthquake Resistant Design of Buildings in Egypt [Sobaih,1988] .

For buildings symmetrical about at least one axis and for buildings with seismic resisting elements located along two perpendicular directions, the specified forces may be assumed to act separately along each of these two horizontal directions .

Design load combinations

The ultimate design loads for the limit states design method, shall not be less than the load combinations given in the Egyptian Code of Practice for the Design and Construction of Reinforced Concrete Structures [RCHBP,1995] .

Calculation of Internal Forces

The internal forces are calculated by the using computer programs for structural analysis such as SAP-90 program .

Design of the Structural Elements

The reinforced concrete sections are designed according to the Egyptian Code of Practice for Design and Construction of Reinforced Concrete Structures using the limit states design method [RCHBP,1995] .

Cost Estimation

The additional cost of aseismic design is estimated by comparing the cost of the quantities of steel and concrete given in [El-Bakary,1997] in the reinforced concrete structural elements , due to aseismic design (case of dead

loads, live loads and earthquake loads) to the cost of the quantities of steel and concrete due to non-seismic design (case of dead loads, live loads and wind loads) . To calculate the additional cost of aseismic design as a percentage of the total cost of the building for different economic levels of housing (low-cost, moderate and luxury housing) the percentage of the cost of reinforced concrete skeleton to the total cost of the building should be calculated for each economic level of housing .

Seismic Risk Evaluation for Egypt

To evaluate the seismic risk for Egypt a method for seismic risk evaluation suitable for buildings in Egypt proposed by [Sobaih,1992b] is used. The distinctive feature of the method consists in the possibility of a practically continuous description of the seismic quality of the buildings. By applying this method, the cost of damage due to an expected earthquake occurring during the expected life-time of the building can be evaluated.

Cost-Benefit Analysis of Aseismic Design

It is very important to know if it is profitable , from the purely economic point of view , to design buildings to resist earthquakes or not . This can be evaluated by the estimation of the gain (the money saved) of the earthquake-resistant design . The money saved due to aseismic design is calculated by subtracting the additional cost of aseismic design from the expected cost of damage due to an expected earthquake occurring during the life-time of the building . If the cost of damage is greater than the additional cost of aseismic design ,then the earthquake resistant design will be economic and , vice-versa , if the additional cost of aseismic design is greater than the cost of damage , then the earthquake-resistant design will be uneconomic from the purely economic point of view .

Computer Implementation

A computer program was developed for the purpose of the design of reinforced concrete sections for beams , columns and footings. The reinforced concrete sections are designed according to the Egyptian Code of Practice for Design and Construction of Reinforced Concrete Structures ,1995 using the limit states design method. Another program was developed to perform some calculations to get the quantities of the steel and concrete in the reinforced concrete structural elements .

COST OF ASEISMIC DESIGN IN EGYPT

To estimate the additional cost of aseismic design of reinforced concrete buildings in various areas in Egypt , the proposed method described above was applied on three examples of reinforced concrete buildings which have the same architectural plans (Fig.1) but with different number of stories (5, 8 and 10 stories) and located in different regions in Egypt , i.e., with different seismicity .

A cost-benefit analysis was done for all examples following the methodology for risk evaluation which was applied to know if it is profitable, from the purely economical point of view, to design the buildings in Egypt to resist earthquakes or not .

ANALYSIS OF RESULTS

Additional Cost of Aseismic Design

The percentage of the additional cost of aseismic design was calculated for each example for the different economic levels of housing. The percentage of the additional cost of aseismic design for low-cost, moderate-cost and luxury housing are shown in Fig. 2, 3 and 4, respectively .

Cost of Damage

To estimate the percentage of the cost of damage calculated for each example for the different economic levels of housing and to estimate the benefit of aseismic design (the money saved due to aseismic design) due to an expected earthquake occurring during the life-time of the building , the methodology for the risk evaluation was followed . The percentage of the money saved due to aseismic design for low-cost, moderate-cost and luxury housing are shown in Fig. 5, 6 and 7, respectively .

