THE EFFECT OF CONCRETE QUALITY ON EARTHQUAKE DESIGN : ECONOMICAL ASPECTS

by

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ABSTRACT

THE EFFECT OF CONCRETE QUALITY ON EARTHQUAKE DESIGN: ECONOMICAL ASPECTS

There is a great advance in maximum concrete compressive strengths reached throughout years. So, today we have a large variety of concrete classes that can be produced by the concrete industry. But, the use of higher strength concrete would lower the cost of the building is a question. There are investigations done on the optimization of columns. But these optimizations have the lack of artificial limitations set by the codes.

A numerical investigation is done on the use of different concrete classes according to Turkish Standards and Earthquake Codes. The investigation combinations includes three different story heights, four different concrete classes and First and Second Earthquake Regions. The costs of combinations are analyzed and compared. A market design computer program is used and its results are compared with a structural modeling computer program.

ÖZET

BETON KALİTESİNİN EKONOMİK YÖNDEN DEPREME GÖRE DİZAYNDA ETKİSİ

Geçen yıllar boyunca ulaşılan maksimum basınç dayanımlarında oldukça büyük gelişmeler yaşandı. Böylece bugün endüstri tarafından üretilebilen geniş bir yelpazede beton sınıfları bulunmaktadır. Fakat yüksek basınç dayanımlarının yapıların maliyetlerini düşüreceği bir soru işaretidir. Kolon optimizasyonu üzerine yapılmış araştırmalar vardır fakat bunlar yönetmelikler tarafından konulan yapay sınırlamaları içermez.

Türk standardları ve deprem yönetmeliğine göre numerik bir araştırma yapılmıştır. Bu araştırma kombinasyonu üç farklı kat sayısı , dört farklı beton sınıfı ve birinci ve ikinci derece deprem bölgelerini içermektedir. Kombinasyonlar hesaplanıp maliyetleri karşılaştırılmıştır. Projelerde bir bilgisayar dizayn programı kullanıldı ve sonuçları yapı modelleme programlarıyla karşılaştırılmıştır.

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LIST OF SYMBOLS/ABBREVATIONS

A	Spectral acceleration coefficient
A_O	Effective ground acceleration coefficient
A_c	Area of columns and shear wall edge parts
A_{ch}	Area of shear walls
E	Earthquake loads
EI	Buckling rigidity
f_{cd}	Design compreesion strength of concrete
f_{ctd}	Design tension strength of concrete
f_{yd}	Yield strength of reinforcement
f_{ck}	Characteristic strength
F_i	Forces acting on the story
g_i	Dead load at the i^{th} segment
G	Dead loads
H	Story Height
	Lateral soil loads
h_i	i^{th} story height from ground
I	Importance factor
l_k	Length of effective column length
l_{sn}	Clear span in of short side of slab
m	The ratio of long side to short side
m_i	story mass
n	Live load factor
M_{ra}	Moment capacity of columns down part
$M_{r\ddot{u}}$	Moment capacity of columns up part
M_{ri} and M_{rj}	Ultimate moment strength of beam in neagatif or positive direction
M_x	Moments in x direction
N_d	Designed axial force
N_{dmax}	Maksimum axial force from combination loads
R	Ductility Factor
S	Spectral coefficient

q_i	Live Load at the i^{th} segment
Q	Live loads
T	Loads from temperature changes
T_1	First natural period
T_a, T_b	Characteristic spectrum periods
T_x	Periods in X direction
T_y	Periods in Y direction
T_e	Periods around its mass center
u_i	displacements under F_i forces
V_t	Base Shear
Vr	Shear capacity of column , beam or shear wall
w_i	Story weight
W	Wind loads
	Total Weight
W_g	Total dead load
W_q	Total live load
α_s	the ratio of continuous sides to total sides
ρ_{sh}	Reinforcement ratio
ΔF_n	The equivalent earthquake load load on the N^{th} top floor
Δ_{imax}	Drift of i^{th} floor
EE	Earthquake loads with eccentricity
X0	No risk corrosion attack
XC1	Concrete carbonation risk for dry or permanently wet
XC2	Concrete carbonation risk for humidity
XC3	Concrete carbonation risk for always wet
XC4	Concrete carbonation risk for cycling wet and dry

1. INTRODUCTION

The rise of concrete quality is an important part of contemporary building technology. The progresses in quality control schemes in concrete and new mix designs have improved concrete quality. Also the use of chemical and mineral admixture makes high quality concrete production easier. So without any extra effort and cost concrete quality can be enhanced.

The use of high quality concrete is increasing in relation with the rise in the use of ready mixed concrete over the last 20 years. Especially after 1999 Marmara Earthquake the concrete classes used are higher. But small contractor groups, sub contractors and foremen have the tendency that high quality would rise the cost of the building. Small project groups working with these groups have the same tendency or at least cannot convince their customers to use high quality concrete.

The thought that using high quality concrete will rise the cost prevent the use of high quality concrete. In the scope of this project , project groups and contractors will be tried to be convinced that the use of high quality concrete does not increase the cost of the buildings.

The use of low quality concrete also affects the service life of the concrete because of low durability. Also large column sections decrease the useable area of the building.

2. LITERATURE REVIEW

2.1. Introduction

In the research titled "The Effect Of Concrete Quality On Earthquake Design: Economical Aspects" "concrete quality" is taken as "compressive strength. So, only one aspect of concrete quality, which is strength, is taken. With the rise of compressive strength other aspects of concrete quality also rise. The only quantative property of concrete quality is compressive strength. Compressive strength classes in TS 11222 – February 2001 [1] are C14-C16-C18-C20-C25-C30-C35-C40-C50-C60-C70-C80-C90-C100. This research will take concrete compressive strengths as concrete quality.

There are various type of structures. The structure can be beam and column frame structure or only shear walls or in combination of frame and shear wall types. The choice is done according to the architectural type of the building constructed. In Turkey most of the buildings constructed are shear walls and frames working together. The building types given in Turkish Earthquake Code [2] are:

- Earthquake load carried by frame,
- Earthquake load carried by shear walls with coupling beams,
- Earthquake load carried by solid shear walls,
- Earthquake load carried by frames and shear walls with/without coupling beams.

2.2. Factors Considered in The Research

2.2.1. Concrete

Concrete is a mixture of inert aggregates , Portland cement and water forms the paste in classical terms. Admixtures and additives are also used in the modern concrete production. Cement , aggregates , admixtures and additives are used according to the standards in order to have desired strength and durability [3].

There is a great importance of water /cement ratio in both establishing the required strength and durability [3].

2.2.1.1. Concrete Compressive Strength. Concrete can be made having compression strength up to about 200 N/mm^2. The rise in compressive strength over years can be seen in Figure 2.1. , the compressive strength can even be more depending mainly on the relative proportions of water and cement , that is , the water/cement ratio, and the quality of the aggregates [4].

The compressive strength of concrete is influenced by a number of factors in addition to water/cement ratio and good compaction.

- Type of cement and its quality: Both rate of strength gain and the ultimate strength may be affected.
- Type , grading and surface texture of aggregate: There is a considerable evidence to suggest that some aggregates produce concrete of greater compressive and tensile strengths than others but due to the wide range between individual rock types generalization can be misleading.
- Efficiency in curing: A loss in strength up to about 40 per cent may result from premature drying out. Curing is therefore of considerable importance both in the field and in the experimental research.
- Temperature: In general , the initial rate of hardening of concrete is increased by an increase in temperature but may lead to lower ultimate strength. At room temperatures the crushing strength may remain low for some time but may lead to a higher ultimate strength.
- Age: When moisture is available concrete will increase in strength with age. The rate being greatest initially and progressively decreasing over time.
- Admixtures: used as an agent to reduce water cement ratio to increase strength or to improve properties of concrete [3].

2.2.1.2. Concrete Strength Classes. Concrete is classified according to compressive strength in both TS 11222 February 2001 [1] Concrete Standard and TS 500

February2000[5]. The compressive strength of concrete is defined as the strength of 28 days old specimen tested under monotonic uniaxial compression [5].

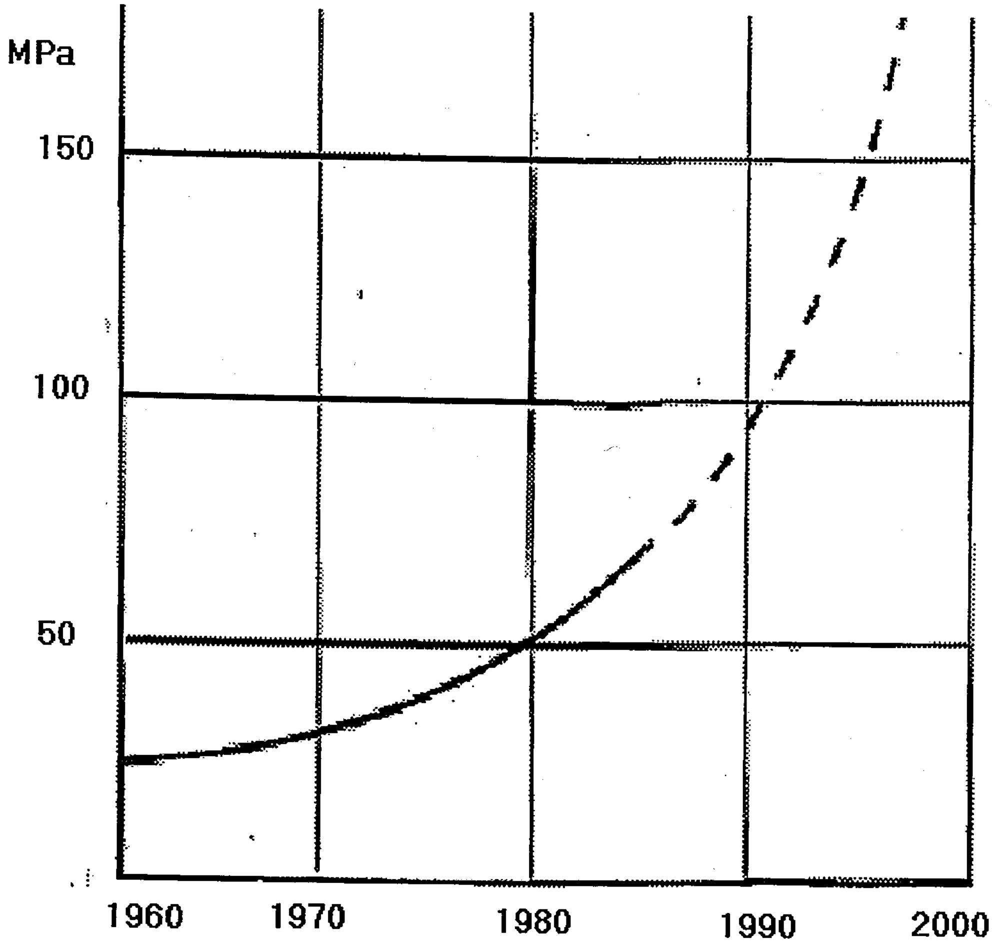

Figure 2.1. Concrete class developments through years [4]

The concrete strength classes are as follows for TS 11222 February 2001 [1] :C14 – C16 – C18 – C20 – C25 – C30 – C35 – C40 – C45 – C50 – C55 – C60 – C70 – C80 – C90 – C100.

However in TS 500 February 2000 [5]: C16 – C18 – C20 – C25 – C30 – C35 – C40 – C45 – C50.

Per cent of concrete classes used in the construction industry in Turkey over the years are given in Table 2.1[6]. The concrete classes used are increasing over the years. The use of C14 has decreased to 11.5 per cent from 37.5 per cent in year 2000. This concrete class is mostly used for ground concrete today. The main concrete class used has increased to C20. There is a great role of Marmara Earthquake (1999) and Turkish Earthquake Code published in 1998 on the increased concrete class used in the construction industry.

Table 2.1. Concrete classes used in Turkey [6]

Years	C14 Per cent (%)	C18 Per cent (%)	C20 Per cent (%)	C25 Per cent (%)	C25+ Per cent (%)
1996	37.5	52.3	6.4	3.4	0.6
1997	27	51.1	12	7.6	2.3
1998	24.4	45.4	18	8.1	4.1
1999	22.7	35.9	27.6	10.3	3.3
2000	11.5	25.1	41.3	13.2	4.9

The minimum concrete classes used in ERMCO countries is given in Table 2.2. The table shows the minimum concrete class used in construction industry in these countries. Turkey uses these lowest concrete class among the countries.

In Figure 2.2 the concrete classes used in some of the tallest buildings in United States is shown. The concrete classes are all above C50 which is allowed in TS500. The use of higher concrete classes in tall buildings allows higher usable areas so higher classes are preferred. In İş Bankası Buildings in İstanbul C35 concrete is used. The height of the building is 176 m.

2.2.1.3. Reinforced Concrete. The weakness in tension of the plain concrete makes it economical only for footings , concrete slabs laid on the ground and for massive structures.

With the use of steel bars tension capacity of the concrete is improved remarkably. The steel yield strength is about 15 times of an ordinary concrete compressive strength and 100 times its tensile strength [7].

Table 2.2. Minimum concrete classes used in buildings in several ERMCO countries [4]

Countries	C16/20	C20/25	C25/30	C30/35	C35/45
Finland			✓		
France			✓		
Germany		✓			
Israel				✓	
Italy		✓			
Holland		✓			
Portugal		✓			
Russia		✓			
Sweden			✓		
Turkey	✓				
USA					✓

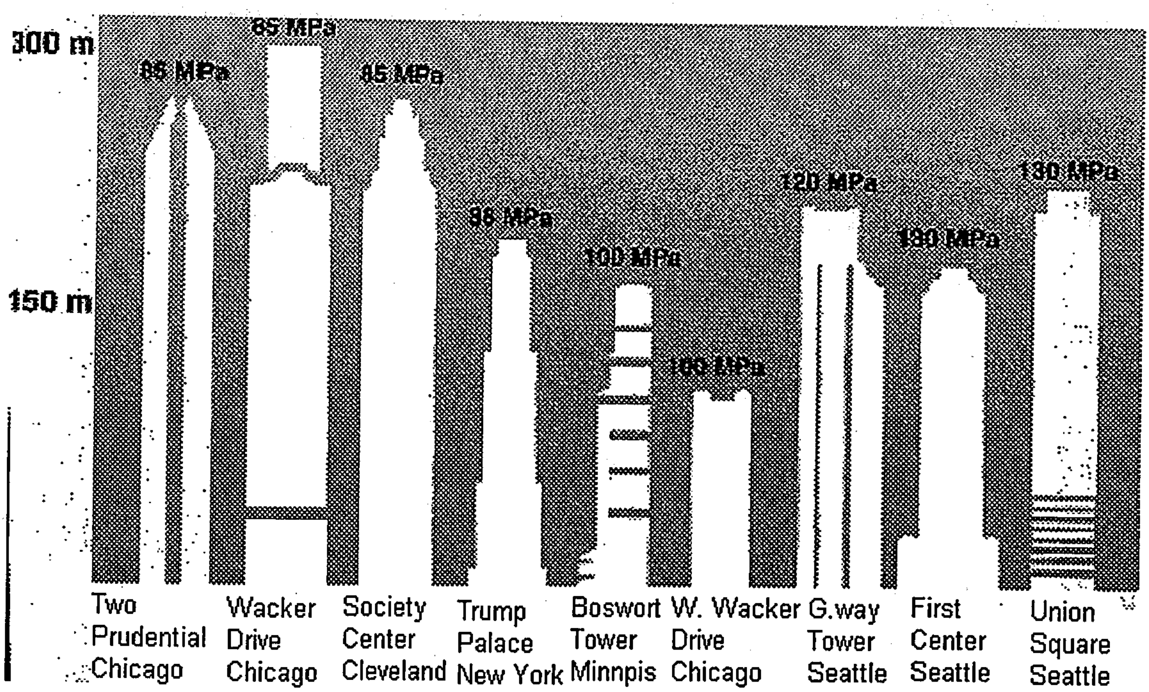

Figure 2.2. Concrete classes used in several buildings [4]

For the most effective reinforcing action, it is essential that concrete and steel work together. Strong bond between the two materials ensure no relative movements. This bond is provided by chemical adhesion and surface roughness of the steel [7].

