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Integrating Civil Defense Emergency Management of Cities

(Case Study: District 10 of Tehran)

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ABSTRACT: Earthquake has always endangered cities. This article mainly focuses on the question "whether seismic damages could be diminished through the presentation a preventive operational pattern dealing with physical and nonphysical features of civil defense". Tehran, the most populous metropolis among Iranian cities is to the south of Alborz mountain range, located on potentially dangerous fault- lines.

By Civil Defense Emergency Management (CDEM) preventive guidelines in a part of district 10 of Tehran, within the Ray fault's danger zone, it is recommended that the earthquake vulnerability zoning plot of the area be compiled and accordingly, operational solutions encompassing organizing open spaces, redistributing and re-allocating land uses, enhancing relocating disaster management centers to more commanding locations are offered to be implemented within the physical structure of the area. The IHWP method and the Raster Calculator tool in GIS have been used for compiling the zoning of earthquake vulnerability.

Keywords: *Civil defense, Earthquake, Preventive measures, CDEM pattern, Tehran.*

INTRODUCTION

Natural disasters are among the biggest threats faced by big cities across the globe. Iranian plateau is situated on a high risk part of the globe and is thus inexorably threatened by environmental crises and natural catastrophe.

Tehran, the capital city of Iran is a high risk city with regard to earthquake. It is crisscrossed by 15 large and active fault lines, 3 of which have the potential to trigger a ≥ 7 magnitude quake.

Tehran has 22 districts. According to studies by JICA (Japan International Co-ordination Agency), municipal districts 10, 12 and 17 are the most at risk. A part of district 10 which is inside the high risk zone of Ray fault line has been selected for the current study. This area incorporates physical dilapidation, an urban fabric constituted of small parcels, and weak infrastructure as well as lack of proper planning of land uses. This area fully represents high risk areas of Tehran. Studies have shown that 40% of buildings here are designated for demolition and are worthless as buildings. About 40% of the land is in small parcels which increases the vulnerability. Deploying civil defense assets seems a must in the face of such clear and present danger.

Presence of this potential danger calls for attention being focused on disaster management and especially on civil defense. Civil defense is a set of physical and nonphysical measures which are aimed at reducing or eliminating consequences of natural disasters such as quakes, floods, forest fires or manmade disasters such as wars.

It seems reasonable that by defining and implementing physical elements of civil defense within the purview of urbanism and creating a comprehensive preventive pattern of civil defense strategies, earthquake effect can be reduced.

Fundamental research method has been employed in the current study. Views and theories of experts in the two fields "civil defense" and "urbanism" have been studied and combined whenever necessary.

First an outline on basic definitions and their theoretical importance in the fields of civil defense and urbanism has been presented, then attention is focused on compiling a procedure for recognizing physical indicators which affect the utility of civil defense in the prevention stage.

Library method has been used for collecting information. Information has been collected from Tehran municipality office library, Iran census center, library documents of the Ministry of Urban Development. Field survey methods including distribution of questionnaires have been used for collecting supplementary information and correcting and editing the different layers of data.

MATERIALS AND METHODS

Disaster and Its Types

The term disaster means natural or manmade incident with consequences of such magnitude that responding to them would require exceptional capabilities and specific skills.

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Many definitions have been presented for the term "disaster". Some are given below.
The term *disaster* is derived from the Latin roots *dis*-and *astro*, meaning away from the stars'. Historically, a disaster event was understood to be caused by unfortunate astrological configuration (Coppola, 2007, 25).
An international disaster, as defined by the UN (1992) is a serious disruption of the functioning of the society, causing widespread human and material or environmental loss which exceeds the ability of the affected society to cope using its own resources (Ibid).
Disasters may be defined as "any destructive event that disrupts the normal functioning of a community." (Veenema, 2007).
Disasters can be caused by natural phenomena, such as extreme weather and the effects of climate change, or human-made and technological threats, such as terrorism, bioterrorism, and chemical, biological, radiological, or nuclear devices. Disasters and overwhelming crises could arise from the ever-present threat of emerging infectious diseases, such as severe acute respiratory syndrome (SARS) and avian influenza, and increasingly can be the result of a breakdown of traditional state structures, armed conflict, and the upsurge of ethnicity and micro-nationalism and etc. To mitigate the potential disasters that confront humanity in the new millennium, an evidence-based approach to disaster management is required (Smith et al., 2009).

