Japan International Cooperation Agency (JICA)
Tehran Disaster Mitigation and Management Center (TDMMC)

No.

THE COMPREHENSIVE MASTER PLAN STUDY ON URBAN SEISMIC DISASTER PREVENTION AND MANAGEMENT FOR THE GREATER TEHRAN AREA IN THE ISLAMIC REPUBLIC OF IRAN

FINAL REPORT
- SECTOR REPORT -

December 2004

Pacific Consultants International
OYO International Corporation

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PREFACE

In response to the request from the Government of the Islamic Republic of Iran, the Government of Japan decided to conduct a Comprehensive Master Plan Study on Urban Seismic Disaster Prevention and Management for the Greater Tehran Area in the Islamic Republic of Iran and entrusted the Study to the Japan International Cooperation Agency (JICA).

JICA selected and dispatched the Study Team headed by Mr. Itaru Mae of Pacific Consultants International, consisted of Pacific Consultants International and OYO International Corporation, to the Islamic Republic of Iran from August 2002 to August 2004. JICA set up an Advisory Committee chaired by Dr. Kimiro Meguro from the University of Tokyo, which examined the study from the specialist and technical points of view.

The Study Team held discussions with the officials concerned of the Government of the Islamic Republic of Iran and conducted the Study in collaboration with the Iranian counterparts. Upon the last return to Japan, the Study Team finalized the study results for delivery of this Final Report.

I hope that this report will contribute to the promotion of relevant projects for urban seismic disaster prevention and management and to the enhancement of friendly relationship between the two countries.

Finally, I wish to express my sincere appreciation to all the officials concerned of the Government of the Islamic Republic of Iran for their close cooperation extended to the Study.

December 2004

Estuo KITAHARA
Vice President
Japan International Cooperation Agency

Mr. Estuo KITAHARA
Vice President
Japan International Cooperation Agency
Tokyo, Japan

December 2004

Letter of Transmittal

Dear Mr. KITAHARA,

We are pleased to formally submit herewith the final report entitled “The Comprehensive Master Plan Study on Urban Seismic Disaster Prevention and Management for the Greater Tehran Area in the Islamic Republic of Iran”.

This report compiles the results of the study which was undertaken in the Islamic Republic of Iran from August 2002 to August 2004 by the Study Team organized jointly by Pacific Consultants International and OYO International Corporation under the contract with the JICA

The Final Report is composed of the “Executive Summary”, “Main Report”, and “Sector Report”. In the Main Report, mitigation countermeasures for pre-earthquake, emergency response just after earthquake, and post-earthquake rehabilitation and reconstruction are prepared in the form of comprehensive master plan on urban seismic disaster prevention and mitigation, including the project profiles for urgent action projects. In addition, the Sector Report compiles overall procedures of the master plan formulation in each sector. It is truly hoped that the outcomes of the Final Report will contribute to reducing the risks of earthquake occurrence in the Islamic Republic of Iran.

Finally, we would like to express our sincere gratitude and appreciation to all the officials of your agency, the JICA advisory Committee, the Embassy of Japan in the Islamic Republic of Iran, and Ministry of Foreign Affairs. We also would like to send our great appreciation to all those who have extended their kind assistance and cooperation to the Study Team, in particular, relevant officials of Tehran Disaster Mitigation and Management Center (TDMMC), the Iranian counterpart agency.

Very truly yours,

Itaru Mae
Team Leader, JICA Study Team
The Comprehensive Master Plan Study on
Urban Seismic Disaster Prevention and Management for the
Greater Tehran Area in the Islamic Republic of Iran

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Abbreviations and Acronyms

3C-S	Command-Control-Communication Structure
ADPCM	Adaptive Differential Pulse Code Modulation
AEO	Atomic Energy Organization; Office of the President
AMP	Advance Medical Post
BHRC	Building and Housing Research Center
BOR	Bed Occupancy Ratio
BSCSRA	Bureau for Studies and Coordination of Safety and Recovery Affairs
BTS	Base Transmitting Station
CAR	Contractors All Risk
CBO	Community Based Organization
CDE	Council for Determination of Exigencies (see also SEC)
CDMA	Code Division Multiple Access
CEAAAO	Civil Employment And Administrative Affairs Organization; Office of the President
CEMS	Tehran Comprehensive Emergency Management Plan Secretariat
CEST	Center for Earthquake and Environmental Studies of Tehran
CGC	Council of Guardians of the Constitution
CIC	Commander-in-Chief
CP	Collecting Point or Command Post
CPMR-SCCR	Council of Policy Making for Reconstruction – The Supreme Council of Cultural Revolution
CRO	Civil Retirement Organization; Office of the President
DAMA	Demand Assignment Multiple Access
DEG	Diesel Engine Generator
DEMP-NL	Disaster Emergency Master Plan at National Level
DHC	District Health Center
DM	Disaster Management
DMG	Disaster Management Group
DMH	Disaster Medical Hospital
EAR	Erect All Risks
ECS	Emergency Communications System
EMS	Emergency Medical Service
EMT	Emergency Medical Treatment
EMTFM-DL	Emergency Management Task Force – District Level
EMTFM-ML	Emergency Management Task Force – Municipality Level
EMTFM-SDL	Emergency Management Task Force – Sub-district Level
EOC	Emergency Operations Center
EPO	Environmental Protection Organization; Office of the President
ER	Emergency Response
ER	Emergency Room
ERP	Emergency Response Plan
FEMA	Federal Emergency Management Agency
FWA	Fixed Wireless Access
GIS	Geographic Information System
GNP	Gross National Product
GOI	Government of Iran
GOJ	Government of Japan
GSM	Global System for Mobile communications
GTA	Greater Tehran Area
GTGC	Greater Tehran Gas Company
GTMA	Greater Tehran Municipality Area
HDPE	High Density Polyethylene

HLR	Home Location Register
H&S	Health & Sanitation
I.R.I.	Islamic Republic of Iran
ICA	Islamic Consultative Assembly (also “Majlis”)
ICB	International Competitive Bidding
ICS	Incident Command System
ICU	Intensive Care Unit
IIEES	International Institute of Earthquake Engineering and Seismology
INDMP	Integrated Disaster Management Plan
INGC	Iran National Gas Company
ITU	International Telecommunication Union
IUMS	Iran University of Medical Science
JICA	Japan International Cooperation Agency
KDD	Kokusai Densin Denwa Corporation
LHP	Local Health Personnel
LOS	Length of Stay
LS	Local Switch
MCM	Mass Casualty Management
MDF	Main Distributing Frame
MMI	Modified Mercali Intensity
MOAJ	Ministry of Agriculture Jihad
MOC	Ministry of Commerce
MOCHE	Ministry of Culture & Higher education
MOCO	Ministry of Cooperatives
MODAFL	Ministry of Defense & Armed Forces Logistics
MOE	Ministry of Energy
MOEAF	Ministry of Economic Affairs & Finance
MOET	Ministry of Education & Training
MOFA	Ministry of Foreign Affairs
MOH	Ministry of Health (and Medical Education)
MOHUD	Ministry of Housing & Urban Development
MOI	Ministry of Interior
MOIC	Ministry of Information & Communication
MOICG	Ministry of Islamic Culture & Guidance
MOIM	Ministry of Industry & Mines
MOIS	Ministry of Intelligence & Security
MOJ	Ministry of Justice
MOLSA	Ministry of Labor & Social Affairs
MOP	Ministry of Petroleum
MORT	Ministry of Roads & Transport
MPO	Management & Planning Organization, Office of the President
MU	Medical University
NCNDR	Law of Foundation of National Committee for Mitigation of Natural Disaster Effects
NDOI	National Documents Organization of Iran; Office of the President
NDTF	National Disaster Task Force
NDTFOrg	National Disaster Task Force Organization
NGO	Non-Governmental Organization
NIGC	National Iranian Gas Company
NPWG	National Preparatory Working Group
NTF	North Tehran Fault
NTT	Nippon Telegraph and Telephone Corporation
ODA	Official Development Assistance
OM	Operation & Maintenance
PAHO	Pan American Health Organization
PDC	Personal Digital Cellular telecommunication system
PDTF	Provincial Disaster Task Force
PDTFOrg	Provincial Disaster Task Force Organization

PE	Polyethlene
PEO	Physical Education Organization; Office of the President
PGA	Peak Ground Acceleration
PHS	Personal Handyphone System
PO	The President's Office
PP	Participation Papers
PPP	Public-Private-Partnership
PPWG	Provincial Preparatory Working Group
PR	Public Relations
PTA	Parents Teachers Association
PTFOrg	Provincial Task Force Organization
QPSK	Quadrature Phase Shift Keying
R&R	Reconstruction & Rehabilitation
RCS	Red Crescent Society of Islamic Republic of Iran
RRCP	Rescue & Relief Comprehensive Plan
SCI	Statistics Center of Iran
SEC	State Exigency Council (also referred to as CDE)
SMTCI	State Management Training Centre of Iran; Office of the President
SNG	Satellite News Gathering
SOP	Standard Operation Plan
SPV	Special Project Vehicle
STD	Subscriber Trunk Dial
SUMS	Shahid Beheshti University of Medical Science
TCEMP	Tehran Comprehensive Emergency Management Plan
TCI	Telecommunication Company of Iran
TCIP	Turkish Catastrophe Insurance Pool
TCT	Telecommunication Company of Tehran
TCTTS	Tehran Comprehensive Traffic and Transportation Study
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
TDMMC	Tehran Disaster Mitigation and Management Center (Merged CEST and CEMS)
TDMO	Tehran Disaster Management Organization
TERMOP	Tehran Emergency Response Management and Operations Plan
TETCO	Tehran Engineering Technical Consulting Organization
TF	Task Force
TFFSSO	Tehran Fire Fighting and Safety Services Organization
TFOrg	National Task Force Organization
TGIS	Tehran GIS Center
TM	Tehran Municipality
TMCSO	Tehran Municipality Computer Service Organization
TMN	Total Management Network
TPWG	Township Preparatory Working Group
TREC	Tehran Regional Electric Company
TTTO	Tehran Traffic and Transportation Organization
TUMS	Tehran University of Medical Science
TWSC	Tehran Water and Sewage Company
UBC	Uniformed Design Code
UNDP	United Nations Development Program
VSAT	Very Small Aperture Terminal
WB	World Bank
WHO	World Health Organization
WLL	Wireless Local Loop
WTO	World Trade Organization

1 BUILDING

1. BUILDING

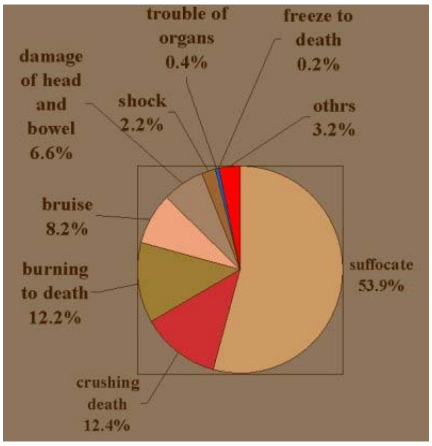
1.1 Outline

This chapter was prepared in order to explain a main concept, which is applied to description of building investigation in "Chapter 3 of Main report". Moreover, the assessment method about the building earthquake damage was proposed. However, the effort of the improvement must be continued considering the particular situation in Tehran.

1.1.1 Purpose of Building Investigation

First of all, earthquake motion itself does not have harm effect to human life. However, collapse of the buildings is the most significant reason of human casualty. Figure 1.1.1 shows the cause of death in 1995 Kobe Earthquake. For example building collapse caused 66.3% of death at this disaster. (i.e. "Suffocate and Crashing death")

Therefore preventing building collapse is the most effective way to reduce human casualty and then demand of emergency response after earthquake can become possible amount. We must identify present situation of earthquake resistance of the buildings in Tehran, and strengthen them if the earthquake resistance is not enough.



Source: Earthquake Disaster Management Handbook, 2000

Figure 1.1.1 Cause of Death in 1995 Kobe Earthquake

Purposes of building investigation are described as follows;

- Comprehend earthquake resistant capacity of buildings in study area by objective and logical prospect
- Estimate earthquake damage quantitatively utilizing above study result
- Comprehend weak points of the buildings

- Estimate improvement obtained by above method

  (A way to estimate the effect of strengthening is made and offered in this report.)

- Offer some suggestions for implementation of building strengthening

1.1.2 Building Diagnosis Method

There is not specific building diagnosis method that has the force of law in Tehran at this stage. Some case examples were carried out referring to the manual, which was established by IIEES or US specification “FEMA356”.

In this study a main concept of Japanese building diagnosis system “Specification on Earthquake Resistant Diagnosis and Strengthening for Governmental Buildings (Building Maintenance and Management Center of Japan)” is relied on. This system is linked with legislation and it is being implemented systematically for public buildings in Japan. An index obtained by utilizing “Specification on Earthquake Resistant Diagnosis and Strengthening for Governmental Buildings” is *seismic index of structure* GI_S, (hereinafter referred to as GI_S system). There are some specifications for building diagnosis in Japan, but only GI_S system can evaluate earthquake resistant capacity of steel frame structure and RC structure by a unified point of view, and these two types of structure are major structure types in Tehran. This is one of the reasons why the main concept of GI_S system is relied on.

As the first thing of discussion how large earthquake motion is targeted should be defined. So Design earthquake, which is prescribed in “Iranian Code of Practice for Seismic Resistant Design of Buildings Standard #2800”, is interfaced with GI_S system (hereinafter referred to as Standard #2800).

Regarding masonry structure, a method that is described in Standard #2800, which is similar to US code UBC, is reflected because descriptions in Japanese code are too much strict for Iranian situation.

Regarding steel frame structure, some detail discussions are needed because steel frame structures in Tehran are quite different from Japanese ones; therefore, *Incremental loading method* is utilized in analysis.

Regarding RC structure, a simplified method developed in Japan is utilized because there is no essential difference between structures in Tehran and Japanese one. A similar simplified method is utilized for masonry structure.

Following deficiency of RC buildings in Tehran was pointed out by Iranian counterpart, but applying corresponsive coefficient can reflect these findings.

“There are many deficiency of RC buildings in Tehran, like as existence of soft storey, protrusion of the building in the second floor, low quality of the construction material,

inappropriate placement of reinforcing bars in the beam-column conjunction, use of brittle vitrified clay infill walls and use of joint and block floorings"

Detail observation with peeling off exterior cladding was not done exactly in this project, because strengthening does not necessarily follow up after building investigation. So this report does not offer the diagnosis result for each individual building.

Representative GI_S value for each building type was shown in 5. 3.4. These values were served as a baseline of present situation of the buildings in Tehran, and necessary effort to strengthen is estimated in the section 5.4.3.

1.1.3 Estimation of Building Damage

Some representative buildings that can be disaster-prevention facilities are selected (i.e. School buildings, Hospitals, Public buildings and Lifeline facility). Some ordinary residential buildings are also selected. Building diagnosis was carried out utilizing GI_S system.

Result of building diagnosis was gathered to respective building type.

However, building type classification of this report might be improved for future study, because sufficiently accurate database cannot be obtained at this time. Building census under structural point of view was not carried out in Tehran yet, so only the database in tax book of Tehran was available at this time.

Average GI_S value for each building type is presented in Table 1.2.1.

It is inherent in definition that GI_S value is physical quantity that is obtained by structure capacity divided by required capacity. Therefore GI_S value can be converted to damage ratio of buildings because the damage ratio is defined as probability of damage. So this conversion was carried out in this study. Main concepts of this conversion are probability theory and reliability method.

The probability in which buildings reach heavily damaged threshold, floor area of damaged buildings, and number of damaged buildings were estimated by analysis based on average value GI_S of each building types and database of tax book of Tehran. The earthquake motion in this analysis is the design earthquake, which is prescribed in Standard #2800.

The extent of building damage assessed by above analysis exceeds the extent possible for emergency response activity. Therefore draft countermeasure under the condition that is possible for emergency response activity was generated. (i.e., strengthening and replacement of building)

1.2 Remarks of Existing Conditions for Building in Tehran

The number of existing buildings in Tehran is summarized in Table 1.2.1, according to the taxation data obtained from Tehran Municipality Computer Service Organization (called as "Momayezi" in Tehran). Hereinafter this data is referred to as "TMCSO 2002".

Table 1.2.1 Numbers of Existing Buildings in Tehran by Structural Type and Usage

Building Type	Number of Buildings	Ratio (This Type/Total)	Detaile of Structure	Usage	Number of Buildings
Masonry	783,171	67.0%	Unreinforced Masonry	Educational	5,203
				Health	411
				Residential	563,182
				Governmental	1,147
				Other	39,104
			Brick skeleton with middle steel or concrete columns	Educational	572
				Health	59
				Residential	167,672
				Governmental	243
				Other	5,578
Steel	256,790	22.0%		Educational	1,301
				Health	117
				Residential	237,631
				Governmental	906
				Other	16,835
RC	38,023	3.3%		Educational	446
				Health	35
				Residential	35,889
				Governmental	278
				Other	1,375
Hangars	75,467	6.5%			
Adobe	7,570	0.6%			
Other	7,974	0.7%			

Source: TMCSO, 2002

The building type Masonry occupies the largest part. As explained later, strengthening this type of building to resist against earthquake motion within reasonable cot is very difficult. This is the first problem.

However, if the masonry buildings are going to be reconstructed as steel or RC buildings with careful design and undertaking construction, they can contribute to earthquake resistance of the city.

Table 1.2.2 shows the number of permits segregated by type issued by Tehran Municipality in 2001.

Table 1.2.2 Numbers of Building Construction Permits Issued in 2001

	Semi-Steel	Steel	RC	Other	Total
Number of Permit	3	15,802	7,417	996	24,218

	New Construction	Demolition & Reconstruction
Number of Permit	3,420	20,798

Source: Tehran Municipality Performance in 2001, TMCSO, 2004

Due to the less availability and lack of information, the above statistical information was the only source relating to the construction permit issued in 2001. It is difficult to grasp how many masonry buildings have been converted to steel frame or RC buildings.

Approximately 626,000 of Masonry buildings exist in Tehran as shown in Table 1.2.1. This implies that the issue of vulnerability of Tehran due to the dominance of Masonry buildings remains, since swift conversion from Masonry to Steel or RC frame structures has not been observed.

Building aspect in Tehran is quite particular not only comparing with that in Japan but also comparing with international standard. The aspect from earthquake resistance point of view can be summarized as follows;

1) Major building type is masonry.

This building type occupies about 70% of total building number in Tehran. Earthquake resistant capacity of the buildings is very poor in the great majority of this building type.

Therefore this building type may make up the majority of disaster. There must be the most careful thinking of earthquake-proof concerning masonry structure.

2) The existing numbers of structure type following Masonry are RC structure and steel frame structure.

The ratio of each building types may be changed since the majority of the building types, which are now producing, is RC structure and steel frame structure.

It is said that trend of selection whether RC structure or steel frame structure is chosen depends on price of material.

In a particular case a RC building was constructed even though engineering drawings were made as a steel frame structure.

3) The majority of steel frame structure in Tehran is quite different from that of Japan.

The most glaring difference between the two countries' steel frame structures is the column-beam connection, in which bending and shear capacity is less than base material in almost all cases. Design concept, which makes the earthquake resistance depend on the ductility of steel, seems to be the same as Japanese design concept, but most of steel frame structure in Tehran does not actualize enough ductility since the column-beam connection would be distracted before non-linear behavior effect is obtained.

In most cases, steel is composed of multiple cast steel using splice plate by fillet welding, because the availability of cast steel is quite limited in Iran. The spliced plate does not cover the whole length of the steel, and it is welded discretely. As a result, wide-ranging types of section are brought up, so that some errors may occur at design calculation and construction stages.

Many engineers in Iran think that steel frame section of buildings is not poor compared with international standard, most of which, though, is poorer than that of Japan.

Those characteristics are seen in most of steel frame structure buildings in Tehran. However, some excellent buildings exist in particular for office or high-class residential buildings.

4) RC structure in Tehran does not have fundamental difference from that of Japan.

In some cases, although the specification of RC structure or the amount of reinforcement bars is insufficient, it can be said that there is no fundamental difference between RC structures in Tehran and that of Japan in terms of design.

Many engineers are conscious about forming reinforcing bar and confining effect of hoop bar, which prevent a serious problem of structural weakness of RC building.

5) The main problem of RC structure and steel frame structure is exceeding mass that is caused by interior and exterior materials.

In most cases, infill wall is composed of hollow brick or porous brick. These kinds of materials are relatively heavy even though shear capacity is not expected. This is a main reason of poor earthquake resistance capacity.

6) Most of masonry structure is not designed by appropriate procedure, so enough capacity cannot be expected.

The most serious problem is found at foundation. Foundation is composed of sand and lime, and bricks are directly piled on the surface.

Grout material is also composed of sand and lime for the most case, which have little shear capacity.

In addition, tie and beam is not fixed to vertical part sufficiently in many cases. Round wood is used as tie and beam in some cases.

1.3 Building Diagnosis

1.3.1 What is Recommended for Building Diagnosis in Tehran

1) Framework

There is not specific building diagnosis method that has the force of law in Tehran at this stage.

Even in Japan, there are multiple index, which are provided by manuals and specification, but each individual result from different method cannot be compared with each other without careful thinking, so uniformed index is needed.

In this study a main concept of Japanese building diagnosis system, GI_S system, is going to be recommended.

Analytical background of this method is very clear since this system is based on a main concept of procedure that is utilized in design aspect. If the design concept is clear, adjusting capability for the structure of another region can be maintained.

For instance, a condition of earthquake motion in original text of GI_S system is based on Japanese Building Standard Law, but response spectrum that is provided by Standard #2800 is applied for this study.

The structure design methodology is an assembly of results from various engineering fields, so that newly developed concept must be added to specification day by day. Considering this aspect, most of Japanese specification does not describe all of definition in one book. Instruction is offered amendments as detail equations. This is a general way of adapting newly developed findings flexibly.

The main concept of GI_S system is recommended as a basic method of building diagnosis in Tehran.

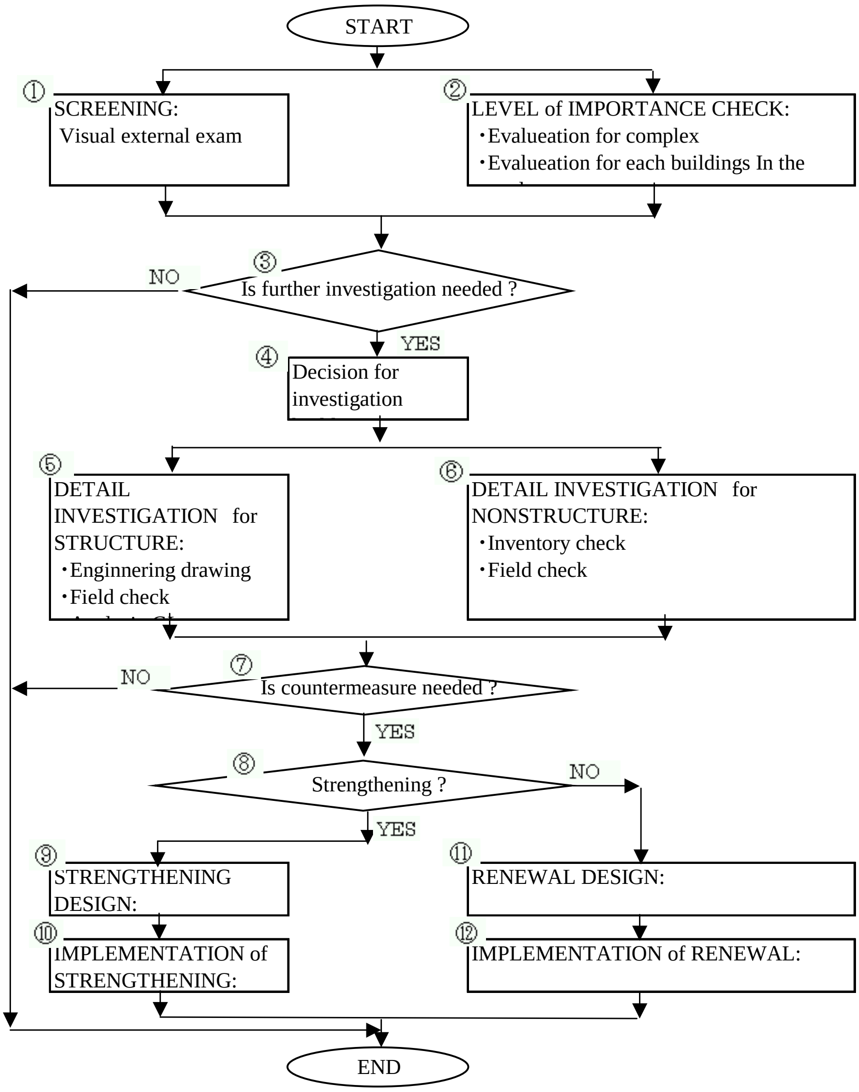
However some detail procedure can be changed if necessary with careful discussion, because Iranian condition concerning construction method and lifestyle in individual region must be esteemed.

First of all, “Orientation” is described in next paragraph 2).

As an engineering issue, the main concept of diagnosis is described in the section 1.3.2, “Draft of Building Diagnosis Method”, and further issue is described in the section 1.3.4, “Further Issue Concerning Improvement of Building Diagnosis”.

2) Orientation

The process of building diagnosis is shown as a flowchart in Figure 5.3.1. This approach is for evaluations and countermeasure process for concrete large research area.



Source: JICA Study Team

Figure 1.3.1 Evaluations and Countermeasure Process

The process shown in Figure 1.3.1 describes a flow of work and the judgment, which shall be applied to a project covering multi building complex in concrete large research area such as earthquake mitigation center in Tehran.

The steps of ①～③ is applied to assessment about each building complex, those of ④～⑦ to earthquake-resistant diagnosis, and those of ⑧～⑫ to design for retrofitting for earthquake resistance and construction work.

It is not possible realistically that all of candidate building cannot be started to construction, because budget of project is limited. However some partial demolish is needed for a building investigation. Partial demolish can be acceptable if that building is selected as object of starting construction, but useless task such as recovery should be done if that building is not selected as object of starting construction. So some simple methods, which do not need extensive demolition, should be applied to the steps of ①~④ in Figure 1.3.1. (so called "Rapid screening")

At the same time, a importance level of each candidate complex should be checked at the step of ② in Figure 1.3.1. The higher importance level of that building is, the larger a priority of countermeasure is. The poorer earthquake resistance of that building is, the larger a priority of countermeasure is

Some detail investigation, to which some partial demolition is required, shall be done after the step of ④ in Figure 1.3.1.

When a building cannot be improved sufficiently because of critical deficiency in structure, that case shall be sort at the judgment of the step of ⑧. The building should be demolished and reconstructed, or the usage of that building should be changed to unimportant one.

Anyway, checking accuracy of structure is the most sensitive point, and some difficulty in Tehran concerning this issue is pointed out as follows;

- Most of buildings in Tehran are covered by thick exterior cladding, so structure detail cannot be evaluated from outside
- Engineering drawing can hardly be kept
- As-built situation is very different from the engineering drawings even if drawing was obtained
- Consequently detail evaluation cannot be carried out without some extent of peeling off the exterior cladding

It may be serious problem which extent of peeling off can be allowed at each step of building investigation, and what kind of repairing procedure must be obligated when that building cannot be objective to strengthening.

The procedure shown in the step of ⑤ and analysis is going to be described in next section.

1.3.2 Draft of Building Diagnosis Method

In this section the real analysis of building diagnosis is recommended.

1) Indication of Building Resistance

To express seismic resistance quantitatively, s*eismic index of structure* GI_S is shown in Eq.(1.3.1). This index shows how many times of capacity is equivalent to existing building capacity when the building capacity is compared with the required capacity.

$$GI_S = \frac{Q_u}{\alpha \cdot Q_{un}} \qquad (1.3.1)$$

Where,

GI_S : Seismic Index of Structure

Q_u : Seismic force level for ultimate ductility check

Q_{un} : Required seismic force level for ultimate ductility check

α : Correction coefficient

The basic standpoint of the diagnosis is to set up the size of earthquake motion to be targeted. Concerning this, it is represented by required seismic force level for ultimate ductility check, Q_{un}.

Next point is assessment of capacity of buildings. It is represented by seismic force level for ultimate ductility check, Q_u.

Remaining points are criteria for designing policy. They are represented by correction coefficient, α, for seismic force level for ultimate ductility check.

Concerning the above Q_{un}, Q_u and α, their definition and formulation are explained in Appendix 1-1.

An American diagnosis system "FEMA 310" also offers numerical evaluation for elastic region, but only "Compliant" and "Non-Compliant " are judged as digital to the examination of a nonlinear region.

2) Process of operation for earthquake-resistant building diagnosis

Definition and formulation is explained in Appendix 1-1. The method of earthquake resistant diagnosis, which takes into account peculiar circumstances related to building construction in Iran, is explained with reference to basic conception of GI_S system described in "Specification on Earthquake Resistant Diagnosis and Strengthening for Governmental Buildings, Building Maintenance and Management Center of Japan". This basic conception of GI_S system is description based on compelling legal force, which has specific style in its written structure. That is, the below-described principles are followed.

- Avoidance of misunderstanding is given more priority to than clarification for better understanding
- Definition of conception is given more priority to than explanation of calculation procedure

Therefore, readers who wish to comprehend calculation procedure in a sequential manner may encounter with difficulty in understanding due to inconsiderateness in its description. In addition, there is no description that straightforwardly explains the standard of GI_S system itself; therefore, without reference to other standards, notices and commentaries, it is difficult to comprehend the whole GI_S system. Therefore, in Appendix 1-1, these essential references such as other standards, notices and commentaries are included as much as possible in order to enable readers to comprehend GI_S system; nevertheless, there still exists difficulty because it is extremely hard to compensate a considerable gap between the items commonly recognized in Japan and those in Iran. Considering the above-mentioned matters, this reference material is prepared with purpose of promoting better understanding by compensating this gap. Therefore, giving priority to 'clarification for better understanding' and 'explanation of calculation procedure', a flowchart is used as shown in Figure 1.3.2 and Figure 1.3.3. Numbers for equations and tables are those shown in Appendix 1-1.

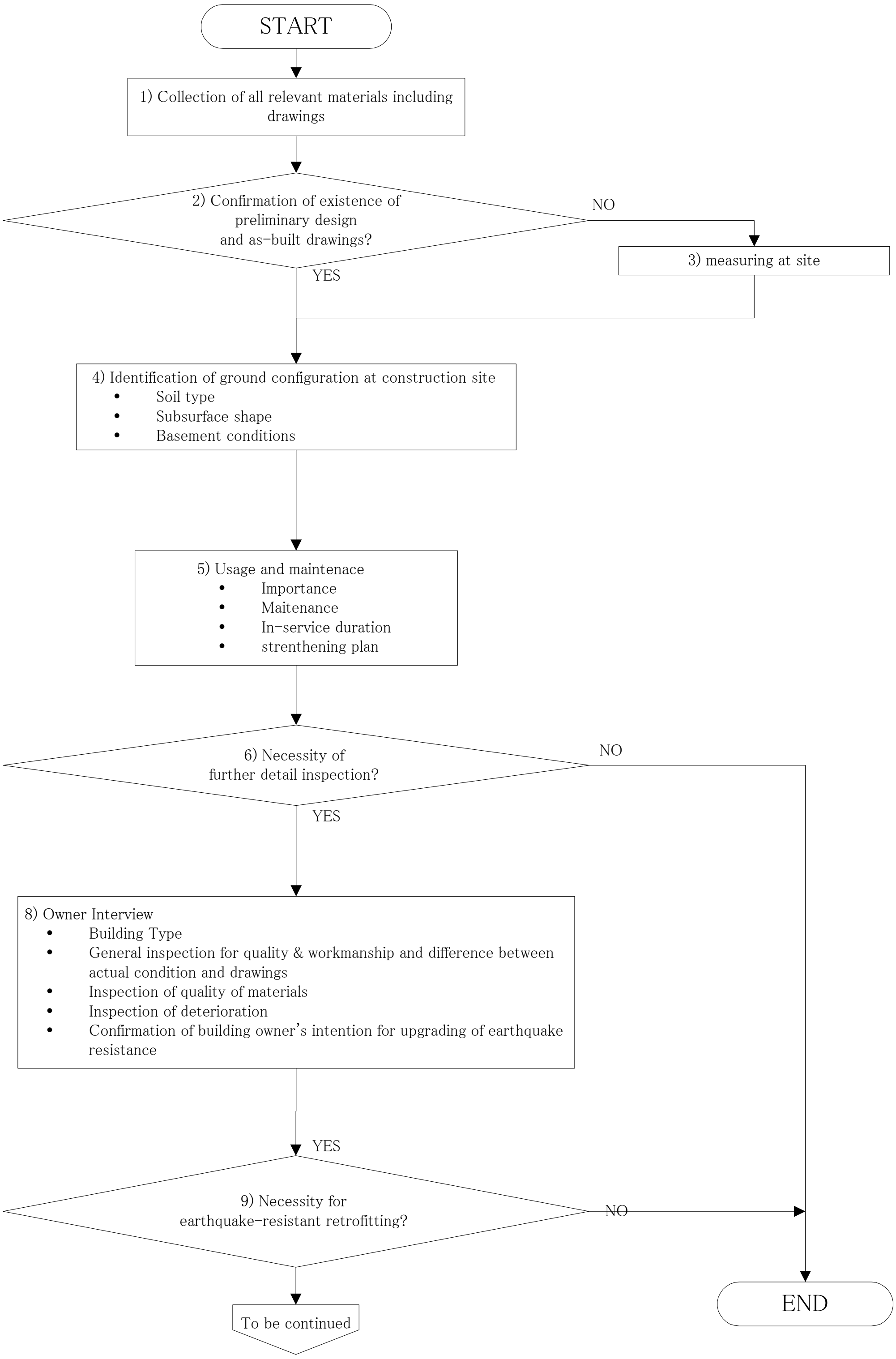
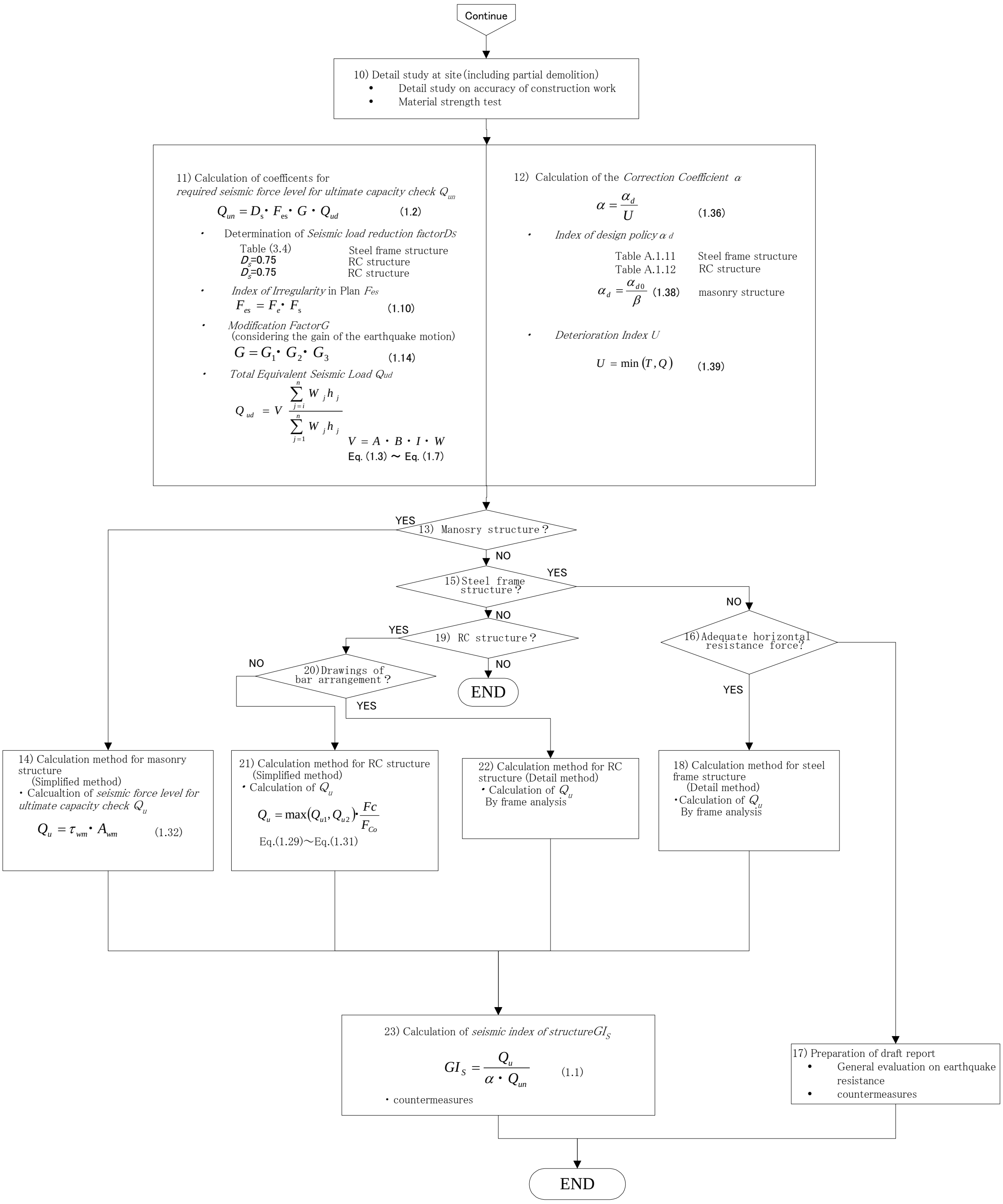


Figure 1.3.2 Flowchart (Part 1)



Note: Numbers for equations and tables are those shown in Appendix 1-1.

Figure 1.3.3 Flowchart (Part 2)

(1) Collection of all relevant materials including drawings

In Japan, request for earthquake resistant diagnosis is not officially accepted with regards to a building whose preliminary design and as-built drawings are not appropriately preserved.

(2) Confirmation of existence of preliminary design and as-built drawings

However, it is not realistic to compulsorily apply this principle to Iran, because preliminary design and as-built drawings are rarely preserved there.

(3) Measuring at site

Therefore, based on the judgment in 2), measuring at site is conducted with regards to a building whose preliminary design and as-built drawings are not preserved. By measuring general shape and dimensions of the building and size of frames, drawings are prepared. It is necessary to conduct more detailed measuring at site in case that a building concerned is judged as YES in '9) Necessity of rebuilding for earthquake resistance' mentioned later, it is necessary to conduct more detailed measuring at site.

(4) Identification of ground configuration at construction site

- Soil type

Choosing Ⅰ～Ⅳ are conducted in order to determine $T_{0,}$ Figure according to soil classification, in Table A.1.2 included in Appendix 1-1.

- Subsurface shape

Specific characteristics of ground configuration are clarified in order to determine G_1, Factor of irregularity in ground configuration, in Table A.1.7 included in Appendix 1-1.

- Confirmation of existence of preliminary design and as-built drawings of basement conditions

Existence of basement and its preliminary design and as-built drawings is confirmed in order to determine *Factor with or without basement, G_2*, in Table A.1.8 included in Appendix 1-1. In addition, it is indispensable to verify existence of underground equipments such as sewage wells and their record, which directly affect stability of building against earthquake.

Moreover, in case that there exits a sanitary system specific to Iran called a sewage well or septic tank, there is a possibility that this system directly affects stability of building. Therefore, investigating the existence of underground equipments, it is necessary to judge whether these equipments have independent structure from building base. It is dispensable to certify records of construction works because there are cases that several sewage wells and septic tanks are left without careful treatment.

(5) Usage and maintenance

This item needs to be conducted based on technical judgments by professional experts with enriched experience of earthquake resistant diagnosis.

- Importance

Choosing Ⅰ～Ⅳ are conducted with consideration of function and using condition in order to determine *Importance Factor*, *I*, in Table A.1.3 included in Sector Report.

- Maintenance Condition

Information related to maintenance condition should be obtained by observation.

- In-Service Duration

In-service duration is an essential factor to judge the degree of deterioration and to comprehend the details of building construction method.

- Strengthening Plan

In-service duration with the existing usage condition is confirmed through interviews.

(6) Necessity of further detailed inspection

There is no need to largely destroy a building, for example, by removing claddings and taking samples in the inspections of the above-mentioned items. If these inspections do not show any deficiency in earthquake resistance, earthquake resistant diagnosis will be completed after preparation of a draft evaluation report.

(7) Preparation of the draft evaluation report

In the draft evaluation report, quantitative evaluation of earthquake resistance is not conducted. After an owner understands the draft evaluation report, inspection at site will be conducted if he/she requests more detailed inspection even if accompanied with building removal such as peeling off exterior cladding and taking samples.

(8) Owner Interview

In case that judgment in 6) reveals necessity of strengthening and rebuilding for earthquake resistance, the following items will be dealt with.

- Building Type

Building type and details of building structure are verified.

- General inspection for quality & workmanship and difference between actual condition and drawings

In case that preliminary design and as-built drawings are adequately preserved, accuracy of building construction is evaluated, and difference between the actual condition of a building and drawings is identified. In case that any drawings are not adequately preserved, accuracy of building construction is evaluated and difference between the present condition of a building and the ideal is identified based on technical knowledge.

Information related to *Index of design policy*, α_d , is obtained, which is required for determining *Correction Coefficient*, α ,shown in 4) , section 1.5 included in Sector Report.

- Inspection of quality of materials

Observation

- Inspection of deterioration

Information related to *Deterioration Index, U*, is obtained by observation, which is required for determining *Correction Coefficient*, α ,shown in 4), Section 1.5.3 included in Sector Report.

- Confirmation of owner's intention for upgrading of earthquake resistance

By informing a building owner of the fact that subsequent inspections require more large-scale building removal such as peeling off claddings and taking samples, his/her intention towards upgrading for earthquake resistance should be confirmed.

(9) Necessity for earthquake-resistant retrofitting

If an building owner has intention for carrying out upgrading, further operation will proceed in accordance with the following steps after that of ⑩. However, it is appropriate to proceed in preparation of the draft evaluation report through informing a building owner of this matter if the previous study reveals that upgrading does not achieve its improvement to effective extent.

(10) Detail study at site (including partial demolition)

- Detail study on accuracy of construction work

In case of masonry structure, it should be conducted to measure the size of members of structural framework by peeling off exterior cladding of a major wall at each floor.

In case of steel frame structure, it should be conducted to intimately measure the size of members of steel framework by peeling off exterior cladding (size of each member of framework, detail of yielding parts and joints).

In case of RC structure, it should be conducted to intimately measure the size of elements of frame by peeling off exterior cladding.

- Material strength test

In case of masonry structure, if possible, tensile strength test and shear strength test in grouts should be conducted. In case of steel frame structure, tension strength test should be conducted by taking a test sample. In case of RC structure, if possible, compression strength test should be conducted by picking up a sample core of concrete. (Alternatively, it is possible to replace this test with Schmidt hammer test.)

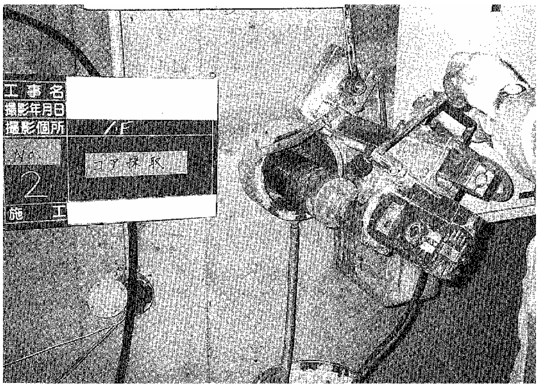


Figure 1.3.4 Core Sampling

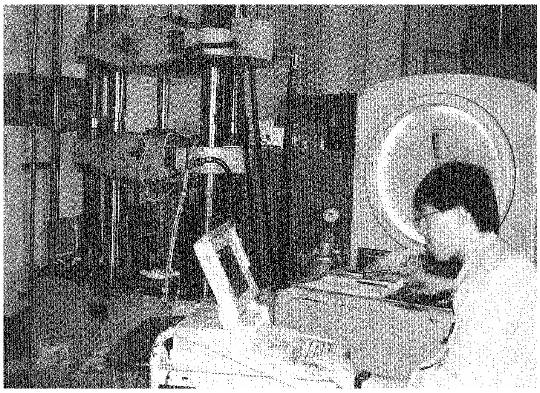


Figure 1.3.5 Compression Strength Test

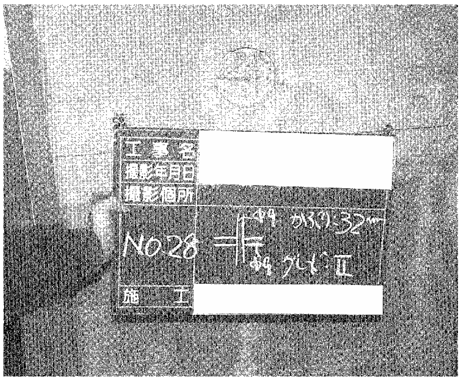


Figure 1.3.6 Observing Ripping out Concrete and Observing Rust of Reinforcing Bar

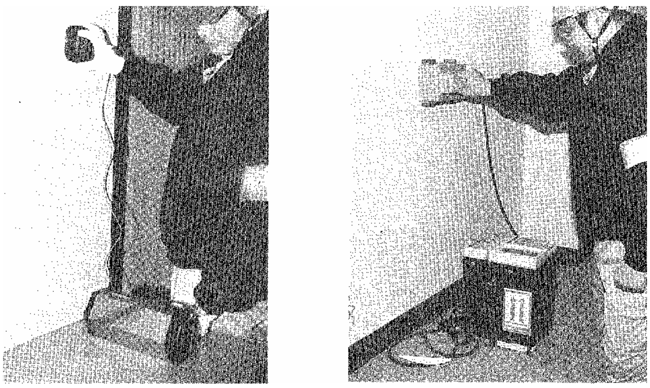


Figure 1.3.7 Scanning Reinforcing Bars and Steel Beams

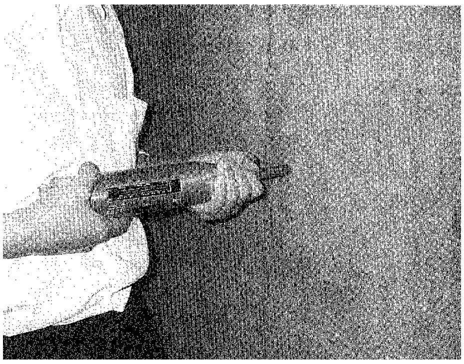


Figure 1.3.8 Schmidt Hammer test

(11) Calculation of *required seismic force level* Q_{un}

The *required seismic force level for ultimate capacity check*, Q_{un}, is given by Eq.(1.2) in Appendix 1-1.

$$Q_{un} = D_s \cdot F_{es} \cdot G \cdot Q_{ud}$$

Where,

Q_{un} : Required seismic force level for ultimate capacity check

D_S : Seismic load reduction factor

F_{es} : Index of Irregularity in Plan

G : Modification Factor (considering the gain of the earthquake motion)

Q_{ud} : Total Equivalent Seismic Load (base shear force)

(12) Calculation of the *correction coefficient* α

The *correction coefficient*, α, is given by Eq. (1.3) in Appendix 1-1.

$$\alpha = \frac{\alpha_d}{U}$$

Where ;

α : Correction coefficient

α_d : Index of design policy (This index represents effect of redundancy)

U : Deterioration Index (This index is given by the inspection of as build)

(13) Masonry structure

Judge if structure is masonry or not.

(14) Calculation method for masonry structure (simplified method)

Simplified method given by Eq. (1.32) in Appendix 1-1 is applied.

$$Q_u = \tau_{wm} \cdot A_{wm}$$

(15) Steel frame structure

Judge if structure is steel frame or not.

(16) Adequate horizontal resistance force

In case of steel frame structure, building diagnosis will proceed to the step of ⑰ by judging that there is not adequate horizontal resistance force if it does not function as moment resisting frame because every joint between columns and beams is inappropriate in strength or there is no bracing. Moreover, building diagnosis will proceed to the step of ⑰ as well if there is insufficiency in strength of bracing. In these cases, it is obvious that building structure is judged as inappropriate without carrying out frame analysis.

(17) Preparation of the draft evaluation report

- General evaluation on earthquake resistance

In this case, impossibility of improving earthquake resistance should be reported to a building owner by explaining horizontal resistance force.

- Countermeasures

In case that section area of columns and beams is insufficient, the possibility of earthquake-resistant retrofitting should be examined and proposed to a building owner.

In case that section area of columns and beams is seriously insufficient and there is no possibility of improvement of earthquake resistance by retrofitting, reconstruction should be recommended.

(18) Calculation method for steel frame structure (detail calculation)

- *Calculation for seismic force level for ultimate capacity check,* Q_u

Seismic force level for ultimate capacity check, Q_u , should be calculated by frame analysis. Here, Q_u represents base shear of each floor obtained by frame analysis, representing the maximum value before brittle failure occurs in elements of frame. In case that brittle failure does not occur in elements of frame, Q_u represents the maximum value of shearing force obtained when story drift ratio becomes more than 1/200. In case that incremental loading method should be conducted, *seismic load reduction factor* can be determined with use of equal-energy principle on the basis of deformation values at yield point and at reaching point to decay mechanism.

(19) RC structure

Judge if structure is RC or not.

(20) Bar arrangement drawing

In case that bar arrangement drawings are preserved as as-built drawings and the present condition is not so different from those drawings, building diagnosis will proceed to the step of 22. In case that bar arrangement is uncertain, building diagnosis will proceed to the step of 21.

