Post-Earthquake Quick Inspection of Damaged Buildings in Bam Earthquake of 26 December 2003

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ABSTRACT: *A procedure developed for quick inspection of buildings in earthquake damaged areas of Bam by a group of volunteer engineers is introduced. The procedure is applied to 550 masonry, steel and reinforced concrete buildings. Distribution and statistics of the buildings characteristics such as their use, number of stories, penthouse and stairs damages, type of material and structural systems and type of diaphragms are determined. The information has provided important data about the design, detailing and construction deficiencies of common types of buildings in Bam.*

Keywords: Bam; Post-earthquake inspection; Damaged building

1. Introduction

Following any major damaging earthquake that disrupts and threatens life and normal activities, there is likely to be shock, confusion and chaos in the period following that usually lasts some appreciable time. Although, there might be a scene of apparent disruption and emotion, actions are required to respond to the emergency and to start the process of recovery. An important action is to address the safety of buildings, to establish those that cannot be used, to make those damaged so that they can be used, and to identify those that can continue to be fully used. There will be a mix of extent of damage to buildings within an area and between different areas. Many buildings at first may appear to be undamaged, but on closer inspection these may be found to be perhaps severely damaged. Very often the full extent of damage continues to emerge over time.

With Iran's history of earthquakes and other disasters, one of the most important post-disaster activities is to determine the safety and functionality of buildings and especially the key facilities. These facilities include emergency operation centers, hospitals, sewage plants, water treatment systems, and airports. However, the most challenging task is to address the safety of large stack of private homes.

In some countries, a group of professionals immediately after earthquake begin to evaluate the damaged buildings. The evaluation consists of some phases. At the beginning, the first phase of evaluation that is called "rapid screening" or "quick inspection" is done. The aim of this step is to find out whether a building is safe for occupying or it need some structural and non-structural retrofitting or it is not recommended for occupying. Because inspection is done very quickly, providing retrofitting details in this phase is not possible. Although, there are some countries that have developed postearthquake evaluation procedures, only Japanese and American quick inspection development histories are briefly reviewed here.

When the Southern Italy Earthquake struck in 1980, the then Ministry of Construction of Japan (at present, the Ministry of Land, Infrastructure and Transportation) started the "project for advanced repairing technology for earthquake damaged buildings" in 1981. It created a series of methods; from risk evaluation of damaged buildings to repairing technology of wooden, steel and reinforced concrete structure buildings. When the Mexico Earthquake occurred in 1985, the temporary risk evaluation method for damaged reinforced concrete buildings was applied. After the project of comprehensive technology was undertaken, the Building Disaster Prevention Association of Japan published, "The standard of damage evaluation and the guidance of repairing technology for the buildings hit by earthquakes". Then a technological standard was established, Shizuoka government established a temporary risk evaluation system of damaged buildings in 1991, followed by the Kanagawa government in 1992. When the Great Hanshin-Awaji Earthquake occurred in 1995, the temporary risk evaluation of damaged buildings was applied for the first time in Japan. Then many other local governments established their own system.

In July 1987 the California Governor's Office of Emergency Services (*OES*), California Office of Statewide Health Planning and Development (*OSHPD*), and Federal Emergency Management Agency (*FEMA*), jointly awarded *ATC* a contract to develop procedures for postearthquake safety evaluation of buildings. This led to the development of the *ATC*-20 [1] report "Procedures for Post earthquake Safety Evaluation of Buildings". *ATC*-20 documents procedures and guidelines for the safety evaluation of damaged buildings. These are written specifically for volunteer structural engineers, and building inspectors and structural engineers from city building departments and other regulatory agencies, who would be required to make on-the-spot evaluations and decisions regarding continued use and occupancy of damaged buildings [2]. To provide the ATC-20 methodology in a concise, easy to use field reference document, a Field Manual was developed as part of the *ATC*-20-1 [3] project. The Field Manual is intended to be taken into damaged areas and used by those trained in the *ATC*-20 methodology.

A three-tier posting classification system is recommended by ATC-20 and is described in the publication series Procedures for Postearthquake Safety Evaluation of Buildings. The modified forms and placards are described in the Addendum to *ATC*-20 (*ATC*-20-2) [4]. The colored placards (tags) are tools posted on inspected structures to easily identify facility damage assessment results from a distance. They are normally posted at all building entrances. The following describes the circumstances by which inspectors should post each type of placard.

