EARTHQUAKE RESISTANCE DIAGNOSIS AND STRENGTHENING TECHNIQUES FOR EXISTING BUILDINGS IN TEHRAN

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SUMMARY

Earthquake resistance diagnosis was carried out for some 350 buildings in Tehran. Buildings were selected based on their age, usage, structure and distribution. The investigation covered Disaster Management Buildings, Emergency Response Organizations, hospitals, schools as well as residential buildings. Factors affecting seismic resistance of buildings in this investigation included age, construction quality, and ductility condition. Diagnosis of buildings took place in several steps: 1) Preparation, 2) Field survey, and 3) Diagnosis and judgment. The diagnosis method used in this study was Seismic Index Method. The method is to calculate the value of 'Seismic Index of structure' for each building. The calculated value is compared with the 'Seismic Index Requirement' and the result was used to evaluate the level of building safety. Results of the study show that Un-reinforced Masonry (URM) and URM plus partial frame buildings, that comprise almost 80% of total buildings in Tehran, are extremely vulnerable to strong earthquakes. Other types of buildings including Steel and Reinforced Concrete frames have variable level of vulnerability depending on their age and the level of compliance with the seismic code and the quality of construction. Appropriate strengthening techniques for all three types of buildings were examined and developed. Among possible techniques the most appropriate ones are introduced. This paper presents the details of the diagnosis method implemented in this study as well as the proposed strengthening methods.

Keywords: Concrete; Steel; Un-Reinforced Masonry; Evaluation and Retrofit; Buildings; Building Diagnosis; Strengthening Techniques

INTRODUCTION

The Greater Tehran Area comprises of 22 Districts with an area of over 700 km^2 and a population of over 6.7 million people (1996 census). Majority of the old existing buildings in Tehran and for that matter in the entire country are constructed of Un-Reinforced Masonry (URM) or of combination of URM and Partial Frame. According to the 1996 report of the Statistical Center of Iran, nearly 70% of total buildings in the Iranian cities (aside from Tehran) are URM and the majority of them are brick URM. From these, 55% are 1 story, 33% are 2 stories, and the rest are 3 stories or more, Tasnimi [1].

The reports published in recent years indicate that almost 80% of buildings in Tehran consist of jack-arch brick floors and load bearing walls and about 12% are Reinforced Concrete (RC) and Steel. There are small percentage of wood and adobe (sun dried brick) buildings still existing. Therefore, appropriate selection of buildings for diagnosis within the 22 districts was quite important.

PURPOSE

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The purpose of building diagnosis was to obtain structural information about the existing buildings located within the 22 districts of the Greater Tehran Area. The information from the diagnosis and the subsequent analysis were used for:

- Obtaining comprehension on earthquake resistant capacity of the buildings in Tehran
- Establishing a method of earthquake resistance diagnosis for existing buildings of Tehran
- Finding the structural weakness of different structural types
- Recommending general method of strengthening
- Recommending the countermeasures for future design and construction

DIAGNOSIS METHOD

Method of Analysis

The diagnosis method adopted for analyzing seismic resistance of buildings was the "Specification on Earthquake Resistance Diagnosis and Strengthening of Governmental Buildings" (Building Maintenance and Management Center of Japan). The method was modified considering the specific situation of the buildings in Iran. The design earthquake was based on "Iranian Code of Practice for Seismic Resistant Design of Buildings (Standard 2800), [2]. This method expresses the seismic resistance of a building in a quantitative manner. It provides the Seismic Index of Structure, "GIs", in order to evaluate the seismic resistance capacity of building structures. GIs is obtained from the following equation:

$$GIs = Qu / (a*Qun)$$

Where,

GIs: Seismic Index of Structure
Qu: Seismic force level for ultimate capacity check
Qun: Required seismic force level for ultimate capacity check
a: Correction coefficient

The basic feature of the diagnosis is to set up the size of the target earthquake motion. This is referred as "Required Building Capacity". Next, is the assessment of capacity of the building itself, referred as "Building Capacity". Finally, is the "Correction Coefficient" which refers to features such as the criteria for designing policy, judgment of construction, and deterioration through aging.

TYPES OF BUILDINGS IN TEHRAN

Most of the old buildings throughout Tehran and in particular at the central and southern districts are of URM type, with hardly any resistance to earthquake motion.

The use of URM buildings combined with interior partial frame became common since early 1960's. This type of construction was very popular among architects as it provided total freedom to design any plans, without worrying about the location of columns or implementing any bracings. The partial frames consist of few posts with saddle supported main beams (locally called Khorjini) attached to them, using angle profiles as support. The posts usually run somewhere along the middle of the building. This kind of support (Joint) is usually called "Khorjini Connection". The floor joists are either I beams or concrete joists.

