Evaluation of Existing Reinforced Concrete Buildings with Structural Package Programs

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ABSTRACT

Seismic performances of the structures shall be investigated due to lack of strength, seismic forces and change of intended purpose. Package softwares are developed to perform the complicated performance analyses easily. However, engineers must investigate the efficiency of these softwares. In this study, three different packaged softwares are used to compare the linear performance analyses according to Turkish Seismic Code-2007. Since non-linear performance analysis methods are not available in all programs, it is not taken into consideration in the scope of this study.

Linear performance analysis of five different reinforced concrete (R/C) structures such as column-beam frame systems and systems with shear walls are analyzed and seismic performances are obtained. Furthermore, performance values are inclusively compared with figures. The reasons of the differences are presented. With the analyses, r values differ from each other. The main reason of this situation is the difference in remnant moment and efficient moment values. Modeling techniques also affect this case. According to the results, seismic performances of structures that have basic geometry, small sections and less irregularities are close each other. On the other hand, the results become different with the irregularity. Especially, seismic performances of the structures with shear walls differ from each other due to the various acceptances.

INTRODUCTION

98 % of Turkey's total population and 96 % of the surface area are at the risk of an earthquake. In addition, 42% of the country's surface area and 44% of the population are located in the first degree seismic zone. Our country, which is in seismic belt, has been exposed to large earthquakes for centuries. Especially 1992 Erzincan, 1995 Dinar, 1998 Adana-Ceyhan, 1999 Kocaeli, 1999 Düzce, 2003 Bingöl earthquakes recently revealed that existing buildings should be examined and design methods to be used for new buildings should be reexamined. Many of the concrete buildings in those areas were damaged and/or destroyed due to their design, shortage of materials and workmanship in the earthquakes mentioned hereinabove.

In this study, existing building evaluations of 5 different buildings were examined via X, Y, Z which are commonly used by engineers. As a result of this evaluation, it was analyzed whether differences between programs occurred or not. In package programs used for existing structure evaluations, element damage levels, in the event of a probable difference occurring between building target performance levels, the reasons were examined. Various reinforced concrete buildings being regular, having irregularities at the horizontal and vertical levels were addressed.

BUILDINGS AND PERFORMANCE ANALYSES

In this section, an analysis with commercial package programs which are the subject of this study was carried out. To determine earthquake performances, linear elastic analysis was performed and results obtained were presented comparatively.

Type A building is shown at Figure 1. It consists of short direction, single space and space length is 5 m, the long direction consists of two spaces and its space length is 3 m. Its floor height is 3 m. Flooring system of the building is plate floor and its thickness is 12 cm.

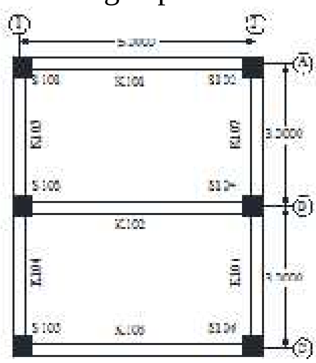

Figure 1. Plan view of type A building

All beams in the ground floor and normal floors are designed as 25x50 cm dimension. Column dimensions are 40x40 cm. Quality of outfit steel is S220. Concrete compressive strength to be the basis for reinforced concrete building to verify calculations is 20N/mm^2. According to ground survey reports, local ground class was determined as Z3. Building is in the first degree seismic zone. Effective earth acceleration coefficient is A_0=0.40g. Floor dead load is 0.45 t/m^2 and floor moving load is 0.35 t/m^2. Wall load in the building was not considered. Finite element models created with commercial package programs of building are shown in Figure 2.

Figure 2. The models of type A building prepared with package programs

Type B building addressed within the scope of the project comprises of frame systems. Flooring system of the building is plate flooring and its thickness is 15 cm. All beams in the ground and all normal floors were designed in 25x45 cm dimension.

Its column dimensions are 45x45 cm. Quality of outfit steel is S420. Concrete compressive strength to verify calculations is 20 N/mm^2. According to ground survey reports, local ground class was determined as Z2. Effective ground acceleration coefficient is A_0=0.40g.

Floor dead load is 0.5 t/m^2 and floor moving load is 0.3 t/m^2. Walls in the building are 9 cm in thickness and height is 2.7 m. Walls outside the building are 19 cm thick and their height is 2.75 m. Plan view of structure is shown in Figure 3. Finite element models created with commercial package programs of structure are shown in Figure 4.

