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Research Article

Evaluation of Different Strengthening Projects of Yenice Kalaycılar Primary School According to 2007 and 2019 Turkish Earthquake Regulations

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Abstract

Earthquakes that frequently occur in Turkey may cause structural damage in structures, and/or existing structures cannot provide the new earthquake code requirements. This matter requires us to check the static suitability of existing structures and strengthen them when necessary. In this article, a comparative evaluation of two different strengthening projects, which are considered to be implemented in Kalaycılar primary school in Yenice district of Karabük province, according to 2007 and 2019 Turkish earthquake regulations, is made. For this purpose, the survey projects of the said school building were first prepared, and laboratory experiments were carried out according to the level of comprehensive knowledge. Then, according to the findings obtained from the laboratory experiments, the performance analyses of the school building in question were made according to the 2007 and 2019 Turkish earthquake regulations. According to carried out the performance analyses, two different strengthening projects prepared for the school building have presented some results and suggestions by comparing the 2007 and 2019 Turkish earthquake regulations. The findings obtained reveal that there is more than one option for strengthening a reinforced concrete structure, and all parameters should be evaluated together when deciding to strengthen the structure in question.

Keywords: Reinforced concrete buildings, repair-strengthening, performance analysis

2007 ve 2019 Türk Deprem Yönetmeliklerine Göre Yenice Kalaycılar İlkokulunun Farklı Güçlendirme Projesinin Değerlendirilmesi

Öz

Türkiye'de sıklıkla meydana gelen depremler yapılarda yapısal hasarlara neden olabilmekte ve/veya mevcut yapılar yeni deprem yönetmeliği gerekliliklerini sağlayamamaktadır. Bu husus mevcut yapıların statik açıdan uygunluğunu kontrol etmemizi ve gerekli durumlarda güçlendirilmesini gerektirmektedir. Bu makalede Karabük ili Yenice ilçesindeki Kalaycılar ilkokulunda uygulanması düşünülen iki farklı güçlendirme projesinin 2007 ve 2019 Türk deprem yönetmeliklerine göre karşılaştırmalı değerlendirilmesi yapılmaktadır. Bu amaçla önce söz konusu okul binasının rölöve projeleri hazırlanmış ve kapsamlı bilgi düzeyine göre laboratuvar deneyleri gerçekleştirilmiştir. Daha sonra laboratuvar deneylerinden elde edilen bulgulara göre söz konusu okul binasının 2007 ve 2019 Türk deprem yönetmeliklerine göre performans analizleri yapılmıştır. Yapılan performans analizlerine göre okul binası için hazırlanan iki farklı güçlendirme projesi 2007 ve 2019 Türk deprem yönetmeliklerine göre karşılaştırılarak bazı sonuçlar ve öneriler sunulmaktadır. Elde edilen bulgular betonarme bir yapının güçlendirilmesinde birden fazla seçeneğin olduğu ve söz konusu yapının güçlendirilmesine karar verilirken tüm parametrelerin birlikte değerlendirilmesi gerektiğini ortaya koymaktadır.

Anahtar Kelimeler: Betonarme binalar, onarım-güçlendirme, performans analizi

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1. Introduction

Due to its location, Turkey is a critical region in terms of seismicity. Therefore, earthquake-resistant building design is very important for civil engineers in Turkey [1, 2, 3, 4]. On the other hand, it is compulsory to evaluate the existing buildings, with economic factors being the main effect. For this reason, the number of buildings whose performance analysis has been carried out has been increasing recently. The earthquake codes used for this purpose allow the application of many methods for performance analysis and strengthening existing buildings.

After the recent earthquakes in Turkey, it has been seen that many reinforced concrete structures need to be repaired and strengthened. As a result of the observations and performance analyses made in reinforced concrete structures, it has been understood that the lateral stiffness of most of them is insufficient [5]. Cast-in-situ shear walls are the most preferred and applied strengthened methods that will provide lateral rigidity to the structure in question in reinforced concrete structures. However, applying this strengthening method is a disadvantage as the structure in question is emptied and cannot be used for a long time. For this reason, many researchers have turned to developing structurally effective, easy-to-apply, and economical strengthening methods [6-12]. In addition, in some references, design principles related to the evaluation and strengthening of existing buildings according to Specification for Buildings to be Built in Seismic Zones (SBBSZ) and Turkish Building Earthquake Code (TBEC) were given comparatively [5, 13].

After the last earthquakes in our country, administrations demand performance states of public buildings hence performance analyses. The performance status of public buildings for which performance analysis is requested (especially in buildings designed according to the 2007 earthquake regulation but not completed) is evaluated according to the regulations of the year they were built. When this is the case, it is aimed to reveal the performance differences between earthquake codes in this article. On the other hand, both the administration's requested issues and the cost of the retrofitting processes to be made by the owner reveal different results according to the regulations.

Since Karabük province is a critical region in terms of seismicity, it is very important to examine the school buildings that have completed their economic life according to the current regulations. In this article, a reinforced concrete school building was chosen as an example to obtain information about the static sufficiency of school buildings. Laboratory studies were performed first according to the comprehensive knowledge level specified in the TBEC. Then in the light of the data obtained from the experiments, the school building in question performed performance analyses by modeling in the Sta4-CAD program [14]. The findings obtained from the structural analyses were evaluated according to the SBBSZ and TBEC, and strengthening methods were proposed [15, 16].

2. Gathering Information About Kalaycılar Primary School

This study examined Kalaycılar primary school, located in the Yenice district of Karabük province. Kalaycılar primary school was chosen as the sample school building because the cost of strengthening is rational compared to the cost of rebuilding, and it has not completed its economic life. Kalaycılar primary school structural system consists of a 3-story reinforced concrete frame and shear wall, and the construction year was 2005. Accordingly, the school building consisting of ground, 1st and 2nd normal storeys is 1051,02 m² in total (see Figure 1). The ground storey of Kalaycılar primary school is 3,55 m high, and the 1st and 2nd typical storeys are 3,15 m high. Since no project exists for the mentioned school building, static and architectural survey projects were prepared [13]. On the other hand, the performance results of the said school building are more likely to be sufficient according to today's regulations. Experimental studies were carried out according to the comprehensive knowledge level of the school building whose projects were prepared. Accordingly, 4 core sampling were taken from each storey (see Table 1). From this table as a TBEC condition, when the bigger *average-standard deviation* or *0,85*average* values is considered as the existing concrete compressive strength, 20 MPa on the ground storey, 13 MPa on the 1st storey, and 12 MPa on the 2nd storey are considered. In addition, the detection of destructive reinforcement (peel test) was carried out with 4 structural elements on the ground storey and 3 structural elements on the other storeys. In addition, the non-destructive reinforcement detection method (X-ray) was performed on 40 structural elements throughout the building (see Figure 2~Figure 4). The studies performed on detecting destructive reinforcement in the said school building are shown in Figure 5 and Figure 6.

Figure 1. A view of the Kalaycılar primary school building

Table 1. Obtaining the average pressure values for the existing drilling core results of Kalaycılar primary school

Storeys	Compressive Strength (N/mm²)	Evaluation of the lowest value	Standard deviation values (SD)	Average SD	Average*0,85
Ground storey	15,89	21,38*0,75=16,04 16,04 > 15,89	0,85	20,53	18,17
	20,88				
	22,37				
	20,90				
1st storey	10,03	16,14*0,75=12,105 12,105 > 10,03	4,46	11,68	13,71
	15,96				
	20,69				
	11,77				
2nd storey	19,39	15,73*0,75=11,8 11,8 < 12,32	3,1	11,78	12,64
	12,32				
	13,71				
	14,11				

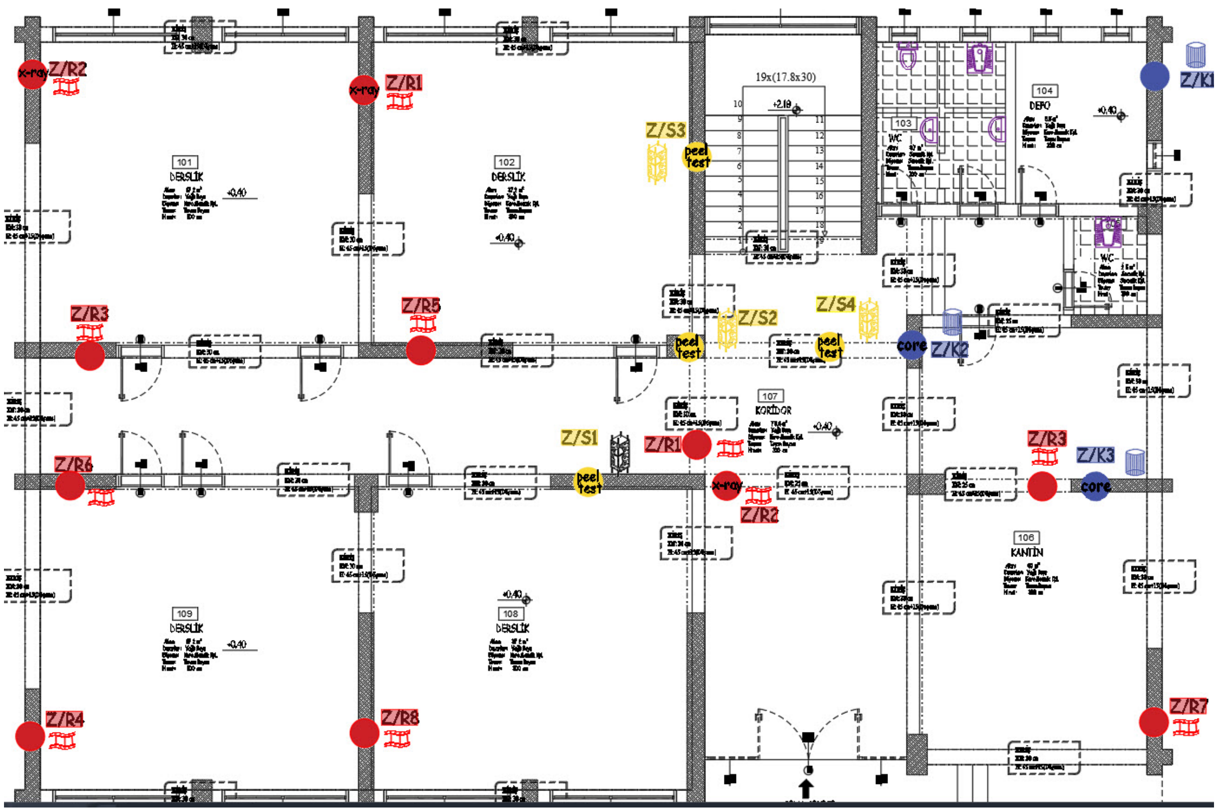


Figure 2. Structural elements where experiments are performed on the ground storey

