Take Step 1 For a Safe Life!

Istanbul Seismic Risk Mitigation and
Emergency Preparedness Project
ISMEP

Structural Retrofitting Against Earthquake

ISTANBUL AFAD
PROVINCIAL DISASTER AND EMERGENCY DIRECTORATE

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Güvenli Yaşam İçin 1 Adım At!

Dear residents of Istanbul,

Istanbul is a city, which is under the threat of earthquakes and many other disaster risks. In many parts of the world, precautions are taken and some preparation plans are carried out against these kinds of risks. In Turkey, there are studies, which aim at the protection of public buildings, particularly schools and hospitals, and historical monuments and there are retrofitting studies for the whole infrastructure system, especially for transportation and communication, with the participation of the professionals in our country by evaluating the studies made in developed countries.

Physical retrofitting studies have the aim of eliminating the physical threats by earthquakes. But the case of earthquake preparedness is not limited with these activities. What's more important is to change our way of life in such a way to be ready for earthquakes and to be more sensitive for our surrounding.

In order to be ready for earthquakes firstly at individual and then at the national level, we should know about earthquakes, we should develop ourselves by having safe life awareness at our home, in our offices and surrounding, we should get training and above all we should become conscious about what we can do before a possible earthquake strike.

Therefore, we have prepared these awareness raising and training materials to reach you by the means of ISMEP (Istanbul Seismic Risk Mitigation and Emergency Preparedness Project), which is conducted by Istanbul Governorship Provincial Disaster and Emergency Directorate and Istanbul Governorship Special Provincial Administration Istanbul Project Coordination Unit. The documents, which are prepared with the help of specialists from civil and private sectors, are given the last shape after the controls of experts and relevant departments.

Fifteen different training titles have been defined for our editions, which require the preparation of different documents with different themes and appropriate contents for them have been developed to reach all our citizens living in Istanbul and to ensure the institutional preparedness in every sense. We wholeheartedly believe that these training materials which are thought to be appreciated by each institution and individual would meet an important need. Before anything else, to know that our dear citizens would benefit from these activities that would help earthquake preparedness, gratifies us and enlivens our studies.

In Istanbul, where the future is strengthened by us, we share happiness of looking to the future with confidence.

Best regards,
Muammer Güler
Governor of Istanbul

Within the context of Enhancing Emergency Preparedness Capacity, which is the A component of Istanbul Seismic Risk Mitigation and Emergency Preparedness Project, multiple cooperation has a significant role in Community Disaster Preparedness Training Materialsí shaping within the framework of best practice and achieving objectives.

Within the framework of this project, which is a product of long and intensive study, and emerged in the light of profound knowledge and experiences of a good deal of people and institutions, we thank all public corporations and institutions who do not withhold their contributions from us;

Republic of Turkey Prime Ministry 'The Presidency of Disaster and Emergency Management Agency'
Republic of Turkey Prime Ministry Undersecretariat of Treasury and Foreign Trade
Republic of Turkey Prime Ministry State Planning Organization
Republic of Turkey Prime Ministry Housing Development Administration
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Search and Rescue Association (AKUT)
Istanbul Union of Chamber of Merchants and Craftsmen
Radio Amateurs Association
Confederation of Turkish Chamber of Merchants and Craftsmen Union
Confederation of Turkish Labor Unions
Social Service Employees Association
Turkish Psychological Association
The Psychiatric Association of Turkey
Turkish Federation for the Physically Disabled
Japan International Cooperation Agency Istanbul Office (JICA)

And we thank non-governmental organizations, all publication owners in the bibliography, and project team for their meticulous and devoted efforts.

Republic of Turkey Governorship of Istanbul
Provincial Disaster and Emergency Directorate

CONTENT

INTRODUCTION

The main aim in this study is to develop public awareness on purpose of seismic structural retrofit, determination and application of the selected retrofit method of a building which has been damaged during an earthquake or structural deficiencies determined.

In this respect, technical aspects of rehabilitation and retrofit applications of a building are evaluated in terms of content, benefit, challenges in application seismic safety upgrade. Based on the "Specification for the Buildings to be Constructed in Seismic Zones, 2007" document, conventional retrofit methods used in RC and masonry buildings which constitute the majority of the building stock in Turkey and innovative technologies used in seismic upgrade of the buildings are mentioned.

WHAT IS RETROFIT?

Retrofit involves all the works done in order to upgrade the seismic upgrade of the buildings. In some cases these applications are applied on the whole structure or just on some of the structural members. There are mainly two reasons for structural retrofit applications. The first one is for the upgrade of the seismic safety of the structure which has damage due to earthquake. The second one is determination of deficiency in the seismic safety of the structure although it has no damage. In both cases retrofit applications should be performed in order to upgrade the seismic safety of the building to the desired level.

DETERMINATION OF SEISMIC SAFETY AND RETROFIT REQUIREMENT

"Specification for the Buildings to be Constructed in Seismic Zones, 2007" has come into force as it has been issued in Official Gazette since March 2007. The Code enforces the basic priciples of earthquake resistant design of structures. The general principle of earthquake resistant design to this Specification is to prevent structural and non-structural elements of buildings from any damage in low intensity earthquakes; to limit the damage in structural and non-structural elements to repairable levels in medium-intensity earthquakes, and to prevent the overall or partial collapse of buildings in high-intensity earthquakes in order to avoid the loss of life. The so called high-intesity earthquake is defined as the seismic event which has 10% probability of exceedance in 50 years and all the seismic zoning is defined based on this definition. It is exceptable for a building to have damage without causing loss of life in this level of earthquake.

In addition to design of buildings, specifications for the assessment an retrofit of existing buildings are also defined in TSC07. The seismic performance of a building is directly related to the expected damage level under design level earthquake. The performance levels can be listed as;

- Immidiate Occupancy
- Life Safety
- Collapse Prevention
- Collapse

The minimum target performance level of a building differentiates depending on the type and occupancy of the building and the different earthquake levels with different probabilities. (i.e. 2%, 10% and 50% of probability of ecxeedance in 50 years). For example buildings like schools, dormatories, military barracks which are intensively and long-term used by people has a target perforemance level of “Immediate Occupancy” in which minimum structural damage is allowed during an earthquake with 10% probability of ecxeedance in 50 years. In the same earthquake level residential buildings, hotels and offices have a target performance level of “Life Safety” where moderate damage is expected.

In high intensity earthquake damage is expected in the structural and non-structural members of a earthquake resistant designed building. On the other hand, it is inevitable for non-earthquake resistant designed building to have heavy damage in the same earthquake level. This situation results in as a retrofit need. In some cases due to architectural or usage needs the structural system of the building can be changed, also this situation results in retrofit need. The existing buildings need to be retrofitted so as to satisfy the modern Seismic Code regulations or/and due to the change in the target seismic performance level of the building under consideration. The other reason for retrofit need may be due to change of situation and function of the building or historical importance.

Another decisive element is the cost of retrofit applications. In order to apply the retrofit scheme the ratio of the retrofit cost to the reconstruction of the building should be in acceptable limits.

