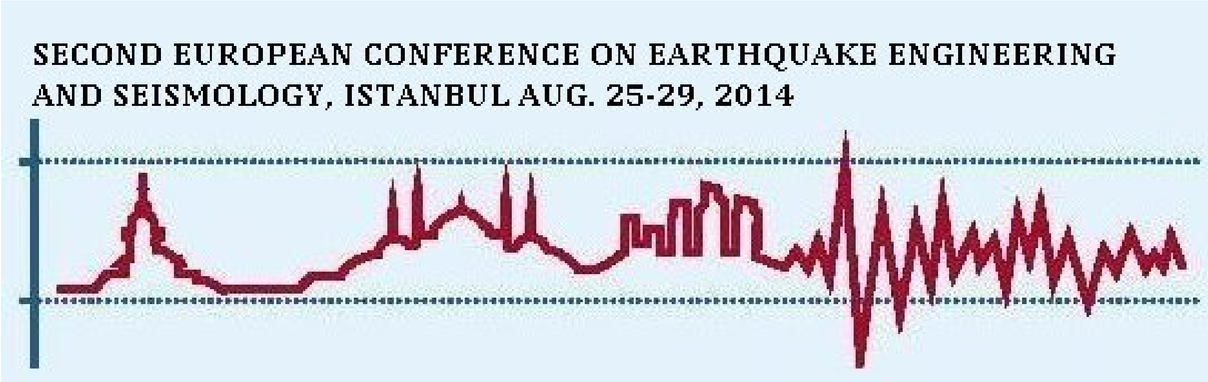

SEISMIC SAFETY EVALUATION AND STRENGTHENING OF SCHOOL BUILDINGS AFTER 2011 VAN EARTHQUAKES

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ABSTRACT

After Van earthquakes of October 23 and November 9, 2011 a large number of buildings including school buildings were damaged. Istanbul Technical University investigated these damaged buildings to determine the damage level of the school buildings and to decide whether they can be used further schooling. Later another team of experts of Istanbul Technical University was involved in preparation of strengthening projects and in their application including their field supervision. This paper focuses on strengthening and field supervision of school buildings and summaries of the experiences gained in these processes are presented to initiate a discussion on this subject which is of prime importance in Turkey.

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INTRODUCTION

Van province experienced two earthquakes, October 23 and November 9, 2011, which caused damages in large number of buildings including school buildings. Immediately after the earthquakes, a team of experts of Istanbul Technical University, including Institute of Earthquake Engineering and Disaster Management, Faculty of Civil Engineering and Faculty of Mining were come to Van to investigate buildings to determine the extent of the damage in detail to decide whether they have minor, medium or severe damages by using the official damage classification. As it is well known, generally minor damage level means that the structural safety of the structural system is not affected by the earthquake and the level of seismic safety of the building does not display any noticeable change.

It is of prime importance to notice that generally, it does not indicate that the building has the seismic safety as required by the code. Furthermore, it should be remembered that the safety level required for buildings to be constructed is quite high. In other words, although this level is quite reasonable for new buildings, the same level of safety is generally high for existing buildings which are constructed according to the requirements of the older version of the seismic codes and has been used for years without any having any problem. The medium damage in buildings indicates that the structural system of the building is affected seriously and it cannot be used without structural intervention i.e., strengthening is required prior its usage. In fact it is quite reasonable to strengthen buildings by increasing its safety level up to the level required. In the preparation of the strengthening projects, they are generally accepted rules. However, it is well known that it is not an easy task, when it comes to the field application of these projects. In the second stage of this process, another team of experts of Istanbul Technical University took parts in their field applications. In this paper the experiences gained in these processes are presented and also critical points of these processes are expressed to initiate a discussion on this subject which is of prime importance in Turkey.

RECENT EARTHQUAKES

In Van province two recent earthquakes took place i.e., Tabanlı having a focal depth of 10-20km on October 23, 2011 (M_L = 6.9, Mw = 7.1) and in Edremit having a focal depth of 5km (November 9, 2011 M_L = 5.6). The first one has an epicentral distance of 32km to Van and an estimated acceleration 0.10g in Van. On the other hand, the second the corresponding distance and acceleration are 20km and 0.25g, respectively. It should be remembered that the estimated or measured accelerations are well below than effective ground acceleration A_o g = 0.4g and 0.3g, which correspond to those defined in the first and second seismic regions in Turkish Seismic Code, respectively.

SCHOOL BUILDINGS IN THE TURKISH SEISMIC CODE

Design and construction of reinforced concrete buildings in Turkey is regulated by the rules given TS500 which has general requirements for design and construction of concrete buildings. Turkish Seismic Code defines seismic loads and has requirements for using capacity design and providing ductility. The code includes comprehensive requirements which reflect the developments in earthquake engineering, as well as the design of reinforced concrete buildings. In addition, lessons learned from evaluation of recent earthquake damages can be found in the seismic code as well. The code has a special chapter for seismic safety evaluation of the existing buildings. It has also general requirement for strengthening application.