- ♦ ***Inspected:*** (Green Tags) Buildings can be damaged, yet remain safe. If the safety of a building was not significantly changed by the disaster, it should be posted with a green placard reading *INSPECTED*.
- ♦ ***Unsafe:*** (Red Tags) Buildings damaged by a disaster that pose an imminent threat to life or safety under expected loads or other unsafe conditions should be posted with a red placard reading *UNSAFE*. These are not demolition orders.
- ♦ ***Restricted Use:*** (Yellow Tags) When there is some risk from damage in all or part of the building that does not warrant red-tagging, a yellow tag should be used. The placard should indicate the specific restriction (i.e., entry, duration of occupancy, use, etc.). When the extent of damage is uncertain or cannot be ascertained within the time and resources available to a Rapid Evaluation team, the building should be posted with a yellow placard reading Restricted Use indicating additional inspection requirements, and any restrictions on use or occupancy should be clearly noted on the placard. Although a building may be placarded Restricted Use, specific areas in and around the building could be further identified as unsafe. This specific area should be identified and posted with a red placard reading Area Unsafe. An Area Unsafe placard helps identify dangerous situations that may exist around or within an otherwise structurally sound building. A building posted Restricted Use may have a specific area that is posted Area Unsafe. In this situation, the Restricted Use placard should indicate the specifics of the restrictions and identify the location of the Area Unsafe [1].

In this paper, a procedure for quick inspection of buildings that has been developed by a group of volunteer engineers is introduced. The procedure then applied to 550 buildings in Bam. For each building, a set of forms has been filled. Then the data is collected in a database. A study on the data provides some statistics about buildings and common construction practices in Bam area.

2. Procedure Used

In order to quickly inspect damaged buildings of Bam city, a form has been prepared that contains some structural and non-structural related items. The items are selected based on the available quick inspection forms, considering special features of common buildings in Iran. In the conclusion part of this form three cases have been mentioned:

1. Building is relatively safe and can be occupied with probably some non-structural retrofitting;

2. Building can be occupied with structural retrofitting;
3. The building is not recommended for occupation. A translation of forms to English is included in Appendix [A].

The questions in the forms are intended to summarize the type and extent of damages in a building. They are also designed to compare the building characteristics with the minimum requirements of "Iranian Code of Practice for Seismic Resistant Design of Buildings" [5].

3. Quick Inspection Form Items

Rapid evaluation form has been shown in Appendix [A]. This form has nine parts. The form items should be completed according to the available data in the location of building. A brief explanation of each part of the form follows.

Part A) Building general information: In this part, the general information of the building, such as address, area, building use and its owner are mentioned.

Part B) Building general characteristics: In this part, general characteristics of the building such as number of stories, height of stories, existence or lack of basement, penthouse and cantilever and their damage level are marked.

Part C) Material: In this part, the material of structural elements (frame, wall, and foundation) and non-structural elements (partitions, finishing and ceiling) are entered.

Part D) Stairs: In this part, the stairs and stairs side wall damages are mentioned.

Part E) Structural system characteristics: This part is one of the most important parts in the quick inspection report and contains structural data of the building such as structural system type in each direction, type of bracing, slab system, foundations system and structural elements such as columns, beams, bracings, connections, base plates and infills.

Part F) Visible plastic deformations: The large story drifts and inappropriate deformations shall be mentioned in this part.

Part G) Non-structural elements damage: In this part the damage level of non-structural elements such as ceilings, pipes, partitions, facets, parapets and electrical and mechanical equipments are mentioned.

Part H) Conclusion: By evaluating the items in each section of the form, the buildings can be classified into three categories:

1. Building is relatively safe and can be occupied with probably some non-structural retrofitting;
2. Building can be occupied with structural retrofitting;
3. The building is not recommended for occupation.

Due to rapid nature of inspection, the conclusion is somehow dependent to the level of skill of inspector. To avoid inconsistent results, some training session was held for the volunteer engineers for familiarizing them to interpretation of form items.

Part I) Recommendations: In order to prevent later damages and dangers and guarantee the safety of the residents, any special point that may have been observed during the evaluation, shall be recommended to the residents. These recommendations are mentioned in the last part of the form. At the end of the form, a schematic drawing of the structure should be drawn.

