Vulnerability & Risk Assessment of Hospitals & Health Centres

Improving the Multi-Hazard Resilience of Health Facilities in Iran (BEHTAB)

Vulnerability & Risk Assessment of Hospitals & Health Centres	
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This stage focuses on vulnerability and risk assessment of HFs in consultation with MoHME. The main tasks which were conducted in this stage of the project includes preparing the project methodology, recruitment of project consultants, defining work processes of various project components, developing a procedure to receive consultancy services, developing the GIS analysis tool as well as conducting the hazard analysis of a number of HFs. The main activities conducted under any of above-mentioned tasks are as follows:
Employing a holistic approach, BEHTAB methodology is composed of several components including hazard analysis, Rapid Visual Assessment (RVA), Preliminary Engineering Analysis (PEA), Non-Structural hazard mitigation including physical and institutional dimensions, and resilience of HFs in urban grid.

Hazard analysis

Hospitals and health care facilities are exposed to a variety of hazards. In line with the multi-hazard approach adopted by the project, the following hazards have been selected for analysis:

- Earthquakes;
- Floods;
- Land-related hazards such as: landslides; liquefaction; and subsidence.

Hazard maps for three pilot cities of Tehran, Isfahan and Tabriz prepared, as the main input for complete hazard assessment. Since health care facilities are essential lifelines whose functions must not be interrupted especially during disasters, it is highly important to assess and analyze their resilience. To this end, the methodology for this analysis at the urban scale was prepared. Seismic hazard levels for certain locations as determined by the Ministry of Health, Care and Medical Education are estimated in terms of Peak Ground Accelerations (PGA). These estimations are essential for determining most hazardous zones in the area of study.
The general seismic hazard estimation completed for all selected hospitals located in three target cities of Tehran, Tabriz and Isfahan. Probabilistic seismic hazard analysis for selected hospital sites also completed according to BEHTAB methodology. In each case, Uniform Hazard Spectrum (UHS) has been developed for two return periods of 475 and 2475 years corresponding to the hazard levels of 10% and 2% in 50 years, respectively.

Rapid Visual Assessment (RVA) of HFs

In order to perform the Rapid Visual Assessment (RVA) on the target hospitals, a comprehensive checklist including a wide range of questions about various hazards, structural and non-structural aspects of the hospital buildings and facilities were provided and finalized. This checklist presented as a mobile application and is evaluated by performing site investigations. An abridged version of questions also were developed for health centres. The list of hospitals and health centers for which RVA studies was implemented, is as tables below:

Table 1 List of hospitals for RVA studies

NO.	Medical University of	CITY	NAME OF HEALTH FACILITY
1	Az-east	Tabriz	Sarab
2	Az-east	Tabriz	Souktegi Sina

3	Az-east	Tabriz	Emam Reza
4	Az-east	Maraghe	Bou Ali Sina Maraghe
5	Az-east	Azar shahr	Azar shahr
6	AZ-west	Oroumie	Takmil e Khoy
7	AZ-west	Oroumie	2nd Wing Mian doab
8	AZ-west	Oroumie	Saratan Emam
9	AZ-west	Oroumie	Zanan Zayman
10	AZ-west	Oroumie	Takmil e Ayatolah Khoy e Oroumie
11	AZ-west	Takab	Takab
12	Ardebil	Pars abad	Pars abad
13	Ardebil	Ardebil	Souktegi e Emam (Trauma)
14	Esfahan	Najaf abad	Najaf abad
15	Esfahan	Esfahan	Feyz
16	Esfahan	Kashan	Emam Hasan Mojtaba
17	Esfahan	Esfahan	Trauma Ayatolah Kashani
18	Esfahan	Esfahan	Almahdi nour & Ali asghar
19	Alborz	Karaj	Bahonar
20	Tehran	Shahr e Ghods	Shahr e Ghods
21	Tehran	Tehran	Soukhtegi
22	Tehran	Tehran	Razi
23	Tehran	Tehran	Amir Alam
24	Shahid Beheshti	Tehran	Shohaday e Tajrish
25	Shahid Beheshti	Tehran	Emam Hasan (Masih Danesh)
26	Shahid Beheshti	Gharchak Varamin	Gharchak Varamin
27	Fars	Shiraz	Ravani
28	Fars	Fasa	Emam Hosein
29	Ghom	Qom	Nirougah
30	Mazandaran	Tonekabon	Emam
31	Markazi	Khomeyn	Emam
32	Iran	Shahryar	Emam Khomeyni
33	Semnan	Shahroud	Fatemiye
34	Tavanbakhshi	tehran	Nezam Mafi