The use of tie beams and later tie beams plus tie columns in URM buildings started upon the Iranian seismic code. This type of construction is used in some residential and school buildings in Tehran.

Early style of steel construction was the use of more saddle supported framing with URM infill. The infill walls are not tied to the framing. Bracings are generally used as lateral load resisting system in recent steel construction.

The use of RC has been a common practice in the construction of governmental, hospital, some school, and recently residential buildings.

SELECTION OF BUILDINGS

Building selection was generally made according to the building type, age, usage, number of stories, and the geographical location of the building. Other types of buildings such as government and special structures (lifelines) were selected based on their actual locations. Total number of buildings to be surveyed was set to 350 with top priority based on the availability of architectural as well as structural drawings. The required number of each type of building was selected according to table 1.

Table –1 number of buildings

Building Type		Sample No.
Public Facilities	Major Public Facility : Municipality, Fire Brigade, Police	70
	Hospitals	80
	Schools	100
	Other Public Facility : Library, Museum, Theaters	10
Residential Buildings	South of the city	10
	Middle of the city	40
	North of the city	40
Total		350

SURVEY PROCEDURE FOR DIFFERENT BUILDING TYPES

General Criteria

Buildings were inspected to collect the following information:

- General building layout and configuration such as location, structural type, age, usage, number of stories, outlook; Architectural and structural drawings, if available, etc.

During the survey the followings were investigated:

- Deterioration through aging such as crack, rust; quality of construction in general and more specifically construction materials such as brick and mortar; workmanship such as welding, etc.

Schools

There are more than 5000 schools in the Greater Tehran Area. The age of the schools in use date back to more than 80 years ago. The list of schools was sorted by the following criteria:

- The type of construction (Masonry, RC and steel)
- The ascending order of year of construction from 1960's to date
- Ascending order of number of stories
- Ascending order of floor areas (number of classes and students)

- Ascending order of playground area (for availability to provide space for accommodating earthquake victims)

Approximately 5 buildings were surveyed at each district. The building types were: URM, URM with tied beams, RC and Steel. On the average 10-12 photographs were taken from each building covering different parts and details for further clarification and verification.

Hospitals

Many of the old hospital buildings do not have drawings. Some hospitals provided architectural or mechanical-HVAC drawings. The more recent ones and the ones that had undergone renovation provided adequate or reasonable number of drawings. The very old general hospital buildings (40 years or beyond) are of URM type, but they are very important and provide major health care services. There are numerous old and new RC hospitals in Tehran. However, a reasonable effort was made to consider RC, steel and masonry buildings that are distributed throughout the 22 districts. The method of surveying was the same as explained for schools.

Large general hospitals have huge floor areas and are built in several stories. There are therefore few expansion joints in such buildings. The surveying team identified and photographed those expansion joints. Whenever the surveying team noticed the lack of expansion joints, or improper attachments of old masonry building to the newly built RC or steel frame they were mentioned in the field survey sheets. Again all the necessary data were collected in the field survey forms in order to enable determination of the level of building's resistance to earthquake. However, in some instances due to lack of access for inspection these data are limited and a strong engineering judgment needs to be exercised to assess them.

Residential

Residential buildings, for which owners granted permit, were inspected. Many of the homeowners even allowed the opening of parts of their building for the actual measurement of the building parts and accurate inspection. For the older buildings only architectural drawings were made available. The newer buildings of the last 8 years had complete set of drawings. The reason for their availability is the new municipality requirement for filing building permits.

GENERAL OBSERVATION (ALL BUILDINGS)

Buildings dead weight is large. There are unnecessary heavy loads imposed by the walls and floors and their material density is very high, for example:

- There are thick walls and floors which do not necessarily have proper thermal insulating properties such as solid brick covered with thick layer of clay, mixed with gypsum and gypsum finish at interior, and thick layer of grout plus stone or brick for façade.
- Typical floor of jack arch brick, or joist and block floors are heavy with dead weight of 540-600 kg/m^2. A relatively significant portion of dead weight is due to the application of a layer of volcanic ash on the floor, with or without cement additive. This layer is used throughout the floor areas just to provide adequate thickness for the passage of piping and electrical conduits.
- The infill walls and parapets are not tied to the structural framing system, thus there is no safeguard against their movement during an earthquake.
- Using untrained laborers such as steel or concrete workers had resulted in many defects in the workmanship.
- Lack of proper and frequent supervision by experienced and qualified engineers has left most of the workmanship defects in place.

Un-Reinforced Masonry (URM) Buildings

Properties

URM buildings are of type A or B as shown in Figures 1 and 2. The earlier version is type A. Type A is very common in the buildings that were built in the past up to the enforcement of the Iranian seismic code.