(21) Calculation method for RC structure (simplified method)

The *seismic force level for ultimate capacity check*, Q_u, for RC frame structure is given by Eq.(1.29)～Eq.(1.31) in Appendix 1-1.

$$Q_u = \max(Q_{u1}, Q_{u2}) \cdot \frac{Fc}{F_{Co}}$$

$$Q_{u1} = \tau_W \cdot A_{w1} + \tau_C \cdot (A_c + A_{w2})$$

$$Q_{u2} = \tau_E \cdot A_{w1} + \tau_E \cdot A_c$$

Where;

Q_u : Seismic force level for ultimate ductility check

A_{w1} : Cross section area of shear wall, which is effective for considering direction

Corresponding wall to the under mentioned condition shall be taken as a shear wall.

- Wing wall with width wider than 45cm and wider than 30% of the opening
- Ratio of “total round of the opening / total round of the wall” is larger than 0.4

The value of A_{w1} should be multiplied by $\cos^2\theta$ when the angle that wall cross considering direction at θ.

A_{w2} ; Cross section area of other wall which is effective for considering direction

Corresponding wall to the under mentioned condition shall be taken as other wall.

- Infill wall that does not meet the condition of A_{w1}
- Over sailing wall that is connected to the beam or floor (thickness > 10cm, width > 100cm)

A_c ; Cross section area of column that is effective for resisting horizontal force

τ_w ; Standard value of shear wall capacity (= 25 kgf/cm^2 = 2.5 MPa)

τ_C ; Standard value of column capacity (= 7 kgf/cm^2 = 0.7 MPa)

τ_E ; Equalize value of wall capacity including column capacity (= 13.5 kgf/cm^2 = 1.35 MPa)

F_c ; Compressive strength of concrete

F_{c0} ; Benchmark value of compressive strength of concrete (= 200 kgf/cm^2 = 20 MPa)

(22) Calculation method for reinforced concrete building structure (detail method)

- Calculation of *seismic force level for ultimate capacity check* Q_u

Seismic force level for ultimate capacity check, Q_u , should be calculated by frame analysis.

Here, Q_u represents base shear of each floor (base shear) obtained from frame analysis on the proposition of elasticity, and also represents the maximum value obtained when brittle failure occurs in elements of frame. In case that brittle failure does not occur in elements of frame, Q_u represents the maximum vale of shear force obtained when story drift ration becomes more than 1/200. In case that incremental loading method should be conducted, seismic load reduction factor can be determined with use of equal-energy principle on the basis of deformation values at yield point and at reaching point to decay mechanism.

Note: There are not so many buildings of RC structure in Tehran. However, in terms of most of them, section area of columns and beams is seriously insufficient. On the contrary, buildings can be seen whose design and construction works are conducted with appropriate consideration. These two cannot be discriminated because it is not possible to comprehend the detail of bar arrangement in RC structure even by means of the latest scan technique after completion of construction work. Taking these circumstances into consideration, this Sector Report does not deal with description about preparation of model which should be used for elastic-plastic frame analysis. However, this does not disturb conducting incremental loading method in terms of RC structure designed with adequate consideration of prevention of shearing destruction and buckling by means of the latest technique.

Calculation of seismic index of structure, GI_S

- *Seismic Index of Structure,* GI_S , as the ultimate result.

To express seismic resistance quantitatively, *Seismic Index of Structure,* GI_S **,** is given by Eq. (2.1) in Appendix 1-1. This index shows how many times of capacity is equivalent to existing building capacity when the building capacity is compared with the required capacity.

$$GI_S = \frac{Q_u}{\alpha \cdot Q_{un}}$$

Where,

GI_S : Seismic Index of Structure

Q_u : Seismic force level for ultimate ductility check

Q_{un} : Required seismic force level for ultimate ductility check

α : Correction coefficient

- Recommendation for measures

It can be considered that if building diagnosis proceeds to the step of 24, a building concerned has some kind of possibility of being improved in terms of earthquake resistance. Therefore, strengthening should be proposed by examining its possibility. However, if calculated seismic index of structure, GI_S , is extremely low, reconstruction should be recommended instead of earthquake-resistant retrofitting.

In addition, even in case that GI_S may be improved to be more than 1.0 by means of strengthening, retrofitting should be proposed after completion of construction work if building owner cannot afford to reconstructing a building. It is because at least strengthening can reduce a possibility of earthquake disaster.

1.3.3 Overview Value of GI_S in Tehran

Building investigation was carried out for the building in Teheran city utilizing GI_S system.

In this investigation some representative buildings, each of which can be a disaster-prevention facility, are selected (i.e. School buildings, Hospitals, Public buildings and Lifeline facility). Some ordinary residential buildings are also selected. However, the result for each individual building is not identified, because these results are only for a purpose to obtain rough understanding about situation of the buildings in Tehran.

In this section average GI_S value for each building type is summarized in Table 1.3.1. This table was prepared to give basic data for examination on assessment of the effect, which can be obtained by strengthening or reconstruction of vulnerable building.

In Table 1.2.1, the building of Teheran was sorted to six kinds of building type according to information from database "TMCSO 2002", and the number of buildings of each building type was shown. (Masonry, Steel, Reinforced concrete, Hangers, Adobe and Other)

In this paragraph the building was sorted to nine kinds of classifications with different earthquake-resistance as shown in Table 1.3.1 based on information, which was able to be distinguished by Database "TMCSO 2002". Following respect was considered in sorting the building.

- The building is sorted according to the number of stories when the earthquake-resistance was different depending on the number of stories. (Database "TMCSO 2002" gives information on the number of stories partially)
- The building is sorted according to the usage when the earthquake-resistance was different depending on the usage. (Database "TMCSO 2002" gives information on the usage partially)

Average GI_S value for each building type is summarized in Table 1.3.1. The value for each building type was set referring to the result of above-mentioned building investigation. Following respect was considered in setting the value of GI_S.

- Category “Weak Masonry” corresponds to (Brick or cement block or stone skeleton with middle steel columns) and (Brick skeleton with middle steel or concrete columns with 3 stories and up). It was assumed GI_S=0.16. Because this kind of Masonry hardly have capacity for horizontal inertia force. Difference of the number of stories and usage do not affect earthquake resistance.

Category “Unreinforced Masonry” corresponds to a building only of the piling of Brick. This type of Masonry has less capacity for horizontal inertia force compared with Masonry with tie. GI_S =0.14 was set for Unreinforced Masonry with the number of stories 1~2.

The value of GI_S is rather high in the study area though Unreinforced Masonry with 3 stories or more is not permitted in the code of Iran. It was thought that deliberate design with consideration of high stories caused this tendency, so GI_S =0.19 was set for Unreinforced Masonry with 3 stories or more. (If another tendency was found in future study, this setting can be changed)

- The category of “Semi-Engineered Masonry” was made through database “TMCSO 2002” does not classify this building type. This category was sorted referring to the list of the school building. Category “Semi-Engineered Masonry” corresponds to a Masonry which has Tie. The reason why this category was made is that this type of Masonry is thought to have higher resistance than Unreinforced Masonry. GI_S =0.2 was set for this category.
- Steel building was sorted by the usage. GI_S =0.21 was given for "Residential" and GI_S =0.25 was given for that of other usage. A significant difference was not admitted in the difference of earthquake resistance depending on the number of stories.
- The RC building was sorted to " 1~3 stories ", " 4~7 stories ", and " more than 7 stories". GI_S =0.5, GI_S =0.4 and GI_S =0.5 were given respectively.
- Regarding “Adobe”, it was thought that no significant capacity of earthquake resistance admitted. GI_S =0.02 was given for this category.
- Additionally, GI_S =0.15 was given for other category as an intermediate value.

Table 1.3.1 Average GI_s value for each building type

Structure	Usage	Number of Story	GI_s
Reinforced Concrete Structure	All	1～3	0.50
		4～7	0.40
		more than 7	0.50
Weak Masonry (Brick or cement block or stone skeleton with middle steel columns) (Brick skeleton with middle steel or concrete columns with 3 stories and up)	All	All	0.16
Unreinforced Masonry	All	1～2	0.14
		more than 2	0.19
Semi-Engineered Masonry	Educational	ALL	0.20
Steel	Educational	All	0.25
	Health		0.25
	Residential		0.21
	Governmental		0.25
	Other		0.25
Adobe	All	All	0.02
Hangars and Canopies	All	All	0.15
Mix	All	All	0.15
Others	All	All	0.15

Source: JICA Study Team

The building type of masonry is divided into three categories in this table. “Unreinforced Masonry” means a building type, which is simply composed of bricks, natural stones or concrete brocks. “Semi-Engineered Masonry” ” means a masonry building type, which has tie. “Weak Masonry” means a masonry building type, which is composed of brick wall and has the partial frames consisted 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.

“Semi-Engineered Masonry” means a masonry building type, which has structure that is common RC Frame, but this type is classified as masonry because the RC frame part of them is not certified to have structural safety by analysis.

Above explained classification is on condition that number and floor area are identified by a database “TMCSO 2002”.

It is known that construction period can offer effective information for evaluating earthquake resistance of the buildings although above-mentioned database does not give that information. Each building, which was built in different period, has individual earthquake resistance level, because design concept is shifting with design code. It is recommended to formulate the database emphasizing structure detail.

Considerably high quality buildings with careful earthquake design are found even though in rare cases. (i.e., some office buildings and some lifeline facilities) These buildings are also identified in the database.

1.3.4 Further Issue Concerning Improvement of Building Diagnosis

It was mentioned that the main concept of GI_S system is recommended as a basic method of building diagnosis in Tehran, but some detail procedure can be changed if necessary with careful discussion, because Iranian condition concerning construction method and lifestyle in individual region must be esteemed.

The points, which should be discussed, are as follows;

- Method for evaluating the reduction factor induced by ductility

In the GI_S system reduction effect is taken into account by the procedure, which is defined as D_s in Appendix 1-1, if the member has sufficient ductility.

The standard #2800 also defines *Behavior Coefficient of the Building, R*. Both of them offer practical translation from linear response spectra intensity to equivalent intensity considering reduction effect induced by ductile behavior.

However, there is considerable difference between the result from D_s value and that from R.

The lowest value given in standard #2800 is *R*=4 for "Reinforced masonry shear walls" while the lowest value given in Japanese standard is D_s=1.0 for the structure, which does not have significant ductility. Margin other than the ductility effect, which corresponds to 4.0, is included in R provided by standard #2800.

Table 1.3.2 Value of Behavior Coefficient of the Building, R（standard #2800）

values of building behaviour factor(R) and maximum height of the building in regions of high relative hazard (H)*

Structural system	Lateral force resisting system	R	H*
a) Load bearing wall system[1]	1-Ordinary reinforced concrete shear walls	5	70
	2- Reinforced masonry shear walls	4	30
b)Simple frame system[7]	1-Reinforced concrete shear walls	7	50
	2-Reinforced masonry shear walls	5	30
	3-Eccentric steel bracing[2]	7	50
	4-Concentric steel bracing [2]	6	40
c) Moment resisting frame	1-Special moment resisting concrete frame[3]		
	2-Intermediate moment resisting concrete frame[4]	10	180
	3-Ordinary moment resisting concrete frame[5]	8	50
	4- Special moment resisting steel frame [2]	5	15[6]
	5-Ordinary moment resisting steel frame [2]	10	180
		6	50
d) Dual system	1- Special moment resisting frame(steel or concrete)+ Special reinforced concrete shear walls	11	
	2- Intermediate moment resisting reinforced concrete frame +	9	
	Intermediate reinforced concrete shear walls +	7.5	
	3- Ordinary moment resisting steel frame+ ordinary reinforced shear walls	10	
	4- Special moment resisting steel frame + Eccentric steel bracing	7.5	
	5- Ordinary moment resisting steel frame + Eccentric steel bracing	9	
	6- Special moment resisting steel frame + Concentric steel bracing	6.5	
	7-Ordinary moment resisting steel frame + Concentric steel bracing		

Source: Standard 2800

It can be said that this situation will prevent ductility design from spreading. It is known that many of buildings in Teheran hardly have sufficient ductility. It is hoped to reconsider the above-mentioned circumstances, and to create a suitable environment for the spread of ductility design.

The main concept of Japan is recommended in this report, but another effective discussion should be done in order to obtain consensus among Iranian scientific society.

- Validation and calibration by experimental way

Engineering procedure must be verified not only by theoretical way but also by crosschecking experimental information. If the procedure in this report is thought over crosschecking viewpoint, it is not sufficiently discussed. The procedure may be improved by effort of calibration utilizing real disaster. Relationship between the damage ratio and the GI_S value must be examined.

- Implementation of building census

In this report, database "TMCSO 2002" was looked up in order to assume a number of buildings and floor area of each building. This database was made for property investigation originally. Therefore it does not offer so exact information about structure of each building. It is necessary to implement the building census by considering the structural engineering when follow-up study about the strengthening effect will be carried out in the future.

1.4 Application Method of Building Diagnosis

1.4.1 Means of GI_s Value

The meaning of the GI_S value is described as follows;

It is inherent in definition that GI_S value is physical quantity that is obtained by structure capacity divided by required capacity. The required capacity in this context is defined as equivalent linear intensity of response sector by means of equal-energy principle. In the condition that requirement of the response sector of #2800 is satisfied just in proportion, the value of GI_S is defined as 1.0. On the other hand some kind of countermeasure is needed when the value of GI_S is less than 1.0.

However it is natural process that the buildings, which are designed by following previous design code, do not satisfy present code, because design code is updated reflecting newest engineering findings. This situation is common in every country. The important things are that these existing inadequate buildings must be recognized and that some practical measures are done for them. Then some another indicator is needed in order to point out practical meaning of the GI_S value.

Damage Ratio, which is defined as probability of heavily damage, can offer effective information, if the GI_S value is converted.

In this context "heavily damage" is a damage state, in which the building shows obvious destruction like as large crack and cannot be in service without fundamental restore. It is inherent in definition that 50 buildings in 100 buildings suffer from the damage more than "heavily damage".

If the buildings suffer from "heavily damage", considerable number of human dead and injured, caused by crashing of structure members, may occur. That is why we pick up the damage state of "heavily damage" on.

1.4.2 Relationship between GI_s Value and Damage Ratio

1) Fragility function

Fragility curve is assumed to have an indicator of acceleration response spectrum S_a as horizontal axis.

Iranian earthquake resistance design code “#2800” proves Eq. (1.4.1) as acceleration response spectrum.

$$Sa = ABI \tag{1.4.1}$$

Where;

S_a : Spectral acceleration
A: Design base acceleration
B: Response coefficient of the building obtained from the design response spectrum
I : Importance factor

Damage ratio P that is defined in Eq. (1.4.2) shall be set as vertical axis of fragility curve.

$$P = \frac{\text{Number of damaged buildings}}{\text{Total number of buildings}} \tag{1.4.2}$$

Following formulation is based on hypothesis which belongs to reliability design.

- Every parameter in design code is set in expectation of its own *safety factor* S_f.
- Above safety factor conforms product of *index of. reliability* β and *standard deviation* ζ.

Fragility function can be described by lognormal distribution as shown in Eq. (1.4.3).

$$P \equiv F(S_a) = \Phi\left\{\frac{\ln\left(\frac{S_a}{\overline{S_a}}\right)}{\zeta}\right\} \tag{1.4.3}$$

where;

P : damage ratio
S_a : spectral acceleration
$\overline{S_a}$: median of S_a at which the building reaches the threshold of heavily damage
ζ : standard deviation of $\ln S_a$
Φ : standard normal cumulative distribution function

In this formulation S_a value means spectral acceleration which is modified to equivalent linear response considering bi-linear characteristics of a structure. In “Specification on Earthquake Resistant Diagnosis for Governmental Buildings and strengthening”, a way of equalization based on a concept of equal energy assumption is applied.

A hypothetical benchmark model represents a structure which satisfies an earthquake resistant design code in just proportion.

Following conditions are made as attribute of benchmark model;

- Spectral acceleration which is required by the earthquake design code is S_{ab}
- Value of GI_S evaluated in building diagnosis is equal to 1.0

Fragility function of benchmark model can be described by lognormal distribution, and damage ratio P for spectral acceleration S_{ab} must be limited in acceptably small value.

Therefore following conditions shall be made in order to define relationship between S_{ab} and $\overline{S_{ab}}$.

Condition 1 : Difference between S_{ab} and $\overline{S_{ab}}$ is given by Eq.(1.4.4) through the. intermediary of *index of reliability* β.

Condition 2 : Ratio of S_{ab} and $\overline{S_{ab}}$ is given by Eq. (1.4.5) through the intermediary of *safety factor* S_f

Eq. (1.4.4) is given when the condition 1 is comprised at log scale.

$$\ln(\overline{S_{ab}}) = \ln(S_{ab}) + \beta\zeta \qquad (1.4.4)$$

Where;

β : index of reliability

ζ : standard deviation of $\ln S_a$

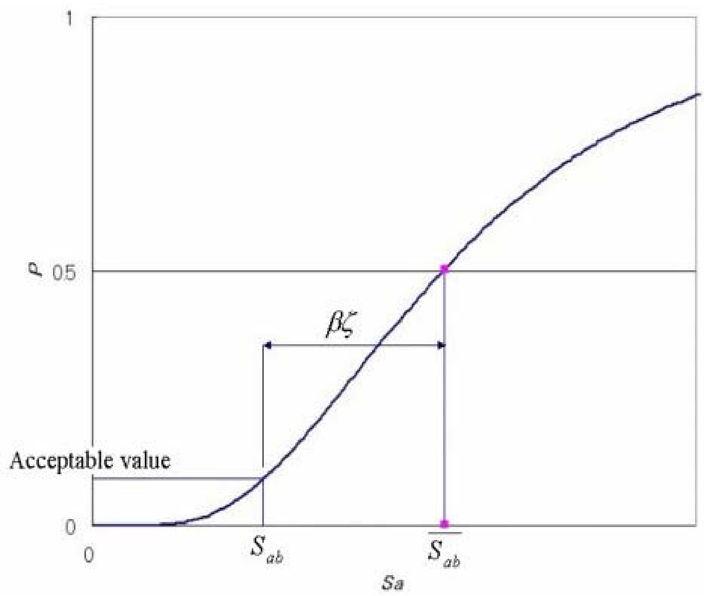


Figure 1.4.1 Schematic drawing of cumulative distribution function of benchmark model

Eq. (1.4.5) is given considering the reliability design concept the condition 2.

$$\overline{S_{ab}} = S_f \cdot S_{ab} \qquad (1.4.5)$$

Where;

S_f : safety factor

From Eq. (1.4.4) and Eq. (5.4.5) the standard deviation of $\ln S_a$, ζ_b is given by Eq. (1.4.6).

$$\beta\zeta_b = \ln(\overline{S_{ab}}) - \ln(S_{ab})$$

$$= \ln(S_f \cdot S_{ab}) - \ln(S_{ab}) = \ln(S_f)$$

$$\therefore \qquad \zeta_b = \frac{\ln(S_f)}{\beta} \qquad (1.4.6)$$

For a next step a model, which represent an objective building is described as follows; (i.e., evaluation value GI_S other than 1.0).

Median of S_a at which the building reaches the threshold of heavily damage, $\overline{S_{ao}}$ is given by Eq. (1.4.7) because the GI_S value is defined as a ratio of building capacity and capacity required by earthquake resistant code.

$$\overline{S_{ao}} = GI_S \cdot \overline{S_{ab}} = GI_S \cdot S_f \cdot S_{ab} \qquad (1.4.7)$$

The value ζ of the objective building is the same as the value ζ of the benchmark model, because the objective building also has same uncertainty as the benchmark model

2) Example

Regarding the benchmark model designed under following condition;

A=0.3 T_0=0.5 sec (Soil type 2) I=1.0

From "1990-Iranian Code for Seismic Resistant Design of Buildings.#2800" the value of S_{ab} is ;

S_{ab}=484 gal

The *safety factor S_f* and *index of reliability β* are ;

S_f=6.0 β=2.0

The *median of* S_a *at which the building reaches the threshold of heavily damage,* $\overline{S_{ab}}$ is ;

$\overline{S_{ab}} = S_f \cdot S_{ab}$ =6.0×484=2904 gal

The *standard deviation of* $\ln S_a$, ζ_b is ; $\zeta_b = \dfrac{\ln(S_f)}{\beta}$ = -0.896

Regarding the objective building which is evaluated as G_{IS}=0.25 ;

$\overline{S_{ao}} = GI_S \cdot \overline{S_{ab}}$ =0.25×2904=726gal

The value ζ of the objective building is the same as the value ζ of the benchmark model.

Then the damage ratio of the benchmark model and the damage ratio of the objective building are shown inFigure 1.4.2.

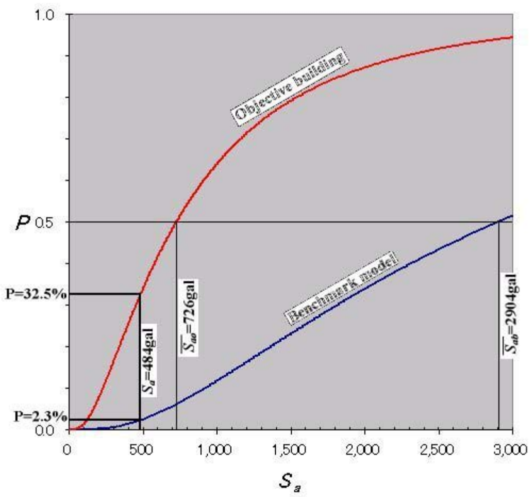


Figure 1.4.2 Cumulative distribution function for benchmark model and distribution function for objective building

The *damage ratio of the benchmark model P* can be obtained as a scale reading of vertical axis at S_{ab} =484 gal.

P = 0.023 viz. 2.3%

The *damage ratio of the objective building P* can be obtained as a scale reading of vertical axis at S_{ab} =484 gal.

P = 0.325 viz. 32.5%

3) Conclusion

Having described the damage ratio of the benchmark model and the objective building model, damage ratio of the objective building can be obtained using spectral intensity S_{ab} by Eq. (1.4.8).

From Eq. (1.4.3), Eq. (1.4.6), Eq. (1.4.7) ;

$$P = \Phi\left[-\beta\left\{1+\frac{\ln(GI_S)}{\ln(S_f)}\right\}\right] \quad (1.4.8)$$

Where;

P : damage ratio

β : index of reliability

GI_S : seismic index of structure

S_f : safety factor

1.4.3 Evaluation of Strengthening Measures Making Use of Diagnosis Results

Former explanations proved the capability to estimate the damage ratio on the basis of GI_S value of existing buildings in Tehran. Furthermore, it is possible to evaluate the effect of strengthening of buildings by estimating the extent of increased GI_S value.

The following procedures were adopted for this evaluation:

- Based on the cadastral database of existing buildings in Tehran and GI_S values for each structure types, the numbers of damaged building, its floor area and amount of damage were estimated, assuming the earthquake motion prescribed in Standard #2800.
- Compared with assumed GI_S value improved by strengthening or rebuilding, the most effective countermeasure for reducing building damage was proposed for the purpose of conducting emergency response operation just after the earthquake disaster.

1) Damage in Current Condition

Table 1.4.1 and Table 1.4.2 show the number of damaged building for each building type, and damaged floor area and amount of damage by cost, respectively. The cost of damage was estimated by unit costs for each building type on the basis of construction cost, as shown in Table 1.4.3

Table 1.4.1 Number of Damaged Buildings before Strengthening

Structure	Usage	Number of Story	GI_s	Damage Ratio P	Number of Buildings under the category	Number of Damaged Buildings
Reinforced Concrete Structure	Educational	1～3	0.50	11.0%	280	31
		4～7	0.40	16.4%	133	22
		more than 7	0.50	11.0%	30	3
	Health	1～3	0.50	11.0%	26	3
		4～7	0.40	16.4%	7	1
		more than 7	0.50	11.0%	0	0
	Residential	1～3	0.50	11.0%	20,557	2,262
		4～7	0.40	16.4%	14,885	2,445
		more than 7	0.50	11.0%	421	46
	Governmental	1～3	0.50	11.0%	123	14
		4～7	0.40	16.4%	105	17
		more than 7	0.50	11.0%	44	5
	Other	All	0.50	11.0%	1,360	150
Weak Masonry (Brick or cement block or stone skeleton with middle steel columns) (Brick skeleton with middle steel or concrete columns with 3 stories and up)	Educational	1～2	0.16	51.8%	437	226
		more than 2	0.16	51.8%	130	67
	Health	1～2	0.16	51.8%	55	28
		more than 2	0.16	51.8%	4	2
	Residential	1～2	0.16	51.8%	148,977	77,196
		more than 2	0.16	51.8%	17,456	9,045
	Governmental	1～2	0.16	51.8%	163	84
		more than 2	0.16	51.8%	79	41
	Other	All	0.16	51.8%	5,508	2,854
Unreinforced Masonry	Educational	1～2	0.14	57.7%	3,416	1,972
		more than 2	0.19	44.2%	393	174
	Health	1～2	0.14	57.7%	361	208
		more than 2	0.19	44.2%	13	6
	Residential	1～2	0.14	57.7%	395,149	228,062
		more than 2	0.19	44.2%	18,599	8,218
	Governmental	1～2	0.14	57.7%	861	497
		more than 2	0.19	44.2%	75	33
	Other	All	0.14	57.7%	33,963	19,602
Semi-Enginerred Masonry	Educational	1～2	0.2	41.9%	380	159
		more than 2	0.20	41.9%	44	18
	Health	All	0.20	41.9%	0	0
	Residential	All	0.20	41.9%	0	0
	Governmental	All	0.20	41.9%	0	0
	Other	All	0.20	41.9%	0	0
Steel	Educational	1～3	0.25	32.5%	974	317
		4～7	0.25	32.5%	295	96
		more than 7	0.25	32.5%	17	6
	Health	1～3	0.25	32.5%	94	31
		4～7	0.25	32.5%	19	6
		more than 7	0.25	32.5%	2	1
	Residential	1～3	0.21	39.8%	182,123	72,524
		4～7	0.21	39.8%	52,413	20,872
		more than 7	0.21	39.8%	703	280
	Governmental	1～3	0.25	32.5%	461	150
		4～7	0.25	32.5%	371	121
		more than 7	0.25	32.5%	56	18
	Other	All	0.25	32.5%	16,535	5,381
Adobe	All	All	0.02	99.1%	6,770	6,709
Hangars and Canopies	All	All	0.10	71.6%	11,054	7,912
Mix of 1~6	All	All	0.10	71.6%	6,769	4,845
Others	All	All	0.10	71.6%	894	640
Total					943,584	473,399

Source: JICA Study Team

Table 1.4.2 Floor Area and Estimated Cost of Damaged Buildings before Strengthening

Structure	Usage	Number of Story	GI_s	Damage Ratio P	Floor Area of Buildings under the category	Floor Area of Damaged Buildings under the category (m2)	Damaged Property (Rial)
Reinforced Concrete Structure	Educational	1～3	0.50	11.0%	476,759	52,464	104,928,000,000
		4～7	0.40	16.4%	375,818	61,721	123,442,000,000
		more than 7	0.50	11.0%	1,816,062	199,847	439,663,400,000
	Health	1～3	0.50	11.0%	51,342	5,650	12,995,000,000
		4～7	0.40	16.4%	28,024	4,602	10,584,600,000
		more than 7	0.50	11.0%	0	0	0
	Residential	1～3	0.50	11.0%	11,997,012	1,320,199	2,640,398,000,000
		4～7	0.40	16.4%	15,072,278	2,475,334	4,950,668,000,000
		more than 7	0.50	11.0%	3,779,451	415,906	914,993,200,000
	Governmental	1～3	0.50	11.0%	444,252	48,887	97,774,000,000
		4～7	0.40	16.4%	387,840	63,695	127,390,000,000
		more than 7	0.50	11.0%	504,682	55,537	122,181,400,000
	Other	All	0.50	11.0%	3,525,277	387,935	775,870,000,000
Weak Masonry (Brick or cement block or stone skeleton with middle steel columns) (Brick skeleton with middle steel or concrete columns with 3 stories and up)	Educational	1～2	0.16	51.8%	287,218	148,828	223,242,000,000
		more than 2	0.16	51.8%	158,255	82,003	123,004,500,000
	Health	1～2	0.16	51.8%	35,806	18,554	27,831,000,000
		more than 2	0.16	51.8%	8,593	4,453	6,679,500,000
	Residential	1～2	0.16	51.8%	31,712,062	16,432,305	24,648,457,500,000
		more than 2	0.16	51.8%	7,985,972	4,138,108	6,207,162,000,000
	Governmental	1～2	0.16	51.8%	83,390	43,210	64,815,000,000
		more than 2	0.16	51.8%	88,253	45,730	68,595,000,000
	Other	All	0.16	51.8%	2,312,057	1,198,043	1,797,064,500,000
Unreinforced Masonry	Educational	1～2	0.14	57.7%	1,211,532	699,240	1,048,860,000,000
		more than 2	0.19	44.2%	544,765	240,709	361,063,500,000
	Health	1～2	0.14	57.7%	178,311	102,913	154,369,500,000
		more than 2	0.19	44.2%	39,040	17,250	25,875,000,000
	Residential	1～2	0.14	57.7%	47,651,954	27,502,496	41,253,744,000,000
		more than 2	0.19	44.2%	5,297,738	2,340,856	3,511,284,000,000
	Governmental	1～2	0.14	57.7%	300,014	173,154	259,731,000,000
		more than 2	0.19	44.2%	107,096	47,321	70,981,500,000
	Other	All	0.14	57.7%	8,566,353	4,944,101	7,416,151,500,000
Semi-Enginerred Masonry	Educational	1～2	0.2	41.9%	134,615	56,453	84,679,500,000
		more than 2	0.20	41.9%	60,529	25,384	50,768,000,000
	Health	All	0.20	41.9%	0	0	0
	Residential	All	0.20	41.9%	0	0	0
	Governmental	All	0.20	41.9%	0	0	0
	Other	All	0.20	41.9%	0	0	0
Steel	Educational	1～3	0.25	32.5%	1,186,178	386,009	733,417,100,000
		4～7	0.25	32.5%	826,865	269,080	511,252,000,000
		more than 7	0.25	32.5%	115,614	37,623	79,008,300,000
	Health	1～3	0.25	32.5%	124,480	40,509	85,068,900,000
		4～7	0.25	32.5%	90,650	29,500	61,950,000,000
		more than 7	0.25	32.5%	46,089	14,998	34,495,400,000
	Residential	1～3	0.21	39.8%	57,732,965	22,990,094	43,681,178,600,000
		4～7	0.21	39.8%	37,569,511	14,960,718	28,425,364,200,000
		more than 7	0.21	39.8%	3,351,268	1,334,523	2,802,498,300,000
	Governmental	1～3	0.25	32.5%	555,457	180,758	379,591,800,000
		4～7	0.25	32.5%	917,017	298,418	626,677,800,000
		more than 7	0.25	32.5%	366,099	119,137	274,015,100,000
	Other	All	0.25	32.5%	12,425,064	4,043,395	7,278,111,000,000
Adobe	All	All	0.02	99.1%	1,018,090	1,008,954	1,008,954,000,000
Hangars and Canopies	All	All	0.10	71.6%	1,900,427	1,360,187	2,040,280,500,000
Mix of 1~6	All	All	0.10	71.6%	8,542,106	6,113,817	6,113,817,000,000
Others	All	All	0.10	71.6%	532,909	381,417	381,417,000,000
Total					272,523,139	116,922,026	192,242,343,100,000

Source: JICA Study Team

Table 1.4.3 Unit Cost (used for estimation of damage)

Structure	Usage	Number of Story	Unit Cost (10^6Rial/m^2)	comment
Reinforced Concrete Structure	Educational	1～3	2.00	
		4～7	2.00	
		more than 7	2.20	Middle to High-rise 1.1times
	Health	1～3	2.30	
		4～7	2.30	
		more than 7	2.40	Middle to High-rise 1.1times
	Residential	1～3	2.00	
		4～7	2.00	
		more than 7	2.20	Middle to High-rise 1.1times
	Governmental	1～3	2.00	
		4～7	2.00	
		more than 7	2.20	Middle to High-rise 1.1times
	Other	All	2.00	
Weak Masonry (Brick or cement block or stone skeleton with middle steel columns) (Brick skeleton with middle steel or concrete columns with 3 stories and up)	All	1～2	1.50	
Unreinforced Masonry	Educational	1～2	1.50	
Semi-Enginerred Masonry	Educational	1～2	2.00	
	Health	All	0.00	data not available
	Residential	All	0.00	
	Governmental	All	0.00	
	Other	All	0.00	
Steel	Educational	1～3	1.90	
		4～7	1.90	
		more than 7	2.10	Middle to High-rise 1.1times
	Health	1～3	2.10	
		4～7	2.10	
		more than 7	2.30	Middle to High-rise 1.1times
	Residential	1～3	1.90	
		4～7	1.90	
		more than 7	2.10	Middle to High-rise 1.1times
	Governmental	1～3	2.10	
		4～7	2.10	
		more than 7	2.30	Middle to High-rise 1.1times
	Other	All	1.80	
Adobe	All	All	1.00	
Hangars and Canopies	All	All	1.50	
Mix of 1~6	All	All	1.00	
Others	All	All	1.00	

Source: JICA Study Team

2) Effect of Strengthening and rebuilding

The basis of proposal for the extent of strengthening and rebuilding for the purpose of conducting emergency response operation in the event of disaster is lead by assuming improved GI_S value by strengthening and rebuilding. The effects of strengthening and rebuilding were differentiated, given the fact that it is not feasible to strengthen the very old buildings to meet the capacity demand of Standard #2800.

Table 1.4.4 summarizes the improved GI_S value for each building types.

Table 1.4.4 Improved GI_s value for each building types

Structure	Usage	Number of Story	GI_s	comment
Reinforced Concrete Structure	Educational	1～3	0.70	Apply Confinement of Column Apply Shear Prevention Strengthen Beam-Column Connection
		4～7	0.56	
		more than 7	0.70	
	Health	1～3	0.70	
		4～7	0.56	
		more than 7	0.70	
	Residential	1～3	0.70	
		4～7	0.56	
		more than 7	0.70	
	Governmental	1～3	0.70	
		4～7	0.56	
		more than 7	0.70	
	Other	All	0.70	
Weak Masonry (Brick or cement block or stone skeleton with middle steel columns) (Brick skeleton with middle steel or concrete columns with 3 stories and up)	Educational	1～2	0.32	Install Bracing to necessary panel
		more than 2	0.32	
	Health	1～2	0.32	
		more than 2	0.32	
	Residential	1～2	0.32	
		more than 2	0.32	
	Governmental	1～2	0.32	
		more than 2	0.32	
	Other	All	0.32	
Unreinforced Masonry	Educational	1～2	0.21	1.3 times of original
		more than 2	0.29	
	Health	1～2	0.21	
		more than 2	0.29	
	Residential	1～2	0.21	
		more than 2	0.29	
	Governmental	1～2	0.21	
		more than 2	0.29	
	Other	All	0.21	
Semi-Enginerred Masonry	Educational	1～2	0.25	Install Steel Frame or Bracing to necessary panel
		more than 2	0.25	
	Health	All	0.25	
	Residential	All	0.25	
	Governmental	All	0.25	
	Other	All	0.25	
Steel	Educational	1～3	0.38	Prevention of Brittle Failure Strengthen Beam-Column Connection
		4～7	0.38	
		more than 7	0.38	
	Health	1～3	0.38	
		4～7	0.38	
		more than 7	0.38	
	Residential	1～3	0.32	
		4～7	0.32	
		more than 7	0.32	
	Governmental	1～3	0.38	
		4～7	0.38	
		more than 7	0.38	
	Other	All	0.38	
Adobe	All	All	0.00	data not available
Hangars and Canopies	All	All	0.15	
Mix of 1~6	All	All	0.15	
Others	All	All	0.15	

Source: JICA Study Team

On the other hand, for the case of rebuilding, it is assumed that the rebuilding building satisfies the capacity demand of Standard #2800, and that 2.3% of estimated damage ratio, which is for the case of GI_S value 1.0, as explained in subsection 5.4.2, is applied for rebuilding buildings.

The fundamental judgment for the necessity of strengthening or rebuilding is made on the basis of assumed GI_S value obtained from building diagnosis.

It is assumed that the actual GI_S values of existing buildings accords with normal distribution. Considering the result of building diagnosis in the Study, the fluctuation coefficient of GI_S values of existing buildings in Tehran was set as 0.4. However, the mean value of GI_S of remained building without strengthening or rebuilding is shifted upward. This effect can be corrected by the following procedure.

After omitting the left part from x_c of normal distribution curve in the conceptual graph shown in Figure 1.4.3, remained right part is only considered.

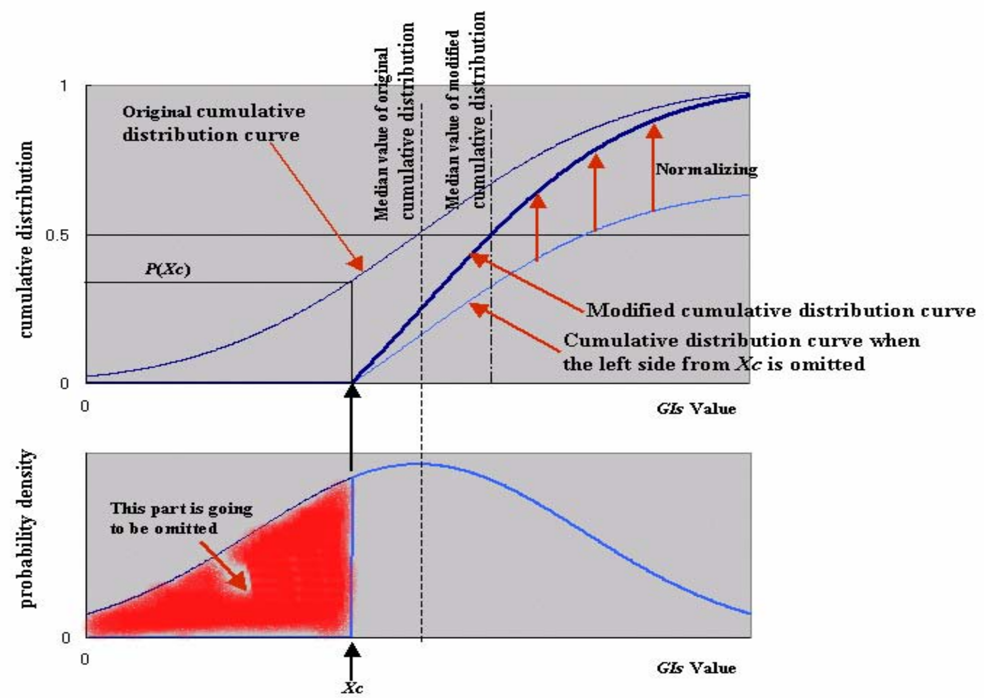


Figure 1.4.3 Conceptual Graph of Normal Distribution of GI_S Value

Since cumulative value of omitted part is $P(x_c)$, probability density function of the remained right part should be multiplied with $\frac{1}{\{1-P(x_c)\}}$

$$p(x)=\frac{1}{\{1-P(x_c)\}}\frac{1}{\sigma\sqrt{2\pi}}\exp\left\{-\frac{(x-\bar{x})^2}{2\sigma^2}\right\} \qquad x_c \le x \le \infty$$

$$p(x) = 0 \qquad x \le x_c$$

$$z = \frac{x - \bar{x}}{\sigma} \ , \quad z_c = \frac{x_c - \bar{x}}{\sigma}$$

Providing that $z_c = \frac{x_c - \bar{x}}{\sigma}$,

$$p(z) = \frac{1}{\{1 - P(z_c)\}} \frac{1}{\sigma\sqrt{2\pi}} \exp\left\{-\frac{z^2}{2}\right\} \qquad z_c \le z \le \infty$$

$$p(z) = 0 \qquad z \le z_c$$

Cumulative distribution function $P(z)$ is,

$$P(z) = \frac{1}{\{1 - \Phi(z_c)\}} \{\Phi(z) - \Phi(z_c)\}$$

The median value zm can be provided by $P(z) = 50\%$.

$$\frac{1}{\{1 - \Phi(z_c)\}} \{\Phi(z) - \Phi(z_c)\} = 0.5$$

$$\Phi(z) = \frac{1 + \Phi(z_c)}{2}$$

$$z_m = \Phi^{-1}\left(\frac{1 + \Phi(z_c)}{2}\right)$$

The median value x_m can be given by the following.

$$\sigma \cdot z_m = x_m - \bar{x} \ ,$$

$$x_m = \bar{x} + \sigma \cdot z_m \ ,$$

In addition, following aspects were considered in proposing countermeasure for strengthening and rebuilding;

- For the public facilities that should be disaster protection activity base in the case of disaster, high proportion of rebuilding was given, considering the priority of physical implementation.
- On the other hand, for the private residential buildings, low proportion of rebuilding was given, considering the fact that property owner is relatively reluctant to rebuild their own building even having financial support from public bodies.

Shift of GI_S median value caused by strengthening and reconstruction is shown in Table 1.4.5

Table 1.4.5 Shift of GI_S median value caused by strengthening and reconstruction

Structure	Usage	Number of Story	Applied/Total	*GIs* (Original)	Coefficient of variation of *GIs*	Cutback of *GIs*	Median value of *GIs* after cutback
Reinforced Concrete Structure	Educational	1～3	90%	0.50	0.40	0.756	0.829
		4～7	90%	0.40	0.40	0.605	0.663
		more than 7	90%	0.50	0.40	0.756	0.829
	Health	1～3	90%	0.50	0.40	0.756	0.829
		4～7	90%	0.40	0.40	0.605	0.663
		more than 7	90%	0.50	0.40	0.756	0.829
	Residential	1～3	83%	0.50	0.40	0.693	0.777
		4～7	83%	0.40	0.40	0.555	0.621
		more than 7	83%	0.50	0.40	0.693	0.777
	Governmental	1～3	90%	0.50	0.40	0.756	0.829
		4～7	90%	0.40	0.40	0.605	0.663
		more than 7	90%	0.50	0.40	0.756	0.829
	Other	All	33%	0.50	0.40	0.414	0.586
Weak Masonry (Brick or cement block or stone skeleton with middle steel columns) (Brick skeleton with middle steel or concrete columns with 3 stories and up)	Educational	1～2	100%	0.16	0.40	0.160	0.160
		more than 2	100%	0.16	0.40	0.160	0.160
	Health	1～2	100%	0.16	0.40	0.160	0.160
		more than 2	100%	0.16	0.40	0.160	0.160
	Residential	1～2	100%	0.16	0.40	0.160	0.160
		more than 2	100%	0.16	0.40	0.160	0.160
	Governmental	1～2	90%	0.16	0.40	0.242	0.265
		more than 2	90%	0.16	0.40	0.242	0.265
	Other	All	90%	0.16	0.40	0.242	0.265
Unreinforced Masonry	Educational	1～2	100%	0.14	0.40	0.140	0.140
		more than 2	100%	0.19	0.40	0.190	0.190
	Health	1～2	100%	0.14	0.40	0.140	0.140
		more than 2	100%	0.19	0.40	0.190	0.190
	Residential	1～2	100%	0.14	0.40	0.140	0.140
		more than 2	100%	0.19	0.40	0.190	0.190
	Governmental	1～2	100%	0.14	0.40	0.140	0.140
		more than 2	100%	0.19	0.40	0.190	0.190
	Other	All	100%	0.14	0.40	0.140	0.140
Semi-Enginerred Masonry	Educational	1～2	90%	0.2	0.40	0.303	0.332
		more than 2	90%	0.20	0.40	0.303	0.332
	Health	All	0%	0.20	0.40	0.200	0.200
	Residential	All	0%	0.20	0.40	0.200	0.200
	Governmental	All	0%	0.20	0.40	0.200	0.200
	Other	All	0%	0.20	0.40	0.200	0.200
Steel	Educational	1～3	100%	0.25	0.40	0.250	0.250
		4～7	100%	0.25	0.40	0.250	0.250
		more than 7	100%	0.25	0.40	0.250	0.250
	Health	1～3	100%	0.25	0.40	0.250	0.250
		4～7	100%	0.25	0.40	0.250	0.250
		more than 7	100%	0.25	0.40	0.250	0.250
	Residential	1～3	100%	0.21	0.40	0.210	0.210
		4～7	100%	0.21	0.40	0.210	0.210
		more than 7	100%	0.21	0.40	0.210	0.210
	Governmental	1～3	100%	0.25	0.40	0.250	0.250
		4～7	100%	0.25	0.40	0.250	0.250
		more than 7	100%	0.25	0.40	0.250	0.250
	Other	All	67%	0.25	0.40	0.293	0.347
Adobe	All	All	67%	0.02	0.40	0.023	0.028
Hangars and Canopies	All	All	67%	0.15	0.40	0.176	0.208
Mix of 1~6	All	All	67%	0.15	0.40	0.176	0.208
Others	All	All	67%	0.15	0.40	0.176	0.208

Source: JICA Study Team

The number of damaged building after conducting strengthening and rebuilding countermeasure is shown in from Table 1.4.6 to Table 1.4.9, and damaged floor area and amount of damage by cost are in from Table 1.4.10 to Table 1.4.13.

The construction process cost for strengthening and rebuilding is shown in Table 1.4.14.

The unit cost for strengthening and rebuilding is shown in Table 1.4.15 and Table 1.4.16 respectively.