Van is located in the second seismic region (A_o = 0.3) and Erçiş District in the first seismic region (A_o = 0.4). In this case, the ratios of the equivalent seismic static load to the weight for a building of high ductility are $0.3\times2.5/8 = 0.094$ and $0.4\times2.5/8 = 0.125$ for the second and the first seismic regions, respectively. Here the largest spectral value of 2.5 is adopted and the seismic load reduction factor of 8 is considered, which corresponds to the high ductile reinforced concrete frame buildings. In Seismic Code of 1975 the corresponding values are 0.08 and 0.10. This simple and disputable comparison shows that an increase of 17-25% in the equivalent static seismic forces.

Design of new residential buildings are carried out by considering the design earthquake (A_o) and adopting a building importance factor of I = 1 and targeting the life safety performance level, as it is stated in Seismic Code. On the other hand, new school buildings are designed by adopting a building importance factor of I = 1.4 to the spectrum of the design earthquake (A_o) and targeting the life safety performance level. However, the code requires existing school buildings to be checked by considering the design earthquake (A_o) and targeting the immediate occupancy performance level. It additionally requires that the school buildings should satisfy the life safety performance level under the maximum considered earthquake ($1.5A_o$). Generally, the second condition is much more stringent than the first one. In fact, these conditions are stricter than those applied to new school buildings to be design. It is not guaranteed that these two conditions can be satisfied by the newly designed buildings. This fact once more indicates that the level of safety of existing buildings required by the code is quite high and should be decreased. A reasonable level could be 2/3 of the safety level required by the code. However, when strengthening of a building is necessary, the strengthening should be designed to increase the safety level up to the level required by the code. In this case, there will be a safety margin of the buildings accepted and that of the buildings to be strengthened.

There are various typical structural layouts for school buildings prepared by the Ministry of Educations. Generally, they are reinforced concrete buildings having a dual system consisting of frames-and shear walls, having various numbers of stories, such as 3, 4 and 5 (including basement story). However, there are large number of school buildings constructed by donations of institutions and individuals. Often each of them has various structural layouts and their constructions are carried out without careful inspection.

DAMAGES IN SCHOOL BUILDINGS

After Tabanlı and Edremit Earthquakes of 2011 a large number of school buildings are investigated to give an opinion of expert on the further use of the buildings. To develop an expert opinion, buildings are investigated thoroughly in view of the seismic damages. Since often no structural engineering drawings were available for the structural system of the buildings, evaluation of damages was not an easy task. In this evaluation process, the following points deserve attention:

a. It is often drawings of the structural system of school buildings were not available. Even for the school buildings, which seem to be a reproduction of a typical layout, the drawings cannot be obtained. This situation often prevented a reliable assessment. The authors believe that each school should have a copy of the structural engineering drawings of their buildings. When drawings are available, column locations can be checked more easily and there will be no dispute in locating shear walls and partition walls.
b. Although, the maximum acceleration in the seismic events are found to be considerable lower than the design acceleration foreseen in the region, various levels of damages starting from fine cracks to the serious damages in the structural members are observed. Besides of the structural damages, often non-structural damages are found to be surprisingly high. Not very seldom, non-structural damages were decisive on the further use of the school buildings. This fact shows that these kinds of damages in non-structural elements are of prime importance and it is a critical point for the owner. As it is well known, partition walls produced in Turkey are very brittle compared to the structural systems. Even in a small ground motion they display cracks which have psychologically bad effect on building users. Van has cold climate and very often outer walls have two layers having a thermal insulation layer in between. Since connection of the two layers to each other is very weak, they are soften separated (a kind of out-of-plane failure) at a medium earthquake and give an impression of a serious damage. This fact is very crucial in school and hospital buildings for their further use. The first solution that comes to correct of this deficiency is the separation of structural elements and partition walls. A deformable material can be put between them. Furthermore, out-of-plane movement of walls should be prevented. In fact this kind of details is employed in shopping malls today only. Another solution would be adoption of stringent lateral displacement restrictions which may lead to more stiff structure and smaller cracks in partition walls. Improvement of properties of wall units should be one of the important aspects of the problem.

c. In Van area relatively large number of schools is constructed in the last 10 years. When school buildings are compared to residential buildings, they are expected to be designed and constructed under some kind of inspection, especially regarding concrete quality and workmanship. However, it is found that concrete quality of the existing school buildings was low and they also display a low quality workmanship.

In fact damages and deficiencies in structural systems are not new, they have been seen in the previous events as well and they can be stated as follows:

- Most of them due to simple engineering errors done in construction stage. In other words, buildings did not receive adequate engineering attention,
- Low concrete quality, inadequate granulometry,
- Low bond strength, inadequate workmanship,
- Inadequate lateral reinforcement detailing,
- Inadequate lap splice length.