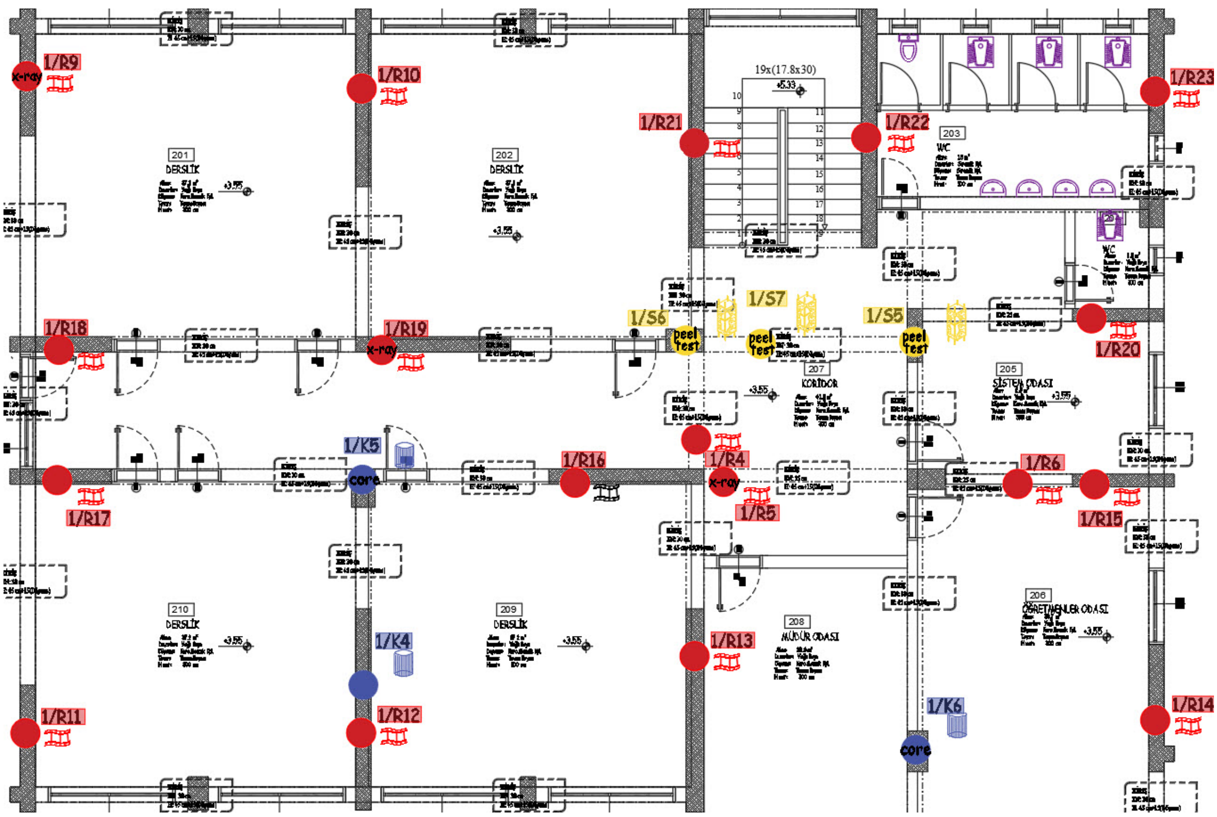


Figure 3. Structural elements where experiments are performed on the 1st storey

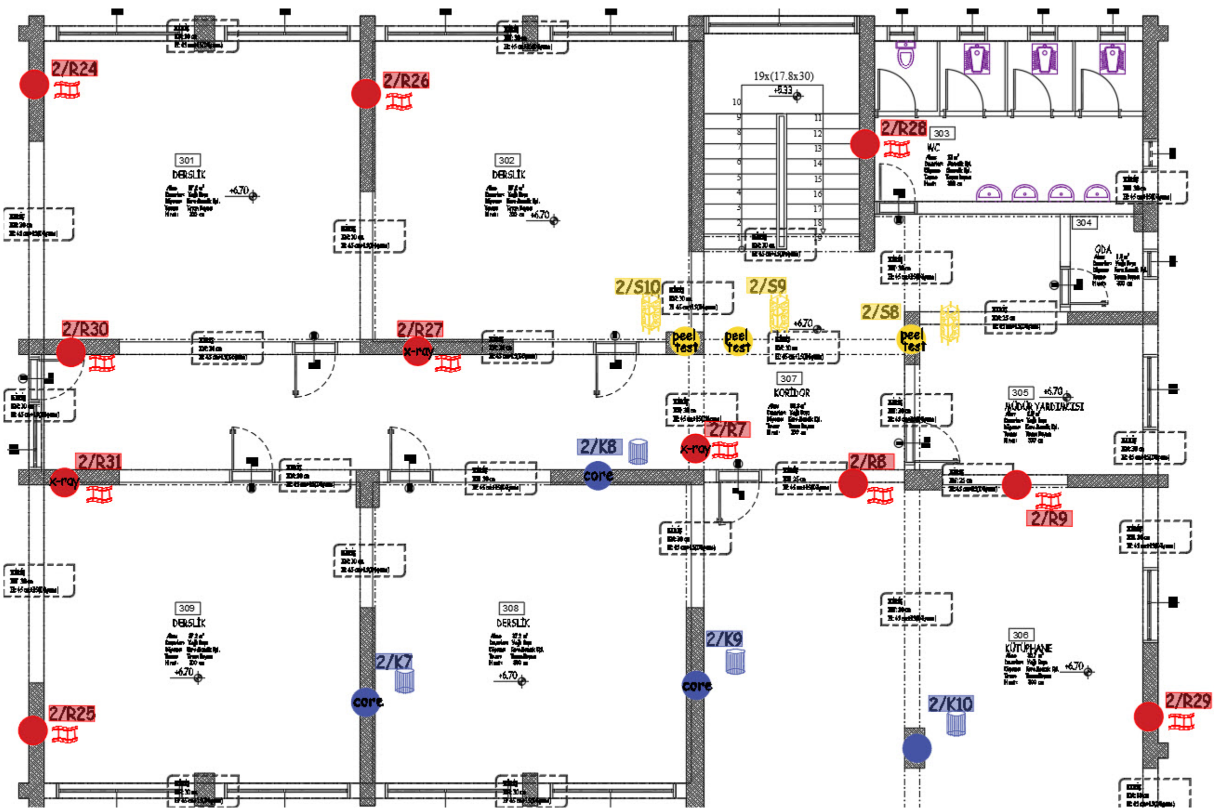
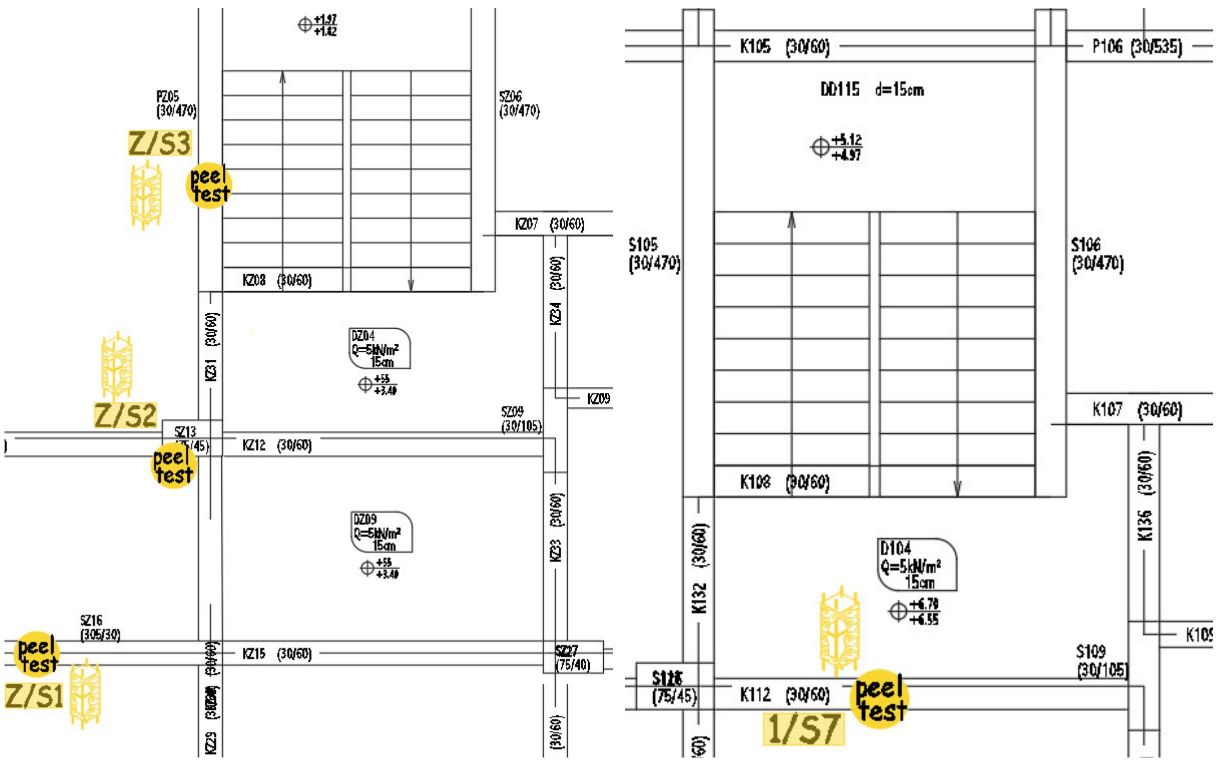