Table 1.4.6 Number of heavily damaged buildings (No action buildings)

Structure	Usage	Number of Story	Not applied/Total	Nnumber of not applied	Median value of GI_s after cutback	Damage Ratio P after cutback	Number of damaged buildings
Reinforced Concrete Structure	Educational	1～3	10%	28	0.829	3.7%	1
		4～7	10%	13	0.663	6.2%	1
		more than 7	10%	3	0.829	3.7%	0
	Health	1～3	10%	3	0.829	3.7%	0
		4～7	10%	1	0.663	6.2%	0
		more than 7	10%	0	0.829	3.7%	0
	Residential	1～3	17%	3,426	0.777	4.3%	147
		4～7	17%	2,481	0.621	7.1%	176
		more than 7	17%	70	0.777	4.3%	3
	Governmental	1～3	10%	12	0.829	3.7%	0
		4～7	10%	11	0.663	6.2%	1
		more than 7	10%	4	0.829	3.7%	0
	Other	All	67%	907	0.586	8.0%	73
Weak Masonry (Brick or cement block or stone skeleton with middle steel columns) (Brick skeleton with middle steel or concrete columns with 3 stories and up)	Educational	1～2	0%	0	0.160	51.8%	0
		more than 2	0%	0	0.160	51.8%	0
	Health	1～2	0%	0	0.160	51.8%	0
		more than 2	0%	0	0.160	51.8%	0
	Residential	1～2	0%	0	0.160	51.8%	0
		more than 2	0%	0	0.160	51.8%	0
	Governmental	1～2	10%	16	0.265	30.2%	5
		more than 2	10%	8	0.265	30.2%	2
	Other	All	10%	551	0.265	30.2%	166
Unreinforced Masonry	Educational	1～2	0%	0	0.140	57.7%	0
		more than 2	0%	0	0.190	44.2%	0
	Health	1～2	0%	0	0.140	57.7%	0
		more than 2	0%	0	0.190	44.2%	0
	Residential	1～2	0%	0	0.140	57.7%	0
		more than 2	0%	0	0.190	44.2%	0
	Governmental	1～2	0%	0	0.140	57.7%	0
		more than 2	0%	0	0.190	44.2%	0
	Other	All	0%	0	0.140	57.7%	0
Semi-Enginerred Masonry	Educational	1～2	10%	38	0.332	22.1%	8
		more than 2	10%	4	0.332	22.1%	1
	Health	All	100%	0	0.200	41.9%	0
	Residential	All	100%	0	0.200	41.9%	0
	Governmental	All	100%	0	0.200	41.9%	0
	Other	All	100%	0	0.200	41.9%	0
Steel	Educational	1～3	0%	0	0.250	32.5%	0
		4～7	0%	0	0.250	32.5%	0
		more than 7	0%	0	0.250	32.5%	0
	Health	1～3	0%	0	0.250	32.5%	0
		4～7	0%	0	0.250	32.5%	0
		more than 7	0%	0	0.250	32.5%	0
	Residential	1～3	0%	0	0.210	39.8%	0
		4～7	0%	0	0.210	39.8%	0
		more than 7	0%	0	0.210	39.8%	0
	Governmental	1～3	0%	0	0.250	32.5%	0
		4～7	0%	0	0.250	32.5%	0
		more than 7	0%	0	0.250	32.5%	0
	Other	All	33%	5,512	0.347	20.7%	1,140
Adobe	All	All	33%	2,257	0.028	97.7%	2,206
Hangars and Canopies	All	All	33%	3,685	0.208	40.2%	1,482
Mix of 1~6	All	All	33%	2,256	0.208	40.2%	908
Others	All	All	33%	298	0.208	40.2%	120
Total				21,583			6,440

Source: JICA Study Team

Table 1.4.7 Number of heavily damaged buildings (Strengthened buildings)

Structure	Usage	Number of Story	Applied/Total	Applied Number	*GIs*	Damage Ratio P	Damaged Number
Reinforced Concrete Structure	Educational	1～3	0.0%	0	0.70	5.5%	0
		4～7	0.0%	0	0.56	8.8%	0
		more than 7	0.0%	0	0.70	5.5%	0
	Health	1～3	0.0%	0	0.70	5.5%	0
		4～7	0.0%	0	0.56	8.8%	0
		more than 7	0.0%	0	0.70	5.5%	0
	Residential	1～3	33.3%	6,852	0.70	5.5%	523
		4～7	33.3%	4,962	0.56	8.8%	590
		more than 7	33.3%	140	0.70	5.5%	11
	Governmental	1～3	0.0%	0	0.70	5.5%	0
		4～7	0.0%	0	0.56	8.8%	0
		more than 7	0.0%	0	0.70	5.5%	0
	Other	All	0.0%	0	0.70	5.5%	0
Weak Masonry (Brick or cement block or stone skeleton with middle steel columns) (Brick skeleton with middle steel or concrete columns with 3 stories and up)	Educational	1～2	0.0%	0	0.32	23.3%	0
		more than 2	0.0%	0	0.32	23.3%	0
	Health	1～2	0.0%	0	0.32	23.3%	0
		more than 2	0.0%	0	0.32	23.3%	0
	Residential	1～2	10.0%	14,898	0.32	23.3%	6,248
		more than 2	10.0%	1,746	0.32	23.3%	732
	Governmental	1～2	0.0%	0	0.32	23.3%	0
		more than 2	0.0%	0	0.32	23.3%	0
	Other	All	0.0%	0	0.32	23.3%	0
Unreinforced Masonry	Educational	1～2	0.0%	0	0.21	39.8%	0
		more than 2	0.0%	0	0.29	27.5%	0
	Health	1～2	0.0%	0	0.21	39.8%	0
		more than 2	0.0%	0	0.29	27.5%	0
	Residential	1～2	0.0%	0	0.21	39.8%	0
		more than 2	0.0%	0	0.29	27.5%	0
	Governmental	1～2	0.0%	0	0.21	39.8%	0
		more than 2	0.0%	0	0.29	27.5%	0
	Other	All	0.0%	0	0.21	39.8%	0
Semi-Enginerred Masonry	Educational	1～2	0.0%	0	0.25	32.5%	0
		more than 2	0.0%	0	0.25	32.5%	0
	Health	All	0.0%	0	0.25	32.5%	0
	Residential	All	0.0%	0	0.25	32.5%	0
	Governmental	All	0.0%	0	0.25	32.5%	0
	Other	All	0.0%	0	0.25	32.5%	0
Steel	Educational	1～3	0.0%	0	0.38	18.3%	0
		4～7	0.0%	0	0.38	18.3%	0
		more than 7	0.0%	0	0.38	18.3%	0
	Health	1～3	0.0%	0	0.38	18.3%	0
		4～7	0.0%	0	0.38	18.3%	0
		more than 7	0.0%	0	0.38	18.3%	0
	Residential	1～3	20.0%	36,425	0.32	23.9%	8,497
		4～7	20.0%	10,483	0.32	23.9%	2,445
		more than 7	0.0%	0	0.32	23.9%	0
	Governmental	1～3	0.0%	0	0.38	18.3%	0
		4～7	0.0%	0	0.38	18.3%	0
		more than 7	0.0%	0	0.38	18.3%	0
	Other	All	33.3%	5,512	0.38	18.3%	985
Adobe	All	All	33.3%	2,257	0.00	100.0%	2,236
Hangars and Canopies	All	All	33.3%	3,685	0.15	54.7%	2,015
Mix of 1~6	All	All	33.3%	2,256	0.15	54.7%	1,234
Others	All	All	33.3%	298	0.15	54.7%	163
Total				89,512			25,679

Source: JICA Study Team

Table 1.4.8 Number of heavily damaged buildings (Reconstructed buildings)

Structure	Usage	Number of Story	Applied/Total	Applied Number	GI_s	Damage Ratio P	Damaged Number
Reinforced Concrete Structure	Educational	1〜3	90.0%	252	0.70	5.5%	6
		4〜7	90.0%	120	0.56	8.8%	3
		more than 7	90.0%	27	0.70	5.5%	1
	Health	1〜3	90.0%	23	0.70	5.5%	1
		4〜7	90.0%	6	0.56	8.8%	0
		more than 7	90.0%	0	0.70	5.5%	0
	Residential	1〜3	50.0%	10,279	0.70	5.5%	234
		4〜7	50.0%	7,443	0.56	8.8%	169
		more than 7	50.0%	211	0.70	5.5%	5
	Governmental	1〜3	90.0%	111	0.70	5.5%	3
		4〜7	90.0%	95	0.56	8.8%	2
		more than 7	90.0%	40	0.70	5.5%	1
	Other	All	33.3%	453	0.70	5.5%	10
Weak Masonry (Brick or cement block or stone skeleton with middle steel columns) (Brick skeleton with middle steel or concrete columns with 3 stories and up)	Educational	1〜2	100.0%	437	0.32	23.3%	10
		more than 2	100.0%	130	0.32	23.3%	3
	Health	1〜2	100.0%	55	0.32	23.3%	1
		more than 2	100.0%	4	0.32	23.3%	0
	Residential	1〜2	90.0%	134,079	0.32	23.3%	3,050
		more than 2	90.0%	15,710	0.32	23.3%	357
	Governmental	1〜2	90.0%	147	0.32	23.3%	3
		more than 2	90.0%	71	0.32	23.3%	2
	Other	All	90.0%	4,957	0.32	23.3%	113
Unreinforced Masonry	Educational	1〜2	100.0%	3,416	0.21	39.8%	78
		more than 2	100.0%	393	0.29	27.5%	9
	Health	1〜2	100.0%	361	0.21	39.8%	8
		more than 2	100.0%	13	0.29	27.5%	0
	Residential	1〜2	100.0%	395,149	0.21	39.8%	8,990
		more than 2	100.0%	18,599	0.29	27.5%	423
	Governmental	1〜2	100.0%	861	0.21	39.8%	20
		more than 2	100.0%	75	0.29	27.5%	2
	Other	All	100.0%	33,963	0.21	39.8%	773
Semi-Enginerred Masonry	Educational	1〜2	90.0%	342	0.25	32.5%	8
		more than 2	90.0%	39	0.25	32.5%	1
	Health	All	0.0%	0	0.25	32.5%	0
	Residential	All	0.0%	0	0.25	32.5%	0
	Governmental	All	0.0%	0	0.25	32.5%	0
	Other	All	0.0%	0	0.25	32.5%	0
Steel	Educational	1〜3	100.0%	974	0.38	18.3%	22
		4〜7	100.0%	295	0.38	18.3%	7
		more than 7	100.0%	17	0.38	18.3%	0
	Health	1〜3	100.0%	94	0.38	18.3%	2
		4〜7	100.0%	19	0.38	18.3%	0
		more than 7	100.0%	2	0.38	18.3%	0
	Residential	1〜3	80.0%	145,698	0.32	23.9%	3,315
		4〜7	80.0%	41,930	0.32	23.9%	954
		more than 7	100.0%	703	0.32	23.9%	16
	Governmental	1〜3	100.0%	461	0.38	18.3%	10
		4〜7	100.0%	371	0.38	18.3%	8
		more than 7	100.0%	56	0.38	18.3%	1
	Other	All	33.3%	5,512	0.38	18.3%	125
Adobe	All	All	33.3%	2,257	0.00	100.0%	51
Hangars and Canopies	All	All	33.3%	3,685	0.15	54.7%	84
Mix of 1~6	All	All	33.3%	2,256	0.15	54.7%	51
Others	All	All	33.3%	298	0.15	54.7%	7
Total				832,489			18,939

Source: JICA Study Team

Table 1.4.9 Number of heavily damaged buildings (Total)

Structure	Usage	Number of Story	Number of not applied buildings	Number of strengthened buildings	Number of reconstructed buildings	Total
Reinforced Concrete Structure	Educational	1〜3	1	0	6	7
		4〜7	1	0	3	4
		more than 7	0	0	1	1
	Health	1〜3	0	0	1	1
		4〜7	0	0	0	0
		more than 7	0	0	0	0
	Residential	1〜3	147	523	234	904
		4〜7	176	590	169	935
		more than 7	3	11	5	19
	Governmental	1〜3	0	0	3	3
		4〜7	1	0	2	3
		more than 7	0	0	1	1
	Other	All	73	0	10	83
Weak Masonry (Brick or cement block or stone skeleton with middle steel columns) (Brick skeleton with middle steel or concrete columns with 3 stories and up)	Educational	1〜2	0	0	10	10
		more than 2	0	0	3	3
	Health	1〜2	0	0	1	1
		more than 2	0	0	0	0
	Residential	1〜2	0	6,248	3,050	9,298
		more than 2	0	732	357	1,089
	Governmental	1〜2	5	0	3	8
		more than 2	2	0	2	4
	Other	All	166	0	113	279
Unreinforced Masonry	Educational	1〜2	0	0	78	78
		more than 2	0	0	9	9
	Health	1〜2	0	0	8	8
		more than 2	0	0	0	0
	Residential	1〜2	0	0	8,990	8,990
		more than 2	0	0	423	423
	Governmental	1〜2	0	0	20	20
		more than 2	0	0	2	2
	Other	All	0	0	773	773
Semi-Enginerred Masonry	Educational	1〜2	8	0	8	16
		more than 2	1	0	1	2
	Health	All	0	0	0	0
	Residential	All	0	0	0	0
	Governmental	All	0	0	0	0
	Other	All	0	0	0	0
Steel	Educational	1〜3	0	0	22	22
		4〜7	0	0	7	7
		more than 7	0	0	0	0
	Health	1〜3	0	0	2	2
		4〜7	0	0	0	0
		more than 7	0	0	0	0
	Residential	1〜3	0	8,497	3,315	11,811
		4〜7	0	2,445	954	3,399
		more than 7	0	0	16	16
	Governmental	1〜3	0	0	10	10
		4〜7	0	0	8	8
		more than 7	0	0	1	1
	Other	All	1,140	985	125	2,250
Adobe	All	All	2,206	2,236	51	4,493
Hangars and Canopies	All	All	1,482	2,015	84	3,581
Mix of 1~6	All	All	908	1,234	51	2,193
Others	All	All	120	163	7	290
Total			6,440	25,679	18,939	51,058

Source: JICA Study Team

Table 1.4.10 Floor area of heavily damaged buildings (No action buildings)

Structure	Usage	Number of Story	Not applied/Total	Floor area of not applied buildings (m^2)	Median value of *GIs* after cutback	Damage Ratio P after cutback	Floor area of damaged buildings (m^2)
Reinforced Concrete Structure	Educational	1～3	0.100	47,676	0.829	3.7%	1,749
		4～7	0.100	37,582	0.663	6.2%	2,315
		more than 7	0.100	181,606	0.829	3.7%	6,661
	Health	1～3	0.100	5,134	0.829	3.7%	188
		4～7	0.100	2,802	0.663	6.2%	173
		more than 7	0.100	0	0.829	3.7%	0
	Residential	1～3	0.167	1,999,502	0.777	4.3%	85,815
		4～7	0.167	2,512,046	0.621	7.1%	178,245
		more than 7	0.167	629,909	0.777	4.3%	27,034
	Governmental	1～3	0.100	44,425	0.829	3.7%	1,629
		4～7	0.100	38,784	0.663	6.2%	2,389
		more than 7	0.100	50,468	0.829	3.7%	1,851
	Other	All	0.667	2,350,185	0.586	8.0%	188,484
Weak Masonry (Brick or cement block or stone skeleton with middle steel columns) (Brick skeleton with middle steel or concrete columns with 3 stories and up)	Educational	1～2	0.000	0	0.160	51.8%	0
		more than 2	0.000	0	0.160	51.8%	0
	Health	1～2	0.000	0	0.160	51.8%	0
		more than 2	0.000	0	0.160	51.8%	0
	Residential	1～2	0.000	0	0.160	51.8%	0
		more than 2	0.000	0	0.160	51.8%	0
	Governmental	1～2	0.100	8,339	0.265	30.2%	2,518
		more than 2	0.100	8,825	0.265	30.2%	2,665
	Other	All	0.100	231,206	0.265	30.2%	69,815
Unreinforced Masonry	Educational	1～2	0.000	0	0.140	57.7%	0
		more than 2	0.000	0	0.190	44.2%	0
	Health	1～2	0.000	0	0.140	57.7%	0
		more than 2	0.000	0	0.190	44.2%	0
	Residential	1～2	0.000	0	0.140	57.7%	0
		more than 2	0.000	0	0.190	44.2%	0
	Governmental	1～2	0.000	0	0.140	57.7%	0
		more than 2	0.000	0	0.190	44.2%	0
	Other	All	0.000	0	0.140	57.7%	0
Semi-Enginerred Masonry	Educational	1～2	0.100	13,461	0.332	22.1%	2,979
		more than 2	0.100	6,053	0.332	22.1%	1,339
	Health	All	1.000	0	0.200	41.9%	0
	Residential	All	1.000	0	0.200	41.9%	0
	Governmental	All	1.000	0	0.200	41.9%	0
	Other	All	1.000	0	0.200	41.9%	0
Steel	Educational	1～3	0.000	0	0.250	32.5%	0
		4～7	0.000	0	0.250	32.5%	0
		more than 7	0.000	0	0.250	32.5%	0
	Health	1～3	0.000	0	0.250	32.5%	0
		4～7	0.000	0	0.250	32.5%	0
		more than 7	0.000	0	0.250	32.5%	0
	Residential	1～3	0.000	0	0.210	39.8%	0
		4～7	0.000	0	0.210	39.8%	0
		more than 7	0.000	0	0.210	39.8%	0
	Governmental	1～3	0.000	0	0.250	32.5%	0
		4～7	0.000	0	0.250	32.5%	0
		more than 7	0.000	0	0.250	32.5%	0
	Other	All	0.333	4,141,688	0.347	20.7%	856,320
Adobe	All	All	0.333	339,363	0.028	97.7%	331,671
Hangars and Canopies	All	All	0.333	633,476	0.208	40.2%	254,814
Mix of 1~6	All	All	0.333	2,847,369	0.208	40.2%	1,145,348
Others	All	All	0.333	177,636	0.208	40.2%	71,454
Total				16,307,536			3,235,456

Source: JICA Study Team

Table 1.4.11 Floor area and damaged property of heavily damaged buildings (Strengthened buildings)

Structure	Usage	Number of Story	Applied/Total	Floor area of applied buildings (m²)	GI_s	Damage Ratio P	Floor area of damaged buildings (m²)	Floor area of damaged buildings (m²)
Reinforced Concrete Structure	Educational	1～3	0%	0	0.70	5.5%	0	23,020,551,444
		4～7	0%	0	0.56	8.8%	0	20,019,254,074
		more than 7	0%	0	0.70	5.5%	0	96,458,427,771
	Health	1～3	0%	0	0.70	5.5%	0	3,098,843,316
		4～7	0%	0	0.56	8.8%	0	1,865,994,897
		more than 7	0%	0	0.70	5.5%	0	0
	Residential	1～3	33%	3,999,004	0.70	5.5%	218,314	881,189,880,827
		4～7	33%	5,024,093	0.56	8.8%	442,425	1,584,236,817,555
		more than 7	33%	1,259,817	0.70	5.5%	68,776	305,363,983,458
	Governmental	1～3	0%	0	0.70	5.5%	0	21,450,934,371
		4～7	0%	0	0.56	8.8%	0	20,659,647,755
		more than 7	0%	0	0.70	5.5%	0	26,805,710,512
	Other	All	0%	0	0.70	5.5%	0	430,435,755,467
Weak Masonry (Brick or cement block or stone skeleton with middle steel columns) (Brick skeleton with middle steel or concrete columns with 3 stories and up)	Educational	1～2	0%	0	0.32	23.3%	0	9,801,371,533
		more than 2	0%	0	0.32	23.3%	0	5,400,483,437
	Health	1～2	0%	0	0.32	23.3%	0	1,221,886,891
		more than 2	0%	0	0.32	23.3%	0	293,237,839
	Residential	1～2	10%	3,171,206	0.32	23.3%	739,729	2,083,555,611,252
		more than 2	10%	798,597	0.32	23.3%	186,284	524,696,778,529
	Governmental	1～2	0%	0	0.32	23.3%	0	6,338,207,919
		more than 2	0%	0	0.32	23.3%	0	6,707,829,038
	Other	All	0%	0	0.32	23.3%	0	175,732,078,032
Unreinforced Masonry	Educational	1～2	0%	0	0.21	39.8%	0	41,343,781,365
		more than 2	0%	0	0.29	27.5%	0	18,590,200,622
	Health	1～2	0%	0	0.21	39.8%	0	6,084,898,437
		more than 2	0%	0	0.29	27.5%	0	1,332,247,786
	Residential	1～2	0%	0	0.21	39.8%	0	1,626,132,433,920
		more than 2	0%	0	0.29	27.5%	0	180,786,365,827
	Governmental	1～2	0%	0	0.21	39.8%	0	10,238,037,585
		more than 2	0%	0	0.29	27.5%	0	3,654,672,359
	Other	All	0%	0	0.21	39.8%	0	292,328,504,592
Semi-Enginerred Masonry	Educational	1～2	0%	0	0.25	32.5%	0	11,470,258,177
		more than 2	0%	0	0.25	32.5%	0	5,157,593,081
	Health	All	0%	0	0.25	32.5%	0	0
	Residential	All	0%	0	0.25	32.5%	0	0
	Governmental	All	0%	0	0.25	32.5%	0	0
	Other	All	0%	0	0.25	32.5%	0	0
Steel	Educational	1～3	0%	0	0.38	18.3%	0	48,574,272,985
		4～7	0%	0	0.38	18.3%	0	33,860,319,641
		more than 7	0%	0	0.38	18.3%	0	5,260,467,744
	Health	1～3	0%	0	0.38	18.3%	0	5,663,873,102
		4～7	0%	0	0.38	18.3%	0	4,124,599,106
		more than 7	0%	0	0.38	18.3%	0	2,306,767,932
	Residential	1～3	20%	11,546,593	0.32	23.9%	2,755,921	6,852,000,862,587
		4～7	20%	7,513,902	0.32	23.9%	1,793,405	4,458,913,928,619
		more than 7	0%	0	0.32	23.9%	0	152,483,585,166
	Governmental	1～3	0%	0	0.38	18.3%	0	25,273,441,207
		4～7	0%	0	0.38	18.3%	0	41,724,517,352
		more than 7	0%	0	0.38	18.3%	0	18,323,362,038
	Other	All	33%	4,141,688	0.38	18.3%	756,627	3,072,908,395,391
Adobe	All	All	33%	339,363	0.00	100.0%	339,363	678,754,919,420
Hangars and Canopies	All	All	33%	633,476	0.15	54.7%	346,391	923,424,945,251
Mix of 1~6	All	All	33%	2,847,369	0.15	54.7%	1,556,969	2,767,095,242,412
Others	All	All	33%	177,636	0.15	54.7%	97,133	172,628,384,445
Total				41,452,744			9,301,338	27,688,794,164,061

Source: JICA Study Team

Table 1.4.12 Floor area and damaged property of heavily damaged buildings (Reconstructed buildings)

Structure	Usage	Number of Story	Applied/Total	Floor area of applied buildings (m^2)	*GIs*	Damage Ratio P	Floor area of damaged buildings (m2)
Reinforced Concrete Structure	Educational	1〜3	0.900	429,083	1.00	2.3%	9,762
		4〜7	0.900	338,236	1.00	2.3%	7,695
		more than 7	0.900	1,634,456	1.00	2.3%	37,184
	Health	1〜3	0.900	46,208	1.00	2.3%	1,051
		4〜7	0.900	25,222	1.00	2.3%	574
		more than 7	0.900	0	1.00	2.3%	0
	Residential	1〜3	0.500	5,998,506	1.00	2.3%	136,467
		4〜7	0.500	7,536,139	1.00	2.3%	171,448
		more than 7	0.500	1,889,726	1.00	2.3%	42,992
	Governmental	1〜3	0.900	399,827	1.00	2.3%	9,096
		4〜7	0.900	349,056	1.00	2.3%	7,941
		more than 7	0.900	454,214	1.00	2.3%	10,333
	Other	All	0.333	1,175,092	1.00	2.3%	26,734
Weak Masonry (Brick or cement block or stone skeleton with middle steel columns) (Brick skeleton with middle steel or concrete columns with 3 stories and up)	Educational	1〜2	1.000	287,218	1.00	2.3%	6,534
		more than 2	1.000	158,255	1.00	2.3%	3,600
	Health	1〜2	1.000	35,806	1.00	2.3%	815
		more than 2	1.000	8,593	1.00	2.3%	195
	Residential	1〜2	0.900	28,540,856	1.00	2.3%	649,308
		more than 2	0.900	7,187,375	1.00	2.3%	163,514
	Governmental	1〜2	0.900	75,051	1.00	2.3%	1,707
		more than 2	0.900	79,428	1.00	2.3%	1,807
	Other	All	0.900	2,080,851	1.00	2.3%	47,340
Unreinforced Masonry	Educational	1〜2	1.000	1,211,532	1.00	2.3%	27,563
		more than 2	1.000	544,765	1.00	2.3%	12,393
	Health	1〜2	1.000	178,311	1.00	2.3%	4,057
		more than 2	1.000	39,040	1.00	2.3%	888
	Residential	1〜2	1.000	47,651,954	1.00	2.3%	1,084,088
		more than 2	1.000	5,297,738	1.00	2.3%	120,524
	Governmental	1〜2	1.000	300,014	1.00	2.3%	6,825
		more than 2	1.000	107,096	1.00	2.3%	2,436
	Other	All	1.000	8,566,353	1.00	2.3%	194,886
Semi-Enginerred Masonry	Educational	1〜2	0.900	121,153	1	2.3%	2,756
		more than 2	0.900	54,476	1.00	2.3%	1,239
	Health	All	0.000	0	1.00	2.3%	0
	Residential	All	0.000	0	1.00	2.3%	0
	Governmental	All	0.000	0	1.00	2.3%	0
	Other	All	0.000	0	1.00	2.3%	0
Steel	Educational	1〜3	1.000	1,186,178	1.00	2.3%	26,986
		4〜7	1.000	826,865	1.00	2.3%	18,811
		more than 7	1.000	115,614	1.00	2.3%	2,630
	Health	1〜3	1.000	124,480	1.00	2.3%	2,832
		4〜7	1.000	90,650	1.00	2.3%	2,062
		more than 7	1.000	46,089	1.00	2.3%	1,049
	Residential	1〜3	0.800	46,186,372	1.00	2.3%	1,050,746
		4〜7	0.800	30,055,609	1.00	2.3%	683,769
		more than 7	1.000	3,351,268	1.00	2.3%	76,242
	Governmental	1〜3	1.000	555,457	1.00	2.3%	12,637
		4〜7	1.000	917,017	1.00	2.3%	20,862
		more than 7	1.000	366,099	1.00	2.3%	8,329
	Other	All	0.333	4,141,688	1.00	2.3%	94,224
Adobe	All	All	0.333	339,363	1.00	2.3%	7,721
Hangars and Canopies	All	All	0.333	633,476	1.00	2.3%	14,412
Mix of 1~6	All	All	0.333	2,847,369	1.00	2.3%	64,778
Others	All	All	0.333	177,636	1.00	2.3%	4,041
Total				214,762,859			4,885,884

Source: JICA Study Team

Table 1.4.13 Floor area and damaged property of heavily damaged buildings (Total)

Structure	Usage	Number of Story	Floor area of not applied buildings (m^2)	Floor area of strengthened buildings (m^2)	Floor area of reconstructed buildings (m^2)	Total (m2)	Damaged Property (Rial)
Reinforced Concrete Structure	Educational	1～3	1,749	0	9,762	11,510	23,020,551,444
		4～7	2,315	0	7,695	10,010	20,019,254,074
		more than 7	6,661	0	37,184	43,845	96,458,427,771
	Health	1～3	188	0	1,051	1,240	3,098,843,316
		4～7	173	0	574	746	1,865,994,897
		more than 7	0	0	0	0	0
	Residential	1～3	85,815	218,314	136,467	440,595	881,189,880,827
		4～7	178,245	442,425	171,448	792,118	1,584,236,817,555
		more than 7	27,034	68,776	42,992	138,802	305,363,983,458
	Governmental	1～3	1,629	0	9,096	10,725	21,450,934,371
		4～7	2,389	0	7,941	10,330	20,659,647,755
		more than 7	1,851	0	10,333	12,184	26,805,710,512
	Other	All	188,484	0	26,734	215,218	430,435,755,467
Weak Masonry (Brick or cement block or stone skeleton with middle steel columns) (Brick skeleton with middle steel or concrete columns with 3 stories and up)	Educational	1～2	0	0	6,534	6,534	9,801,371,533
		more than 2	0	0	3,600	3,600	5,400,483,437
	Health	1～2	0	0	815	815	1,221,886,891
		more than 2	0	0	195	195	293,237,839
	Residential	1～2	0	739,729	649,308	1,389,037	2,083,555,611,252
		more than 2	0	186,284	163,514	349,798	524,696,778,529
	Governmental	1～2	2,518	0	1,707	4,225	6,338,207,919
		more than 2	2,665	0	1,807	4,472	6,707,829,038
	Other	All	69,815	0	47,340	117,155	175,732,078,032
Unreinforced Masonry	Educational	1～2	0	0	27,563	27,563	41,343,781,365
		more than 2	0	0	12,393	12,393	18,590,200,622
	Health	1～2	0	0	4,057	4,057	6,084,898,437
		more than 2	0	0	888	888	1,332,247,786
	Residential	1～2	0	0	1,084,088	1,084,088	1,626,132,433,920
		more than 2	0	0	120,524	120,524	180,786,365,827
	Governmental	1～2	0	0	6,825	6,825	10,238,037,585
		more than 2	0	0	2,436	2,436	3,654,672,359
	Other	All	0	0	194,886	194,886	292,328,504,592
Semi-Enginerred Masonry	Educational	1～2	2,979	0	2,756	5,735	11,470,258,177
		more than 2	1,339	0	1,239	2,579	5,157,593,081
	Health	All	0	0	0	0	0
	Residential	All	0	0	0	0	0
	Governmental	All	0	0	0	0	0
	Other	All	0	0	0	0	0
Steel	Educational	1～3	0	0	26,986	26,986	48,574,272,985
		4～7	0	0	18,811	18,811	33,860,319,641
		more than 7	0	0	2,630	2,630	5,260,467,744
	Health	1～3	0	0	2,832	2,832	5,663,873,102
		4～7	0	0	2,062	2,062	4,124,599,106
		more than 7	0	0	1,049	1,049	2,306,767,932
	Residential	1～3	0	2,755,921	1,050,746	3,806,667	6,852,000,862,587
		4～7	0	1,793,405	683,769	2,477,174	4,458,913,928,619
		more than 7	0	0	76,242	76,242	152,483,585,166
	Governmental	1～3	0	0	12,637	12,637	25,273,441,207
		4～7	0	0	20,862	20,862	41,724,517,352
		more than 7	0	0	8,329	8,329	18,323,362,038
	Other	All	856,320	756,627	94,224	1,707,171	3,072,908,395,391
Adobe	All	All	331,671	339,363	7,721	678,755	678,754,919,420
Hangars and Canopies	All	All	254,814	346,391	14,412	615,617	923,424,945,251
Mix of 1~6	All	All	1,145,348	1,556,969	64,778	2,767,095	2,767,095,242,412
Others	All	All	71,454	97,133	4,041	172,628	172,628,384,445
Total			3,235,456	9,301,338	4,885,884	17,422,677	27,688,794,164,061

Source: JICA Study Team

Table 1.4.14 Cost required for counter measure

Structure	Usage	Number of Story	Cost for strengthening (Rial)	Cost for reconstruction (Rial)	Total (Rial)
Reinforced Concrete Structure	Educational	1～3	0	1,029,799,440,000	1,029,799,440,000
		4～7	0	811,766,880,000	811,766,880,000
		more than 7	0	4,314,963,312,000	4,314,963,312,000
	Health	1～3	0	138,623,400,000	138,623,400,000
		4～7	0	75,664,800,000	75,664,800,000
		more than 7	0	0	0
	Residential	1～3	719,820,720,000	14,396,414,400,000	15,116,235,120,000
		4～7	904,336,680,000	18,086,733,600,000	18,991,070,280,000
		more than 7	251,963,400,000	4,988,875,320,000	5,240,838,720,000
	Governmental	1～3	0	959,584,320,000	959,584,320,000
		4～7	0	837,734,400,000	837,734,400,000
		more than 7	0	1,199,124,432,000	1,199,124,432,000
	Other	All	0	2,820,221,600,000	2,820,221,600,000
Weak Masonry (Brick or cement block or stone skeleton with middle steel columns) (Brick skeleton with middle steel or concrete columns with 3 stories and up)	Educational	1～2	0	620,390,880,000	620,390,880,000
		more than 2	0	341,830,800,000	341,830,800,000
	Health	1～2	0	85,934,400,000	85,934,400,000
		more than 2	0	20,623,200,000	20,623,200,000
	Residential	1～2	570,817,116,000	61,648,248,528,000	62,219,065,644,000
		more than 2	143,747,496,000	15,524,729,568,000	15,668,477,064,000
	Governmental	1～2	0	162,110,160,000	162,110,160,000
		more than 2	0	171,563,832,000	171,563,832,000
	Other	All	0	4,494,638,808,000	4,494,638,808,000
Unreinforced Masonry	Educational	1～2	0	2,616,909,768,000	2,616,909,768,000
		more than 2	0	1,176,691,536,000	1,176,691,536,000
	Health	1～2	0	427,946,400,000	427,946,400,000
		more than 2	0	93,696,000,000	93,696,000,000
	Residential	1～2	0	102,928,220,640,000	102,928,220,640,000
		more than 2	0	11,443,114,080,000	11,443,114,080,000
	Governmental	1～2	0	648,030,240,000	648,030,240,000
		more than 2	0	231,327,360,000	231,327,360,000
	Other	All	0	18,503,322,480,000	18,503,322,480,000
Semi-Enginerred Masonry	Educational	1～2	0	261,690,976,800	261,690,976,800
		more than 2	0	117,669,153,600	117,669,153,600
	Health	All	0	0	0
	Residential	All	0	0	0
	Governmental	All	0	0	0
	Other	All	0	0	0
Steel	Educational	1～3	0	2,562,144,480,000	2,562,144,480,000
		4～7	0	1,786,028,400,000	1,786,028,400,000
		more than 7	0	277,473,600,000	277,473,600,000
	Health	1～3	0	298,752,000,000	298,752,000,000
		4～7	0	217,560,000,000	217,560,000,000
		more than 7	0	121,674,960,000	121,674,960,000
	Residential	1～3	15,010,570,900,000	99,762,563,520,000	114,773,134,420,000
		4～7	9,768,072,860,000	64,920,115,008,000	74,688,187,868,000
		more than 7	0	8,043,043,200,000	8,043,043,200,000
	Governmental	1～3	0	1,333,096,800,000	1,333,096,800,000
		4～7	0	2,200,840,800,000	2,200,840,800,000
		more than 7	0	966,501,360,000	966,501,360,000
	Other	All	5,384,194,400,000	8,946,046,080,000	14,330,240,480,000
Adobe	All	All	0	678,726,666,667	678,726,666,667
Hangars and Canopies	All	All	114,025,620,000	1,266,951,333,333	1,380,976,953,333
Mix of 1~6	All	All	512,526,360,000	5,694,737,333,333	6,207,263,693,333
Others	All	All	31,974,540,000	355,272,666,667	387,247,206,667
Total			33,412,050,092,000	470,609,722,922,400	504,021,773,014,400

Source: JICA Study Team

Table 1.4.15 Unit cost of strengthening

Structure	Usage	Number of Story	Unit Cost (106Rial/m2)	comment	
Reinforced Concrete Structure	Educational	1～3	0.18	refer to Steel Shear Walls	
		4～7	0.18		
		more than 7	0.18		
	Health	1～3	0.20		Careful treatment is needed for hospital
		4～7	0.20		
		more than 7	0.20		
	Residential	1～3	0.18		
		4～7	0.18		
		more than 7	0.20		1.1 times of ordinary cost for high-rise and midle-rise buildings
	Governmental	1～3	0.18		
		4～7	0.18		
		more than 7	0.20		1.1 times of ordinary cost for high-rise and midle-rise buildings
	Other	All	0.18		
Weak Masonry (Brick or cement block or stone skeleton with middle steel columns) (Brick skeleton with middle steel or concrete columns with 3 stories and up)	Educational	1～2	0.18	refer to Steel Shear Walls	
		more than 2	0.18		
	Health	1～2	0.20		Careful treatment is needed for hospital
		more than 2	0.20		
	Residential	1～2	0.18		
		more than 2	0.18		
	Governmental	1～2	0.18		
		more than 2	0.18		
	Other	All	0.18		
Unreinforced Masonry	Educational	1～2	0.15	refer to Concrete Shear Wall	
		more than 2	0.15		
	Health	1～2	0.17		Careful treatment is needed for hospital
		more than 2	0.17		
	Residential	1～2	0.15		
		more than 2	0.15		
	Governmental	1～2	0.15		
		more than 2	0.15		
	Other	All	0.15		
Semi-Enginerred Masonry	Educational	1～2	0.18	refer to Concrete Shear Wall	
		more than 2	0.18		
	Health	All	0.00		data not available
	Residential	All	0.00		
	Governmental	All	0.00		
	Other	All	0.00		
Steel	Educational	1～3	1.30	refer to Steel Bracing	
		4～7	1.30		
		more than 7	1.40		
	Health	1～3	1.50		Careful treatment is needed for hospital
		4～7	1.50		
		more than 7	1.60		1.1 times of ordinary cost for high-rise and midle-rise buildings
	Residential	1～3	1.30		
		4～7	1.30		
		more than 7	1.40		1.1 times of ordinary cost for high-rise and midle-rise buildings
	Governmental	1～3	1.30		
		4～7	1.30		
		more than 7	1.40		1.1 times of ordinary cost for high-rise and midle-rise buildings
	Other	All	1.30		
Adobe	All	All	0.00	impossible	
Hangars and Canopies	All	All	0.18		
Mix of 1~6	All	All	0.18		
Others	All	All	0.18		

Source: JICA Study Team

Table 1.4.16 Unit cost of reconstruction

Structure	Usage	Number of Story	Unit Cost (106Rial/m2)	comment	
Reinforced Concrete Structure	Educational	1～3	2.40	1.2 times of brand new construction considering demolishing	
		4～7	2.40		
		more than 7	2.64		
	Health	1～3	3.00		
		4～7	3.00		
		more than 7	3.30		
	Residential	1～3	2.40		
		4～7	2.40		
		more than 7	2.64		1.1 times of ordinary cost for high-rise and midle-rise buildings
	Governmental	1～3	2.40		
		4～7	2.40		
		more than 7	2.64		1.1 times of ordinary cost for high-rise and midle-rise buildings
	Other	All	2.40		
Weak Masonry (Brick or cement block or stone skeleton with middle steel columns) (Brick skeleton with middle steel or concrete columns with 3 stories and up)	Educational	1～2	2.16	Construct new steel frame	
		more than 2	2.16		
	Health	1～2	2.40		Careful treatment is needed for hospital
		more than 2	2.40		
	Residential	1～2	2.16		
		more than 2	2.16		
	Governmental	1～2	2.16		
		more than 2	2.16		
	Other	All	2.16		
Unreinforced Masonry	Educational	1～2	2.16		
		more than 2	2.16		
	Health	1～2	2.40		Careful treatment is needed for hospital
		more than 2	2.40		
	Residential	1～2	2.16		
		more than 2	2.16		
	Governmental	1～2	2.16		
		more than 2	2.16		
	Other	All	2.16		
Semi-Enginerred Masonry	Educational	1～2	2.16		
		more than 2	2.16		
	Health	All	0.00		data not available
	Residential	All	0.00		
	Governmental	All	0.00		
	Other	All	0.00		
Steel	Educational	1～3	2.16	1.2 times of brand new construction considering demolishing	
		4～7	2.16		
		more than 7	2.40		
	Health	1～3	2.40		Careful treatment is needed for hospital
		4～7	2.40		
		more than 7	2.64		1.1 times of ordinary cost for high-rise and midle-rise buildings
	Residential	1～3	2.16		
		4～7	2.16		
		more than 7	2.40		1.1 times of ordinary cost for high-rise and midle-rise buildings
	Governmental	1～3	2.40		
		4～7	2.40		
		more than 7	2.64		1.1 times of ordinary cost for high-rise and midle-rise buildings
	Other	All	2.16		
Adobe	All	All	2.00	Construct new steel frame	
Hangars and Canopies	All	All	2.00		
Mix of 1~6	All	All	2.00		
Others	All	All	2.00		

Source: JICA Study Team

1.4.4 Remaining Issues and Their Solution

Following points remained in this study;

- There are some high quality buildings with high holding capacity in Tehran, which are office buildings and hotel, but they were not identified in this study, because the database based on tax book does not offer that kind of information. These buildings might have relatively high capacity of earthquake resistance. (We heard that some of them were already strengthened)
- There can be some quite low quality shop buildings. These buildings might cause afflictive disaster.
- Graded effect of earthquake motion based on scenario earthquake is not identified in this study, because the database based on tax book does not offer sufficient information about detail location.

There must be more effective information for earthquake disaster mitigation if more appropriate database is formulated

1.5 Countermeasure for Earthquake Resistance

1.5.1 Strengthening, Reconstruction and Redevelopment

There are tree types of earthquake-proof methods, i.e., strengthening existing building／demolish and reconstruction／redevelop city block.

Many buildings in study area do not have sufficient GI_S value. For this case demolition and reconstruction is ideal if absolute solution is needed, but strengthening existing structure can be another effective solution. For the selection whether strengthening or reconstruction is reasonable GI_S value can offer effective information, but findings obtained during GI_S calculation also offer effective information. Some weak points of structure and critical condition might be found in the process of building diagnosis.

For instance there can be buildings, which have relatively high capacity of transient direction, but do not have insufficient capacity of longitudinal direction. This is an example.

It goes without saying that strengthening is the lowest-cost measure, but this measure has practical limitation that GI_S value is not necessarily increased to the level of 1.0 by strengthening. However strengthening can be effective even in these cases. If some increasing can be obtained, probability of collapse is decreased certainly.

Additional mass caused by strengthening may increase inertia force of that story consequentially. Decreasing of lower story's resistance surely result if any kind of structure added. Therefore it must be avoided to pursue the level of GI_S =1.0 unnecessarily. Reasonable target is to decrease probability of collapse as much as possible.

If the best countermeasure is needed, demolition and reconstruction is a solution. Building type should be RC or Steel frame.

Strengthening single building is not effective in the city block which is composed of buildings without any void in adjacent building, because inertia force of adjacent un-reinforced building may be transferred and push down that building. In this kind of case demolishing the block and reconstruction of collective building can be a reasonable solution.

The cases of close-packed block or block with narrow road have origin own problem of disaster prevention, so switch to redevelopment should be discussed as a reasonable solution.

1.5.2 Strengthening of Masonry Building

1) General issue

The most critical problem of strengthening masonry buildings is that any engineering drawing cannot be obtained in major case, especially that any counter measure can not be discussed when the information of the foundation is not offered.

Most of masonry buildings does not have possibility to be strengthened to the level of GI_S =1.0. The building, which possesses historical meaning or nonmaterial meaning, are worth much to be strengthened if large expenses is needed, but innovative engineering should be needed like as “seismic isolation” in order to decrease inertia force itself.

It is impossible to pursue the level of GI_S =1.0 for masonry building, because owners of masonry building in Tehran do not have that kind of economic serviceability

As a result, following target should be recommended;

- Decrease probability of pancake-crash of the buildings possessed by low-income people and facilities, which is important for disaster prevention activity (like as school and hospital) as much as possible.
- If the pancake-crash is prevented that facility can offer effective help for citizens.

There are some commonly observed features in masonry structure, but a certain level of knowledge and experiences are needed to identify weak points of an individual building. Well-educated engineer should diagnose each building, because there cannot be an all-around solution.

Some kind of handbook or manual concerning building strengthening is distributed in Tehran, but some contents of them are copy from foreign example or simple scheme. It is important to discuss application for an individual building in Tehran and systematize the procedure.

2) Construction method

Following methods are recommended for masonry building;

- Installing additional wall for a area which need shear capacity
- Installing additional steel frame or steel frame + brace for a area which need shear capacity
- Reduce excessively large openings
- Reinforce the part of wall in surroundings in opening
- Reinforce the part of wall by FRP
- Reduce upper part of story if the building height of story is more than 2
- Reinforce floor by "steel mesh+ mortar" or "steel tie" if the floor stiffness is not sufficient
- Fix Joist-end and beam-end by steel bolt
- Increase stiffness of foundation and capacity of foundation

Main purposes of above counter measures are making up for capacity of most weak member. It must be understood that good sense of proportion may be lost if excessive member is added.

1.5.3 Strengthening of RC Building

1) General issue

Regarding RC buildings many examples of excessively thin members and defect of reinforcing bar can be seen, but there are some carefully designed buildings on the other hand. It is thought that these aspects may be caused by non-fulfillment of design specification. So the most important checkpoint is justifying whether the building design applies to the specification or not. Followings must be checked;

- Big turning point is whether the engineering drawings of building design are found or not. If engineering drawings is not found, there may be large possibility of non-fulfillment of design specification.
- It is possible to justify when attention should be paid at the construction age. There can be turning period concerning constitution of specification. (i.e. 1970's) It is thought that the buildings, which are built before that period, were designed without any consideration of mathematical way.
- It is useful to compare section area of vertical members to mass of upper part. GI_S system can offer help for this estimation.
- If engineering drawing can be found detail of reinforcing bar should be checked. Checking points are whether lap length of axial direction bar is sufficient or not, and whether shape of bar-end is appropriate or not.

- It should be checked whether the column-beam connections have sufficient capacity to give the structure sufficient ductility or not. Brittle failure may occur when the column-beam connections do not have sufficient capacity, or when sufficient confinement by hoop bar of column is expected.

2) Construction method

Effective information about selection in which strengthening can be carried out or not. That is;

- If the engineering drawings cannot be found and serious error of design is found, that building should be demolished and reconstructed.
- If some defect is found by checking the engineering drawings, section of the member should be increased or reinforcing bar should be added.
- If some defect of shear reinforcing or confinement of member is found by checking the engineering drawings, additional reinforcing should be done. Applying steel plate or FRP reinforcing can be effective measure.
- If sufficient reinforcing can not be obtained by above measure, installing “shear wall”, “Steel Frame” or “Steel Frame + Brace” should be discussed in order to
- Decrease story drift.

Following methods are recommended for reinforcing;

- Steel plate jacketing of column
- Steel plate jacketing of beam
- FRP reinforcing of column
- FRP reinforcing of beam
- Increasing column section
- Adding stirrup
- Install RC shear wall
- Install steel shear wall
- Install Steel Frame + Brace
- Reinforcing column by adding wing wall

1.5.4 Strengthening of Steel Building

1) General issue

Many of steel Frame structures in Tehran are quite different from that of Japan except a few examples. The typical example can be seen in Khorjini connection shown in Figure 1.5.1.

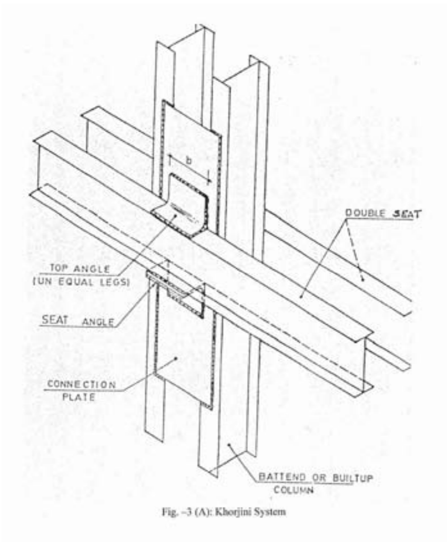


Figure 1.5.1 Khorjini System

As shown in Figure 1.5.1, all of bonding part are welded by fillet welding (not groove welding) that is done on site. This aspect is common to almost all steel buildings. Quality of welding is not necessarily good except a few good examples. Good examples are found in some office buildings and high-class residential buildings. In the worst case, beam is put on the bracket, which is welded at column simply, there can be found no welding between column and beam. In almost all case, bending capacity and shear capacity of column-beam connection is less than base metal because length of welding is not sufficient.

At design calculation these connection is assumed as hinge (not Moment Frame). Consequently horizontal resistance of the building is offered by bracing, but situation of bracing as built is not sufficient. In the worst case, there can not be found any bracing for a direction, and this situation were found in some examples of building investigation of this study. In another case, some bracing were designed at drawing step, but there are not in truth. In another case, brace was cut in middlength in order to make opening like window or door.

Cross-section of members is composed of combination of cast steel (H section or I section) by splicing steel plate. Splice plates are welded at discrete part, so cross section feature is changed on each changing part. Therefore number of section modulus type extends across enormous variation. This may cause some error on analysis and construction. As a matter of fact, there are some examples in which there is no sufficient splice plate at necessary part.

As mentioned above, there are many possibilities of defect in steel buildings. If building diagnosis is carried out, many points, which should be collected, may be found. There can be some possibilities of improvement. However effect of improvement cannot be expected when original member is accessibly poor.

Analysis of steel frame needs relatively high engineering approach and skill, so building investigation by well organized engineers is needed.

2) Construction method

Following methods are recommended for steel frame building;

- Reinforcing column-beam connection by adding splice plate and welding
- Reinforcing brace end
- Setting additional panels of bracing
- Setting additional column on the purpose of increasing stiffness
- Adding splice plate and welding
- Adding rib and stiffener
- Adding T section splice
- Concrete injection to section column

1.5.5 Examples from Japanese Manual

A Japanese manual for building strengthening shows a menu of strengthening method as Table 1.5.1. Some method in this table can be applied to the buildings in Tehran but some method needs relatively expensive cost. Careful discussion must be undertaken. However, if those methods are familiarized in Iran, cost may become reasonable by mass production effect.

Table 1.5.1 Strengthening Method

Parts of Strengthening		Strengthening Method
Strengthening of *RC* Structure	Wall Strengthening	Adding shear walls
		Expanding shear walls
		Adding wing walls
		Installing steel shear walls
	Brace Installation	Installing brace (with the shape of X type, K type, etc.)
	Column Strengthening and Confinement	Increase dimension of the existing column
		Additional rebars (to increase axial/shear reinforcement)
		Steel Plate Jacketing
		Fiber Jacketing
	Beam Strengthening	Increase dimension of the existing beam
		Additional rebars to increase shear reinforcement
		Steel Plate Jacketing
		Fiber Jacketing
Strengthening of Steel Structure		Increase dimension of the existing members (columns and beams)
		Strengthening column-beam joint (and panel zone)
		Strengthening anchor of column
		Strengthening brace-frame connection
		Installing additional stiffener/bulkhead/rib (to prevent local failure)
		Installing/strengthening of brace
Masonry		Installing steel frame
		Installing steel frame + brace
		Installing RC tie and column
		Strengthening by fiber reinforced plastic
		Adding shear walls
		Reducing mass of floor
		Strengthening/extension foundation
Strengthening of Both of Above Structure		Installing seismic isolation device
		Installing seismic response control device (Bracing, wall or dumper)

Source: JICA Study Team

Appendix 1-1

Method of Earthquake Resistance Diagnosis

1.1 Preface

In the Sector Report, the method of earthquake resistant diagnosis is explained in accordance with calculation procedure. This appendix explains principles for analysis in earthquake resistant diagnosis. The sectional sequence is the order of fundamental equations and relevant variables, which means that it does not follow the actual procedure of earthquake resistant diagnosis. The theory introduced here, based on "Specification on Earthquake Resistance Diagnosis and Strengthening for Governmental Buildings (Building Maintenance and Management Center of Japan)", published in 1996, is structured with reference to earthquake resistant code of Iran such as Standard #2800. It is expected that further revises be made with best efforts for improvement in rational and effective aspects.

1.2 Seismic Index of Structure GI_S

To express seismic resistance quantitatively, *seismic index of structure* GI_S is shown in Eq.(1.1). This index shows how many times of capacity is equivalent to existing building capacity when the building capacity is compared with the required capacity.

$$GI_S = \frac{Q_u}{\alpha \cdot Q_{un}} \tag{1.1}$$

Where,

GI_S :Seismic Index of Structure

Q_u :Seismic force level for ultimate ductility check

Q_{un} :Required seismic force level for ultimate ductility check

α :Correction coefficient

A logical contexture of this Appendix 1 is as follows. As a basic standpoint of the diagnosis, a set up of the size of targeted earthquake motion is described in the section 1.3, "Required Seismic Force Level for Ultimate Capacity Check, Q_{un}". Sequentially, the section 1.4, "Seismic Force Level for Capacity Check Q_u" describes an assessment of capacity of buildings itself. For an explanation of the remaining component of the above Eq.(1.1), the section 1.5, "Correction Coefficient α" describes a correction coefficient as criteria for designing policy, judgment for construction and deterioration through aging.

It is noted that another type of diagnosis system "FEMA 310" developed in United States also offers numerical evaluation for elastic region. However, it offers digital judgment of concordance or discordance for nonlinear region. On the other hand, the theory introduced in the Study offers numerical evaluation for nonlinear region. This is an advantage of GI_S system in applying to earthquake resistant diagnosis.

1.3 Required Seismic Force Level for Ultimate Capacity Check, Q_{un}

This section describes a required capacity of the structure, which corresponds the denominator of Eq.(1.1).

1.3.1 Basic Formula

As shown in Eq.(1.1), seismic resistance of building is expressed as a ratio of building capacity and required building capacity. Required Building Capacity is calculated as the product of *required seismic force level for ultimate ductility check* Q_{un}, given by Eq. (1.2).

$$Q_{un} = D_s \cdot F_{es} \cdot G \cdot Q_{ud} \tag{1.2}$$

Where,

Q_{un} :Required seismic force level for ultimate capacity check
D_S :Seismic load reduction factor
F_{es} :Index of irregularity in plan
G :Modification factor (considering the gain of the earthquake motion)
Q_{ud} :Total equivalent seismic load (base shear force)

1.3.2 Total Equivalent Seismic Load Q_{ud} (Base Shear Force)

In this Study, the intensity of earthquake motion is set applying the Iranian earthquake resistant code "Standard#2800", and the total Equivalent Seismic Load Q_{ud} is given by Eq. (1.3)～(1.7).