The plans for most of the so-called semi-engineered buildings constructed between 20 to 35 years ago are of type B, in which the outer walls are un-reinforced masonry bearing walls (about 22-35 cm in residential buildings). The walls are up to 60 cm thick in some school buildings. For the interior of this type of building the architects used to specify steel posts (typically 2-IPE or 2-UNP profiles with connecting strip or cover plates) and 2-IPE or 2-CPE beams that form Saddle Supported beams. The floors consist of steel joists typically at 100 cm spacing filled with jack arch, or are flat and constructed of concrete joists at about 50 cm spacing, with 5 cm concrete topping. In between the floor joists are hollow filler bricks. Type B applies to all types of buildings including residential, schools, hospitals and other buildings.

Bearing Walls

The bearing walls in type B residential buildings are typically 22-35 cm thick and in schools they are up to 60 cm thick. The bricks are solid or hollow with round holes. The expected compression strength of the bricks is 15-25 kg/cm^2.

Mortar

The mortar material is as follows:

- In the older buildings, about 35 years or older it is Clay or Lime + Clay. They have negligible shear strength.
- In the more recent ones, about 30 years or less it is Lime + Sand + Cement, called “Batard Mortar”. The shear strength of this grout is about 5 kg/cm^2
- In the engineered buildings constructed within the last 30 years or less, it is Cement + Sand with shear strength about 6 kg/cm^2

URM Buildings' Characteristics

The building type B became very popular in Iran and dominated the architectural style of construction for more than thirty years even after publication of the early edition of the Iranian seismic code. The reason for its popularity was the ease and speed of construction and also because it gave the architect total freedom to arrange or modify the floor plans during all the stages of building construction, without being concerned about providing earthquake resistant shear walls or bracing. That explains why the as built plan in many of the surveyed buildings is quite different from the original architect’s drawings.

Due to the lack of beam ties and column ties at the foundation and at the floor levels, the URM buildings of type A and B do not meet the principal code requirements of today. In type B buildings the numbers of walls that resist earthquake shear force are less than what is used in type A buildings, which is even less desirable. Bearing walls as well as the vertical posts and their attached beams, or the so called “partial frame” resists the gravity load of floors. Therefore, there is no need for thick load bearing walls to support gravity loads. Furthermore, the partition walls at different floors are not necessarily aligned in the vertical direction, since the architect relies on the partial frame to resist and transfer the wall loads. The partial frame in building type B utilizes Saddle Support for connecting beams to posts. This type of support can be very effective, if adequate size and numbers of connecting plates are utilized to provide the needed fixity and joint energy absorption capability during earthquake motion. In other words provide a meaningful panel zone. A typical Saddle Support is shown in Figure 3. The beams are connected to post by two angles. The length and leg size of the angles depend on the beam flange width and the column width. The welding is done along the lines at points A, B, C, D, and on rare occasions along point E. If the leg size of the lower support angle were less than the beam flange width, the welding would be necessarily of overhead type.

By definition, a connection is considered rigid, if its degree of rigidity is 80%, or more, of that of a fully rigid connection. A connection is considered pinned when its degree of rigidity is 25% or less than the fixed Connection. The saddle support connection is considered semi-rigid, in which its degree of rigidity is somewhere between the above two limits (Figure 4). Laboratory tests indicate that the degree of fixity of a properly constructed Saddle Support, comprised of 2 angles, is about 60–70% of that of a fully fixed connection, Tahooni [3].

The degree of connection rigidity depends on the support angle length, its leg width, thickness, the amount and quality of weld used to connect the supporting angles to the post and beams. If in addition of the support angles, two stiffening plates such as a, and b are also used to connect the beams to post and together, the degree of joint fixity would increase and its energy absorption capability would be enhanced. However, the use of stiffening plates has not been the common practice on the buildings that were surveyed.

It should be noted that the saddle supports are also very weak in the transversal direction, as their rigidity in this direction depends entirely on the bending rigidity of the supporting angle legs and how the two beams are tied together along the span.

The observation of the real situation in the survey showed many defects such as:

- Short angle length (top and bottom)
- Insufficient thickness of angle legs
- Lack of top angle
- Poor welding such as:
  - a - Inadequate weld leg, or throat size
  - b- Insufficient length of weld
  - c- Poor quality weld
  - d- Insufficient length, or in some instances complete lack of weld between beam and lower support angle

These defects are similar to the ones that were observed in the saddle supported building frames, which were destroyed during the past earthquakes. For instance, during the 1990 Manjil earthquake the beams easily separated from columns because of the poor welding.