Disaster Management

According to Warfield (2008) Disaster management aims to reduce, or avoid the potential losses from hazards, assure prompt and appropriate assistance to victims of disaster, and achieve rapid and effective recovery.
In other words and from another perspective, disaster management is an applied science which seeks, through systematic observation and analysis of disasters, to find ways to prevent them or to mitigate their effects, to create readiness and to facilitate rescue and relief operations and to streamline post disaster recovery.
The disaster management cycle describes the process through which emergency managers prepare for emergencies and disasters, respond to them when they occur, help people and institution recover from them, mitigate their effects, reduce the risk of loss, and prevent disasters such as fires from occurring. It is crucial to take into account each of the disaster management phases. Integrating all emergency management activities, throughout all phases of an emergency. And across all functions increases accountability, provides continuity of resource application, establishes a clear chain of command and coordination, and identifies responsibilities for critical task performance (Kondo et al., 2004).
The costs of ineffectual or suboptimal disaster management throughout all phases of the disaster cycle (preparedness, mitigation, response and recovery), are difficult to calculate, but are potentially prohibitive when excessive human suffering is considered (Beaton et al., 2007).
Considering the current state of cities' physical structures, it would be better, in our bid to combat natural disasters and specially an unpredictable one such as earthquake, to focus on civil defense than merely on disaster management (which deals mainly with post disaster situations and controlling them). Studying pathological measures (preventive and mitigating procedures) and precisely defining pre-earthquake preventive measures are the main focus of civil defense. By drawing preventive measures and correctly estimating and predicting values of relevant variables before the disaster hits we will be able to prevent or reduce the destruction caused by natural disasters. A thorough discussion of civil defense seems thus necessary at this point.

Civil Defense

The following definition is given for civil defense by Marriam Webster dictionary
"The system of protective measures and emergency relief activities conducted by civilians in case of hostile attack, sabotage, or natural disaster"
It is worth mentioning that Civil defense was one aspect of attack preparedness. Although its most ambitious elements were never fully implemented, techniques linked to civil defense gradually came to take on broader significance as they migrated into new domains of threat, such as natural disasters and industrial accidents. As well as other definitions Civil Defense means all those activities and measures designed or undertaken (1) to minimize the effects upon the civilian population caused, or which would be caused, by an attack, (2) to deal with the immediate emergency conditions which would be created by any such attack, and (3) to: effectuate emergency repairs to, or the emergency restoration of, vital utilities and facilities destroyed or damaged by any such attack (Whitney et al., 1995).
Like many terms, civil defense has several different connotations and communication is often impossible when different meanings are used without some agreement on usage. In its most inclusive meaning, civil defense connotes a function. Thus, civil defense is a description of any and all activities carried out by governmental or quasi-governmental agencies in preparation for and during actual emergencies (Anderson, 1969).
The new concept is described by a number of terms, each of which has its own specific shade of meaning, such as crisis management, emergency management, emergency preparedness, contingency planning, emergency services, and civil protection. While "civil protection" is a popular term in Europe, terms such as "disaster planning", "emergency management" and even "civil defense" are used in many other countries. There is substantial, but not complete overlap in these different terms, although they are often used synonymously. For example, the International Civil Defense Organization (ICDO) states that "civil defense is also known as civil protection and encompasses the protection of persons and property against disasters (Backman et al., 2007).
Considering the above discussion, a more comprehensive definition of civil defense can be thus given that Civil defense is the set of actions and measures which are aimed at reducing economic loss or loss of life incurred by civilian population in wars or in natural disasters such as, droughts, earthquakes, floods, forest fires, typhoons.

History of Civil Defense

Modern civil defense began in the 1930s as a spontaneous attempt to organize civilian populations against the effects of aerial bombardment, for example, in 1937 at Guernica during the Spanish Civil War. This role became institutionalized during the Second World War, but its focus changed during the Cold War to that of readying civilians for a thermonuclear

exchange (Alexander, 2006).
In USA beginning in the early sixties, and with increasing momentum over the next decades, an alternate variant of preparedness developed in parallel to the Federal government's efforts to mobilize for nuclear war. State and local agencies sought to use federal civil defense resources to prepare for natural disasters, such as hurricanes, floods, and earthquakes. Despite its different set of objects, the field of emergency preparedness was structured by the underlying logic of civil defense: anticipatory mobilization for disaster (Lakoff, 2007).
As a result, since the end of the Cold War, the focus of civil defense has largely shifted from military attack to emergencies and disasters in general.
Of course, it is worth mentioning that at the national level, a civil defense system developed earlier than any comparable disaster planning or emergency management system. However, at the local level, the prime concern after World War II became to prepare for and respond to disasters (Dynes et al., 1975).
While methods and principles of civil defense are, broadly speaking, universally accepted, their mode of implementation can vary in line with wisdom and resourcefulness of those who implement them. Application of such methods and principles cannot always be subject to constraints and this is why principles of civil defense can be applied resiliently and in a versatile way.
Hence, to successfully implement civil defense procedures, it is needed that the action is co-ordinated and unified. Here is where civil defense emergency management or CDEM comes into play.
Civil defense emergency management (CDEM) (a) means the application of knowledge, measures, and practices that—are necessary or desirable for the safety of the public or property; and are designed to guard against, prevent, reduce, or overcome any hazard or harm or loss that may be associated with any emergency; and (b) includes, without limitation, the planning, organization, co-ordination, and implementation of those measures, knowledge and practices (The Ministry of New Zealand Civil Defense and Emergency Management, 2008).

Civil Defense Emergency Management (CDEM) Strategy

4Rs means:

Reduction [Mitigation] (identifying and analyzing long-term risks to human life and property from natural or non-natural hazards; taking steps to eliminate these risks if practicable, and, if not, reducing the magnitude of their impact and the likelihood of their occurring); and

Readiness [Preparation] (developing operational systems and capabilities before a civil defense emergency happens, including self-help and response programmers for the general public, and specific programmers for emergency services, lifeline utilities, and other agencies); and

Response (actions taken immediately before, during, or directly after a civil defense emergency to save lives and property, and to help communities recover); and

Recovery (the co-ordinate efforts and processes used to bring about the immediate, medium-term, and long-term holistic regeneration of a community following a civil defense emergency) (The Ministry of New Zealand Civil Defense and Emergency Management, 2008).