The forms have been filled for 550 buildings in Bam. The collected data of buildings has been transferred to a database program that has been developed for gathering and processing the data. Figure (1) shows the forms in database format.

4. Damage Statistics

Having compiled all the form items for 550 buildings in the database, one may extract different statistics out of the information. The statistics are about different buildings characteristics such as their use, number of stories, penthouse and stairs damages, type of material and structural systems and type of diaphragms. The information helps identifying many design, detailing and construction deficiencies of common types of buildings in Bam. Some of this information is presented in this section.

Shown on Figure (2) is the percentage of buildings function and use. It is noteworthy that the buildings are mainly private homes that are registered for surveying by their owners in municipality. Therefore, it is not surprising that the number of residential buildings is much more than other types of buildings.

Shown on Figure (3) is the number of stories for the surveyed buildings. Almost 75% of surveyed buildings are single story buildings. It can be concluded that most of these building are short period structures.

The widespread damage to penthouses was a

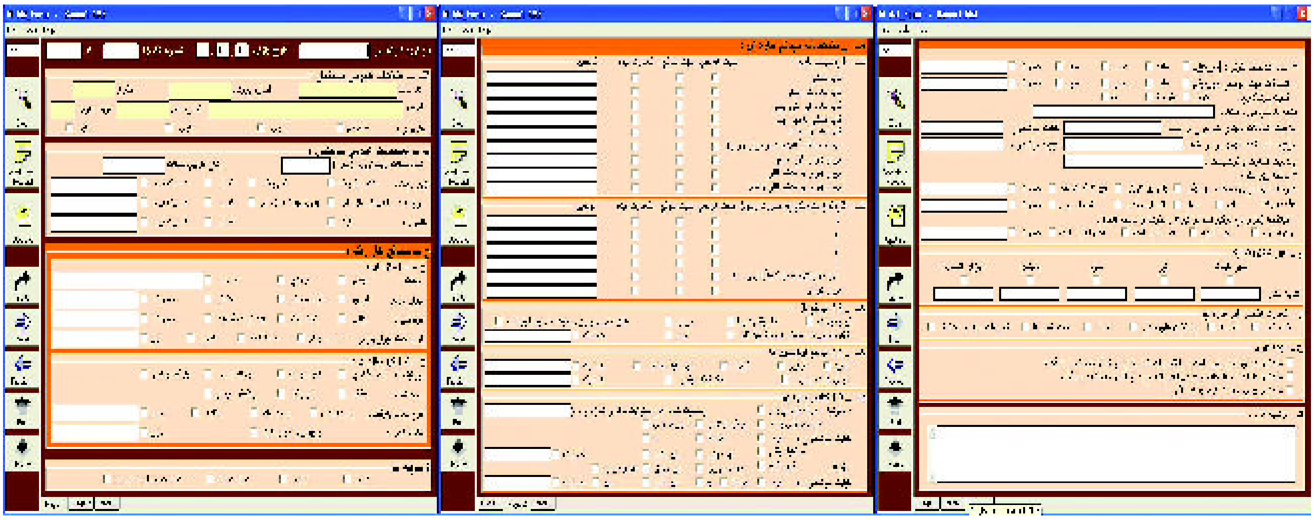

Figure 1. Building database for quick inspection (Appendix I).

feature of Bam earthquake. In many buildings the penthouse was built without any structural integrity to the main structure and without any structural system. An item in the inspection form was designed to identify whether the penthouses has structural system or not. Another item in the form shows whether the penthouse has been severely damaged. According to Figure 4, the cause of damage in more than 75% of penthouses was lack of structural system.

Figure (5) shows the percentage of each building type in the surveyed buildings. Masonry solid brick wall buildings are by far the dominant type of building in this study. The relative percentage of building as shown in Figure (5) is consistent with the data in most other cities of Iran.

Stairs are important items in any quick inspection approach. A damaged stair causes difficulty for occupants to exit building in an emergency situation. Shown on Figure (6) is the percentage of damaged stairs in the surveyed buildings. According to the figure, in more than 25% of cases, both stairs and its sidewall have been damaged. Also, more than 20% of sidewalls were damaged, while the stair itself was undamaged. On the other hand in less than 10% of cases, the stair has been damaged while its sidewall was undamaged. The high number of damaged stairs

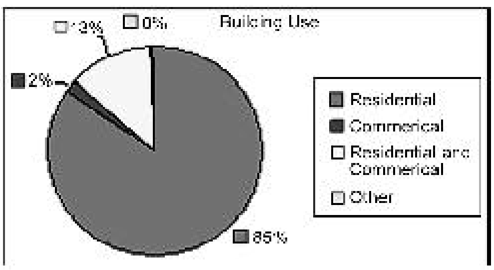

Figure 2. Types of building uses.