After evaluation of damages, the crucial question asked by the governorship of Van was "*Can the school buildings be used for schooling?*" The team has grouped the school buildings into three categories:

a. School buildings which do not have almost structural and non-structural cracks and damages. Most of them are new buildings and have received engineering attention in construction stage. Usually they can be used for schooling.
b. School buildings which have limited cracks in the structural elements. They can be used for schooling temporarily, however it should be investigated in detail later to decide whether any strengthening is required or not.
c. School buildings which have serious cracks and damages in the structural elements. They cannot be used for schooling; however it should be investigated thoroughly to prepare strengthening project and decide whether strengthening is economical.

NUMERICAL INFORMATION

Large numbers of information are gathered in all these inspection, strengthening and supervision activities. Figure 1 and Figure 2 show variation of buildings investigated by the team of TU Istanbul. As seen approximately the half of the school buildings investigated are found to deserve strengthening. These figures show another interesting fact that the most of the school buildings investigated have a reinforced concrete structural system, only one seventh of them are masonry. Similarly, approximately the half of the reinforced concrete buildings investigated is found to deserve strengthening. Figure 3 shows variation of concrete compressive strength in the school buildings. As seen, the average strength is in between 7MPa~9MPa. It is important to remember that most of them are constructed approximately in the last ten to fifteen years. Furthermore, they are expected to be constructed under supervision of several authorities. Figure 4 displays characteristic and average concrete compressive strength versus construction year of school buildings. Usually, one expects that the strength should improve along the time significantly due to developing technologies. However, as seen, almost no change can be detected. Comparison of these variations displays that the variation of the concrete strength in a building is large as well, which clearly shows the inadequate control in production and placing of concrete. Figure 5 illustrates variation of concrete strength depending on buildings having various numbers of stories. Generally, it is expected that concrete strength should increase, as number of stories of a building increases, since more attention is given to higher building. However, almost no such relation can be seen. All these figures show once more that the deficiencies in these buildings are not complex but very simple, in other words, earthquake resistant school buildings can be constructed easily provided that required structural attention is given, since most school buildings have regular structural layouts.

STRENGTHENING OF SCHOOL BUILDINGS

For various numbers of buildings, strengthening projects are prepared and supervised by the team of Istanbul Technical University upon request of the governorship of Van. Following steps have been taken in development of the project:

a. Since most of the school buildings do not have structural drawings available, structural configuration is obtained including the geometry of structural elements by carrying out corresponding measurements at buildings.
b. Compressive strength of concrete is determined by taking core samples from columns and shear walls. Furthermore, these results are extended by applying rebound hammer tests in the whole building.
c. In some of the selected columns and shear walls of the system reinforcement details are determined by removing the concrete cover. Furthermore, these inspection results are extended by applying magnetic inspection in the other columns and the shear walls as well.
d. Model for the structural system of the building is developed and analyzed to find out its deficiencies in the system.
e. As the seismic code requires, existing school buildings should satisfy the immediate occupancy performance level under the design earthquake and the life safety performance level under the maximum considered earthquake. Generally, the school buildings which are selected to strengthen do not satisfy the both performance levels. However, it is found that the first condition is much more difficult to satisfy.

School buildings which do not satisfy one of the performance levels are strengthened usually by adding shear walls in two orthogonal directions. Jacketing of columns can be necessary, when the inadequacy in cross sectional area of the columns is determined. However, it is not preferred, because the jacketing of columns increases duration and cost of construction. On the other hand their detailing is difficult to do. A large portion of the seismic load is resisted by the existing and added shear walls. Architectural considerations were affective for position of shear walls and number, length and thickness of shear walls are selected by considering level of deficiency of the structural system. However, the selection of the shear walls is checked by analyzing the structural system. When the two performance levels are satisfied, then the strengthening configuration found to be an acceptable solution. However, in order to find the most suitable solution, the following checks are carried out additionally. It is expected that in a suitable solution the existing structural system should resist a reasonable portion of the lateral loads. When it is not the case, it means that the strengthening shear walls are more than necessary, their number, length and thickness could be decreased. On the other hand, it is expected that the existing structural system should not be overstressed, i.e., a good portion of the lateral loads should be carried by the added shear walls. When it is not the case, it means that the strengthening walls are less than necessary, their number, length and thickness could be increased. In order to be on the safe side, the added shear wall is shown in a sketch and forwarded to Van, to check once more, whether they have suitable position and location in terms of architectural aspect. At the last step, the approval of the school principal is received. When all these checks are done, then the design is finalized and corresponding detailed drawings are completed (Figure 6, 7 and 8).