Three main phases can be distinguished within the CDEM pattern. These are:
pre- disaster mitigation ;
preparation and response;
Post disaster recovery;

Pre-earthquake Civil Defense Emergency Management (CDEM) strategic pattern in the pathology of physical structure of the city

To reduce the effect of natural disasters, it is imperative that executive plans and policies are put in place to ensure implementation of engineering techniques and correct measures of urbanism during normal times with the aim of reducing the damage inflicted during disasters.
Versatile and resilient urbanism plans are needed if cities are to gain preparedness for natural disasters and protection against extensive damage and loss of life in earthquakes.
Implementation of such plans can also facilitate post- quake operations, reconstruction of the environment and recovery of the stricken community. The focus of CDEM should be prevention of post- quake crisis by reducing vulnerability and risk.
Quake vulnerability in the physical structure of cities can be considered a result of inappropriate land use planning, lack of proper infrastructure (transportation network and urban installations), and incongruity in urban fabric and in physical form.
Special capabilities for encountering a disaster should also be maintained through general training and specialized training for rescue and relief operations.
Lack of preventive plans and methods can drastically exacerbate the situation.
Readiness is, to a large degree, a function of natural geographical conditions as well as of positioning and physical characteristics of residential units. Thus, as we expand the purview of CDEM beyond short term or long term post- earthquake operations, it becomes more entangled with architecture, urban planning and urban design.

Civil defense indicators for pathological (preventive and mitigating) measures before earthquake: Before setting out to discussing civil defense indicators in relation to pathological measures, and to have a better understanding of such measures, a definition of vulnerability should be offered: Vulnerability is a multidimensional approach, and focuses on how a society interacts in terms of education, government, values, laws, beliefs and cultural practices, in response to different hazards (Baumwoll, 2008).

Vulnerability as a result of lack of proper land use planning: Land-use planning represents an attempt to reduce the number of conflicts and adverse environmental impacts in relation to both society and nature. It involves, in the first instance, the collection and evaluation of relevant data from which plans can be formulated (Faidi, 2007). Hazard researchers have identified land use planning as a critical activity for reducing natural hazard-related losses (Stevens, 2010). The main purpose of hazard-related land planning is to zone land so that new development can be steered away from dangerous sites (Smith and Petely, 2009, 96).
Hence, in quake prone regions, earthquake is a factor which influences both the selection of land uses and the positioning of these land uses. The manner of land use planning, and using indicators in the study of "vulnerability as a consequence of lack of proper land use planning" in a way that the damage inflicted to both man made physical elements and social order

and environment is minimized, are of utmost importance. First, the functioning of a city should be the focus of attention. Functioning of a city is an indication of the dominant economic activity within that city. The dominant economic activity within a city is the determining factor in forming the land uses which are prevalent there. Damage incurred by land-uses in disasters such as earthquakes can thus endanger economic existence of a city. “In general, and from an economic and even a physical point of view, damage is inflicted with more intensity when a city’s dominant economic activity is industrial than when it is agricultural. Economic vulnerability is also high where many businesses are of a non-productive type” (Alidousti et al., 1994).

Another important criteria is the type of land use. “Some land uses are more vulnerable to earthquake than others” (Shiae et al., 2010). Residential land uses are, for instance, more vulnerable than other land uses.

Special land uses such as plots allocated as public health centers, rescue and relief headquarters, learning institutes are in the second rank of vulnerability. Military and official land uses are still less vulnerable and the least vulnerable of all, as is expected, are open spaces. That is because “open spaces in the urban centers in several areas which are accessible to most of the people will be reserved for emergency evacuation. While reserving the land for open space, several lands will be identified for emergency evacuation of certain communities and evacuation routes will also be identified in case of emergency” (UNDP/ERRRP, 2009).

Positioning of land uses with respect to geo-morphological value is another criterion which should be taken into consideration if the vulnerability is to be reduced (Azizi and Akbari, 2007). Tectonic factors such as distance from fault lines, slope of land and soil material are important factors which should be accounted for when land uses are positioned.

Another important criterion is proximity of land-uses. This criterion should be observed in such a way that proximal land uses do not pose a threat to one another in an earthquake scenario.

The risk increases when proximal land uses are incompatible with regard to form, space and activity and decreases when land uses are compatible in those respects.

Vulnerability of different land uses is also determined by their time dependence. The more continuity in the functioning of a land use, the more vulnerable it would be Land uses are divided in three categories with regard to time dependant risk. Round the clock land uses with time dependence which are utilized day and night are the most vulnerable, examples are houses and residential complexes which are used round the clock as accommodation, but which are used differently depending on time (as resting place during the night). Round the clock land uses which are not time dependent, such as hospitals and police stations, which do the same function throughout, are less vulnerable. The least vulnerable are land uses which are utilized through the day only, such as commercial land-use, Institutional and official land uses (Habibi et al., 2009).