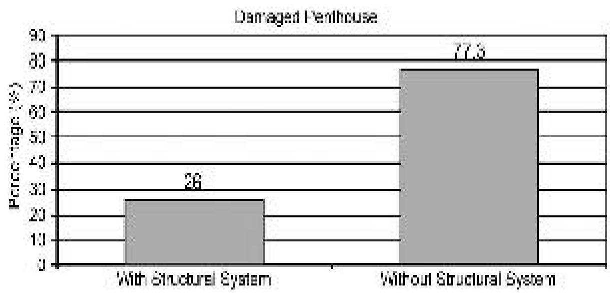

Figure 4. Damage to penthouses.

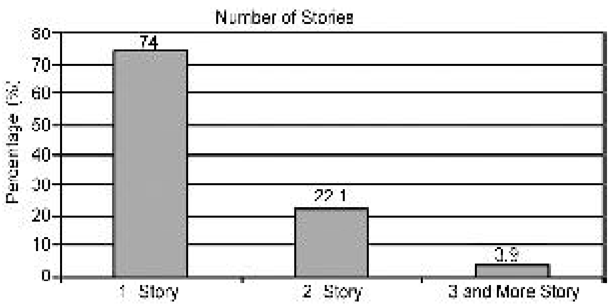

Figure 3. Number of stories for buildings.

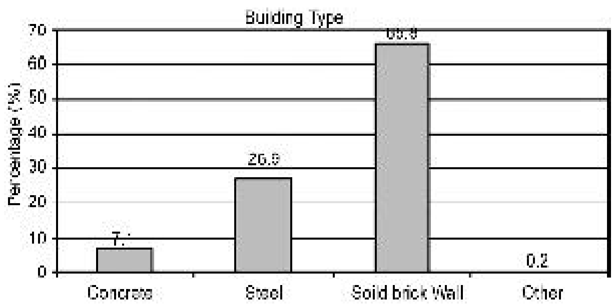

Figure 5. Distribution of building types.

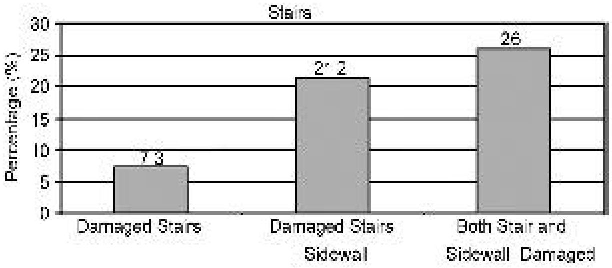

Figure 6. Damage to stairs.

shows some serious flaws in construction practice in Bam.

Shown on Figure (7) is the distribution of structural systems for the buildings surveyed. According to this figure, almost half of the buildings have somehow used unreinforced bearing wall. The use of tie beams as emphasized by the Iranian Building Code [5] is not common. The satchel type of simple framing is the second popular system. According to the Iranian Building Code [5], a satchel frame is a simple frame that can not resist lateral loads and needs bracing. However, in most cases in Bam, no bracing is used.

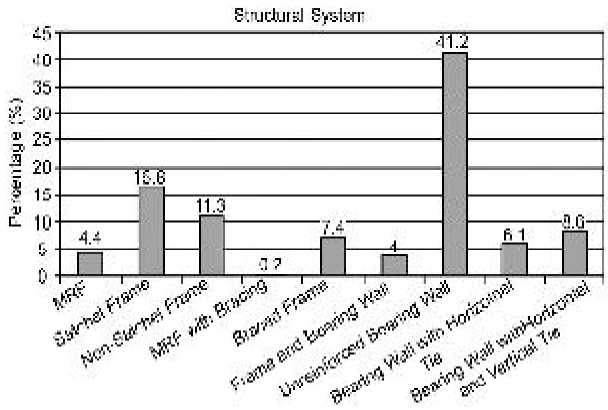

Figure 7. Structural system types.