Figure 4. Structural elements where experiments are performed on the 2nd storey



Ground storey 1st storey

Figure 5. Locations of the peel test structural elements on the ground storey of Kalaycılar primary school

Ground SZ13 column Ground-storey SZ16 column Ground storey PZ05 shear wall Ground K112 beam Ground SZ27 beam

Figure 6. Views from the scraping process applied to some structural elements of Kalaycılar primary school

3. Structural Analyses of Kalaycılar Primary School

The performance results were obtained by performing a pushover analysis in the Sta4-Cad program of the Kalaycılar primary school building. In the Sta4-Cad program, plastic hinge properties are automatically assigned to structural elements. In this article, the lumped plastic hinge model is preferred in the analyses. In addition, pushover analyses of Kalaycılar primary school can be performed as single-mode and multi-modal. For the single-mode pushover analysis to be valid, the building height class, torsion coefficient, and mass participation rates in TBEC are considered. Accordingly, since the mass participation rates in the x and y directions of the school building are less than 70%, the results of the unimodal pushover analysis cannot be verified. For this reason, the multi-modal pushover analysis method was applied as the calculation method. On the other hand, the processes of the panel elements and the columns sheathing used for strengthening in the Sta4-Cad program are modeled by considering the regulations.

For structural analyses, the model of Kalaycılar primary school was created as in Figure 7 with the Sta4-Cad program, considering the TS498 and TS500 codes [17, 18]. An earthquake-free analysis was made, and cross-section adequacy was checked when the school building did not have application projects. As a result of the earthquake-free analyses, it was seen that there were no insufficient structural elements and that the school building had sufficient strength under service loads. Then, the existing concrete compressive strengths and rebars are defined separately for each storey. Accordingly, 20 MPa concrete strength on the ground storey, 13 MPa on the 1st storey, and 12 MPa on the 2nd storey, and existing S420 rebar information determined on-site were entered into the school building model (see Table 1). In addition, the parameters in Table 2 were considered for the structural analyses. First, performance analysis was made according to SBBSZ of the school building model in that information was entered. Accordingly, performance levels should be provided *Life Safety* (LS) for earthquake effects with a 2% probability of being exceeded in 50 years and *Immediate Use* (IU) for earthquake effects with a 10% probability of being exceeded in 50 years [15]. From structural analyses, the school building failed to provide the target performance levels (see Figure 12 and Figure 15). As a result of the performance analyses made according to TBEC, while Kalaycılar primary school provided the target performance level at the DD1 earthquake level, it could not provide the target performance level at the DD3 earthquake level (see Figure 16 and Figure 19). In other words, this result shows that the target performance *Limited Damage* (LD) level could not be achieved at the DD3 earthquake level. In contrast, the target performance *Controlled Damage* (CD) performance level was achieved in the DD1 earthquake.

Here, it would be useful to state that the S420 type rebar is detected in the structural elements where made the peel test, that the tensile test is not performed to breaking. Because re-be adding the rebars will affect their mechanical properties, the rebar detection methods in the 2007 and 2019 Turkish earthquake codes are considered in determining the said rebars.

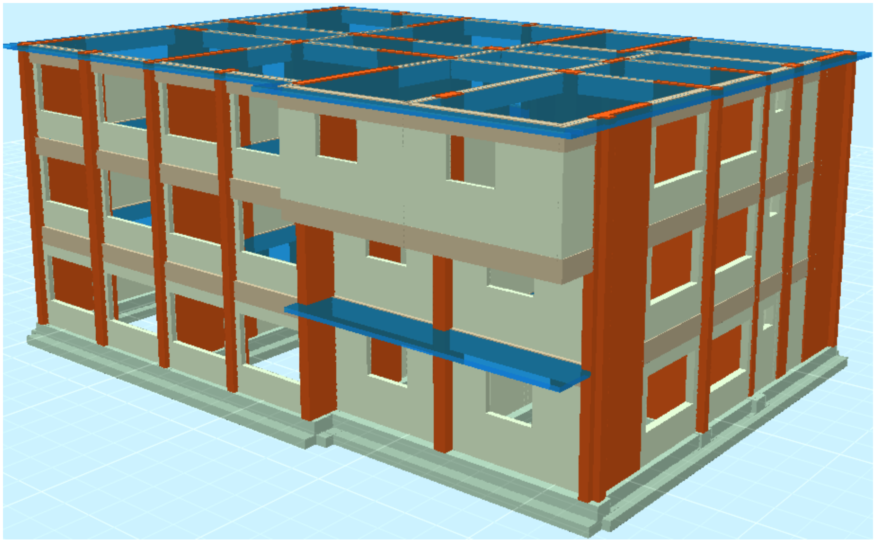


Figure 7. A view from the created model of Kalaycılar primary school

Table 2. Project parameters used in structural analyses

Parameters	SBBSZ	TBEC
Building importance coefficient (School)	1,5	
Building behaviour coefficient (R)	4	
Live load participation coefficient (n)	0,6	
Short-period spectral acceleration coefficient (S_s)	-	0,599
Spectral acceleration coefficient for 1s period (S_1)	-	0,203
Short-period design spectral acceleration coefficient (S_{ds})	-	0,791
Design spectral acceleration coefficient for 1s period (S_{d1})	-	0,445
Earthquake levels	-	DD1 / DD3
Earthquake Design Class (EDC)	-	1a
Building Height Class (BHC)	-	7
Coefficients of strength excess (D)	-	2,5
Soil bearing capacity (t/m²)	51,46	
Soil bedding coefficient (t/m³)	2882	
Earthquake zone coefficient (A_o)	0,4	-
Spectrum characteristic period (Ta/Tb)	0,2 / 0,9	-
DD1: Earthquake level with a 2% probability of exceeding in 50 years (recurrence period of 2475 years) DD3: Earthquake level with 50% probability of exceedance in 50 years (recurrence period of 72 years)		

4. Preparing the Strengthening Projects of the Kalaycılar Primary School

For this purpose firstly, studies in the technical literature on the strengthening of the school building and the location and effects of the shear wall were examined [19-31]. Later, two different strengthening projects were prepared when the existing school building could not provide the target performance levels. All storeys to the structural system in the model 1 strengthening were added to two shear walls in the y direction. In model 2 strengthening, shear walls were added in the x and y directions, and some columns were sheathed.

4.1. Model 1 strengthening project

While deciding on the strengthening process, the structural irregularities in the school building were considered, and intervention methods were preferred in a way that would not cause torsion problems and would affect the architectural plan the least. In addition, the cost of strengthening the school building was also considered. Accordingly, in model 1 strengthening, The axle, which did not provide the current performance condition and where the most structural damage occurred, was intervened. Because there is *Advanced Damage Region* (ADR) condition to the beams and columns on this axis, for this reason, by adding reinforcement bulkheads to the axis in question, both structural damage situations are reduced, and TBEC conditions are met.

While preparing the strengthening project of Kalaycılar primary school, torsional irregularities and structural elements damaged at the DD3 earthquake level were considered. Accordingly, a shear wall was added to the polygonal columns in case of *Marked Damage* (MD) in the y-direction on the ground story (see Figure 8). Performance analyses of the strengthened school building (model 1) were made according to SBBSZ and TBEC. As a result of the analyses, while the model 1 strengthening did not provide the target performance level according to SBBSZ, it provided the target performance level according to TBEC (see Figure 12~19). In addition, it was observed that there were no brittle structural elements with the model 1 strengthening.

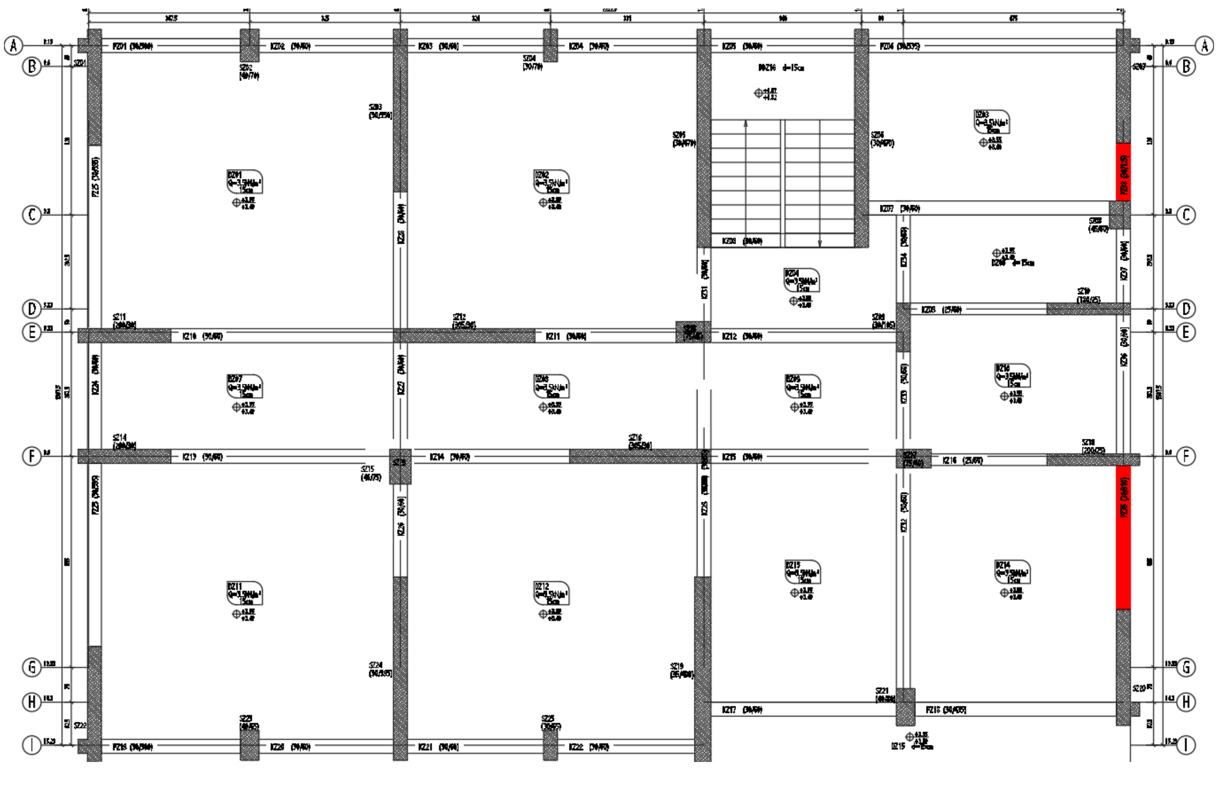


Figure 8. Locations of shear walls added to Kalaycılar primary school for strengthening purposes (model 1).