Position of building in block can affect its vulnerability. Individual plots of land within a block are more vulnerable and incur more damage in earthquakes compared to similar plots which are on the side of other plots or in the middle, surrounded by other plots. Hence, the higher the number of neighborhoods, and the more a plot is surrounded by other neighboring plots, the less the vulnerability will be (Raveshti and Ziyari, 2010).

The resistance of various building types to earthquake loads can be defined by the use of vulnerability analysis. The vulnerability of a building is one of the principal factors affecting
the occurrence of casualties in earthquakes (Okada and Takai, 2000) (Table1).

Physical characteristics of building including age, façade materials, building material, quality of construction, number of floors and type of skeleton are of prime importance in determining vulnerability. Modern, well fortified skeletons made of steel or concrete are much less vulnerable when compared to skeletons constructed from masonry material and based on traditional methods. Also, lower age, lower number of floors and new construction (new built) are among other important factors for reduced vulnerability of land uses. Using lower – risk facade materials such as stone slabs or cement results in lower vulnerability compared to higher – risk material such as ornamental bricks or glass. Important physical criterion is the rate of occupation. The less the rate of occupation is, another less vulnerable the building will be (Habibi et al., 2009) (Table1).

Infrastructure – Related Vulnerability (Urban Installations and Equipment, Transport Network)

The indicator of urban infrastructure, which includes transport network and urban installations, has an important effect in reducing overall earthquake vulnerability. “Some land uses are pivotal in determining the overall earthquake vulnerability. These uses, collectively referred to as special land use, include schools, universities, hospitals, rescue and relief centers, urban management centers, factories, fuel depots (Habibi et al., 2009).

Overall vulnerability is reduced if the transport network is capable of providing for the fulfillment of the criterion of access to special land uses. Vulnerability can be reduced if the proper access hierarchy is implemented and especially if proper and resourceful variety is incorporated within that hierarchy.

The availability of the transportation network is critical for efficient emergency response under earthquakes. It entails the identification of critical routes in a planning context that remain functional following an earthquake, to enable the response operators to access as much population as possible in a minimum amount of time (Viswanath and Peeta, 2003).

Overall vulnerability is lower where the pattern of access roads is simpler than where it is complicated. Also an orderly, short and direct access routes pattern results in reduced overall vulnerability.

Another transport network related criterion which is of decisive importance in determining vulnerability is the enclose degree. It is a function of the ratio of width of a road to its height of embankment. Vulnerability is reduced if the said ratio conforms to accepted standards (Alidousti et al.,1994) (Table1).

With regard to the indicator “urban installations”, it can be said that damage to this part of urban infrastructure can drastically increase loss of life and other losses in an earthquake scenario. Damage to gas pipelines, electricity lines and water transport pipelines can cause severe issues. Damaged gas pipelines, for instance, may result in gas leakage and ensuing fires.

Table 1: Main indicators with their criteria and measures.

Main indicators		Sub-Criteria	Measures
land use planning		City Function	Agricultural, Industrial, Services
		Type of land use	Residential, Special land use, Official and military, Open spaces
		Positioning of land uses with respect to geo-morphological value	Correct, Incorrect
		proximity of land uses	Non risk, Low risk, High risk
		Time of functioning of land use	Round the clock, Different usage during day and night, Useless at night
		position of building in the block	Middle, Side, Individual
		Building Skeleton	Steel, Concrete, Masonry(brick, adobe and wood)
		Age of building	0-10 , 10-20 , 20-30 , 30-40 , 40-50 , More than 50
		Quality of building	New, Restoration-old, Old, Destructive
		Façade materials	Cement, Stone, Brick, Glass
		Number of floors	1 floor, 2 floors , 3 floors , 4 floors , 5 floors ,
		Rate of occupation	0-25% , 25-50% , 50-75% , 75-100%
infrastructure	transport network	Accessibility to special land uses	Good, Middle, Weak
		Pattern of access	Orderly and short, Orderly and long, Disorderly and short, Disorderly and long
		Enclose degree	Proportionate, Disproportionate
		Access hierarchy	Correct, Incorrect
		Variety of access hierarchy	Varity of accessibility, Limitation of accessibility
	urban installations and equipment	The type of urban infrastructure network	telecommunications network, water distribution network, waste water disposal network, Electricity network, gas distribution network
		Proximity of urban infrastructure	To transportation network, to residential and non- residential land uses
		Poisoning of urban furniture	Correct, Incorrect
urban form		manner of expansion of the city	Horizontal expansion, Vertical expansion
		Continuity and compactness of plots	Discontinuous and orderly, Discontinuous and disorderly, continuous and orderly, Continuous and disorderly
		Adherence to proper hierarchical physical division of the city	Correct, Incorrect
urban fabric		Buildings density	Low, Medium, High
		Residential density	Low, Medium, High
		population density	Low, Medium, High
		Surface area of parcelized plots of land	More than 150 m2, between 100 - 150 m2, Less than 100 m2
		parcelization pattern	Orderly rectangular patterns, orderly polygon patterns, Disorderly combining

Any of the installed networks (gas distribution network, electricity network, waste water disposal network, telecommunications network, and water distribution network) can be damaged as a result of an earthquake. Such damage will have primary consequences such as intensified risks, fires, pipeline explosion, etc, and also secondary consequences such as loss of life as a result of malfunctioning of the networks or the ensuing pollution of the environment.