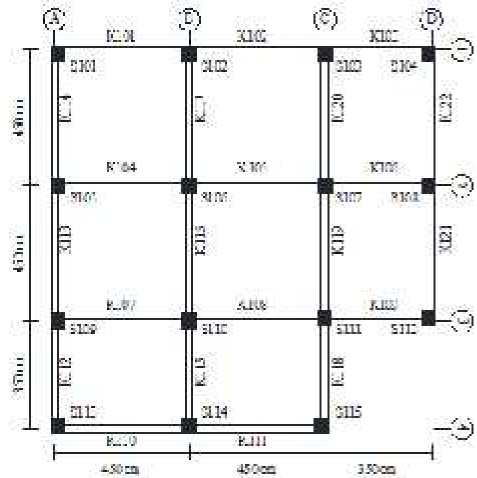

Figure 3. Plan view of type B building

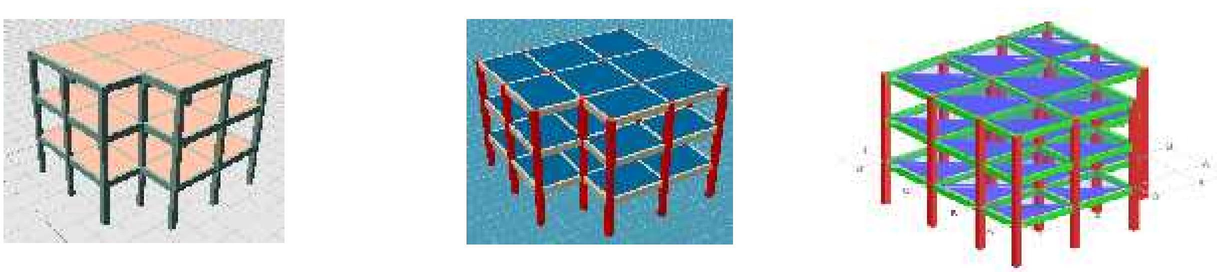

Figure 4. The models of type B building prepared with package programs

Type C building addressed within the scope of the project is used as school building. Building has 4 floors and its floor height is 3.4 m. Column application plan of the building is shown in Figure 5. Concrete and steel class used for structure is C16 and S220. Since the building is a school building, floor moving load is 0.3 t/m^2 and dead load is 0.5 t/m^2. All beam dimensions are 25x50 cm. Wall loads inside the building are 9 cm and height is 2.9 m and walls outside the building are 19 cm and height is 2.9 m.

According to ground survey reports, local ground class was determined as Z2. Seismic zone is at zone 1. Effective ground acceleration coefficient is A_0=0.40g. Carrier system consists of shear walls in both directions and frames. Shear walls being 30 cm in thickness and 6 m in length in the short direction and shear walls being 25 cm in thickness and 4.15 m in length in the long direction of the building were used. Finite element models created with commercial package programs for the building are shown in Figure 6.

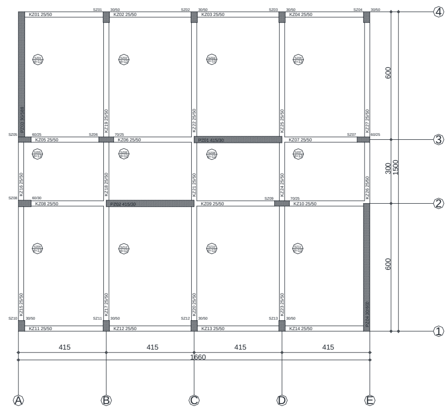

Figure 5. Plan view of type C building

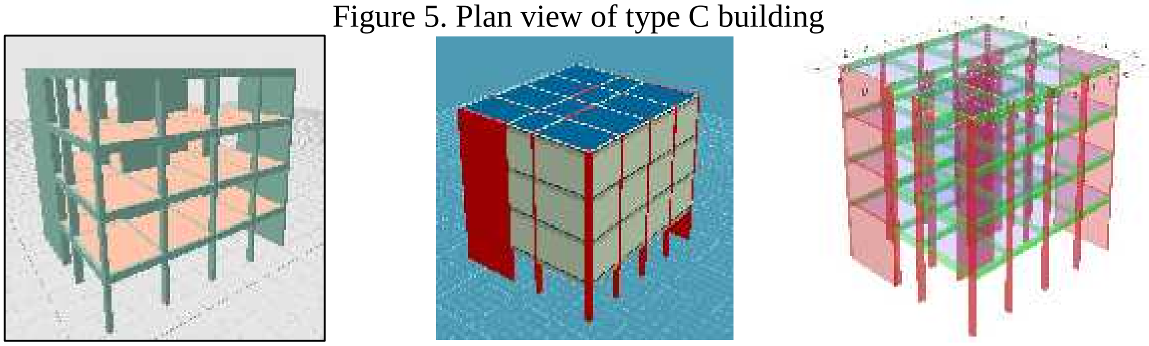

Figure 6. The models of type C building prepared with package programs

Type D building examined within the scope of the project was used for residential building and collapsed during 19th August 1999 Kocaeli earthquake [30]. Building consists of ground and 4 normal floors. Plan view of structure is shown in Figure 7.