Observation

There are not many structural drawings available for the older buildings that were constructed before the issuance of the Iranian seismic code. The drawings are limited only to one or two sheets of architectural plans. Furthermore, it was also found that often the As-Built construction is different from the architectural drawing. This is particularly true for the case of residential buildings.

The buildings that were checked have the following characteristics:

1- Older floors and flat roofs are made of jack arch brick with I beam joists. The more recent ones are hollow brick with concrete joists and concrete slabs.
2- There are no ties or anchors between the walls, or floors and the walls.
3- Vertical and horizontal ties can be found in URM school buildings that were built in recent years. For such schools minimum percentage of wall/floor area at each story is provided according to the seismic code. The actual use of horizontal tie beams started after the 1962 Buin-Zahra earthquake; and the use of vertical ties was enforced following to the 1972 Ghir-Karzin earthquake.
4- Roofs are flat and a few are sloped. Sloped roofs are typically made of wooden trusses, or are seldom made of steel.

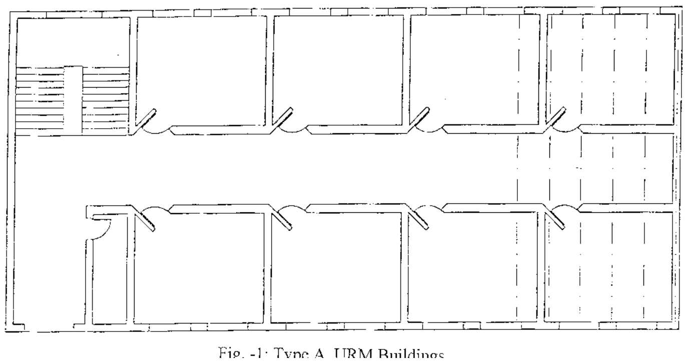

Figure 1-Type A, URM Building

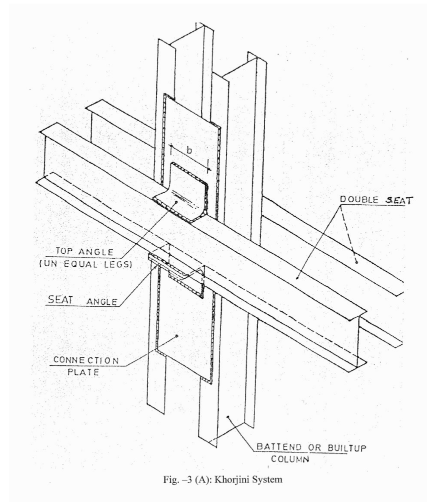

Figure 3- Khorjini System

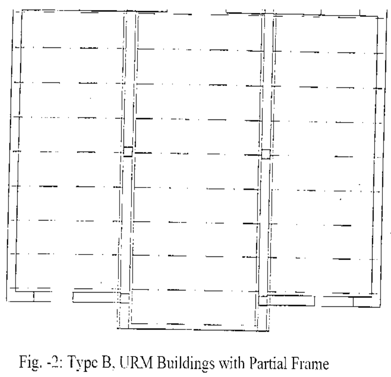

Figure 2- Type B, URM Building with Partial Frame

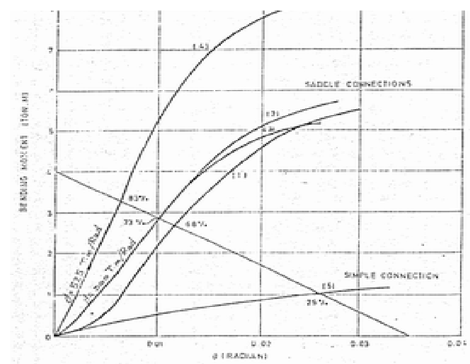

Figure 4- Degree of Rigidity of Khorjini Support

Evaluation

URM buildings and in particular type B, lack adequate bearing walls and ties between the walls and the floors. Therefore, the walls can easily separate from the floors during earthquakes. Furthermore, the floor system is also weakly tied to saddle support system, which itself lacks proper rigidity in its longitudinal as well as the transversal directions.

Because of architectural consideration, no bracings are specified in the partially framed URM buildings. Since the external or internal bearing walls are not tied together and to the floor system, and at the same time the saddle supports lack adequate longitudinal and transversal (out of plane) rigidity, these types of buildings are not earthquake resistant.

The field surveying forms provide adequate steps for evaluating the URM building types A and B. Based on the bearing wall resisting area and their allowable shear resisting strength, one can estimate the building resistance against earthquake. However, there are other factors, aside from force resistance, such as lack of ties between walls and floors, poor proportions of walls etc. that may significantly affect the URM building behavior during an earthquake.