Additional features that make concrete and steel work together are:

- The thermal expansion coefficients being close.
- The concrete surrounding the steel provides excellent corrosion protection hence maintains the bond.
- The steel is protected from fire by concrete 's low thermal conductivity [7].

2.2.1.4. Other Properties of Concrete. With the increasing compressive strength the changing properties of concrete are:

- Modulus of elasticity of concrete: As the strength of concrete increases the stress strain curve gets linear up increasing the modulus of elasticity [5].
- Ductility: Concrete without reinforcement has less ductility with increasing ultimate strength [5].
- Durability: It is one of the most apparent property of concrete which is enhanced by increasing compressive strength. Higher concrete classes solve most of the problems like freezing and thawing , alkali aggregate reaction , corrosion , leaching , abrasion and resistance to chemical attack [1].

The durability requirements in TS 11222 [1] have limits concerning compressive strength against durability. Which are given in Appendix A.

2.2.2. Structural Systems

Special care is to be taken while selecting an economical and structurally efficient system for buildings. With increasing height, the structural behavior of the building will change. Lateral sway under earthquake loading and consideration of stiffness will govern the design of structural system [8].

Lateral load resisting units are:

- Frames.
- Shear walls.

From these units the structural systems derived are:

- Moment resisting frames.
- Shear wall systems.
- Shear wall- frame systems.
- Framed tube systems.
- Multicell tube systems.

Framed tube and multicell tube systems are used especially in high rise buildings. The general structure type used in regular construction of five , ten , fifteen stories is shear wall with frame systems [8].

As given in Figure 2.3 with moment resisting frames only, fifteen story building height can be reached , on the other hand with the introduction of shear walls the building height increases to 45 stories. The inclusion of shear walls seems to be an economical way to increase over all rigidity of concrete buildings. Since the rigidity of shear walls is higher so an increase in the dimension of shear wall would increase rigidity rapidly [8].

2.3. Turkish Building Code

The designs are done according to the rules set in TS 500 [5]. The structural elements' dimensions, load combinations, calculations, and reinforcement is designed according to this standard.

Load combinations in Turkish Building Code[5] are as follows:

- For only vertical loads,

$$F_d=1.4G+1.6Q \qquad (2.1)$$

$$F_d=1.0G+1.2Q+1.2T \qquad (2.2)$$

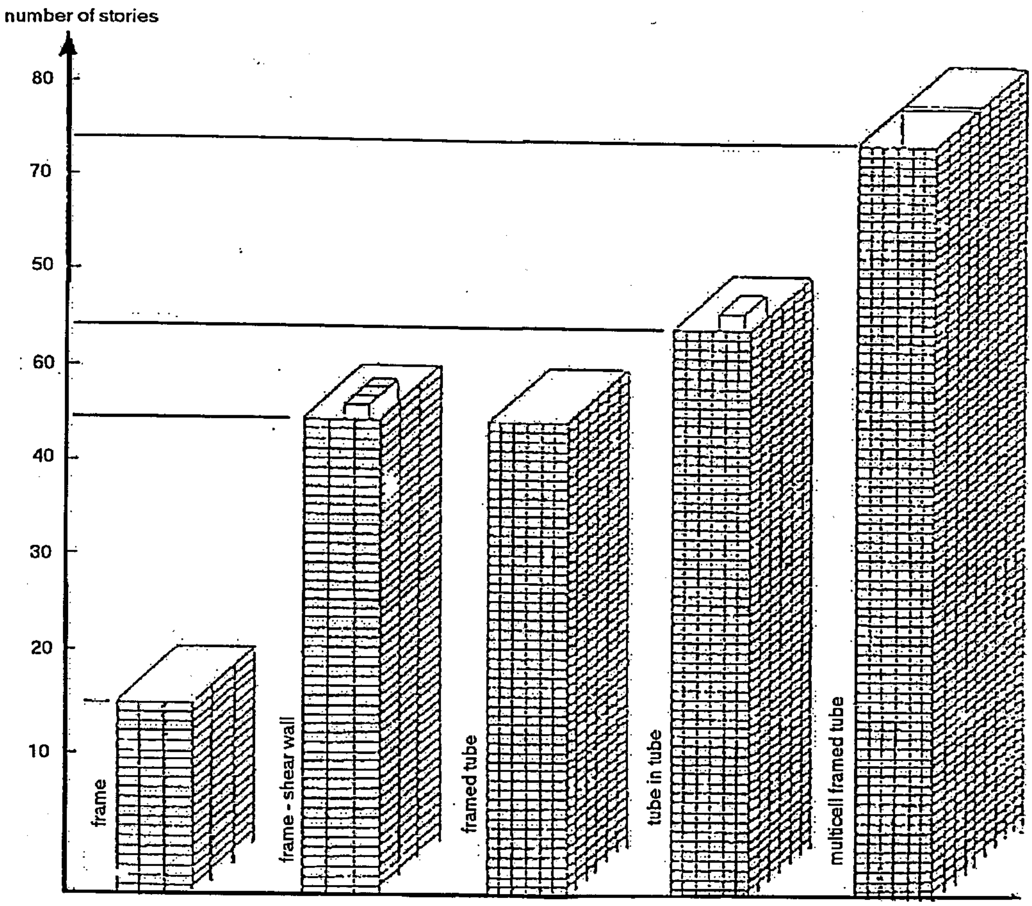

Figure 2.3. Structural systems and story numbers reached [8]

- For wind loads,

$$F_d=1.0G+1.3Q+1.3W \quad (2.3)$$

$$F_d=0.9G+1.3W \quad (2.4)$$

- For earthquake loads,

$$F_d=1.0G+1.0Q+1.0E \quad (2.5)$$

$$F_d=0.9G+1.0E \quad (2.6)$$

- In case of lateral soil pressure,

$$F_d=1.4G+1.6Q+1.6H \tag{2.7}$$

$$F_d=0.9G+1.6H \tag{2.8}$$

G=Dead loads
Q=Live loads
T=Loads from temperature changes
W=Wind loads
E=Earthquake loads
H=Lateral soil loads

For columns, dimensional limits in TS500 [5] are:

- Width cannot be less than 250 mm. When column is L or T shaped the width cannot be less than 200 mm and when box shaped the thickness cannot be les than 120 mm.
- For circular columns the diameter cannot be less than 300 mm
- Buckling of the columns is calculated with Euler equation.

$$N_k = \frac{\pi^2 (EI)}{l_k^2} \tag{2.9}$$

l_k=length of effective column length
EI=buckling rigidity

The rigidity of the columns should be increased when the columns buckle by increasing their sizes.

- The axial force should be:

$$N_d \leq 0.9 f_{cd} A_c \tag{2.10}$$

N_d=Designed axial force

A_c=Area of columns

f_{cd}=Compressive strength

For beam dimensional limits in TS500 [5] are:

- Beam depth cannot be less than 300 mm or 3 times the slab depth.
- Beam width cannot be less than 200 mm.
- Beam width cannot be more than beam depth plus column width.

The minimum dimensions of slabs in deflection control are given in Table 2.3. The slabs are generally continuous for a building and the depth found from Table 2.3 is 1/30 of clear span. For slab depth the limits in TS500 [5] are:

$$h \geq \frac{l_{sn}}{15 + \frac{20}{m}}\left(1 - \frac{\alpha_s}{4}\right) \quad \text{and} \quad h \geq 80mm \tag{2.11}$$

m=the ratio of long side to short side

l_{sn}=clear span in of short side of slab

α_s=the ratio of continuous sides to total sides

Table 2.3. The minimum depth of slabs that do not require deflection calculation [5]

Member	Simple Span	Side Span	Mid Span	Cantilever
Slab working in one direction	1/20	1/25	1/30	1/10
Slabs working in two directions	1/25	1/30	1/35	-

2.4. Turkish Earthquake Code

There are five earthquake zones described in Turkish Earthquake Code [2]. These are first , second , third and fourth zones. There is another zone without any risk which is fifth zone. 92 per cent of the country is in first and second earthquake zone. In these seismically active areas, the 95 per cent of the population and 98 per cent of the industrial plants and 93 per cent of the dams are located. In the last century 60,000 people have died 120,000 people are injured during the earthquakes. Over 400,000 structures have been heavily damaged or have collapsed in Turkey because of earthquakes according to the statistics [11].

In 1998 the new Turkish Earthquake Code was published and consists general rules for designing and analyses of structures against earthquake.

2.4.1. Earthquake Forces

Turkish Earthquake Code [2] (1998) gives provisions for computing earthquake forces by equivalent static analysis or dynamic analysis. The dimension limits of the members are also given in Turkish Earthquake Code [2].

The main steps in the procedure are to determine the period of the fundamental mode of vibration and the base shear ,and then distribute the base shear as lateral forces along the building from which member forces can be computed. These member forces are than transformed by a variable multiplier into design earthquake forces.

In view of these explanations , total equivalent base shear is given by the following equation:

$$V_t = \frac{W \times A_0 \times I \times S}{R} > 0.10 \times A_0 \times I \times W \qquad (2.12)$$

$$S > 0.10 \times R \qquad (2.13)$$

$$W = \sum w_i \qquad (2.14)$$

$$w_i = g_i + n \times q_i \qquad (2.15)$$

V_t=Base Shear

W=Total Weight

w_i=Story weight

R=Ductility Factor

g_i=Dead load at the i^{th} segment

q_i=Live Load at the i^{th} segment

n=0.3 (for our case)

A=Spectral acceleration coefficient

A_O=Effective ground acceleration coefficient

I=Importance factor

S=Spectral coefficient (S>0.10R)

$$S = 1 + \frac{(1.5T)}{T_A} \qquad (0<T<T_A) \qquad (2.16)$$

$$S = 2.5 \qquad (T_A<T<T_B) \qquad (2.17)$$

$$S = 2.5(\frac{T_B}{T})^{0.8} \qquad (T>T_B) \qquad (2.18)$$

T_A, T_B= Characteristic periods which depend on soil types. These soil type values can be taken from Turkish Earthquake Code [2] Table 12.1 and Table 12.2.

The total static equivalent earthquake load is given by the following equation:

$$V_t = \Delta F_N + \sum_{i=1}^{N} F_i \qquad (2.19)$$

The fraction of V_t as an additional earthquake load for H>25 m and first mode is:

$$\Delta F_N = 0.07 \times T_1 \times V_t < 0.2V_t \qquad (2.20)$$

T_1= First mode period

Equivalent earthquake loads for each story is given by:

$$F_i = (V_t - \Delta F_N)\left(\frac{w_i H_i}{\sum_{j=1}^{N} w_j H_j}\right) \tag{2.21}$$

H=Height of the stories , from j=1 to j=N

In the Turkish Earthquake Code the structure type frames with shear walls system with R=7 and Z4, which is the worst base condition, is chosen. S(T) is found from the Figure 2.4.

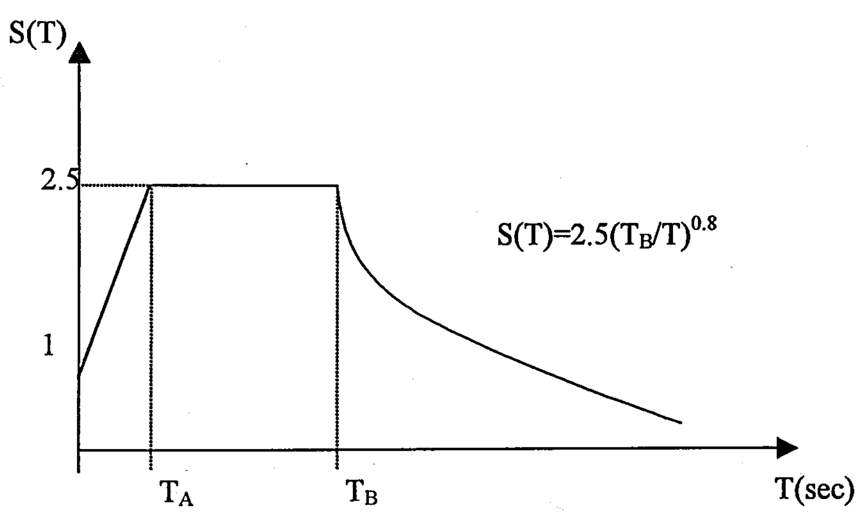

Figure 2.4. The response spectrum diagram

There are methods given in Turkish Earthquake Code [2] to find the natural periods of the structures. SAP2000 also gives the natural periods of the structures.

$$T_1 \cong T_{1A} = C_t H_N^{3/4} \tag{2.22}$$

C_t=0.07 when all loads are carried by frames

$C_t=0.075/A_t^{1/2} <0.05$ when loads carried by shear walls

$$A_t = \sum_j A_{wj}(0.2 + (l_{wj} / H_N)^2) \quad (2.23)$$

C_t=0.05 in all other structures.

When accurate results are needed the below equation is used

$$T_1 = 2\pi(\sum_{i=1}^{N}(m_i u_i^2) / \sum_{i=1}^{N}(F_i u_i))^{1/2} \quad (2.24)$$

m_i=story mass
F_i=forces acting on the story
u_i= displacements under F_i forces

$$A(T) = A_O \times I \times S(T) \quad (2.25)$$

I= Importance factor (I=1 for our case)
Ao= Earthquake zone factor

The forces found are applied on the model created in SAP2000 with other load combinations. Earthquake forces found in the design are applied to the mass center in one combination and to take into account of the torsion effects with five per cent eccentricity.

2.4.2. Member Dimensions

For columns the dimension limits given in Turkish Earthquake Code [2] are:

- In rectangular columns one dimension cannot be less than 250 mm and the area cannot be less than 75,000 mm^2. Circular column diameter should be at least 300 mm.
- For axial force the columns should satisfy

$$A_c \geq N_{d\max} / (0.50 f_{ck}) \quad (2.26)$$

There are also other factors affecting the dimensions of columns in a design.