When T<0.7 (s) ;

$$Q_{ud} = V \frac{\sum_{j=i}^{n} W_j h_j}{\sum_{j=1}^{n} W_j h_j} \tag{1.3}$$

When T>0.7 (s) ;

for each story except top

$$Q_{ud} = (V - F_t) \frac{\sum_{j=i}^{n} W_j h_j}{\sum_{j=1}^{n} W_j h_j} \tag{1.4}$$

for top story

$$Q_{ud} = (V - F_t)\frac{\sum_{j=i}^{n} W_j h_j}{\sum_{j=1}^{n} W_j h_j} + F_t \qquad (1.5)$$

$$F_t = 0.07TV \qquad (1.6)$$

$$V = A \cdot B \cdot I \cdot W \qquad (1.7)$$

Where;

- Q_{ud} :Total Equivalent Seismic Load (shear force)
- V :Base shear force (total seismic lateral force)
- W_i :Floor i Weight consisting of floor weight and its live load and half of wall and column weights which are located above and under of that floor.
- h_i :The height of level i (height of ceiling at level i) from ground level.
- F_t :Additional Lateral Force at the level of the nth story that is determined by means of the equation (3.5). Maximum force of Ft is considered 0.25V
- T :Natural period of the structure (s)
- i :Number of stories of building from basic level to up
- n :Total number of stories
- A :Design base acceleration
- B :Response coefficient of the building obtained from the design response spectrum
- I :Importance factor
- W :Total weight of the building (total dead load and weight of fixed installations) plus some of the live load

Table A. 1. 1 Design Base Acceleration

Region	Description	Base Acceleration *A*
1	Very high seismic relative hazard	0.35
2	High seismic relative hazard	0.30
3	Intermediate seismic relative hazard	0.25
4	Low seismic relative hazard	0.20

Source: Iranian Code of Practice for Seismic Resistant Design of Buildings, Standard No. 2800 2nd Edition, 1999

The *response coefficient of the building obtained from the design response spectrum* B is given by Eq. (1.8). but $B \leqq 2.5$

$$B = 2.5\left(\frac{T_0}{T}\right)^{2/3} \qquad (1.8)$$

Where;

T : Fundamental natural period

T_0 : Figure according to soil classification

Table A. 1. 2 Figures According to the Soil Classification

Soil classification	T_0
Ⅰ	0.4
Ⅱ	0.5
Ⅲ	0.7
Ⅳ	1.0

Source: Iranian Code of Practice for Seismic Resistant Design of Buildings, Standard No. 2800 2nd Edition, 1999

Table A. 1. 3 Importance Factor I

Category	Required state of the building	I
Ⅰ The most important disaster-prevention facility	The building must be available for service even after earthquake without restoring Life safe The entire function of the building must be	1.5
Ⅱ The disaster-prevention facility	The building must be available for service even after earthquake without large restoring Life safe The function of the building must be hold	1.3
Ⅲ State department buildings	Some partial damage can be allowed, but load capacity of the building must be hold almost perfectly even after earthquake Life safe	1.0

Source: Iranian Code of Practice for Seismic Resistant Design of Buildings, Standard No. 2800 2nd Edition, 1999

1.3.3 Seismic Load Reduction Factor *Ds*

1) Principle

The method of earthquake resistant diagnosis takes advantage of response spectrum stipulated in Standard#2800 for seismic motion conditions. This response spectrum is defined on the presumption of elasticity; therefore, if a building has meaningful ductility effect, some kind of conversion is necessary. For this conversion, seismic load reduction factor, *Ds* is defined.[1]

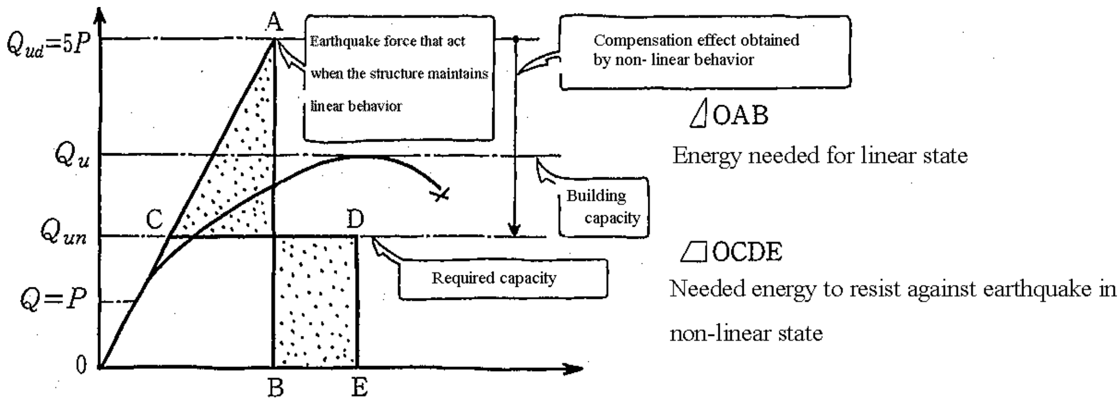
In case that a building concerned signifies significant ductility effect, it is necessary to analyze nonlinear characteristics in the region beyond the yield point of a element of framework, and in strict sense, it is ideal that the analysis is conducted by nonlinear time history response analysis. However, considering labor required for practical design, it is not realistic to take advantage of

[1] If objective structure does not have any sufficient ductility on a view point of structure engineering that kind of structure should be classified "brittle". The *seismic reduction factor Ds* should be 1.0 in that case. Also, *seismic reduction factor Ds* is defined for every different value for each different story of a building.

nonlinear time history response analysis. Therefore, some kind of a simplified method is required and generally, equal-energy principle or equivalent-linear method is applied for this analysis.

In case of near field earthquake adopted as scenario earthquake in this project, equal-energy principle should be applied because an envelope curve of seismic motion obviously shows principal motion. Therefore, this concept is precisely described as follows.

Figure A. 1. 1 represents the concept of equal-energy principle. Considering that elastic response is shown by point A and deformation capacity by point E, reduced effect is obtained as Q_{un} shown in the vertical axis. The area OCDE is equivalent to absorption energy with consideration of plasticity, and the area OAB is to input energy on the presumption of perfect elasticity. Assuming that these areas are equal, reaction force at the yield point, Q_{un}, that is required for elements of framework is obtained.



Source: Yukio Maeda (1999) Handbook of Building Design

Figure A. 1. 1 Concept of Equal-Energy Principle

In the regulation for earthquake resistance of Iran, Behavior Coefficient of the Building *R* is stipulated with the same objective. However, *R* stipulated there serves as a denominator, and on the other hand, *Ds* stipulated in Japan does as a numerator. Therefore, their relation is represented by the equation '$Ds \fallingdotseq 1/R$'.

However, a fundamental difference exists in the relation between *Ds* in Japanese design criteria and standard #2800. *Ds* in Japanese design criteria is derived only from consideration of the effect of ductility. The value of *R* stipulated in standard #2800 additionally takes into account other engineering judgments, and consequently its value is considered to be determined in an optimistic way. That is, the value of *R* is considered not to appropriately reflect only the effect of ductility. Considering the above-mentioned matters, it is recommended that *Ds* stipulated in Japanese design criteria should be applied.

In the above, in order to analyze nonlinear particularities, it is ideal to take advantage of time history response analysis in strict sense, and equal-energy principle can be applied as an simplified method. However, it is necessary to make an application of Incremental Loading Method in order to strictly apply equal-energy principle. The main frame of this analysis is in common with pushover analysis developed in United States. However, it is not realistic to apply Incremental Loading Method to earthquake resistant diagnosis of all buildings because of the much amount of required labor. Therefore, an easier method shown as follows is prepared with consideration of practical use of “Specification on Earthquake Resistant Diagnosis for Governmental Buildings and Strengthening’.

2) Seismic Reduction Factor *Ds* for Steel Frame Structure

The *seismic reduction factor Ds* for steel frame structure is given by Table A. 1. 4.[2]

Table A. 1. 4 Seismic Reduction Factor Ds (for Steel Frame Structure)

Bracing \ Type of	BA or βu=0	BB			BC		
		βu≦0.3	0.3＜βu≦0.7	βu＞0.7	βu≦0.3	0.3＜βu≦0.5	βu＞0.5
FA	0.25	0.25	0.30	0.35	0.30	0.35	0.40
FB	0.30	0.30	0.30	0.35	0.30	0.35	0.40
FC	0.35	0.35	0.35	0.40	0.35	0.40	0.45
Other than the above-mentioned FD	0.40	0.40	0.40	0.50	0.40	0.45	0.50

Source: Building Code amendment by Ministry of Land, Infrastructure and Transport of Japan, 1982

Definition of “FA”, “FB” and “FC” are described in Table A. 1. 5.

[2] This table gives value of *seismic reduction factor Ds* for steel frame structure in every different case (i.e. situation of beam, situation of column and value of *βu* are defined in the following formula). $\beta_u = \frac{\text{Total shear story force capacity that is depending on braces of considering story}}{\text{Total shear story force capacity of considering story}}$

Coefficient *βu* represents a degree of dependence on force capacity of brace. The value of *Ds* is small when the value of *βu* is large, because brace does not offer ductility.
If a specially designed brace such as “unbonded brace” is used, it is considered as an exception.

Table A. 1. 5 Type of Frame (for Steel Frame Structure)

Type of Frame				FA	FB	FC	FD
Member	Type of Cross section	Site	Type of Steel	Width/Thickness	Width/Thickness	Width/Thickness	
Column	H Section	Flange	Class 400	9.5	12.0	15.5	Other than right record
			Class 490	8.0	10.0	13.2	
		Web	Class 400	43.0	45.0	48.0	
			Class 490	37.0	39.0	41.0	
	Square Steel Tubes	-	Class 400	33.0	37.0	48.0	
			Class 490	27.0	32.0	41.0	
	Circular Cross Section	-	Class 400	50.0	70.0	100.0	
			Class 490	36.0	50.0	73.0	
Beam	H Section	Flange	Class 400	9.0	11.0	15.5	
			Class 490	7.5	9.5	13.2	
		Web	Class 400	60.0	65.0	71.0	
			Class 490	51.0	55.0	61.0	

* Class 400 : SS400, SM400, SMA400, SN400B, SN400C, STK400, STKR400
* Class 490 : SM490, SMA490, SM490Y, SN490B, SN490C, STK490, STKR490

Source: Building Code amendment by Ministry of Land, Infrastructure and Transport of Japan, 1982

The followings describe an example for the case of “FD”.

- End connection of bracing has less strength compared with base material of bracing.
- Column-Beam connection has less strength compared with base material of column and beam.
- Beam is not stiffened considering effective prevention of local failure such as “lateral buckling” or “local shear failure”.

Regarding above defined “Material Class” (i.e.Class 400 and Class 490), the numbers are equal to the breaking point in N/mm^2.

The type of brace is defined in Table A. 1. 6.

Table A. 1. 6 Type of Brace (for Steel Frame Structure)[3]

BA	BB		BC
$\lambda_e \leqq \frac{50}{\sqrt{F}}$	$\frac{50}{\sqrt{F}} < \lambda_e \leqq \frac{90}{\sqrt{F}}$	$\lambda_e \geqq \frac{200}{\sqrt{F}}$	$\frac{90}{\sqrt{F}} < \lambda_e < \frac{200}{\sqrt{F}}$

Source: Building Code amendment by Ministry of Land, Infrastructure and Transport of Japan, 1982

[3] The numbers in Table A.1.4, A.1.5 and A.1.6 were obtained through the analysis of relationship between structural characteristics and the value of *Ds* with trial and error from a numbers of case studies, in producing Japanese. In case that those numbers does not reflect Iranian special condition, it is recommended that a simplified method to define the value of *Ds* shall be devised, considering the Iranian special condition.
It should be noted that there are some problems to be solved before considering the value of. Many of steel frame structure in Tehran have such an insufficient cohesion at column-beam connection part that the structure itself does not function as a moment resisting frame. In addition, not a small numbers of buildings in Tehran are a steel frame structure without bracing. In those cases, the structure does not resist seismic lateral inertia force, hence it is judged as nonqualified building before conducting frame analysis. Even for the case of buildings with bracing, it is useless to consider the *seismic reduction factor Ds*, if the cohesion of column-beam connection part is insufficient.
Nonetheless, a steel frame with bolted connections, which is found in Tehran, is a good construction example. For this case, shop welding and friction grip connection with high strength bolts are applied for all the connection parts, considering that a field welding does not give enough strength. The *seismic reduction factor Ds* can be applied to such a structure. It is recommended that such a good example shall be distinguished with the mentioned structure with insufficient connection part.

Where ,

F :Strength of base metal (N/mm^2) $F =_{\min} \left(\sigma_{\mathrm{y}},\ 0.7\sigma_{\mathrm{b}}\right)$

σ_y :Yield strength(N/mm^2)

σ_b :Maximum tensile strength (N/mm^2)

λ_{e} :Effective slenderness ratio of bracing

$$\lambda_e = \frac{L_X}{i} \tag{1.9}$$

Where ;

L_X :Buckling length

i :Radius of gyration of area

3) Seismic Reduction Factor *Ds* for RC Frame Structure

The *seismic reduction factor Ds* for RC frame structure is set as follows;

- 0.75 for RC structure
- 0.7 for RC structure reinforced with steel

4) Seismic Reduction Factor *Ds* for Masonry

The *seismic reduction factor Ds* for masonry structure is set as 0.75.

1.3.4 Index of Irregularity in Plan F_{es}

Index of Irregularity in Plan F_{es}, which is defined for each story of the building independently, is consisted of the following two coefficients:

- The "factor depend on eccentricity of rigidity, F_s ", in which vertical distribution of story rigidity is reflected.
- The "factor depend on torsional eccentricity, F_e ", in which horizontal distribution of rigidity is reflected.

The Index of Irregularity in Plan, F_{es} is given by Eq. (1.10).

$$F_{es} = F_e \cdot F_{\mathrm{s}} \tag{1.10}$$

where ;

F_{es} :Index of irregularity in plan

F_e :Factor depending on torsional eccentricity

F_s :Factor depending on eccentricity of rigidity

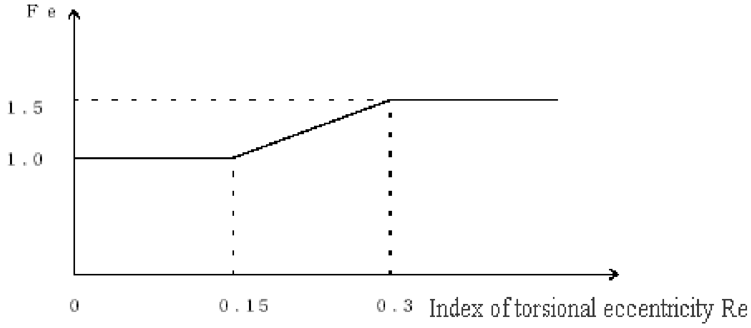


Figure A. 1. 2 Index of Irregularity in Plan F_{es}

$$R_{ex} = \frac{e_y}{r_{ex}} \qquad R_{ey} = \frac{e_x}{r_{ey}} \tag{1.11}$$

Where ;

R_{ex}, R_{ey} :Index of torsional eccentricity

e_x, e_y :Throw of an eccentric (Distance between center of rigidity and center of gravity)

r_{ex}, r_{ey} :Elasticity radius

$$r_{ex} = \sqrt{\frac{J_{xy}}{D_x}} \qquad r_{ey} = \sqrt{\frac{J_{xy}}{D_y}} \tag{1.12}$$

Where ;

J_{xy} :Torsional rigidity

D_x, D_y :Rigidity of the story

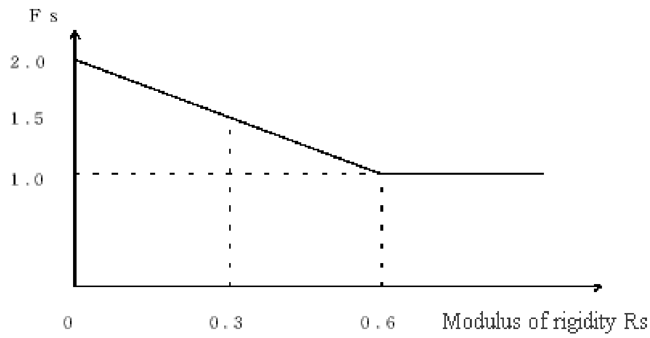


Figure A. 1. 3 Factor Depending on Modulus of Rigidity F_s

$$R_S = \frac{r_S}{\overline{r_S}} \tag{1.13}$$

where ;

R_S :Modulus of rigidity of the story

r_S :Inverse number of story drift ratio $r_S = \dfrac{\delta}{H}$

$\overline{r_S}$:Average of r_S

1.3.5 Modification Factor G

A coefficient, *modification factor* G, reflects "local site effect" and "effect of input loss of seismic motion", considering "ground configuration" and "basement floor availability".

$$G = G_1 \cdot G_2 \cdot G_3 \tag{1.14}$$

where,

G :Modification factor (considering the gain of the earthquake motion)

G_1 :Factor of irregularity in ground configuration

G_2 :Factor with or without basement

G_3 :Factor of interruption between structure and ground

Table A. 1. 7 Factor of Irregularity in Ground Configuration G_1 [4]

Configuration of Ground	Drop-off *	Tilted Support Stratum	Local Hill	Others
G1	1.1	1.1	1.1	1.0

*Drop-off ; The ground tilting more than 30 degree

Source: Building Code amendment by Ministry of Land, Infrastructure and Transport of Japan, 1982

[4] The Factor of Irregularity in Ground Configuration G_1 is to reflect the influence of the ground motion acceleration, commonly known as "local site effect". An abnormal amplification can be absorbed at the top of slope for the case of jutting ground sphere. In general, it is set as 1.1 for the uniform ground condition due to the difficulty in evaluating this effect numerically. For the case of Tehran where locates on the hill side of the mountains, a careful attention should be paid for the application of G_1.

Table A. 1. 8 Factor with or without basement G_2 [5]

Factor \ Area Ratio	A1/A0＜0.75	A1/A0≧0.75
G2	1.0	0.9

Source: Building Code amendment by Ministry of Land, Infrastructure and Transport of Japan, 1982

Where,

A_1 :Floor area of basement

A_0 :Building area

The *Factor of Interruption Between Structure and Ground* G_3 was prepared to take "radiation damping" and "damping due to energy dissipation around foundation" into account. However, the value of G_3 = 1.0 should be applied until concrete knowledge is obtained in near future.[6]

Those dynamic interruptions of ground and building as mentioned above have possibilities of causing both energy dissipation and amplification impacts on seismic motion, which makes the application of G_3 ongoing discussion in Japan. Nonetheless, the Eq. (1.14) has a coefficient G_3 so as to keep the theoretical background.

1.4 Seismic Force Level for Capacity Check Q_u

1.4.1 Introduction

In this section, existing capacity of the structure, which corresponds to the numerator of Eq. (1.1), is described. The *seismic force level for capacity check*, Q_u represents the building capacity. This value is calculated for each story and for each direction. The smallest value represents the evaluation for corresponding building. There are two methods to analyze building capacity; a detailed analysis such as Incremental Loading Method and a simplified analysis.

The detailed analysis is an incremental loading method, considering a plasticity of the frame elements. This method obtains the relationship between base shear force and displacement of each story of building. The *seismic load reduction factor* D_S explained in the section 1.3 can be determined by the use of equal-energy principle or equivalent linear method.

[5] The Factor With or Without Basement G_2 is to reflect the reduction effect of seismic motion due to the existence of underground structure. It is commonly known that the effect of seismic motion is reduced for the case of building with underground RC frame structure that has enough volume and perfect rigidity as a rectangular parallelepiped. However, most buildings in Tehran seldom have RC frame underground structure with perfect rigidity, since the ground in Tehran is relatively solid. In such a case, the ground was simply excavated for the underground structure, which does not have enough rigidity. In addition, a special attention should be paid for the case of buildings on the relatively steep slope, which have one floor gap at the inclined ground surface. In this case, the existence of underground structure would cause a negative effect on its seismic resistance.

[6] Those dynamic interruptions of ground and building as mentioned above have possibilities of causing both energy dissipation and amplification impacts on seismic motion, which makes the application of G_3 ongoing discussion in Japan. Nonetheless, the Eq. (3.14) has a coefficient G_3 so as to keep the theoretical background.

It is, however, unrealistic to obligate the application of incremental loading method to all the structural design. The simplified analysis is to utilize the figures set in the section 1.3.3, and it requires only the maximum value of base shear force so as to obtain the value of Q_u.

The ideal method to obtain the maximum base shear force is frame analysis. However, the simplified analysis can substitute, in case the buildings in targeted area have similar structural characteristics. In the Study, the below modification was adopted, considering Iranian circumstances of building structure.

- As to steel frame structure, frame analysis that is recommended in Japanese GI_S system is proposed.
- As to RC frame structure, the theories of simplified analysis applied in Japan are proposed, since there is little difference in structural characteristics of RC buildings between Japan and Iran. However, it is noted that some modification coefficient as to construction quality shall be carefully applied to.
- Although a discrete element method is an ideal analysis for masonry structure, it is not a recommendable to obligate the application of discrete element method from the view point of cost-benefit performance, since it takes much time and effort to analyze. In the Study, a simplified method is applied to masonry buildings with reference to Uniform Building Codes developed in United States.

1.4.2 Q_u for Steel Structure

1) Concept

The value of Q_u represents the base shear force at each floor when the whole structure reaches to collapse mechanism. Therefore, the analysis is based on the frame model of the structure.

The lords for the frame model are dead load, live load considered in the event of earthquake as defined in standard#2800 and lateral seismic force. Standard#2800 defines lateral force by Eq. (1.15) ~ (1.18). Those equations set the base shear force V obtained by the single degree of freedom model and its distribution at each floor of the structure in frame model. Figure A. 1. 4 shows a schematic drawing of the distribution of the lateral force at each floor in the frame model.

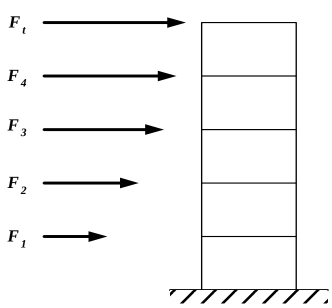


Figure A. 1. 4 Distribution of Lateral Force at Each Level

$$F_i = V \frac{W_i h_i}{\sum_{j=1}^{n} W_j h_j} \tag{1.15}$$

When T>0.7 (s) ;

The Equation below applies to every story except the top level;

$$F_i = (V - F_t) \frac{W_i h_i}{\sum_{j=1}^{n} W_j h_j} \tag{1.16}$$

For the top level, the equation below applies;

$$F_i = (V - F_t) \frac{W_i h_i}{\sum_{j=1}^{n} W_j h_j} + F_t \tag{1.17}$$

$$F_t = 0.07TV \tag{1.18}$$

Where;

F_i	:Lateral force at level i
V	:Base shear force (total seismic lateral force)
W_i	:Weight of floor i consisting of floor weight, its live load, and half of wall and column weights which are located above and under of that floor.
h_i	:The height of level i (height of ceiling in level i) from ground level.
F_t	:Additional Lateral Force at the level of the nth story that is determined by means of the Equation (1.18) Maximum force of Ft is considered 0.25V
T	:Natural period of the structure (s)
i	:Number of stories of building from basic level to up
n	:Total number of stories

The lateral seismic force is proportional to base shear force V, as indicated in the above formulation.

The statement of collapse mechanism is to represent a condition to reach an unstable condition of building by plastic behavior of frame. This mechanism can be categorized into two types judged by the ductile ability of the building as explained below.

(1) Force capacity type

Some low quality steel frame buildings have an imperfect column-beam connection due to poor welding or fillet welding, which are considered as hinge connection in the frame analysis. When all the column-beam connections are imperfect and bracing does not exist, the building is judged to have no seismic resistance.

However, even all the column-beam connections are imperfect, the building with bracing, which welding part is reliable, it is judged to have seismic resistance by force capacity. In this case, the vale of Q_u is obtained by frame analysis, assuming its elasticity. The vale of Q_u is a base shear force when the structure reaches to collapse mechanism caused by buckling of bracing, compression fracture of column elements, shear fracture of beam elements etc. The value of V, when the stress of elements reaches to collapse mechanism, is obtained by inverse operation, since the lateral seismic force is proportional to base shear force V as mentioned above. The value of Q_u is obtained when this V value is applied to. In this type, *seismic load reduction factor* D_S equals to 1.0, since the whole structure does not have ductility.

(2) Ductility type

When the building have perfect column-beam connection with enough strength to be over yield strength of die steel composing columns or beams, the structure does not reach to collapse mechanism immediately after some part of structural elements turns to be plastic or collapsed. In this case, the building is judged to have ductility.

For this type, the analysis starts from the frame analysis with its elasticity assumption in order to select the elements that are judged to be brittle failure and connection parts that are judged to be plastic. In the next step of analysis, the selected elements that are judged to be brittle failure are eliminated and plastic connection parts are assumed to be plastic hinge. The base shear force obtained by this Elastic-Plastic Analysis, explained later, tends to be over the value of the base shear force obtained by frame analysis with its elasticity assumption. The value of Q_u is a maximum value of the base shear force obtained by the above procedure.

It is, however, noted that when the story drift ratio exceeds the allowable value, the horizontal load value Q of this step is defined as the *seismic force level for ultimate capacity check* Q_u, even if sufficient number of plastic hinges does not appear. The allowable value of the story drift ratio is usually set at δ/H=1/200.

When the column-beam connection encounters shear or local failure, the analysis model must be changed at that calculation step. Usually the hinge does not transfer bending moment set at that part. This is not a plastic hinge. The situation described in this context is called the brittle failure.

Seismic load reduction factor D_S are obtained from the values explained in the section 1.3.3.

The actual procedure of Elastic-Plastic Analysis is described below.

The elimination of elements that are judged to be brittle failure is applied to the elements that do not endure vertical load. Those elements are eliminated in Elastic-Plastic Analysis, since the collapse of those elements does not lead the building collapse.

The assumption of plastic connection parts to be plastic hinge is to assume those connection parts do not transfer bending moment as it is a plastic hinge. Then, in Elastic-Plastic Analysis, bending moment at the yielding point is given as an external force to the end of hinge, as shown in Figure A. 1. 5. Therefore, the value of Q_u is given with keeping pseudo elastic assumption in the frame analysis.

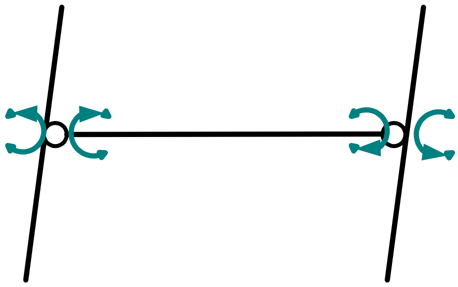


Figure A. 1. 5 Modeling of Plastic Hinge

Through the above procedure, a few trial times of Elastic-Plastic Analysis gives the value of Q_u , if appropriate selections of elements to be brittle failure and connection parts to be plastic hinges are made.

2) Plastic Hinge and Its Reaction Moment

The judgment of connection part to be plastic hinge is explained in this section. Plastic hinge shall be set among the beam end or column end depending on the weaker point considering the viewpoint of the entire plastic moment capacity. However, in case of welded connection, the moment capacity is limited to the total strength of welded part. In many cases of fillet welded connection, the total strength of welded part is less than the base metal section. Therefore, following calculation is needed to judge whether the structure has sufficient ductility or not:

- When the bending moment capacity of the column-beam welded point is larger than the bending moment capacity of the base- beam, the connection can be determined to have ductility.
- Otherwise, the column-beam connection is determined not to have ductility. (it shall be treated as a brittle connection in the calculation of Q_u)

(1) The bending moment capacity of base -metal

The bending moment capacity of the base- beam is given by Eq. (1.19).

$$M_p = FZ_p \tag{1.19}$$

where;

M_p :Bending moment capacity of the base- beam

F :Strength of base metal $F =_{\min} (\sigma_y,\ 0.7\sigma_b)$

σ_y :Yield strength

σ_b :Maximum tensile strength

Z_p :Plastic section modulus (geometrical moment of area)

Z_p can be given when the section of the base- beam is given by Figure A. 1. 6.

$$Z_{px} = \left(A_f + \frac{1}{4} A_w \right)(H - t_f) \tag{1.20}$$

$$Z_{py} = \frac{1}{2} A_f B + \frac{1}{4} A_w t_w \tag{1.21}$$

$$A_f = Bt_f \tag{1.22}$$

$$A_w = (H - 2t_f)t_w \tag{1.23}$$

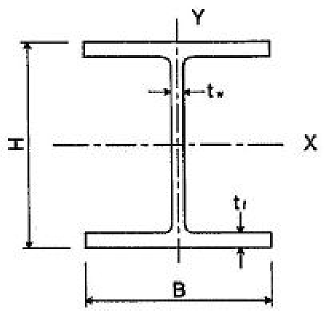


Figure A. 1. 6 Section of the Base- Beam

(2) The bending moment capacity of the column-beam welded point

The bending moment capacity of the column-beam welded point is given by following equations.

$$M_{pw} = P_w H_w \tag{1.24}$$

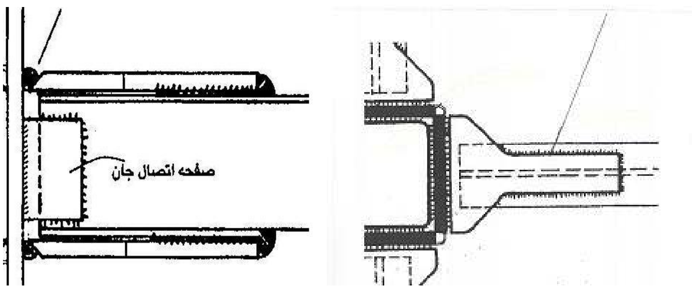
$$P_w = \min\left(P_{wp}, Q_{ws}\right) \tag{1.25}$$

Where;

M_{pw}	:Bending moment capacity of the “column-beam” welded point
P_w	:Tensile capacity at edge
P_{wp}	:Tensile strength of the “column - beam” welded point
Q_{ws}	:Shear strength of the “splice plate- beam” welded point
H_w	:Distance between the welded points of the top and bottom flange

Welded points to be considered in judging the bending moment capacity are shown in Figure A. 1. 7.

Column-Beam Welded Point   Splice Plate-Beam Welded Point



a. Sıde view   b. plan

Source: Iranian Code of Practice for Seismic Resistant Design of Buildings No. 2800, 2nd edition

Figure A. 1. 7 Welded Point

A. In the case of fillet welding

a. Tensile Strength P_{wp} at the Column-Beam Welded Point

$$P_{wp} = A_W F_W \tag{1.26}$$

$$A_w = \sum a l_e \tag{1.27}$$

Where;

P_{wp}	:Tensile strength of the "column - beam" welded point
A_w	:Cross-sectional area of fillet weld
F_W	:Strength of welding materials
σ_y	:Yield strength
σ_b	:Maximum tensile strength
a	:Throat of fillet weld
l_e	:Length of fillet weld

b. Shear Strength Q_{we} at the Column-Beam Welded Point

$$Q_{ws} = 2 \times \frac{s}{\sqrt{2}} \cdot l \cdot {}_w f_s \quad (1.28)$$

Where;

Q_{ws}	:Shear strength of welded part
s	:Leg of weld
l	:Length of weld (all of periphery)
${}_w f_s$	:Shear strength of weld metal

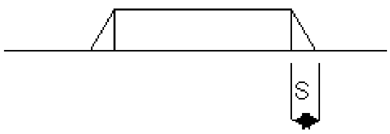


Figure A. 1. 8 Leg of Weld

B. In the case of groove welding

When the cross-sectional area of the splice plate is effectively large and it is groove welded, the "column – beam connection" can be considered sufficient. It is, however, noted that the connecting panel of the column must be stiffened by the diaphragm or stiffener to form panel zone.

1.4.3 Q_u for RC Structure

The *seismic force level for ultimate capacity check* Q_u for RC frame structure is given by Eq. (1.29)～(1.31).

$$Q_u = \max(Q_{u1}, Q_{u2}) \cdot \frac{Fc}{F_{Co}} \quad (1.29)$$

$$Q_{u1} = \tau_W \cdot A_{w1} + \tau_C \cdot (A_c + A_{w2}) \quad (1.30)$$

$$Q_{u2} = \tau_{\mathrm{E}} \cdot A_{w1} + \tau_{\mathrm{E}} \cdot A_c \tag{1.31}$$

Where;

Q_u :Seismic force level for ultimate ductility check

A_{w1} :Cross section area of shear wall, which is effective for considering direction

Corresponding wall to the under mentioned condition shall be taken as a shear wall.

- Wing wall with width wider than 45cm and wider than 30% of the opening
- Ratio of "total round of the opening / total round of the wall" is larger than 0.4

The value of A_{w1} should be multiplied by $\cos^2\theta$ when the angle that wall cross considering direction at θ.

A_{w2} :Cross section area of other wall which is effective for considering direction

Corresponding wall to the under mentioned condition shall be taken as other wall.

- Infill wall that does not meet the condition of A_{w1}
- Over sailing wall that is connected to the beam or floor

  (thickness > 10cm, width > 100cm)

A_c :Cross section area of column that is effective for resisting horizontal force

τ_w :Standard value of shear wall capacity (= 25 kgf/cm^2 = 2.5 MPa)

τ_C :Standard value of column capacity (= 7 kgf/cm^2 = 0.7 MPa)

τ_E :Equalize value of wall capacity including column capacity (= 13.5 kgf/cm^2 = 1.35 MPa)

F_c :Compressive strength of concrete

F_{c0} :Benchmark value of compressive strength of concrete (= 200 kgf/cm^2 = 20 MPa)

1.4.4 Q_u for Masonry Structure

1) Basic Formula

Basically, the seismic force level for ultimate capacity check, Q_u for masonry structure is given by Eq. (1.32).

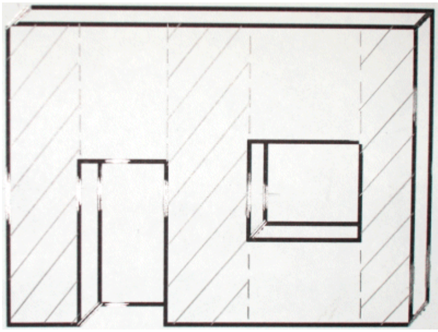
$$Q_u = \tau_{wm} \cdot A_{wm} \tag{1.32}$$

Where;

τ_{wm} :Standard value of masonry wall capacity

A_{wm} :Cross section area of brick wall which is effective for considering direction

The brick wall effective for shear force is parallel to the considering direction of Q_u , and its cross section area is the part without windows nor openings, shown as a hatched part in Figure A. 1. 9.



Source: JICA Study Team

Figure A. 1. 9 Effective Part of Brick Wall

The standard value of masonry wall capacity τ_{wm} is given by allowable shearing stress of the grout material vt and applied compression due to gravity load σ_c, as shown in Eq. 4.19.

$$\tau_{wm} = 0.1v_t + 0.15\sigma_c \quad (1.33)$$

Where;

τ_{wm} :Standard value of masonry wall capacity
v_t :Allowable shearing stress of the grout material
σ_c :Applied compression due to gravity load

The standard value of masonry wall capacity τ_{wm} is given by the Allowable shearing stress of the grout material v_t and applied compression due to gravity load σ_c, as shown in Eq. 4.19.

Allowable shearing stress of the grout material v_t is a lower shearing stress value of materials such as brick or cement block, or grout material to attach the interspaces of those materials. In case if the standard value of masonry wall capacity τ_{wm} can be judged only by the compression stress of a piece of brick and grout material, the Eq. (1.34) is applied.

$$v_t = m \cdot v_t' \quad (1.34)$$

Where;

v_t :Allowable shearing stress of the grout material
v_t' :Compression stress of brick
m :Coefficient shown in Table A.1.9.

Table A. 1. 9 The value of *m* in case *h/d* ≤ 10

Brick Min Strength kg/cm^2	~ 10		10-15		15-25	
Grout Type	B	S-C	B	S-C	B	S-C
m	0.09	0.12	0.08	0.06	0.063	0.088

* *h/d* = Ratio of Wall Height to thickness
B = Bastard (Cement + Lime + Sand)
S-C = Sand - Cement

Clay + Lime grout that is commonly used in old URM buildings in Iran does not have structural strength and thus buildings of this type cannot be considered as earthquake resistant.

Source: Iranian Code Practice for Seismic Resistant Design of Building Standard No.2800, 2nd Edition

Where;

h :Height of wall
d : :Thickness of wall

In case $h/d \leq 10$, the allowable shearing stress of the grout material v_t is decreased according to the value of h/d and Table A. 1. 10.

Table A. 1. 10 The value of v_t' to be decreased in case of *h/d* ＞10

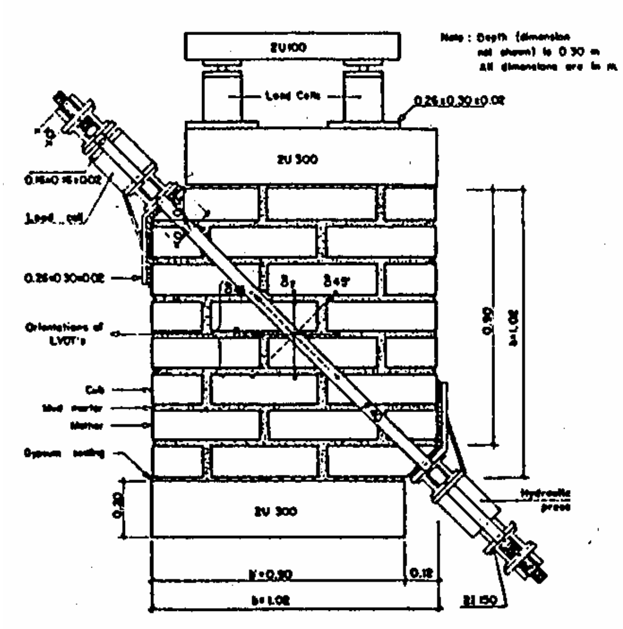
h/d \ v_t	5	6	7	8	9	10	12	16	22
10	5	6	7	8	9	10	12	16	22
12	3	4	5	6	6	7	8	11	15
14	−	3	3	4	4	5	6	8	10
16	−	−	−	3	3	3	4	6	7
18	−	−	−	−	−	−	3	4	7
20	−	−	−	−	−	−	−	−	3

Source: Iranian Code Practice for Seismic Resistant Design of Building Standard No.2800, 2nd Edition

If the value of v_t is over 6/kg/cm^2 through above procedure, it is set as v_t = 6/kg/cm^2.

2) Loading Test

In case the value of τ_{wm} is obtained by the field test by extracting a part of masonry wall of the targeted building, a careful attention should be made in order not to be overestimated. The selection of the part of masonry wall and distribution of measured values should be appropriate. The schematic drawing of loading test is shown in Figure A. 1. 10.



Source: Strength of Earthen Wall Subassemblies: An Experimental and Analytical Study

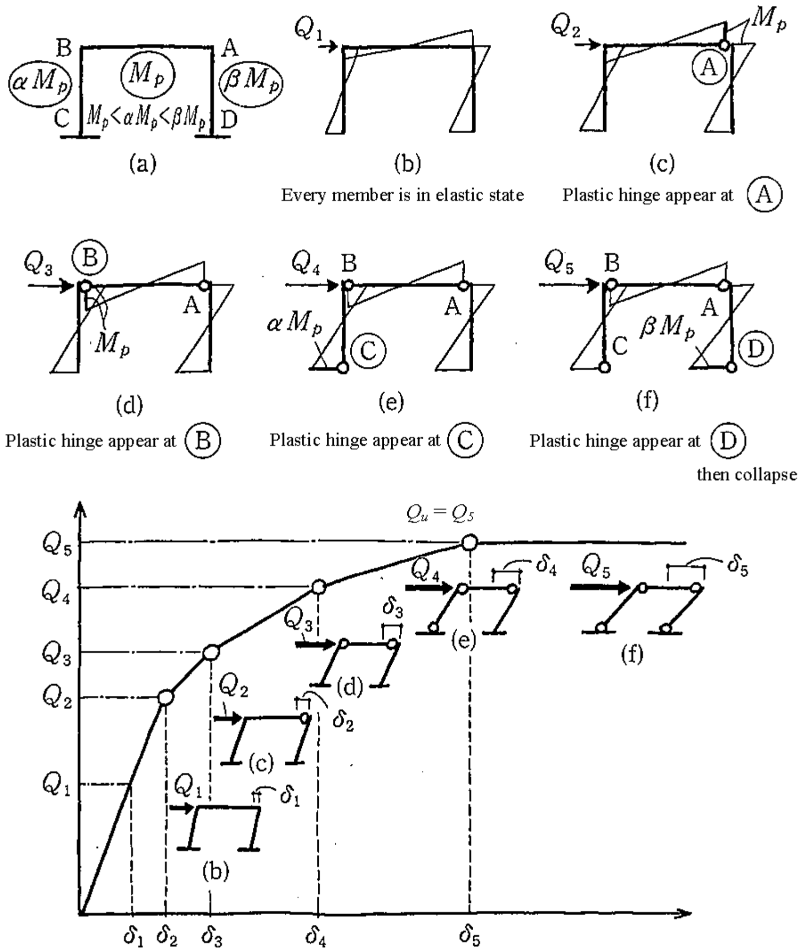
Figure A. 1. 10 Schematic Drawing of Loading Test

1.4.5 Epexegesis for Incremental Loading Method

The value of Q_u is a maximum value of base shear force of the considering floor. Therefore, a simple linear analysis of frame model can give the seismic force level for ultimate capacity check Q_u. In Iran, computer aid software such as "SAP" or "ESTABS" developed in United States, which can conduct frame analysis, are commonly used. The value of Q_u can be obtained by application of above explained procedure. In the Study, a basic explanation for frame analysis is not given, since enough information is given in text books of structural mechanics or manuals attached to computer aid software.

The most buildings in Tehran are vulnerable as its seismic resistance depends on force capacity by bracing, etc. It is often the case that this kind of structure reaches to collapse mechanism originating from the fracture of a part of structural elements. However, it is considered that an improvement of welding workability at column-beam connection part would prevent from local brittle failure, hence collapse mechanism. This is an advantage of capacity design. Suggestive examples are described below.

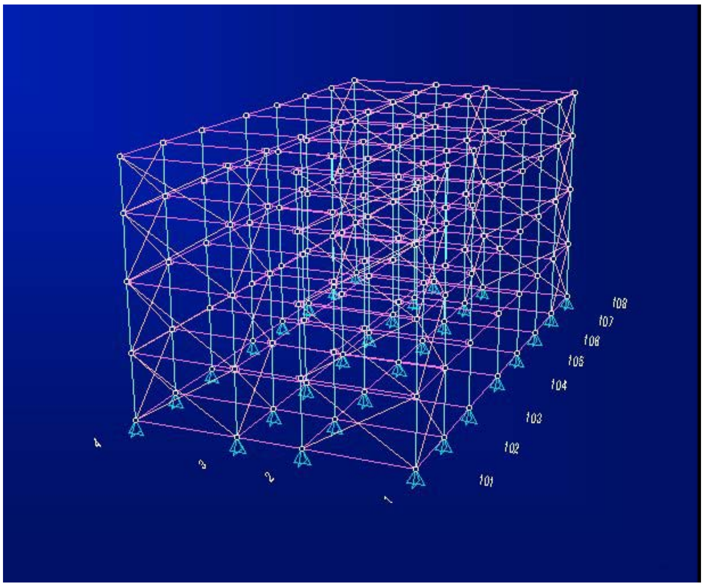
As to the structure of ductility type mentioned in the section 1.4.1, the relationship between base shear force Q_u and deformation obtained by incremental loading method with gradually increasing seismic lateral force is shown in Figure A. 1. 11.



Source: Yukio Maeda, Handbook for Building Design, 1999

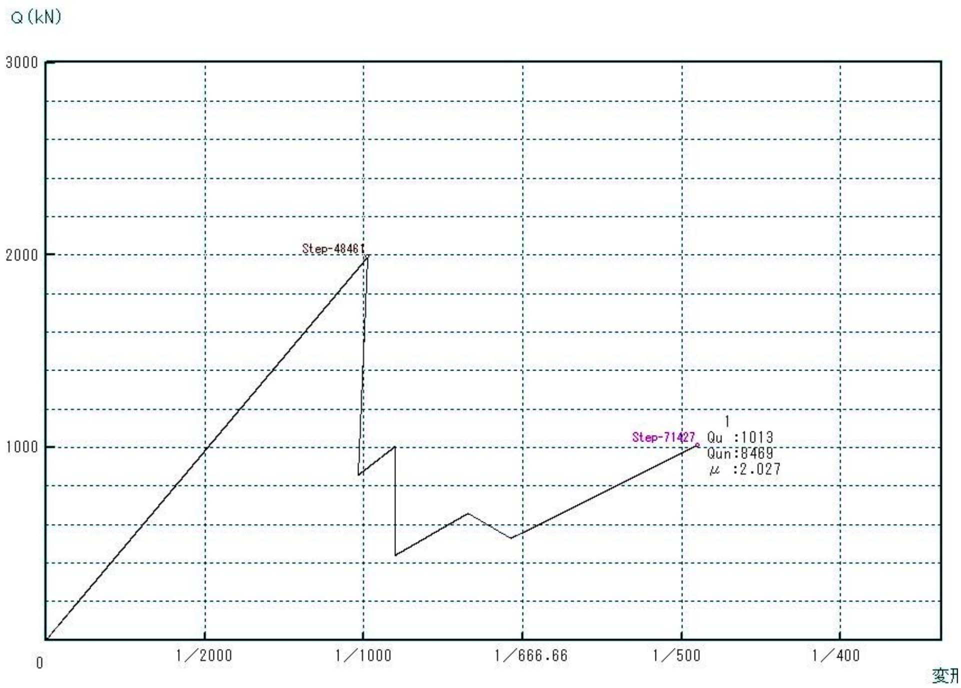
Figure A. 1. 11 Relationship Between Base Shear Force Q_u and Deformation of Ductility Type Structure

A modeling sample of existing building in Tehran is shown in Figure A. 1. 12. As a result, a relationship between base shear force and story drift ratio as shown in Figure A. 1. 13 is obtained.



Source: JICA Study Team

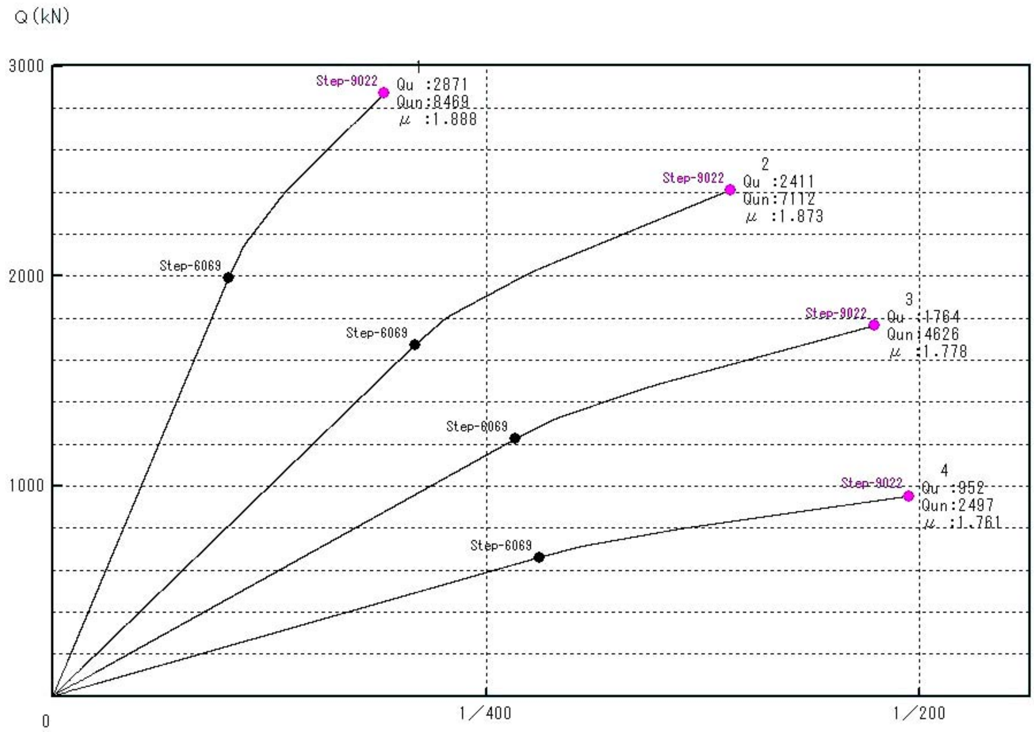
Figure A. 1. 12　Modeling Sample of Existing Building in Tehran



Source: JICA Study Team

Figure A. 1. 13　Relationship Between Base Shear Force and Story Drift Ratio

The building reaches to the collapse mechanism by a steep decrease of lateral reaction force due to the buckling failure of column. The value of Q_u is obtained at the point just before the buckling. Assuming that the buckling would not happen because of enough cross section area of column, a relationship between lateral reaction force and story drift ratio is obtained as shown in Figure A. 1. 14.



Source: JICA Study Team

Figure A. 1. 14 Relationship Between Base Shear Force and Story Drift Ratio (In Case the Column Has Enough Cross Section Area)

From above figure, it is recognized that base shear force of the building with enough cross section area is increased compared to the value in Figure A. 1. 13.

The collapse mechanism in this analysis is determined to be the condition that the building is unstable due to the story drift ratios of 4th story over 1/200. The setting of 1/200 for story drift ratio is not always a threshold for building stability. However, this is the threshold for the analysis as this story drift ratio would cause falling off of exterior materials. Those explanation indicates the advantage of ductility type structure, which has a possibility to increase base shear force even after the occurrence of yield failure.