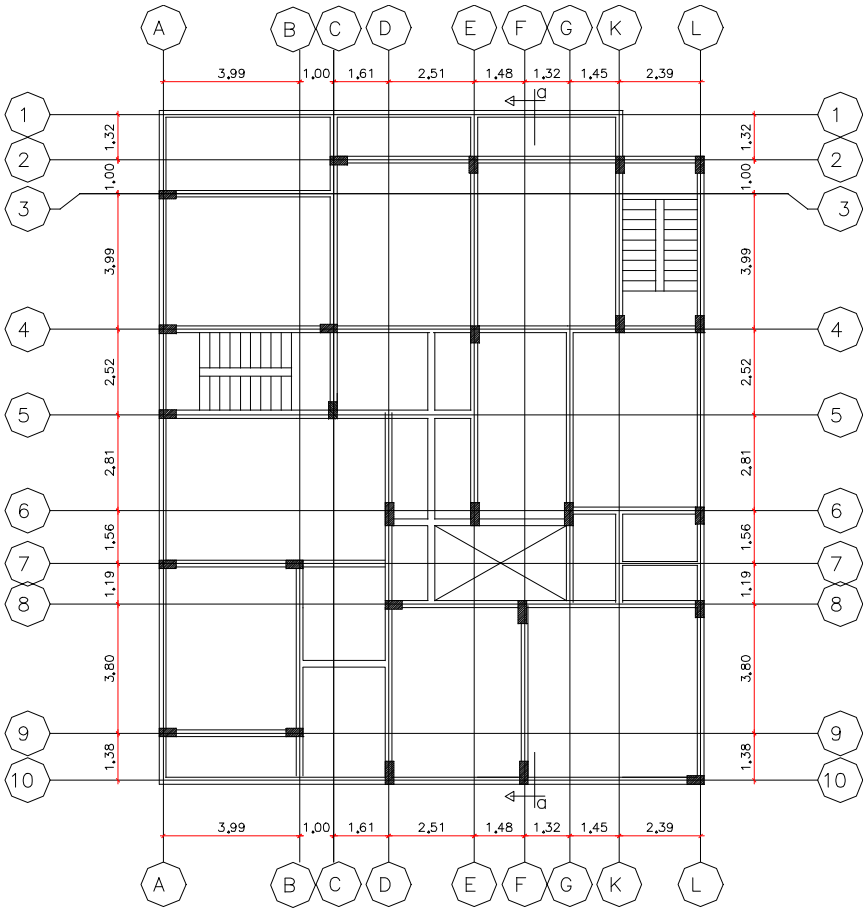

Figure 1: Plan of the example considered

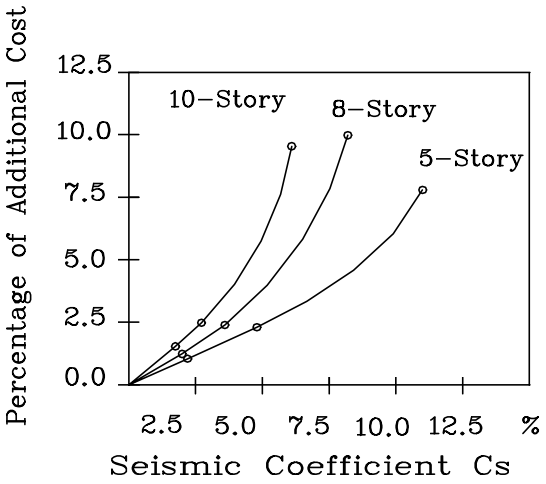

Figure 2: Additional cost for low-cost housing

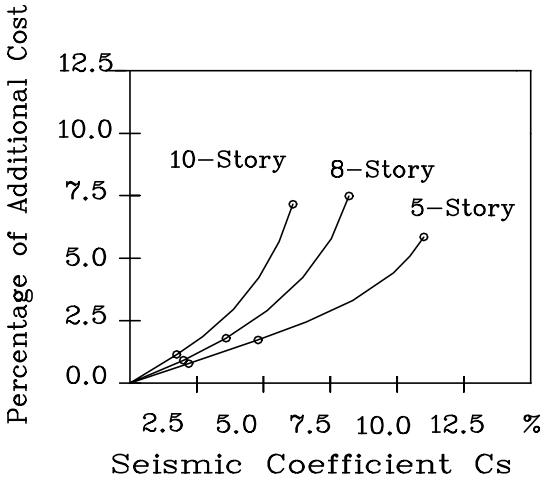

Figure 3: Additional cost for moderate-cost housing

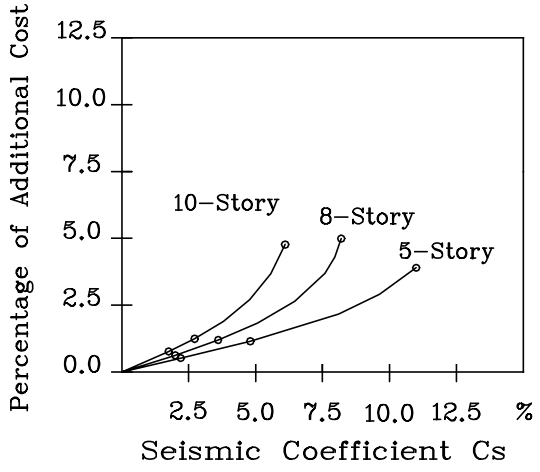

Figure 4: Additional cost for luxury housing

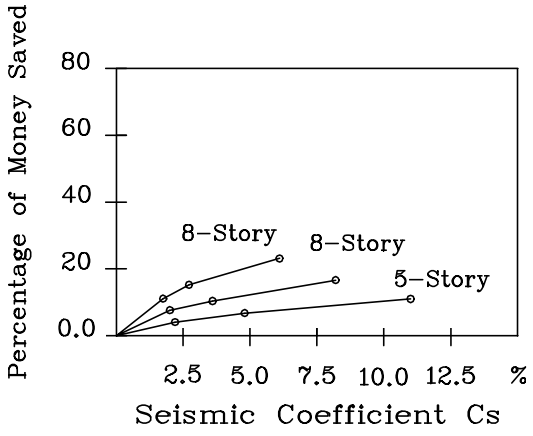

Figure 5: Money saved for low-cost housing

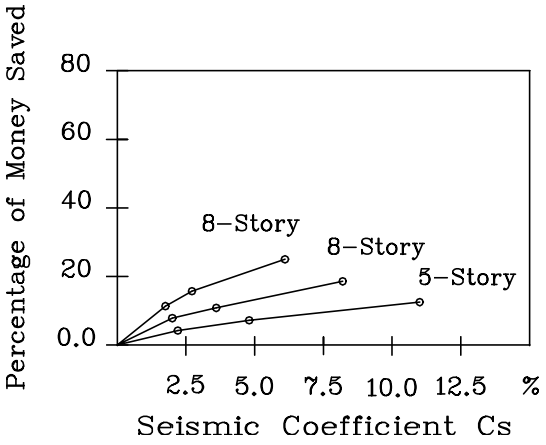

Figure 6: Money saved for moderate-cost housing

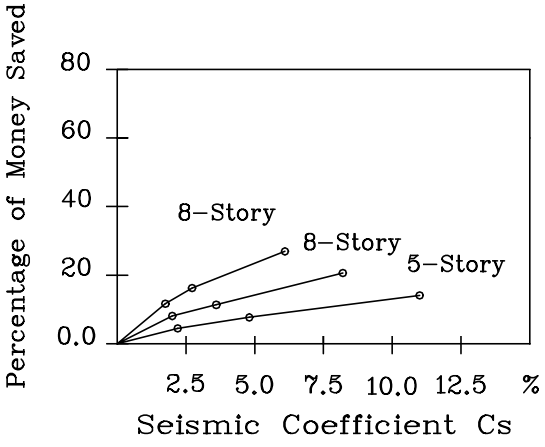

Figure 7: Money saved for luxury housing

CONCLUSIONS

1. The percentage of the additional cost of aseismic design in Egypt is lower than 10 % of the total cost of the buildings in the worst case .

2. The percentage of the additional cost of aseismic design increases with the increase in the number of stories of the building and the earthquake intensity of the region .

3. The percentage of the additional cost of aseismic design to the total cost of the building increases when the economical level of the building decreases . That is the additional cost of aseismic design for luxury housing is much lower than moderate-cost and low-cost housing .

4. The cost of damage due to an expected earthquakes occurring during the life-time of the buildings is much higher than the additional cost of aseismic design . This means that the earthquake resistant design of buildings in Egypt is beneficial ,from the purely economic point of view, neglecting the losses in life .

5. The benefits of aseismic design increases with the increase in the number of stories of the building, the earthquake intensity of the region and the economic level of the building .