The energy absorption during the seismic excitations is expected to be in the beams , rather than in columns. Therefore , strong column –weak beam design concept is utilized in the code and the following equation is used to assure this equation 2.27.

$$(M_{ra} + M_{rü}) \geq 1.2(M_{ri} + M_{rj}) \tag{2.27}$$

M_{ra}=Moment capacity of columns down part
$M_{rü}$= Moment capacity of columns up part
M_{ri} and M_{rj} moment capacity of beams

Drift of structures is also related with the dimensions of the columns in the Turkish Earthquake Code [2]:

$$(\Delta_i)_{\max} / h_i \leq 0.0035 \tag{2.28}$$

$$(\Delta_i)_{\max} / h_i \leq 0.02 / R \tag{2.29}$$

For beams the dimension limits given in Turkish Earthquake Code [2] are:

- Beam width cannot be less than 250 mm
- Beam depth cannot be less than 3 times the slab depth and 300 mm and cannot be more than 3.5 times the beam width
- Beam depth cannot be more than 1/4 of clear span (special requirements will be applied)

2.5. Design Tool Sta4Cad

In the market most of the projects designed are done with computer programs. One of those programs is Sta4Cad. These programs advantage is the number of iterations. One can do high number of models in the program and optimize the dimensions.

The design programs results' deviation is examined on similar projects and member forces are compared. That way the performance of the program is examined.

3. RESEARCH SCOPE

Shear wall with frame structural systems are the most used in conventional buildings. With this structural system up to 40 story height buildings can be reached as shown in Figure 2.3. With moment resisting frames up to 15 story height may be reached [8]. So in the research shear wall with frames structural system models are used.

The concrete classes that can be used for a project is as follows according to TS 500 February 2000[5];C16, C18 ,C20, C25, C30, C35, C40, C45, C50.

According TS 11222 February 2001 [1] to have the required durability concrete classes start with C20. (See Appendix A).

So the concrete classes which can be used in current research models are;C20, C25 ,C30, C35 ,C40, C45, C50.

Four of these concrete classes are chosen for model. These are C20, C30, C40, C50.

In Turkey there are four earthquake regions, but 95 per cent of the population lives in first and second region. So the earthquake regions chosen are; first earthquake region and second earthquake region.

The models are chosen for different story numbers. The building behavior changes with the increasing story number. So the cost effect may change with story number. 5 –10-15 number of story projects are chosen for comparison. The criteria chosen are:

- C20, C30, C40, C50 concrete classes.
- 5-10-15 stories numbers.
- Shear walls with frames structural system.
- 1st and 2nd Earthquake regions.
- Z4 soil type is chosen from the Turkish Earthquake Code [2] Table 12.2.

In Table 3.1 the sample combinations are given. There are twenty-four combinations to be investigated in order to highlight the effect of concrete compressive strength on the cost of construction.

Table 3.1. Research combinations

Combination No	Story	Earthquake Zone	Concrete Class
1	5	1	C20
2			C30
3			C40
4			C50
5		2	C20
6			C30
7			C40
8			C50
9	10	1	C20
10			C30
11			C40
12			C50
13		2	C20
14			C30
15			C40
16			C50
17	15	1	C20
18			C30
19			C40
20			C50
21		2	C20
22			C30
23			C40
24			C50

3.1. Calculation Steps

3.1.1. General

As summarized in the previous section for a typical floor plan with different story heights , earthquake zones and concrete classes we have 24 combinations. For these combinations the followings will be done:

- Structural analysis will be done.
- Reinforcement calculation will be done.
- Cost calculation.

For all these calculations the change in reinforcement , concrete and form will be the subjects for the cost calculations. The increase of concrete quality will decrease column sizes in the load carrying members columns and shear walls.

3.1.2. The Member Dimensions

With the change in concrete quality form, concrete and reinforcement of the members will change. But in some members especially in beams and slabs the rise in the concrete quality does not necessarily decrease the sizes of the members. Since these members sizes depend on the geometric restrictions in the building codes.

According to Turkish Earthquake Code [2] beam dimensions should be:

- beam thickness should not be less than 250 mm.
- minimum beam depth should be three folds the slab depth or 300 mm and maximum beam depth should be 3.5 folds the beam thickness.

According to the equation 2.11 the minimum slab depth can be 100 mm. In practice about 150 mm slabs are chosen. In Table 2.3 minimum slab depth recommendations are also given if crack control is not to be done. The value for continuous slabs is 1/30 of clear span. So slab depth is chosen is 130 mm for the research model.

The minimum beam dimension is therefore 400 mm in depth and 250 mm of thickness. With increasing concrete quality the sizes of these members cannot be changed. So the concrete quality increase is investigated only in vertical elements, which are columns and shear walls. But the reinforcement ratio can decrease and the effect of concrete class increase in all members will also be investigated in Section 4.1.1.4.

The column sizes are chosen as the minimum size that would be enough for the control of columns being stronger than beams in equation 2.27 of Turkish Earthquake Code [2]. This size is obtained by trial and error. The columns are chosen as squares ,and the dimension are decreased with the multiplies of 5 cm. The column dimensions remain same for 5 stories and then checked if the dimension can be reduced according to the equation 2.27 of Turkish Earthquake Code [2] case. The shear walls dimensions are chosen to have the same effect on the building. The shear walls are designed to carry all the shear force that would result from earthquake forces in the middle floor. The shear force capacity of the shear walls are found from the equation 3.1 of Turkish Earthquake Code [2].

In the Turkish Earthquake Code [2] there are several specifications for the dimensions of the members. The shear wall dimensions in the projects are found as if the shear walls will carry the entire shear in the half floor. Although this equation is for the ultimate shear capacity of the shear walls, this equation is used here to find the area of the shear walls. As the dimensions of the shear walls decrease ,the weight of the building will decrease and this will decrease the dimensions again. So each combination will have shear walls with the same shear capacity.

$$V_r = A_{ch} \times (0.65 \times f_{ctd} + \rho_{sh} \times f_{yd}) \tag{3.1}$$

ρ_{sh} is taken as 0.0025 as minimum reinforcement ratio in the shear walls.

$$f_{ctd} = \frac{0.35\sqrt{f_{ck}}}{1.5} \tag{3.2}$$

According to Turkish Earthquake Code [2] the beam limits are mentioned before. The beam thickness is 250 mm in thickness and 400 mm in depth. These are the minimum limits so these dimensions cannot be reduced in other models.

3.1.3. Structural Analyses

The computer programs used are Sta4Cad and SAP2000. Sta4Cad is used commercially as a design tool in Turkey. It gives simplicity in modeling and cost analysis. But the result obtained will also be checked with the results from SAP2000 in Section 6.

The loads are chosen according to the traditional Turkish construction. There are bricks wall over the beams of 19 cm thick and 0.729 ton/m and 0.148 ton/m^2 of slab coating and finish. The live loads are Q=0.15 ton/m^2. The loads are put as trapezoidal over beams. Story height is 3 m in all building samples used within the content of current research.

The earthquake loads are applied according to Turkish Earthquake Code [2] as stated in Section 2.4.1.

4. CALCULATIONS

According to the research combinations given in previous section the calculations are done. The costs are taken from ministry of public works.

4.1. Five Story Combinations

The combinations with five story are given in Table 4.1. Figure 4.1 shows the plan view of the model. Columns and shear walls dimensions are same and their dimensions are given in Figure 4.3. and Figure 4.4. There are four shear walls and 18 columns. The system is symmetric. The span lengths are 4 m. Total area of the building is 256 m^2. There are 4 spans in both dimensions. In Figure 4.2 shear walls and columns connection is given in detail.

Table 4.1. Combinations for five story

Combination No	Story	Earthquake Zone	Concrete Class
1	5	1	C20
2			C30
3			C40
4			C50
5		2	C20
6			C30
7			C40
8			C50

4.1.1. The First Earthquake Region

4.1.1.1. Five Story with 20 MPa. The column dimension according to equation 2.27 is X=40 cm for concrete class C20. The shear force in the middle floor is 168.57 ton.

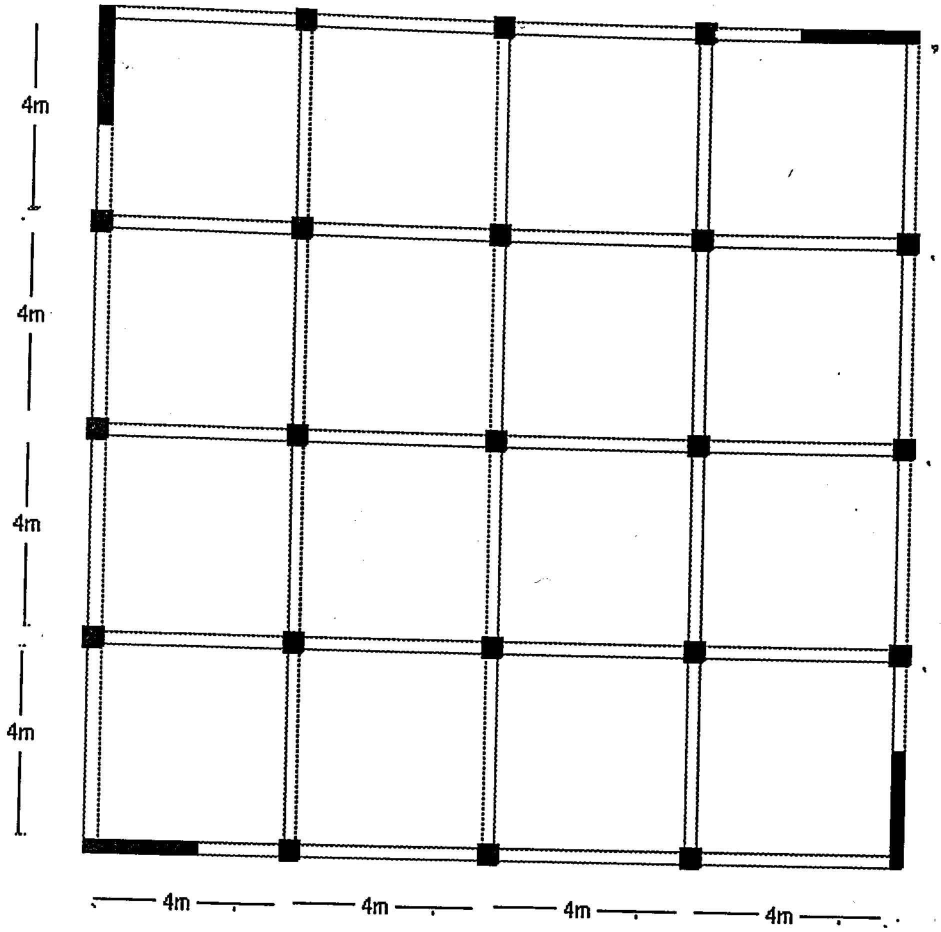

Figure 4.1. Five story plan view

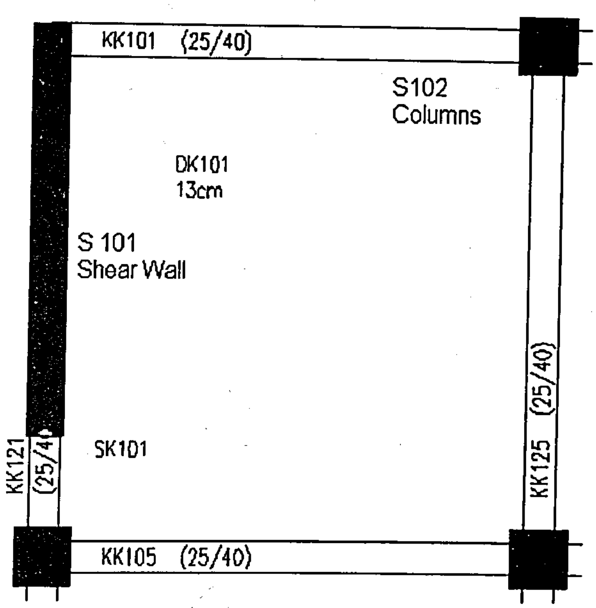

Figure 4.2. Five story plan view detail

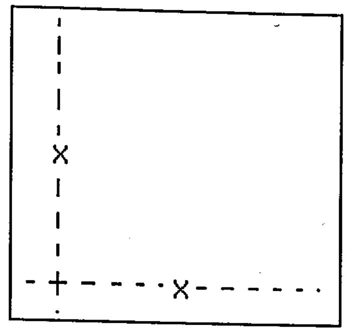

Figure 4.3. Column dimensions

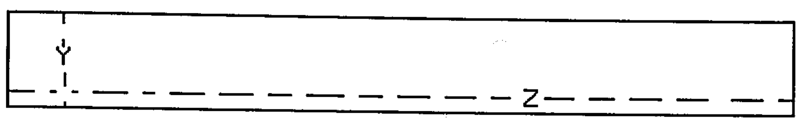

Figure 4.4. Shear wall dimensions

According to the assumption that the shear wall will be large enough to resist the shear in the mid floor for the model.

$$A_{ch} = \frac{V_r}{(0.65 \times f_{ctd} + \rho_{sh} \times f_{yd})} \qquad (4.1)$$

The shear wall area is found from equation 4.1 as 1.059 m^2. When the shear wall thickness is taken as Y=25 cm and since there are two shear walls the length of the shear wall is Z=210 cm. The total volumes of the construction materials for structural members are given in Table 4.2.

Total overturning moment of the structure from earthquake loads is 2316 ton.m. The shear walls take 646 ton.m in one direction and this is 27.8 per cent of the total moment. The period of the structure is 0.524 sec.

4.1.1.2. Five Story with 30 MPa. For C30 the column dimensions do not change since the dimension cannot be reduced because of the weak beam strong column requirement equation 2.27. The column dimensions are X=40 cm. The shear wall will be large enough to resist the shear in the mid floor 167.95 ton. According to equation 4.1 the shear wall area found is 0.963 m^2.

Table 4.2. Five story combination with C20 cost analyses

Material	Cost table code	Unit price (TL.)	Amount
C 20 concrete	16.0581	33,522,957	296.74 m^3
Forms	21.011	4,087,903	2445.87 m^2
8-12 reinforcement bars	23.014	305,156,250	15.5 ton
14-26 reinforcement bars	23.015	282,937,500	15.66 ton
Total Cost		29,106,804,696 TL.	

When the shear wall thickness is taken as Y=25 cm and since there are two shear walls the length of the shear wall is Z=190 cm. The volumes of the construction materials for structural members are given in Table 4.3.

Table 4.3. Five story combination with C 30 cost analyses

Material	Cost table code	Unit price (TL.)	Amount
C 30 concrete	16.0591	37,422,957	78.9 m^3
C 20 concrete	16.0581	33,522,957	215.24 m^3
Forms	21.011	4,087,903	2425.87 m^2
8-12 reinforcement bars	23.014	305,156,250	15.33 ton
14-26 reinforcement bars	23.015	282,937,500	15.89 ton
Total Cost		29,193,720,805 TL.	

Total overturning moment of the structure from earthquake loads is 2309 ton.m. The shear walls take 578.7 ton.m in one direction and this is 25 per cent of the total moment. The period of the structure is 0.525 sec.