4.2. Model 2 strengthening project

Since the strengthening project prepared as model 1 did not provide the target performance level according to SBBSZ, the strengthening project defined as model 2 was prepared. Accordingly, the views of the structural elements to which strengthening is applied are seen in Figure 9~Figure 11, respectively. As a result of the analyses of the school building (model 2) strengthened according to SBBSZ and TBEC regulations, it is seen that the model 2 strengthening provides all target performance levels according to both SBBSZ and TBEC (see Figure 12~Figure 19).

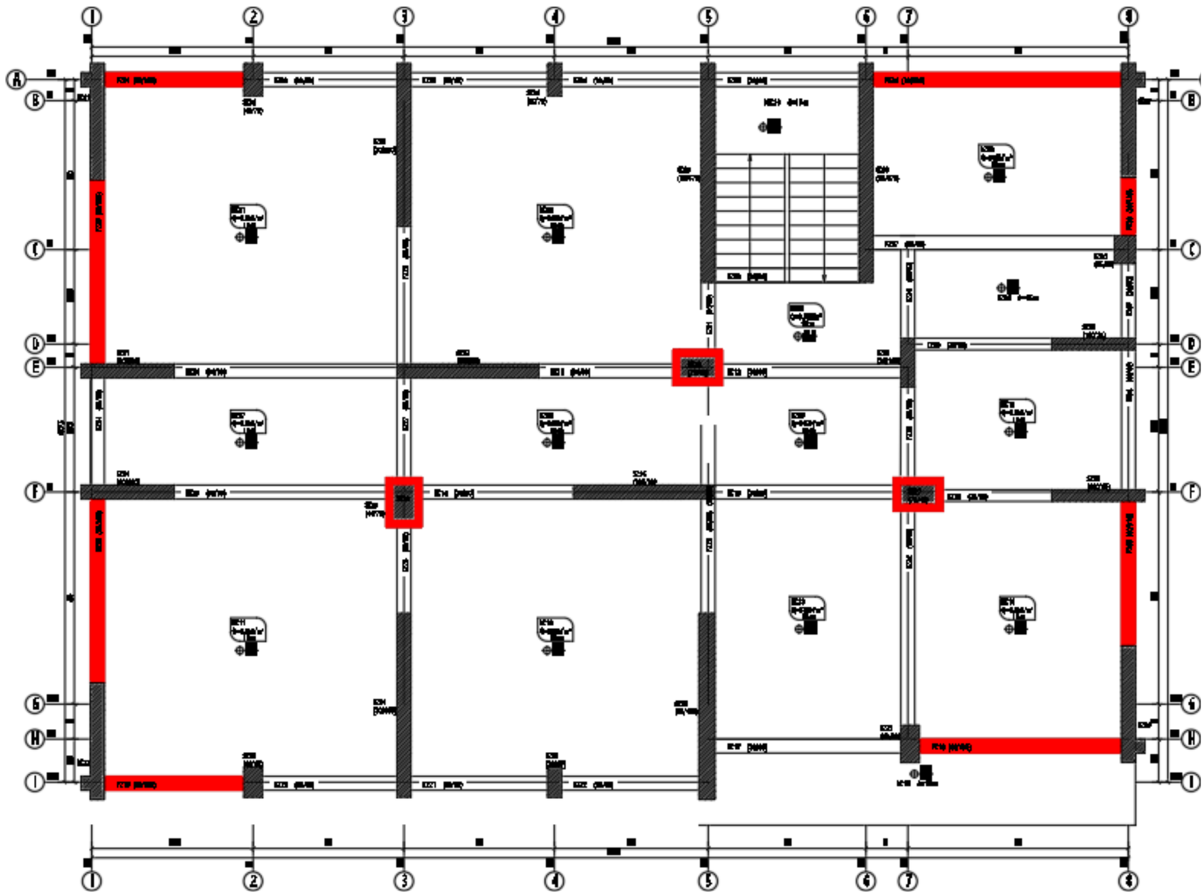


Figure 9. Strengthening applied to the ground-storey structural elements of Kalaycılar primary school (model 2).

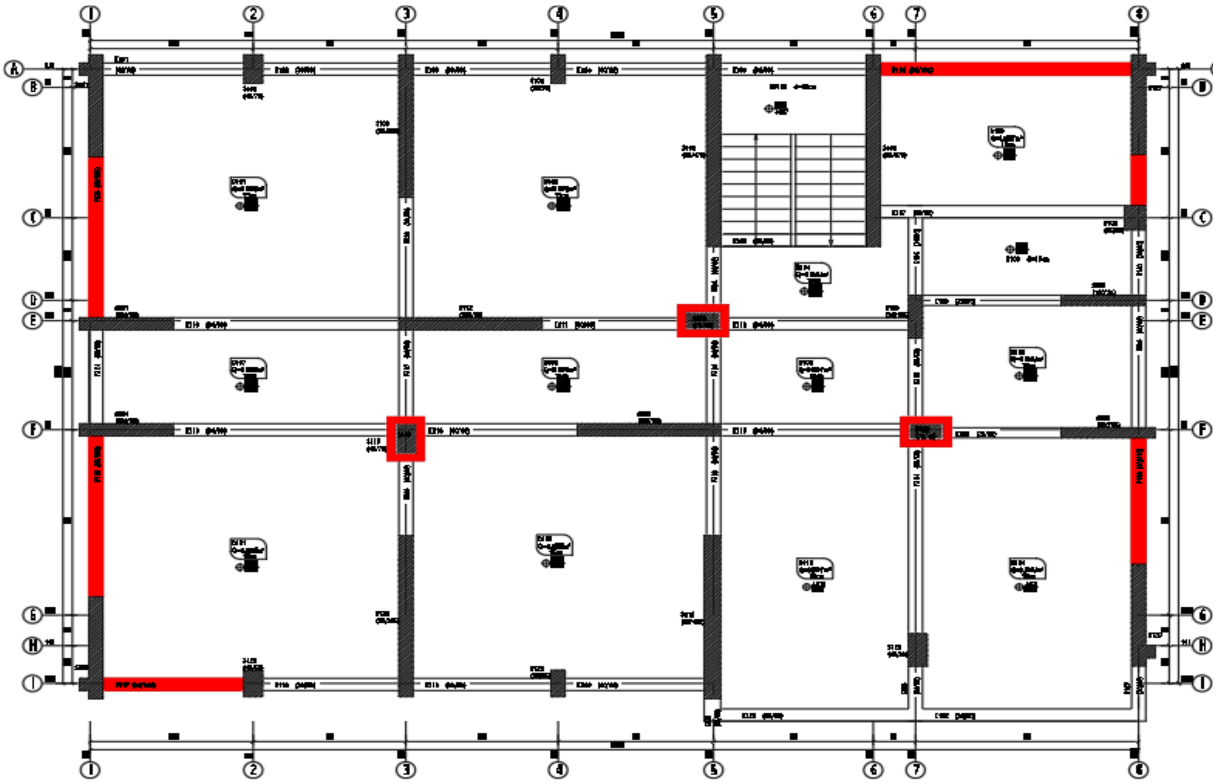


Figure 10. Strengthening applied to the 1st storey structural elements of Kalaycılar primary school (model 2).