The purpose of the retrofit application is to upgrade the seismic safety of the building with the best and appropriate techniques in shortest time with minimum disturbance to the building residents.

Retrofit applications have social, economical and legal aspects in addition to technical issues. During the decision process for the retrofit applications of the buildings with high seismic risk in a certain area decision makers should also take into account all the aspects of the issue metioned above. It should be noted that the dicison will be specific for each case since each case has it own boundry conditions.

In the retrofit applications against earthquake site investigations and test are of graat importance. Depending on the data obtained from the site investigations seismic safety of the bulding is determined by using the appropriate analysis methods. Once the existing performance of the building is less than the desired performance structural retrofit decision is given.

In order to achive this performance level the following applications may be applied;

- Prevention of any kind of deficiencies that may cause seismic damage
- Addition of new structural members in order to upgrade the seismic safety
- Reduction of weight of the building
- Providing a continous load path system

RETROFIT METHODS

Basically retrofit methods are divided into two methods as ; member retrofit and system retrofit.

Retrofit applications are performed on the exisiting structural resistance system such as columns, beams, shear walls and connection regions. In some cases seismic upgrade of the system is done by addition of new structural members. Once the building has edequate lateral resistance but threre are some seismically insufficient members in a building, retrofit of the unsafe members would be sufficient. But on the otherhand once the building have a quite a lot seismically unsafe members, low lateral resistance, structural deficiencies such as soft story, weak story the retrofit application should be performed on overall structural system basis.

STRUCTURAL MEMBER RETROFIT

"Structural member retrofit" shall be defined as increasing strength and deformation capacity of the columns, beams, shear walls and connection regions of the building.

Retrofit of the Beams

The increase of strength and deformation capacity of beams are achived by addition of stirrups, attachement of steel plated, wraping by carbon polymers and application of full or partial jacketing.

Addition of stirrups: Shear strength of the beams in the support regions shall be increased by addition of adequalte number of stirrups on the both sides of the beam (Figure 1).

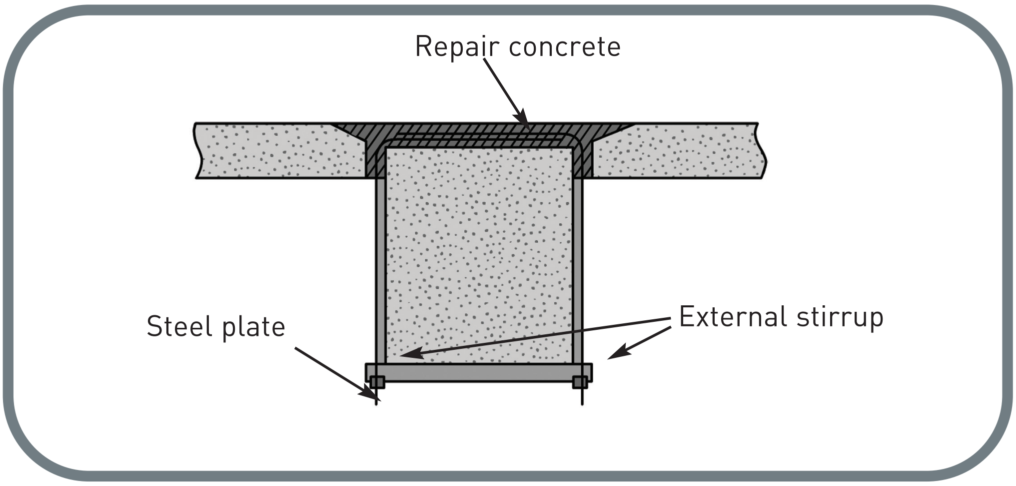


Figure 1. Addition of stirrups to beam.

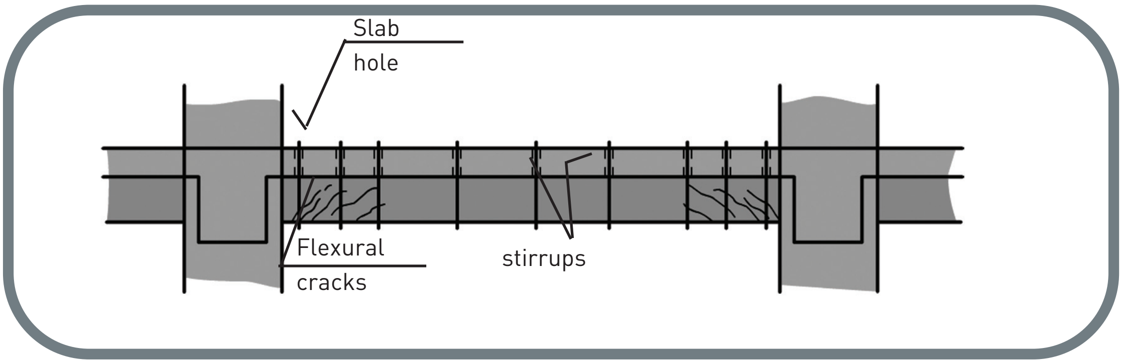


Figure 2. Anchorage of the added stirrups to the slab.

Attachment of steel plates: Retrofit of beams shall be perfomed by attachment of steel plates on both sides and bottom of the beam section. In the attachment process of steel plates, surfaces of both beam and steel plate should be properly prepared for effective and proper connection. The steel plates on both sides and bottom should be welded at the connection zones.

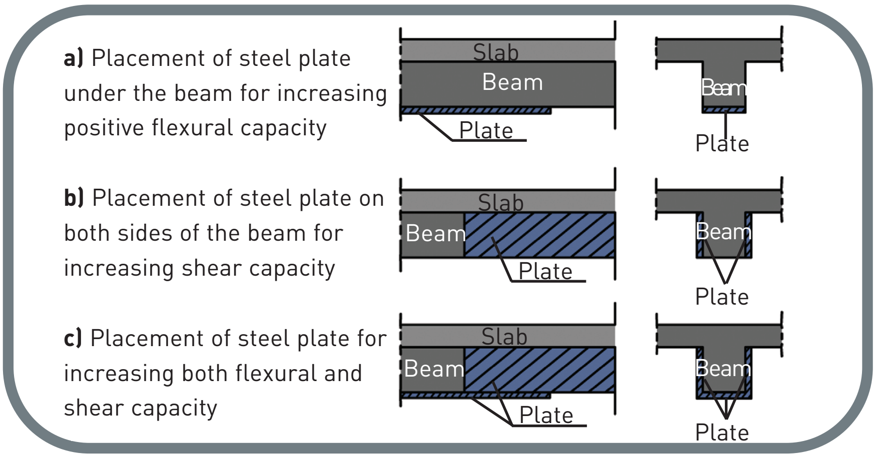


Figure 3. Steel plate application to beams.

Figure 4. Wrapping of beams by carbon fiver polymers.

Carbon Fiber Polymer: The beams wraped by carbon fiber polymers shall have adequate strength and ductility capacity. In the case of application carbon fiver polymer strips instead of wrapping, distance between the strips and development length should satisfy the limits given in the Codes.