SUPERVISION OF THE STRENGTHENING APPLICATION

Application of the strengthening project are carried out by various construction companies most of which being local. Although, the strengthening projects were prepared with great care, a large number of problems arose in the application. These problems are sometimes solved by modifying the strengthening projects significantly and sometimes it was necessary to develop new details. Following points deserve to mention:

a. Configurations of the structural system of buildings are obtained and corresponding drawings are prepared by considering on-site inspection as well. However, when the building elements are removed for strengthening application, occasionally, some of inconsistencies related to positions of columns and shear walls and their cross sections are found. This lead modification of the drawings.

b. Since very limited investigation is carried out due to the difficulties on foundations of buildings, various differences are detected, when foundations are excavated. Consequently, a lot of modification is necessary in the foundation strengthening. Not very seldom, it is found that geometry of foundations were not compatible with the drawings developed at design stage. (Figure 9, 10, 11 and 12).

CONCLUSIONS

After recent Van Earthquakes of 23 October and 9 November, 2011, numerous school buildings in Van are investigated, their structural system is evaluated and for a large number of schools, the strengthening projects are prepared and supervised by the team of experts of Istanbul Technical University. Lessons learned from these activities may be summarized as follows:

a. After every earthquake, strengthening of buildings is emerging as a major problem. It brings a significant cost burden to our government in fact to our society. It is not easy to solve this problem in a short time. The well-known fact is that this problem can be solved very easily and cheaply in long run, when new buildings are built properly i.e., according to the rules and the regulations. With zero tolerance new buildings should be constructed. No deficiency should be accepted in design and construction phases of new buildings, including school buildings. Only when it is done, number of the insufficiencies of existing buildings can be decreased, since buildings are renewed continuously.
b. The most important problem in the evaluation and strengthening of existing buildings is that reliable design documents which reflect the structural configuration of the building cannot be found. When some documents are available, they do not reflect the existing configuration. Every school should keep a copy of the structural engineering drawings of the school.
c. It is known that Turkish Seismic code will be updated soon. The authors strongly believe the following points should be reviewed:
    - Columns are prime elements in structural system. Therefore plastic hinges are expected to be in beams not in columns, in case of a strong earthquake larger that the design earthquake. Furthermore, beams are connected to slabs, whereas columns stand along. Consequently, this fact should be reflected in the damage limiting values of beams given in the code as well. It is expected that they can be decreased.
    - Seismic safety level required for existing buildings should be lower than buildings to be constructed. However, seismic safety level of building to be strengthened is to at the level of the new building. Remembering that existing building generally shorter service life than the new building. Furthermore, it important to remind that the code gives the minimum level, higher requirements can be put forward by the owner always.
    - It is not seldom that unacceptable foundation, in other word, no foundation only beams are found even in school structures. Various modifications in structural configuration are noticed in the investigations, most of them are improper application. Most of these modifications are due to insufficient preparation of the project, I.e., the various details are missing. They are somehow done in construction stage without giving proper attention. In other word, the structures have widely not complex but simple deficiencies. On the other hand the deformation base evaluation methods are quite complex and assumes that structures designed and constructed by using proper engineering attention, even they do not have very low seismic safety. They may have no proper foundation, concrete strength may display a change in large interval, bond of reinforcement cannot be provided. The authors believe that in these or similar cases the complex deformation based evaluation method is inappropriate. Much more simple evaluation method, such as force based should be developed.
    - In the seismic code school buildings are designed by adopting a building importance factor of I = 1.4 (almost by considering the maximum considered earthquake) and satisfy the life safety performance level. However, evaluation of a school building is carried out by considering two cases. In the first stage the maximum considered earthquake (almost by adopting a building importance factor of I = 1.5) is taken into consideration and the life safety performance level is targeted. In the second case the design earthquake is considered and the immediate occupancy

performance level is targeted. The authors believe the requirement for existing school building should be much more easy satisfy that the buildings to be constructed. In fact the comment is not only for schools also several other type of building, since similar requirement are given for them as well.

ACKNOWLEDGEMENT

A large number of academicians from Istanbul Technical University participated in damage assessment of residential and school buildings in Van. Their contributions are greatly appreciated.