Floor height is 4 m for ground floor and 2.8 m for normal floors. The concrete and steel class to be used for the building is C16 and S420. Since the building is the residential building, its floor moving load is 0.2 t/m^2 and its floor dead load is 0.523 t/m^2. All beam dimensions are 25x60 cm. Wall loads inside the building are 9 cm and 2.8 m height and wall loads outside the building are 19 cm and 2.8 m height. According ground survey reports, local ground class was determined as Z3. Seismic zone is at zone 1. Moving load contribution coefficient is n=0.3. Carrier system consists of frames in both directions and elevator shear walls. Dimensions of elevator shear walls are 1.5x1.7x0.25 m. Structure plan and finite element models created with commercial package programs of structure are shown in Figure 8.

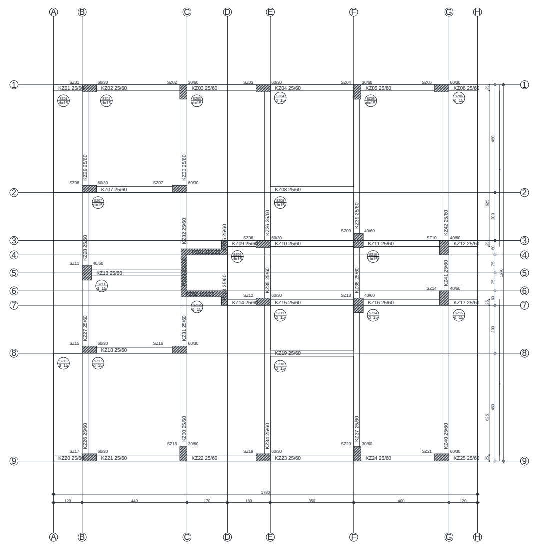

Figure 7. Plan view of type D building

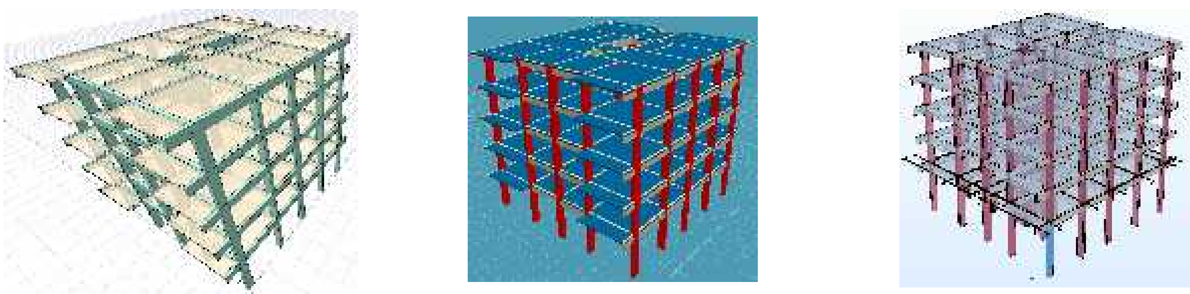

Figure 8. The models of type D building prepared with package programs

Existing reinforced concrete type E building is 6-floor and was built in 2011 and column-beam lay-out of the building is shown in Figure 9.

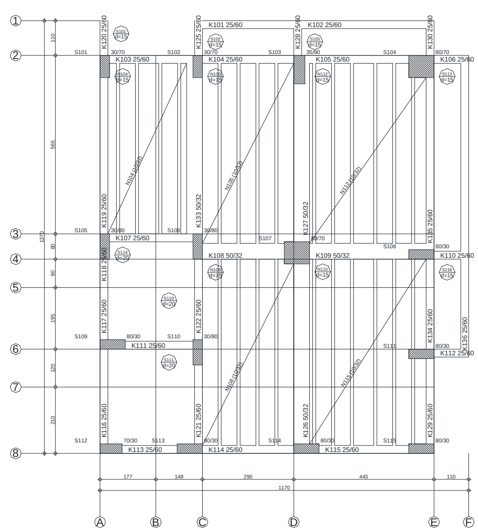

Figure 9. Plan view of type E building

Floor heights of building were arranged as basement floor being 2.70 m, ground floor being 4.70 m and 1., 2., 3. and 4. floors being 2.70 m. Knowledge level for the building is comprehensive and its knowledge level coefficient is 1. Its concrete compressive strength is 30 MPa. Its building steel is S420. As a result of tests, building is in Z3 ground class and its ground allowable stress was calculated as 15.20 t/m^2.