Jacketting: eams shall also retrofitted by jacketing. In this applation additional longitudinal and transverse reinforcements are placed in the outer part of the beam inside the jacket. In the application of jacketing newly placed reinforcement in the jacket should be connected to the exisiting reinforcement of the beam. This connection shall be achived by welding of “U” or “Z” sheped connection rods.

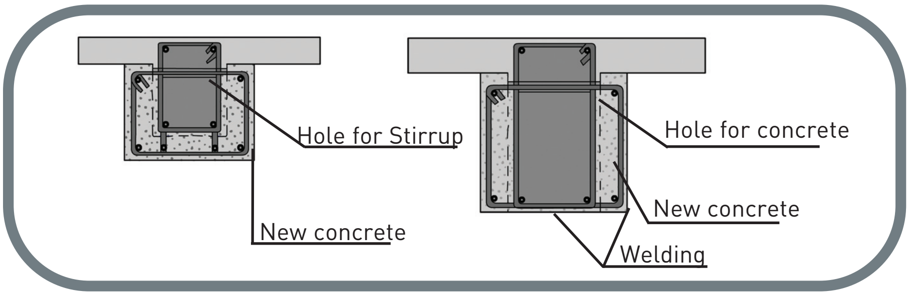


Figure 5. Jacketing of beams.

Retrofit of Columns

Columns shall be retrofitted by reinforced concrete jacketing, steel jacketing and corbon fiber polymers in order to satisfy the continuity or increase the capacity of the columns.

Reinforced Concrete Jacketing: Reinforeced concrete jacketing can be defined as addition of a reinforced concrete layer with a certian thickness around the existing column.

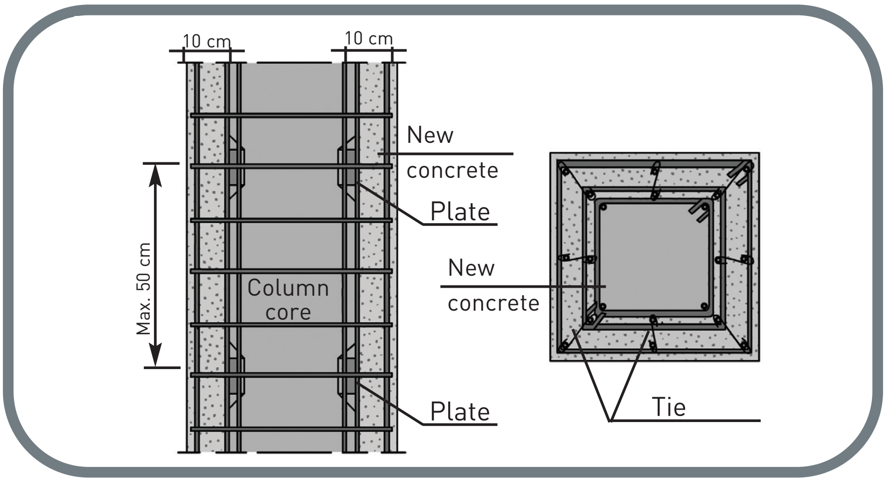


Figure 6. Reinforced concrete column jacketing.

Reinforced concrete jacket shall be continious from the top of the slab of the below storey to the bottom of the slab of the upper storey. In this application connection between the new and the existing concrete, existing reinforcement and additional reinforcement is of great importance (Figure 7).

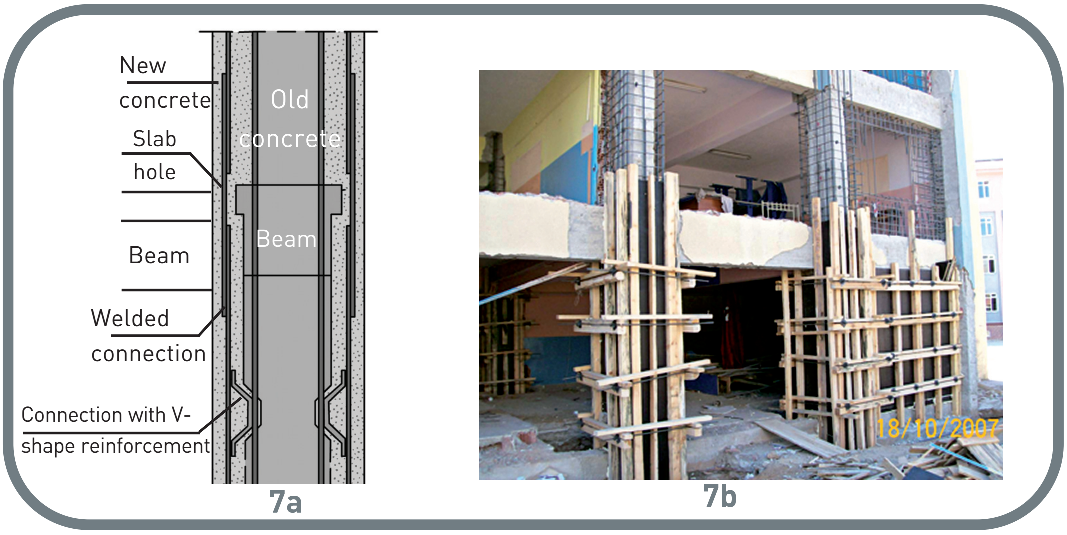


Figure 7a. Connection of new and existing longitudinal reinforcement in column jacketing.
Figure 7b. Application sample (from ISMEP archive).

Firstly, the cover of the column and the damage portion of the column, if any, should be removed. Secondly, exisiting concrete should be cleaned from dust and loose material by pressured water. The jacketing application should be performed after providing a rough surface on the existing concrete. When the jacketing application is continued to the upper storey, detail of the development length of the longitudinal reinforcement can be seen in Figure 8.

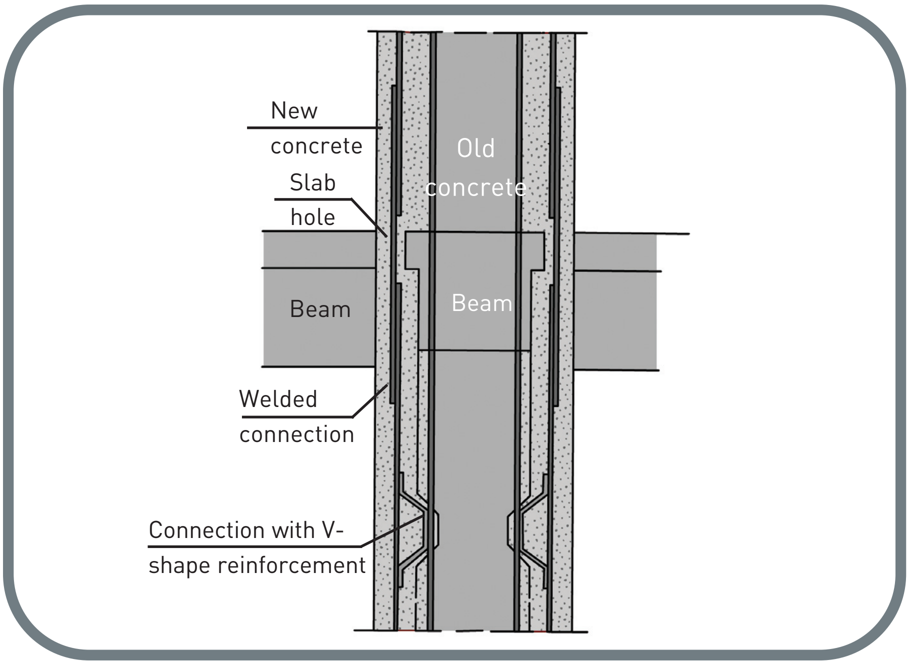


Figure 8. Detailing of newly added longitudinal reinforcement.