4.1.1.3. Five Story with 40 MPa. For C 40 the column dimensions do not change since the dimension cannot be reduced because of the weak beam strong column requirement equation 2.27. The column dimensions are X=40 cm. The shear wall will be large enough to resist the shear in the mid floor 167.73 ton. According to the equation 4.1 the shear wall area found is 0.845 m^2.

When the shear wall thickness is taken as Y=25 cm and since there are two shear walls the length of the shear wall is Z=180 cm. The volumes of the construction materials for structural members are given in Table 4.4.

Table 4.4. Five story combination with C40 cost analyses

Material	Cost table code	Unit price (TL.)	Amount
C 40 concrete	16.0593	40,022,957	77.4 m^3
C 20 concrete	16.0581	33,522,957	215.24 m^3
Forms	21.011	4,087,903	2415.39 m^2
8-12 reinforcement bars	23.014	305,156,250	15.28 ton
14-26 reinforcement bars	23.015	282,937,500	15.9 ton
Total Cost		29,348,631,914 TL	

Total overturning moment of the structure from earthquake loads is 2306 ton.m. The shear walls take 546 ton.m in one direction and this is 23.67 per cent of the total moment. The period of the structure is 0.5284 sec.

4.1.1.4. Five Story with 50 MPa. For C 50 the column dimensions can be reduced to X=35 cm The column dimensions are 35x35 cm. The shear wall will be large enough to resist the shear in the mid floor 165.43 ton according to the equation 4.1 the shear wall area found is 0.833 m^2.

When the shear wall thickness is taken as 25 cm and since there are two shear walls the length of the shear wall is 166 cm. But the minimum shear wall length 25x7=175 cm. So we can try the two options with 20 cm thickness and with 25 cm thickness.

When 175x25 cm shear walls are used the volumes of the construction materials for structural members are given in Table 4.5.

Table 4.5. Five story combination with C50 and 175 x 25 cm shear walls

Material	Cost table code	Unit price (TL.)	Amount
C 50 concrete	16.0595	42,102,957	64.85 m^3
C 20 concrete	16.0581	33,522,957	216.95 m^3
Forms	21.011	4,087,903	2354.81 m^2
8-12 reinforcement bars	23.014	305,156,250	14.95 ton
14-26 reinforcement bars	23.015	282,937,500	14.73 ton
Total Cost		28,359,295,096 TL.	

Total overturning moment of the structure from earthquake loads is 2274 ton.m. The shear walls take 602 ton.m in one direction and this is 26.5 per cent of the total moment. The period of the structure is 0.560 sec.

When 20 cm x 205 cm shear walls are used the volumes of the construction materials for structural members are given in Table 4.6.

Table 4.6. Five story combination with C50 and 205 x 20 cm shear walls

Material	Cost table code	Unit price (TL.)	Amount
C 50 concrete	16.0595	42,102,957	64.43 m^3
C 20 concrete	16.0581	33,522,957	215.87 m^3
Forms	21.011	4,087,903	2380.86 m^2
8-12 reinforcement bars	23.014	305,156,250	15.22 ton
14-26 reinforcement bars	23.015	282,937,500	14.02 ton
Total Cost		28,293,280,859 TL.	

The difference in cost when all members are C50 is investigated. When 20x205 cm shear walls are used the cost is given in Table 4.7.

So in Table 4.7 it can be seen that the reinforcement decrease because of concrete quality increase does not decrease the total cost.

Table 4.7. Sample cost analyses with C50 concrete only

Material	Cost table code	Unit price (TL.)	Amount
C 50 concrete	16.0595	42,102,957	280.3 m^3
Forms	21.011	4,087,903	2380.86 m^2
8-12 reinforcement bars	23.014	305,156,250	15.44 ton
14-26 reinforcement bars	23.015	282,937,500	13.32 ton
Total Cost		30,014,523,584 TL.	

4.1.2. Second Earthquake Region

4.1.2.1. Five Story with 20 MPa. According to equation 2.27 column sizes are X=40 cm. The shear force in the middle floor is 125.07 ton. The shear wall will be large enough to resist the shear in the mid floor which is 125.07 ton. According to the equation 4.1 the shear wall area found is 0.786 m^2.

When the shear wall thickness is taken as Y=20 cm and since there are two shear walls the length of the shear wall is Z=200 cm. The volumes of the construction materials for structural members are given in Table 4.8.

Table 4.8. Five story combination with C20 cost analyses

Material	Cost table code	Unit price (TL.)	Amount
C 20 concrete	16.0581	33,522,957	290.68 m^3
Forms	21.011	4,087,903	2431.28 m^2
8-12 reinforcement bars	23.014	305,156,250	15.53 ton
14-26 reinforcement bars	23.015	282,937,500	13.2 ton
Total Cost		28,157,141,509 TL.	

4.1.2.2. Five Story with 30 MPa. For C 30 the column dimensions can be reduced to X=35 cm. The shear wall will be large enough to resist the shear in the mid floor 123.3 ton. According to the equation 4.1 the shear wall area found is 0.775 m^2.

When the shear wall thickness is taken as Y=20 cm and since there are two shear walls the length of the shear wall is Z=190 cm. The volumes of the construction materials for structural members are given in Table 4.9.

Table 4.9. Five story combination with C30 cost analyses

Material	Cost table code	Unit price (TL.)	Amount
C 30 concrete	16.0591	37,422,957	62.54 m^3
C 20 concrete	16.0581	33,522,957	216.17 m^3
Forms	21.011	4,087,903	2365.62 m^2
8-12 reinforcement bars	23.014	305,156,250	15.59 ton
14-26 reinforcement bars	23.015	282,937,500	11.15 ton
Total Cost		27,145,181,744 TL.	

4.1.2.3. Five Story with 40 MPa. The column dimensions are X=35 cm. The shear wall will be large enough to resist the shear in the mid floor 123.07 ton. According to the equation 4.1 the shear wall area found is 0.657 m^2.

When the shear wall thickness is taken as Y= 20 cm and since there are two shear walls the length of the shear wall is Z= 165 cm. The volumes of the construction materials for structural members are given in Table 4.10.

4.1.2.4. Five Story With 50 MPa. For C50 the column dimensions are 35x35 cm. The shear wall will be large enough to resist the shear in the mid floor 122.84 ton. According to the equation 4.1 the shear wall area found is 0.618 m^2.

When the shear wall thickness is taken as Y=20 cm and since there are two shear walls the length of the shear wall is Z=155 cm.

The volumes of the materials for structural members are given in Table 4.11.

Table 4.10. Five story combination with C40 cost analyses

Material	Cost table code	Unit price (TL.)	Amount
C 40 concrete	16.0593	40,022,957	59.69 m^3
C 20 concrete	16.0581	33,522,957	216.67 m^3
Forms	21.011	4,087,903	2342.62 m^2
8-12 reinforcement bars	23.014	305,156,250	15.35 ton
14-26 reinforcement bars	23.015	282,937,500	11.62 ton
Total Cost		27,200,974,910 TL.	

4.2. Ten Story Combinations

The model combinations with 10 story can be seen in Table 4.12. The plan for ten story combinations is given in Figure 4.6. The plan is same as five story combinations.

There are twenty-one columns four shear walls. The column's dimensions can be changed if the condition in equation 2.27 is satisfied. In Table 4.11 five story combination with C50 is given.

Table 4.11. Five story combination with C50 cost analyses

Material	Cost table code	Unit price (TL.)	Amount
C 50 concrete	16.0595	42,102,957	58.73 m^3
C 20 concrete	16.0581	33,522,957	216.67 m^3
Forms	21.011	4,087,903	2333.02 m^2
8-12 reinforcement bars	23.014	305,156,250	15.35 ton
14-26 reinforcement bars	23.015	282,937,500	11.64 ton
Total Cost		27,250,856,102, TL.	

In Figure 4.5 plan view of the model can be seen. Columns and shear walls can be seen in detail in Figure 4.6. In Figure 4.7 and Figure 4.8 dimensioning of the shear walls and columns is given.

Table 4.12. Ten story combinations

Combination No	Story	Earthquake Zone	Concrete Class
9	10	1	C20
10			C30
11			C40
12			C50
13		2	C20
14			C30
15			C40
16			C50

In Figure 4.5 plan view of the model can be seen. Columns and shear walls can be seen in detail in Figure 4.6. In Figure 4.7 and Figure 4.8 dimensioning of the shear walls and columns is given.

4.2.1. The First Earthquake Region

4.2.1.1. Ten Story with 20 MPa. The column dimension according to equation 2.27 from Turkish Earthquake Code is X=45 cm. The shear force in the middle floor is 308 ton. According to this shear and our assumption that in the shear wall will be large enough to resist the shear in the mid floor which is 308.77 ton. According to the equation 4.1 the shear wall area found is 1.914 m^2.

When the shear wall thickness is taken as Y=30 cm and since there are two shear walls the length of the shear wall is Z=320 cm. The volumes of the construction materials for structural members are given in Table 4.13.

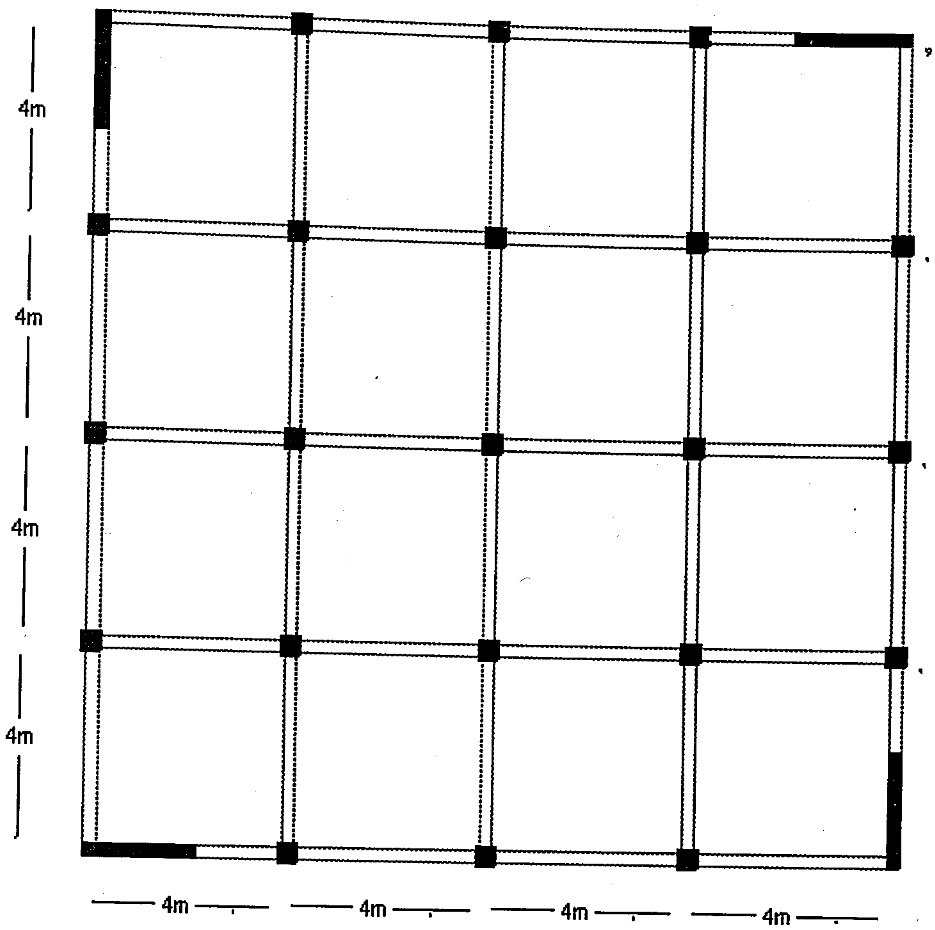

Figure 4.5. Ten story plan view

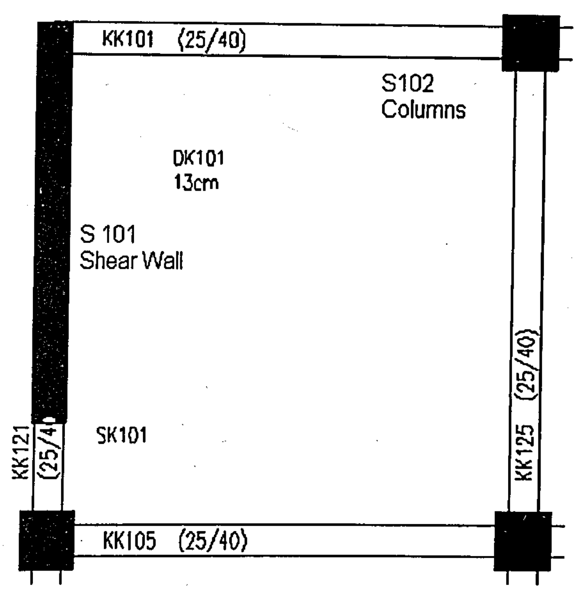

Figure 4.6. Ten story plan view detail

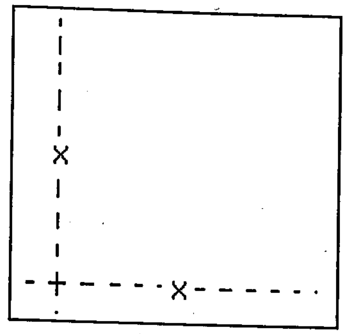

Figure 4.7 Column dimensions

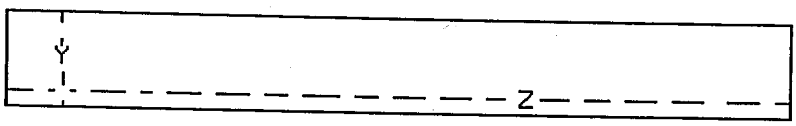

Figure 4.8. Shear wall dimensions

Total overturning moment of the structure from earthquake loads is 8947 ton.m. The shear walls take 2532 ton.m in one direction and this is 28.3 per cent of the total moment. The period of the structure is 0.975 sec.

4.2.1.2. Ten Story with 30 MPa. For C30 the column dimensions cannot be reduced. The column dimensions are X=45 cm. The shear wall will be large enough to resist the shear in the mid floor 307.2 ton. According to the equation 4.1 the shear wall area found is 1.76 m^2.

Table 4.13. Ten story combination with C20 cost analyses

Material	Cost table code	Unit price (TL.)	Amount
C 20 concrete	16.0581	33,522,957	666.16 m^3
Forms	21.011	4,087,903	5237.34 m^2
8-12 reinforcement bars	23.014	305,156,250	34.01 ton
14-26 reinforcement bars	23.015	282,937,500	54.3 ton
Total Cost		69,483,261,246 TL.	

When the shear wall thickness is taken as Y=30 cm and since there are two shear walls the length of the shear wall is Z=290 cm. The volumes of the construction materials for structural members are given in Table 4.14.

Total overturning moment of the structure from earthquake loads is 8902 ton.m. The shear walls take 2274 ton.m in one direction and this is 25.5 per cent of the total moment. The period of the structure is 0.9745 sec.