For the case of incremental loading method with gradually increasing seismic lateral force, the displacements at the yielding point of elements, δ_y,, and the displacements at the yielding point of collapse mechanism of structure, δ_u is obtained. The *seismic load reduction factor* D_S can be obtained from the ductility ratio, $\mu = (\delta_u - \delta_y)/\ \delta_y$.. Then an energy-equal principle by a bi-linear Elastic-Plastic Model gives the relationship between D_S and μ , as shown in Eq. (1.35).

$$D_S = \frac{1}{\sqrt{2\mu - 1}} \tag{1.35}$$

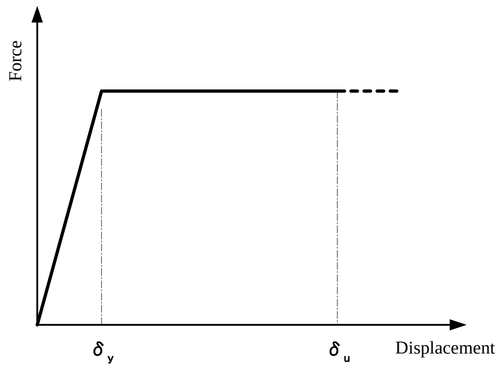


Figure A. 1. 15 A Bi-linear Perfect Elastic-Plastic Model

1.5 Correction Coefficient α

1.5.1 Basic formula

The *correction coefficient*, α is given by Eq. (1.36).

$$\alpha = \frac{\alpha_d}{U} \tag{1.36}$$

Where ;

α :Correction coefficient
α_d :Index of design policy (This index represents effect of redundancy)
U :Deterioration Index (This index is given by the inspection of as build)

Ductility index α_d achieves evaluation of structure ductility.

Aged Deterioration Index U achieves evaluation that shall be obtained from the field survey (i.e. Aging effect and Finishing quality).

1.5.2 Index of design policy α_d

This is an index which reflects ductility of the structure. When the structure is ductile the value of α_d shall be small, then the *seismic index of structure*, GI_S appearing in Eq. (1.1) become large as a result.

1) Index of design policy α_d for Steel structure

The *Ductility Index* α_d for steel structure is given by Table A. 1. 11

Table A. 1. 11 Ductility Index (Steel Frame)

Case in which the capacity design is followed	Case in which the capacity design is not followed
1.0	1.5

Source: Specification on Earthquake Resistance Diagnosis and Strengthening for Governmental Buildings

In the above table the capacity design is composed of following two requirements:

- Column-beam connection: Connected part has larger force capacity than base metal.
- Preventing local failure: Every part of structure is reinforced by rib, stiffener or diaphragm.

2) Index of design policy α_d for RC structure

The *ductility index* α_d for RC structure is given by Table A. 1. 12.

Table A. 1. 12 Ductility Index α_d (RC Frame)

Type of wall / Type of Frame	Policy for RC structure is satisfied		Policy for RC structure is not satisfied	
	$\beta_U \leqq 0.3$	$0.3 < \beta_U$	$\beta_U \leqq 0.7$	$0.7 < \beta_U$
FA, FB	1	1	1.2	1.2
FC	1.2	1	1.6	1.2
FD	1.6	1.2	1.6	1.2

Source: Building Code maendment by Ministry of Land, Infrastructure and Transport of Japan, 1982

Where;

$$\beta_U \ : \ \frac{\text{Horizontal force capacity due to shear wall}}{\text{Entire horizontal force capacity}} \qquad (1.37)$$

It is noted that the most of low and middle rise buildings in Tehran do not have effective shear wall. Therefore, the value of β_U regarding these buildings could be zero.

The type of frame is given in Table A. 1. 13.

Table A. 1. 13　　Type of Frame

Class of Column and Beam		FA	FB	FC	FD
Common term		Shear capacity is larger than Bending capacity			Except FA, FB, FC
Column	h_0／D	$h_{0/}D \geqq 2.5$	$h_0/D \geqq 2$	-	
	σ_o／Fc	$\sigma_o/F_c \leqq 0.35$	$\sigma_o/F_c \leqq 0.45$	$\sigma_o/F_c \leqq 0.55$	
	P_t	$P_t \leqq 0.008$	$P_t \leqq 0.01$	-	
	$\tau_{u/}F_c$	$\tau_u/F_c \leqq 0.1$	$\tau_u/F_c \leqq 0.125$	$\tau_u/F_c \leqq 0.15$	
Beam	τ_u/F_c	$\tau_u/F_c \leqq 0.15$	$\tau_u/F_c \leqq 0.2$	-	

Source: Building code announcement by Ministry of Land, Infrastructure and Transport of Japan, 1982

Where;

h_0　　:Height of column

D　　:Width of column

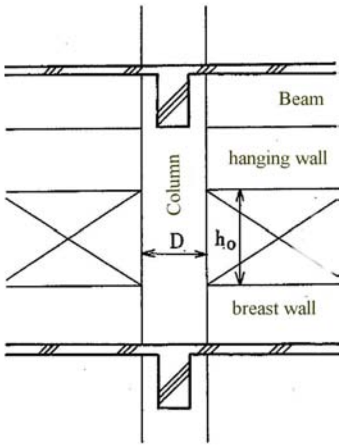


Figure A. 1. 16　　Inner Dimension *h_o*

When the thickness of the hanging wall or the breast wall is made of brick or thinner than 15 cm, this wall must be neglected.

σ_0　　:Axial stress of column in the most severe case

F_C　　:Strength of concrete

P_t　　:Cross sectional area of reinforcing bar / cross sectional area of the element

τ_u　　:Average shear stress of the element in the most severe case

3)　Index of design policy α_d for Masonry structure

The ductility index   for masonry structure is given by Eq. (1.38).

$$\alpha_d = \frac{\alpha_{d0}}{\beta} \tag{1.38}$$

α_{d0}	:benchmark value for *Index of design policy* (α_{d0} = 1.6)
β	:adjusting coefficient
	(β = 1.0 for unreinforced masonry)
	(β = 1.3 for semi engineering masonry)

1.5.3 Deterioration Index U

1) Basic Formula

The *deterioration index* U is given by Eq. (1.39).

$$U = \min(T, Q) \tag{1.39}$$

where;

U	:Deterioration Index
T	:Aged Index
Q	:Quality Index

2) Deterioration Index U for Steel structure

Object building is checked against a list, as shown in Table A. 1. 14, and the lowest value is selected.

Table A. 1. 14 Checklist of Aged Index T for Steel Structure

Item	Location	judging standard	Application
Reduction of base metal (actual／by drawing)	Column，Beam Bracing Anchor bolt	Less than 5%	1.0
		5%～10%	0.9
		10%～20%	0.8
Crack of foundation concrete	Column Base	Hairline fracture	1.0
		largish	0.9
		Very large	0.8
Differential settlement	Foundation	Less than 2/1000	1.0
		2/1000～5/1000	0.9
		5/1000～10/1000	0.8
Deterioration caused by specific condition *	Frame	Negligible	1.0
		Reduce Slightly	0.9
		Need to reduce	0.8

* Engineer should use his/her judgement

Source: Specification on Earthquake Resistance Diagnosis and Strengthening for Governmental Buildings, 1996

Object building is checked against a list, as shown in Table A. 1. 15, and the lowest value is selected.

Table A. 1. 15 Checklist of Quality Index Q for Steel Structure

Item	Location		Judging standard	Application
Error of Dimension	Framemembers (Span, Height)		Less than 3%	1.0
			3%〜5%	0.9
			5%〜10%	0.8
Deformation or Rotation under Torsion	Frame		Negligible	1.0
			Reduce Slightly	0.9
			Very large	0.8
Gap and distortion	Column-Beam connection Brace end		No gap	1.0
			Obvious gap	0.9
			Considerable degree of gap	0.8
Error of alignment	Column-Beam connection	Web of beam (horizontal direction) tw:thickness of web	Less than 0.5･tw	1.0
			0.5･tw〜2.0･tw	0.95
			More than 2.0･tw	0.9
		Flange of beam (vertical direction) tf:thickness of flange	Less than 0.3･tf	1.0
			0.3･tf〜1.0･tf	0.95
			More than 1.0･tf	0.9
Quality of welding	Welding point		Good	1.0
			Sort of Fair	0.95
			Defective	0.9
Gap	between base plate and foundation		Less than 5mm	1.0
			5mm〜10mm	0.9
			10mm〜30mm	0.8
Quality of warkmanship	Entire Structure		Ordinary grade	1.0
			Some trouble	0.95
			Trouble at assembling members	0.9
Drawing and specification			Sufficient	1.0
			Not sufficient	0.95
			No drawing or No specification	0.9

Source: Specification on Earthquake Resistance Diagnosis and Strengthening for Governmental Buildings, 1996

3) Deterioration Index *U* for RC structure

Object building is checked against a list, as shown in Table A. 1. 16, and the lowest value is selected.

Table A. 1. 16 Checklist of Aged Index T ／Quality Index Q for RC Structure

	Item	judging standard	Application
Aged Deterioration ***T***	Deformation or Distortion under torsion	does not exist	1.0
		Window or door is not easy to open	0.95
		Obvious deformation of columns and beams	0.9
		Obvious tilt or differential settlement	0.9
	Crack of wall or column	does not exist	1.0
		Slight obvious cracks	0.9
		Many cracks is seen on outside wall	0.9
		Rainwater damage is seen but no rust is seen	0.9
		Rainwater damage and rust is seen	0.8
	Deterioration and falling off finishing work	does not exist	1.0
		Deterioration and falling off is seen outside	0.9
		Deterioration and falling off is seen inside	0.8
	Deterioration caused by specific condition	Negligible	1.0
		Reduce Slightly	0.9
		Need to reduce	0.8
Quality ***Q***	Construction quality	Ordinary grade	1.0
		Some trouble	0.9
		Considerable degree of trouble	0.8
	Quality of material	There is no problem	1.0
		Some problem is found	0.8

Source: Specification on Earthquake Resistance Diagnosis and Strengthening for Governmental Buildings, 1996

4) Deterioration Index *U* for Masonry structure

Object building is checked against a list, as shown in Table A. 1. 17 and the lowest value is selected.

Table A. 1. 17 Checklist of Aged Index T ／Quality Index Q for Masonry Structure

	Item	judging standard	Application
Aged Deterioration ***T***	Deformation or Distortion under torsion	does not exist	1.0
		Window or door is not easy to open	0.95
		Obvious deformation of columns and beams	0.9
		Obvious tilt or differential settlement	0.9
	Crack of wall or column	does not exist	1.0
		Slight obvious cracks	0.9
		Many cracks is seen on outside wall	0.9
		Rainwater damage is seen but no rust is seen	0.9
		Rainwater damage and rust is seen	0.8
	Deterioration and falling off finishing work	does not exist	1.0
		Deterioration and falling off is seen outside	0.9
		Deterioration and falling off is seen inside	0.8
	Deterioration caused by specific condition	Negligible	1.0
		Reduce Slightly	0.9
		Need to reduce	0.8
Quality ***Q***	Construction quality	Ordinary grade	1.0
		Some trouble	0.9
		Considerable degree of trouble	0.8
	Quality of material	There is no problem	1.0
		Some problem is found	0.8

Source: Specification on Earthquake Resistance Diagnosis and Strengthening for Governmental Buildings, 1996

2 URBAN DISASTER MANAGEMENT

2. URBAN DISASTER MANAGEMENT

2.1 Urbanization in Tehran

2.1.1 Overview of Development Process in Tehran

It is now more than 200 years that Tehran has been the capital of Iran since the Qajar dynasty chose it as the seat of government. Throughout the last two centuries, Tehran has become one of the larger cities in the world. As the capital city, Tehran has experienced several periods of reformations in the history of Iran, including two major revolutions, the Constitutional Revolution in 1906 and the Islamic Revolution in 1979. The formation and development process of Tehran is briefly described below, divided into three phases with respect to the periods of Qajar dynasty, Pahlavi dynasty and after the Islamic Revolution[1].

1) Qajar Dynasty (1779-1925)

Before being chosen as a capital city by Agha Muhammad Kahn, the founder of the Qajar dynasty, Tehran was just one of the larger villages in Iran, located closely to the ancient city, Ray. On becoming the capital, the city started to flourish due to its strategic location and centralization process as a political and economic hub. The population of Tehran has increased rapidly since the beginning of the Qajar dynasty and the city has spread out beyond its physical boundary. Table2.1.1 below shows the population growth of Tehran in the twentieth century.

During the long reign of Nasser al-Din Shah (1848-1896), the first reformation of the city, including the royal compound, restoration of city wall, and improvements of roads, streets and squares, took place. In particular, the completion of a new city wall in 1890, which stretches 18 km^2, approximately four and a half times as the size of the previous territory, changed the formation of the city drastically. The construction of a new city boundary aimed to accommodate the rapidly growing population, reaching 150,000 at the time of its construction. This, however, led to the special segregation of social classes in Tehran city. The construction activity attracted large numbers of unskilled workers from the surrounding countryside, and they formed the lower stratum of society in the southern part of the city.

Tehran witnessed a continuous population growth during decades after the first reformation. The population density increased from 43.5 persons per hectare in 1883 to 65.5 in 1891 and 80.5 in 1922. In addition, the increase in international trade, change in social and economic structure of the country, and the centralization of the state power all meant a greater importance for Tehran.

[1] The descriptions in this section are derived from the following publication: Ali Madanipour (1998) Tehran: The Making of a Metropolis, John Wiley & Sons.

The central government, however, did little to cope with social unrest and revolutionary struggle, with annual governmental budget of only 2% of the GDP. It was not until the establishment of the Pahlavi dynasty that the second reformation of Tehran city was carried out, after the Constitutional Revolution in 1906, which aimed to replace the arbitrary power of the monarch with the rule of law.

2) Pahlavi Dynasty (1925-1979)

At the beginning of the era of Pahlavi dynasty, the government put a serious effort on the improvement of transportation nationwide in order to meet the demands for higher mobility and to unify and control the national territory. The shift towards industrialization was also made with neglect of the agricultural sector. The growing political and economic importance of Tehran called for the second reformation of the city with expansion of its territory and creation of road network. As a result, 58.5% of all domestic capital investment was made in Tehran by 1940.

Land and property market flourished in the period of the relaxation of control after the Second World War, due to the rise in oil revenue and the increase in immigration to the city. It took the form of free expansion of the city into the surrounding land and the growing suburban villages and satellite towns.

The social segregation was enhanced in the process of suburbanization. The density in the southern areas of Tehran reached over 600 persons per hectare in mid-1950, while that in northern areas remained low.

This was not only the case for Tehran. The income gap widened between urban and rural areas throughout the nation due to the government policy, so called “White Revolution”. In the 1960s, the government encouraged the capitalist transformation of the countryside by land reformation, which led to the decline of agricultural sector. The contribution of the agricultural sector to GNP declined further from 33% in 1959 to 25% in the late 1960s. Instead, the revenue for the governance became much dependent on oil sector.

3) After Islamic Revolution

The Islamic Revolution in 1979 was partly triggered by underdevelopment of political system and an economic crisis resulting from a fall of oil revenue. Revolutionary rhetoric, economic instability and the continuation of a centralized administrative system further stimulated urbanization.

The town planning for Tehran in the latter half of the twentieth century has mainly focused on physical development, as did the earlier forms of planning mentioned above. The 1966 Municipality Act for the first time provided a legal framework for the formation of the Town

Planning High Council and the consequent 1974 Act changed the name of the Ministry of Housing and Urban Development, putting forward a clear definition of comprehensive plans.

2.1.2 Population Growth

1) Tehran

In 1996, Tehran had a population of 6,742,164 based on the census results. The concentration of the population in Tehran area started during 1946-1956, when the suburban population of the urban area was included in Tehran's population. Table2.1.1 shows the population and growth rate of Tehran.

Table2.1.1 Population Growth in Tehran

	1956	1966	1976	1986	1996
Tehran	1,512,082	2,719,730	4,530,223	6,042,584	6,758,845
Growth Rate		6.05%	5.23%	2.92%	1.13%
National Level	18,964,704	25,788,722	33,708,744	49,445,010	60,055,488
Growth Rate		3.12%	2.71%	3.91%	1.96%

Source: Iran Statistical Yearbook, 1379 Statistical Center of Iran

The long-term population projection in Tehran shows that population in Tehran was only 425 thousands in 1937 (Taleghani, 1992), yet the urbanization in Tehran has started after World War II, when the new urban development was started. Indeed, the rate of urbanization reached 6 percent during 1946 to 1966, which was far beyond the national average of 3.1 percent. Between 1966 and 1976, the inclusion of Tajirish and Ray in Tehran urban area has added more population in Tehran. It is pointed out that the reasons for the concentration of population in Tehran are economic in nature and the establishment of more central and governmental organizations.

After the heavy concentration in population in Tehran area, the increase of population has become a moderate growth rate. Recent census results show that the population growth is stable, about less than 1 percent growth rate between 1991 and 1996, which is lower than the national average of 1.5 percent.

The population growth outside of Tehran municipality has grown constantly. The population growth rate of the city's suburbs has reached more than 10 percent per year.

2) District

According to the population census, the most populous district is District 4, which counted at 663 thousands, followed by District 15 of 622 thousands. Table 2.1.2 shows the population in each district and its population density.

Table 2.1.2 Population and Population Density by District

District	Population	Area (ha)	Population Density (Pop./ha)
1	229,143	3,454	66
2	464,773	4,956	94
3	237,301	2,938	81
4	647,207	7,243	89
5	424,960	5,901	72
6	242,049	2,144	113
7	300,212	1,537	195
8	332,005	1,324	251
9	173,482	1,955	89
10	282,308	806	350
11	234,251	1,206	194
12	189,625	1,358	140
13	238,735	1,389	172
14	367,432	1,456	252
15	595,856	2,846	209
16	289,999	1,655	175
17	287,367	796	361
18	272,534	1,785	153
19	202,994	1,149	177
20	293,100	2,028	145
21	131,202	5,196	25
22	57,230	6,140	9
Total	**6,493,805**	**59,262**	**110**

Source: JICA Study Team

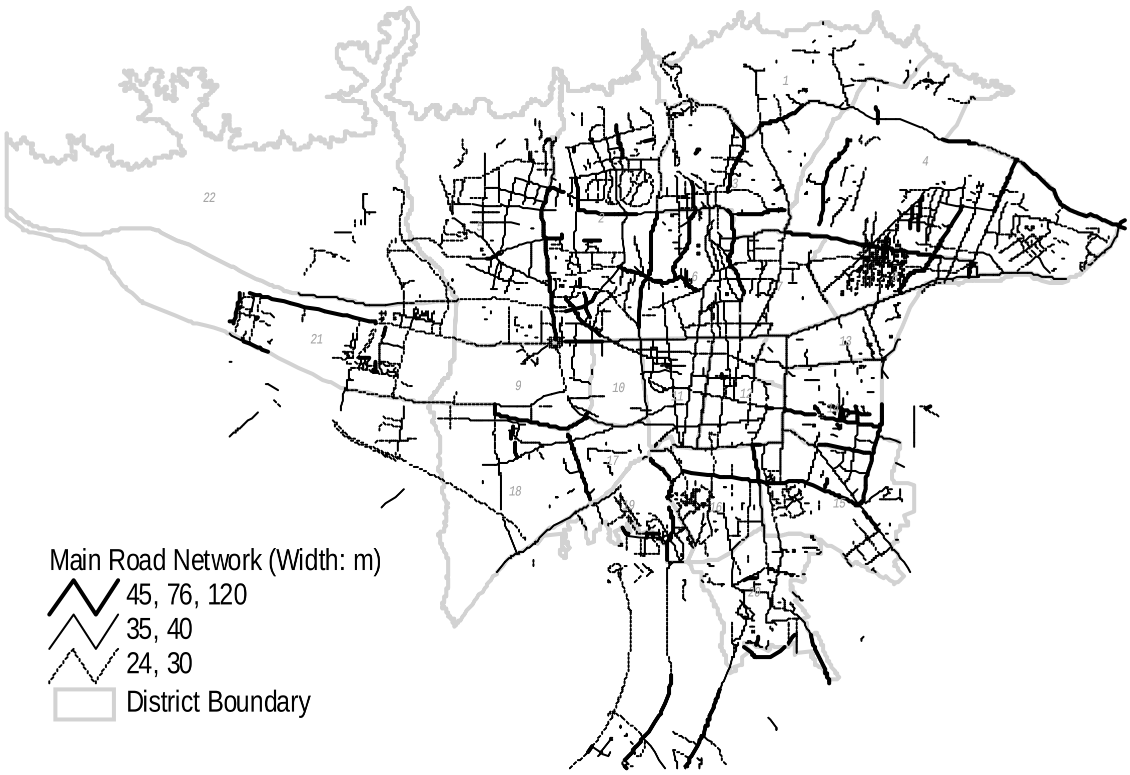
The average population density in Tehran was 110 persons/ha in 1996. The population density is relatively high in the southern part of the city. The most populous district is District 17 at 361 persons/ha, followed by District 10 at 350 persons/ha.

2.1.3 Urban Structure

1) Transportation Network System

(1) Road network

Tehran has a well-designed road network system within the city. Almost all roads in Tehran are paved and have multiple lanes. The road network system can be classified into three types: motorways, arterial road and access road. The motorway network is developed to connect major urban centers within Tehran municipality. There are six inter-city roads to connect other cities in Iran.



Source: JICA Study Team 2004

Figure 2.1.1 Major Road Network in Tehran

Tehran has depended heavily on private transport in the urban area. Public bus is operated in the city, yet its modal share is relatively low because of inefficient and inconvenient routes and frequencies. Private taxis, both licensed and non-licensed, have played an important role in the urbanized area.

(2) Railway

The railway system connects outside cities and Tehran and its contribution to the urban transport is negligible. The railway is run by the Railway Company in Iran. There are three lines to connect outside cities.

(3) Subway system

To solve the urban transport problems, the government decided to introduce the subway system. The Tehran Urban and Suburban Railway Cooperation is responsible for construction, operation and maintenance of the subway system. The subway network forms a North-South line and East-West line, connected at Eman Khomeini station. North-South line, called Line 1, starts from

Mirdamad station in the northern part of Tehran and extends to the shahid Mofatteh, Sa'adi and Khayyam Streets and ends at Imam's Holy Shrine. Line 1 is 28.1 km long and with 22 stations.

East-West line, called Line 2, starts at Iman Khomeini Square to Sadeghyeh Square station. The length of the line is approximately 9.3 km. The line extends towards west, ending at Karaji station.

(4) Airport

The airport is located at Mehradad, the western part of Tehran. The airport is run by the airport organization, and caters to both military and civilian use. The existing airport has caused many problems due to its proximity to Tehran urban area. The new airport is constructed 60 km south of Tehran and it will open this year.

2) Parks and Open Space

The Tehran Parks and Green Area Organization is responsible for facilitation and management of parks in Tehran Municipality. The organization had been established in the 1960s and its management system was changed in the 1990s. Recently, the organization has set four goals:

- Organizing, planning and introducing the affected to the parks and urban plantations;
- Development or supervision on the construction of new parks, and of the "green belt of Tehran";
- Supervision of urban plantations maintenance; and
- Study and research on various plant species, choosing and producing suitable varieties.

There are 859 parks under the control of the organization, which accounts for 31,802 hectares. Within Tehran municipality, there are 705 parks and those accounts for 732 hectares. The number of parks has increased the last twelve years under the organization's efforts. The distribution of the parks has been found to be dense in the northern part of the municipality.

3) Urban Land Use

In order to understand existing land use in the study area, the Study Team used the TGIS database and analyzed the land use in Tehran. Table 2.1.3 shows the existing land use of Tehran.

Table 2.1.3 Urban Land Use

Items	Area (ha)	Area per person (m2)	Composition (%)
Road	10,400	15.43	20.54
Park and Green Area	5,215	7.74	10.30
Residential Area	35,016	51.94	69.16
Break down			
Residential area	21,120	31.33	41.71
Commercial area	843	1.25	1.66
Educational Facility	973	1.44	1.92
Religious and Cultural Facility	472	0.70	0.93
Tourism facility	111	0.16	0.22
Medical and Health Facility	281	0.42	0.55
Public Facility	1,298	1.93	2.56
Military Facility	3,940	5.84	7.78
Industrial Facility	1,685	2.50	3.33
Urban Facility	429	0.64	0.85
Transportation Facility	838	1.24	1.66
Social Service Facility	112	0.17	0.22
Others	2,914	4.32	5.76
Sub-Total	35,016	51.94	69.16
Total	50,631		

Note: The data is extracted from the TGIS land use data in 2002. The data have not included the northern part of Districts 5 and 22 due to limitation of digitalization by TGIS. Therefore, total urban area in Tehran is less than actual area of 65,000 ha.

Source: TGIS database

Table2.1.1 shows Tehran's existing land use. In 2002, Tehran has 20 percent of road space, 10 percent of park and open space and 70 percent of residential area. The breakdown of residential area is shown in the table as well. Most of residential area is used for residential purpose, yet the military facility shares 7.8 percent of land area partly because of inclusion of three airports. The parks and green area include agricultural land; Tehran's open area comes to 10 percent of urban land use.

The existing land use in Tehran shows that Tehran has already developed urban land use. Land has developed as a residential purpose to absorb population flow into the city. The municipal government provides roads and open spaces with large capital investment.

Figure 2.1.2 shows the existing land use, which is supplied by TGIS data.

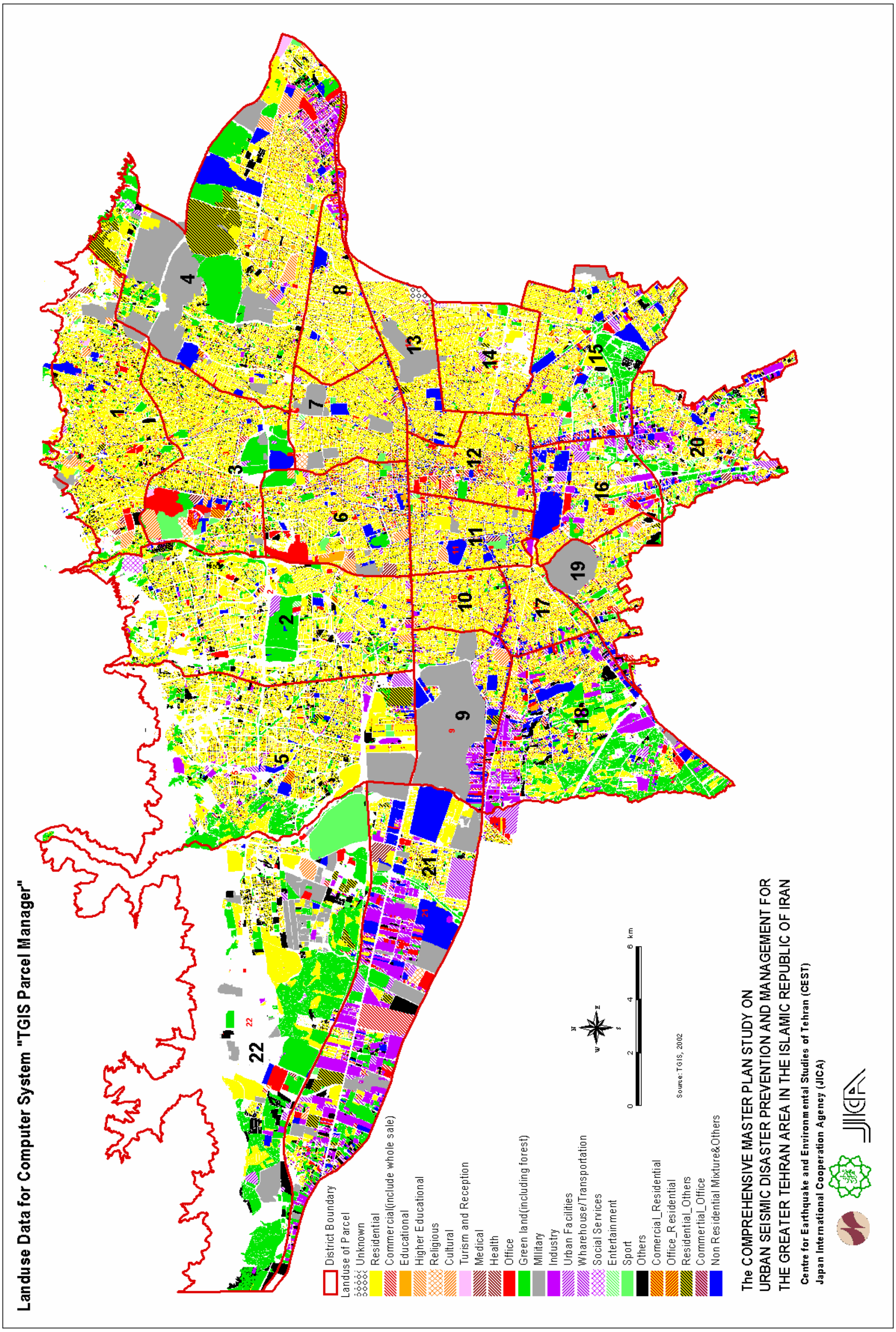


Figure 2.1.2 Existing Land Use

2.1.4 Building Construction

1) Building Construction Process

The previous study used 1996 census data to obtain the number of buildings. The shortcoming of the census data is that it only covers residential buildings and contains only dwelling units. Apartment houses or connected buildings should be counted as one residential building unit. The Study Team converted dwelling unit to the building numbers based on the analysis of the database. According to the previous building data, the construction of buildings in Tehran is summarized as follows:

Table 2.1.4 Construction of Building

District	Before 1966	Age	Age	After 1988	Unkown	Total
		1966-75	1976-88			
1	5,595	6,474	12,231	15,334	616	39,634
2	3,222	9,635	16,147	35,637	998	64,641
3	4,382	8,732	11,451	12,236	456	36,801
4	3,541	9,364	40,846	28,891	1,332	82,642
5	810	1,610	17,359	33,573	845	53,352
6	7,963	7,319	6,008	7,163	286	28,453
7	14,881	10,908	8,053	11,050	515	44,892
8	13,083	15,800	12,600	9,856	633	51,339
9	4,916	9,125	4,449	2,190	227	20,680
10	18,499	10,228	5,005	6,597	575	40,329
11	14,156	6,471	5,180	6,457	526	32,264
12	14,078	4,529	4,725	5,359	556	28,691
13	10,378	9,921	8,026	7,203	422	35,528
14	13,733	14,815	14,306	12,494	998	55,348
15	7,889	11,680	34,773	20,913	1,579	75,255
16	9,481	12,090	10,585	5,282	805	37,438
17	6,944	12,813	9,208	4,247	694	33,212
18	970	5,008	19,963	9,735	766	35,676
19	217	1,693	17,520	7,300	375	26,730
20	5,548	8,124	18,577	11,029	750	43,278
21	280	872	9,114	12,101	366	22,367
22	33	417	1,728	4,560	75	6,738
Total	160,599	177,628	287,854	269,207	14,395	895,288
Percent	18%	20%	32%	30%	2%	100%

Source: The Study on Seismic Microzoing of the Greater Tehran Area in the Islamic Republic of Iran

The building accumulation shows that more than 18 percent of buildings are built before 1966. The buildings built after 1988 share only 30 percent of total buildings. The building age and location have a very close relation.

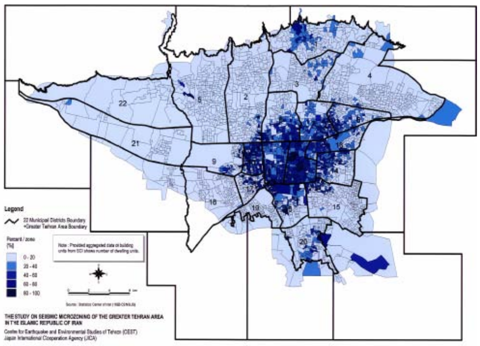
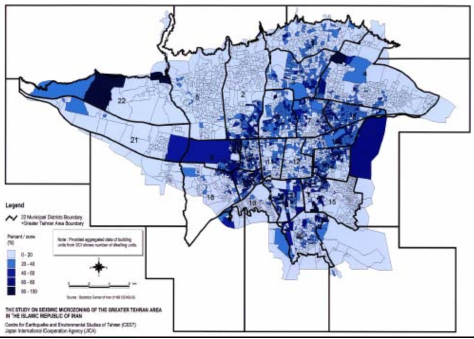
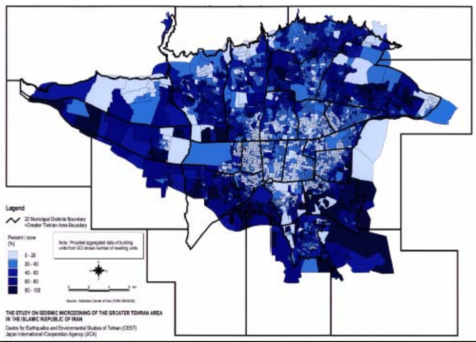
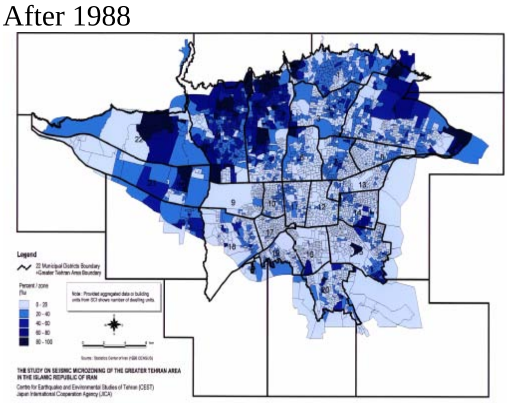
Before 1966 	Population: 2,719,730 (1966) Number of Buildings: 160 thousand Urbanized area is limited only at middle of the municipality, which was developed by the previous dynasty, and the northern part of the city.
1966-1975 	Population: 4,530,223 (1976) Number of Buildings: 337 thousand The construction of buildings started at the suburb of the central area. The city expansion is continued along the major road system.
1976-1988 	Population: 6,042,584 (1986) Number of Buildings: 624 thousand The construction of buildings can be found across the whole district, especially at the edge of the city boundaries.
After 1988 	Population: 6,475,527 (1991) Number of Buildings: 893 thousand The building construction has shifted towards the northern side of the municipality.

Figure 2.1.3 The Building Construction and Expansion of Urban Area

2) Number of Buildings

During Phase 1 of this Study, Tehran Computer Service Organization (TCSO) provided cadastral data, which was developed for tax collection purpose, for the building analysis. The Study Team reviewed the data structure and quality of data itself and concluded that it is reliable data for building. Table 2.1.5 shows the comparison between previous data and cadastral data in terms of number of buildings.

Table 2.1.5 Building in Tehran Municipality

District	Previous Data Year 1996	TCSO data Year 2002	Difference
1	39,634	35,357	-4,277
2	64,641	50,606	-14,035
3	36,801	34,191	-2,610
4	82,642	101,761	19,119
5	53,352	37,812	-15,540
6	28,453	33,748	5,295
7	44,892	53,395	8,503
8	51,339	54,574	3,235
9	20,680	63,705	43,025
10	40,329	72,096	31,767
11	32,264	54,738	22,474
12	28,691	54,874	26,183
13	35,528	49,091	13,563
14	55,348	75,203	19,855
15	75,255	96,635	21,380
16	37,438	72,769	35,331
17	33,212	64,925	31,713
18	35,676	56,433	20,757
19	26,730	46,230	19,500
20	43,278	58,266	14,988
21	22,367	-	-
22	6,738	4,639	-2,099
Total	895,288	1,171,048	298,127

Source: The Study on Seismic Microzoning of the Greater Tehran Area in the Islamic Republic of Iran, Cadastral data from the Tehran Computer Service Organization

Based on the cadastral data, Tehran had more than 1.1 million buildings in 2002, while the census data contained only 895,288 buildings. The possible explanations of this difference are inclusion of business use buildings and more buildings in the municipality, and survey time difference between two sources.

2.2 Urban Economy

2.2.1 National and Tehran Economy

The Iranian economic structure has depended heavily on oil sector in the last forty years. The government has directed to promote non-oil sector. The oil sector's share has declined from 30-40 percent in the 1970s to 10-20 percent (EIU, 2000). However, export earning and government budgets depend on the oil revenue. The recent economic performance is relatively good at 3.2 percent growth during 1993 to 1998 (EIU, 2002)[2]. The GDP at 1998 is US$ 59,698 million.

Information on the economic activity in Tehran is not available. According to the information from the Iran Statistical Center, the share of economic activity in Tehran is approximately 26 percent of the national economy.

1) Employment and economic activities

The Iranian statistics shows the number of employment by economic sector. Table 2.2.1 shows the number of employment by sector of both national level and Tehran.

Table 2.2.1 Employment Data for National Level and Tehran

	National	(%)	Tehran	(%)
Agriculture and Mining	**3,477,147**	**23.9%**	**150,443**	**5.2%**
Agricultural, hunting and forestry	3,318,536	22.8%	128,922	4.5%
Fishing	38,727	0.3%	228	0.0%
Mining and quarrying	119,884	0.8%	21,293	0.7%
Industry	**4,353,074**	**29.9%**	**949,995**	**33.1%**
Manufacturing	2,551,962	17.5%	657,176	22.9%
Electricity, gas and water supply	150,631	1.0%	31,401	1.1%
Construction	1,650,481	11.3%	261,418	9.1%
Service	**6,741,353**	**46.3%**	**1,773,301**	**61.7%**
Wholesale and retail trade	1,842,289	12.6%	542,439	18.9%
Hotels and Restrunts	84,778	0.6%	21,633	0.8%
Transport, storage and communications	972,792	6.7%	235,097	8.2%
Financial and intermediation	152,872	1.0%	55,429	1.9%
Real estate rentin and business activities	149,090	1.0%	59,849	2.1%
Public administration and defence, compulsory social security	1,618,100	11.1%	408,191	14.2%
Education	1,041,058	7.1%	201,581	7.0%
Health and social work	303,139	2.1%	76,399	2.7%
Other community, social and personal services activity	224,405	1.5%	69,179	2.4%
Private house holds with employed persons	61,970	0.4%	14,795	0.5%
Central offices and bureaus	32,952	0.2%	10,930	0.4%
Extra Territorial organizations and bodies	880	0.0%	677	0.0%
Activities not specified and not stated	257,028	1.8%	77,102	2.7%
Total	**14,571,572**	**100.0%**	**2,873,739**	**100.0%**

Source: Iran Statistical Yearbook 1379, Statistical Center of Iran

[2] Economist Intelligence Unit (2000) Country Profile 2000, Iran

The agricultural and mining sector is only 5.2 percent of total employment. The share of agricultural sector is the lowest among the economic sectors.

Industrial sector in Tehran shares more than 33.1 percent of the total employment in Iran. The number of employment is relatively high compared with national level. Industrial sector in Tehran shares more than 26 percent in terms of establishments with more than 10 workers (see Table 2.2.2).

Table 2.2.2 Industrial Sector

Level of Government	Unit	10-49 workers	50-99 workers	100 workers and more	Total
National Level	Establishment	8,362	1,164	1,476	11,002
	Value added (million rial)	5,526,697	2,926,816	49,308,853	57,762,366
Tehran	Establishment	2,128	358	421	2,907
	as a percent of national	25.4%	30.8%	28.5%	26.4%
	Value added (million rial)	1,637,029	945,270	14,493,697	17,075,996
	as a percent of nation	29.6%	32.3%	29.4%	29.6%

Source: Iran Statistical Yearbook 1379, Statistical Center in Iran

Tehran has more than 2,900 industrial establishments with more than 10 workers. It shares 26 percent of the national total establishment, while industrial value added is more than 29 percent. Those industries are located in the western part of Tehran, especially large industry. Small size industry is found along the major arterial road.

Service sector is the prominent sector in Tehran, which shares more than 60 percent of employment. Retailing is the most important in service sector, which means that purchasing power of Tehran is large comparing to the other area. More than 1.7 million people are employed by the service sector. Wholesale and retail trade shares more than 18 percent of total employees followed by the public administration of 14 percent. Because Tehran is also a national capital town, there is the concentration of government sector.

2.3 Urban Administration in Tehran

2.3.1 National and Municipal Government

The central and municipal governments implement the administrative organization for urban development. Ali Madanipour[3] summarized Tehran's administrative system. In this chapter, the description of Tehran urban administrative system is derived from the book.

The responsibility of Tehran municipality can be categorized into three areas: administrative services, urban services and urban development. Each department's role is summarized as follows:

Department	Role and responsibility
Urban Services	• Garbage collection, • Environmental maintenance and improvement • Fire fighting and security • Traffic control and urban transport • Social services • Distribution of drinking water
Urban Development	• Formulation of urban development plan • Development and improvement of infrastructures, such as water, sewerage and transportation system

The central government role and responsibilities are summarized as follows:

Ministry and organization	Role and responsibility
Ministry of Interior	• Establishment and abolition of municipalities • Election and abolition of city councils • Determining municipal boundaries • Supervising the implementation of town planning rules and regulations • Land and priority development process
Ministry of Housing and Urban Development	• Provision of urban land development • Preparation of land for future development • Preparation of development plan and implementation of the plan

2.3.2 Administrative System in Tehran

In 1976 regulations set the definitions of the city boundaries for Tehran, subdividing the urban area into 20 districts with their own mayor and municipality. The number of districts is 22 in whole Tehran, because of inclusion of Districts 21 and 22. The administrative unit of district is further divided into Nahiye, the number of which is 158 in Tehran. Nahiye council is formed as an administrative unit.

[3] Ali Madanipour (1998), Tehran: The Making of a Metropolis, John Wiley & Sons

2.3.3 Development Plan

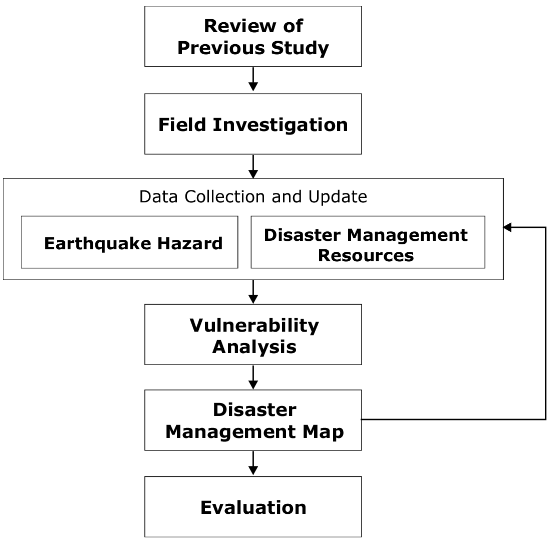
The Ministry of Housing and Urban Development formulated a master plan for the Tehran municipality for the period of 1996 to 2001. The land use plan was also formulated to regulate development direction of the municipality. However, the plan has not been fully implemented by the municipality. The Tehran municipality seeks to formulate a revised version of the master plan in Tehran.

2.4 District Diagnosis Analysis

2.4.1 Earthquake Hazard Analysis

In order to evaluate district earthquake hazard and response, the Study Team carried out a district earthquake disaster diagnosis analysis. The purpose of the analysis is to keep each district informed about disaster hazard and resources, so that they understand the existing situations. The results of analysis are presented as both a GIS map and a district disaster diagnosis sheet. The GIS map, called "Disaster Management Map," shows the earthquake hazard and disaster management resource. A district disaster diagnosis sheet shows the basic information of district and hazard, disaster resources and vulnerability of the district. Based on this analysis, each district should formulate a disaster management plan. (see Appendix2-1)

The Study Team took the following steps to conduct the analysis:



Source: JICA Study Team

Figure 2.4.1 Procedure of District Diagnosis Analysis

The Study Team utilizes the previous study results for disaster diagnosis analysis. *The Study on Seismic Microzoning of the Greater Tehran Area in the Islamic Republic of Iran, 2000,* shows the detailed and comprehensive earthquake hazard in Tehran. Basic idea of this study makes use of previous study results and integrated data and information as a GIS database. Table 2.4.1 below shows data used for the analysis.

Table 2.4.1 Data Used for Earthquake Hazard Analysis

Items	Data Review and Update
Area of Liquefaction	In the previous study, only one borehole among 52 boreholes was identified to have a “relatively high” potential of liquefaction. No additional information for liquefaction potential was collected. Therefore, it is presumable that the area of liquefaction is quite limited in the study area.
Area of Landslide	The previous study showed that the unstable areas exist at the edge of the Alborz Mountains. However, these areas are not in residential areas. The analysis concluded that there is not high slope-failure risk in the residential and commercial area generally prevailing in hill, terrace and fan areas in Tehran. On the other hand, many small-scale slope failures and stone falls would occur at cut slopes during an earthquake. However, there is no detailed date for such small scale cut slopes.
Building Damage	Previous study used census data for building damage estimation. During Phase 1, the Study Team obtained cadastral data from TCSO. For the diagnosis analysis, previous study results are applied.
Bridges	Previous study results show that five bridges have high possibility of collapse. The Study found one new bridge
Lifeline	As for lifeline damage, the data update is not continued after the previous study. In this analysis, previous study results are applied.
Lifeline Facility	Lifeline facility is collected by the previous study. In this study, the building for lifeline facility is evaluated.

Source: The Study on Seismic Microzoning of the Greater Tehran Area in the Islamic Republic of Iran, 2000, JICA Study Team.

2.4.2 Disaster Management Resource

There are two sources of information on disaster management resource. One is land use data from Tehran GIS Center (TGIS) database and the data collection efforts by the Study Team. The following section explains the details of the data and data collection situations.

1) TGIS Database

The previous study collected the data on disaster management resources for each district. Since land use data in Tehran in 2002 from TGIS is obtained, the Study Team uses this database to identify the disaster management resource locations by facility name, which is identified from the database information.

2) Data Collection by the Study Team

For the required emergency response tasks, emergency response centers and resource data were requested to the related agencies since the beginning of the project.

(1) Parks and Open Space

Park data is almost established with the required attribute data for evacuation planning study by the park organization of Tehran municipality and 22 district offices.

(2) Public Educational Facilities

Public educational facility list is compiled from the previous educational facility list of JICA's previous study and the categorized educational facility land parcel data on the land use database of TGIS. The compiled educational facility list was requested to check and add required attribute data to the Ministry of Education's.