Once column jacketing is not continued to the upper storey anchorage of the longitudinal reinforcement shall be applied as it is shown in Figure 9. On the other hand, newly added tranverse reinforcement should properly confine the newly added longitudinal reinforcement and concrete.

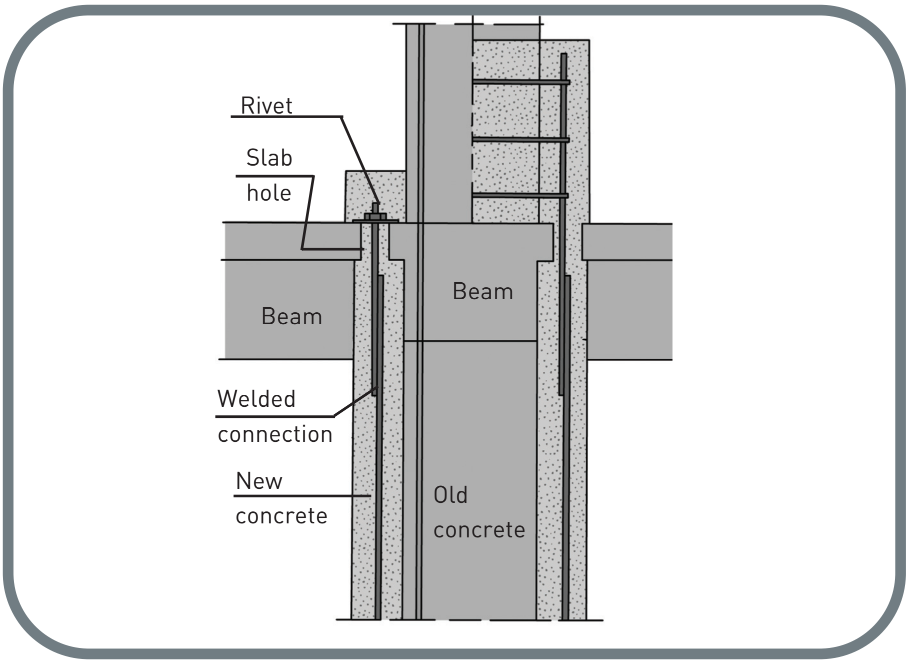


Figure 9. Anchorage of the newly added longitudinal reinforcement.

Steel jacketing: Rectangular column shall be retrofitted by placing angels on each corner of the column and conneting them in horizontal direction by steel plates with appropriate spacing (Figure 10). In this application steel angles should be placed without any space between the existing column and horizontal plates should be continious. Steel angles should also be continous between upper and below storeys by anchoring by bolts to the slabs. The thickness, width, spacing of the horizontal plates should satisfy the limits given in the Code.

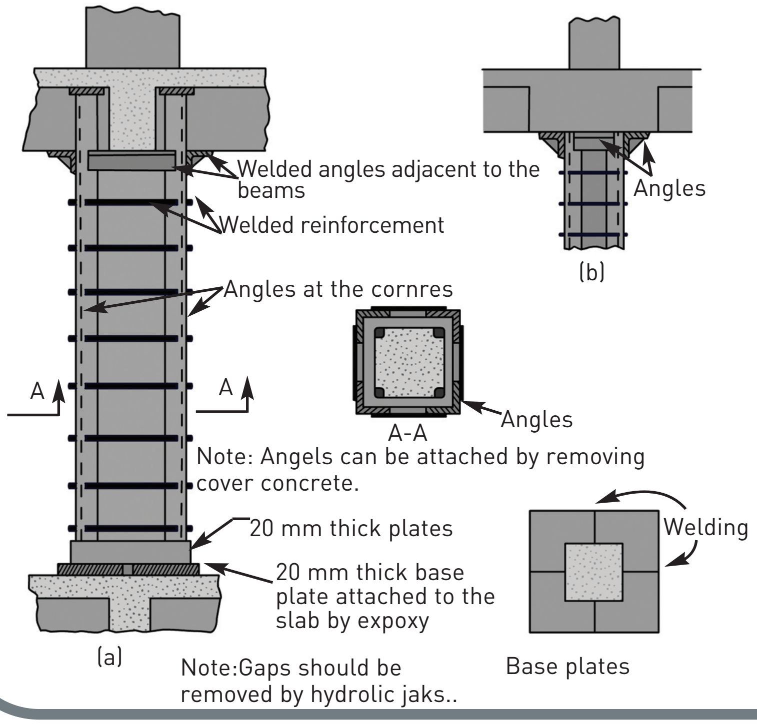


Figure 10. Steel jacketing of column.

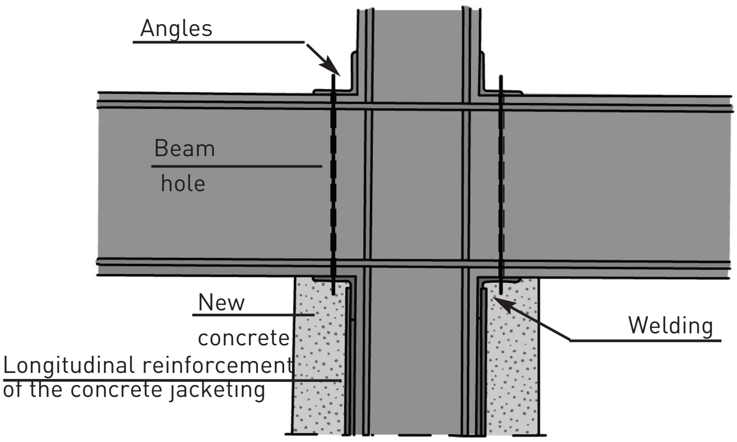


Figure 11. Anchorage of steel angels.

Carbon fiber polymer: Columns shall be wraped in such a way that carbon fiber polymers are parallel to the transverse reinforcement (Figure 12). In this application strength and ductility capacity of the columns are increased additionally development length of columns with lap-splice problems are also increased.

Carbon fiber polymer should be applied all around the column and requirements given in the Code for lap-splice and joints should be applied.

STRUCTURAL SYSTEM RETROFIT

The so-called system retrofit can be defined as addition of new structural members into the structural system of the building in order to increase the lateral strength and deformation capacity of the building and provide homogeneous distribution of internal forces.