Table 4.14. Ten story combination with C30 cost analyses

Material	Cost table code	Unit price (TL.)	Amount
C 30 concrete	16.0591	37,422,957	232 m^3
C 20 concrete	16.0581	33,522,957	424.56 m^3
Forms	21.011	4,087,903	5176.38 m^2
8-12 reinforcement bars	23.014	305,156,250	34.01 ton
14-26 reinforcement bars	23.015	282,937,500	53.72 ton
Total Cost		69,652,938,542 TL.	

<u>4.2.1.3. Ten Story with 40 MPa.</u> For C 40 the column dimensions do not change. The column dimensions are X=40 cm. The shear wall will be large enough to resist the shear in the mid floor 284.98 ton. For this shear according to the equation 4.1 the shear wall area found is 1.522 m^2.

When the shear wall thickness is taken as Y= 30 cm and since there are two shear walls the length of the shear wall is Z= 255 cm. The volumes of the construction materials for structural members are given in Table 4.15.

Total overturning moment of the structure from earthquake loads is 8260 ton.m. The shear walls take 1942 ton.m in one direction and this is 23.51 per cent of the total moment. The period of the structure is 1.041 sec.

Table 4.15. Ten story combination with C40 cost analyses

Material	Cost table code	Unit price (TL.)	Amount
C 40 concrete	16.0593	40,022,957	194.6 m^3
C 20 concrete	16.0581	33,522,957	427.78 m^3
Forms	21.011	4,087,903	4994.26 m^2
8-12 reinforcement bars	23.014	305,156,250	33.03 ton
14-26 reinforcement bars	23.015	282,937,500	51.93 ton
Total Cost		67,317,232,727 TL.	

4.2.1.4. Ten Story with 50 MPa. The column dimensions are X=40 cm. The shear wall will be large enough to resist the shear in the mid floor 285.6 ton. According to the equation 4.1 the shear wall area found is 1.442 m^2.

When the shear wall thickness is taken as Y= 25 cm and since there are two shear walls the length of the shear wall is Z= 285 cm. The volumes of the construction materials for structural members are given in Table 4.16.

Table 4.16. Ten story combination with C50 cost analyses

Material	Cost table code	Unit price (TL.)	Amount
C 50 concrete	16.0595	42,102,957	186.3 m^3
C 20 concrete	16.0581	33,522,957	426.68 m^3
Forms	21.011	4,087,903	5044.14 m^2
8-12 reinforcement bars	23.014	305,156,250	33.82 ton
14-26 reinforcement bars	23.015	282,937,500	49.6 ton
Total Cost		67,121,395,595 TL.	

Total overturning moment of the structure from earthquake loads is 8433 ton.m. The shear walls take 2176 ton.m in one direction and this is 25.8 per cent of the total moment. The period of the structure is 1.0025 sec.

4.2.2. Second Earthquake Region

4.2.2.1. Ten Story with 20 MPa. The column sizes are X=45 cm. The shear force in the middle floor is 217.4 ton. The shear wall will be large enough to resist the shear in the mid floor which is 217.4 ton. According to equation 4.1 the shear wall area found is 1.366 m^2.

When the shear wall thickness is taken as Y= 25 cm and since there are two shear walls the length of the shear wall is Z= 275 cm. The volumes of the construction materials for structural members are given in Table 4.17.

4.2.2.2. Ten Story with 30 MPa. For C 30 the column dimensions is reduced to X=40 cm. The shear wall will be large enough to resist the shear in the mid floor 201.5 ton. According to the equation 4.1 the shear wall area found is 1.156 m^2.

When the shear wall thickness is taken as Y = 25 cm and since there are two shear walls the length of the shear wall is Z= 230 cm. The volumes of the materials for structural members are given in Table 4.18.

Table 4.17. Ten story combination with C20 cost analyses

Material	Cost table code	Unit price (TL.)	Amount
C 20 concrete	16.0581	33,522,957	635.36 m^3
Forms	21.011	4,087,903	5134.82 m^2
8-12 reinforcement bars	23.014	305,156,250	33.54 ton
14-26 reinforcement bars	23.015	282,937,500	41.76 ton
Total Cost		63,340,202,667 TL.	

4.2.2.3. Ten Story with 40 MPa. The column dimensions are X=40 cm. The shear wall will be large enough to resist the shear in the mid floor 201.06 ton. According to the equation 4.1 the shear wall area found is 1.074 m^2.

Table 4.18. Ten story combination with C30 cost analyses

Material	Cost table code	Unit price (TL.)	Amount
C 30 concrete	16.0591	37,422,957	169.8 m^3
C 20 concrete	16.0581	33,522,957	428.88 m^3
Forms	21.011	4,087,903	4932.38 m^2
8-12 reinforcement bars	23.014	305,156,250	32.05 ton
14-26 reinforcement bars	23.015	282,937,500	39.41 ton
Total Cost		61,825,659,583 TL.	

When the shear wall thickness is taken as Y= 25 cm and since there are two shear walls the length of the shear wall is Z= 215 cm. The volumes of the construction materials for structural members are given in Table 4.19.

Table 4.19. Ten story combination with C40 cost analyses

Material	Cost table code	Unit price (TL.)	Amount
C 40 concrete	16.0593	40,022,957	165.3 m^3
C 20 concrete	16.0581	33,522,957	429.48 m^3
Forms	21.011	4,087,903	4901.9 m^2
8-12 reinforcement bars	23.014	305,156,250	31.58 ton
14-26 reinforcement bars	23.015	282,937,500	39.36 ton
Total Cost		61,824,980,455 TL.	

4.2.2.4. Ten Story with 50 MPa. The column dimensions are X= 40 cm. The shear wall will be large enough to resist the shear in the mid floor 201.29 ton. According to the equation 4.1 the shear wall area found is 1.013 m^2.

When the shear wall thickness is taken as Y= 25 cm and since there are two shear walls the length of the shear is Z= 200 cm. The volumes of the construction materials for structural members are given in Table 4.20.

4.3. Fifteen Story Combinations

Table 4.21 shows the model combinations for fifteen stories. The plan view of the project is in Figure 4.9. There are eight shear walls and seventeen columns in this plan. Shear walls and columns detail view can be seen in Figure 4.10. The dimensions of the columns and shear walls are given in Figure 4.11 and Figure 4.12. The cost analysis is given for each concrete quality in tables. The unit costs are taken from ministry of public works cost tables.

Table 4.20. Ten story combination with C50 cost analyses

Material	Cost table code	Unit price (TL.)	Amount
C 50 concrete	16.0595	42,102,957	160.8 m^3
C 20 concrete	16.0581	33,522,957	430.08 m^3
Forms	21.011	4,087,903	4871.42 m^2
8-12 reinforcement bars	23.014	305,156,250	31.3 ton
14-26 reinforcement bars	23.015	282,937,500	39.73 ton
Total Cost		61,894,098,764 TL.	

Table 4.21. Fifteen story combinations

Combination No	Story	Earthquake Zone	Concrete Class
17	15	1	C20
18			C30
19			C40
20			C50
21		2	C20
22			C30
23			C40
24			C50

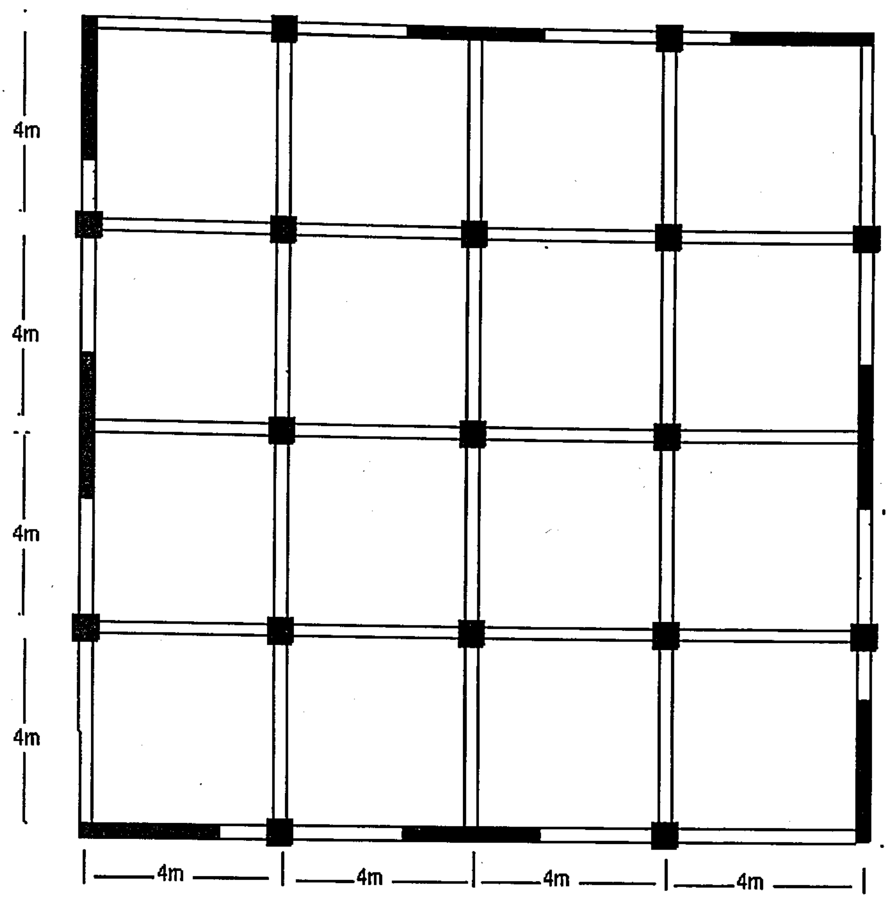

Figure 4.9. Fifteen story plan view

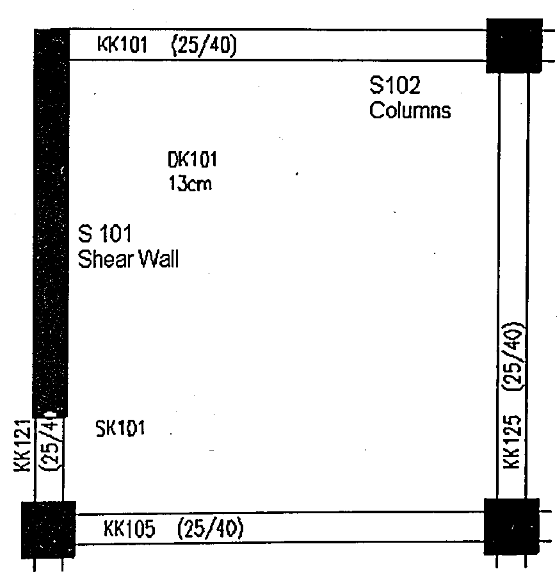

Figure 4.10. Fifteen story plan view detail

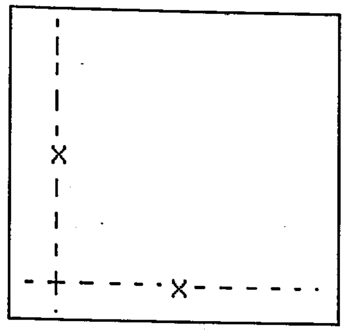

Figure 4.11. Column dimensions

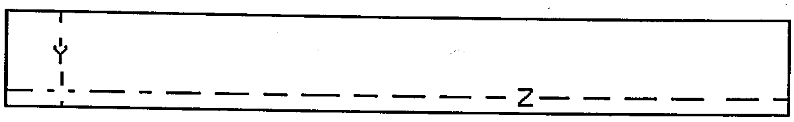

Figure 4.12. Shear wall dimensions

4.3.1. First Earthquake Region

4.3.1.1. Fifteen Story with 20 MPa. The column dimension is X=50 cm. The shear force in the middle floor is 453.12 ton. According to this shear and our assumption that in the shear wall will be large enough to resist the shear in the mid floor which is 453.12 ton. According to the equation 4.1 the shear wall area found is 1.848 m^2.

When the shear wall thickness is taken as Y= 25 cm and since there are four shear walls the length of the shear wall is Z= 285 cm. The volumes of the construction materials for structural members are given in Table 4.22.

Total overturning moment of the structure from earthquake loads is 15167 ton.m. The shear walls take 2912 ton.m in one direction and this is 19.19 per cent of the total moment. The period of the structure is 0.975 sec.

4.3.1.2. Fifteen Story with 30 MPa. For C 30 the column dimensions can be reduced to X=45 cm. The shear wall will be large enough to resist the shear in the mid floor 445.7 ton. According to the equation 4.1 the shear wall area found is 2.24 m^2.

Table 4.22. Fifteen story combination with C20 cost analyses

Material	Cost table code	Unit price (TL.)	Amount
C 20 concrete	16.0581	33,522,957	1069.02 m^3
Forms	21.011	4,087,903	8531.41 m^2
8-12 reinforcement bars	23.014	305,156,250	61.21 ton
14-26 reinforcement bars	23.015	282,937,500	92.93 ton
Total Cost		115,682,607,923 TL.	

When the shear wall thickness is taken as Y= 25 cm and since there are four shear walls the length of the shear wall is Z= 255 cm. But when Z= 255 cm length is chosen because of drift limit shear wall dimension could not be reduced below Z= 280 cm for C30. The volumes of the construction materials for structural members are given in Table 4.23.

Total overturning moment of the structure from earthquake loads is 14943 ton.m. The shear walls take 2532 ton.m in one direction and this is 21 per cent of the total moment. The period of the structure is 1.42 sec.

If shear walls are 20x320 cm. Y=20 cm and Z=320 cm. The volumes and cost of the materials used are given in Table 4.24.

4.3.1.3. Fifteen Story with 40 MPa. For C 40 the column dimensions are X= 45 cm. The shear wall will be large enough to resist the shear in the mid floor 445.71 ton. According to the equation 4.1 the shear wall area is 2.381 m^2.

When the shear wall thickness is taken as Y= 25 cm and since there are four shear walls the length of the shear wall is Z= 240 cm. But for drift the minimum length can be Z=275 cm. The volumes of the construction materials for structural members are given in Table 4.25.

Table 4.23. Fifteen story combination with C30 and 280 x 25 cm shear walls

Material	Cost table code	Unit price (TL.)	Amount
C 30 concrete	16.0591	37,422,957	411.45 m^3
C 20 concrete	16.0581	33,522,957	623.48 m^3
Forms	21.011	4,087,903	8432.38 m^2
8-12 reinforcement bars	23.014	305,156,250	61.38 ton
14-26 reinforcement bars	23.015	282,937,500	85.76 ton
Total Cost		113,615,813,101 TL.	

Table 4.24. Fifteen story combination with C30 and 320 x 20 cm shear walls

Material	Cost table code	Unit price (TL.)	Amount
C 30 concrete	16.0591	37,422,957	396.87 m^3
C 20 concrete	16.0581	33,522,957	619.52 m^3
Forms	21.011	4,087,903	8583.38 m^2
8-12 reinforcement bars	23.014	305,156,250	61.74 ton
14-26 reinforcement bars	23.015	282,937,500	85.55 ton
Total Cost		113,754,683,698 TL.	