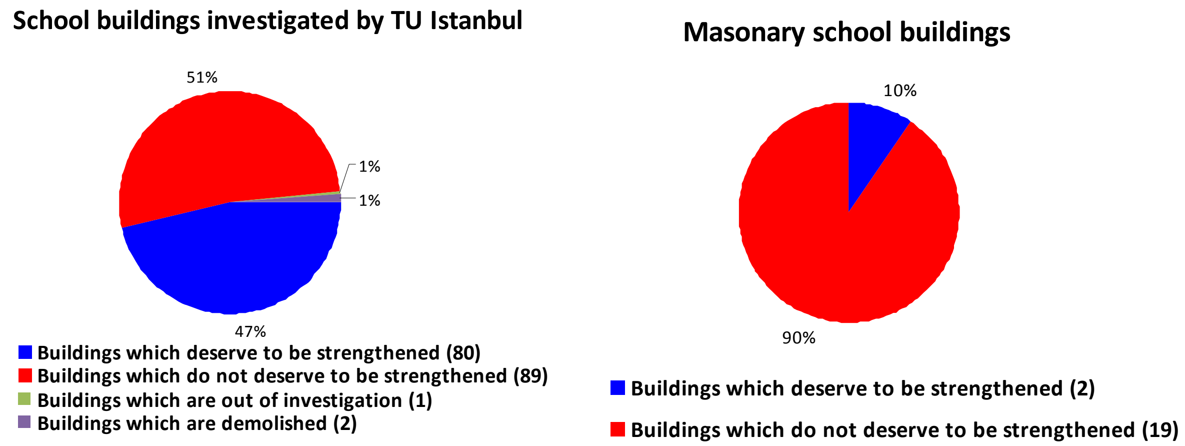

Figure 1. Total and masonry buildings investigated by TU Istanbul

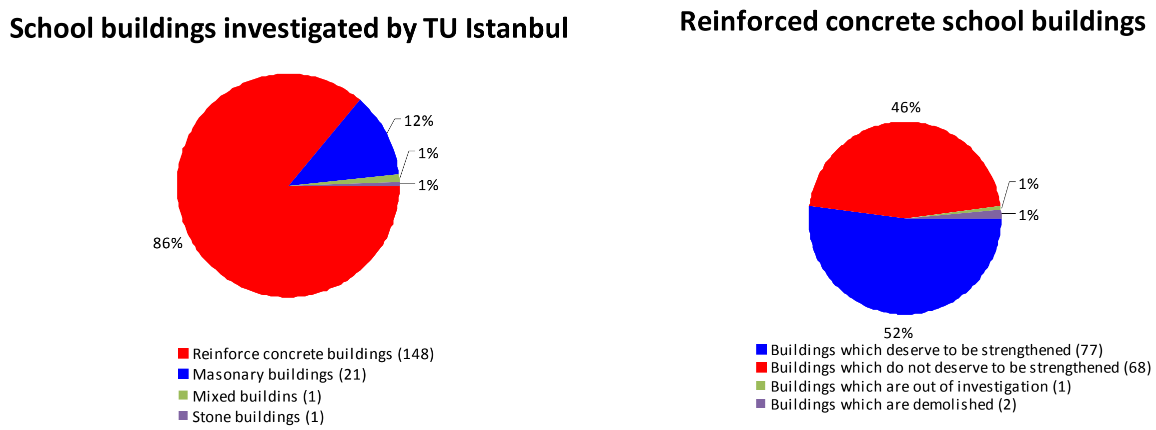

Figure 2. Total and reinforced buildings investigated by TU Istanbul