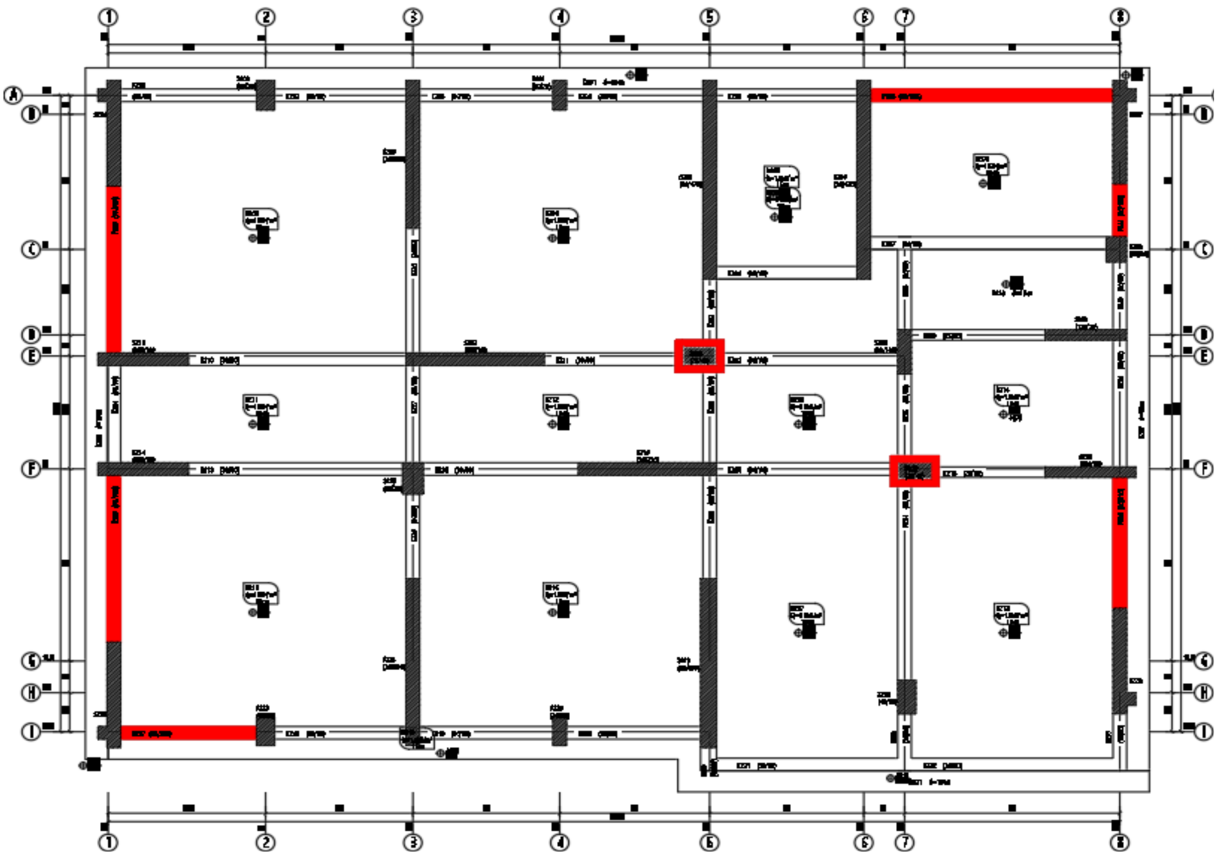


Figure 11. Strengthening applied to the 2nd storey structural elements of Kalaycılar primary school (model 2).

5. Findings And Assessments

From the analyses of the current and strengthened models (models 1 and 2) of Kalaycılar primary school according to SBBSZ, their performance status is given in Figure 12~Figure 15, respectively. These figures show that the required performance target could not be provided when the current and the strengthened school building, according to model 1, is evaluated according to the LS and IU performance levels. Since the Kalaycılar primary school cannot be provided, target performance levels of the situation strengthened according to existing and model 1, and a better performance level is obtained when the strengthened school building according to model 2 is evaluated according to the LS and IU. In other words, the target performance level is provided when the strengthened school building, according to model 2, is evaluated according to the LS and IU performance levels.

From the analyses of the current and strengthened models of Kalaycılar primary school according to TBEC, their performance status is given in Figure 16~Figure 19, respectively. According to this, it is seen that the required performance target is provided when the current and strengthened school-building models are evaluated according to the CD performance level. When the current and the strengthened school building according to model 1 is evaluated according to the LD performance level, the target performance level according to the DD3 earthquake level does not provide. By contrast, it is seen that the school building strengthened with the model 2 method provides all target performance levels.

When the Sa and Sd values in the x and y directions are examined for the earthquake levels recommended in the 2007 and 2019 Turkish earthquake codes, it is seen that model 2 strengthening has more spectral acceleration than the current situation and model 1 strengthening. In contrast, the model 2 strengthening has less spectral displacement value. This situation shows that the rigidity of the structural system in question increases due to the large number of shear walls added to the structural system in the model 2 strengthening. In addition, it is seen from these figures that the energy absorption capacity of the strengthened school models is higher than the current situation for all earthquake levels.

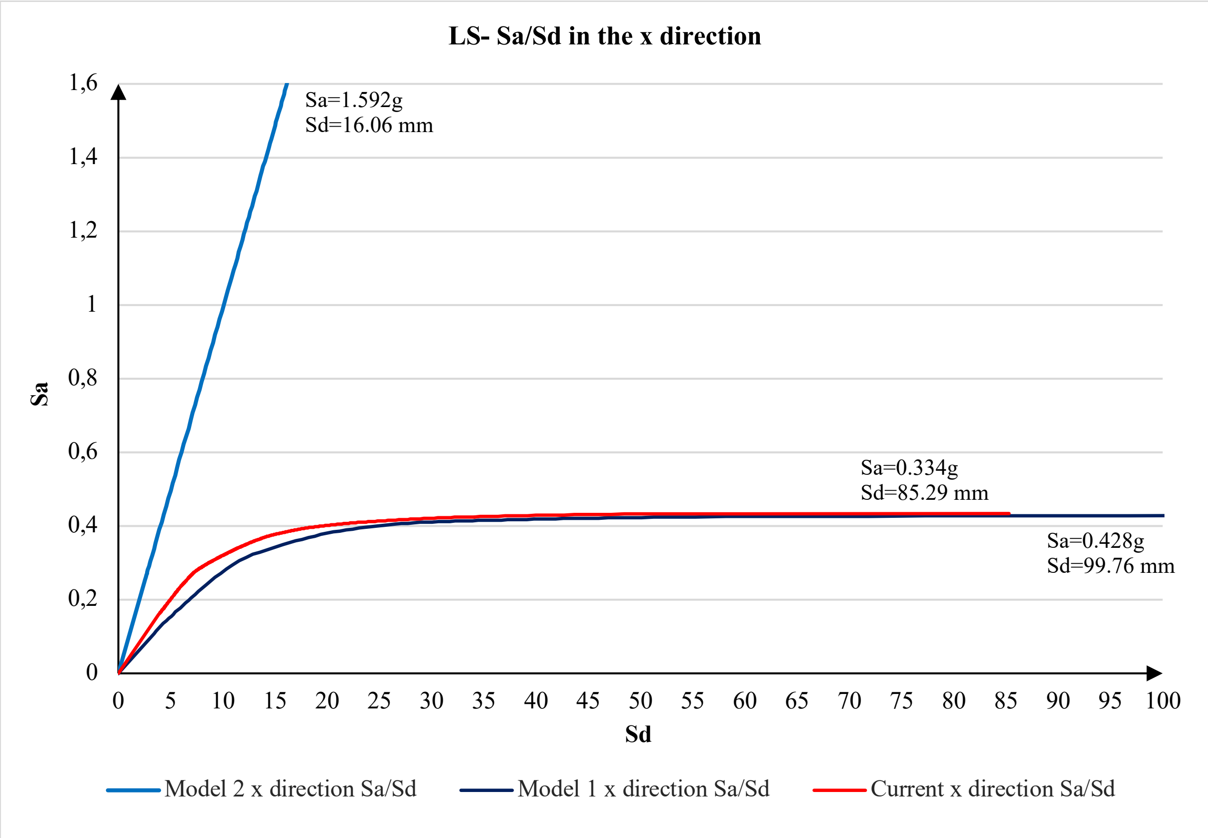


Figure 12. Performance results in LS earthquake of Kalaycılar primary school with the current situation, the model 1 and model 2 strengthening's in the x direction

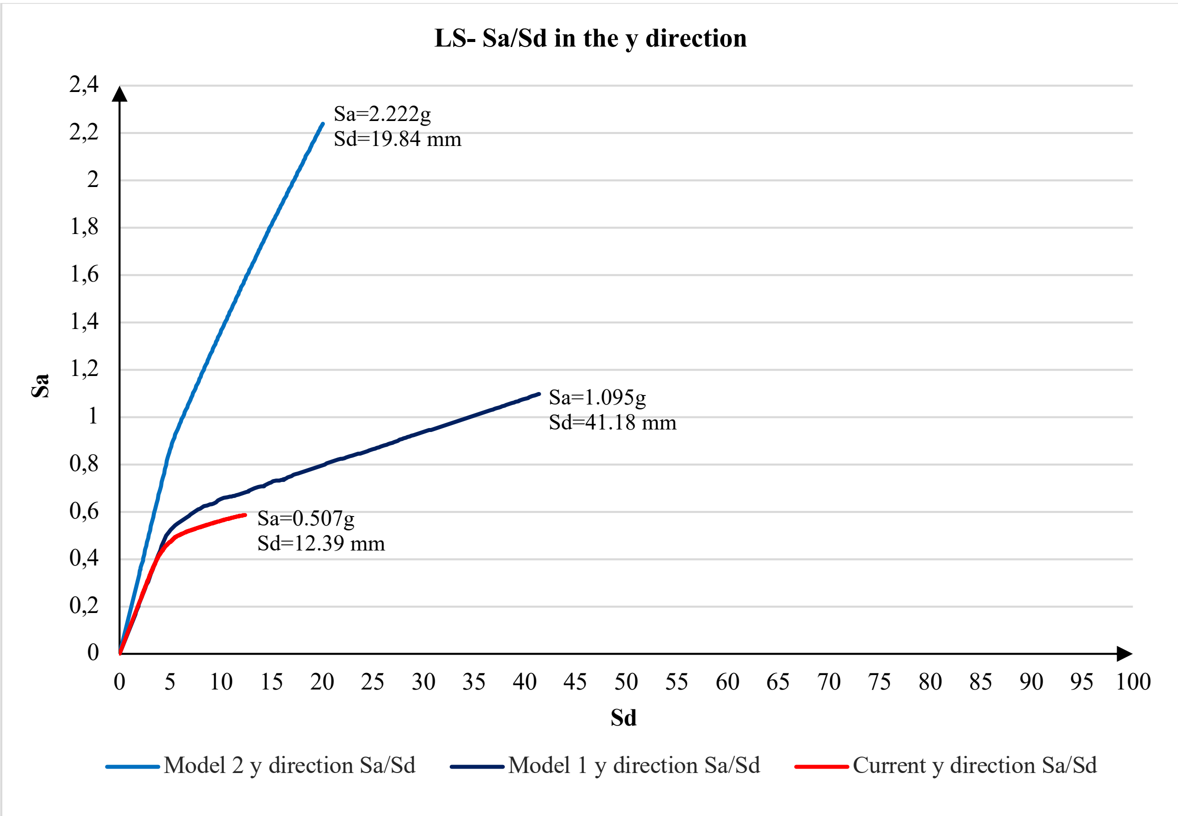


Figure 13. Performance results in LS earthquake of Kalaycılar primary school with the current situation, the model 1 and model 2 strengthening's in the y direction