(3) Disaster Management Facility

Data on other disaster management facilities are collected from other organizations, such as Ministry of Health, Fire Brigade, Red Crescent Society and Police department. The identified information on disaster management facility is shown as follows:

Table 2.4.2 Identified Disaster Management Resources and Locations

			District																					
		Total	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
NCNDR	Total	33	1	1	2	1	0	18	2	0	2	0	1	5	0	0	0	0	0	0	0	0	0	0
Local Government	Total	139	9	10	4	11	8	10	7	4	2	5	1	9	5	9	7	8	4	6	4	8	3	3
	Tehran Municipality	7	0	0	1	0	0	3	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
	District	32	1	1	1	1	2	1	1	1	0	2	1	2	1	4	3	3	1	2	1	2	0	1
	Nahiyeh	100	8	9	2	10	6	6	5	3	2	3	0	5	4	5	4	5	3	4	3	6	3	2
Disaster Management Center of Local Government	Total	126	9	11	1	11	8	7	6	4	2	5	1	6	5	6	7	7	4	6	4	8	3	3
	Tehran Municipality	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	District	23	1	1	1	1	1	1	1	1	0	2	1	1	1	1	1	1	1	2	1	2	0	1
	Nahiyeh	102	8	9	0	10	7	6	5	3	2	3	0	5	4	5	6	6	3	4	3	6	3	2
Police	Total	106	9	8	7	5	8	8	3	3	2	1	8	6	3	6	5	6	2	2	2	6	3	2
Fire Fighting	Total	73	3	5	5	6	3	4	2	2	0	3	5	3	4	2	3	1	2	3	2	2	3	2
	Emergency Response (Office)	4	0	0	1	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
	Emergency Response (Station)	52	1	4	3	3	3	4	2	2	0	1	5	3	3	2	2	1	1	1	2	2	2	2
	Other (Station)	6	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0
	Other (Under Construction)	11	2	1	0	2	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0	1	0
Red Crescent	Total	11	1	0	0	0	0	0	1	0	0	0	1	2	0	0	0	2	0	0	0	2	1	1
	District Relief and Rescue Base	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0
	Other	9	1	0	0	0	0	0	1	0	0	0	1	2	0	0	0	1	0	0	0	1	1	1
Ambulance Service	Total	44	1	2	3	5	6	2	1	2	3	0	3	2	4	1	2	3	0	1	1	2	0	0
Health Center	Total	127	3	7	1	7	7	11	4	6	8	4	5	5	4	4	5	6	7	8	4	5	6	3
	Center	99	3	4	1	7	6	2	4	6	5	2	5	5	4	4	5	6	6	4	4	5	3	1
	Post	28	0	3	0	0	1	9	0	0	3	2	0	0	0	0	0	0	1	4	0	0	3	2
Traffic Police	Total	16	1	5	2	0	1	0	2	1	0	1	2	0	0	1	0	0	0	0	0	0	0	0
Hospital	Total	255	10	10	20	9	5	37	26	7	6	12	27	17	9	5	2	8	8	5	6	13	3	2
	Regional Hospital	45	4	2	6	1	0	9	1	0	1	1	4	5	2	0	1	1	1	1	0	2	0	0
	Other hospital	210	6	8	14	8	5	28	25	7	5	11	23	12	7	5	1	7	7	4	6	11	3	2
Park	Total	5,283	524	817	235	531	516	248	81	82	21	73	36	25	36	66	629	231	71	99	179	267	273	189
	Potential Regionnal Evacuation Place	11	0	1	1	1	0	1	0	0	0	0	1	0	0	0	2	1	0	1	0	0	0	1
	Potential Primary Evacuation Place	364	18	17	13	29	39	11	3	10	7	14	8	12	8	22	31	16	6	25	14	36	12	3
	Small Place	533	35	19	18	96	51	28	50	31	6	7	7	10	13	14	13	15	37	15	2	39	6	7
	Only from LPM	4,375	471	780	203	405	426	208	28	41	8	52	20	3	15	30	583	199	28	58	163	192	255	178
Primary School	Total	1,454	91	94	74	96	88	59	86	72	27	70	76	81	69	75	77	58	48	61	25	76	30	12
Secondary, High and Other School	Total	2,365	169	209	167	200	153	145	112	97	50	75	116	111	124	85	124	77	62	69	44	103	44	15
Water Supply	Total	76	10	9	5	13	8	6	4	1	1	0	0	0	0	3	1	0	1	3	2	0	0	0
	HQ and Purification	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Purification	4	0	0	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Reservoir	71	10	9	5	10	7	5	4	1	1	0	0	0	0	3	1	0	1	3	2	0	0	0
Electricity Supply	Total	127	8	13	11	8	7	8	6	2	1	6	4	8	6	5	2	3	1	1	3	5	4	3
	HQ and Main Offices	17	0	3	3	0	3	0	3	0	0	1	0	0	2	2	0	0	0	0	0	0	0	0
	Power Plant	4	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
	Reginal Emergency Services	20	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	0	1
	High Voltage Sub Station	86	6	7	7	7	3	7	2	1	0	4	3	7	3	2	1	2	1	1	2	4	4	2
Petrol Station	Total	117	7	6	9	5	2	9	8	3	6	3	7	10	9	4	5	6	1	2	0	6	2	5

*1: SELECT DISTINCTROW DISTRICT, Sum(COVERAGE_AREA) AS [Total_COVERAGE_AREA] FROM JICA2 GROUP BY DISTRICT;

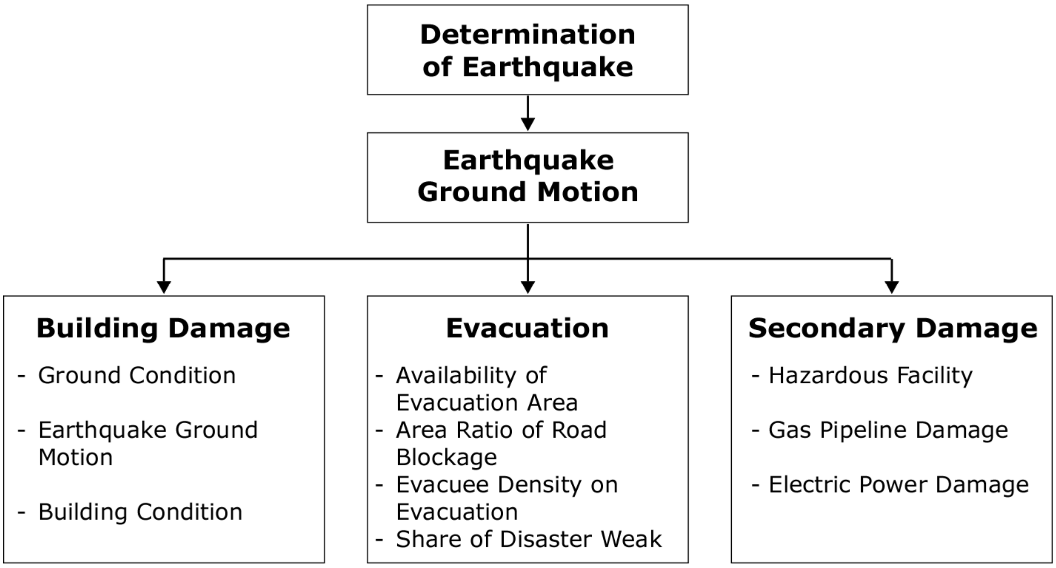
Source: Data Collected from various organization and Compiled by JICA Study team

2.5 Vulnerability Analysis in Tehran Municipality

2.5.1 Methodology

The previous study quantified the damage caused by earthquake in terms of building, human casualty, bridge and lifeline by microzone. In this study, the area's vulnerability to the earthquake should be clarified. In order to evaluate the area's vulnerability to earthquake, the Study Team carried out area vulnerability analysis.

The analysis takes the following steps:



Source: JICA Study Team

Figure 2.5.1 Procedure of Vulnerability Analysis

To analyze an area's vulnerability, the Study Team selects three variables; building damage, secondary damage and evacuation, and indices are used to represent each variable. The variables and indices are summarized as shown below:

Table 2.5.1 Variables used for Vulnerability Analysis

Items	Index	Items included in the index
Building	Ground condition	Based on the previous study
	Earthquake ground motion	
	Building condition	
Evacuation	Availability of evacuation area	By regional evacuation place
	Area ratio of road blockage	By collapsed building
	Evacuee density on evacuation	Road wider than 15 meters
	Share of disaster weak	Population of over 65 years old and less than 5 years old
Secondary Damage	Hazardous Facility	Major fuel/ gas tank, Petrol station, and Chemical facility
	Gas Pipeline damage	Pipeline damage, and Inner pipe of damaged gas supply building
	Electric power damage	Network damage, and Inner cable in damage building

Source: JICA Study Team

Each variable is independent of each other and is analyzed separately. After ranking each variable, all the ranks are integrated to identify the vulnerability of Tehran.

2.5.2 Data Used for the Analysis

1) Determination of Earthquake

The previous study established scenario earthquakes to estimate earthquake damage. Three scenario earthquakes are selected for analysis: Ray fault, NTF and Mosha models. Among the scenario earthquake, two models, Ray fault and NTF model, would have a great impact on Tehran municipality. Therefore, the Study applied either of the earthquakes.

2) Earthquake Ground Motion

In order to analyze the most plausible areas to seismic vulnerability, the Study Team has considered the largest PGA in each microzone. The NTF model is applied for the northern part of the city, while the Ray fault model is for the southern part of the city. Therefore, the earthquake ground motion for the analysis is the largest earthquake in each microzone.

3) Building Damage

The building damage is estimated by the previous study. The building damage ratio, the number of the damaged buildings in each microzoing per total number of building, is used for the analysis. The building damage ratio is calculated from earthquake ground motion, building structure type and the year of construction and number of stories of the buildings (see Chapter 3 in this report, or Chapter 5 in the Sector Report, Volume 3 of the Final Report for more details)

4) Evacuation

The following data are used for the evaluation of the evacuation possibility. Three variables are used for the analysis.

(1) Evacuation Space

Data from the evacuation space and open space is used to evaluate the availability of the evacuation space. The Study Team collected those data from Tehran Municipality.

(2) Road Network

Road network data are derived from the Tehran Comprehensive Transportation and Traffic Studies and the Study Team collects their errors based on the data from Traffic and Transportation Organization. Road centerline data is supplied by the TGIS.

(3) Evacuation Route

Road network is the same data as collected in (2) above, and then more than 15 meters width road are selected for safety evacuation route.

Width of evacuation route is determined by an actual measure used in Japan. Appropriate width is more than 15 meters, which is calculated from required space for rescue activities, blocked space with roadside hazard and evacuee’s space (more detail is provided in Chapter 5 in this report).

(4) Disaster Weak

In previous study, census data are collected for the analysis. From the census data, aged population, those more than 65 years old, and children less than 5 years of age are identified. Handicapped persons are not identified in this Study.

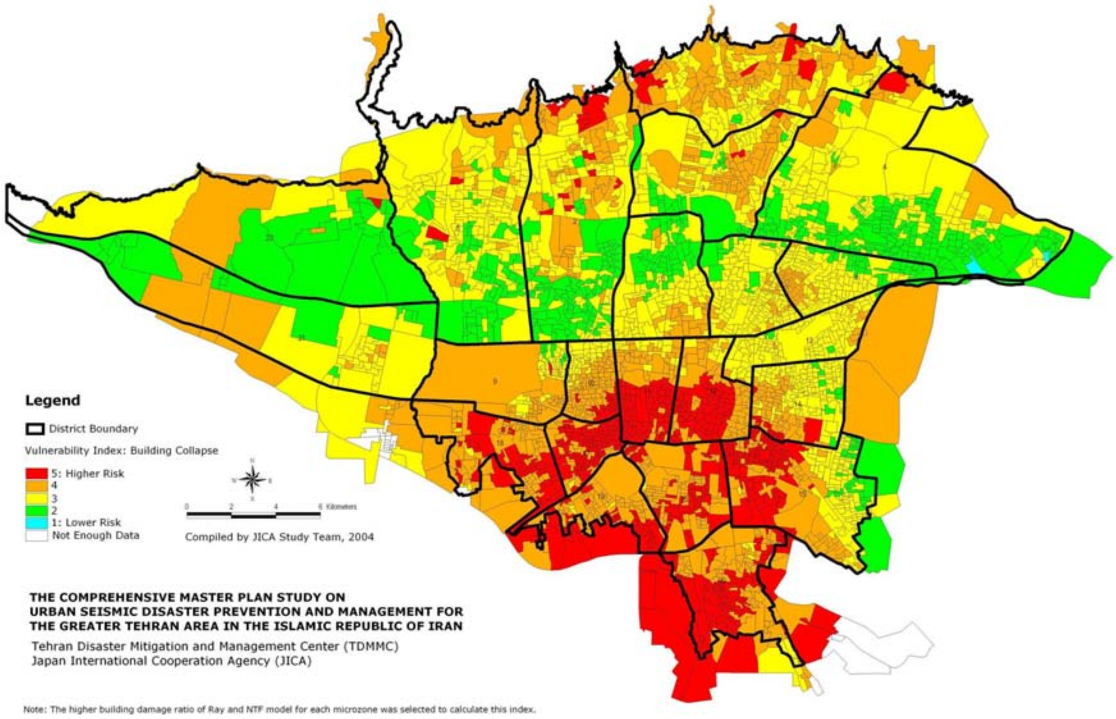
5) Secondary Damage

The previous microzoning study results are used to evaluate vulnerability on gas and electricity damage. Data for hazardous facility are collected from the district government, fire department and industrial reorganization and relocation organization. Those data included gasoline stations and other hazardous facilities.

2.5.3 Analysis

1) Building Collapse

Almost all human casualties and loss were caused by collapsed weak structure buildings in the past urban earthquake disaster. Vulnerability to building collapse in each microzone is assessed on the estimated maximum building damage ratio of the three earthquake scenarios of Ray Fault, North Tehran Fault and Mosha Fault from the previous JICA Microzoning Study. As a result of the analysis, the following figure shows vulnerability to building collapse.



Source: JICA STUDY Team

Figure 2.5.2 Vulnerability to Building Collapse

2) Evacuation

After an earthquake event, more serious human casualties will be caused by hazards of aftershocks and secondary disasters, when people could not be properly evacuated to safe evacuation place through proper evacuation route. Vulnerability to people's evacuation is assessed on the four sub-fields as follows.

(1) Availability of Evacuation Place by District

Available existing parks and open space (data obtained from Park Organization of Tehran Municipality) is assessed and classified into five categories, according to semi-gross evacuation area per capita. Detail regarding evacuation place by district is provided in Chapter 5 in this report.

(2) Population Share of Disaster Weak by District

Handicapped persons, those more than 65 years old, and children under 5 years of age are categorized as disaster weak, which means they cannot evacuate by themselves. Population share of those persons are assessed and classified into five categories.

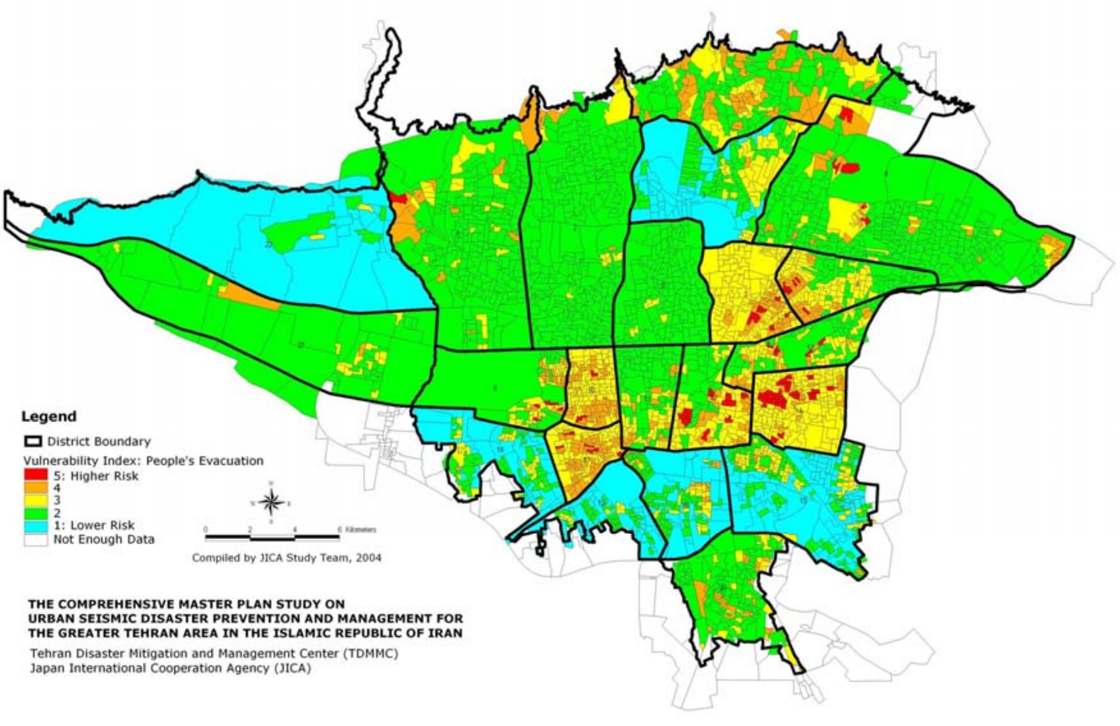
(3) Road Blockage Ratio by Microzone

Debris of collapsed and heavily damaged buildings on roads will disturb people's evacuation and emergency vehicle operation. The estimated road area covered by debris ($30m^2$/collapse and heavily damaged building) is assessed and classified into five categories.

(4) Evacuee Density on Evacuation Route by Microzone

Population density (evacuee) on the wider than 15m width roads, which are categorized as safe evacuation route without influence of roadside hazard, is directly related to evacuation speed. High evacuee density will reduce evacuation speed as follows:

The results of those analyses are shown in the following figure.



Source: JICA Study Team

Figure 2.5.3 Vulnerability to People's Evacuation

Table 2.5.2 Relationship Between Evacuee Density and Evacuation Speed

Density	Daytime speed	Night time speed	Reduced ratio
1.2person/m^2 and less	5.4km/hour	3.6km/h	Ordinary speed
3 person/m^2	1.6km/h	1.1km/h	30%
4 person/m^2	0.5km/h	0.3km/h	Less than 10%

Source: The 5th study on regional vulnerability measurement for earthquake, 2002, Bureau of Urban Planning, Tokyo Metropolitan Government Office, Japan

Evacuation conditions with high density and slow speed will generate serious situation and panic.

Areas classified under Index-5 means most seriously vulnerable area and are mainly located on the part of old town areas without urban renewal in the past half century, where safe evacuation place and proper wider evacuation road are lacking. They have a 1% (5.2 km^2) share of the urbanized district area and 3% share of the municipal population (176,000 pop.).

Areas classified under Index-4 are more widely located on the old town areas and old villages, where they have a 6% (around 40 km^2) share of the urbanized district area and 13% share (842,000 pop.) of the municipal population.

Areas classified under Index-3 are more widely spread in the urbanized area, where they have a 12% share (around 88 km^2) of the urbanized district area and 28% share (1.8 million pop.) of the municipal population.

Areas classified under Index-2 have a comparatively safe evacuation area and a high 47% share (around 331km^2) of the urbanized area and 44% share (2.9 million pop.) of the municipal population.

3) Secondary Disaster

After an earthquake event, more serious human casualties will be caused by secondary disasters, which will be generated by hazardous facilities and damaged hazardous infrastructures as follows:

(1) Identified Hazardous Facility:

The estimated number of the identified facilities of high pressure gas filling and refilling facility, chemical materials/products storage and factory, and petrol station,

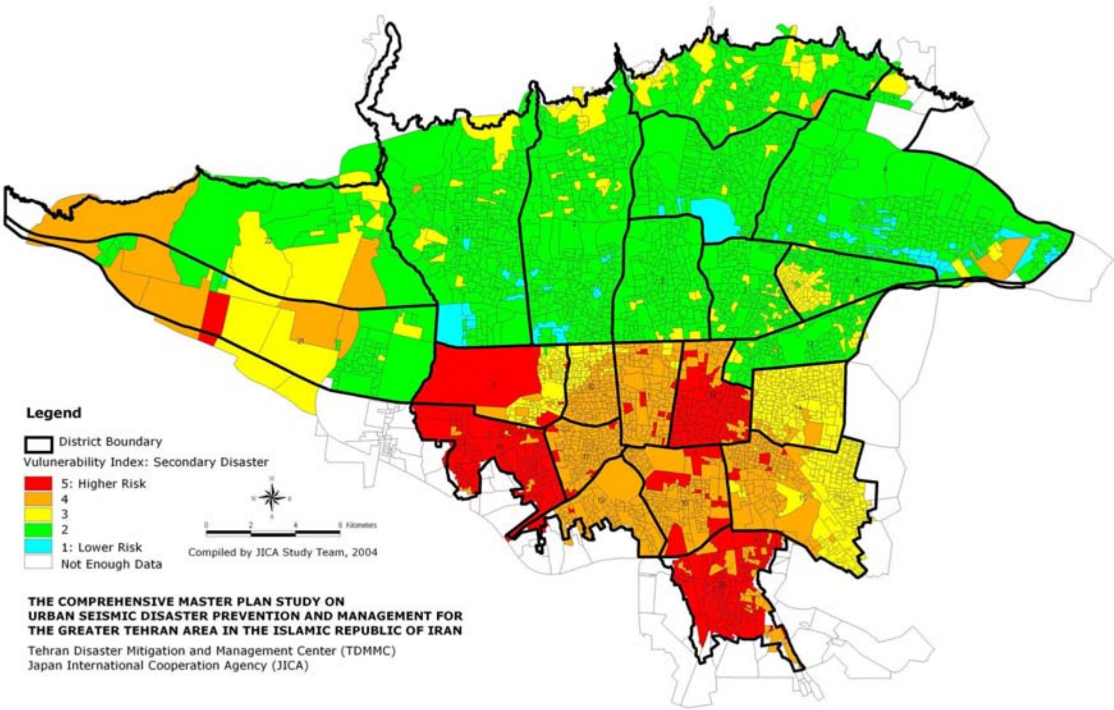
(2) Damaged Point of Natural Gas Supply Pipe:

The estimated number of damaged points of pipeline and number of collapsed/heavily damaged buildings with natural gas supply, and

(3) Damaged Point of Electric Power Supply Cable:

The estimated number of damaged length of cable and number of collapsed or heavily damaged buildings.

Based on those analyses, vulnerability to secondary disaster is shown in Figure 2.5.4.



Source: JICA Study Team

Figure 2.5.4 Vulnerability to Secondary Disaster

2.5.4 Integrated Vulnerability

Integrated vulnerability is assessed on the sum of the estimated three vulnerability indices of building collapse, people's evacuation and secondary disaster. Three variables are weighted as shown below.

- Vulnerability to Building Collapse: 2
- Vulnerability to People's Evacuation: 2
- Vulnerability to Secondary Disaster: 1

The weighted sum of the estimated vulnerability indices in each microzone is classified into five ranks of 1 to 5.

(1) Index-5

It categorized as most vulnerable area, are concentrated in the central districts of 10/11/12, the eastern district of 14, and the southern districts of 17/20, where there are comparatively old town areas. The share of Index-5 is 2% (16 km^2) of the urbanized area and 8% (around half million) of the municipal population.

(2) Index-4

It categorized as secondary vulnerable area, are concentrated in the northern mountain skirt district 1, the central districts of 10/11/12, the eastern district of 8/14, the southern districts of 15/16/17/18/20 and the western district 9. The share of Index-4 is 14% (99 km^2) of the urbanized area and 27% (around 1.7 million) of the municipal population.

(3) Index-3

Those are widely spread in the urbanized districts except district 17 (all the area is classified to index 5 or 4). The share of Index-3 is 27% (188 km^2) of the urbanized area and 32% (around 2.1 million) of the municipal population.

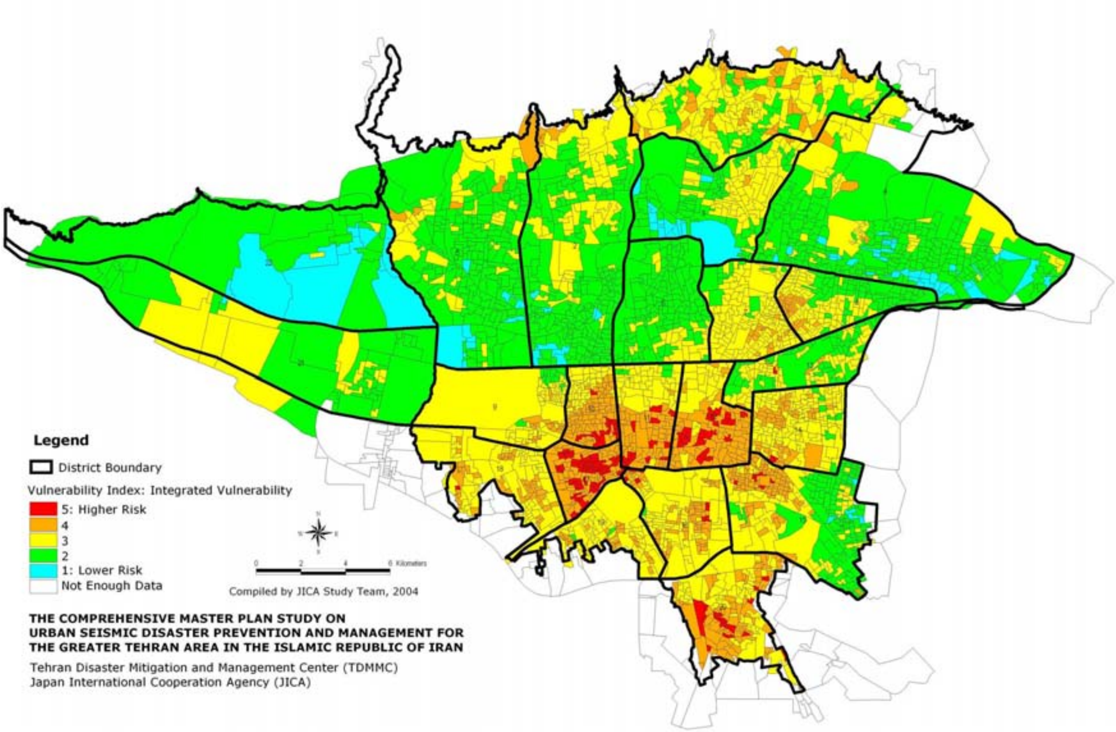
(4) Index-2

Those are concentrated in the northern, eastern and western districts, which share 38% (270 km^2) of the urbanized area and 30% (around 2 million) of the municipal population.

(5) Index-1

Those are very limited in the districts of 3, 4 and 22, which share 2% (13 km^2) of the urbanized area and 1% (around 34,000 pop.) of the municipal population.

The figure below shows the result of this analysis.



Source: JICA Study Team

Figure 2.5.5 Integrated Vulnerability Index

2.5.5 Regional Characteristics of Urban Vulnerability

Integrated vulnerability, which combined three variables of building collapse, evacuation possibility and secondary damage, would be appropriate to evaluate the relative vulnerability of the Tehran Municipality, yet it is insufficient to indicate the specific problem for urban disaster management and introduction of project and program to solve the problems.

In order to understand specific vulnerability, the Study Team reorganized each vulnerability index into eight categories. A five-ranked evaluation has been carried out in the previous section. In this section, those evaluation indices are used, but are re-categorized into "A" and "B." Risk levels 1 to 3 are re-grouped under "A" and risk levels 4 and 5 are under "B." Under this evaluation, there are three letters given, for ex., AAA. The first letter applies to building, the second, evacuation, and the third, secondary disaster.

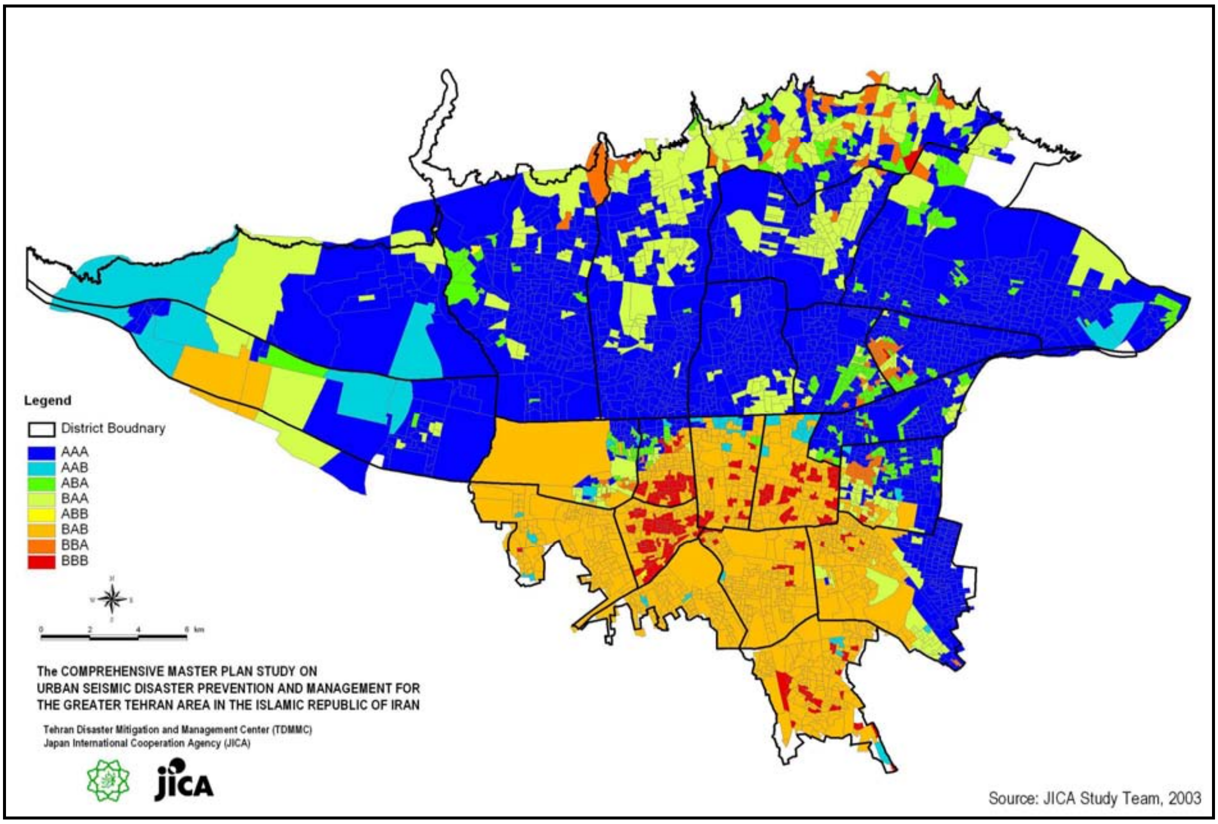
The evaluation of regional vulnerability is reorganized by district as shown in Table 4.2.4. Characteristics of risk can be identified in this table. It shows districts 10 and 17 as the most vulnerable districts in Tehran Municipality registering a vulnerability index of BBB.

Table 2.5.3 Evaluation Criteria and Urban Characteristics

Evaluation Index	Characteristics of Disaster Management
AAA	Relatively less vulnerable urban structure
AAB	High risk on secondary disaster
ABA	High risk on evacuation possibility
BAA	High risk on building collapse
ABB	High risk on evacuation possibility and secondary disaster
BAB	High risk on building collapse and secondary disaster
BBA	High risk on building and evacuation possibility
BBB	High risk on all variables

Source: JICA Study Team

The results of the vulnerability analysis shown in Figure 2.5.6 are given according to the eight categories of risk.



Source: JICA Study Team

Figure 2.5.6 Characteristics of Vulnerability

Table 2.5.4 Characteristics of Vulnerability by District Municipality

District		AAA	AAB	ABA	ABB	BAA	BAB	BBA	BBB	Unknown	Total
1	Area (ha)	980	0	384	0	1,479	0	457	40	113	**3,454**
	%	28.4%	0.0%	11.1%	0.0%	42.8%	0.0%	13.2%	1.2%	3.3%	
2	Area (ha)	3,272	0	18	0	1,523	1	68	0	74	**4,956**
	%	66.0%	0.0%	0.4%	0.0%	30.7%	0.0%	1.4%	0.0%	1.5%	
3	Area (ha)	2,031	0	1	0	884	0	22	0	0	**2,938**
	%	69.1%	0.0%	0.0%	0.0%	30.1%	0.0%	0.7%	0.0%	0.0%	
4	Area (ha)	5,167	249	417	0	761	0	37	0	612	**7,243**
	%	71.3%	3.4%	5.8%	0.0%	10.5%	0.0%	0.5%	0.0%	8.5%	
5	Area (ha)	4,446	0	304	12	546	2	167	0	424	**5,901**
	%	75.3%	0.0%	5.2%	0.2%	9.3%	0.0%	2.8%	0.0%	7.2%	
6	Area (ha)	1,838	0	0	0	306	0	0	0	0	**2,144**
	%	85.7%	0.0%	0.0%	0.0%	14.3%	0.0%	0.0%	0.0%	0.0%	
7	Area (ha)	1,210	0	219	0	71	0	37	0	0	**1,537**
	%	78.7%	0.0%	14.3%	0.0%	4.6%	0.0%	2.4%	0.0%	0.0%	
8	Area (ha)	1,049	0	102	0	53	0	115	5	0	**1,324**
	%	79.2%	0.0%	7.7%	0.0%	4.0%	0.0%	8.7%	0.4%	0.0%	
9	Area (ha)	169	41	78	0	179	1,452	36	0	0	**1,955**
	%	8.7%	2.1%	4.0%	0.0%	9.2%	74.2%	1.8%	0.0%	0.0%	
10	Area (ha)	168	8	59	0	28	308	13	221	0	**806**
	%	20.8%	1.0%	7.4%	0.0%	3.5%	38.2%	1.7%	27.4%	0.0%	
11	Area (ha)	46	86	15	0	0	946	0	113	0	**1,206**
	%	3.8%	7.1%	1.3%	0.0%	0.0%	78.4%	0.0%	9.3%	0.0%	
12	Area (ha)	0	117	0	0	0	973	1	266	0	**1,358**
	%	0.0%	8.6%	0.0%	0.0%	0.0%	71.7%	0.1%	19.6%	0.0%	
13	Area (ha)	1,125	0	147	0	76	0	7	4	30	**1,389**
	%	81.0%	0.0%	10.6%	0.0%	5.5%	0.0%	0.5%	0.3%	2.2%	
14	Area (ha)	743	25	138	0	254	158	125	10	2	**1,456**
	%	51.0%	1.7%	9.5%	0.0%	17.4%	10.8%	8.6%	0.7%	0.2%	
15	Area (ha)	920	7	0	0	402	1,414	6	19	77	**2,846**
	%	32.3%	0.3%	0.0%	0.0%	14.1%	49.7%	0.2%	0.7%	2.7%	
16	Area (ha)	0	7	0	0	0	1,589	0	59	0	**1,655**
	%	0.0%	0.4%	0.0%	0.0%	0.0%	96.0%	0.0%	3.6%	0.0%	
17	Area (ha)	0	0	0	7	0	451	0	338	0	**796**
	%	0.0%	0.0%	0.0%	0.9%	0.0%	56.7%	0.0%	42.4%	0.0%	
18	Area (ha)	0	29	0	0	0	1,675	0	4	77	**1,785**
	%	0.0%	1.6%	0.0%	0.0%	0.0%	93.8%	0.0%	0.2%	4.3%	
19	Area (ha)	0	16	0	0	0	1,069	0	1	64	**1,149**
	%	0.0%	1.4%	0.0%	0.0%	0.0%	93.0%	0.0%	0.1%	5.6%	
20	Area (ha)	0	53	0	0	0	1,549	0	172	255	**2,028**
	%	0.0%	2.6%	0.0%	0.0%	0.0%	76.4%	0.0%	8.5%	12.6%	
21	Area (ha)	2,295	1,298	174	0	674	679	0	0	76	**5,196**
	%	44.2%	25.0%	3.4%	0.0%	13.0%	13.1%	0.0%	0.0%	1.5%	
22	Area (ha)	3,133	1,503	14	0	1,281	0	0	0	209	**6,140**
	%	51.0%	24.5%	0.2%	0.0%	20.9%	0.0%	0.0%	0.0%	3.4%	
Total	Area (ha)	**28,600**	**3,440**	**2,073**	**19**	**8,520**	**12,275**	**1,091**	**1,252**	**1,994**	**59,263**
	%	**48.3%**	**5.8%**	**3.5%**	**0.0%**	**14.4%**	**20.7%**	**1.8%**	**2.1%**	**3.4%**	

Source: JICA Study Team 2003

2.6 Urban Development for Disaster Prevention

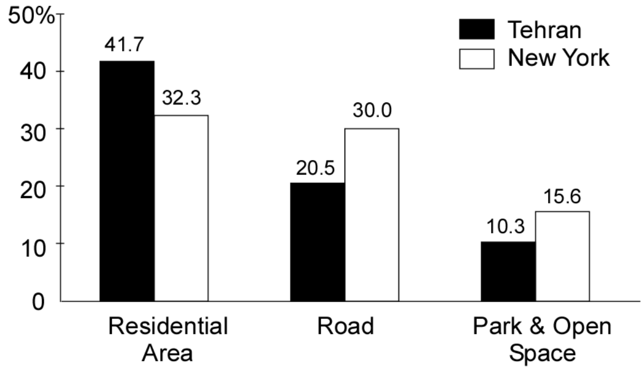
2.6.1 Planning Issue

Based on the vulnerability analysis in the previous section, it is found that Tehran is not strong enough against earthquake. Also it can be said that the most vulnerable area is typical of congested with weak and old buildings and lack of open spaces through the sight survey conducted by the study team. Accordingly, the following issues should be solved;

- Inadequate evacuation places
- Structurally weak and old buildings

2) Inadequate Evacuation Places

The most vulnerable areas are distributed mainly in the central and northern parts of Tehran where have been settled without any land use plan and regulation. In terms of land use in Tehran, evacuation space is inadequate. Comparing other metropolitan city, New York, land use pattern is different as shown in Figure 2.6.1. In Tehran, there is larger area use of residence, on the contrary, smaller area use of urban infrastructure such as roads and open spaces. There is a room to improve for efficient use of land.



Source: Financial Information Services Agency, The city of N.Y., 1995 and TGIS, compiled by JICA Study Team

Figure 2.6.1 Comparison of Land Use Ratio

In case of District 17 designated as the most vulnerable district, there are no appropriate spaces for regional evacuation place. Additionally, only 3.1% of the total area is used for open space.

3) Structurally Weak and Old Buildings

In the vulnerable area, the process of settlement and construction of residential units was supposed to start during years 1956 to 1869 and followed by immigration to this area that composed mainly from the northwestern part of the countries and large Azarbaijani tribes, the division of lands into small parcels started without any plan preparation. Most of the buildings in the area have never been rebuilt to date, that is, three to five decades have been passed already.

Source: JICA Study Team 2004

Figure 2.6.2 Examples of the Congestion Settlement in Vulnerable Area (District 17)

In terms of building structure, in principal, most of the buildings are not strong enough against earthquake. In District 17, large portion of the buildings are built in bricks and passed for long time without any rebuilt or rehabilitation. A proportion of construction material of the buildings in District 17 is shown in Table 2.6.1.

Table 2.6.1 Construction Material of Buildings in District 17, 1996

Construction Material	Steel Frame	RC	Brick with Iron/ Wood	Other
%	22.3	0.6	72.6	4.5

Source: District 17 Municipality Ofiice

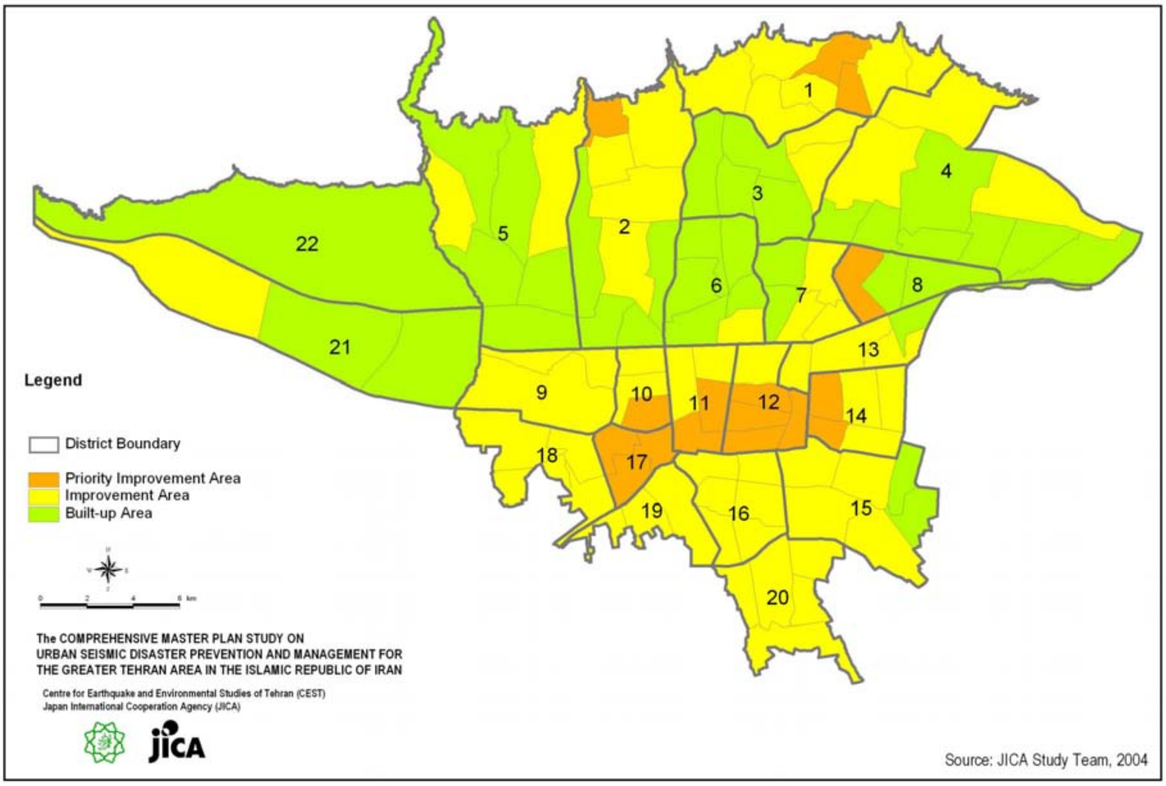
2.6.2 Strategy and Plan

1) Strategy

Given the major two issues, types of vulnerability in Tehran can be classified into three categories as followings.

- Area 1 (Priority Improvement Area): there are both major issues which are inadequate evacuation place and structurally weak and old buildings.
- Area 2 (Improvement Area): there is either one major issue which are inadequate evacuation place or structurally weak and old buildings.
- Area 3 (Built-up Area): there are no major issues.

Objectives, approach and plan of each category should be considered separately. First of all, based on the vulnerability analysis, the study team carried out analysis to classify Nahiye districts in the study area into three categories, namely “Priority Improvement Area,” “Improvement Area” and “Built-up Area”. The criterion of these areas is based on the result of vulnerability analysis, distance of the regional evacuation place and sight surveys done by the study team (see Figure 2.6.3).



Source: JICA Study Team

Figure 2.6.3 Zoning of Improvement Area

2) Plan of Each Category

Major features, objectives and basic plans of each category are in followings.

(1) Priority Improvement Area

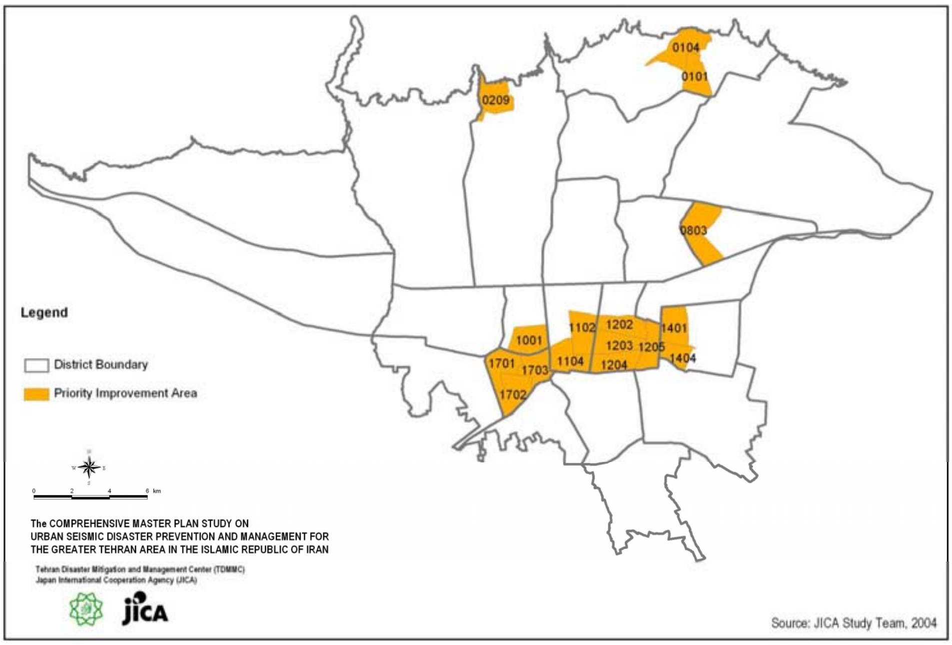
A. Specification of Priority Improvement Area

Priority Improvement Areas are selected from Improvement Areas which are most vulnerable area and need urgent actions.

The measures are the following items:

- Including many vulnerable zones of building collapse index - “B” (more than 60% of buildings will be heavily damaged or collapsed) and evacuation index – “B” (lack of evacuation place, proper evacuation road, and most of roads disturbed by debris and so on)
- Out of coverage of the regional evacuation area
- High-density area with old buildings

The priority improvement area is approximately 4,450 ha, included 16 sub-districts and the population is approximately 933,000 (see Figure 2.6.4 and Table 2.6.2).



Source: JICA Study Team

Figure 2.6.4 Distribution of Priority Improvement Area

Table 2.6.2 List of Priority Improvement Area

District	**Sub-district**	**Area** (ha)	**District**	**Sub-district**	**Area** (ha)
1	Nahiye 0101	242	12	Nahiye 1202	248
	Nahiye 0104	354		Nahiye 1203	262
2	Nahiye 0209	302		Nahiye 1204	258
8	Nahiye 0803	456		Nahiye 1205	227
10	Nahiye 1001	282	14	Nahiye 1401	285
11	Nahiye 1102	280		Nahiye 1404	176
	Nahiye 1104	282	17	Nahiye 1701	262
				Nahiye 1702	294
				Nahiye 1703	240

Source: JICA Study Team, 2004

B Objectives and Plan

These areas need to be provided more space for evacuation and rebuilt or strengthened existing buildings. It is necessary to expand the width of roads and alley to evacuate safety.

Area redevelopment is considered one of appropriate countermeasures for priority improvement areas because for the most part those areas are characterized by old, high-density buildings, narrow streets occupied by parked cars and limited open spaces for evacuation. In particular, alleys in residential area are extremely narrow and cannot be widened because the housing units are too small to set back.

(2) Improvement Area

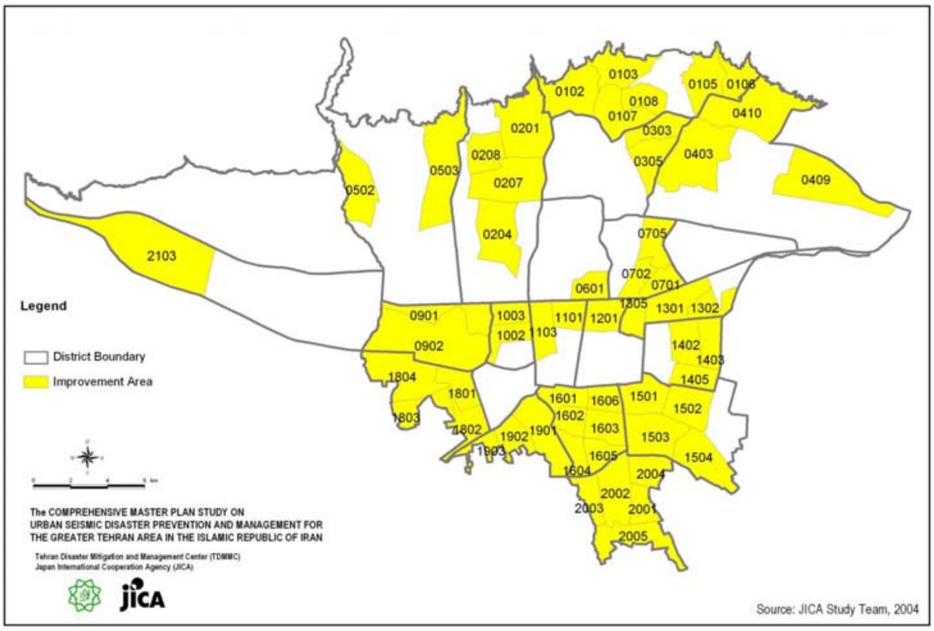
A Specification of Improvement Area

Priority Improvement Area designates high risk area which expects to be seriously damaged by earthquake.

The measures proposed are for the following areas:

- Many vulnerable zones of building collapse index - "B" (more than 60% of buildings will be heavily damaged or collapsed) and assessed not so seriously vulnerable area of evacuation index - "A", or evacuation index – "B" (lack of evacuation place, proper evacuation road, and most of roads disturbed by debris and so on) and assessed not so seriously vulnerable area of building collapse index – "A".
- Out of coverage of the regional evacuation area
- High-density area with old buildings

The improvement area is approximately 28,900 ha, including 57 sub-districts and covering a population of approximately 3,675,000 (see Figure 2.6.5 and Table 2.6.3).



Source: JICA Study Team

Figure 2.6.5 Distribution of Improvement Area

Table 2.6.3 List of Improvement Area

District	**Sub-district**	**Area** (ha)	**District**	**Sub-district**	**Area** (ha)
1	Nahiye 0102	704	13	Nahiye 1301	498
	Nahiye 0103	487		Nahiye 1302	284
	Nahiye 0105	495		Nahiye 1305	244
	Nahiye 0106	319	14	Nahiye 1402	385
	Nahiye 0107	536		Nahiye 1403	318
	Nahiye 0108	316		Nahiye 1405	293
2	Nahiye 0201	949	15	Nahiye 1501	443
	Nahiye 0204	729		Nahiye 1502	485
	Nahiye 0207	817		Nahiye 1503	651
	Nahiye 0208	377		Nahiye 1504	649
3	Nahiye 0303	346	16	Nahiye 1601	296
	Nahiye 0305	313		Nahiye 1602	238
4	Nahiye 0403	1,094		Nahiye 1603	360
	Nahiye 0409	1,089		Nahiye 1604	255
	Nahiye 0410	1,120		Nahiye 1605	261
5	Nahiye 0502	612		Nahiye 1606	247
	Nahiye 0503	1,130	18	Nahiye 1801	341
6	Nahiye 0601	279		Nahiye 1802	351
7	Nahiye 0701	246		Nahiye 1803	306
	Nahiye 0702	245		Nahiye 1804	787
	Nahiye 0705	377	19	Nahiye 1901	660
9	Nahiye 0901	471		Nahiye 1902	311
	Nahiye 0902	1,485		Nahiye 1903	179
10	Nahiye 1002	281	20	Nahiye 2001	249
	Nahiye 1003	243		Nahiye 2002	580
11	Nahiye 1101	275		Nahiye 2003	276
	Nahiye 1103	370		Nahiye 2004	333
12	Nahiye 1201	362		Nahiye 2005	590
			21	Nahiye 2103	1,879

Source: JICA Study Team, 2004

B Objectives and Plan

Based on the vulnerability analysis, the improvement area is not necessary to redevelopment but improvement of disaster prevention facilities is needed, which are community evacuation place, evacuation route and so on.

To achieve such objectives, it is necessary to understand current condition and to make disaster prevention plan in district level. The District Diagnosis Analysis explained in section 1.4 would be useful tool for it.

(3) Built-up Area

A Specification of Built-up Area

Other than both priority improvement area and improvement area is area designated as Built-up Area. This type of area is not considered to be in grave danger from two aspects of building collapse and evacuation.

The measures proposed are for the following areas:

- Many zones of building collapse index - "A" and evacuation index – "A"
- Most of the areas inside of coverage of the regional evacuation area

The built-up area is approximately 25,900 ha, included 36 sub-districts and the population is approximately 1,886,000.

B Objectives and Plan

Built-up Area is not seriously vulnerable compared with other designated areas. But it needs to be improved by individual disaster prevention measures.

For such purpose, those measures should be supported by government sector in such ways that to introduce incentives system for promoting safe buildings and to establish appropriate regulations would be effective. Furthermore, information of disaster prevention should be provided to community and residence.