Retrofit of Infill Walls

Retrofit of infill walls shall be applied in buildings upto 3 storeys, excluding basement floors, which has continous infill wall inside the reinforced concrete frames. The retrofit application shall be performed by welded wire mesh with special mortar, carbon fiber polymers or prefabricated concrete panels.

Welded wire mesh with special mortar: Infill walls shall be retrofitted by welded wire mesh with special mortar as shown in Figure 13. In the application all the specifications given in the Code for content of special mortar, thickness, spacing of the wires, material properties and design rules should be satisfied.

On the other hand appropriate applications should be done in the foundation in order to transfer the internal forces of the retrofitted infill walls to the soil safely.

Figure 12. Wrapping of columns with carbon fiber polymers.

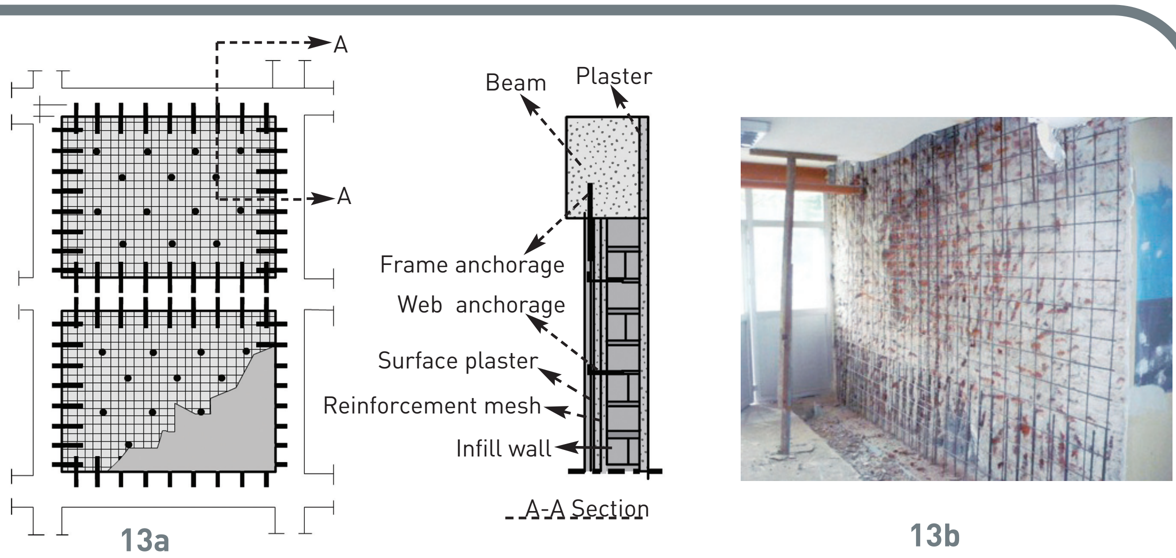


Figure 13a. Retrofit of infill walls by welded wire mesh with special mortar.
Figure 13b. Application sample (from ISMEP archive).

Fiber polymer: Application of fiber polymers shall be applied to the wall with length to height ratio between 0.5 and 2. Material properties, thickness, witdh design of the application should satisfy the specifications given in the Code. The anchorage of fiber polymers applied from corner to corner should be done appropriately with epoxy. As mentioned beforeappropriate applications should be done in the foundation in order to transfer the internal forces of the retrofitted infill walls to the soil safely.

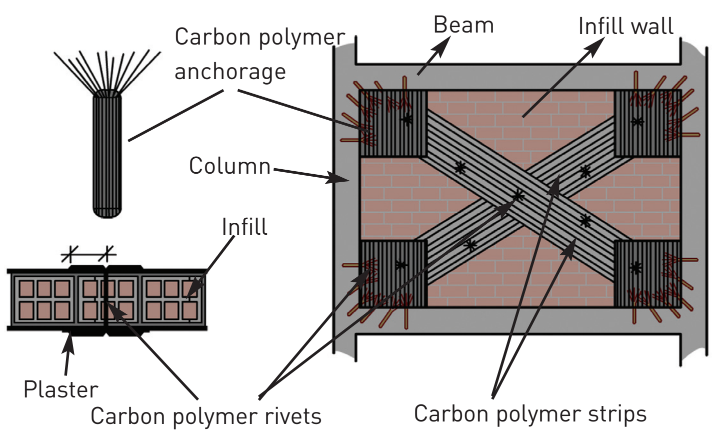


Figure 14. Retrofit of infill walls with fiber polymer strips.

Prefabricated concrete panel: The retrofit of infill walls with prefabricated panels should be performed in such as way that panels should fit inside the frame properly and appropriate achroge should be made in order to transfer the internal loads safely to the frame around it.

In this type of appications shall be applied to the walls with length to height ratio between 0.5 and 2. The prefabricated concrete panels should be connected to the existing infill walls with epoxy based materials. The mechanicalproperties of the panels, thickness, manufacture and design of the application should satisfy the specifications given in the Code.

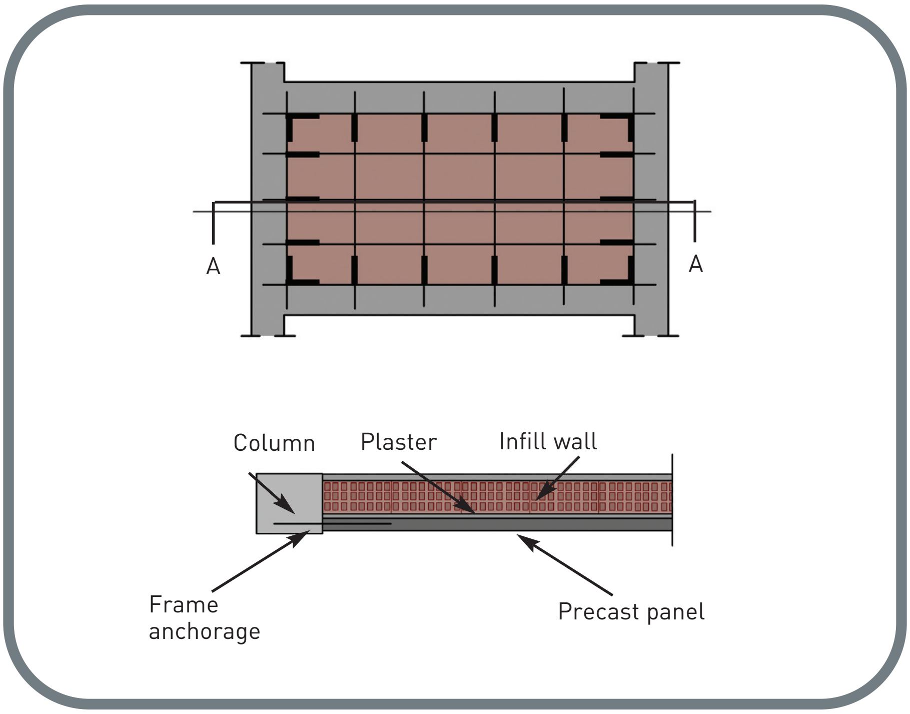


Figure 15. Retrofit of infill wall with prefabricated concrete panel.