"Proximity of urban infrastructure (with the exception of transportation facilities) to residential and non- residential land uses can intensify the damage caused by natural disasters." (Ibid)

Apart from all these, distribution and positioning of urban furniture (all the necessary urban equipment distributed throughout the city such as fire extinguisher pumps, pay phone booths, lamp posts) should contribute to reducing the vulnerability and should be conducive to rescue and relief operations as well (Table 1).

Vulnerability resulting from urban form

Urban physical form which is affected by the main elements within a city and the relationships among these elements is another determining pathological indicator.

Paying due attention to criteria such as adherence to proper hierarchical physical division of the city (into alley, neighborhood, district and urban region) is very important for reducing vulnerability.

Existence of open spaces between plots of land, Discontinuity of plots, and adherence to urban physical order will reduce vulnerability because "open urban forms (discontinuous) are more resilient against change than compact urban forms (continuous). Discontinuous but orderly forms are thus less vulnerable against earthquakes" (Habibi et al., 2009).

Another important criterion is manner of expansion of the city. Expansion in height (vertical expansion) generally increases vulnerability (Table 1).

Vulnerability arising from urban fabric

Urban fabric is another indicator which should be accounted for in civil defense," urban fabric determines shape, size and manner of combination of smallest constituent elements of a city. Vulnerability or resistance to earthquake is different for different types of urban fabric" (Habibi et al., 2009).

Density of buildings and population as well as density of residential units are among determining criteria of urban fabric. "Because the main damage caused by tremors is loss of life, population density is a very important indicator for the last phase of the crisis" (Ahmadpour et al., 2009).

As each one of these densities increases, vulnerability and probability of destruction increases too. Population density, for instance, is a criterion which determines the population load at the time of the quake. "Accordingly, population overload in the city will result in accelerated dilapidation and imposition on city districts of a pressure which exceeds their capacity of coping. Occurrence of earthquake will cause heavy loss of life because of low resistance of buildings and high population densities" (Shiae et al., 2010).

Higher population density can slow down rescue operations and movement toward shelter, while lower population density will have the converse effect.

Surface area of parcelized plots of land is another important criterion in determining the pathology of urban fabrics. The smaller the surface area of parcelized plots, the higher the vulnerability. Another important criterion in determining the pathology of urban fabrics is the parcelization pattern. Geometrical form of plots (orderly and disorderly) is the standard of comparison here, with three different patterns being observed. Orderly, rectangular parcelization patterns reduce overall vulnerability because such patterns lead to more orderliness in building forms, leave more open spaces and are more efficient with regard to providing shelter and temporary residence. Regular, orderly polygon patterns with many acute or obtuse angles lead to disorderliness of building forms, render the open spaces dissected, are less useful as shelter or temporary residence and less suitable as much as rescue operations are concerned. Finally, irregular and combining patterns result in more disorderliness of building forms and higher overall vulnerability compared to the last two types because they totally cut to pieces and render useless open spaces; and are very inconvenient with regard to providing shelter, and accessibility by rescue teams (Habibi et al., 2009) (Table 1).

RESULTS AND DISCUSSION

All of the indicators with their criteria and measures are shown in Table1.

Introducing the Area under Study and Assessing its Condition: The area under study is located in the south of region 10 of Tehran and inside the high risk zone created by Ray fault line (Fig.1).

This area, like the rest of region 10 of Tehran, is mainly comprised of old and distressed urban fabric and is faced with problems such as inadequacy of urban services (including special landuses) and lack of adequate open spaces and green spaces. The existing open spaces are not distributed over the area in a balanced way. Land pieces are too small, residential urban fabric is worn out and population density too high. Add inadequate urban infrastructure to all these.[1]