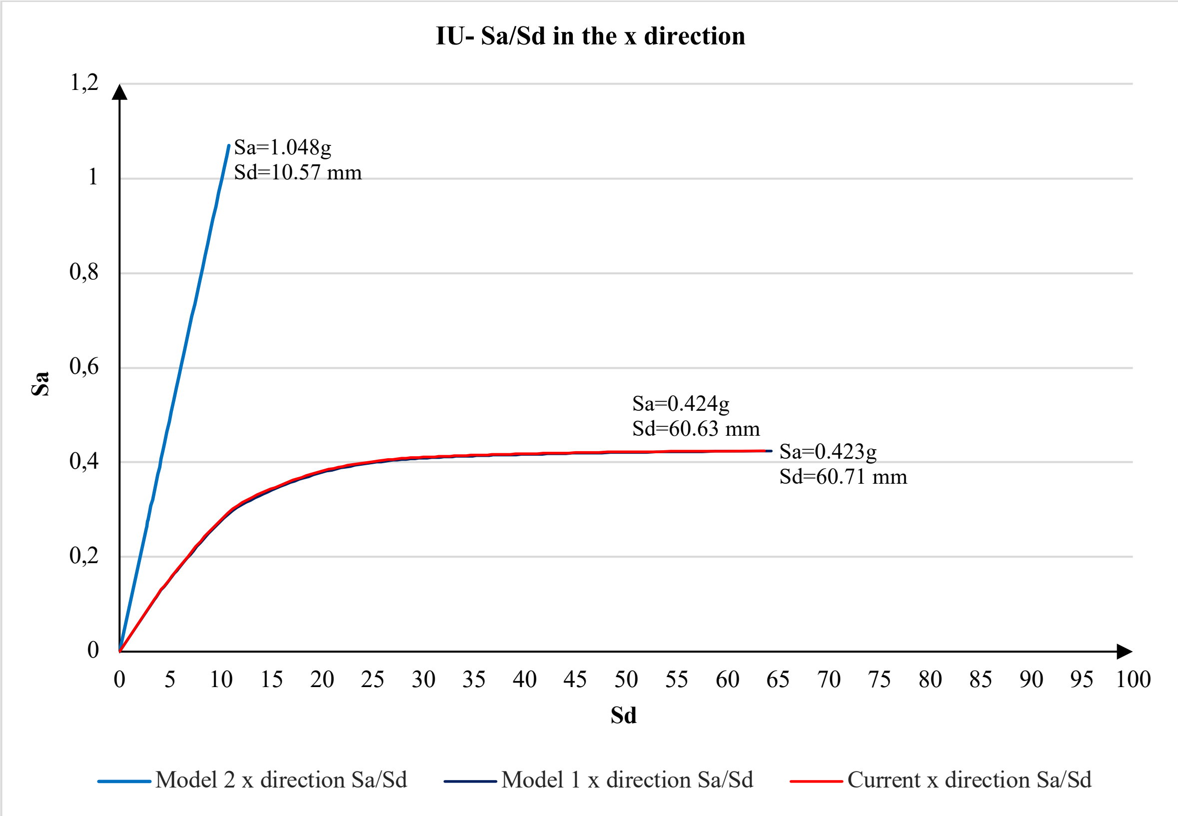


Figure 14. Performance results in IU earthquake of Kalaycılar primary school with the current situation, the model 1 and model 2 strengthening's in the x direction

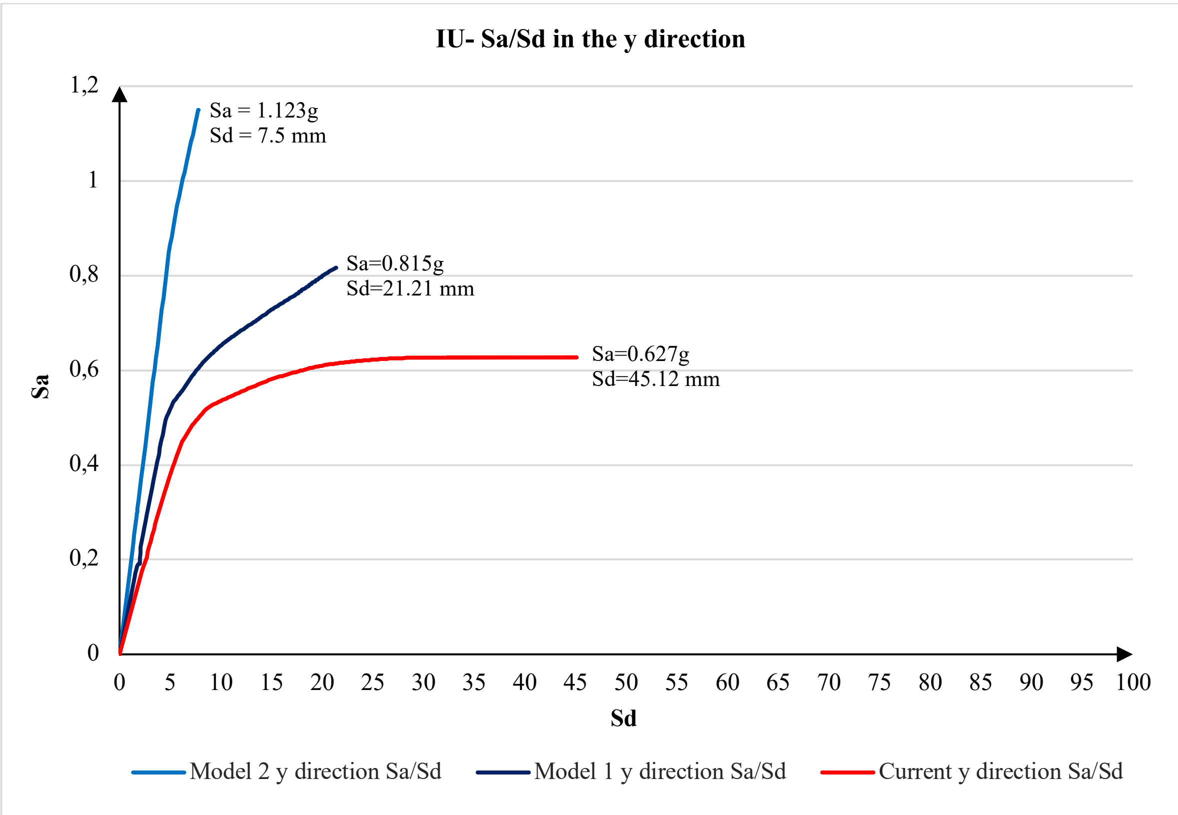


Figure 15. Performance results in IU earthquake of Kalaycılar primary school with the current situation, the model 1 and model 2 strengthening's in the y direction

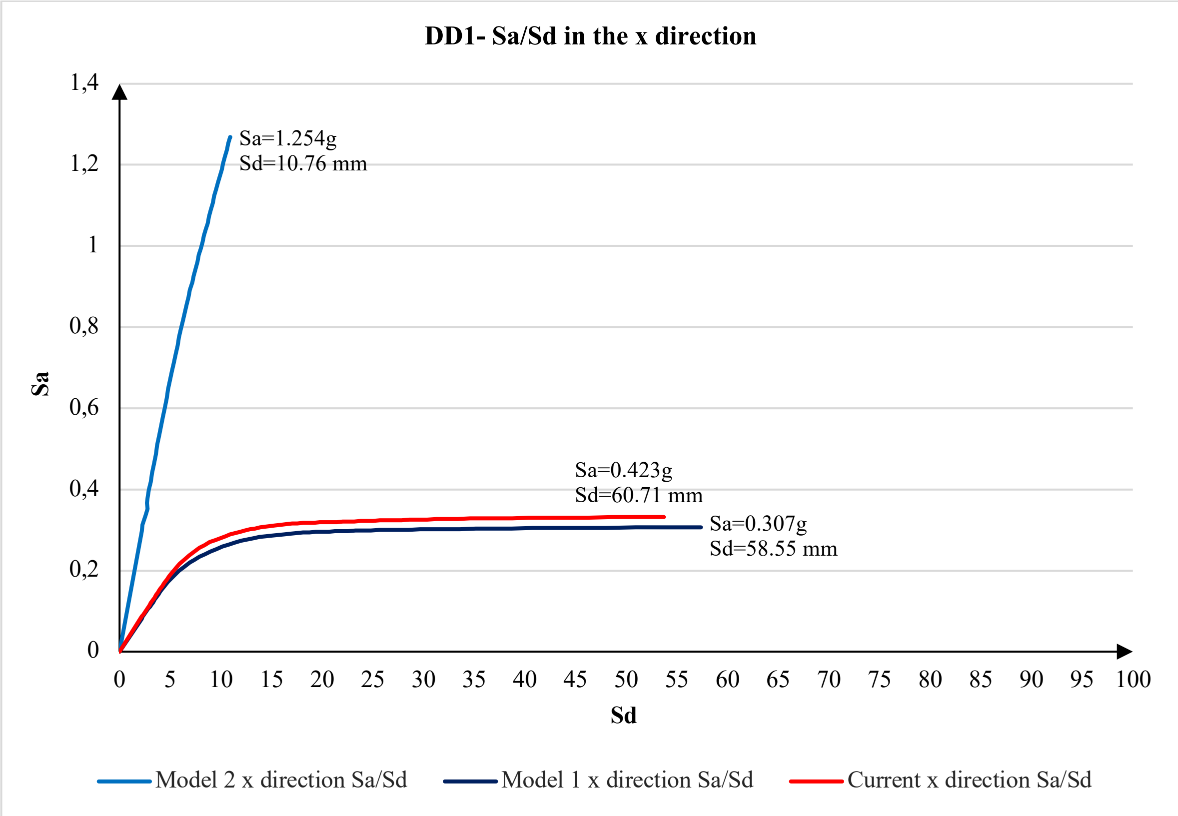


Figure 16. Performance results in DD1 earthquake of Kalaycılar primary school with the current situation, the model 1 and model 2 strengthening in the x direction