Retrofit of RC Structural System with Shear Walls

Reinforced concrete structural systems with inadequate strength and lateral stiffnes shall be retrofitted by RC shear walls. The main purpose of this application is addition of structural members with high lateral stiffness. The RC shear walls shall be applied both inside the exisiting frame or adjacent to it.

Figure 16. Addition of RC shear wall inside the frame plane.

Figure 17. Addition of RC shear wall adjacent to existing frame.

Figure 18. Application of welded wire mesh on masonry walls.

Addition of RC shear wall inside the frame plane: The structural system of the building shall be retrofitted by addition of RC shear walls inside the frame as shown in Figure 16.

In this application added RC shear wall should be continuous from foundation to the top of the building in order to avoid stress concentration and negative effect on the seismic response of the building by cutting it at any level.

Additionally the anchorage of the added RC shear walls to the exisiting frame system is of great importance in order to provide proper transfer of the internal forces. Foundation design of the added shear walls should be properly done in order to transfer the forces of the system to the soil safely. Both the design of anchorage and foundation should be performed according to the specifications given in the Code.

Addition of RC shear wall adjacent to the frame plane: RC hear walls shall be applied adjacent to the existing frame as shown in Figure 17. Similarly, RC shear walls should be continuous from foundation to the top of the building. The new added shear walls should have a proper anchorage to the exisiting frame and new foundations should be constructed under each new shear wall which is design according to the specifications given in the Code.

Retrofit of Masonry Buildings

Since all the walls are load bearing in a masonry building, increase of lateral and vertical capacity of all the walls should be provided.

Similar to infill walls, masonry wall shall be retrofitted on both sides by welded wire mesh with special mortar (Figure 18). The welded wire mesh on both sides should be connected through the holes drilled with certain spacing on the wall.

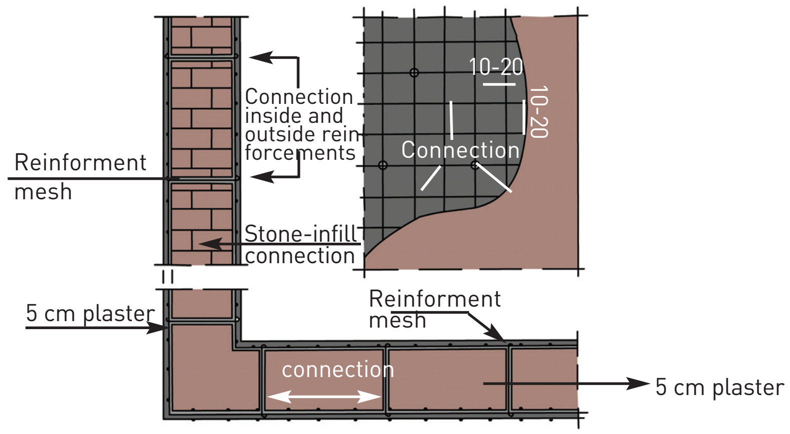


Figure 19. Retrofit of masonry walls by concrete with welded wire mesh.

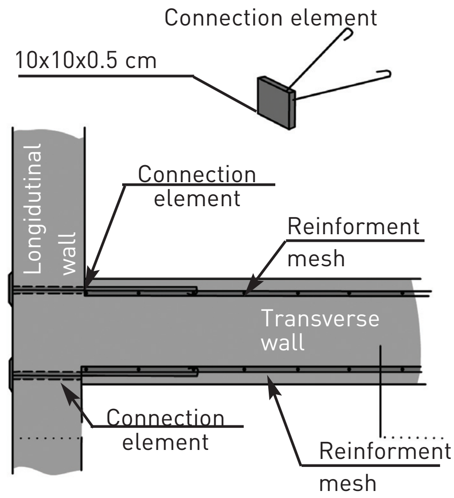


Figure 20. Connection of welded wire mesh to the masonry wall.

The masonry walls shall be retrofitted by addition of reinforcement bars as "tie rods" (Figure 21). The tie rods shall be tightened through the holes drilled on the connection points of two perpendicular walls. Tie rod spacing should be at the one third of the wall for most effective application (Figure 22). The tie rods placed in the walls will take the tensile stress that will occur during seismic action in the masonry wall.

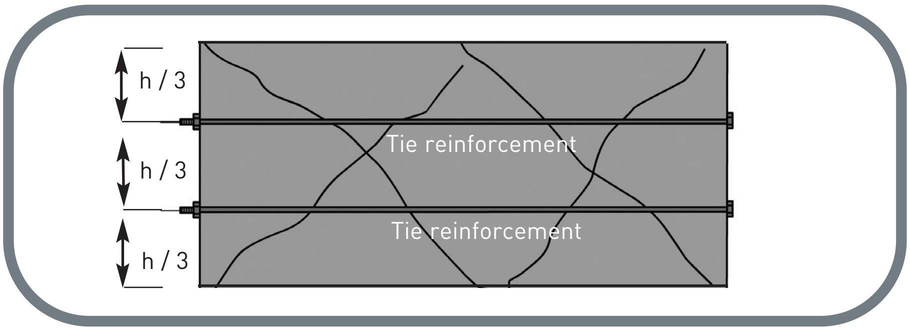


Figure 21. Application of tie rod on masonry wall.

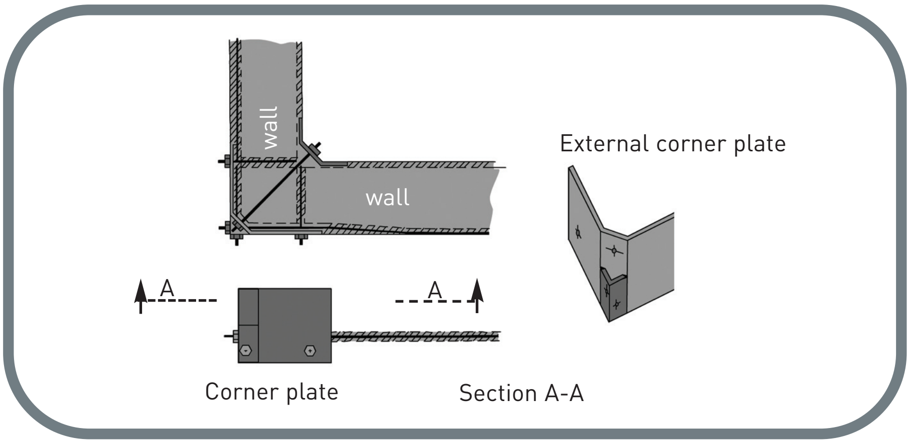
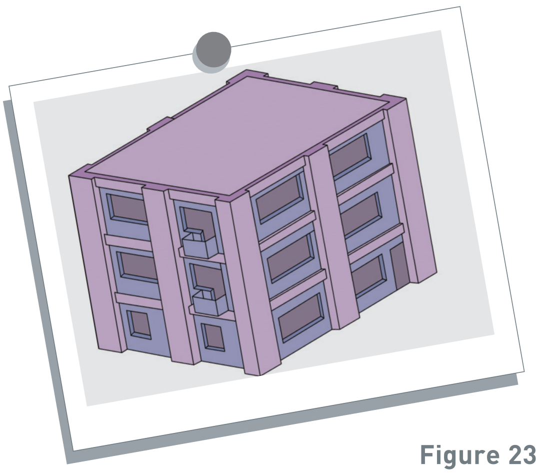


Figure 22. Connection of tie rods on masonry wall corner.