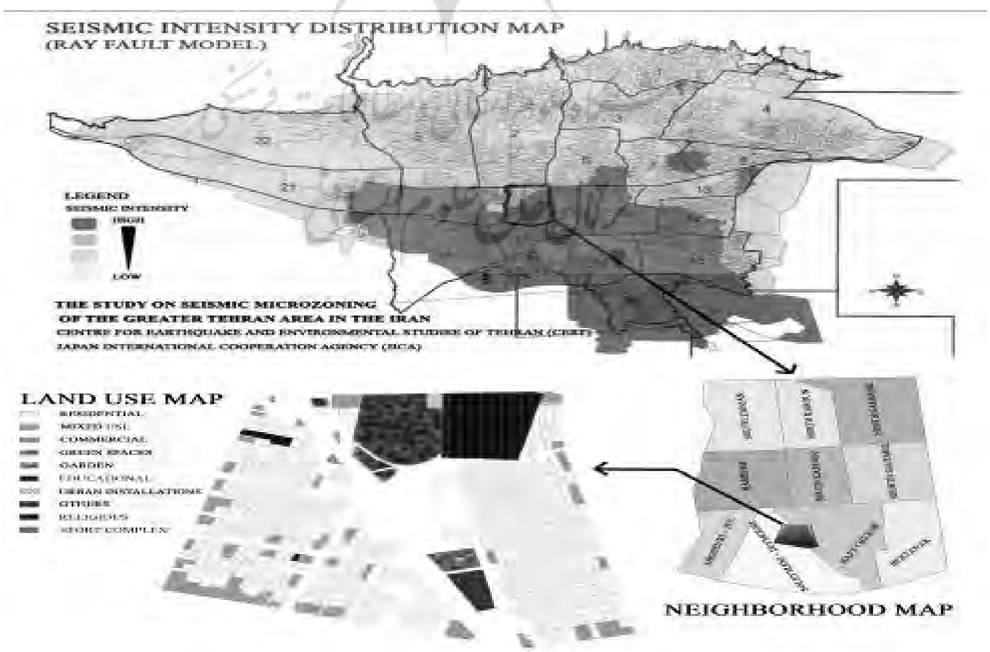

Fig. 1: Map of introducing the area under study

Calculation of the Degree of Earthquake Vulnerability of Region 10 of Tehran

We have used the Inversion Hierarchical Weight Process Model (IHWP) to estimate vulnerability of our case study subject. This model allows incorporation of vulnerability criteria in the form of a continuous spectrum. Using the IHWP in GIS environment we can identify earthquake vulnerable zones and prepare plans for addressing their vulnerability. "The IHWP model is a combination of fuzzy logic method and the Analytic Hierarchy Process (AHP)" (Shiae et al., 2010).

Step one: Selected criteria for identifying earthquake-vulnerable zones. To establish the degree of earthquake vulnerability of the area under study, we have used 11 criteria in accordance with the indicators of the CDEM pre-quake strategic pattern. These are:

skeleton of buildings, age of buildings, quality of buildings, number of floors, positioning of land uses with regard to geomorphologic values, type of land use, surface areas of plots of land (parcelization), situation of the plot of land within the block, proximity of land uses (with regard to space, form and function, time of functioning of land uses and the dominant façade material used.

Second step: presenting the IHWP

Determining importance and rank of data

After identifying layers on the basis of the importance of each factor in creating earthquake vulnerability, criteria are ranked on the basis of the indicator "entropy" (expert opinions). Reciprocal of rank of a layer is used as weight of that layer in the IHWP model (Ibid). These 11 criteria are ranked in different categories with regard to their importance on the basis of expert opinion in Delphi Model. Ranking corresponds to a 1 to 11 scale, the least important criterion with regard to earthquake vulnerability being given a score of 1, the most important criterion a score if 11.

Theoretical basis and assumptions for allocating weights

Here we have presented measures for the eleven criteria under study. Each one of these criteria is expressed in terms of a scale of vulnerability, according to which the value of the criterion is determined quantitatively.

In relation to the criterion "Age of Buildings" for instance, it is assumed that vulnerability increases as age of buildings increases and vice versa.

According to this plan, age of buildings is measured in a discrete scale with six levels. Considering that age of buildings is one criterion within the criteria for vulnerability, the lower age buildings are given lower vulnerability scores while higher age buildings are given higher vulnerability scores.

It is obvious that earthquake vulnerability increases with higher building density, higher ratio of building height to road width, ignorance of standards of construction, age of buildings, incompatibility of land uses, length of infrastructure network lines (such as gas lines) and obstruction of evacuation (Habibi, 2006).

Considering the above facts and the Delphi model (expert opinion), we can categorized the mentioned criteria and give, for each criterion, a rank to the area under study (Table2).

Calculation of Scores Given to Chosen Layers Using the IHWP Model

$$X=\frac{D}{N} \quad (1)$$

Here X is the primary score given to each criterion,
D is the score obtained from Delphi model,
N is the number of measures of each criterion
Also J=D-(N-I) X (2)
Here J is the score obtained for different measures of each criterion and I is the number identifying different measures of each criterion.
The selected criteria and the categorization of each criterion, scores obtained from Delphi model (D), number of categories

Table 2: The physical criteria for identifying scale of vulnerability of the area under study

The physical criteria for identifying scale of vulnerability in case study	Given Scores by Delphi Model
Building skeleton	11
Age of building	10
Quality of building	9
Number of floors	8
Positioning of land uses with respect to geo-morphological value	7
Type of land use	6
Surface area of parcelized plots of land	5
position of building in the block	4
Proximity of land uses	3
Time of functioning of land uses	2
Façade materials	1