Total overturning moment of the structure from earthquake loads is 14942 ton.m. The shear walls take 3056 ton.m in one direction and this is 20.45 per cent of the total moment. The period of the structure is 1.413 sec.

For C 40 the column dimensions do not change since the dimension cannot be reduced. The column dimensions are X=45 cm in the upper 5 stories X= 40 cm in the other stories. The shear wall will be large enough to resist the shear in the mid floor 445.26 ton. According to the equation 4.1 the shear wall area found is 2.378 m^2.

When the shear wall thickness is taken as 20 cm and since there are four shear walls the length of the shear wall is 300 cm. The volumes of the construction materials for structural members are given in Table 4.26.

4.3.1.4. Fifteen Story with 50 MPa. The column dimensions are X=40 cm. The shear wall will be large enough to resist the shear in the mid floor 445.54 ton. According to the equation 4.1 the shear wall area found is 2.244 m^2.

Table 4.25. Fifteen story combination with C40 and 275 x 25 cm shear walls

Material	Cost table code	Unit price (TL.)	Amount
C 40 concrete	16.0593	40,022,957	402.45 m^3
C 20 concrete	16.0581	33,522,957	624.68 m^3
Forms	21.011	4,087,903	8336 m^2
8-12 reinforcement bars	23.014	305,156,250	60.99 ton
14-26 reinforcement bars	23.015	282,937,500	84.95 ton
Total Cost		113,772,139,544 TL.	

Table 4.26. Fifteen story combination with C40 and 300 x 20 cm shear walls

Material	Cost table code	Unit price (TL.)	Amount
C 40 concrete	16.0591	40,022,957	369.89 m^3
C 20 concrete	16.0581	33,522,957	620.66 m^3
Forms	21.011	4,087,903	8526.52 m^2
8-12 reinforcement bars	23.014	305,156,250	61.06 ton
14-26 reinforcement bars	23.015	282,937,500	81.64 ton
Total Cost		112,197,894,869 TL.	

When the shear wall thickness is taken as Y= 25 cm and since there are two shear walls the length of the shear wall is Z= 224 cm. To have the drift under limit 265x25 cm shear walls are chosen. The volumes of the construction materials for structural members are given in Table 4.27.

Total overturning moment of the structure from earthquake loads is 14935 ton.m. The shear walls take 3012 ton.m in one direction and this is 20.2 per cent of the total moment. The period of the structure is 1.41 sec.

The column dimensions can be reduced in upper floors for C50. The column dimension X=35 cm satisfies only the last five stories. So, the column dimensions are X=40 cm for the first 10 stories. The last five stories are X=35 cm. The shear wall will be large enough to resist the shear in the mid floor 446.6 ton. According to the equation 4.1 the shear area found is 2.251 m^2.

When the shear wall thickness is taken as Y= 20 cm and since there are two shear walls the length of the shear wall is Z= 280 cm. To have the drift under limit 280x20 cm shear walls are used. The volumes of the construction materials for structural members are given in Table 4.28.

Table 4.27. Fifteen story combination with C50 and 265 x 25 cm shear walls

Material	Cost table code	Unit price (TL.)	Amount
C 50 concrete	16.0591	42,102,957	393.45 m^3
C 20 concrete	16.0581	33,522,957	625.88 m^3
Forms	21.011	4,087,903	8275 m^2
8-12 reinforcement bars	23.014	305,156,250	59.2 ton
14-26 reinforcement bars	23.015	282,937,500	86.49 ton
Total Cost		114,099,865,334 TL.	

Table 4.28. Fifteen story combination with C50 and 280 x 20 cm shear walls

Material	Cost table code	Unit price (TL.)	Amount
C 50 concrete	16.0595	42,102,957	252.71 m^3
C 20 concrete	16.0581	33,522,957	638.75 m^3
Forms	21.011	4,087,903	8465 m^2
8-12 reinforcement bars	23.014	305,156,250	58.86 ton
14-26 reinforcement bars	23.015	282,937,500	83.89 ton
Total Cost		112,401,730,222 TL.	

4.3.2. Second Earthquake Region

4.3.2.1. Fifteen Story with 20 MPa. The column sizes are X= 45 cm. The shear force in the middle floor is 313.18 ton. The shear wall will be large enough to resist the shear in the mid floor which is 313.18 ton. According to the equation 4.1 the shear wall area found is 1.962 m^2.

When the shear wall thickness is taken as Y= 25 cm and since there are two shear walls the length of the shear wall is Z=190 cm. The volumes of the construction materials for structural members are given in Table 4.29.

Table 4.29. Fifteen story combination with C20 cost analyses

Material	Cost table code	Unit price (TL.)	Amount
C 20 concrete	16.0581	33,522,957	960.83 m^3
Forms	21.011	4,087,903	7817.84 m^2
8-12 reinforcement bars	23.014	305,156,250	52.95 ton
14-26 reinforcement bars	23.015	282,937,500	67.65 ton
Total Cost		99,467,179,676 TL.	

4.3.2.2. Fifteen Story with 30 MPa. For C30 the column dimensions can be reduced to X= 40 cm. The shear wall will be large enough to resist the shear in the mid floor 308.04 ton. According to the equation 4.1 the shear wall area is 1.76 m^2.

When the shear wall thickness is taken as Y= 20 cm and since there are four shear walls the length of the shear wall is Z= 210 cm. The volumes of the construction materials for structural members are given in Table 4.30.

4.3.2.3. Fifteen Story with 40 MPa. The column dimensions are X= 40 cm. The shear wall will be large enough to resist the shear in the mid floor 307.14 ton. According to the equation 4.1 the shear wall area is 1.64 m^2.

Table 4.30. Fifteen story combination with C30 cost analyses

Material	Cost table code	Unit price	Amount
C 30 concrete	16.0591	37¸422¸957	281.16 m^3
C 20 concrete	16.0581	33¸522¸957	635.01 m^3
Forms	21.011	4¸087¸903	7758.57 m^2
8-12 reinforcement bars	23.014	305¸156¸250	52.85 ton
14-26 reinforcement bars	23.015	282¸937¸500	65.77 ton
Total Cost		98¸261¸840¸281 TL.	

When the shear wall thickness is taken as Y= 20 cm and since there are two shear walls the length of the shear wall is Z= 205 cm. The volumes of the construction materials for structural members are given in Table 4.31.

4.3.2.4. Fifteen Story with 50 MPa. The column dimensions are X= 40 cm for the first 10 stories than it decreases to X=35 cm. The shear wall will be large enough to resist the shear in the mid floor 301.66 ton. According to the equation 4.1 the shear wall area is 1.519 m^2.

Table 4.31. Fifteen story combination with C40 cost analyses

Material	Cost table code	Unit price (TL.)	Amount
C 40 concrete	16.0591	40¸022¸957	296.82 m^3
C 20 concrete	16.0581	33¸522¸957	636.78 m^3
Forms	21.011	4¸087¸903	7687.13 m^2
8-12 reinforcement bars	23.014	305¸156¸250	52.43 ton
14-26 reinforcement bars	23.015	282¸937¸500	59.58 ton
Total Cost		96¸426¸743¸042 TL.	

When the shear wall thickness is taken as Y= 20 cm and since there are two shear walls the length of the shear wall is Z= 185 cm. The volumes of the construction materials for structural members are given in Table 4.32.

Table 4.32. Fifteen story combination with C50 cost analyses

Material	Cost table code	Unit price	Amount
C 50 concrete	16.0591	42,102,957	252.71 m^3
C 20 concrete	16.0581	33,522,957	638.75 m^3
Forms	21.011	4,087,903	7581.72 m^2
8-12 reinforcement bars	23.014	305,156,250	51.31 ton
14-26 reinforcement bars	23.015	282,937,500	57.93 ton
Total Cost		95,092,627,898 TL.	

5. EVALUATION OF RESULTS

The increase in concrete quality in all models had the same effect. The costs decreased relatively in all earthquake regions and in all story heights. To verify that this result is independent of the building type , building height ,earthquake zone and architecture type the research has to be done on various other model combinations.

5.1. Five Story Combination

Five story combinations results are summarized in Figure 5.1 as costs and Figure 5.2 as per cents.

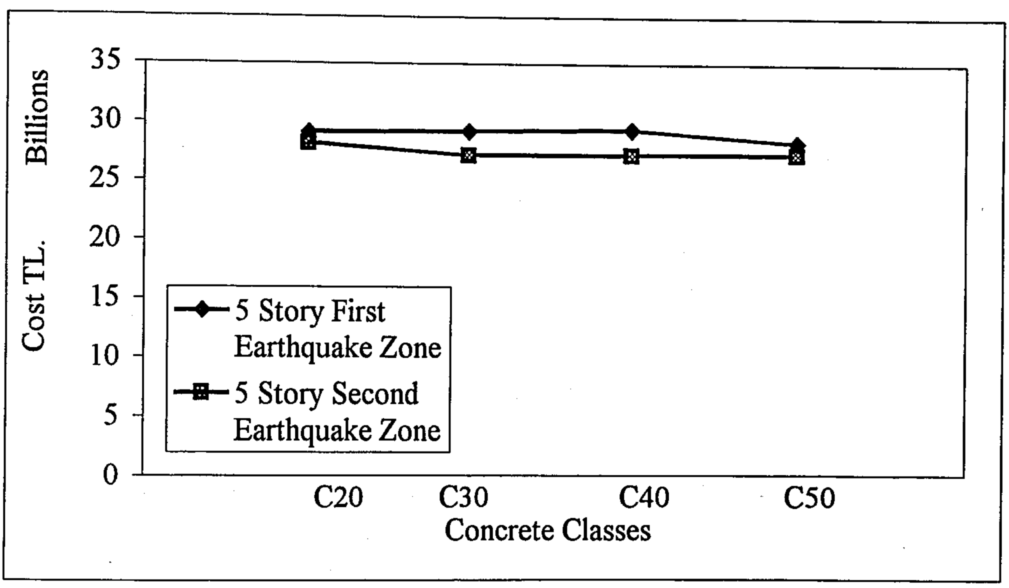

Figure 5.1 Five story building cost comparison

In five story combination the maximum cost difference between C50 and C20 is 2.8 per cent for the first earthquake zone. The cost show an increase up to C40 and then decrease in C50. The reason for that is the column dimension. The column dimension could not be decreased until C50. Up to C 50 the column dimension remained same because of Turkish Earthquake Code requirement 7.3 given in equation 2.27. Which requires that the column should have the 1.2 times the beams strength. When C50 is used this can be managed by 35x35 columns.

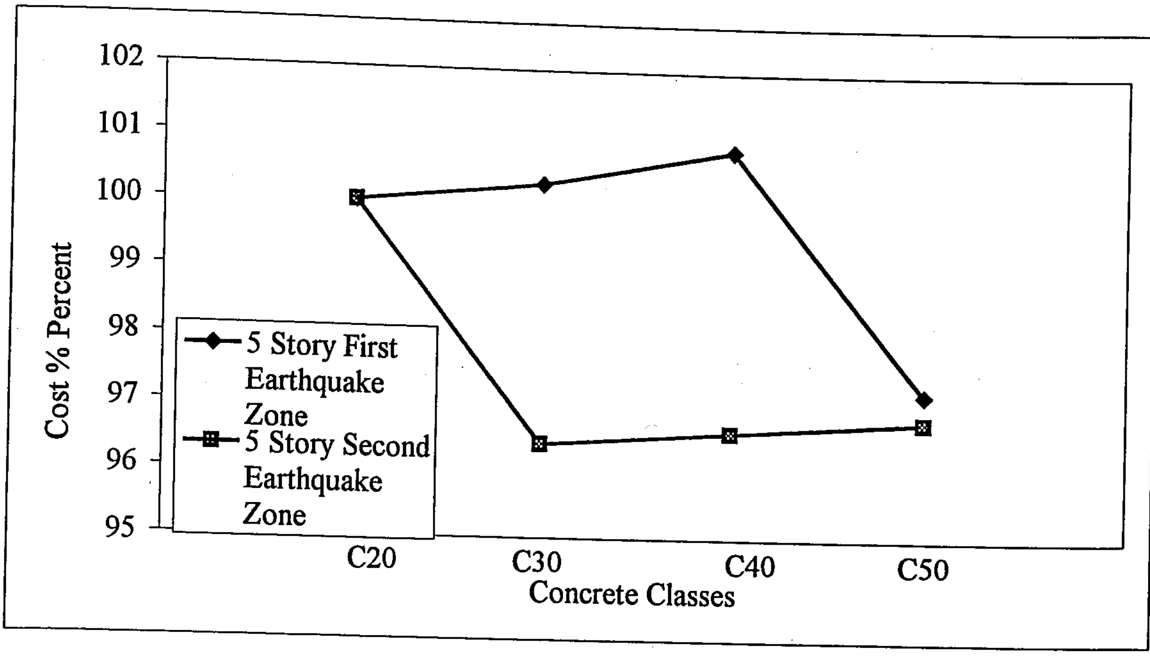

Figure 5.2. Five story building cost comparison in per cent

However in the second earthquake zone the column dimensions could be decreased to 35x35 by C30 and could not be decreased any further. So the costs begin to increase afterwards because the column dimensions cannot be decreased but the concrete class and the cost remains increasing.

5.2. Ten Story Combination

Ten story combinations are summarized in Figure 5.3 as costs and Figure 5.4 as per cents.

In ten story model combination the maximum cost difference between C50 and C20 is 3.4 per cent. The cost show an increase up to C30 and then decrease by C40. The reason for that is the column dimension. Up to C 30 the column dimension remained same because of Turkish Earthquake Code [2].