The percentages of diaphragm systems of buildings are shown in Figure 8. Brick floor (archaic) diaphragms are the most common type in Bam; the same is true for other parts of Iran. According to Figure (8), more than half of all diaphragms are brick floor that does not satisfy code requirements with respect to using rods for their integrity. More reliable diaphragms consist of joist and block is accounted for only 10% of cases.

By completing the set of forms for each building, one may arrive to final conclusion. Due to nature of a rapid inspection, the conclusion is somehow dependent to the level of skill of inspector. To avoid inconsistent results, training sessions were held for

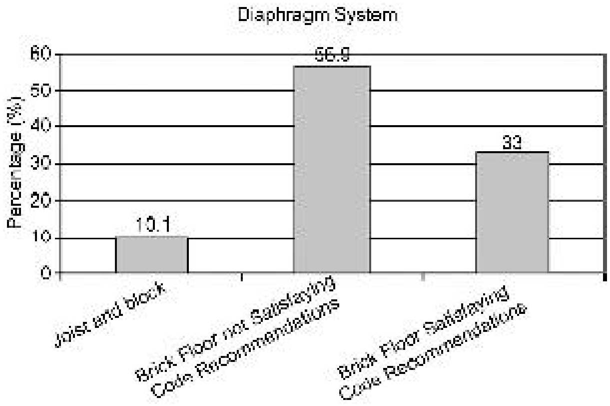

Figure 8. Diaphragm types.

the volunteer engineers for familiarizing them to interpretation of form items. The items in the forms are intended to summarize the building characteristics as well as type and extent of damages in a building. They are also designed to compare the building characteristics with the minimum requirements of "Iranian Code of Practice for Seismic Resistant Design of Buildings" [5]. By careful consideration of all aspects, the inspector arrives at the final conclusion. Figure (9) shows the percentage of each case. Unfortunately most of surveyed buildings did not meet the minimum requirements of codes.

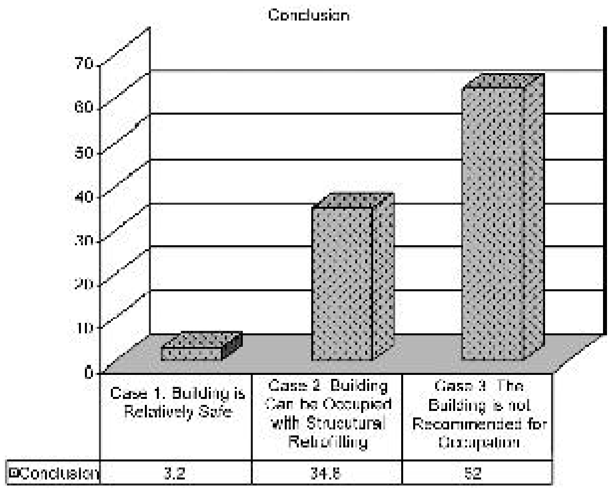

Figure 9. The comparison of results.

5. Some Observations from Application of the Procedure to Damaged Buildings in Bam

Collecting the buildings information in a database greatly facilitates the processing of the information. By carrying out different queries, important data about the common design, detailing and construction deficiencies of buildings in Bam has been provided.

Some of the findings are summarized in following sections for different types of buildings.

5.1. Masonry Buildings

The masonry structures that have been evaluated are categorized in two groups: Bearing wall without vertical and horizontal tie beams, bearing wall with vertical and horizontal tie beams (lintels). In the masonry structures without tie beams, the bearing walls and even partitions had been activated during earthquake and resisted the applied load and had experienced significant damages. Most of the damages are limited to shear cracks (diagonal, 45 degree cracks). In some cases all the wall were damaged and collapsed. According to “Iranian Code of Practice for Seismic Resistant Design of Buildings” [5], these buildings are not acceptable, due to lack of tie beams. If concrete condition and reinforcement detailing in vertical and horizontal tie beams of the masonry structures be proper, then the tie beams act as effective elements and resist earthquake load. Because of their short height and short period, their strength rather than ductility is important. To mobilize their full strength the tie beams should be able to keep the integrity of the walls. In many masonry buildings, because of the inappropriate details and concrete condition, some damages had occurred in tie beams, see Figure (10), and in the connections, see Figure (11). Also the bars had buckled and the concrete cover of tie beams had cracked. Some horizontal tie beams were not at the same level, which is not acceptable according to the code.