It is also possible for masonry buildings to be retrofitted outside the building. Masonry building can be surrounded by RC frame as seen in Figure 23. In this case the frame should be design so as the resist almost all the lateral forces acting on the overall system and foundation design should be performed under this condition.

Figure 23. Masonry building surrounded by RC frame.

INNOVATIVE TECHNOLOGIES FOR SEISMIC RETROFIT

Another retrofit method is reduction of seismic forces on the building during an earthquake. By the advances in technology some type of devices have been introduces that reduces the vibrations on the building during an earthquake. In general these types of devices are called "isolation devices" which are placed on the top of the foundation level which provides to reduce the seismic effect on the building (Figure 24).

Isolation systems are one of the new technologies introduced in Turkey for earthquake resistant design of buildings. Isolation systems are produced in different geometry and from different materials. In the the design process of the isolation system the geometry and material of the isolation unit are determined depending on the type of the building and the expected earthquake level.

In application mostly used isolation types can be listed as elastomeric bearings (lead rubber, rubber, high damper isolators) and flat or siliding bearings (flat and one or two curved surface isolators), roller bearings (ball in cone, distributed ball in cone) and spring dampers (heliptic steel spring, viscous damper) (Figure 25-26).

In addition to isolation systems, thare are specially designed devices that reduce the seismic risk of the buildings. The devices are aimed to absorbe energy resulting from the seismic forces at pre-defined certain locations of the building.

The above mentioned devices are placed at certian points of buildings so as to resist the earthquake effects at that point. So the transfer of earthquake actions to the other members in the building is prevented. Some of these devices can be listed as hydrolic dampers and specially alloyed steel braces.

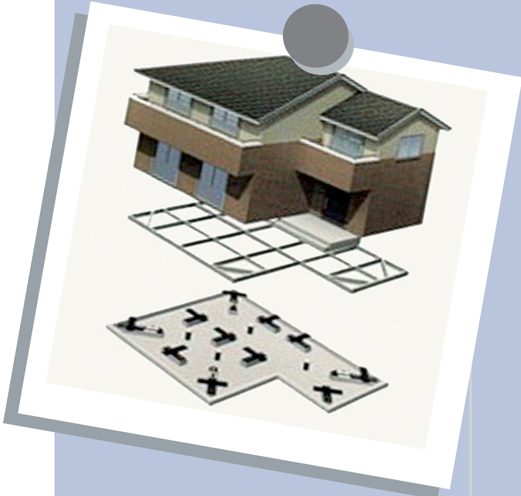


Figure 24. Application of isolation system.

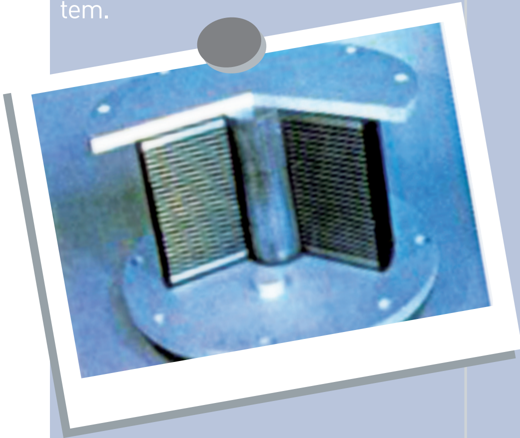


Figure 25. Lead core rubber bearing and application sample.

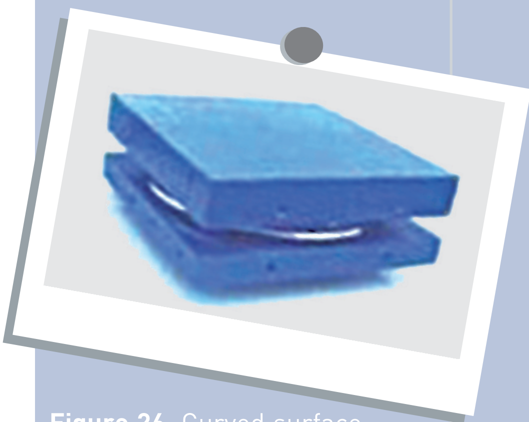
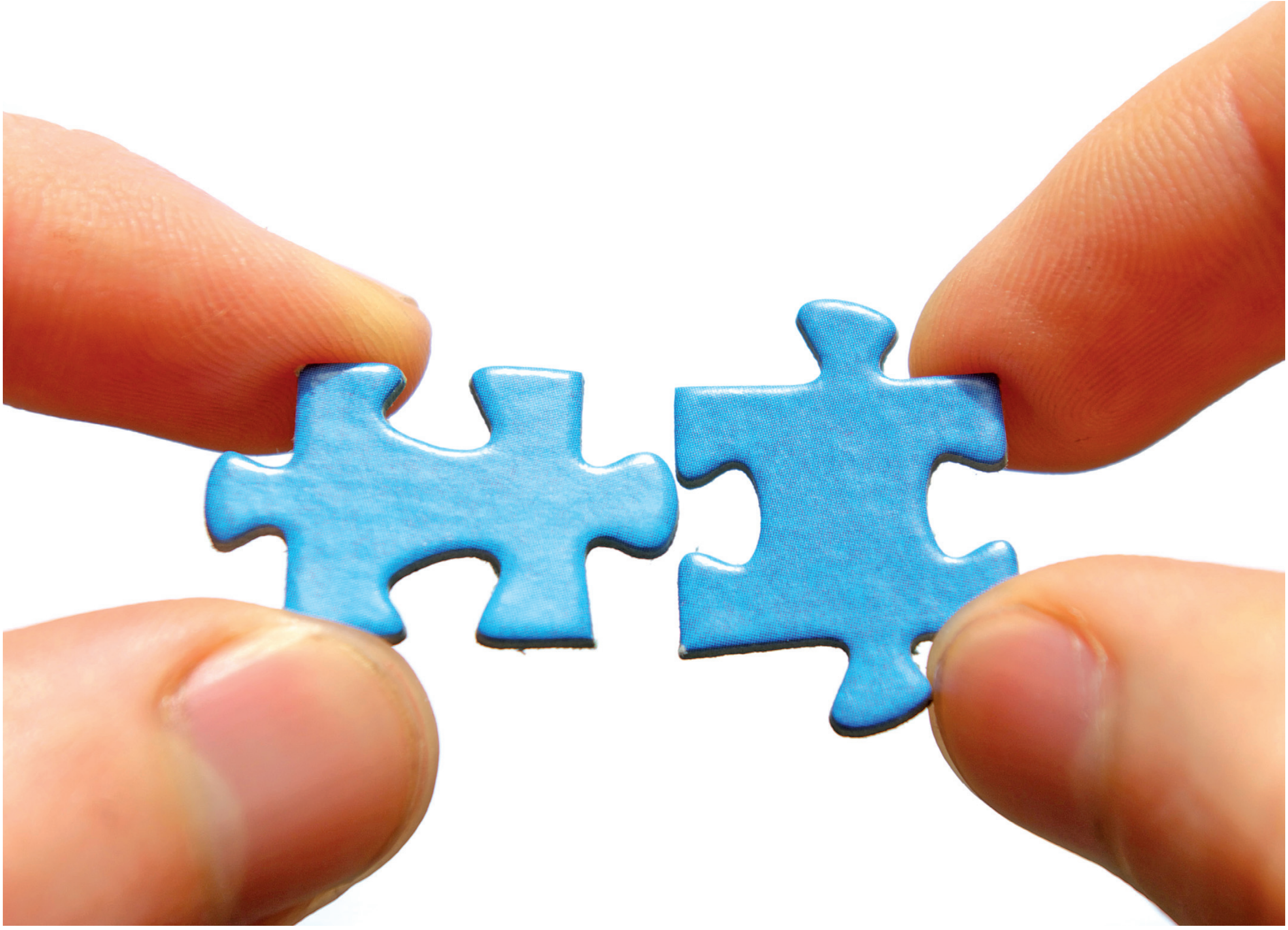