Such factors were identified during survey. The field surveying forms cover those items and they may be so significant that one may reach a conclusion about the insufficient strength of URM buildings, without having to investigate their force resistance capability in detail.

Steel Structures

The older steel buildings are all saddle supported with brick infill. The infill walls are not tied to the framing and can easily separate from the framing during earthquake. The method of connection of beams (2-I beam or 2- channels) to the column is the same as described for the semi-engineered (URM with partial frame) buildings. Practically the same kind of defects as discussed before was observed in old steel building.

The framing of new steel structures that are built in compliance with seismic code, consist of combining existing profiles of different sizes, or are sections made of steel sheets cut to size to form I beams or box sections. Therefore, there are many types of structural members that are particular to Iran. Furthermore, the connections of beams to columns are also done in many varieties that are particular to Iran.

The majority of connections are simple supported (hinged) with bracing. Cases were observed in which the connections possess partial fixity backed by lateral earthquake resistance provided by the bracings.

On rare occasions full penetration welds were observed at the connections. The welded connection between beams and columns are mostly of fillet type. Judging from observation, the welds appeared not to have been properly inspected, because the electrode flux had not been removed. The quality of majority of the welded connections was poor and did not appear to have force and moment resisting capacity larger than the beam or column section. Hence, these connections appeared to lack adequate ductility.

In cases where the survey team was not premiered to strip off the face work, engineering judgment was exercised. The engine rooms proved to be helpful, as the footprints of building members and their connection could be observed.

RC Structures

Most of the reinforced concrete structures of the past are governmental buildings, or hospitals, and a few schools. The observations of RC buildings indicate that up to approximately 20 years ago all the reinforcing bars and stirrups were plain. Removing the concrete cover and exposing the reinforcing bars confirmed these.

The quality of construction in the governmental and hospital buildings is good. No apparent defect, settlement or cracks were observed. The only apparent observation was the appearance of aging and minor breakage of concrete cover, caused by the impact of objects occurring over the years of service.

Unfortunately, hardly any structural drawings were available for such buildings and surveying on older buildings were limited to measuring the exterior dimensions of beams, columns and slabs and sometimes the exposed reinforcing bars. Several detailed photographs backed these observations.

Obviously, the old RC buildings do not necessarily meet the recent seismic code requirements or the ductility demand expected at the connection point. However, judging from their dimensions they appear to be quite robust. The use of RC buildings became very common and was encouraged by government within the last 20 years.

The RC buildings of recent years are of all kinds, Residential, Schools, Hospitals, etc. Fortunately, drawings could be found for many new and recent RC buildings. In these cases the survey team provided adequate number of photographs to show the status of the building or their defects, if any.

SRENGTHENING TECHNIQUES

Structural strengthening and providing seismic resistance for all masonry, reinforced concrete and steel buildings may be done by first considering the direction and location of the weak links in the structure. In case of Tehran buildings it was noted that in all buildings the dead load is quite large and it would be a major factor that contributes to the increase of lateral seismic load. It is therefore reasonable to first consider reducing the overall existing dead load and then provide the necessary strengthening system for the lateral load resisting system of the structure.

Strengthening Un-Reinforced Masonry Buildings

Old masonry buildings are by far the heaviest of the buildings that were surveyed. At the same time the heavy walls and ceiling are not of high quality material. For instance, the grout is clay, clay + sand, or poor quality cement + sand. Essentially brick infill wall can be found in almost all types of buildings. The infill walls are of solid brick in the older buildings. The new buildings mainly use hollow brick, which are substantially lighter than solid brick (850 kg/m^3 compared to 1850 kg/m^3 for solid brick).

There are hardly any ties connecting the floors to the un-reinforced masonry walls, infill or to the structures of RC and Steel Structures. In the case of majority masonry buildings (mostly schools) constructed before 1980's no vertical or horizontal ties are used. Usage of ties in masonry buildings was enforced by Iranian building code in late 1960's. Some of the earlier ones (about 10-15) years old masonry buildings are 3 or even 4 stories. According to Iranian seismic code (Standard 2800) maximum number of stories for tied masonry buildings is 2.

The hysteresis loops of URM buildings show hardly any energy absorption capability during structural deformation. Their behavior is very brittle and failure takes place at the initial cycles of deformation. Adding ties and bracing would greatly improve this shortcoming.

In many instances, school buildings are isolated from their adjacent buildings and therefore external ties can be added without much concern about space limitation for constructing new foundation/or extrusion of ties.