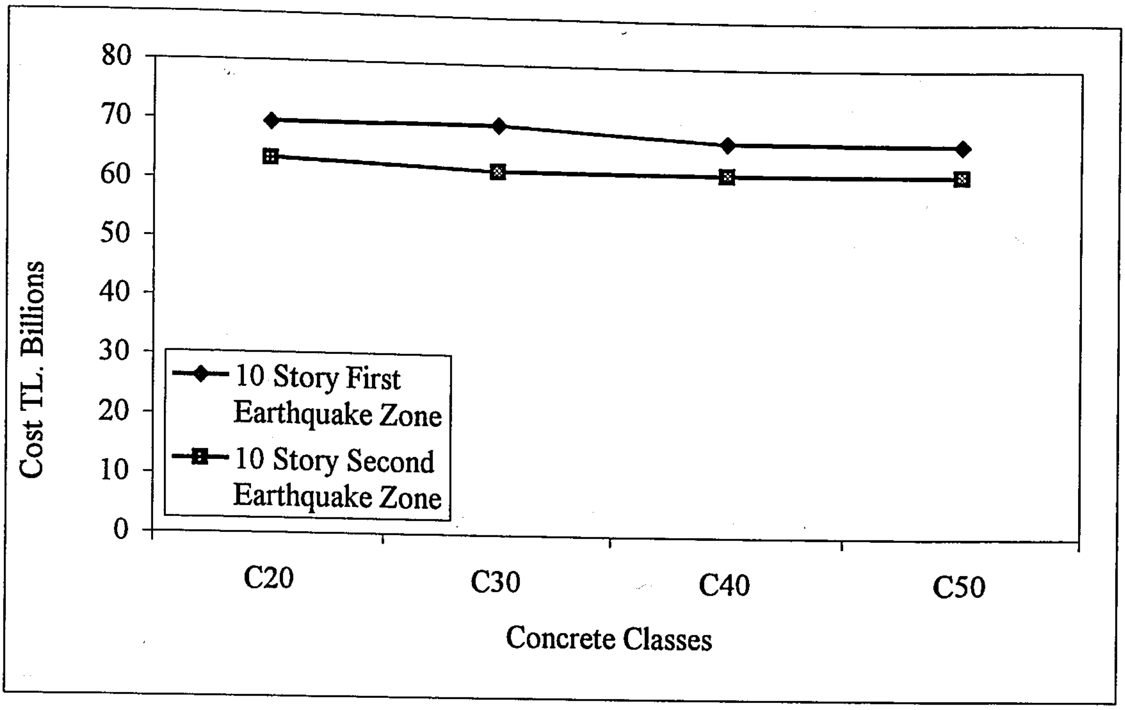

Figure 5.3 Ten story building cost comparison

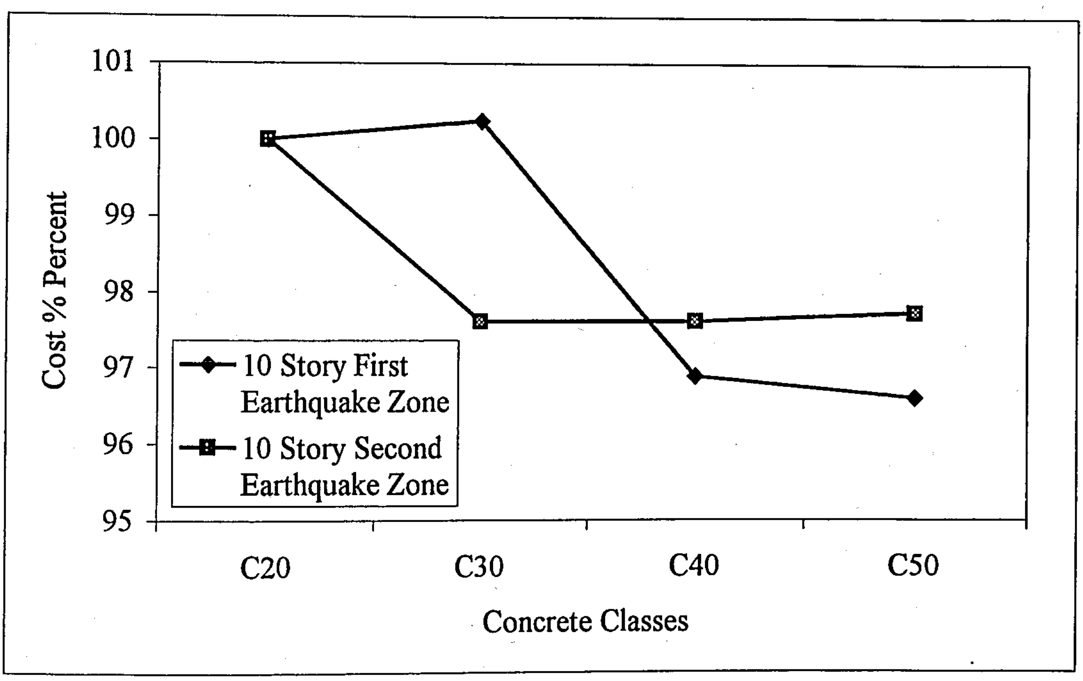

Figure 5.4 Ten story building cost comparison in per cent

However in the second earthquake zone the column dimensions could be decreased to minimum by C30 and could not be decreased any further and the costs begin to increase afterwards.

5.3. Fifteen Story Combination

Fifteen story combinations are summarized in Figure 5.5 as costs and Figure 5.6 as per cents.

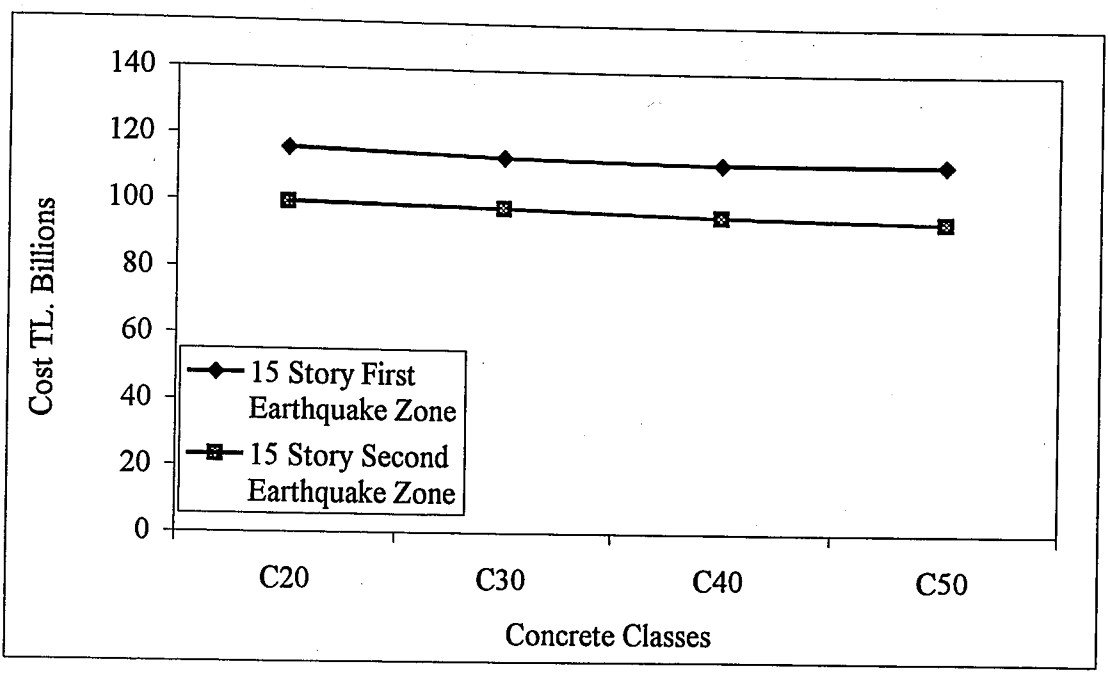

Figure 5.5 Fifteen story building cost comparison

In fifteen story combination the maximum cost difference between C50 and C20 is 2.8 per cent. The cost shows a linear decrease by the concrete class increase, because with each concrete class increase the column dimensions could be decreased. The dimensions get smaller in C50 but the maximum drift allowed is exceeded. So shear walls dimensions can no longer be decreased and the cost show some increase.

In the second earthquake zone there is a greater decrease in the cost. The maximum decrease is 4.4 per cent between C20- C50 classes.

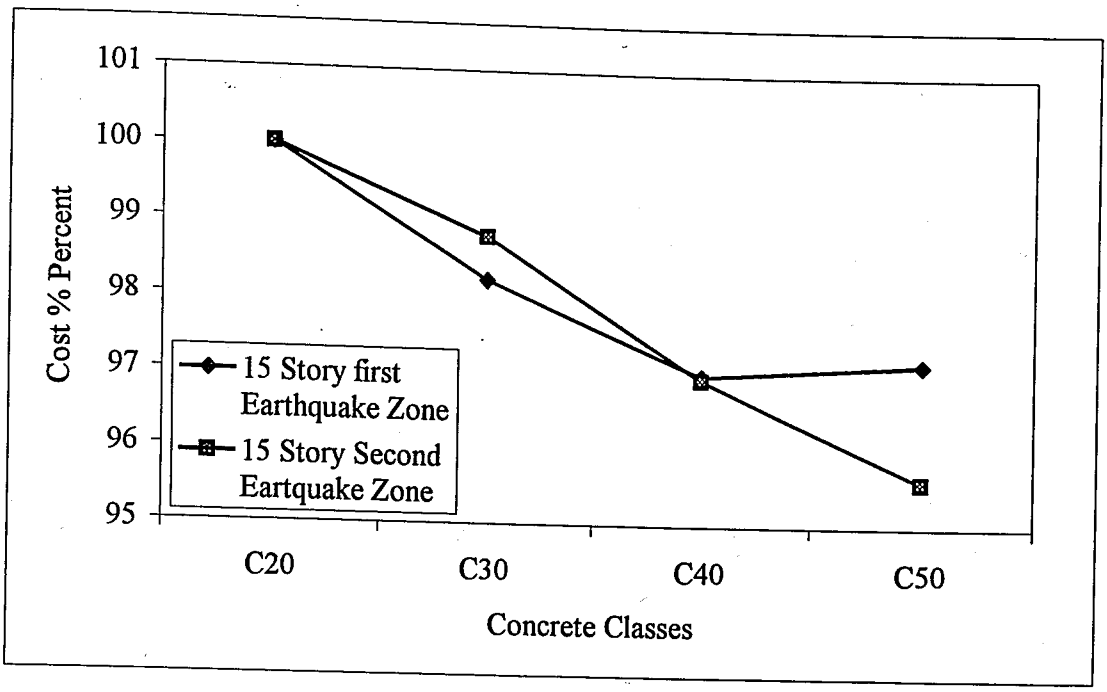

Figure 5.6 Fifteen story building cost comparison in per cent

5.4. Overall Evaluation

It may be thought that the cost decrease about 5 per cent may be neglected. But the research models reveal that with the increase of concrete class the cost does not always decrease.

The dimensions of slabs and beams depend on geometrical reasons as stated before. The moment capacity of the beams therefore is the same for all combinations. Also the beam loadings are nearly the same. So with even decreasing the column dimension, the columns should have the 1.2 times the beams moment strength. With increasing concrete strength the dimensions of the columns can be decreased. But there is a limit for that reduction. In the models for 40cm depth beams are used and for this depth of beam the dimension of the column could not be decreased below 35 cm for even C 50.

The most economic dimension of the columns for the building can be found by using the concrete class that establishes the Turkish Earthquake Code 7.3 requirement with the minimum column dimension. This can be found by trial and error. First the minimum dimension of columns can be found at C50 and then finding the least concrete class that can withstand for that column dimension. This is especially the case for low story buildings. As the building height increases the concrete class increase shows a linear decrease in the costs.

The reason that the decrease does not show a linear decrease in the costs is that the dimensions of the columns or shear walls are changed in 5 cm orders. For example the column dimension for the five-story building remain 40x40 till C 50. But the mid range dimensions like 37 x 37 cm could be used for columns. And if those dimensions were used there would be a linear relationship between the cost decrease and concrete class increase.

There are artificial limitations put by the standards or Turkish Earthquake Code which are drift limits for fifteen story , the Turkish Earthquake Code 7.3 requirement (weak beam strong column requirement) and minimum dimension requirements for shear walls (critical height , minimum width 1/15 of the story height). These specifications limit linear relationship between concrete classes and cost of the buildings.

6. COMPARISON OF SAP2000 RESULTS WITH STA4CAD

6.1. Comparison of Periods between Sta4Cad and SAP2000

In the models for five stories, ten stories and fifteen stories a difference has been found between results of Sta4Cad and SAP2000 especially in periods. The aim of the research is to compare the costs between buildings of the same economy. In the model plans the changing criteria's are concrete class and the shear walls.

So in this part the period change of the model structure will be examined with changing concrete class and shear walls in SAP2000 and Sta4Cad.

6.1.1. Five Story Height

The plan for five story buildings in section 4 is used again. As in section 4 all column dimensions and shear wall dimensions are the same.

6.1.1.1. The Effect of Shear Walls. The period change in models are; 1.7 per cent increase is found in Sta4Cad period and 2.3 per cent increase is found in SAP2000. The periods of five story buildings with different shear walls are in Table 6.1.

Table 6.1. Five story shear wall effect

	Columns	Shear Walls	Concrete Class	Periods Sta4Cad	Periods SAP2000
Model 1	40 x 40 cm	25 x 225 cm	C 20	0.521sec	0.586sec
Model 2	40 x 40 cm	25 x 210 cm	C 20	0.53sec	0.60sec

6.1.1.2. The Effect of Concrete Class. The period increase in models are 4.7 per cent increase is found in Sta4Cad period and 4.5 per cent increase is found in SAP2000. The periods of five story buildings with different concrete classes are in Table 6.2.

Table 6.2. Five story concrete class effect

	Columns	Shear Walls	Concrete Class	Periods Sta4Cad	Periods SAP2000
Model 1	40 x 40 cm	25 x 180 cm	C 40	0.528sec	0.658sec
Model 2	40 x 40 cm	25 x 180 cm	C 20	0.553sec	0.687sec

6.1.2. Ten Story Height

The plan for ten story buildings in section 4 is used again. As in section 4 all column dimensions and shear wall dimensions are the same.

6.1.2.1. The Effect of Shear Walls. The period change is 7 per cent increase is found in Sta4Cad period and 11.5 per cent increase is found in SAP2000. The periods of ten story buildings with different shear walls are in Table 6.3.

Table 6.3. Ten story shear wall effect

	Columns	Shear Walls	Concrete Class	Periods Sta4Cad	Periods SAP2000
Model 1	45 x 45 cm	30 x 220 cm	C 20	0.975sec	1.10sec
Model 2	45 x 45 cm	30 x 250 cm	C 20	1.04sec	1.22sec

6.1.2.2. The Effect of Concrete Class. The period change is; 2.75 per cent increase is found in Sta4Cad period and 2.89 per cent increase is found in SAP2000. The periods of ten story buildings with different concrete classes are in Table 6.3.

6.1.3. Fifteen Story Height

The plan for fifteen story buildings in Section 4 is used again. As in Section 4 all column dimensions and shear wall dimensions are the same.

Table 6.4. Ten story concrete class effect

	Columns	Shear Walls	Concrete Class	Periods Sta4Cad	Periods SAP2000
Model 1	45 x 45 cm	30 x 290 cm	C 30	0.974sec	1.11sec
Model 2	45 x 45 cm	30 x 290 cm	C 20	1.001sec	1.15sec

<u>6.1.3.1. The Effect of Shear Walls</u>. The period change is 3.65 per cent increase is found in Sta4Cad period and 8.16 per cent increase is found in SAP2000. The periods of fifteen story buildings with different shear walls are in Table 6.5.

Table 6.5. Fifteen story shear wall effect

	Columns	Shear Walls	Concrete Class	Periods Sta4Cad	Periods SAP2000
Model 1	50 x 50 cm	25 x 285 cm	C 20	1.42sec	1.51sec
Model 2	50 x 50 cm	25 x 320 cm	C 20	1.36sec	1.39sec

<u>6.1.3.2. The Effect of Concrete Class</u>. The period change is ;1.8 per cent increase is found in Sta4Cad period and 1.89 per cent increase is found in SAP2000.

The periods of fifteen story buildings with different concrete classes are in Table 6.6. As a result the concrete class change has the same effect both in Sta4Cad and SAP2000 in all story heights. The change in the periods are nearly the same.