COMPARISON OF PERFORMANCE ANALYSIS RESULTS

Knowledge levels of type A B,C, D and E buildings are moderate and knowledge level coefficients are 0.9. Design earthquakes at the level of 10% having the possibility of exceeding in 50 years were implemented and whether the buildings met the level of life safety performance or not were examined by linear elasticity elastic method. Behaviour coefficients of carrier system were taken as R=1.

Performance level of type A building by the damage conditions determined with package programs is shown in Table 1 and considering the damage conditions of the structural elements, it was observed that life safety performance level was met.

Table 1. Linear performance levels of type A building

	Dir.	**X**	**Y**	**Z**
Type A	+EX	Life Safety	Life Safety	Life Safety
	-EX	Life Safety	Life Safety	Life Safety
	+EY	Life Safety	Life Safety	Life Safety
	-EY	Life Safety	Life Safety	Life Safety

r values calculated by all programs were found to be close values and all columns were at minimum damage level. Excess capacity moment values calculated with Y were observed as lower than values calculated with other programs. Excess capacity moments calculated with X had the biggest values. On the contrary, impact moments calculated with Z are bigger than the values calculated by other two programs. Z program calculated bigger collapsing capacity compared to other programs. Calculated collapsing force values are close value in each three program. It was observed that r values calculated by X and Y were close to each other but because Z calculated low impact moments, it calculated lower r than other programs. After damage conditions of the elements are determined, performance level of the building is determined. Performance level of the type B building is presented in Table 2.

Table 2. Linear performance levels of type B building

	Dir.	**X**	**Y**	**Z**
Type B	+EX	Life Safety	Collapse Prevention	Life Safety
	-EX	Life Safety	Life Safety	Life Safety
	+EY	Life Safety	Collapse Prevention	Life Safety
	-EY	Life Safety	Life Safety	Life Safety

Although performance levels of the building found with X and Z meet the life safety level, Y points out that building is at the level of collapsing.

Excess capacity moments calculated with X are higher than other programs. In addition to this, impact moments calculated with Y are higher than the values calculated with other programs. Greater collapsing capacity was calculated with X compared to other programs.

Moreover, calculated collapsing force values were taken as the lowest values in X program. It was seen that r values calculated by all programs were close to each other and all columns were at minimum damage level.

It was determined with three programs that all of the columns acted ductile. Although significant differences are not applicable for bending angle for shear wall elements, there are significant differences for collapsing calculations. Owing to the fact that Z calculates collapsing forces in the shear walls more than other programs, shear walls acted as the fragile elements. X showed that shear walls of floor 2 and 3 were fragile in the direction Y and half of shear walls of floor 1 were fragile in the direction Y. In addition to this, collapsing capacities were calculated as close to each other in three programs. It was seen that excess capacity moment values calculated with Y were lower than the values calculated with other programs. Excess capacity moments calculated with Z have the highest values. On the other hand, impact moments calculated with Y are higher than the values calculated by other two programs. Impact moments calculated with Z were quite lower compared to impact moments calculated with other programs. Since Z program calculates low impact moments, lower r values are found compared to other programs. Performance level of the type C building is presented in Table3. The level of earthquake performance of type C building based on the damage condition of structural elements is at the collapsing level in three programs.

Table 3. Linear performance levels of type C building

	Dir.	X	Y	Z
Type C	+EX	Collapsing	Collapsing	Collapsing
	-EX	Collapsing	Collapsing	Collapsing
	+EY	Collapsing	Collapsing	Collapsing
	-EY	Collapsing	Collapsing	Collapsing

Performance level of the type D building is presented in Table 4. Earthquake performance level of type D building was determined as the collapsing in three programs based on damage conditions of structural elements. The building is a building collapsing during Kocaeli earthquake in 1999.

Table 4. Linear performance levels of type D building

	Dir.	X	Y	Z
Type D	+EX	Collapsing	Collapsing	Collapsing
	-EX	Collapsing	Collapsing	Collapsing
	+EY	Collapsing	Collapsing	Collapsing
	-EY	Collapsing	Collapsing	Collapsing

Performance level of the type E building is presented in Table 5. Level of earthquake performance level of type E building based on the damage conditions of structural elements is collapsing in three programs. Floors of 2, 3 and 4 were shown in the collapsing zone in the control of Z relative floor displacement.