All or some of the following steps can be taken depending on the project's need and the consultants design. The steps for strengthening of a typical masonry building are as follows:

1- Removing the non load bearing heavy partition walls and replacing them by lighter weight construction such as Dry Wall, or use light weight walls such as concrete block walls (foam concrete, etc).
2- In jack arch floors remove the volcanic ash, grout, tile etc. Clean and expose the joists. If necessary, strengthen the weak floor joists, install floor diaphragm ties according to seismic code guidelines. Install horizontal steel ties, made of steel channel or angle profiles, at the periphery of floors and if needed at mid span of the floors. Apply reinforcing mesh, weld them to the floor steel ties and then pour a fresh layer of concrete slab. The steel ties provide the followings:
- They provide the necessary floor horizontal seismic ties between the joists and helps in improving the floor diaphragm action.
- They act as formwork for pouring new fresh concrete
- Reinforcing mesh can be placed and welded to them, to form a diaphragm and this way the whole system would be tied together.
- The perimeter ties (channel or angle) can be connected to external or internal vertical or horizontal ties and thus provide an integrated seismic resistant construction.

3- If the exterior of the building allows and there is enough working space available, it would be advantageous to construct horizontal and vertical ties at the exterior of the building. This has the advantage of providing continuity of ties at both vertical and horizontal directions at all floors. It also minimizes the tenant's disturbance during construction. For the masonry schools and hospitals reducing the level of disturbance will be a significant advantage.

4- If the exterior faces of the building and the close proximity to adjacent neighbors do not allow construction of external ties, one may consider installing them internally, or within the wall thickness.

5- In lieu of ties or when there is no available space, it may even be possible to consider shear walls instead of ties. This would be discussed further.

6- In order to save time one may consider utilizing pre-constructed steel components instead of concrete ties that are later assembled in site. They can be hollow, and made of steel plate, that would form a jacket and allow room for placing reinforcing bars and pouring concrete. The proper connection between the jacket and the floor ties will provide a necessary bonded system that would resist the lateral load. This system of ties would be a composite one.

7- As mentioned above, exterior ties are simpler to install and thus are preferable both to the building owner and the contractor. However, space constraint may not always allow this. In this case ties would be internal.

8- The external, in-plane, or internal (steel section, steel jacket or concrete) ties would have to be connected to floors diaphragms and joists at each level in order to serve their intended function as lateral load resisting and transfer system. The connection between floor diaphragm and the ties would be provided by steel or reinforced concrete connecting members.

9- In some strengthening methods it is even possible to use connecting rods below the ceiling that could be post tensioned by turning their double acting nut. This would lower the vertical ties' slenderness ratio.

10- If the grout between the brick layers is of very poor quality (clay, clay + sand, clay + lime) the URM wall between ties may not be capable to withstand out of plane seismic load. In this situation the following options may be considered, based on a time and budget and engineering consideration and limitation.

1. Remove the weak wall completely and construct a lighter and stronger one.
2. Remove portions of grout and some of the bricks, this way provide a rough exterior surface. Clean and wash their surfaces, install reinforcing mesh, moisten the wall and shotcrete, or use form work or Roofix, and apply a layer of cover concrete. This new concrete will bond well with the surface roughened brick wall.

11- On thick load bearing walls it would be even possible to make U shaped vertical grooves by removing vertical strips of brick wall on both inner and outer faces of outer faces of brick wall. Then place vertical rods and form a reinforcing cage inside them and pour concrete inside the groove to form vertical ties within the thick wall. If necessary, a concrete cover layer with appropriate thickness may be poured integrally with ties to form a combination of ties and shear wall or ribbed shear wall.

12- If wall quality and condition allows, (i.e. shear and bearing resistance of the grout is adequate) the vertical rods or metal strip (placed inside the removed strips within the brick wall) may even be post tensioned In order to accomplish this, horizontal steel or RC girders have to be installed at ground floor and other floor levels. The rods would be passed through these girders and then post tensioned. The post-tensioned rods should be installed on both sides of the bearing wall in order to avoid bending moment on either of the wall surface.

13- A layer of reinforcing mesh on both wall surfaces and subsequent concreting would provide shear walls on both sides. The concrete may be applied using formwork or by shotcreting and subsequent smoothing of the final surface.

14- In order to provide further bond between interior and the exterior surfaces, some of the bricks (stretch or bond) can be removed. The removed bricks provide several holes so that the concrete can enter and connect the two surfaces, by placing tie rods within the holes prior to concreting the shear resisting capability between the two surfaces would be greatly enhanced.

15- In order to shorten strengthening time and space, another alternative would be to provide X- bracing made of metal strap or heavy reinforcing bars. This can be accomplished by clearing the four corners of a masonry wall to which the bracing would be attached. By reinforcing the corners and pouring high strength concrete the load transfer system between the bracing and the floor levels would be formed. The above method can be done on one, or both sides of walls, or where the space limitation would not allow extrusion of exterior ties.