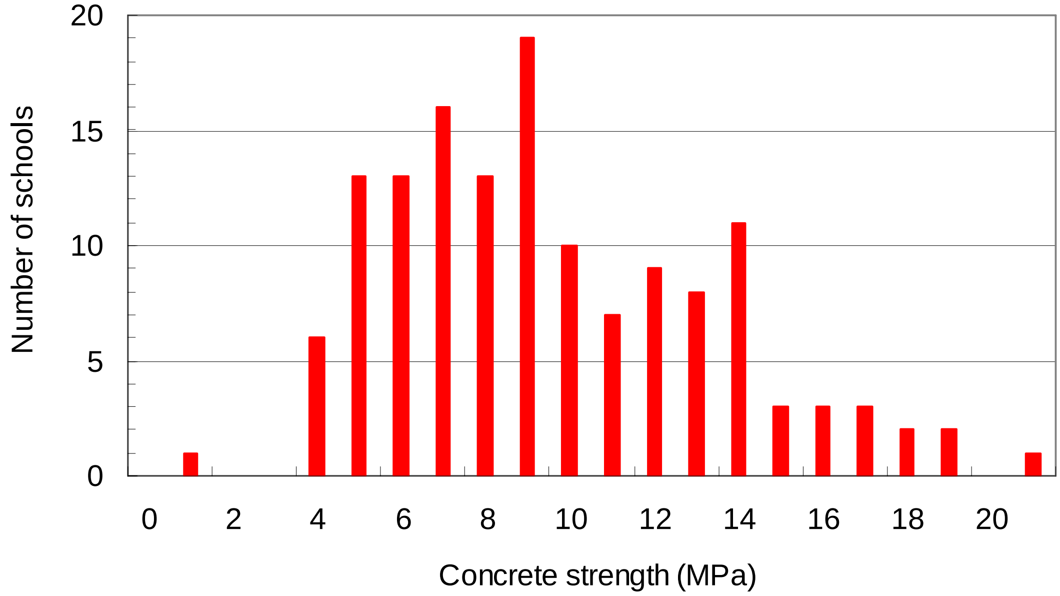

Figure 3. Concrete strength versus number of school buildings

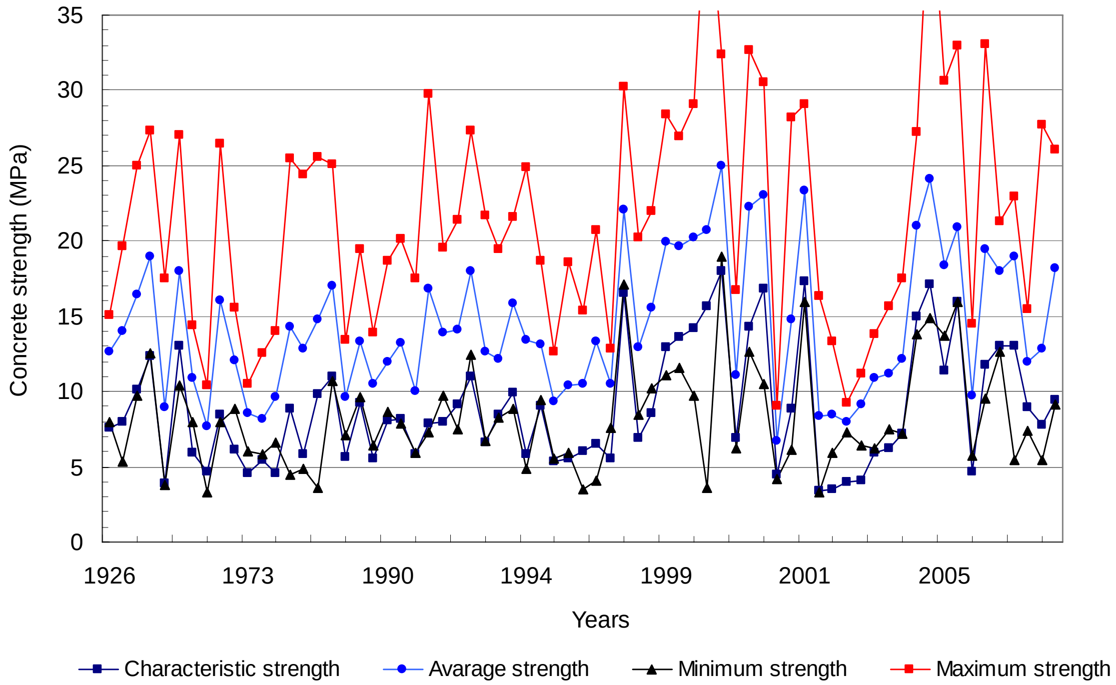

Figure 4. Concrete strength versus construction year of school buildings