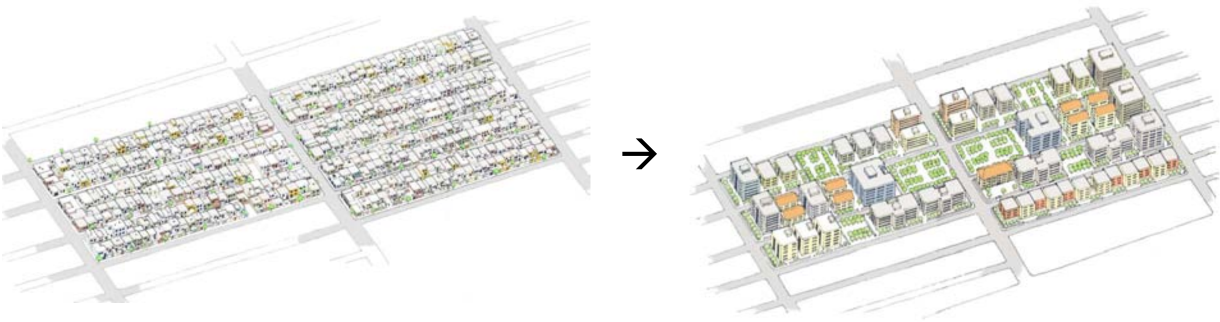
2.6.3 Implementation Plan

1) Implementation Plan of Each Category

(1) Priority Improvement Area

Area redevelopment is able to decrease building density, to make open spaces and roads, and to strength the building structure against earthquake at once. Thus, this countermeasure is efficient for the area designated as the priority improvement area.

Area redevelopment is designated for demolishing the existing congested urbanized area, and reconstructing new buildings with appropriate spaces (see Figure 2.6.6). With a view of utilization of the land due to making open spaces and reserved area for selling, if "right conversion system" applied, floor area should be increased. In other words, new buildings in redeveloped area can be higher raised than current one. Furthermore, building method of earthquake resistance should be fully applied to reconstruction.



Existing Condition → **Redeveloped**

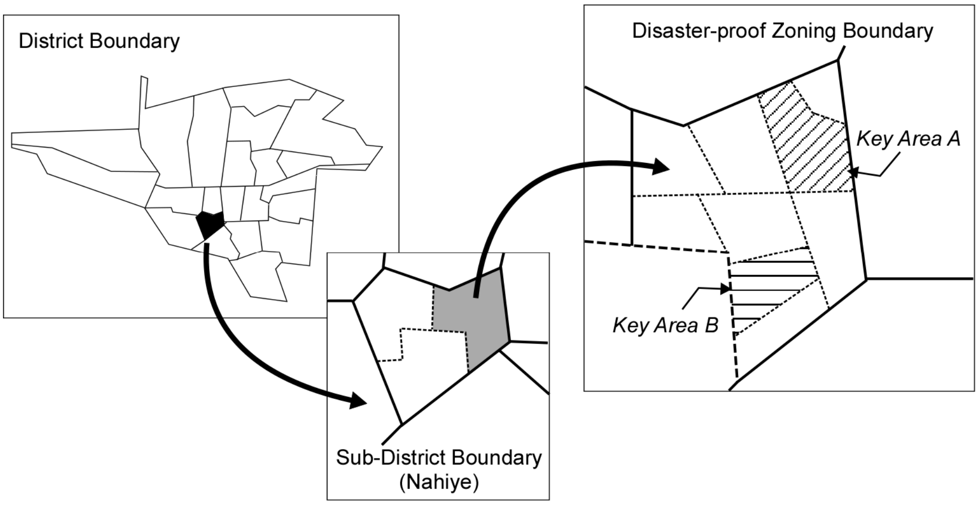
Source: JICA Study Team

Figure 2.6.6 Image of Area Redevelopment for Disaster Prevention

Area redevelopment project should be conducted in phase for the following reasons. One is financial, because this kind of project needs a huge amount of money even if "right conversion system" is applied. It totally depends on the selling price of the reserved floors area for outside people. The other reason involves obtaining the understanding and cooperation of the residents/communities. Thus, phasing method, redeveloping little by little, can be said to be the most practical way. Appropriate land size for redevelopment is from 20 to 50 ha in one phase.

It is preferable that one phase should be completed in a decade. The basic strategy includes a series of steps as follows:

- Make a disaster prevention plan in each sub-district , i.e. disaster-proof zone
- Select and prioritize the disaster-proof zones as designated priority improvement area from the viewpoints of vulnerability and urgency
- To identify small blocks as "Key Area" of which highest priority disaster-proof zones



Source: JICA Study Team

Figure 2.6.7 Image of Disaster-proof Zoning and Key Area

- Create implementation plan and conduct feasibility study on Key Area
- Implement engineering works

Also, it is vital to coordinate the project to fit local attributes and to obtain the residents/ communities' understanding during the course of activities.

Tentative implementation schedule is shown in the following table. Redevelopment project should be conducted in several phases for the following reasons; one is financial issues, because this kind of project needs huge amount of money for construction even if "right conversion system" is applied (more details shows in Appendix 2-2). It is totally dependent on the selling price of the reserved floor areas for outside people or companies. The other reason is that there should be ample time to explain to residents and communities in order for them to understand, and thus pave the way for smooth implementation. Thus, phasing method of redeveloping areas little by little can be the most practical way. Introducing Disaster-proof Zoning should be done only at initial stage which targets at whole area of priority improvement area. One phase is expected to complete in a decade.

This period is perhaps the largest unknown in terms of planning a construction schedule. It is achievable if the Government and implementation agency adopt a progressive and persistent approach toward project implementation.

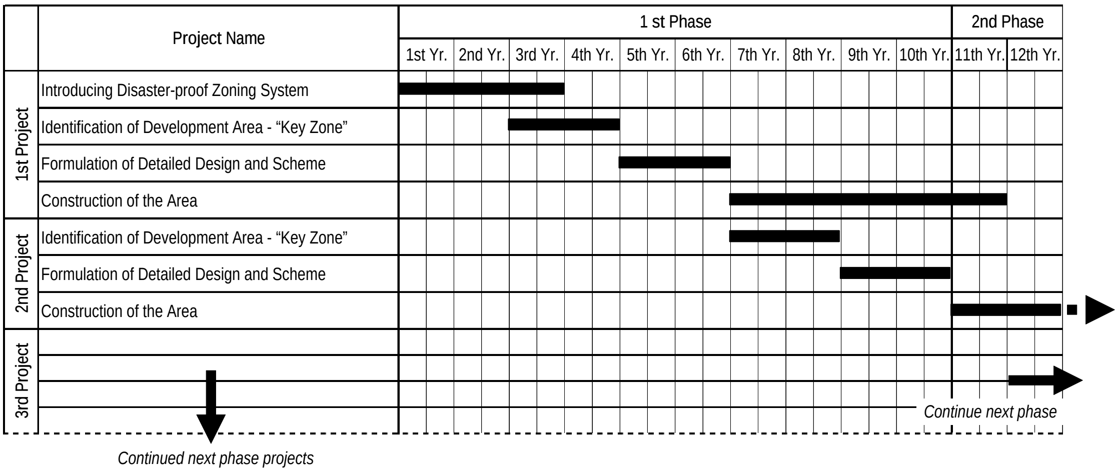


Figure 2.6.8 Tentative Schedule of Area Redevelopment in Phasing System

(2) Improvement Area

In principle, disaster prevention activities for this area should be conducted at district/ sub-district level. Accordingly, it is necessary to prepare disaster prevention plans at community level which should well reflect community attributes, i.e., geological characteristics and social backgrounds. The District Diagnosis Analysis is a helpful tool to understand the current situation and district based vulnerability.

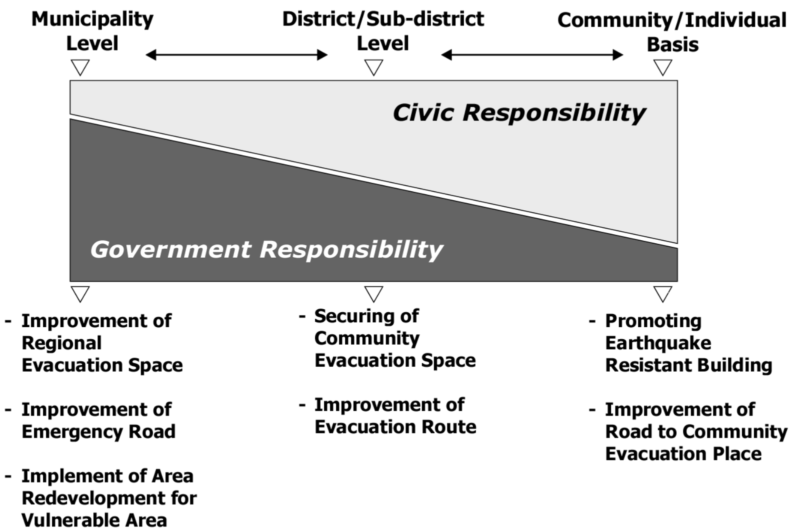
Although the main players are district municipalities and community groups, supports from Tehran municipality and other government entities are also absolutely essential for the disaster prevention activities. Installation of incentive system, establishment of required regulation and provision of inducement system could be efficient and should be enforced by the different sectors of government.

(3) Built-Up Area

To mitigate the risk individually, it is necessary not only efforts by residence but also the supporting system by the government. To review and revise the current building standard, to enforce the regulation, and to introduce incentive system for promoting quake-proof buildings can be considered as efficient practical countermeasures. Moreover, correct information of disaster prevention should be provided to the people and community. To encourage the community disaster prevention activities is also vital measures.

4) Responsibility of Implementation Plan

To pursue implementation plan responsibilities should be clear. In this section, proposed projects in above section classified into three degrees, that is, "municipality level", "district/sub-district level" and "community/individual level".



Source: Based on Urban Disaster Prevention Handbook, 1997, Gyosei, modified JICA Study Team

Figure 2.6.9 Responsibility of Implementation Projects

(2) Municipality Level

Activities for urban development in municipality aim at the whole area of Tehran City. To be precise, improvement of regional evacuation places and emergency roads accordingly disaster prevention master plan should be mainly conducted by municipal government. Also area redevelopment in the most vulnerable areas should be done at municipality level due to those projects need a large budget and to participate and need to coordinate with other organization.

(3) District/ Sub-district Level

Urban development activities at district and sub-district level are smaller scale improvement than the municipality level. In the concrete, to secure community evacuation place and to improve evacuation route should be conducted by not only district government but also cooperation with local people and community.

(4) Community/ Individual Level

Disaster activities at community and individual level are principally to strength individual residence and to clarify the route from the residence to community evacuation place. With a view to support for such activities as legal system, it is necessary to consolidate the current system related to buildings and urban planning. Besides, public awareness of disaster prevention should be increased as well.

5) Disaster-proof Living Zoning System

In order to implement the proposed projects above, the study team recommends to employ "Disaster-proof Living Zoning" system which has been applied in Tokyo. The zoning is in general to divide area into small blocks as one unit and to improve a series of disaster prevention facilities for each block. For such developments, a disaster prevention plan and the implementation plan at community level should be prepared for every block. Appropriate size of the block is supposed to be from 65 to 100 ha, or elementary school district. Nahiye boundaries can be applied to the zoning in light of size of area and administrative jurisdiction.

6) Supporting System

Also due to facilitate those projects explained in above section, appropriate supporting system in terms of financing and regulation should be considered. The following scheme can be applied:

- Public-Private-Partnership (PPP) system
- Dedicated fund for urban redevelopment
- Practical land readjustment and right conversion system
- Financial cross-subsidization system
- Legal process for formulating consensus among residents
- Cadastral-based land registration and appropriate property assessment system
- Taxation systems to capture accrued benefits from beneficiaries
- Enforcement of earthquake-resistant design codes and inspection system to secure design-compliant building act

7) Summary of Implementation Plan

The comparison of each category's characteristics and its implementation plan are shown in Table 2.6.4.

Table 2.6.4 Major Features of Three Categorized Areas

Vulnerability/ Characteristics	Basic Approach	Supporting System	Institution Concerned
1. Priority Improvement Area			
<u>Vulnerability</u> • Building Collapse Index-B and Evacuation Index-B <u>Characteristics</u> • Out of the coverage of regional evacuation place • High density • Old building	<u>Regional Level</u> • Large-scale area redevelopment • Designation and legislation of "Disaster-proof Living Zoning"	• Area redevelopment in right conversion system • PPP scheme • Dedicated fund for urban redevelopment system • Financial cross-subsidization system • Legal process for formulating consensus among residents • Cadastral-based land registration and appropriate property assessment system • Taxation systems to capture accrued benefits from beneficiaries	• TDMMC • Tehran Municipality • Ministry of Housing and Urban Development • Ministry of Interior
2. Improvement Area			
<u>Vulnerability</u> • Building Collapse Index-B and Evacuation Index-A • Building Collapse Index-A and Evacuation Index-B <u>Characteristics</u> • Not all area inside the coverage of regional evacuation place • Middle to high density	<u>District Level</u> • Development for disaster prevention plan at community level • Securing of Community Evacuation Space • Improvement of Evacuation Route • Small-scale land redevelopment	• Dedicated fund for urban redevelopment • Practical land readjustment system • Legal process for formulating consensus among residents • Enforcement of earthquake-resistant design codes and inspection system to secure design-compliant building act	• TDMMC • District Municipality • Local Community
3. Built-up Area			
<u>Vulnerability</u> • Building Collapse Index-A and Evacuation Index-A <u>Characteristics</u> • Inside of coverage of regional evacuation place • Low to middle density	<u>Individual Level</u> • Individual implementation for disaster prevention • Strengthening of individual buildings	• Enforcement of earthquake resistant design codes and inspection system to secure design-compliant building act • Introducing incentive system to promote strengthening buildings • Dedicated fund for urban redevelopment system	• District Municipality • Local Community • Ministry of Housing and Urban Development

Source: JICA Study Team

2.7 Evacuation System

2.7.1 Current Situation

Phase I plan on Emergency Evacuation and Temporary Housing Plan for Tehran citizens have been formulated by Tehran Disaster Mitigation and Management Center (TDMMC) on the basis of the Disaster Management Master Plan approved in June 2001.

1) General Description of Emergency Evacuation and Temporary Housing Plan for Districts of Tehran

The main objective of the whole plan is to predict and design the possible methods for evacuation, transfer, and settlement of the citizens in safe places during the disaster. Planning items are defined as follows:

- Identification and evaluation of existing facilities and capabilities to materialize the main objective of evacuation plan: transfer and settlement of citizens during disaster.
- Formulation of criterion for designating temporary location among urban and suburban areas.
- Designation of safe and immune places for probable temporary housing of Tehran citizens.
- Study on the method of equipping the location designated for temporary settlement of the victims.
- Designation of locations for depot of facilities and equipment for relief operations during disaster.
- Study and introduction of strategies for evacuation of endangered citizens to safe and pre-designated places.
- Designation of main entrance and exit roads from damaged areas to safe places.
- Study on the role of In-Charge, Back-up, and Partner organizations through formulation of managerial structure for evacuation and temporary housing during disaster.

Also, in order to formulate and integrate the major policies of the plan and its executive approaches, a specialized group was selected from TDMMC and Training and Research Institute of RCS. The group prepared the primary scope of work for emergency evacuation and temporary housing master plan based on presumptions as follows:

- Formulation of theoretic principles and framework of required activities for executing the plan;
- Determination of the limitations and prerequisites (resources, managerial, structural);
- Designation of locations for temporary housing;
- Designation of locations for settlement of required facilities, equipment and tools for temporary housing points;
- Managerial structure of evacuation and temporary housing during disaster and of In-Charge, Back-up and Partner organizations; and

- Determination of executive approaches for evacuation and temporary housing master plan.

2) Result of Phase I Plan

In order to coordinate and collect necessary information, it was requested from Deputies for Technical & Civil Affairs of District Municipalities to send their latest information about urban spaces such as vacant, cultural, sport, services, commercial, green spaces such as forest park, parks and recreational centers, fairs, terminals and other open spaces with more than 2,000 m^2 existing in their districts as primary data to TDMMC.

A group of students of Training & Research Institute of RCS was selected as study teams for site visiting to the above locations, filling the forms and technical evaluations from May 2002.

Until September 2002, out of 1,030 dispatched forms, 846 selected locations were visited and evaluated by Training & Research Institute and the results were sent to TDMMC.

In January 2003, the completion of the Phase I of the Plan was announced based on the following acquired outcomes:

1. About 1,030 locations introduced by municipality were evaluated, and selected points were identified and their data registered.
2. Particular software was designed and developed for establishing a database of collected data.
3. All temporary housing locations were marked on map of different districts.
4. Main access roads to these locations were preliminarily marked on districts maps.

Software called “Tehran Temporary Housing Software” is developed to contain all the above information and other requirements of not only each district but also the whole of Tehran, with enough flexibility to suit users.

3) Review of the Phase I Plan

The JICA Study Team briefly reviewed the plan and following points can be singled out for consideration:

1. The plan is quite preliminary and no basic policy of evacuation system is presented.
2. The selection of evacuation place was performed only from among those spaces with an area of more than 2,000m^2.
3. No other criteria such as required area for unit population and allowable maximum distance of evacuation route are taken into account.
4. Evacuation zoning that shows who should evacuate to which place is not identified.

Taking the above points into consideration, the JICA Study Team presents the basic policy and guidelines for formulation of evacuation plan.

2.7.2 Regional Evacuation Place

1) Evacuation System

It is vital that residents can evacuate to safe place through certain route when an earthquake happens. Accordingly, evacuation system, a wide area evacuation place and evacuation roads, should be provided; that is, it is necessary to specify and secure open space which is large enough to accommodate residents and roads which is wide enough and linked with evacuation place. In addition, the system should be well-known by residents.

(1) Regional Evacuation Place

It is an open space such as a large-scale park or green space without any slope and surface, which is for protection of evacuees from any dangers such as falling of buildings and others when a large-scale earthquake hit. Gross open space in the regional evacuation place has to be bigger than 3 m^2 per person (net area more than 2 m^2/person in Tokyo). Appropriate coverage area of the regional evacuation place is less than 2 km-radius.

(2) Community Evacuation Place

It is a place for evacuating persons to form a group temporarily to evacuate to the regional evacuation place. The place shall be such as urban parks, sports field, school, religious facility, etc. in which the safety of assembled persons can be secured. Gross open space in the community evacuation place has to be bigger than 2 m^2 per person (net area more than 1 m^2/person in Tokyo). Appropriate coverage area of community evacuation place is approximately 500 meter-radius.

(3) Evacuation Route

It is a road that leads form the community evacuation place to the regional evacuation place. It is designated in advance to enable residents living in an evacuating zone to evacuate quickly and safely to the regional evacuation place. Appropriate width of road as evacuation route is more than 15 meters.

Width of evacuation route is determined by an actual measure used in Japan. Appropriate width is more than 15 meters which is calculated from required space for rescue activities, blocked space with roadside hazard and evacuee's space.

- Required space for rescue activities stands for passable space for emergency vehicles: 4 meters
- Road block by hazards are collapsed objects and parked or/and left cars: 3~4 meters
- Required road width for evacuation: 7~8 meters
  The method of calculation is as follows;

Space for Evacuation	=	No. of Evacuees	/	Evacuees Density	/	Evacuation Speed	/	Evacuation Time

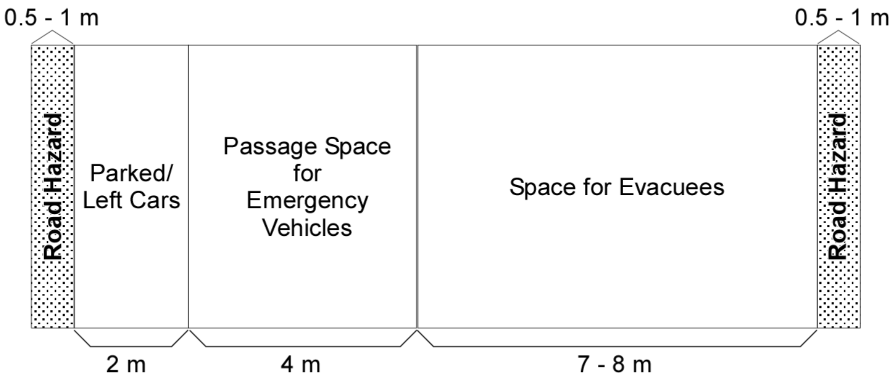
Source: Urban Disaster Prevention Handbook, 1997, Gyosei

Calculation in case of Iran

7.8 meters	=	22,000 * person	/	0.7 ** person/m2	/	2,000 km/hr.	/	2 hr.

*: (Coverage Area of Regional Evacuation Space / 4 direction) x Average Density= (2kmx2km/4)x110=22,000

**: 0.7 person/m2 is spacious compare with the case of Japan which is 1.0 person/m2 because of to take account of national character.



Source: Urban Disaster Prevention Handbook, 1997, Gyosei

Figure 2.7.1 Road Width of Evacuation Route

2) Selection of Evacuation Place and Route

Throughout the study, latest information about urban spaces such as vacant, cultural, sport, services, commercial, green spaces (forest park, parks and recreational centers), fairs, terminals and other open spaces with more than 2,000 m^2 has been corrected as primary data. Approximately 1,030 locations are listed by municipality in which candidate regional evacuation places are selected by using certain software called “Tehran Temporary Housing Software”.

3) Screening of Regional Evacuation Place

Candidates for the place are selected from the list and combined area of those facilities by the criteria as follows:

- Public owned land and facilities for stability,
- Major park, open space and sport ground for flexible utilization,
- Public facilities with enough seismic resistant building structure,
- Without any natural hazard area,
- Without any hazardous chemical facilities in and around the area, and
- Emergency potable water supply, toilet (tank), and emergency goods storage are proposed.

4) Regional Evacuation Space

Based on the criteria as above, the study team identified 96 areas out of 136 identified locations for regional evacuation place.

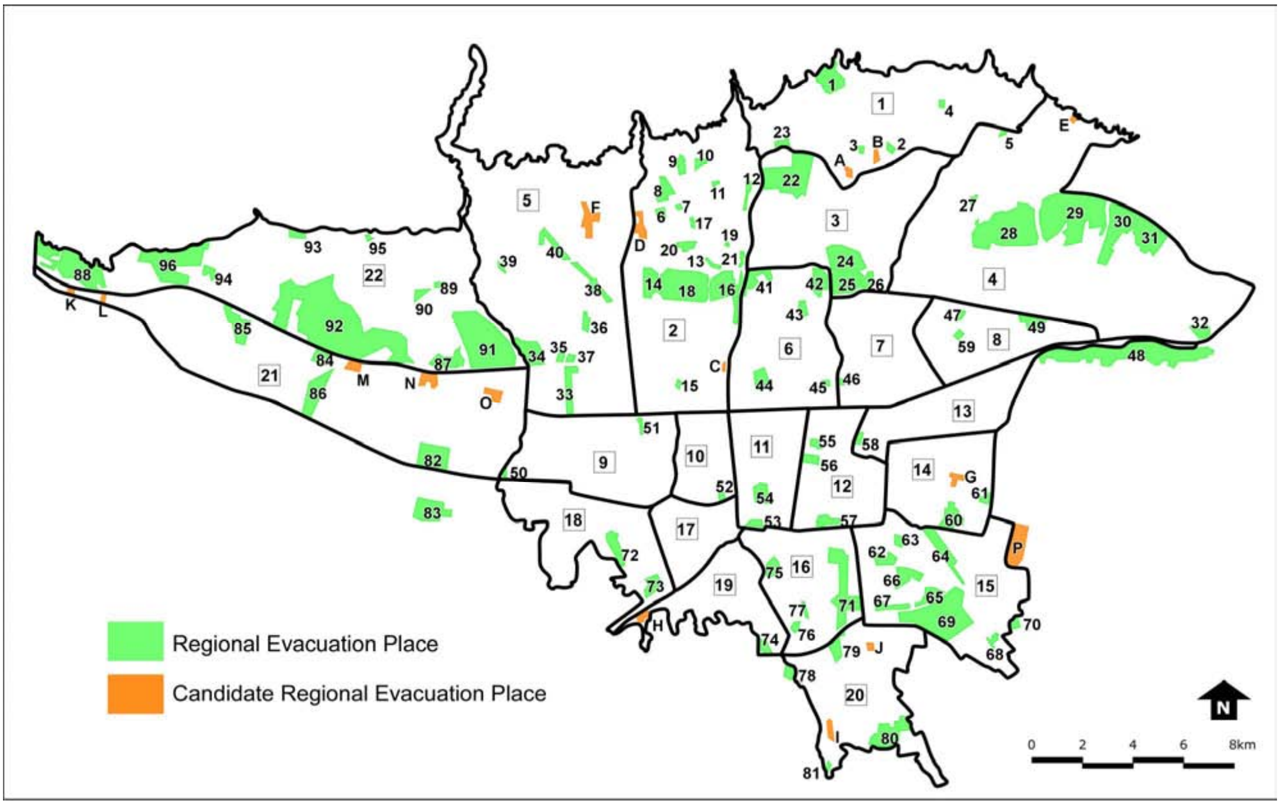
Table 2.7.1 Summary of Evacuation Place Candidate

Type	Number	Area (ha)
Public Space (Park)	96	6,655
Private Land	16	373
Military	19	1,324
Unknown	5	271
Total	**136**	**8,623**

Source: JICA Study Team 2004

Identified regional evacuation places and candidate places are shown in Figure 2.7.2, and list of the regional evacuation places are shown in

Table 2.7.1.



Source: JICA Study Team 2004

Figure 2.7.2 Location of Regional Evacuation Place and the Candidate Place

Table 2.7.2 List of Regional Evacuation Place and Capacity by District

District	Regional Evacuation Place			Required Area for Evacuation (ha)
	Code	Name of Place	Area (ha)	
1	1	Saad Abad Garden	84.2	
	2	Qeytarieh Park	9.9	
	3	Green Space, Next to Qeytarieh Sub Station, TREC	7.5	
	4	Niavaran Park	6.1	
	23	Plan for National Parlement, Islamic Conference Place, North of Chamran Highway	16.8	
	Total		**124.6**	**45.8**
2	6	Surrounding of water reserviour, in Farahzad	16.4	
	7	Vacant for Food Science Faculty, in Farahzad	4.2	
	8	Forest in Farahzad	38.4	
	9	Parvaz Park, Farahzad	21.9	
	10	Vacant, North of Saadat Abad	14.2	
	11	Water Reserviour, Kaj Square	4.1	
	12	Vacant along Darake River	15.1	
	13	Vacant belong to Azad University, Shahrak Ghods	8.8	
	14	Western Part of Pardisan Park	52.1	
	15	Vacant, Water Company in Tarasht Area	4.9	
	16	Nasr Park and Sorrounding area	134.2	
	17	Kanoon Parvaresh Fekri, Shahrak Ghods	8.7	
	18	Main Part of Pardisan Park	219.1	
	19	Vacant, by the Hormozan St.	1.8	
	20	Civil Workshop in Shahrak Ghods	17.2	
	21	Forest Park along Chamran Highway, Surrounding Mollasadra St.	7.6	
	Total		**568.6**	**93.0**
3	22	Surroundings of I. R. I. B. Headquarters	225.9	
	24	Northern Part of Abbas Abad land	136.6	
	25	Northern Part of Abbas Abad land	104.2	
	26	Jahan Kodak Park (National Library in Plan)	25.5	
	Total		**492.1**	**47.5**
4	5	Park, South Eastern Part of Lashgarak St. and Ozgol St. Intersection	5.8	
	27	Javaherian Garden (related to Municipality), Lavizan Area	6.5	
	28	Lavizan Park	334.2	
	29	Narvan Park, Babaiee Highway	431.8	
	30	Pardis Green Land Park	188.5	
	31	National Forest Park, Babaiee Highway	135.3	
	32	Park, Vacant belongs to Municipality, South of Hakimiye	32.0	
	Total		**1134.0**	**129.4**
5	33	Ekbatan Rehabilitation and Renovation Co.	51.8	
	34	Eram Park	79.6	
	35	Ekbatan Rehabilitation and Renovation Co.	11.3	
	36	Green Space, Nour Sq.	14.0	
	37	Green Space, East of South Nour Blvd.	10.7	
	38	South Part of Vacant under Power Cable, Shahrak Gharb	44.6	
	39	Kan Garden	5.9	
	40	North Part of Vacant under Power Cable, Shahrak Gharb	54.8	
	Total		**272.7**	**85.0**

District	Regional Evacuation Place			Required Area for Evacuation (ha)
	Code	Name of Place	Area (ha)	
6	41	Atomic Energy Organization, Chamran and Hemat Highway Intersection	51.9	
	42	Abbas Abad Land, West of Modarres Higway	51.1	
	43	Saiee Park	16.5	
	44	Laleh Park	43.4	
	45	Tehran Garden (Cultural House)	6.5	
	Total		**169.5**	**48.4**
7	46	Shiroudi Sport Land	8.5	
	Total		**8.5**	**60.0**
8	47	Buildings belong to Municipality (Technical Workshop, Storages)	11.7	
	49	Tehran Metro Company and related storage and Technical Office, Between Dardasht and Bagheri St.	47.1	
	59	Sport Land, Storage belong to MOE and Polt National Company	8.0	
	Total		**66.8**	**66.4**
9	50	Workers Sport Complex	5.6	
	51	Almahdi Park, Daily bazar along Mehrabad Airport Zone	6.4	
	Total		**11.9**	**34.7**
10	52	22 Bahman Park, North of Ghazvin St., West of Arab St.	8.9	
	Total		**8.9**	**56.5**
11	53	Shahid Haji Zadeh Educational Complex, N. I. O. P. D. C.	16.8	
	54	Razi Park, Behind Razi and Farabi Hospital	42.3	
	Total		**59.1**	**46.9**
12	55	Open Space, between Hafez and Ferdosi St., along Sakhaiee St.	11.7	
	56	Parke Shahr	24.2	
	57	Boostan and Sport Complex under plan, West of Shoosh Square	31.2	
	Total		**67.0**	**37.9**
13	58	New place for National Parlement, Mojahedin Eslam Intersection	16.9	
	48	Sorkhe Hesar	396.8	
	Total		**413.7**	**47.7**
14	60	Cultivation, Between Nabard and Ahang Highway	57.1	
	61	Basij Park, between Basij and Mahalati Highway	12.4	
	Total		**69.5**	**73.5**
15	62	Daily Bazar, Sport Complex, North of Besat Highway	39.3	
	63	Valiasr Park, Attarbashi St.	16.3	
	64	Cultural House, Green Space along Khavaran St.	69.7	
	65	Northern part of Tooska Forest park	31.5	
	66	Forest Park, South of Besat Highway	57.3	
	67	North west part of Tooska Forest park	21.8	
	68	Mesgar Abad old Cemetry	8.0	
	69	Main Part of Tooska Forest Park	318.1	
	70	Vacant, East of Moshiriye Square	24.6	
	Total		**586.5**	**119.2**
16	71	Besat Poweplant and Surrounding area	159.2	
	75	22 Bahaman Boostan, Bahman Cultural House, Old Koshtargah	36.3	
	76	Shariati Educational Complex, ETKA Factory, South of Barbary Square	11.1	
	77	Shahid Rajaiee Park, long Rajaiee Highway, East of Barbari Square	6.9	
	Total		**213.5**	**58.0**
17	--	--	0.0	
	Total		**0.0**	**57.5**

District	Regional Evacuation Place			Required Area for Evacuation (ha)
	Code	Name of Place	Area (ha)	
18	72	Ghaem Boostan	51.4	
	73	Sepide Park, Sport Land, North of Saeedi Highway	37.0	
	Total		**88.4**	**54.5**
19	74	Cultivation, Intersection of Besat and Beheshte Zahra Highway	17.6	
	Total		**17.6**	**40.6**
20	78	Vacant, West of Shahrake 13 Aban	31.6	
	79	Green Space, Sport Land, South of Azadegan Highway	37.9	
	80	Vacant in ghaleh Gabri Area	97.8	
	81	Green Space along Anbare Naft St.	5.3	
	Total		**172.6**	**58.6**
21	82	Vacant belongs to Properties Org.	104.2	
	83	Norouz Abad Riding Club	99.4	
	84	Vacant belongs to Valiasr Cultural Complex	27.2	
	85	Vacant along Shahrak Cinemaie Ghazali	73.9	
	86	Shahrak Daneshgah Cooperation Company	91.4	
	Total		**396.1**	**26.2**
22	87	Khargoosh Darreh Forest	55.7	
	88	Western Part of Chitgar Park	232.1	
	89	Forest between Shahrak Cheshme and Nabovat Garrison	5.6	
	90	Forest between Nabovat Garrison and Shahrak Rahahan	13.8	
	91	Azadi Stadiuum	359.1	
	92	Chitgar Park	741.1	
	93	Vacant, North of Shahid Namjoo Garrison	19.0	
	94	Forest, North of Vardavard Metro Station	16.8	
	95	Green Space, West of Shahrak Rah Ahan	4.7	
	96	Vardavard Forest Park	52.5	
	Total		**1,500.4**	**11.4**

Source: JICA Study Team 2004

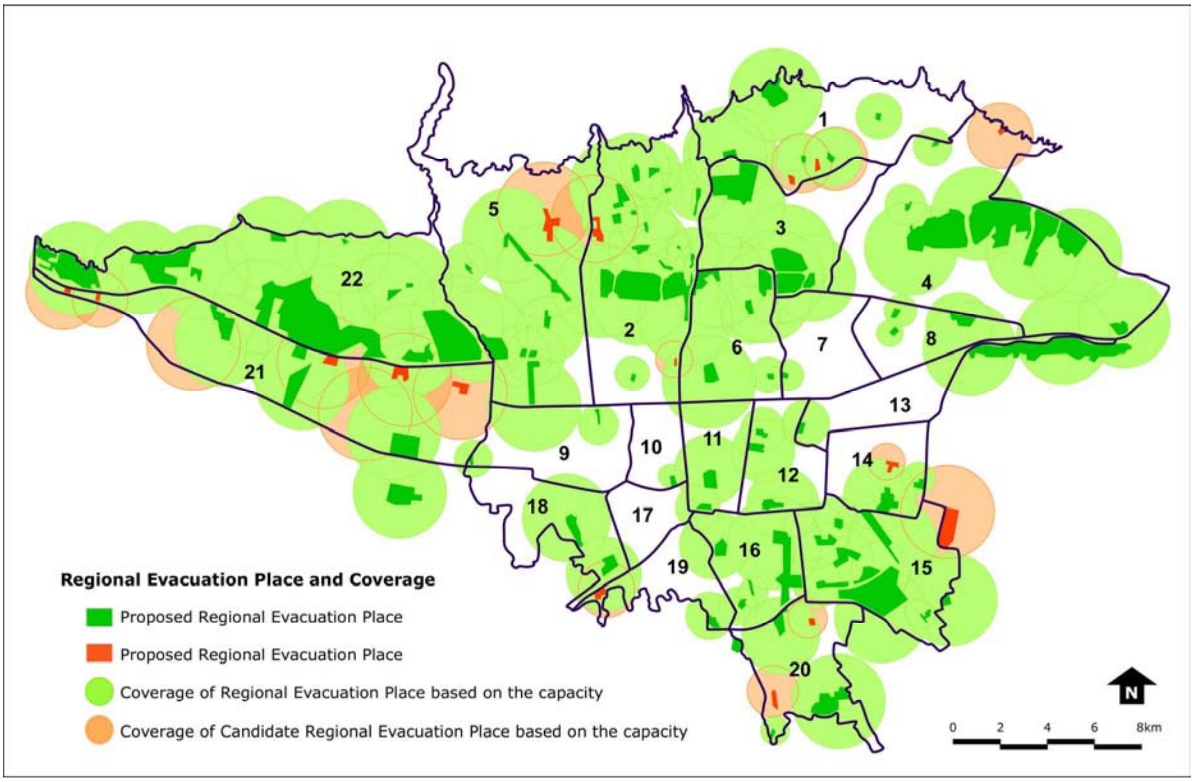
As the above table shows, regional evacuation spaces are not enough for District 7, 9, 10, 12, 14, 17, 19 in term of the capacity. The study team proposed some private land as candidate regional evacuation area. The list of that is in the following table.

Table 2.7.3 List of Candidate Regional Evacuation Place and Capacity

District	Candidate Regional Evacuation Place			
	Code	**Name of Place**	**Usage**	**Area (ha)**
1	A	Private Green Space, Sadr and Modarres Highway Intersection	Private	10.0
	B	Surroundings of Qeytarieh Building Complex	Private	11.6
	Total			**21.6**
2	C	Surrounding of water reserviour, in Farahzad	Private	5.5
	D	Vacant for Food Science Faculty, in Farahzad	Private	30.5
	Total			**36.0**
4	E	Farm, Soohanak	Private	16.5
	Total			**16.5**
5	F	Vacant, Shahrak Almahdi, Iran Pars	Private	41.8
	Total			**41.8**
14	G	Water Company, Armenia Cemetry, North of Shahid Mahalaty Highway and Soleymanie Shahrak	Private	14.8
	Total			**14.8**
19	H	Vacant, Green Space, Brick Factory, South of Saveh Road,West of Khalazair St.	Private	24.0
	Total			**24.0**
20	I	Cultivation along Shahid Rajaiee St.	Private	16.3
	J	Vacant, Storage, Company, along Fadaian Eslam St.	Private	9.5
	Total			**25.8**
21	K	Green Space, west of Sina Drug Production Factory	Private	6.0
	L	Green Space, East of Vilco Factory	Private	3.3
	M	Cultivation, west of Pars Electric Company	Private	21.7
	N	Pars Khodro Storage and Surrounding area	Private	35.3
	O	Iran Tire Factory, Ghods Arial Industry, Karaj Highway	Private	25.1
	Total			**91.4**

Source: JICA Study Team 2004

In light of capacity, seven districts are shortage of the regional evacuation place, as mentioned already above. But in light of distance from those evacuation places, most of the districts hold certain areas outside of coverage of the evacuation place. Figure 2.7.3 shows that area in white spreads means more than 2 kilometers far from evacuation place or area of the nearest evacuation place is not enough to accommodate all evacuees who lives within 2 kilometers-radius of the place. The coverage is calculated from capacity of the evacuation place and population density.



Source: JICA Study Team 2004

Figure 2.7.3 Regional Evacuation Place and the Coverage

5) Basic Approach for Improvement of Regional Evacuation Place

The study team proposed to establish a “Committee for Regional Evacuation Place” in TDMMC or Tehran Municipality Office. Major roles of the committee can be considered as follows;

- To review the regional evacuation place regularly in cooperate with Park and Open Space Organization,
- To coordinate with the private owners of candidate regional evacuation place to designate those areas as regional evacuation place, and
- To approach to land use planning and redevelopment projects for securing open space as regional evacuation place.

Based on GIS data, there are some parks and open spaces belonging to the Military which are not included in the above list. It is one of possibilities to secure these Military areas as regional evacuation place depending on political issues.

The area is outside coverage of the regional evacuation place, white area in Figure 2.7.3, has to be secure as regional evacuation place. In absence of those areas, to improve community evacuation place should be completed at least. Details of community evacuation place are shown in following Section 2.7.3.

6) Installation of Facilities in the Regional Evacuation Place

Based on size of each regional evacuation place, it should keep appropriate facilities and/or equipments for occurrence of an earthquake, that is, helicopter port, toilets, telecommunication system, water tank, food storage, and so on. Accordingly, relevant signboards should be set up at the regional evacuation place. The following figure shows signboards at regional evacuation places in Japan as one of example.

		
Signboard for "Regional Evacuation Place and Temporary Relief Place"	Signboard for "Emergency Heliport"	Signboard for "Relief Supplies Terminal"

Source: Official homepage of Odawara City, Japan

Figure 2.7.4 Examples of Signboard at Regional Evacuation Place

2.7.3 Community Evacuation Place and Evacuation Route

The study team recommends that a "Committee of Evacuation Place and Route" is established at District Municipality which can consist of district officers and volunteers from communities or local residence. As a pilot project in District 17, a district officer specified community evacuation places and evacuation route based on opinions from community's representatives. Advantage of involvement with local people is not only to accumulate local information but also to promote growing awareness of disaster prevention activities.

1) Selection of Community Evacuation Place

Each district shall identify its community evacuation place. Community level evacuation place should cover the whole Tehran Municipality completely. The study team prepared a guideline regarding community level evacuation place identification and distributed it to each district through TDMMC.

2) Evacuation Route

Designation of evacuation route is proposed to link and connect from community gathering/evacuation places to regional evacuation area safely, especially for the area as follows:

- Area in the zone located in the outside, 2 km from the regional evacuation place,

- Hazardous facilities are identified in the zone, and
- Designated emergency road /or expressway, highway and railway are passing through the zone.

In the selection of evacuation route, the following should be considered for safety reasons:

- Select roads wider than 15 m,
- Do not select route adjacent to the identified hazardous facilities as much as possible,
- Do not select route passing through vulnerable building area as much as possible, and
- Do not select the designated emergency road network as much as possible.

Maintenance and improvement of identified evacuation route should be done by district municipality and communities. For example, to carry out road markings on evacuation route is safe announcement for local people and to keep out illegal parking.

Source: Official homepage of Itabashi district municipality, Japan

Figure 2.7.5 Example of Road Marking on Evacuation Routes

2.7.4 Method of Evacuation

1) Recommendation and Instruction of Evacuation

It is necessary to let residents in the disaster area evacuate quickly to a safe place in the following cases:

1. When it is estimated that danger to human lives has seriously increased;
2. When it is estimated that human lives in a wide area will face the danger caused by flowing-out and diffusion of gas, etc.;
3. When a lot of fire breaks out at the same time caused by an earthquake and fires spread and expand; and
4. When it is deemed necessary to protect residents from disaster.

Recommendation and instruction of evacuation by respective agencies are as follows:

(1) TDMMC and District Municipality

When danger is imminent in its area of jurisdiction, the District Municipality shall, upon communicating with TMPMC, recommend or instruct evacuation after the evacuation needed area and evacuation place are specified.

When disaster has arisen or is about to arise and it is deemed necessary to protect human lives, District Municipality shall establish a warning area and restrict or prohibit the entry into such area and shall give the order when to move out from such area.

Even in ordinary time, it is necessary for each area or community (residents association) to grasp the actual condition of the area in respect of forming a group or self-governing situation at the time of evacuation.

(2) Regional Fire Brigade

The Fire Brigade shall recommend or instruct residents to evacuate when it judges that spreading of fire or diffusion of gas is rapid and that the danger to human lives is seriously imminent. On such occasion, it shall immediately notify the District Municipality.

2) Evacuation Guidance

The role and measures for the evacuation guidance in each organization shall be defined by respective agencies.

(1) TDMMC and District Municipality

When recommendation or instruction is issued, TDMMC shall quickly distribute the contents of recommendation or instruction by following measures:

- Announcement using speaker at mosques or schools
- Oral communication to residents or community leaders directly
- By utilizing mass media
- By utilizing publicity activity by Police Department or Fire Brigade

At the community evacuation place, staff members of the District Municipality shall form groups of respective areas, communities or companies with the assistance of Police Department and Fire Brigade. After that, they shall organize a group leader of communities or persons in managerial position of companies and shall guide them to the regional evacuation place. In such an event, evacuation of persons who are vulnerable to disaster such as sick persons, senior citizens or disabled persons is a top priority.

They shall make efforts to carry out evacuation and guidance for the safety of pupils and students, according to the situation of earthquake disaster, centering on each classroom teacher headed by a school principal.

In addition, TDMMC and District Municipality shall consider in advance the method in cases of evacuation when there is no time to issue recommendation or instruction of evacuation that corresponds to the actual situation of the area or the situation in which disaster takes place.

At the time of evacuation guidance, they shall allocate guides at important points of evacuation roads and carry out ad hoc public announcement on the site.

They shall allocate necessary number of guides at the regional evacuation places. They shall collect information relating to damage and public relations activity and help locate missing persons. They shall also take measures of re-evacuation if necessary and shall make efforts to keep the order at the evacuation place.

(2) Fire Brigade Department

The Fire Brigade shall notify TDMMC and the District Municipality about most safe route and directions of evacuation taking into account the size of disaster, situation of roads and bridges, path of fire and operation of fire fighting.

When evacuation begins, the fire-fighters shall engage in evacuation guidance.

Fire fighting activity after the point when recommendation or instruction is issued shall endeavor to secure the safety of evacuation places and evacuation roads.

2.7.5 Operation and Maintenance of Evacuation Place

1) Operation of Evacuation Place

The operation of evacuation places shall be conducted, in principle, by RCS. However, the District Municipality shall cooperate with the RCS.

In order to maintain the safety of evacuating residents, the District Municipality shall take appropriate measures and quickly respond to the progress of situation and shall specify the operation in advance in respect of details and method.

The measures shall involve the following:

- To allocate staff necessary for the operation, taking into account the size of evacuation places and surrounding situation;
- To secure means of information distribution, to provide accurate information in a timely manner and to issue appropriate instruction;
- To secure first-aid station and first-aid trained staff for the purpose of providing emergency medical care for injured or sick persons;

- To make efforts to maintain sanitary condition of evacuation places;
- To arrange water, food and emergency goods with the cooperation of RCS to specify the distribution method and to execute fair and effective allocation; and
- To guide evacuating persons going back to their homes safely and smoothly when evacuation is lifted.

2) Maintenance of Communication Material and Equipment for Evacuation Guidance

TDMMC and District Municipality shall make efforts to maintain the wireless system that is used when they conduct evacuation guidance of disaster victims and rescue and aid activity. The wireless system shall also be used for the purpose of ensuring the direction, order and information distribution between the RCS, the Fire Brigade and the Police Department engaged in the on-site activity.

In addition, since it is necessary to obtain a lot of traffic information, they shall make efforts to maintain the wireless system so that proper and timely decision can be made in the regional and community evacuation places.

2.8 Emergency Road Network

2.8.1 Current Situation of Emergency Road Network

1) Tehran Primary Emergency Road Network Plan Prepared by TDMMC

Tehran Disaster Mitigation and Management Center formulated "Primary Road Network during Disaster (Roads Required by Fire Brigade)" in cooperation with Tehran Comprehensive Traffic and Transportation Study (TCTTS) in 2002.

(1) Scope of the Study

The objective of this study is preliminary designation of emergency roads from existing road network that are required during disaster.

In this study, network of roads is defined as emergency network for relief operations that can provide access to "Relief Center" to "Vulnerable Units" in Tehran City.

A. Relief Center

In this study, Tehran Fire Brigade which have 55 fire-fighting stations, are recognized as relief center. These organizations with 128 vehicles are in charge of relief & rescue and fire-fighting operations. Road network has been analyzed for access of fire stations to vulnerable areas. Fifty-five (55) fire stations and fire-fighting command headquarters have been identified and a GIS file for these stations and centers were prepared.

B. Vulnerable Units

In this analysis, two groups of vulnerable units that require fire-fighting services are taken into consideration. These units are census units and hazardous facilities.

a. Census Units

Census units numbering 3,169 with populations by the Statistics Center of Iran (SCI) recorded in 1996 were used as destinations of network analysis, as residential hazard points.

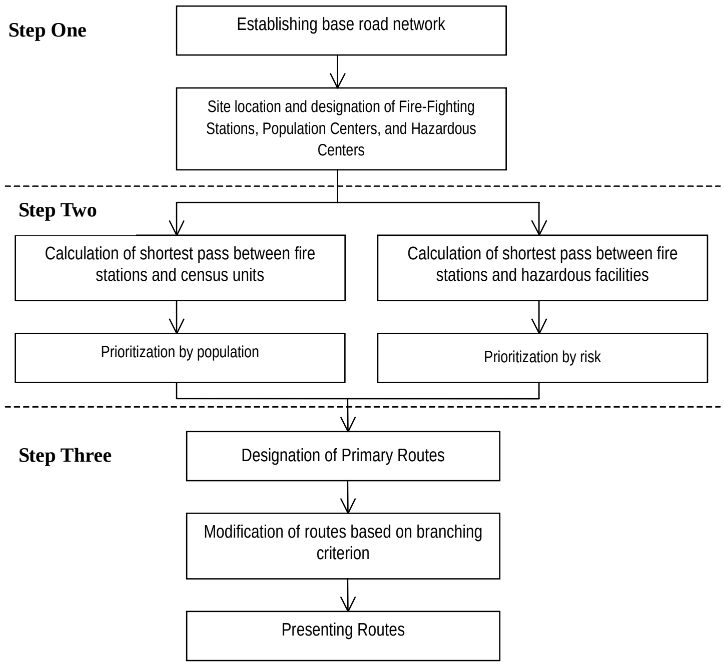
b. Hazardous Facilities

The 814 places identified by JICA Study Team in 2000 were used as destinations of network analysis, as hazardous facilities.

This network is to be designated in such a way that it provides the shortest passing route from relief centers to census units and hazardous facilities.

(2) Process of Analysis

The process of analysis is shown in Figure 2.8.1. In the first step, the road network was edited and modified. Then data files of fire-fighting, population and hazardous centers were established based on ArcView and Network Analysis. In the second step, the shortest routes between fire stations and all census units were calculated by using the shortest pass analysis program. Then the calculated shortest routes between fire-fighting stations and census units were prioritized. Prioritization was done in a way that a value was allocated to each designated route from one fire station to one census unit according to its population. Then by aggregating the routes, the values of connections forming these routes were determined on road network. This process was applied for routes between fire stations and hazardous facilities, but in this case the index for evaluation was the risk factor for each hazardous center. At the end of the second step, the primary emergency routes were designated. These primary routes form a network consisting of 44,258 roads, or 30% of road network. To select the most important road of this network, prioritization was done on the basis of value of each connection in the prepared network. For first priority of the road network between fire stations and populations, the connections were selected in such a way that the sum of their total value was 70% of aggregated value of all connections. In the same way the first priority of road network between fire stations and hazardous facilities was determined, a series of roads were selected that consist of 63% of aggregated value of all roads in the network. After this stage, by merging the selected roads for two situations, the primary routes were selected. Finally, some of the routes were modified based on set criterion and by engineering judgment.