Table 5. Linear performance levels of type E building

	Dir.	X	Y	Z
Type E	+EX	Collapsing	Collapsing	Collapsing
	-EX	Collapsing	Collapsing	Collapsing
	+EY	Collapsing	Collapsing	Collapsing
	-EY	Collapsing	Collapsing	Collapsing

RESULTS AND DISCUSSION

Performance analysis of 5 buildings (Types A, B, C, D and E) were carried out with structural package programs in this study. Level of earthquake performance of type A building having a simple carrier system was determined as life safety with all three programs. All of the columns are at the level of SD as found by three programs. Some of beams are at the level of SD and some of them are at the level of MD. Level of earthquake performance of type B building with A3 irregularity was determined as life safety with X and Z. While the building is at the level of pre-collapsing in the directions of +X and +Y with Y it is at the level of life safety in the directions of –X and –Y. All columns are at the level of SD in three programs. It was seen that some beams were at the level of SD and some of them were at the level of MD in the analysis carried out with X and Z. However since Y calculated that significant parts of ground floor beams exceeded the level of HD, it shows that the building is at the level of pre-collapsing. It was determined that earthquake performance of type C building having shear wall-frame system was at the level of collapsing with all three programs. All of the columns are at the level of SD as found with Y and Z. It was seen that only one column at the ground floor and floor 1 was about to collapse with X. Earthquake behaviour of shear walls shows significant differences in every program. Although it was seen in Z and X that some parts of shear walls were at the level of CD, it was observed that shear walls were at the levels of SD and MD with the analysis. Beams do not display very significant differences as the shear walls. Although all beams were found at the level of SD with Z, some beams were found at the level of advanced damage with X. Significant parts of beams were found at the level of CD with Y. Type D building comprising of elevator shear walls and column beam frame systems was exposed to 1999 Kocaeli earthquake and collapsed with the effect of this earthquake. When the building was analyzed with package programs, it was observed that earthquake capacity was not sufficient. Type D building is at the level of collapsing by three programs. It was designated that majority of columns were at the level of collapsing with Z, X and Y. Considering beams, it was seen that all beams were at the level of SD and MD as per Z program, beams in the ground floor and normal floor 1 were at the level of collapsing in the rate of 15-20% as per X and Y. In conclusion, it is a significant fact that this building collapse during the earthquake is found at the level of collapse based on the analysis results of three programs. It was observed that earthquake performance of reinforced type E building comprising of column beam frame systems and basement shear walls was at the level of life safety as found with Z and X. However, Y showed that the building under the effect of earthquakes applied in all directions was at the level of pre-collapsing. Columns are at the levels of SD and MD as per Z and X. However, Y showed that approximately 15% of columns on floors 1, 2 and 3 exceeded the level of HD. Considering the beams, while all beams are at the level of SD as per Z program, they are at the levels of SD and MD as per Y. Some of beams are at the level of fragile and CD as per X. While shear walls display fragile behaviour as per Y, they are at the level of SD as per Z and X. In addition to this, floors of 2, 3, and 4 were in the zone of collapse in Z relative floor displacement control.

CONCLUSIONS

5 different buildings were examined with Z, Y, X being package programs used to evaluate the existing building in this study. Since non-linear calculation was not taken into consideration in some of these programs, existing buildings were evaluated with only linear analysis methods.

r values calculated with programs showed differences in the analysis. The most significant reason for it is that excess capacity moment and impact moment calculated by the programs varied. Moreover, differences of modeling techniques affect it. Based on the results achieved, it was observed that earthquake performances of the buildings with fewer irregularities, geometries of which were simple, dimensions of which were small determined with package programs were close to each other. However as the geometry becomes more and more complex, results become distant. Especially earthquake performances of the shear wall buildings become distanced from each other due to different acceptances.

Programs show differences at modeling and structural analysis stages. One of them is the acceptance of the column-beam joint areas. The other one is the way of joining of beams to the shear walls. Moreover, way of joining columns to the shear walls shows differences in each program. Cracked section inertia moment is very important for performance analysis. While X and Z determines the cracked section inertia moments in accordance with Turkish earthquake regulations-2007 as not being at the discretion of the user, Y requires the user to apply inertia moment reduction coefficient. Shear wall behaviours of the buildings with rigid ground floor show significant differences.

X and Z determined cracked cracking inertia moments without leaving user compliance with Turkish Earthquake Code-2007, Y request user enter inertia moment decreasing coefficient. Shear wall behaviors in rigid basement floor structures show significant differences.

It should not be forgotten that results obtained are limited to examples analyzed. It is expected that generalizations will be better by increasing analysis examples in less, medium and multi-floor buildings having different irregularities in vertical and horizontal direction.

ACKNOWLEDGMENTS

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