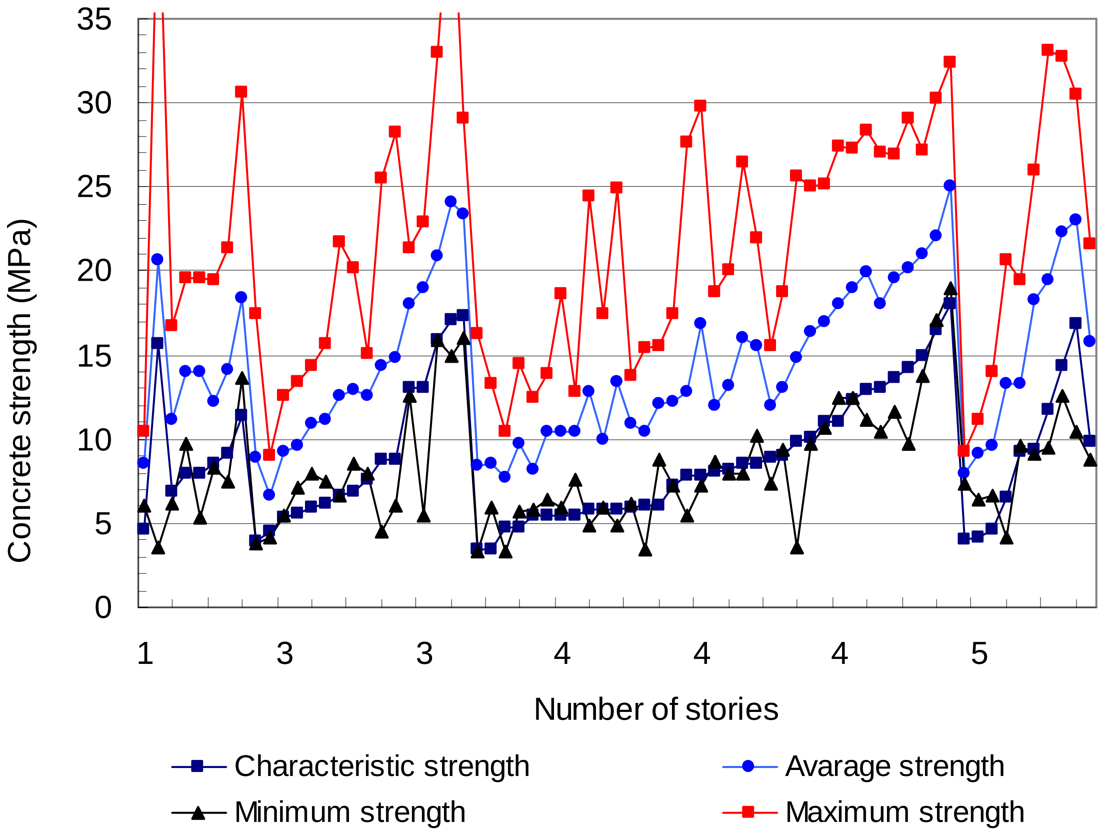

Figure 5. Concrete strength versus number of stories of school buildings

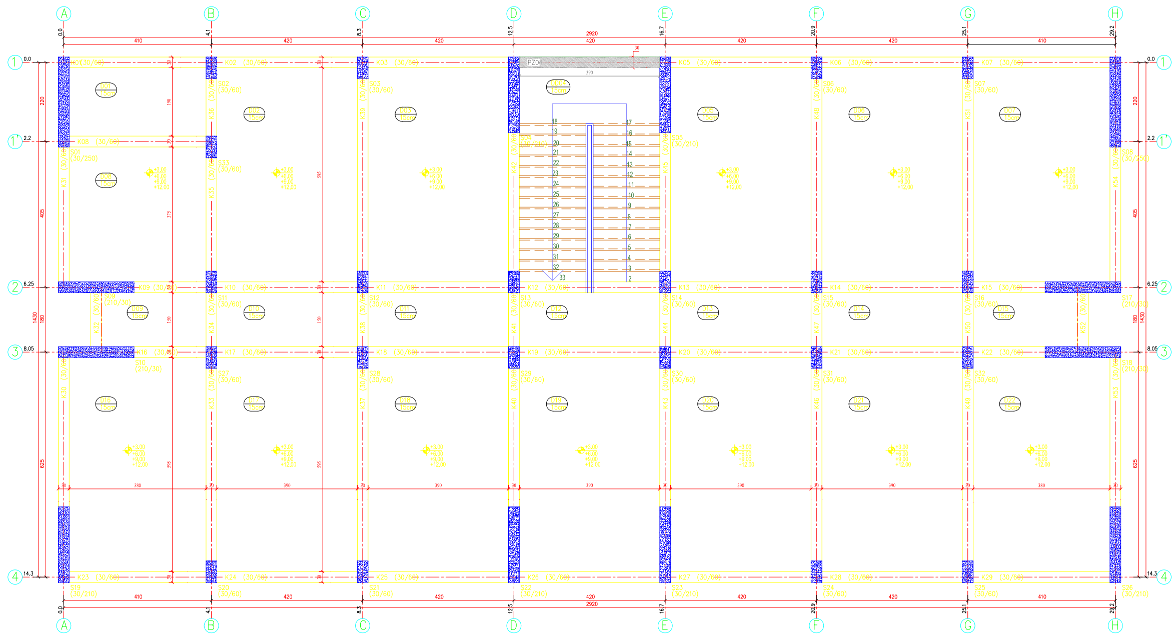

Figure 6. Strengthening of Merkez Cumhuriyet primary school in Van by adding shear wall