Figure 26. Curved surface friction isolator.

Figure 27. Application of steel braces.

CHALLENGES IN RETROFIT APPLICATIONS

The problems encountered in the retrofit process of a building can be basically classified as technical, legal and economical. The technical problems can be listed as; lack of experienced personell in the design process, lack of skilled workman for the applicaiton of the proposed retrofit method, lack of material and equipment for the application of the retrofit method. Additionally the economic resources directly effect the determination of the retrofit method and other related stages of the application process. On the other hand although technical and economical requirements are satisfied other factor such as location of the building, occupancy purpose of the building, attitude of the residents of the building may affect determination of the retrofit method even prevent application of retrofit application.



FREQUENTLY ASKED QUESTIONS

Does it mean that my building would suffer heavy damage since it has been design according to the old Code?

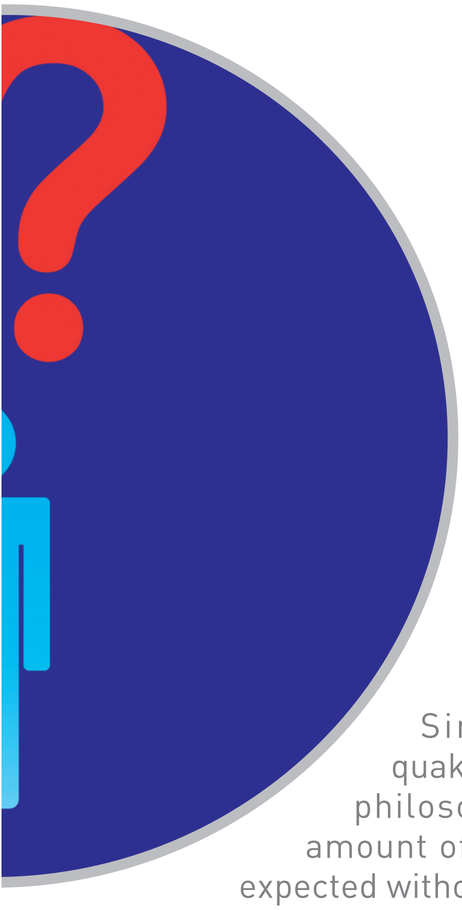
As in the case in the other, countries depending on the developing technology and increase in knowledge and experience Building s Codes are updated. In earthquake resisitamt design phylosopy, there are certain performance levels expected from the buildings at certain earthquake levels. The buildigs design according to old design Codes may suffer a certain amount of damage but this damage lecel is very hard to predict or define.

Does it mean that a building design according to the current Code would not suffer damage?

A building desing according to the current seismic Code would suffer a certain amount of damage with causing loss of life.

How can I learn that whether my building is seismically safe or not? What is the most appropriate way to learn it?

The performance of a building under seismic actions shall be determined through detailed analyses performed under the coordination of an expert structural or earthquake engineer. These processes involve visual inspetion, material testing and analysis of the mathematical model of the building under consideration.



After appli-caiton of seis-mic retrofit in a building, shall I expect any dama-ge in a big earth-quake?

Similar to earth-quake resisitant design philosophy, a certianed amount of damage shall be expected without causing an loss of life. But is is possible for a building to be retrofitted so as not have any damage after an earthquake. But this situation may result in higher economical costs and application problems.

As aresult of the scientific srudies the number of collapsed and heavily damaged buildings are issued on the newspapers. Why do the ourthorited not explain each of the buildings?

The above mentioned studies aim to inform the official and non-offcial establishments related to the issue about the level of damage that would occur in an major earthquake depending on the general building inventory. The so called studies do not involve performance determination of individual buildings.

GLOSSARY

Anchorage: attaching of an element by using another material and an element.

Reinforced concrete jacket: expending the dimensions of a structural element (beam, column) by addition of concrete layer with certain thickness which has transverse and longitudinal reinforcement.

Steel jacket: wraping of a structural element (beam, column) with steel plates and angels.

Infill wall: non-structural elements which are placed inside the frames made of columns and beams of the buildings. There are not involved in the structural system of the building but have a significant effect on seismic behaviour if the building.

Fyber polymer: a material with a fabric appearance that has a very high strength due to carbon inside.

Shear wall: vertical structural reinforced concrete members with a cross section of width to height ration of 1/7.

Base isolator: special devices placed under the main mass of the building for reduction of seismic forces acting on the structural system of the building.

Masonry wall: the load bearing structural element that made up the load resisiting system of a masonry building.

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FIGURES

Figure 4,12 : Sika Product Catalogue
Figure 18 : BASF Product Catalogue
Figure 25 : www.hatlubrekip.com

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- Non-structural Risk Mitigation Against Earthquake
- Structural Retrofitting Against Earthquake
- Structural Risk Mitigation Against Earthquake
- Disaster Emergency Aid Planning Guide for Educational Institutions
- Disaster Emergency Aid Planning Guide for Healthcare Organizations
- First 72 Hours for The Individual and a Family in an Earthquake
- First 72 Hours for Disabled People in an Earthquake
- Disaster Emergency Aid Planning Guide for Industries and Working Places
- Survival Under Extraordinary Conditions
- Psychological First Aid in Disasters
- Disaster Preparedness for Local Disaster Volunteers
- Compulsory Earthquake Insurance Awareness
- Urban Planning and Construction for Disaster Mitigation
    - For Local Decision Makers
    - For Technical Staff
    - For Community Representatives

Notes

Notes

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