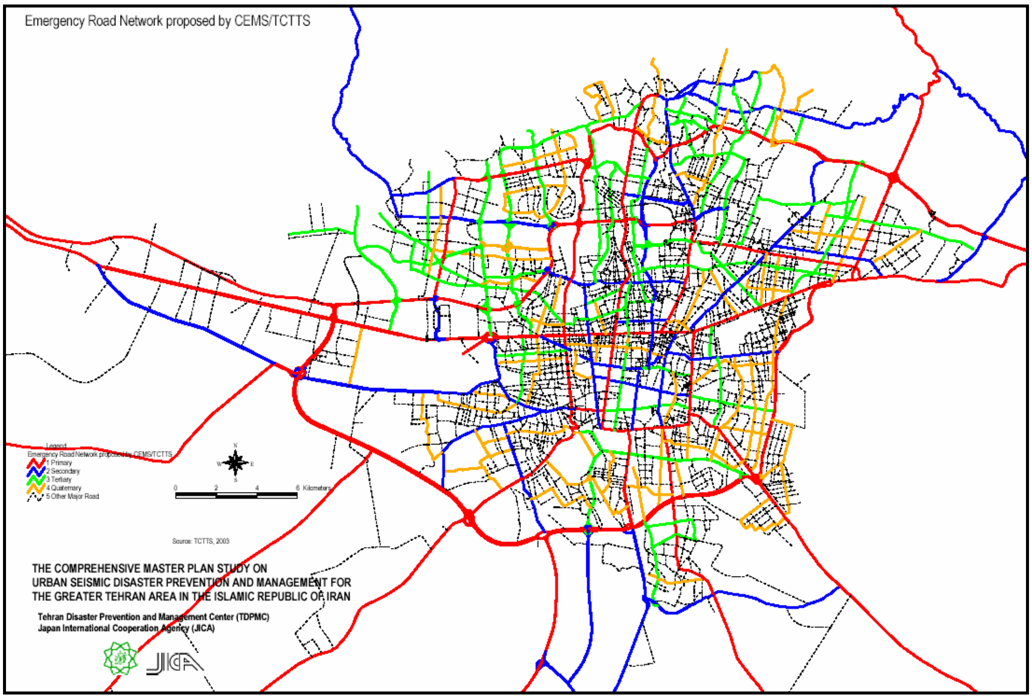


Source: JICA Study Team

Figure 2.8.1 Study Flow of Emergency Road Network by TDMMC

(3) Result of Analysis

Figure 2.8.2 shows the final result of the analysis.



Source: JICA Study Team

Figure 2.8.2 Primary Emergency Road Network by TDMMC

2) Review of the Plan

The JICA Study Team preliminarily proposed the emergency road network. In this proposed network, governmental offices are selected as origins and destinations of shortest pass analysis for primary emergency road network. Rescue and relief centers such as fire-fighting stations, hospitals and medical centers are used for secondary emergency road network. Thus, policy and approach of the JICA Study Team and TDMMC are fairly different.

The JICA Study Team briefly reviewed the report on Primary Road Network during Disaster (Roads Required by Fire Brigade) by TDMMC and following points can be singled out for consideration:

1. Approach to obtain the emergency road network by the JICA Study Team and TDMMC is different. In the JICA Study, government office is considered to be emergency response headquarters and traffic flows between these offices were given the first priority. This is the general procedure for emergency management control. On the other hand, TDMMC focused the road network specialized for rescue operation.

2. It is completely not clear at present which network is superior or important. Comparison of these networks is not meaningful in this very preliminary stage.

3. Both networks use same road network data and similar calculation methods. However, data itself are incomplete and no better than "trial."

4. There is common recognition that emergency transportation network shall be analyzed by the shortest pass analysis using GIS database and programs.

5. It is indispensable to investigate and study what kind of origins and destinations of traffic flows have higher priority. Conditions of velocities and quantities of traffic flow shall be determined in order to obtain appropriate networks.

6. Members of the JICA Study Team have transferred the technology of the shortest pass analysis to TDMMC. Therefore, TDMMC shall go into further step with the cooperation of the Traffic and Transportation Deputy and TCTTS. For this purpose, increment of the accuracy of the GIS data should be achieved. At present, aggregated data for each governmental and relevant organization are only classified by their name. The role, function and capability are not very clear. These must be identified and clarified so that the priority of each organization in case of emergency can be distinguished.

Taking the above circumstances into consideration, the JICA Study Team presents the basic policy and recommendations for traffic control in the next section.

2.8.2 Proposed Emergency Road Network System

The proposed Emergency Road Network System is consist of two levels of road networks, which correspond to the required timing of emergency response activities as follows.

1) Primary Emergency Road

It links with Disaster Management Centers of national, provincial, municipality, district, and sub-district municipalities and major airport and seaport as for transportation nodes.

In order to set-up the network, all of centers have to be clearly identified and categorized on the base map.

2) Secondary Emergency Road

It links with all the identified emergency response centers of rescue/fire fighting/security, emergency road, and medical care.

Also, all emergency response centers have to be clearly identified and categorized on the base map.

Emergency road network should be selected from the existing arterial road network, the roads of which are required wider than 15 m to avoid and minimize influences from roadside building damages and secondary disasters. Emergency road network should not be excessively designated. It should be set in coordination with actual capabilities of each emergency response taskforces of debris removal, traffic control, etc. Otherwise, the designated emergency road network could not work and be used within 3 days after an earthquake, which is the time limit for full operation of emergency response activities.

2.8.3 Approach and Method for Emergency Road Network

GIS-based Shortest Path Analysis Method is proposed and applied to identify the minimum time distance route to link with the identified centers for each level of emergency road. The shortest path is analyzed on the road inventory database of TCTTS. The Preliminary Emergency Road Network of JICA is selected on the sum of estimated trips on each road section between each center based on Shortest Path Analysis.

The following are required reviewing points of the JICA proposed three levels of Emergency Road Network:

1. The identified center on the steps of 1/2/3 should be revised, when the Emergency Response Plan is finalized.
2. Based on the above finalized plan, JICA identified Centers shall be replaced to the finalized center.
3. Shortest path analysis shall be applied for the above new centers. And two levels of emergency road network shall be finalized.
4. Seismic resistance diagnosis is proposed for all bridges on the selected emergency road. And structural strengthening and reconstruction program shall be formulated for the assessed vulnerable bridges.
5. Road improvement program is proposed in the following vulnerable sections:

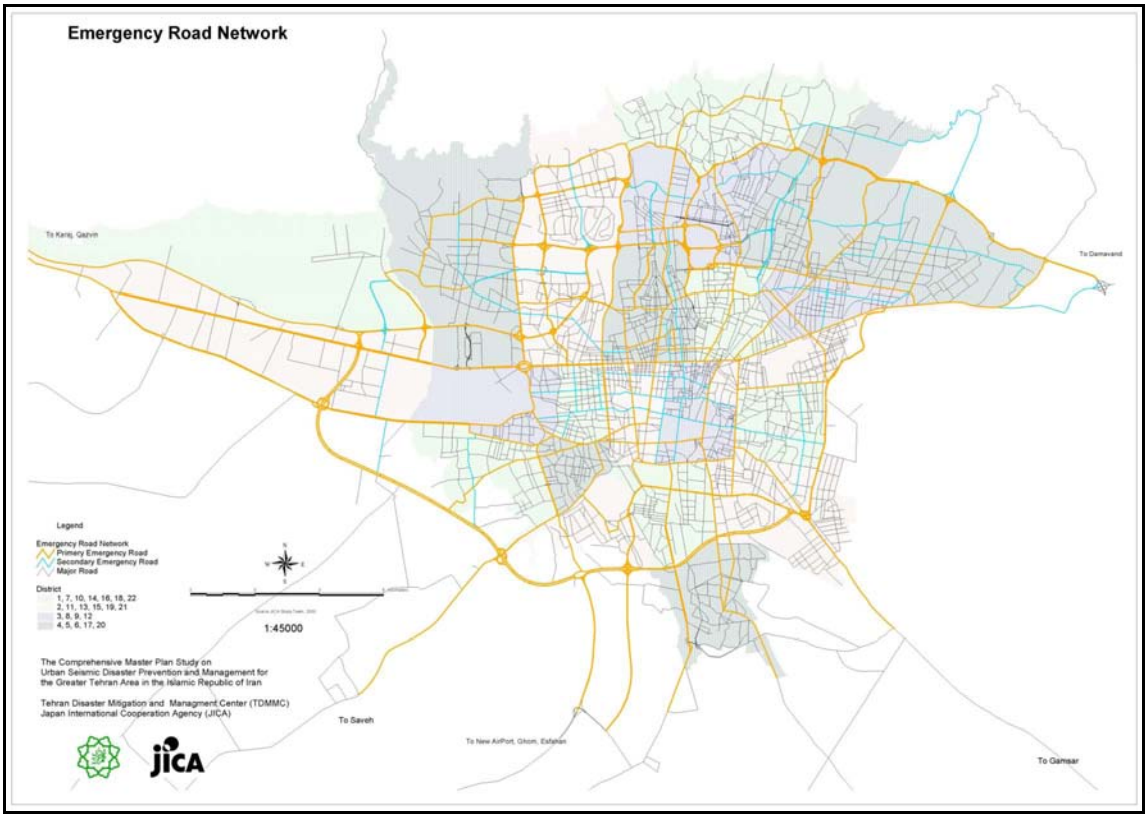
Road widening for narrow road section

Preparation of buffer zone to mitigate influence for hazardous road section

Retrofitting and reconstruction of assessed vulnerable buildings on the roadside.

2.8.4 Emergency Road Network

The Study Team identified the emergency road network by using shortest path analysis. The following figure shows emergency road network in the Study Area.



Source: JICA Study Team

Figure 2.8.3 Proposed Emergency Road Network

1) Primary Network

Identify Disaster Management Centers/Major Transportation Node for Primary Emergency Road (most of required data were provided by responsible agencies).

1. National Level: Ministry of Interior and all the members of NCNDR
2. Provincial Level: Provincial Disaster Management Center
3. Municipality Level: TDMMC
4. District Level: District Disaster Management Center or District Offices
5. Sub-District Level: Sub-District Offices
6. Air Transport Node: the existing and new international airports
7. Public Relation: Radio/TV Station, News Agency

List of Primary Road Network is shown in Figure 2.8.1

Table 2.8.1 List of Primary Road Network

No.	Name	No.	Name	No.	Name
1	17th. Shahrivar St.	36	Jenah Exp.way	71	Rajaee Exp,way
2	Abshenassan Exp.way	37	Karaj Highway	72	Ressalat Exp.way
3	Amin ol molk St.	38	Karaj Special Highway	73	Sadr Exp.way
4	Andisheh Blvd.	39	Kargar North St.	74	Saheb Jam St.
5	Asbdavani Exp.way	40	Karimkhan Zand St.	75	Saidi Exp.way
6	Ashrafi Esfahani Exp.way	41	Keshavarz Blvd.	76	Samadi St.
7	Azadegan Highway	42	Khavaran Exp.way	77	Shahid Ghayori St.
8	Azadi Sq.	43	Kordestan Exp.way	78	Shahid Rajabnia
9	Azadi St.	44	Latifi St.	79	Shahid Tondgoyan Exp.
10	Azari St.	45	Madani Exp.way	80	Shahid_e Gomnam Exp.way
11	Babaee Exp.way	46	Masil Bakhtar St.	81	Shahran Blvd.
12	Basij Exp.way	47	Mehran St.	82	Shariati St.
13	Basij Sq.	48	Meysami Blvd.	83	Sheykh Fazlollah Nouri Exp.way
14	Behdari St.	49	Milad Blvd.	84	Shoush St.
15	Behesht Zahra Highway	50	Misagh St.	85	Taavon Blvd.
16	Beheshti St.	51	Moallem Blvd.	86	Taleqani St.
17	Besat Exp.way	52	Modares Exp.way	87	Tehran_Qom Highway
18	Chamran Exp.way	53	Molavi St.	88	Tehran_Varamin Road
19	Damavand St.	54	Molla Sadra St.	89	Tello_Lashkarak Road
20	Darabad Exp.way	55	Monirieh Sq.	90	Valiasr St.
21	Dasht_e_Azadegan	56	Mostafa Khomeini St.	91	Yadegar_e Emam Exp.way
22	East Azadi Sportland Blvd.	57	Motahari	92	Yaftabad St.
23	Ebn_e Sina St.	58	Navab Exp.way	93	Zamzam St.
24	Emam Hosein Sq.	59	Nejatollahi St.	94	Zandieh St.
25	Enqelab_e Eslami St.	60	Niavaran St.	95	Ziba Shahr St.
26	Estadiom St.	61	Niayesh Exp.way		
27	Estakhr Blvd.	62	Noor St.		
28	Evin Exp.way	63	Parvin Blvd.		
29	Fadaeean_e_Eslam St.	64	Pasdarran St.		
30	Fath Exp.way	65	Pirouzi St.		
31	Haqqani Exp.way	66	Qaleh Morghi St.		
32	Helal_e_Ahmar St.	67	Qazvin St.		
33	Hemmat Exp.way	68	Qoddousi Blvd.		
34	Jahad Sq.	69	Qom Road		
35	Jalal_e Ale Ahmad Exp.way	70	Rah Ahan Sq.		

Source: JICA Study Team 2004

2) Secondary Emergency Road

Identify Emergency Response Centers for Secondary Emergency Road.

1. Fire Fighting/Search/Rescue/Security: Fire-fighting Stations, Red Crescent, Police Station, Military force.
2. Medical/Health Care: Ambulance Center, Hospital, Health Center, Blood Center, and storage of medical equipment/medicine.

3. Emergency Road: Traffic police (GIS Data), Traffic Control Center, Road Maintenance Dept., City Service Center and Related Private Companies for Debris Removal,
4. Autopsy/Identification/Burial Service: Autopsy Organization, Beheshte, and Identification.
5. Building Inspection/Temporary Housing Supply: Responsible agencies could not be identified yet,
6. Debris Removal: City Service Center and Related Private Companies, contractors for Debris Removal, and Debris Disposal Site,
7. Lifeline-1 Water: Purification plants and Reservoir with emergency/ rehabilitation centers
8. Lifeline-2 Gas: All Emergency Response and Rehabilitation Centers
9. Lifeline-3 Electricity: All Emergency Response and Rehabilitation Centers
10. Lifeline-4 Telecom: All Emergency Response and Rehabilitation Centers

Data and information of underlined facilities could not be obtained from responsible agencies. List of Secondary Road Network is shown in Table 2.8.2

Table 2.8.2 List of Secondary Road Network

No.	Name	No.	Name	No.	Name
1	142 West St.	21	Golestan St.	41	Narenjestan 7th
2	15 Th Khordad St.	22	Golha St.	42	Nbovvat Sq.
3	30 m Jey	23	Hafez St.	43	Niayesh Exp.way
4	AbouSaeed St.	24	Hashemi St.	44	Nosrat St.
5	Alghadir Blvd.	25	Janbazan East St.	45	Ostad Hasan Banna St.
6	Amirkabir St.	26	Janbazan West St.	46	Ozgol Exp.way
7	Araqi Exp.way	27	Jeihoun St.	47	Paknejad Blvd.
8	Ayat St.	28	Jomhouri Eslami St.	48	Parvin Blvd.
9	Azizi St.	29	Kamali St.	49	Qanat Kosar St.
10	Badiei St.	30	Kashani Blvd.	50	Qarani St.
11	Bahar Blvd.	31	Khaled Estamboli St.	51	Ressalat Exp.way
12	Baharestan Sq.	32	Khalij St.	52	Rodaki South St.
13	Chogan Blvd.	33	Khayam St.	53	Sattar Khan St.
14	Dolat St.	34	Komail St.	54	Seraj St.
15	Emam Khomeini St.	35	Kordestan Exp.way	55	Sobhani St.
16	Esteqlal St.	36	Laleh Blvd.	56	Soleimani St.
17	Fajr Blvd.	37	Lashkarak Road	57	Vafadar Exp.way
18	Ferdosi St.	38	Mirza_ye Shirazi St.	58	Vahdat_e_Eslami St.
19	Gandi St.	39	Moayeri St.	59	West Azadi Sportland Blvd.
20	Golbarg West St.	40	Nabard St.	60	Zartosht East St.
				61	Zeyneddin Exp.way

Source: JICA Study Team 2004

3) Improvement and Maintenance of the Emergency Road

Improvement of identified emergency roads above, both primary and secondary ones, should be carried out for the time of disaster. The preparation can be considered as the following items and done by TDMMC cooperate with other organizations such as the police department and traffic police;

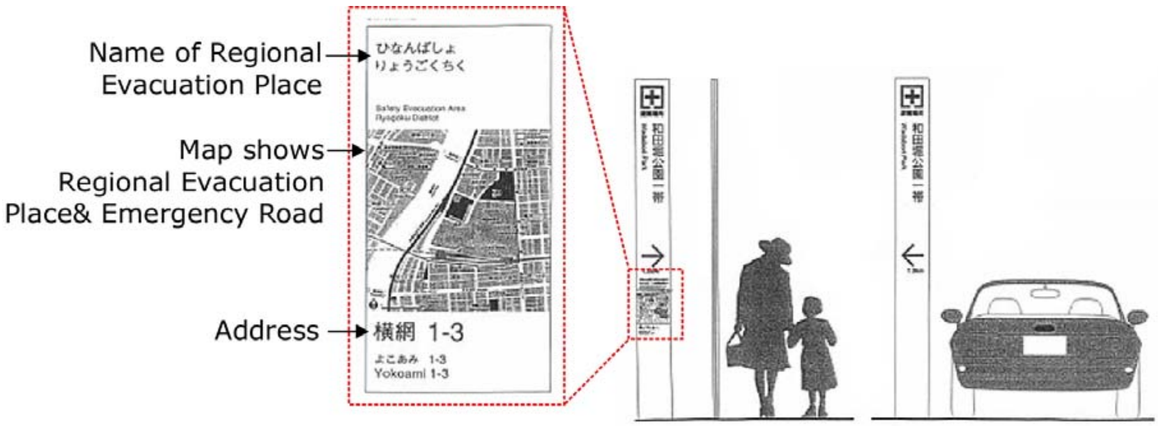
- To avoid blocking the emergency road by collapsed building, it keeps the building along the roads less than seven meters high as well as strengthening the building
- To strengthen bridges and pedestrian decks cross the emergency roads
- To strengthen traffic light and to set up emergency power generating system in major intersections
- To set up emergency telephones and loud speakers along primary emergency road
- To put signboards for announcement of emergency road and for evacuees (see Figure 2.8.4 and Figure 2.8.5)

It is also necessary to maintain those facilities and equipments, and to inspect illegal parking on the emergency roads in cooperation with traffic police department.

Source: Metropolitan Police Department, Japan

Note: Catfish is a symbol of earthquake in Japan

Figure 2.8.4 Signboard of Emergency Road in Tokyo, Japan



Source: Tokyo Metropolitan Government, Japan and modified by JICA Study Team

Figure 2.8.5 Signboards on Emergency Road for Evacuees in Tokyo, Japan

2.8.5 Implementing Policy of Traffic Control

The implementing policy of traffic control can be classified into control from space aspect and time aspect.

1) Control from Space Aspect

Traffic control from space aspect includes route control and area control.

(1) Route Control

The route control covers road sector and route. Total prohibition or partial prohibition on traffic in which passage of vehicles other than designated ones is prohibited is implemented. Designation of emergency road or emergency transportation routes falls under this category. If a user of a vehicle intends to go through a road for which traffic regulation is implemented, the user shall apply to the Traffic and Transportation Deputy of the Tehran Municipality and shall obtain a slip and a certificate after the prescribed confirmation procedures are taken. A slip for emergency transportation vehicle is issued to vehicles that engage in emergency operations. A problem of a slip for passage permission is that hand-written slips or forged slips prepared by copying are used. Since it takes time to establish a system for issuing the slip when a disaster occurs, even formal emergency operation vehicles may try to have counterfeit documents. It becomes necessary to issue a lot of slips immediately after the occurrence of disaster; therefore it is necessary to prepare the system in advance.

Emergency road network and emergency transportation route shall be designated in advance. The JICA Study Team preliminarily proposed the emergency road network shown in Chapter 5. TDMMC also proposed the emergency road for rescue operation. It is not only for enabling persons in charge of traffic control to take subsequent measures promptly, but also for preventing confusion by letting general vehicle users know the emergency transportation routes in advance.

In this sense, nothing is more important than letting the general public fully understand emergency transportation roads and rules for the control. In addition, it is necessary to provide information concerning emergency transportation routes and the situation of control on such routes immediately after the occurrence of a disaster by using any and all media.

(2) Area Control

The area control is to regulate the traffic in a uniform manner, not only for disaster-affected areas but also for surrounding areas. One can imagine possible cases in which it becomes impossible to go through roads because of collapse of structures along roads such as roadside houses, buildings, power poles or fences, and road traffic function is paralyzed in the surrounding blocks of areas. In addition, it becomes necessary for some areas in which traffic of ordinary vehicles must be prohibited on roads other than emergency transportation routes for purposes of works of removing debris and recovering lifelines. It is necessary to carry out traffic control for such areas on passage of vehicles other than emergency vehicles and to determine in advance the scope of establishment of, and the implementation policy for, the regulation.

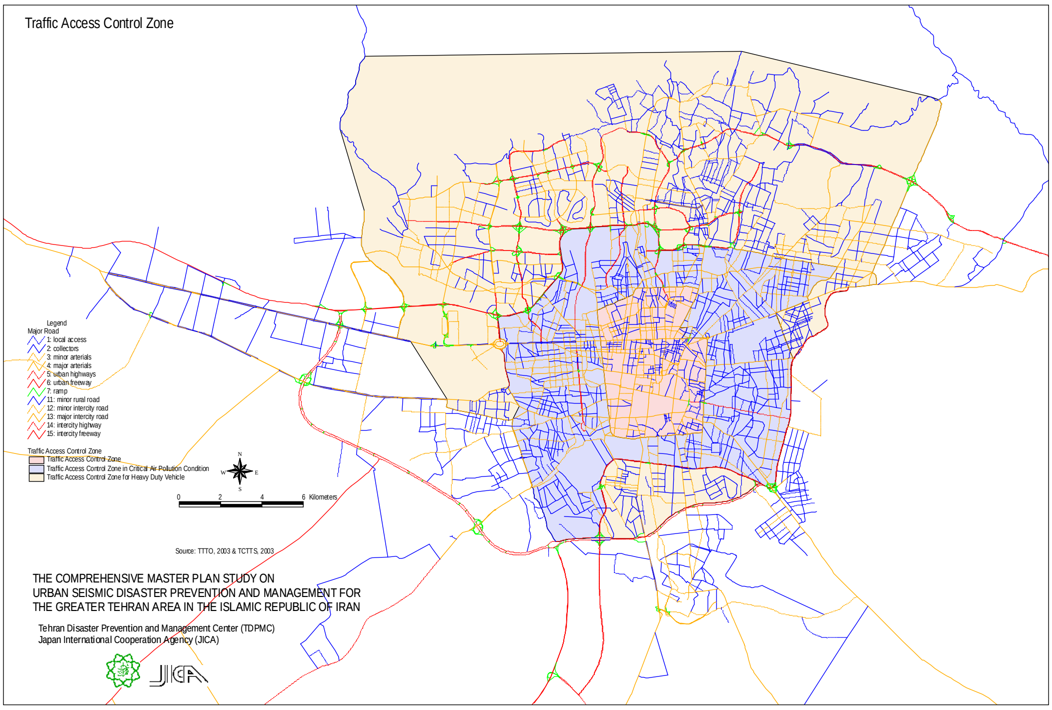
It is desirable for the implementing policy of area regulation to decide, in advance, the unit of blocks for the area regulation. The reason is that it is rather difficult, and it takes time and requires workloads, to establish the subject areas of the area regulation in the confused state of affairs after a disaster occurs. If a unit block for the subject of regulation is decided, in advance, to be the minimum unit of certain areas surrounded by a major trunk road, a trunk road or supplementary trunk road, it is easy to compose a middle unit block or large unit block by combining neighboring unit blocks depending on the situation. In such a case, it would be convenient for the actual regulation, although it depends on the situation of road network, if the minimum unit of a block is made to correspond to the degree by each district.

When a block or a zone for the area regulation is established, the number of inflow roads is limited, and only the permitted vehicles are authorized to enter the subject area. What is important on such occasion is to make ordinary vehicle users be fully aware of information relating to the subject block for which the regulation is implemented, and frequent public relations activity by mass media is necessary.

Enforcement of the area regulation is deemed to be easier than enforcement of route regulation since points of inflow are limited.

Figure 2.8.6 shows the traffic access control zones decided by Tehran Municipality. Red colored zone is central business district and yellow colored zone is heavy-duty vehicle restricted zone. These two zonings are ordinarily applied in the usual time. Blue colored zone is traffic access control zone in case that the condition of air pollution exceeds a certain value.

These zonings are not for emergency. However, these zones are well known and identified by citizens in general who drive vehicles. Therefore, this zoning system can be considered as a first step of the formulation of emergency road control zoning.



Source: JICA Study Team

Figure 2.8.6 Traffic Access Control Zone

2) Control from Time Aspect

Detailed regulation by a unit of time is unrealistic in a state in which traffic is chaotic at the time of disaster, and rough regulation, which takes into account the actual situation of traffic in daytime or nighttime or on weekdays or weekend, is appropriate. However, it would be better to avoid, as much as possible, changing the regulation time depending on the traffic situation. The reasons is that, if the regulation is changed frequently, it becomes difficult to make information concerning regulation fully understood, mistrust to the regulation arises and it is feared that the traffic situation becomes even unstable by contrast.

Since emergency aid is quite important in a confused state immediately after the occurrence of a disaster, it is a basic policy to let emergency vehicles go through on emergency transportation routes firstly and to prohibit any and all passages by ordinary vehicles even on designated roads. As traffic for assistance and recovery gradually increases in two or three days following the occurrence of the disaster and the state of traffic becomes normal, the traffic regulation that makes much of the security of emergency transportation roads is introduced.

In several weeks or approximately a month, it is considered that the volume of traffic becomes different in daytime and nighttime, and it may be thought that the designation of emergency transportation roads is lifted. However, based on the experience at the Great Hanshin Earthquake Disaster, it is considered to be difficult to lift the designation of emergency transportation roads on weekends.

3) Traffic Enforcement and Provision of Information

Whether the traffic regulation can achieve its objectives largely depends on the implementation system of the traffic enforcement. Although emergency transportation routes are proposed, it is quite difficult to restrict the inflow of ordinary vehicles only by means of barrier, cone or allocation of police officers if the number of entry point on crossing roads and areas along roads is enormous. And it can be well imagined that illegal parking or abandoned vehicles on emergency transportation roads causes traffic jam. Therefore, in order to enhance the effect of traffic regulation, it is necessary to provide information quickly by using any and all means.

Disaster information given to vehicle users includes the following:

- Place of occurrence of the disaster;
- Level and scope of the disaster;
- Details of road control;
- Estimated time to recovery, and so on.

The research at the time of the Great Hanshin Earthquake Disaster has revealed that, if the scale of a disaster is large, the percentage of persons who refrain from making a trip by car increases. And, if the situation of traffic regulation is known, users abstain from driving to regulated routes or areas. One can expect an effect of preventing traffic jam from expanding even by providing such simple information.

What is more effective is to offer guided instruction for a roundabout course in addition to the provision of traffic information. In particular, it is desirable to strongly induce traffic through disaster-affected area to take the roundabout course. Information of the situation in which severe regulation is being implemented should be given to vehicles entering the disaster-affected area from points far away from the disaster-affected area.

2.9 Case Study on District 17

Based on the several analyses, it can be said that district 17 is the most vulnerable area in Tehran. The study team visited to the district 17 municipality office in June 2004 and could obtain some information about area redevelopment project. The district municipality has already selected 11 sites as candidate redevelopment area. In this section, the study team prioritizes for those sites with screening from the disaster prevention viewpoints. Most of the data used in this section is based on detailed data provided from the district 17 municipality office, TGIS data and sight surveys by the study team.

2.9.1 Background of District 17 Program

1) Historical Background

Process of immigration, settlement of population and construction of residential units in this district, like many other marginal districts in Tehran, started during years 1956 to 1969 and followed by immigration to the district that was composed mainly of the northwestern part of the countries and large Azarbaijani tribes, the division of lands into small parcels started (about 67.5 percent of existing housing units in the district have an area less than 100 m^2) and construction proceeded in divided parcels without any plan preparation. The first signs of deteriorated and insufficient areas appeared during these years, especially because the immigrants have implemented their own culture and beliefs in construction. Thus the usage changed into urban land usage.

A review on history of formation of the district indicates that the trend of change in physical structure of the district and later changes is more due to trend of socio-economic evolutions at national and metropolitan levels rather than environmental conditions of the district and have been created due to major factors such as rapid growth and development of Tehran, expansion of Tehran urban area because of socio-economic changes and finally migration of population from other parts of the country due to proper working backgrounds for occupation, this district has also suffered from drastic changes as one of marginal districts of Tehran.

2) Social and Economical Background

A population of district 17 was 287,367 persons in 1996. The population is decreasing year by year, in which the annual growth rate was 0.98 during 1986 and 1996. There are several reasons for this decrease that can be pointed out such as deterioration, congestion and lack of urban services in the district. In terms of the population density in district 17, it was the highest density which was 361 persons per ha in 1996. It was more than three times comparing an average density of Tehran which is 110 persons per ha in 1996.

Based on recent studies[4], the household expenses of residents of district 17 were almost half of average household expenses in the Tehran metropolitan. Since there was a direct relationship between income and expenses of households, we can say that this district is one of the poor ones at Tehran level. Table 2.9.1 shows the average of total household expenses segregated by expenses at Tehran and district 17.

[4] The result was made by ATEK's New Master Plan Study (Systemization), 1987

Table 2.9.1 Average Expenses at Tehran and District 17

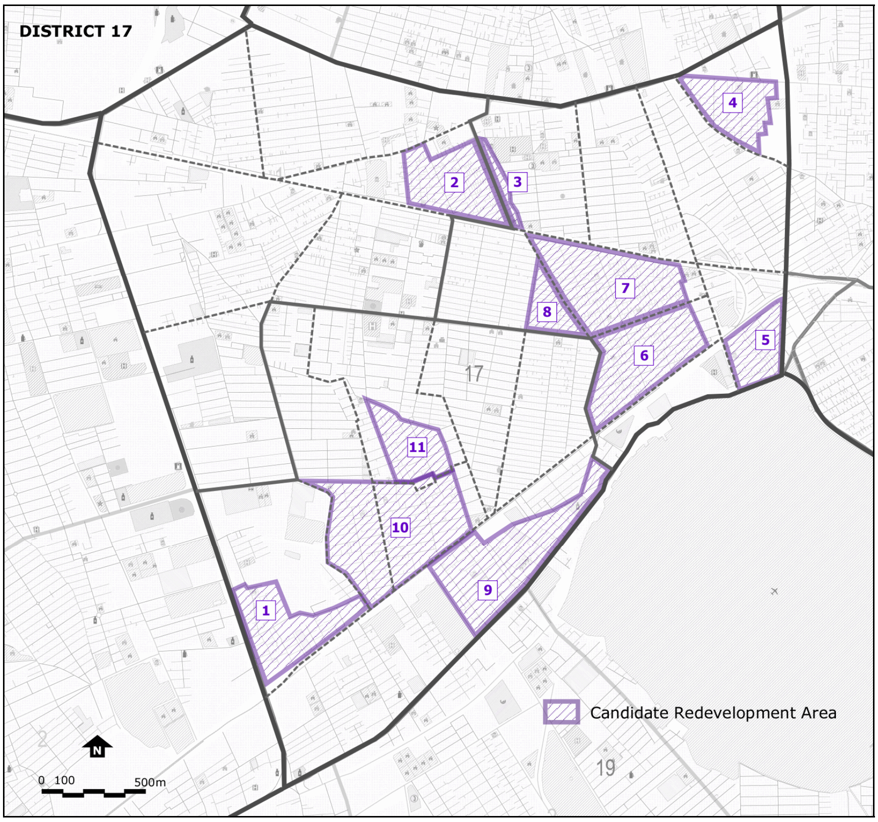
	Average of total expenses (Rial) per month	Food expenses (Rial)	Other expenses (Rial)	% of food expenses to total expenses
Tehran City	131,230	46,355	84,875	35.3
District 17	62,053	29,812	32,241	48

Source: Sampling from household income and expenses in Tehran – 1987, Iran Census Center

Settlement of industrial-workshop units in the district and environmental pollutions caused by them and population density have all caused that the present land price in this district of Tehran metropolitan is very low. Any motivation for private sector investment for rehabilitation and reconstruction in the district have not had because of (the) following reasons such as low land price, existence of disturbing industries, settlement of various production and service businesses, existence of polluting industries, formation of congested texture, lack of immediate and smooth communication between this district and other marginal districts, existence of small land parcels. This is because of low-income social classes; they are not able to take any measures for rehabilitation and reconstruction by themselves.

2.9.2 Candidate Redevelopment Site

Eleven candidate sites of area redevelopment are chosen by District Municipality at June in 2004. The locations are shown in Figure 2.9.1.



Source: District 17 Municipality Office and JICA Study Team 2004

Figure 2.9.1 Location Map of Candidate Sites of Area Redevelopment in District 17

The candidate areas or 11 zones cover an area of 150.8 ha equivalent to 18.9 percent of total lands in the district. In these 11 zones, as per public census of 1996 the population was about 92.275 or 32.1 percent of total district population and according to results from sampling by EMCO Consultants in 2002 these zones had a population of about 81,985.

According to Table 2.9.2, in most of the candidate area, population density is relatively high and each area of housing unit is quite small comparing with the average of district 17.

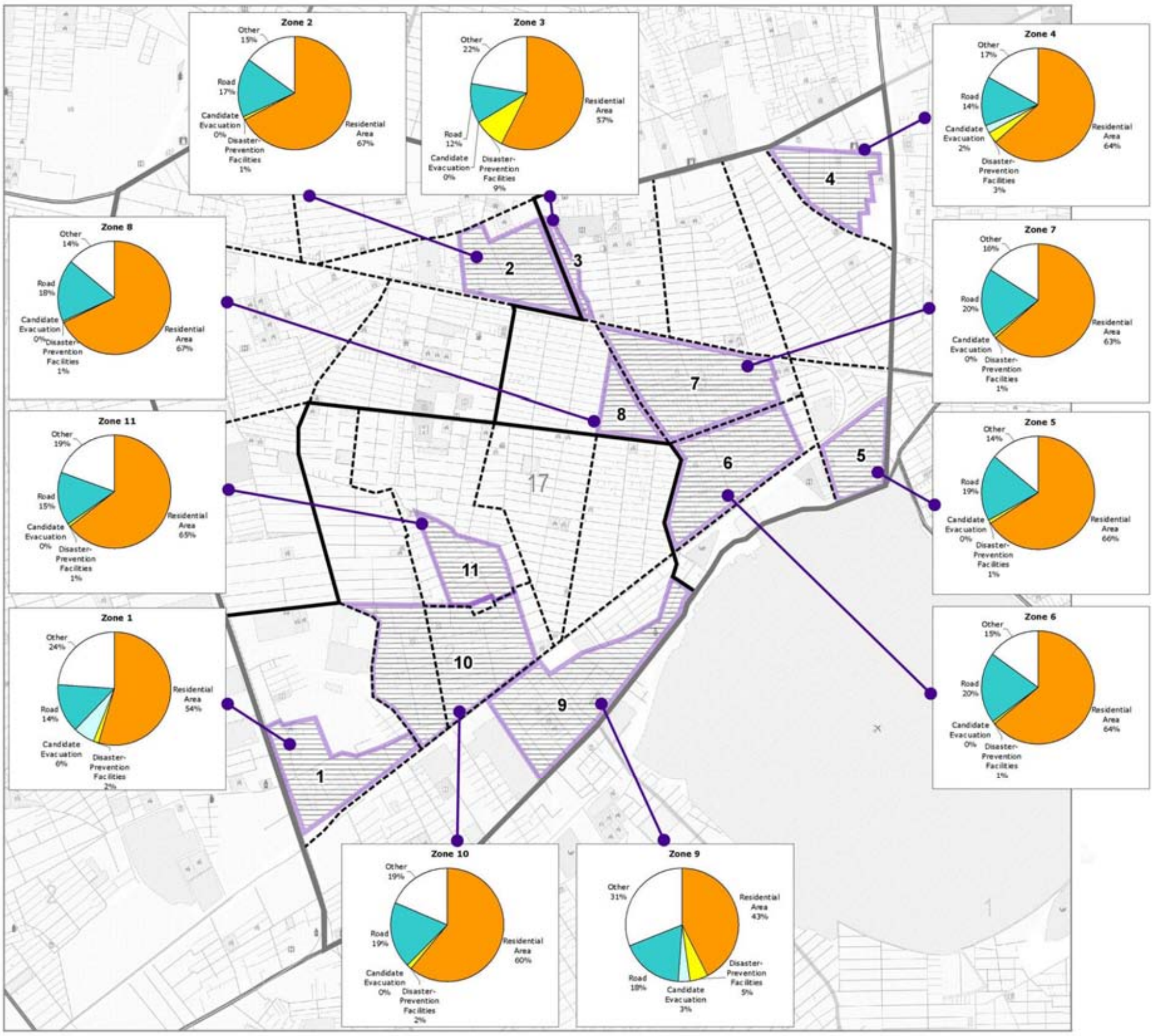
The highest population density is 749 persons/ ha in Area 8, and the next is Area 10. On the other hand, the smallest housing unit is 47m^2/house in Area 8, and the next is Area 3.

Table 2.9.2 Characteristics of Candidate Site

Site No.	Area (ha)	Population in 2002	Density (person/ha)	No. of Household	Area / Housing Unit (m2)
1	13.0	4,924	378	504	141
2	12.9	7,468	577	1,192	73
3	1.7	1,044	602	159	63
4	9.3	3,884	419	614	96
5	9.0	5,684	635	875	67
6	18.3	11,335	620	1,499	78
7	20.2	12,709	631	1,974	65
8	5.0	3,754	749	720	47
9	22.2	5,993	271	691	136
10	29.2	19,794	679	1,750	102
11	8.4	5,396	645	543	99
Average of District 17			361		88

Source: Sampling survey conducted by EMCO consultant. The data is provided by District 17 municipality office.

In terms of land use in the district, it can be said that a major area is used for residential, and on the contrary, available land for evacuation such as parks, open spaces, and sport fields is small. Also disaster prevention facilities such as primary and other schools and mosques are not many in the district despite holding large population. The land use pattern of the candidate sites is shown in Figure 2.9.2.

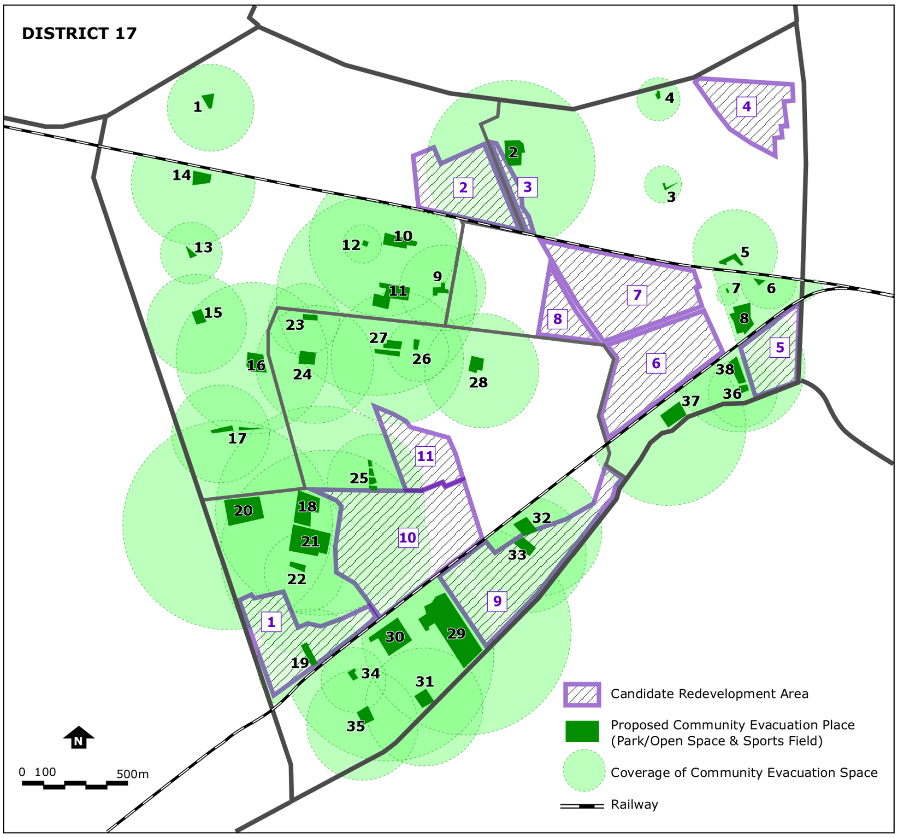


Source: District 17 municipality office

Figure 2.9.2 Land Use Pattern of the Candidate Redevelopment Site

2.9.3 Community Evacuation Place in District 17

Based on Tehran GIS database, the locations of 38 parks, open spaces and sport fields belonging to the municipality can be designated as community evacuation place. Catchment areas of the evacuation place are shown in Figure 2.9.3. The figure shows that area in white spreads means more than 500 meters far from evacuation place or area of the nearest evacuation place is not enough to accommodate all evacuees who live within 500 meters-radius of the place. Since district 17 is divided into three areas by two railways, it is therefore influence on the coverage of proposed community evacuation place as well. Any evacuation places do not cover the candidate sites numbered area 4, 6, 7 and 8.



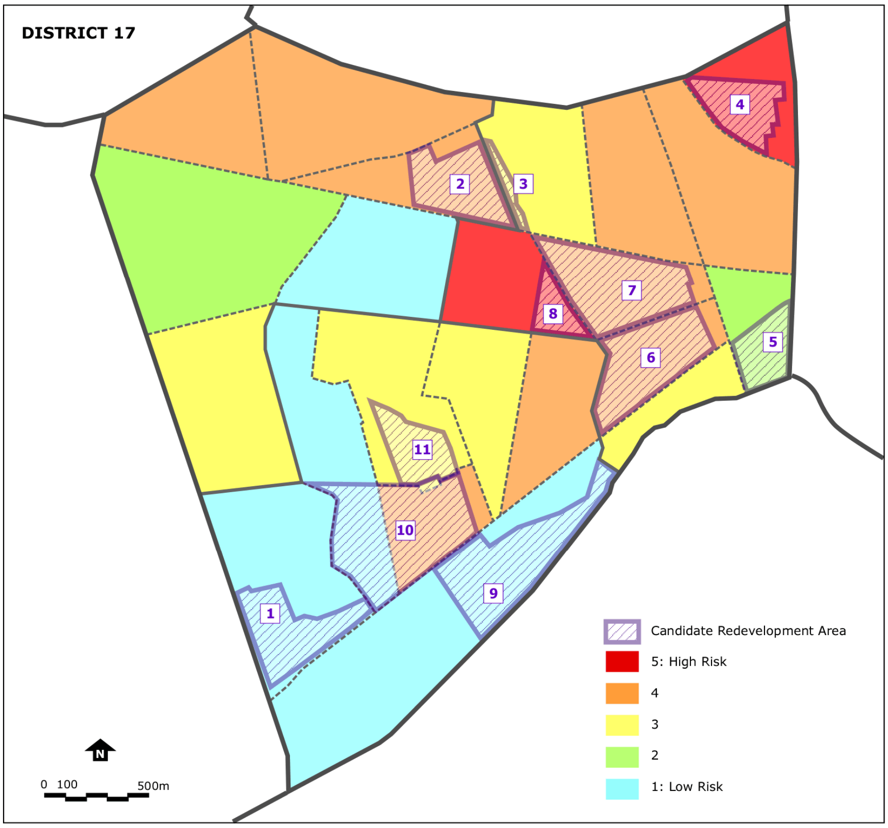
Source: JICA Study Team 2004

Figure 2.9.3 Coverage of Proposed Community Evacuation Place

2.9.4 Preliminary Analysis for Vulnerability by Mahale Boundary

Preliminary analysis carried out by Mahale level with taking account of following indexes those which are 1) number of proposed community evacuation place explained above, 2) number of disaster prevention facilities such as education and religious facilities, and 3) number of facilities that may cause secondary disaster such as gas and petrol stations. The each index is classified into five ranks of 1 to 5. Integrated vulnerability is assessed on the sum of the estimated three indexes. Number of community evacuation place is weighted as 2, others are weighted as 1.

Result of the preliminary analysis is shown in Figure 2.9.4. It shows that areas numbered 4 and 8 are belonging to the most vulnerable Mahale, and areas numbered 2, 7 and 8 are in the second vulnerable Mahale.



Source: JICA Study Team

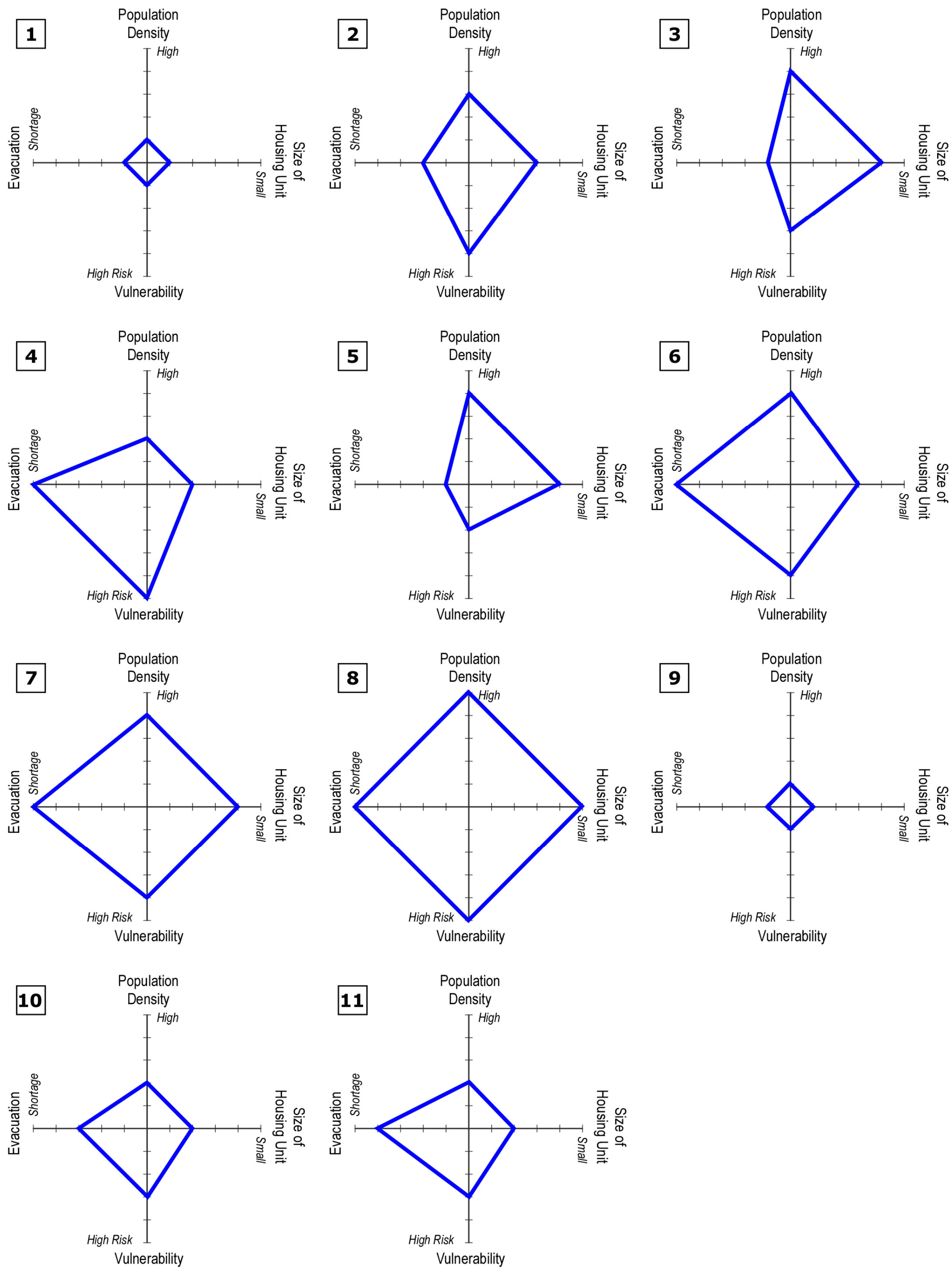
Figure 2.9.4 Preliminary Vulnerability Analysis in District 17

2.9.5 Proposed Priority of Redevelopment in District 17

Based on the data and analyses, a priority of redevelopment sites is proposed in this section. The priority is assessed by two major factors which are vulnerability and density. One is that the most vulnerable area needs argent action to mitigate risks. The other is that, as in high density area, individual efforts or small improvement for disaster prevention might take long time since population and building are in high density. Accordingly, the priority is set by four following indexes each of which is classified into five ranks:

- Population density: high density is prioritized
- Size of housing unit: small size is prioritized
- Proposed community evacuation place: outside coverage of the evacuation place is prioritized
- Vulnerability based on the preliminary analysis: the area belonging to high risked Mahale is prioritized

A result of four indexes in each candidate site is shown in Figure 2.9.5.



Source: JICA Study Team

Figure 2.9.5 A Result of Four Indexes in the Candidate Sites

Based on the results above, the study team proposed to do redevelopment project in Area 8 as the first priority project in terms of vulnerability and density. The following order is shown in Table 2.9.3.

Table 2.9.3 Prioritization for Redevelopment of the Candidate Sites

Priority	Candidate Site No.	Area (ha)
1	Area 8	5.0
2	Area 7	20.2
3	Area 6	18.3
4	Area 4	9.3
5	Area 2	13.0
6	Area 3	1.7
7	Area 11	8.4
8	Area 5	9.0
9	Area 10	29.2
10	Area 9	22.2
11	Area 1	13.0

Source: JICA Study Team 2004