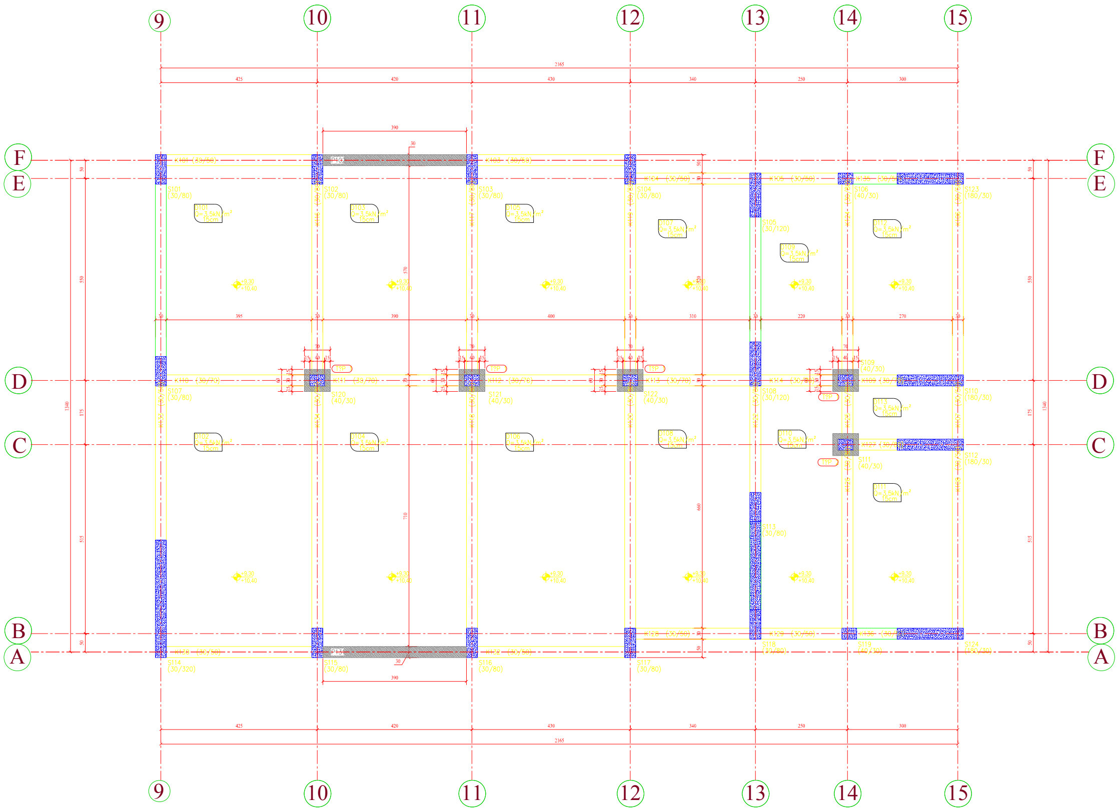

Figure 7. Strengthening of Kazim Karabekir gymnasium hostel B block in Van by adding shear walls and jacketing of columns

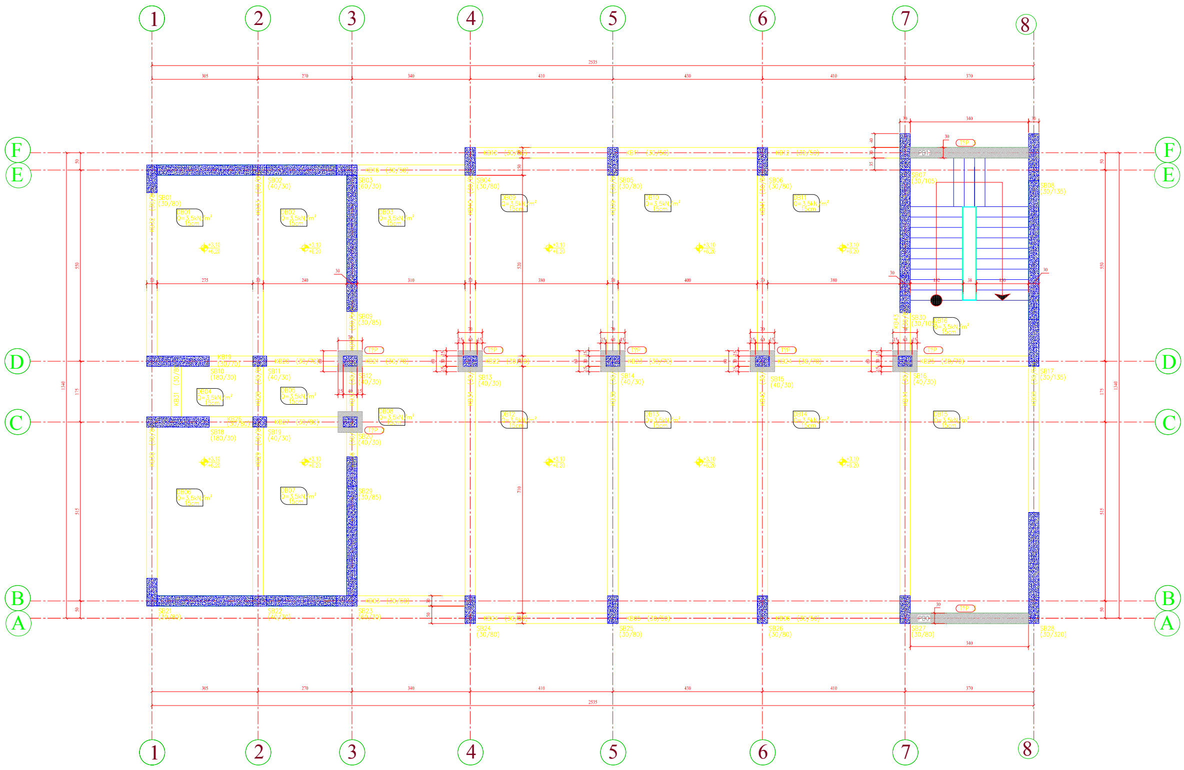

Figure 8. Strengthening of Kazim Karabekir gymnasium hostel A block in Van by adding shear walls and jacketing of columns

Figure 9. Foundation found in application of the strengthening intervention

Figure 10. Foundation found in application of the strengthening intervention

Figure 11. Foundation found in application of the strengthening intervention

Figure 12. Foundation found in application of the strengthening intervention