However when shear wall dimensions are changed the period change in Sta4Cad and SAP2000 are not the same. The increase in period in SAP2000 is more than it is in Sta4Cad. But the difference in periods between Sta4Cad and SAP2000 do not get beyond 0.2 seconds. Because the structural modeling in Sta4Cad and SAP2000 are different from each other.

Table 6.6. Fifteen story concrete class effect

	Columns	Shear Walls	Concrete Class	Periods Sta4Cad	Periods SAP2000
Model 1	45 x 45 cm	25 x 275 cm	C 40	1.41sec	1.58sec
Model 2	45 x 45 cm	25 x 275 cm	C 50	1.39sec	1.56sec

6.2. Member Forces Comparison

For comparison of results a sample model is chosen. The structure is of five stories. The shear walls and the columns have the same dimensions in all stories. The plan view of the project is given in Figure 6.1.

The dimensions of the shear walls and columns are as in Figure 6.2 and Figure 6.3. The dimensions for the project are X=40 cm for columns. And Y=25 cm and Z=225 cm for the shear walls.

The slab is 13 cm and the beams are 25 cm in thickness and 40 cm in depth. The loads are as in Table 6.7.

Table 6.7. Loading for the members

Dead Load for the slabs;	0.523 ton/m^2
Live Load for the slabs;	0.15 ton/m^2
Dead Load for Beams;	1.04 ton/m

6.2.1. Sta4Cad

The information given above is given as input to the program. The periods found for the columns are as in Table 6.8. The earthquake forces are as in Table 6.9. The shear wall base moments are in Table 6.10.

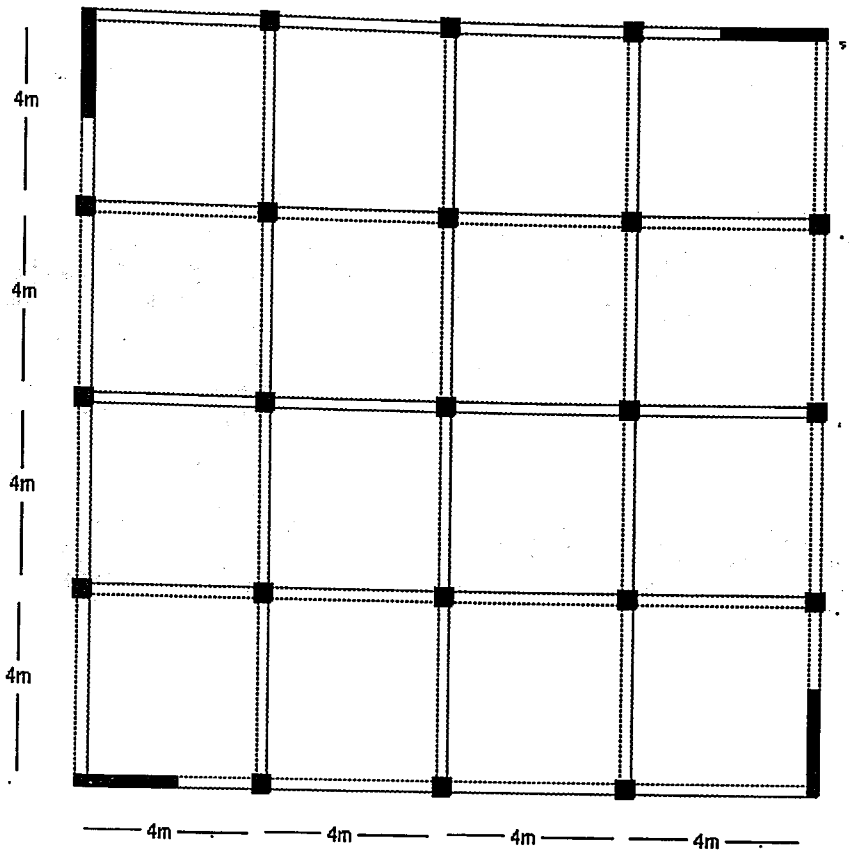

Figure 6.1. Sample plan for member forces comparison

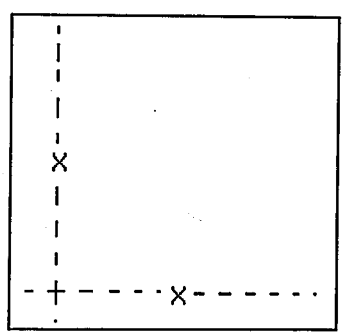

Figure 6.2. Columns

Figure 6.3. Shear wall

Table 6.8. Periods found from Sta4Cad

Mod	Tx (s)	Ty (s)	Té (s)
1	0.521	0.521	0.377

Table 6.9. Earthquake forces applied in Sta4Cad

Floor	H(m)	Wg(ton)	Wq(ton)	Earthquake Forces(ton)
1	3	295.13	38.05	14.673
2	6	295.13	38.05	29.212
3	9	295.13	38.05	43.818
4	12	295.13	38.05	58.425
5	15	295.13	38.05	73.031

6.2.2. SAP2000

The member dimensions and the loads are given to the SAP2000 program. The 3D view is given in Figure 6.6. The period is found as 0.5862 seconds. Mass of each floor is 295.13 ton. The earthquake forces 5 per cent eccentricity is given from one direction. So the loads will be compared under this assumption. Since the base type is Z4 from the spectra the acceleration S(T)=2.5 from the Table 6.6 in Turkish Earthquake Code 6.4.4. So the earthquake loads are found from Equation 6.1 which is the requirement in Turkish Earthquake Code. The weight is calculated with equation 2.12 and 2.13. Equation 2.19 finds total shear and shear force and equation 2.21 finds the shear force for each story.

Table 6.10. Shear wall base moments found in Sta4Cad

Shear Walls	M_x (ton.m)
SK 101	5.46
SK 105	322.31
SK 121	369.34
SK 125	6.15

The earthquake forces found for each floor are same as found in Sta4Cad for SAP2000 and the applied forces are given in Table 6.11.

Table 6.11. Earthquake forces applied in SAP2000

Floor	Earthquake Forces
1	14.7 ton
2	29.2 ton
3	43.8 ton
4	58.5 ton
5	73.1 ton

The forces are applied in several load combination multipliers to SAP2000 which are given in Table 6.12.

As can be seen form Table 6.12 the earthquake load is applied from one side X –5 per cent eccentricity. The frame forces will be compared in detail.

Table 6.12. Combinations applied in SAP2000

	Combination 1	Combination 2	Combination 3	Combination 4	Combination 5
G	1.4	1	1	0.9	0.9
Q	1.6	1	1	0	0
E	0	1	0	1	0
EE	0	0	1	0	1

In SAP2000 the base reactions for the shear walls are as follows. From SAP2000 the shear wall moment base moment is found as in Figure 6.4. The reactions are known from the analysis.

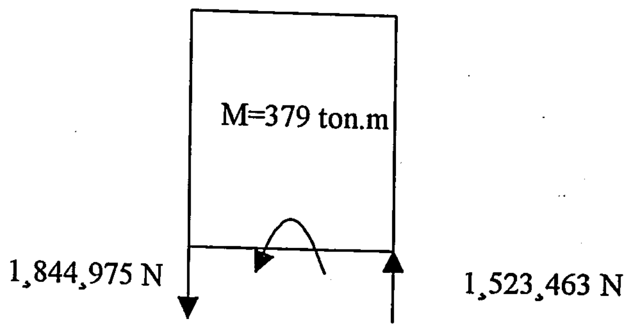

Figure 6.4. Base moments of shear walls

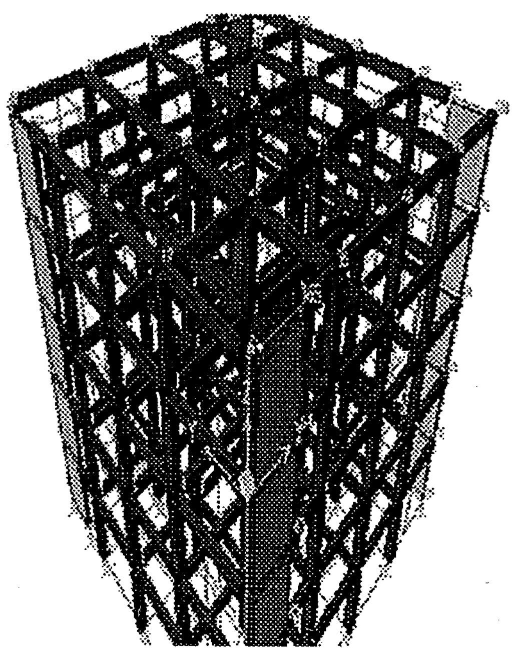

Figure 6.5. SAP2000 3-D model view

6.2.3. Member Forces

In Figure 6.7 and 6.8 the members are shown whose forces are compared. In Table 6.13 and Table 6.14 the member forces are given. The member forces with the maximum value are compared. For both cases all the combinations in TS 500 [5] are applied.

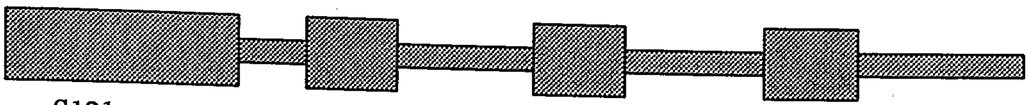

Figure 6.6. Plan view of shear wall and column frame

Table 6.13. Comparison of member forces frame with shear wall

Column	Sta4Cad		SAP 2000	
	M_{down}(ton.m)	M_{up}(ton.m)	M_{down}(ton.m)	M_{up}(ton.m)
S121	369.34		379	
S122	6.729	4.891	6.640	4.331
S123	5.927	3.117	5.578	2.084
S124	5.875	3.008	5.572	2.073

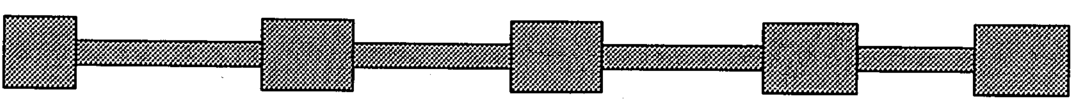

Figure 6.7. Plan view of a frame without shear wall

Table 6.14. Comparison of member forces in frame without shear wall

Column	Sta4Cad		SAP 2000	
	Mdown(ton.m)	Mup(ton.m)	Mdown(ton.m)	Mup(ton.m)
S116	5.408	1.696	4.05	1.04
S117	6.406	3.773	5.45	2.043
S118	6.32	3.595	5.403	2.03
S113 (Mid column)	6.543	3.719	5.226	1.969

6.3. Comparison of Results

In the SAP2000 the shear walls are taken as finite elements. In the Sta4Cad manual it also admits the fact that the values of finite element solutions differ from the Sta4Cad results because of its modeling difference.

As remarked in the manual of Sta4Cad the shear walls modeling take less part of the forces. So the forces of shear walls are higher in SAP2000 and the results of the columns are relatively less than found in Sta4Cad.

The frame element forces are nearly the same for the elements. The comparison of frame member forces as can be seen in Table 6.13 and Table 6.14 for the same loading combination. (EE: Earthquake loads with eccentricity 5 per cent). But the difference remains below 20 per cent and the Sta4Cad results are at the safe side.

The shear walls, which is S121 column, base moments are compared in Table 6.13. The difference between base moments is 3 per cent.

Manually finding the forces by use of SAP2000 requires a higher expertise. The results of the project can be taken from Sta4Cad like programs easily. But one should know the result performance of the program on the similar project.

This kind of programs finds the required reinforcement and, draws the reinforcement details and required amount of materials automatically. This gives the designer a chance to change the dimensions of the members easily. But again it should be emphasized that the program's performance on similar models should be compared with a model solved in SAP2000 like structural analyze programs.

7. CONCLUSIONS AND RECOMMENDATIONS

According to structural analyses following results are derived from the models:

- The use of higher quality concrete especially in vertical members decreases the dimensions. In five story combination the minimum column dimensions 40 x 40 cm for C20 but decreases to 35 x 35 cm for C50.
- With the increase in concrete quality total weight decreases and less earthquake loads applies on the building. In fifteen story combinations the lateral loads for C20 is 453 ton and for C50 it is 445 ton.
- In higher number of story buildings the use of higher quality concrete causes larger decrease on the vertical components' size and relatively higher per cent of cost decrease is seen. In five story combinations the cost decrease is 2.8 and for fifteen story the decrease is 4.4 per cent in first earthquake zone when the concrete class increase from C20 to C50.
- The cost advantage of using higher quality concrete may be relatively small but other advantages such as durability and increase in the usable area of the building should not be neglected. The usable area increase in five story combination between C20 and C50 is 0.6 per cent. The durability is increased since there is a lower water cement ratio in higher quality concrete and the penetration of hazardous ions is lower. With the increase in durability the service costs are lower. These should be included when whole life costs are compared. This research includes only initial costs.
- The cost decrease sometimes does not show a linear relationship between concrete class and the cost of the building. The cost of ten stories with C30 in first earthquake zone increases 0.3 per cent with respect to C20 combination.
- The design program's performance on similar models should be compared with a model solved in structural analysis programs. The models are also calculated in SAP2000 the difference remained below 0.2 seconds and 15 per cent.
- The results are found on a general structural type columns with shear walls but to generalize the results other type of structures has to be taken in to account.

- There are artificial limitations set by the specifications and these restrictions make it difficult to propose a smooth and fixed sound continuous relationship between concrete quality and cost.

APPENDIX A: CONCRETE CLASSES TO BE USED IN BUILDINGS

In EN 206 – January 2001[12] the minimum concrete classes to be used are as in Table Appendix A.1. The minimum concrete class starts with C12. But this concrete can be used for XO exposure class. This concrete should be without reinforcement or embedded metal: All the other exposure classes require higher concrete classes. This is because of durability reasons. There is a concrete class limit for the exposure class. The normal exposure class for a building starts with XC1 (mid range humidity exposure class) and for this exposure class minimum concrete strength is C 20.

Same as in EN 206 new TS 11222- February2001 the same exposure classes are accepted. The same rules apply for TS 11222. So the concrete classes to be start with C 20 in TS 11222. The highest concrete class is C100 in TS 11222.

In Turkish Earthquake Code section 7.2.5.1. In all reinforced concrete structures lower than C16 class concrete cannot be used. And in 1st and 2nd Earthquake Zones in buildings with I=1.4 and I=1.5 importance factor and high ductile framed structure C20 or higher classes should be used.

In Turkish Building Code TS 500 the concrete classes are C16¸ C18¸ C20¸ C25¸ C30¸ C35¸ C 40¸ C 45¸ C 50.

Table A.1 Recommended limiting values for composition and properties of concrete for carbonation exposure

	No risk of corrosion or attack	Carbonation-induced corrosion			
	X0	XC1	XC2	XC3	XC4
Maximum w/c	---	0.65	0.60	0.55	0.50
Minimum strength Class	C12/15	C20/25	C25/30	C30/37	C30/37
Minimum cement content (kg/m^3)	---	260	280	280	300

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