5.2. Steel Buildings

Structural system of the most existing steel structures in Bam city is continuous side connection (satchel connection) simple frame in one direction and simple frame in the other direction, see Figure (12). In some cases, there is not any frame in the other direction. In braced steel structures, the bracings and their connections were often suffering from different construction deficiencies. Most of the bracings had experienced buckling and damaged in the connection region, see Figure (13). In some steel structures without bracing, the stairs were performed as bracing

Figure 10. Crack in tie beam due to lack of reinforcement.

Figure 11. Improper connection of vertical and horizontal tie bars.

Figure 12. Simple steel frame without bracing.

Figure 13. Buckling of bracing and connection damage.

system and prevented the building from collapse. In these buildings, the stairs had often experienced sever damages. Penthouses of the most structures being evaluated had no structural system and had experienced significant damages.

5.3. Reinforced Concrete Buildings

The number of reinforced concrete buildings in Bam was far less than number of masonry or steel buildings. Poor quality of concrete, improper forming, and incorrect reinforcement detailing was widespread. In many reinforced concrete buildings, due to existence of many stiff and strong infills, the beam and columns of frames had performed as tie (lintel) beams for the frames. Therefore, in many reinforced concrete frame buildings, the infills suffer significant damages, but the beams and columns with poor quality remain intact, as they had only acted as tie beams. A sample of poor detailing in connections is shown in Figure (14). A common practice of damaging columns for installing staircase is shown in Figure (15).

Figure 14. Poor detailing in connection.

Figure 15. Removing concrete to install stair case.

6. Conclusions

A procedure for quick inspection of buildings in earthquake damaged areas of Bam that was developed by a group of volunteer engineers is introduced in this paper. The quick inspection forms are tailored for common building types of Iran. The procedure is applied to 550 masonry, steel and reinforced concrete buildings. Distribution and statistics of the buildings characteristics such as their use, number of stories, penthouse and stairs damages, type of material and structural systems and type of diaphragms are determined. The information has provided important data about the design, detailing and construction deficiencies of common types of buildings in Bam.

Based on experience in quick inspection of buildings in Bam, some suggestion can be made. The most important is that an effort should be made to organize a systematic approach for quick inspection of buildings in Iran. Following an earthquake or a catastrophic disaster, there is an immediate need for damaged building inspections. People must be kept from using unsafe buildings. It is essential that qualified inspectors quickly identify safe and unsafe structures. To address this need, a building inspection program for catastrophic disaster events such as earthquakes in Iran should be established. Also specialized training should be organized for engineers, architects and building professionals who will volunteer their time to conduct building inspections after disaster events. Any building professional wishing to become a volunteer must attend the Post Earthquake Safety Evaluation of Buildings course. Graduates should receive inspector credentials and become a team member qualified to inspect earthquake damaged buildings. A panel of earthquake and structural experts and building officials should approve all training materials used in this course. During the course, procedures and documents should be presented to promote uniformity in the rating of building damages so that different individuals examining the same building will arrive at the same conclusion about its relative safety.

Acknowledgment

Data gathering from 550 buildings in Bam and development of quick inspection forms (in Farsi) is done by a group of 20 volunteer engineers that the authors of this paper were among them. The authors wish to thank their colleagues for their hard work. Special thanks to Mr. Taheri-Behbahani (also a team member) and Ms. Beski for their important roles in organizing the effort. Also much appreciation is due to Mr. Rahmankhah for writing the database software. The authors like to thank Mr. Rahmankhah, Ghafarbeigi and Adib-Haji Bagheri for their help in entering the data to the database. The authors wish to thank Memar Magazine and *IIEES* for facilitating their work.

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Appendix I. The quick inspection forms.

Name of inspectors: Inspection date: Photo numbers:

A) Building General Information

Owner name: File number: Area:

Address: Tel.: Inspection No.:

Building use: ❍ Residential ❍Commercial ❍Office ❍Other

B) Building General Characteristics

Number of stories (without basement): Approximate height of stories:

Basement: ❍Portion of the plan ❍All the plan ❍Not exist ❍Damaged ………………

Penthouse: ❍With struc. System ❍Without struc. system ❍Not exist ❍Damaged ………………

Cantilever: ❍Exist ❍Not exist ❍Damaged ………………………………..