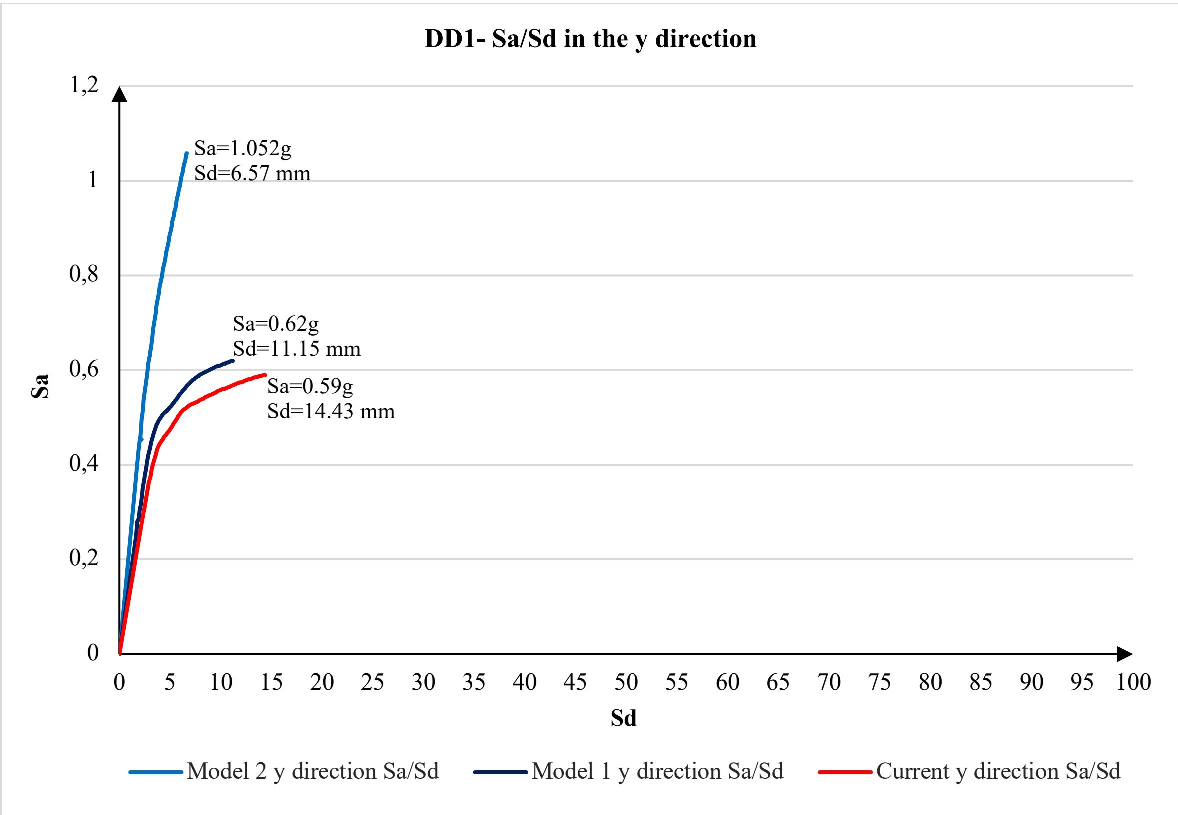


Figure 17. Performance results in DD1 earthquake of Kalaycılar primary school with the current situation, the model 1 and model 2 strengthening in the y direction

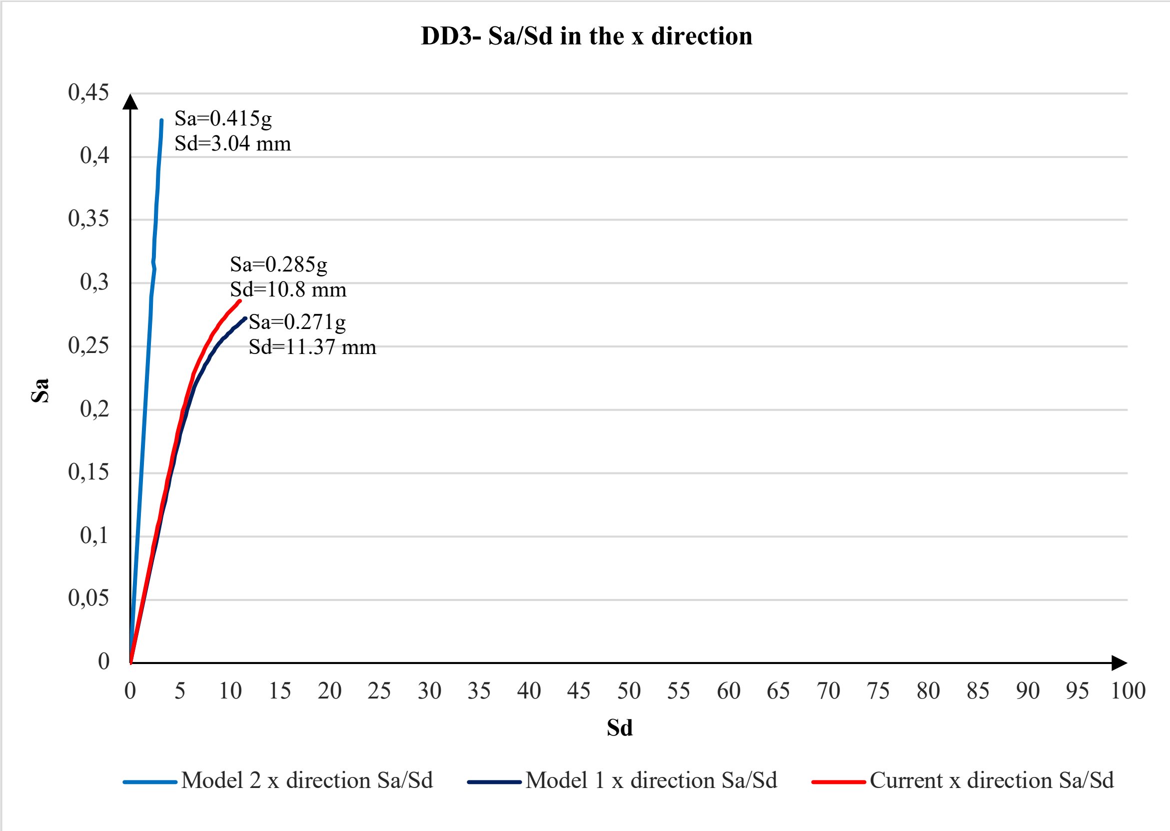


Figure 18. Performance results in DD3 earthquake of Kalaycılar primary school with the current situation, the model 1 and model 2 strengthening in the x direction

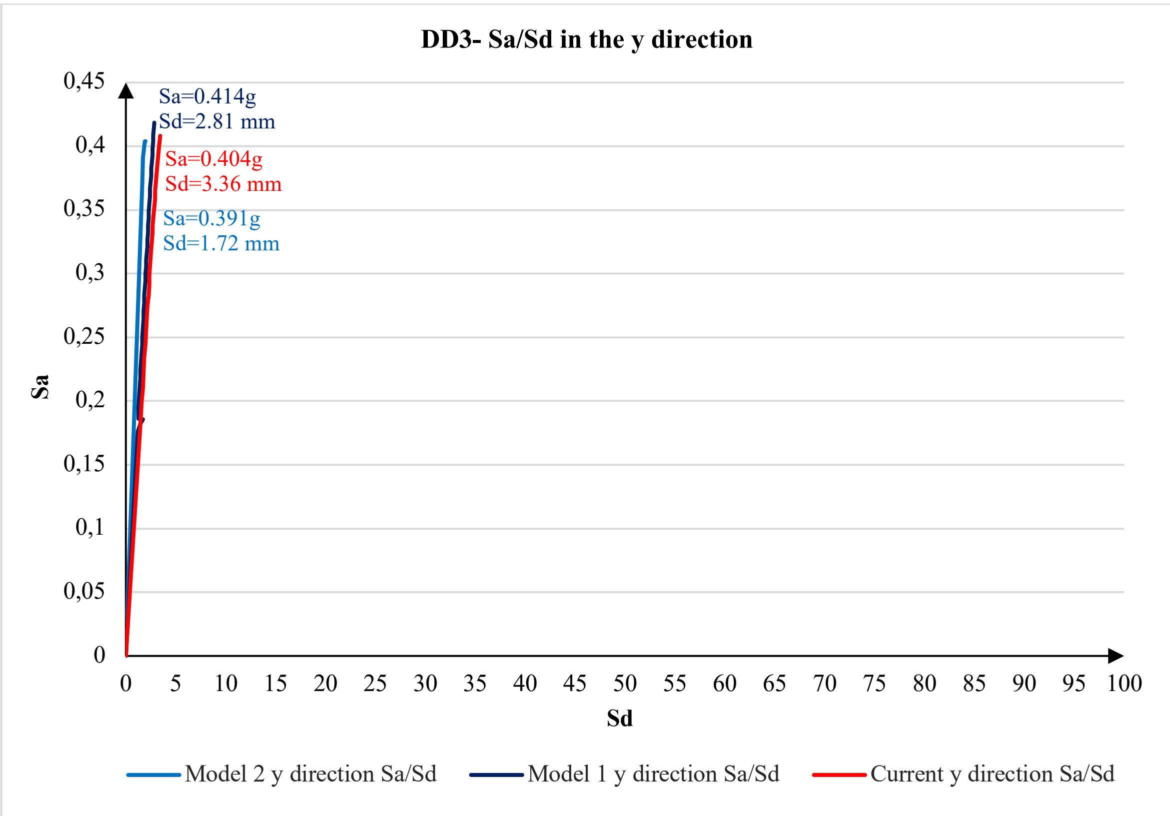


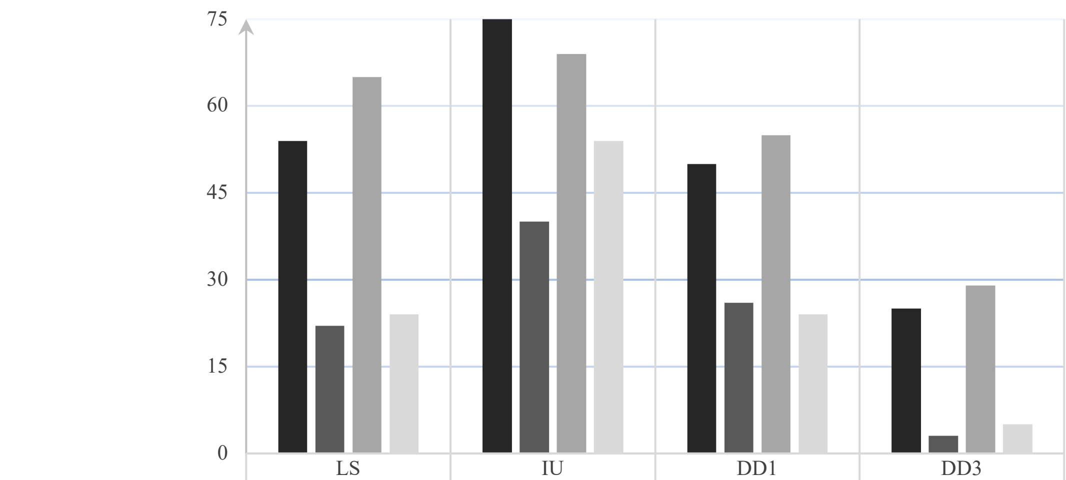
Figure 19. Performance results in DD3 earthquake of Kalaycılar primary school with the current situation, the model 1 and model 2 strengthening in the y direction