Table 3: Calculation of scores given to chosen layers using the IHWP model

Criteria	the score obtained from Delphi model	the number of measures of each criterion	the primary score given to each criterion	Measures (the different categories of each criterion)	the number identifying different categories of each criterion	the score obtained for different categories of each criterion
	D	N	X		I	J
Type of land uses	6	3	2	Special land use	1	2
				Open spaces	2	4
				Residential	3	6
Proximity of land uses	3	3	1	Non risk	1	1
				Low risk	2	2
				High risk	3	3
Positioning of land uses with respect to geo-morphological value	7	2	3.5	Correct	1	3.5
				Incorrect	2	7
Building skeleton	3.66	3	11	steel	1	3.66
				Concrete	2	7.33
				Masonry (brick, adobe and wood)	3	11
Age of building	1.66	6	10	0-10	1	1.66
				10-20	2	3.33
				20-30	3	5
				30-40	4	6.66
				40-50	5	8.33
				More than 50	6	5
Façade materials	0.33	3	1	Cement	1	0.33
				Stone	2	0.66
				Brick	3	1
Quality of building	2.25	4	9	New	1	2.25
				Restoration-old	2	4.5
				Old	3	6.75
				Destructive	4	9
Number of floors	2	4	8	1 Floor	1	2
				2 Floors	2	4
				3 Floors	3	6
				4 Floors	4	8
position of building in the block	1.33	3	4	Middle	1	1.33
				Side	2	2.66
				Individual	3	4
Time of functioning ofLand uses	0.66	3	2	Useless at night	1	0.66
				Different usage during day and night	2	1.33
				Round the clock	3	2
Surface area of parcelized plots of land	1.66	3	5	More than 150	1	1.66
				100 - 150	2	3.33
				Less than 100	3	5

for each criterion (N), primary score given to each criterion (X), the number given to different categories of each criterion (i) and finally the score obtained for each category of each criterion (j) are all given in Table 3.

Third step: combination of maps:

Columns of scores related to each information layer are summed using Raster Calculator. The final vulnerability score given to each plot, or that plot's resistance to earth quake in comparison to other plots, is determined by the sum of the 11 columns (for the 11 data layers). It is noteworthy that all the mathematical operation on the data is performed in a single phase.

Preparing the final vulnerability map (incorporating all plots of land within the area under study):

Here we have compiled a final vulnerability map which depicts levels of earthquake vulnerability. 5 different categories can be recognized with respect to vulnerability (very low vulnerability, low vulnerability, medium vulnerability, high vulnerability and very high vulnerability). Level of vulnerability of each building block has been gauged from the 11 above mentioned criteria and their division and a vulnerability map has thus been generated (Fig. 2).

CONCLUSION

The CDEM pattern presented here is derived based on a simple and resilient structure which primarily, and through presentation of a vision, delineates strategies for encountering dangers.

Considering the importance of prevention before the occurring of the earthquake, preventive strategies have been presented and studied here in terms of physical indicators, criteria, and measures with the aim of arriving at a strategic CDEM plan. One characteristic of this plan is sustained feed-backing between all the elements incorporated within the CDEM pattern (Fig. 3).

Intensity of earthquake damage can be predicted if earthquake vulnerability of an area is well studied before the earthquake happens.

As stated in the case study, the damage can of course be mitigated through effective planning before the earthquake hits and through implementation of solutions inherent in the CDEM pattern.

In general, mitigation of the effect of earthquake can be achieved in micro level by first compiling a vulnerability zoning map while taking into consideration the physical indicators of the CDEM and their criteria, and then presenting objectives and policies based on risk zones and phases of the CDEM. Eventually, comprehensive management of the preventive plans can be achieved through effective combination of detail plans within a city.

To give a measure of vulnerability of the area under study (a part of municipality district 10 of Tehran), 11 factors have

Fig. 2: Map of modeling stages of vulnerability of the area under study

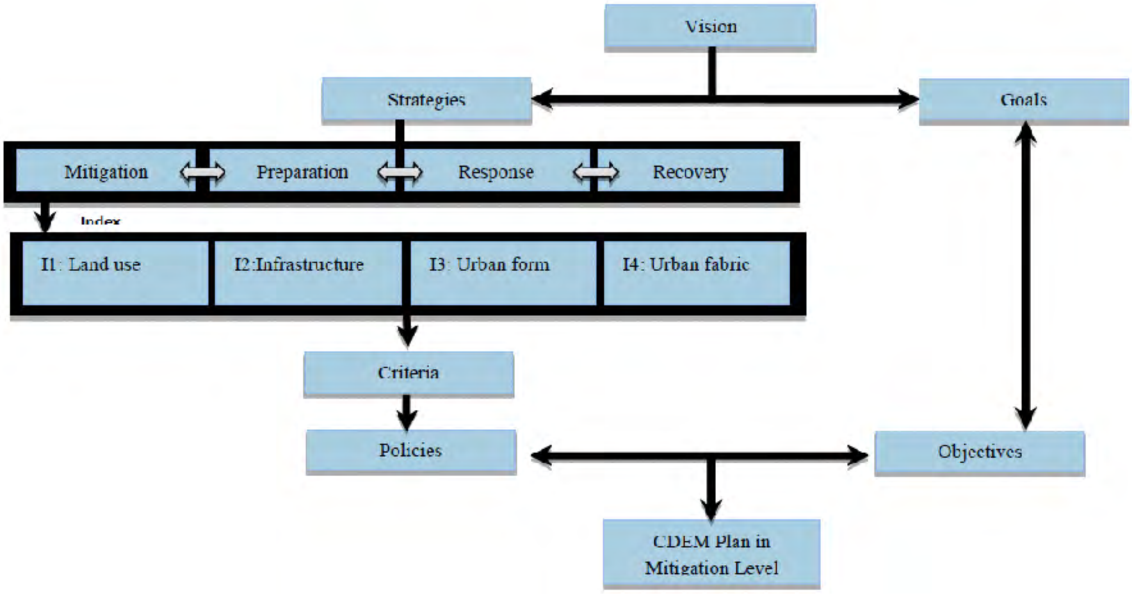

Fig. 3: Diagram of CDEM pattern

been selected from the physical criteria given by the CDEM. These are: skeleton of buildings, age of buildings, building quality, number of floors, positioning of land uses with respect to geomorphologic values, types of land use, surface area of plots of land (parcelization), positioning of each plot within a block, proximity of land uses (with respect to space, form and function, time of functioning of land uses and the facade material commonly used.