C) Material:

C-1) Structural

Frame: ❍Reinforced concrete ❍Steel ❍Damage …………………

Bearing wall: ❍Solid brick ❍Concrete block ❍Clay ❍Damage …………………

Foundation: ❍Concrete ❍Lime soil ❍Invisible ❍Damage ………………

Bearing wall mortar type: ❍Sand and cement ❍Lime ❍Bustard ❍Other

C-2) Non-Structural

Partition: ❍Solid brick ❍Hollow brick ❍Hollow block ❍Concrete block

Finishing : ❍Stone plate ❍Brick ❍Cement plaster

Partition mortar type: ❍Sand and cement ❍Lime ❍Bustard ❍Other

Ceiling:

D) Stairs

❍Exist ❍Not exist ❍Stairs damage ❍Stairs sidewall damage

E) Structural system characteristics

E-1) Load resisting system	Transversal direction	Longitudinal direction	Damaged	Description
Moment frame	❍	❍	❍	....
Continuous side connection (satchel) simple frame	❍	❍	❍	....
Non-continuous side connection simple frame	❍	❍	❍	....
Moment frame with bracing	❍	❍	❍	....
Simple frame with bracing	❍	❍	❍	....
Composite system (simple frame and bearing wall)	❍	❍	❍	....
Unreinforced bearing wall	❍	❍	❍	....
Bearing wall with horizontal tie beams	❍	❍	❍	....
Bearing wall with horizontal and vertical tie beams	❍	❍	❍	....

E-2) Bracing type (if exist)	Transversal direction	Longitudinal direction	Damaged	Description
X	❍	❍	❍	....
Λ	❍	❍	❍	....
V	❍	❍	❍	....
K	❍	❍	❍	....
Other bracings(shear wall,knee bracing,EBF,…)	❍	❍	❍	....

E-3)Slab system

❍Joist and block ❍Cast-in-place concrete slab ❍Composite

❍Brick floor without satisfying the code ❍Brick floor with satisfying the code

❍Other ❍Damage …………………………………...........

E-4) Structure of the foundation

❍Single ❍Combined ❍Mat ❍Invisible ❍Damage……………

❍ With tie beams ❍Without tie beams ❍Damage……………………………

E-5) Structural Elements

-Columns: ❍Open double profile column flat-bars condition (dimensions,…)

❍Closed double profile ❍Steel box ❍Other (steel)

Welding quality: ❍Good ❍Moderate ❍Poor

❍Concrete rectangles ❍Concrete circle ❍Other (concrete) ❍Damage…………

-Beams: ❍Rolled ❍Cast beams ❍Plate girder ❍Composite cross-section

Welding quality: ❍Good ❍Moderate ❍Poor

❍Concrete beam ❍Other ❍Damage ……………………...

-Longitudinal direction connections: ❍Continuous side connection ❍Pin ❍Rigid

❍Other ❍Damage…………………………………

-Transversal direction connections: ❍Continuous side connection ❍Pin ❍Rigid

❍Other ❍Damage…………………………………

-Connections welding quality: ❍Good ❍Moderate ❍Poor

-Bracings:

Bracing cross-section: ………………………………………………………………..

X bracing middle connections details: ……………………………………………….

X bracing connections details at end joints: ……………………………………………

Damage and description: ……………………………………………………………

-Base plate:

Column to base plate connection method: ❍With angle ❍with plate

❍invisible ❍Damage …………………………..

-Bolts: ❍Non-deformed bar ❍Deformed bar ❍Welded connection

❍Bolted connection ❍Damage ……………………………………………………….

-Infill:

❍Exist ❍Not exist ❍Activated ❍Non-activated ❍Damage ……………………

F) Plastic Deformations

	❍Story drift	❍Beam	❍Column	❍Bracing	❍Connection elements
estimation	…………….	..…………	…………..	…………..	……………………….

G) Non-Structural Elements Damage

❍Ceiling ❍Pipes ❍Interior partitions ❍Faces ❍Parapets

❍Electrical and mechanical equipments

H) Conclusions:

❍Building is relatively safe and may be occupied with probably some non-structural retrofitting

❍Building may be occupied with structural retrofitting

❍Not recommended for occupation

J) Schematic drawing of the structure.