The comparison of model 1 and model 2 strengthening methods and costs applied to Kalaycılar primary school, considering the 2021-unit price year with the OSKA program, is given in Table 3. From this table, it is seen that the model 2 strengthening gives better performance than the model 1 strengthening, but the cost of the model 2 strengthening is 2 times more than the model 1 strengthening.

Table 3. Kalaycılar primary school model 1 and model 2 performance levels and strengthening costs for 2021year

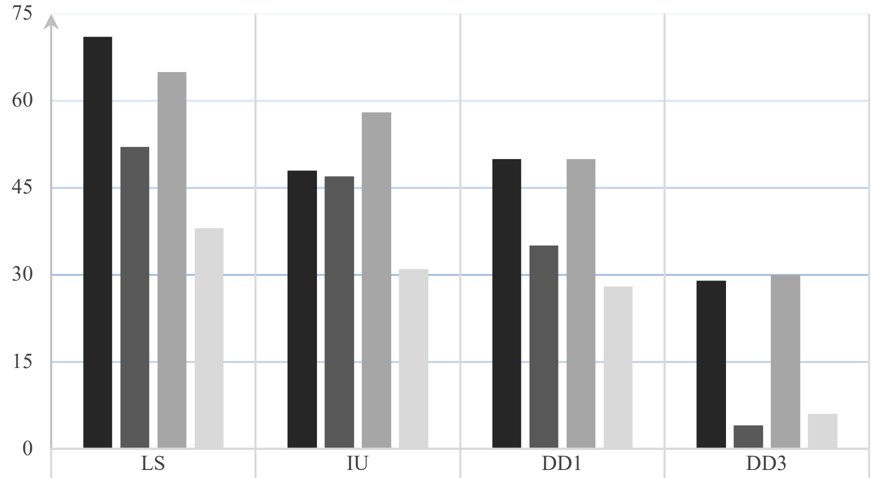
Strengthening Method	Performance Levels				Strengthening Cost	Strengthening Cost / Structure Approximate Cost	Structure Approximate Cost
	LS	IU	DD1	DD3			
Model 1	Collapsing	Collapsing	CD	LD	302.628,03 ₺	%21	1.429.360 ₺
Model 2	IU	IU	LD	LD	663.163,83 ₺	%46	

The total number of plastic hinges formed in the columns and beams according to the earthquake levels recommended in SBBSZ and TBEC for the current and strengthened conditions of Misakı Milli primary school is given in Figures 20~22, respectively. These figures show that the number of plastic hinges formed in the strengthened state according to model 2 has decreased significantly compared to the current situation. Also, for the limited knowledge level, it has been observed that there is a general increase in the total number of plastic hinges formed in the columns and beams compared to the comprehensive knowledge level.



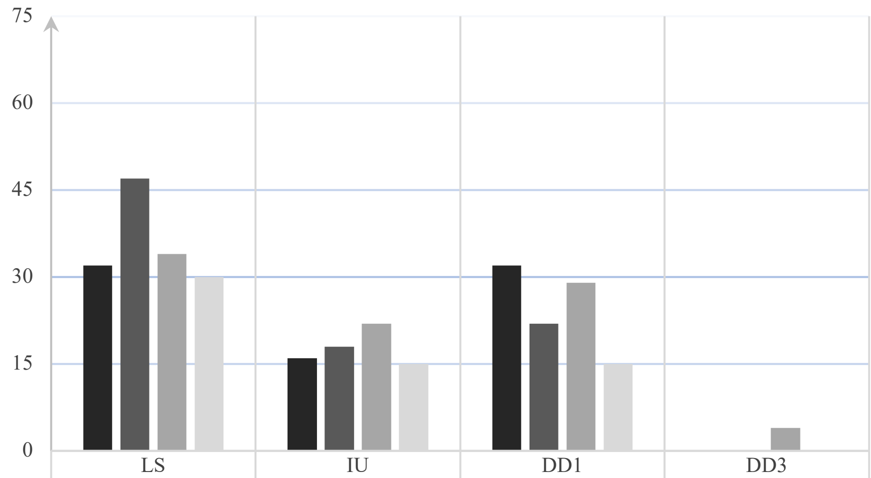
	LS	IU	DD1	DD3
Columns x direction	54	75	50	25
Columns y direction	22	40	26	3
Beams x direction	65	69	55	29
Beams y direction	24	54	24	5

Figure 20. Number of structural elements plasticized in x and y earthquake directions of the current situation of Kalaycılar primary school



	LS	IU	DD1	DD3
Columns x direction	71	48	50	29
Columns y direction	52	47	35	4
Beams x direction	65	58	50	30
Beams y direction	38	31	28	6

Figure 21. Number of structural elements plasticized in the x and y earthquake directions of Kalaycılar primary school model 1 strengthening



	LS	IU	DD1	DD3
Columns x direction	32	16	32	0
Columns y direction	47	18	22	0
Beams x direction	34	22	29	4
Beams y direction	30	15	15	0

Figure 22. Number of structural elements plasticized in the x and y earthquake directions of Kalaycılar primary school model 2 strengthening

In this article, the strengthening method has been chosen in a way that will minimum interfere with the architecture of the school building in question, will not create structural irregularities, and be economical. Accordingly, while the model 1 strengthening method, which is the most optimal method, provided the TBEC target performance levels, the target performance level could not be achieved in the SBBSZ regulation. When this is the case, the model 2 strengthening method has been applied to the school building that will meet the TBEC and SBBSZ earthquake regulations. It reveals that the chosen strengthening method (due to the added structural elements) significantly affects the rigidity and ductility of the building in question. In addition, the cost of strengthening is also effective in selecting the strengthening method. On the other hand, there are many strengthening methods other than the selected strengthening method in this study. Still, the design criteria recommended in the regulations of the selected strengthening method should be considered.

6. Conclusions and Recommendations

It is possible to summarize the results and recommendations obtained from this study as follows.

- Kalaycılar school building, analysed without earthquakes with the Sta4-Cad program, has sufficient stability. However, from the performance analyses made according to SBBSZ, while the required performance target could not be achieved at the earthquake level, which has a 2% probability of exceeding in 50 years, the LS performance target was achieved at the earthquake level which has a 10% probability of exceeding in 50 years. From the performance analyses made according to TBEC, a sufficient performance target was also reached at the DD1 earthquake level. By contrast, it is seen that the target performance level could not be provided at the DD3 earthquake level.

- The target performance is provided at the DD1 and DD3 earthquake levels suggested in TBEC from the structural analyses of Kalaycılar primary school, which was strengthened according to model 1. In contrast, LS and IU earthquake levels recommended in SBBSZ are in the CR.

- From the structural analyses of Kalaycılar primary school that was strengthened according to model 2, it gives a *Limited Damage* performance level at DD1 and DD3 earthquake levels while giving *Immediate Use* performance level at LS and IU earthquake levels. This result shows that for earthquake levels with a 2% probability of exceeding 50 years, a better performance level than the target performance level recommended in the regulations considered in this study is obtained.

- According to model 2 of Kalaycılar primary school, structural analyses of the strengthened situation showed that brittle structural elements are formed in some newly added strengthening elements, except for the DD3 earthquake level. This matter can be eliminated by increasing the distribution rebars' diameter and/or spacing.

• From the structural analyses, the strengthened state of Kalaycılar primary school, according to model 2, outperforms the strengthened state according to model 1.

• The approximate cost of the Kalaycılar primary school, built in 2005, is 1.429.360 ₺. To propose the demolition of Kalaycılar primary school from an economic point of view, the cost of strengthening should exceed 56% of the approximate cost of the building [13, 32]. Today, evaluating the economic life of the 17-year-old school building, the ratio of the cost of model 1 strengthening to the approximate cost of the building is 21%, and that of model 2 strengthening is 46%. Since these calculated rates are lower than 56%, it seems that it would be rational to strengthen the Kalaycılar primary school.

• From the results of this article, it can be seen that there is more than one option for strengthening a reinforced concrete structure. The authors suggest that all parameters should be evaluated together while strengthening a reinforced concrete structure, and the cost/performance optimum of one of the strengthening options should be considered.

Ethics in Publishing

There are no ethical issues regarding the publication of this study.

Author Contributions

This article is part of Mustafa Esat COŞKUN's Master's thesis titled "*Comparison of Reinforcement Principles in Reinforced Concrete School Buildings According to 2007 and 2019 Turkish Earthquake Regulations*" under the supervisor of Prof. Dr. Şenol GÜRSOY. One of the researchers, Assist. Prof. Dr. Zehra Şule GARİP is a jury member of Mustafa Esat COŞKUN's master's thesis defense and contributed to developing the thesis and writing this article.

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