Strengthening Reinforced Concrete Structures

The study of RC buildings in Iran showed that the buildings with shear walls provide significant lateral resistance as compared with the ones with no shear wall. There are not many RC buildings with shear walls in Iran, and it may not be possible to strengthen them by construction of shear walls therefore, the framing has to be strengthened. Hence, in buildings that do not possess sufficient lateral resistance it would be more reasonable to consider strengthening by adding shear walls. The shear wall may be internal or even added at the exterior of the building, provided that the outside space is available to construct shear walls and its required foundation.

Strengthening Framing Members

If building's condition does not allow addition of shear walls, the framing members have to be strengthened. This can be effectively accomplished by using steel jackets around beams and columns. The steel jackets are made of steel plates. The connection between the jacket and concrete is accomplished by anchors. The anchors may be Hilti anchors or regular bolts depending on the budget dedicated to strengthening and the level of strength required. The anchors may be secured to existing RC parts mechanically (wedge action) or by using epoxy or expansive grout. The anchors are placed within the holes drilled in concrete members, using a well designed depth of embedment. Adequate depth for the hole would allow the load transfer from jacket to RC member via anchors. Because of reasonable Iranian labor wages, this method of strengthening would be more suitable for Iran. The use of jacket does not require major and overall increase in existing member size. To ensure proper bond and contact between steel jacket and the RC member a gap of approximately 3-4 cm maybe necessary between the jacket and RC member. This gap would be filled out by expansive mortar. The mortar would be injected through the especially designed holes within the jacket body.

The abovementioned procedure for strengthening does not require complicated technology and all the necessary ingredient or parts to accomplish it, is readily available in Iran. Another advantage of jacketing method is the speed and simplicity of execution without considering complex tolerance.

In the important buildings that time and increasing the member sizes by jacketing imposes constraints and the budget for strengthening is not a major issue, the use of carbon fiber would be an appropriate consideration.

Strengthening the Floor RC Slab

The floor RC slab can be strengthened by:

- Adding a new layer of concrete to the floor. Using concrete glue on the old surface and using anchors that would function as shear keys would attain the bond between the new and old concrete layers.
- Using carbon fiber on the bottom surface.

Adding Lateral Load Resisting System

The lateral load resisting system may be in one of the following forms:

- Concrete shear wall
- Using carbon fiber on the bottom surface
- Using steel shear wall
- Using steel bracing

Strengthening Steel Structures (Khorjini Connections)

Almost all steel structures with khorjini connections and without bracings are designed before the issuance of the Iranian seismic code. Therefore, they do not have sufficient lateral load resistance capability. The surveying of those buildings showed that in many cases the beams are not welded to their supporting seat angles. They had used tack weld just to keep the beams from falling off, not to resist the lateral load. The steel framing with khorjini connections effectively support gravity loads and not so much the lateral load. In order to enable khorjini system to resist lateral load one has to consider the followings:

- Strengthening of foundation; columns; beams; connections; and addition of a new bracing system.

The buildings with khorjini connections have typically few interior walls and they are mostly partition walls not so much the bearing walls. Therefore, the existing architecture and the room arrangements do not usually allow addition of bracing inside the building.

For the cases in which bracing cannot be installed, the khorjini connection has to be strengthened by converting beam-column connection to a moment resisting frame, and if necessary, to strengthen the beam and column itself. The first priority for strengthening a khorjini connection is to add bracing, check the adequacy of member (column, beam) sizes and the weld at other khorjini connections. In this case the khorjini connections should be checked to see if they would suffice as hinged connection. A typical khorjini connection to which bracing is added is presented in Figure 5-Case 3.

If the floor plan arrangement does not allow the inclusion of bracing, the khorjini connection should be strengthened to form a rigid connection. Figure 5-Cases 1 and 2 show such a detail. It should be kept in mind that when khorjini connection is converted to a rigid one, the column and beam members have to be strengthened in order to increase the framing lateral load resistance capability.

The strengthening will be by simply exposing beam and column members and adding stiffening plates. The strengthening of column shall extend to the base plate and include the foundation.

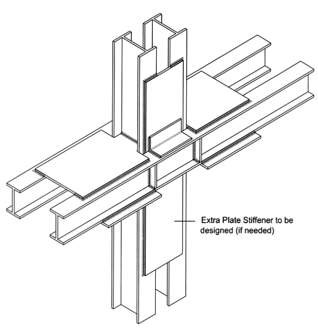

Fig 16 - Case 1: Existing Seat Angle attached to column flanges strengthening Khorjini connection by conversion to rigid connection.