REFERENCES

Altan, M.. and Gulay, G. (1990), " A Comparative study for the cost of masonry and R/C structures in earthquake zones ", *Proc. ECEE* , 9, pp 421-430 .

El-Bakary, A .A. (1997), A*rchitectural Structure*, Anglo Egyptian Bookshop , Cairo, Egypt, (in Arabic) .

El-Hadad, M.(1992), "Basic requirements of earthquake resistant reinforced concrete buildings", *The Engineer Magazine*, KSA ,3, pp 54-59.

Fajfar, P., Fischinger, M. and Rojac, R. (1978), "The additional cost of earthquake resistant shear wall structures ", *Proc. 6 th ECEE* , Dubrovink, Yugoslavia, pp 235-242.

Petrini, V. (1978), " Comparative seismic risk analysis of different buildings in the same site", *Proc. 6 th ECEE*, Dubrovink, Yugoslavia, pp 179-185.

Research Center for Housing, Building and Physical Planning (RCHBP) (1995), *Egyptian Code of Practice for the Design and Construction of Reinforced Concrete Structures* , Cairo , Egypt .

Research Center for Housing, Building and Physical Planning (RCHBP) (1993), *Egyptian Code of Practice for Calculation of Loads and Forces in the Construction and Buildings* , Cairo , Egypt .

Sassi, H., Youssef, N. and Ranous, R. (1997), " Seismic retrofit: the California experience ", *Proc. Second Egyptian Conference on Earthquake Engineering*, Aswan, Egypt, pp 411-429.

Sobaih, M. et al. (1992a), "Development of seismic hazard maps for Egypt", *Int. Journal of Earthquake Engineering* , 2 , 1 , pp 33-58.

Sobaih, M. et al. (1992b), "Seismic risk evaluation for urban areas in Egypt", *Int. Journal of Earthquake Engineering* , 2 , 2 , pp 91-119.

Sobaih, M. et al. (Editor) (1988), Regulations for Earthquake-Resistant Design of Buildings in Egypt, Cairo, Egypt .