Using the IHWP model, vulnerable building plots were identified and the compiled vulnerability map for buildings was superposed on a similar map compiled for streets.

The result was a comprehensive earthquake vulnerability map of the area under study. It can be seen that the eastern part of the area is more vulnerable. This was predictable considering the inefficient and worn-out physical structure of this part. Most territories studied, however, had relatively high vulnerability.

In short, the following results were obtained from the current study: as evident from the vulnerability map, sections with wider streets and better access to urban services centers, buildings with strong skeletons and renovated buildings are in a better state with regard to vulnerability.

In other words, these sections and buildings have obtained a rank of 4 or 5 for vulnerability considering the pentad scale of the vulnerability map (4=low vulnerability and 5= very low vulnerability). These mostly constitute constructions along the main streets in the center and in the north of the area under study. Sections and buildings with medium to high or very high vulnerability, however, dominate, and this can be seen in the following table 4 which shows vulnerability of the plots and vulnerability group percentages.

Considering the overall vulnerability (more than 60% of buildings are very vulnerable), the following recommendations are given with the aim of improving the functionality of the transport network and improving the resistance of the physical structures in an earthquake scenario.

Keeping in check the building density and population density along narrow streets.

Granting public health land uses to some of the land along main access roads.

prevention of increased enclosure of streets

Improving the quality of renovated buildings and demolition and reconstruction of dilapidated buildings.

Improving the strength of structures.

Planning for assembling plots of land and increasing the constructed surface area, with the aim of decreasing the building density.

Identifying plots of land which can be assembled and zone-mapping them with the aim of freeing and re- appropriating some plots for use as rescue and relief centers or other necessary services

Drafting regulations which facilitate assemblage of plots of land and renovation of buildings

Widening streets and geometrically modifying them

Creating possibility of access to main streets via local redistribution avenues.

Table 4 : Vulnerability of plot percentages in case study

Vulnerability of plots	Very low	low	medium	high	Very high
Percentages	0.74	10.53	13.78	10.31	64.64

Creating adequate urban spaces, open spaces and green spaces which can also function as temporary residence.
Taking advantage of unifying factors and offering specialized training with the aim of establishing and fixing the concept of a precinct as a unified whole, thus persuading local co-operation in rescue operations.
Construction of open spaces in dead-end alleys and dense spaces.
Re – equipping and re- designing urban furniture.
Implementing these recommendations along with making changes such as creation of land uses such as green spaces, rescue and relief centers, and disaster management centers, propagation of open spaces, and reducing the degree of enclosure of streets can drastically reduce the vulnerability of the area under study and pave the way to a safer and more sustainable situation.
Here we have compiled a final vulnerability map which depicts levels of earthquake vulnerability. 5 different categories can be recognized with respect to vulnerability (very low vulnerability, low vulnerability, medium vulnerability, high vulnerability and very high vulnerability). Level of vulnerability of each building block has been gauged from the 11 above mentioned criteria and their division and a vulnerability map has thus been generated.
Fourth step: preparing the road vulnerability map and combining it with vulnerability map of plots of land:
The road vulnerability map is compiled based on two criteria. These are: 1-Hierarchy of access and 2- width of roads. Here too we can distinguish 5 categories of earthquake vulnerability from very low to very high (just as presented in the third step). Maps complied here and in the previous step are combined using GIS software and a final comprehensive vulnerability map with regard to physical criteria and transport network is thus obtained for the area under study.

ENDNOTES

1. Table 5: Introducing physical structure of the area under study

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Table 5: Introducing physical structure of the area under study

Introducing physical structure of the area under study		
criteria	Measures	Value
Building skeleton	steel	36.64%
	Concrete	16.23%
	Masonry(brick, adobe and wood)	47.13%
Age of building	0-10	18.42%
	10-20	8.84%
	20-30	3.97%
	30-40	0.74%
	40-50	6.81%
	More than 50	61.23%
Quality of building	New	16.40%
	Restoration-old	1.56%
	old	37.73%
	Destructive	44.31%
Façade materials	cement	52.53%
	stone	27.95%
	brick	19.53%
Number of floors	1 floor	3.98%
	2 floors	50.97%
	3 floors	24.13%
	4 floors	20.92%
Surface area of parcelized plots of land	Less than 100 m2	41.76%
	100 - 150 m2	18.66%
	More than 150 m2	39.58%
Type of land use	Residential	45.27%
	Special land use	7.07%
	Open spaces	0.91%
	Others	46.75%

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