Case 1

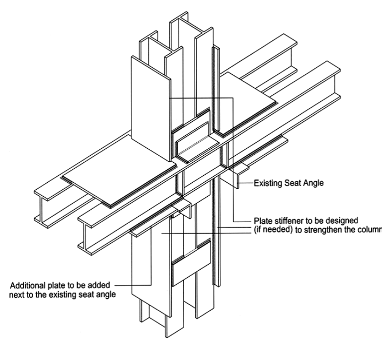

Fig 16 - Case 2: Steel Angle attached parallel to column web.

Case 2

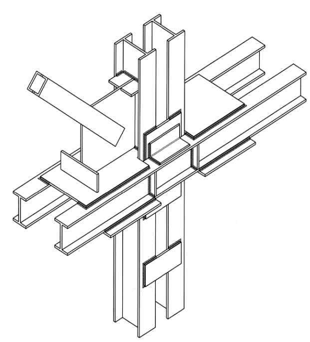

Fig 16 - Case 3: Steel strengthening for lateral load resistance by adding bracing

Case3

Figure 5 Strengthening khorjini connection

Foundation

Foundation for a building, which is strengthened by ties, shear walls or bracing can be in the form of mat, individual or excavated piles. The least disturbance to the occupants would be by the use of excavated piles. They provide a reasonable counter weight against shear and overturning forces transmitted by the strengthened structure. The piles can be well connected to the existing foundation.

It should be noted that in old buildings there are no concrete foundation. They usually have a shallow strip of clay + lime for foundation. In order to provide continuity of load transfer system between shear walls or ties to the ground, a new foundation can be constructed.

The top of piles may be tied together by a strip of concrete or steel member with rectangular cross section that would support the so-called weak existing foundation.

Strengthening by Using Base Isolation System (BIS)

Technical and economic viability of using base isolation system should be considered for strengthening of buildings in Iran. Although base isolation system has not yet been used in Iran, but the needed expertise within Iran and the neighboring countries for design, application and implementation exists. The capability for manufacturing the base isolation components also exists, but due to lack of application no parts has been manufactured yet.

Due to good soil condition, almost in all parts of Tehran, particularly in the northern part, which reduces the demand for heavy strengthening of foundation, the use of base isolation for all types of buildings should be considered.

The Base Isolation system should be particularly considered for hospitals, schools, governmental buildings, and recent short to medium rise residential buildings. The reason for this, among others, is its relatively low cost and the minimum disturbance that it may cause.

Use of Base Isolation System and other types of structural vibration control has not yet been introduced in the Iranian seismic code. However, they can be utilized in strengthening existing buildings in Iran, particularly in Tehran. It is recommended that application of these systems are recognized and encouraged in the seismic code so that they can be used in construction of the new buildings as well.

RESULTS

Most of old buildings in Tehran are made of Un-Reinforced Masonry which is extremely vulnerable against earthquake motion. Therefore, appropriate techniques should be implemented for strengthening this type of buildings.

Most of relatively new buildings are of steel frame structure that has structural deficiency of column-beam connection points without forming a proper structural panel zone. They are mostly made of column-splice connection by field fillet welding and lack of bending rigidity, thus, regarded as a hinged connection.

It should also be noted that many buildings were not built in accordance with their design drawings. There were cases that the as built construction was very different from the specifications made in the drawings.

There exists relatively less number of RC structures in Tehran. They also have structural deficiency without having adequate shear walls. They are mostly made of bricks or hollow blocks and the shearing resistance of such walls is minimal.

CONCLUSIONS AND RECOMMENDATIONS

Seismic Index Method was used for diagnosis of some 350 buildings in Tehran. According to the results of this study most of the existing buildings in Tehran, which are of URM type, are quite vulnerable against earthquakes. Most of Steel and RC structures that have been constructed in the past and even in recent years lack adequate lateral load resistance. Therefore, different methods of strengthening techniques should be utilized to upgrade their resistance against future earthquakes. Some techniques were introduced in this study. However, more emphasis was made to URM buildings since they are dominant in Tehran and the entire country. It is recommended that application of Base Isolation system and other structural vibration control systems are introduced and encouraged in the new edition of the Iranian seismic code so that they can be utilized in construction of new structures as well as retrofitting of existing buildings.

The poor design could have been overcome during the design control phase of the structural drawings. Using trained laborers and continuous supervision by experienced registered engineers could have eliminated the poor execution. Frequent and unannounced field visit by the specialized and experienced municipality/professional organization of engineers would ensure the continuation of the quality work by the owner's contractor.

Finally the emphasis for preparing the as built drawing, after the job completion, would provide a technical identification for the buildings. This in turn will assist in simplifying retrofitting/strengthening efforts.

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