Table 2 List of Health *care* centers *for RVA studies*

NO.	**Medical University of**	**CITY**	NAME OF HEALTH FACILITY
1	Az-east	Tabriz	Sardardoud
2	Az-east	Tabriz	Yousef abad
3	Az-east	Tabriz	Kouye lale
4	Az-east	Tabriz	Shahid Beheshti
5	Az-east	Tabriz	Ahmad abad

6	Az-east	Tabriz	Elahie
7	Az-east	Tabriz	Shahid Motahari
8	Az-east	Tabriz	Baghmishe
9	Az-east	Tabriz	Satarkhan
10	Az-east	Tabriz	Ghataran
11	Az-east	Tabriz	Ostad Jafari
12	Az-east	Tabriz	Kouye Mosala
13	Az-east	Tabriz	Marzadaran (Ana khatoon)
14	Az-east	Tabriz	Nasr
15	AZ-west	Oroumie	Alborz
16	AZ-west	Oroumie	Behdari Oroumie
17	AZ-west	Oroumie	17 Shahrivar
18	AZ-west	Oroumie	Almahdi
19	AZ-west	Oroumie	Razi
20	AZ-west	Oroumie	Tarizlou
21	AZ-west	Oroumie	Savalan
22	AZ-west	Oroumie	Hazrat pour
23	AZ-west	Oroumie	Abouzar
24	AZ-west	Oroumie	Takhasosi e Madar
25	AZ-west	Oroumie	Shohada
26	AZ-west	Oroumie	Aghdash
27	AZ-west	Oroumie	Baadie Pouyan
28	Esfahan	Esfahan	Khorasgan no.1
29	Alborz	Karaj	Shahid Esmail Rousanezhad
30	Alborz	Karaj	Hesarak
31	Alborz	Karaj	Khoramdasht
32	Alborz	Savojbolagh	Ghasem abad
33	Alborz	Savojbolagh	Shahr e Jadid Savojbolagh
34	Iran	Parand	Faze 1 Parand
35	Iran	Nasim Shahr	no.2 Nasim Shahr
36	Iran	Baharestan	no.2 Baharestan
37	Tehran	Eslam shahr	Shahrak e Golha
38	Tehran	Eslam shahr	Mehr Vavan
39	Tehran	Eslam shahr	Mehr Zia abad
40	Tehran	Eslam shahr	Bagh e feyz
41	Tehran	Eslam shahr	Ghasem abad
42	Tehran	Rey	Vali abad
43	Tehran	Tehran	Sheykh Ahmad Kafi
44	Tehran	Tehran	Dolat Khan
45	Tehran	Tehran	Shahid Ahmadi
46	Tehran	Tehran	Meysam
47	Tehran	Tehran	Hakim Etemad

48	Tehran	Tehran	Javadie
49	Tehran	Tehran	Shahid Vahedi jonoub
50	Shahid Beheshti	Gharchak	Ziba shahr 1
51	Shahid Beheshti	Pakdasht	Khatoun abad
52	Ghom	Ghom	Isar
53	Ghom	Ghom	Imam Sadegh
54	Ghom	Ghom	Zarei
55	Ghom	Ghom	Imam reza Pardisan

In line with activities of RVA procedure, the Web GIS-based spatial analysis tool was developed for Iran's hospital and healthcare facilities. In this regard, the services required for this assignment include GIS Modelling of Data and developing a Web GIS-based analysis tool by the selected national consultant. The tool includes the following two key features:

- A Data entry interface that works on Android,
- Supports both English and Persian Languages,
- Includes approximately 150 data fields filled using dropdown lists, text fields, check boxes, combo boxes, date picker control, GPS coordinates and Photographs, and
- Produces filled forms in formats compatible with common database formats used by database software and GIS platforms.

Rapid Visual Assessment (RVA) Android application is a tool that enhances the accuracy of data collecting, documenting and processing. The application is a novel contribution of BEHTAB project that has been tested to achieve the required service quality.

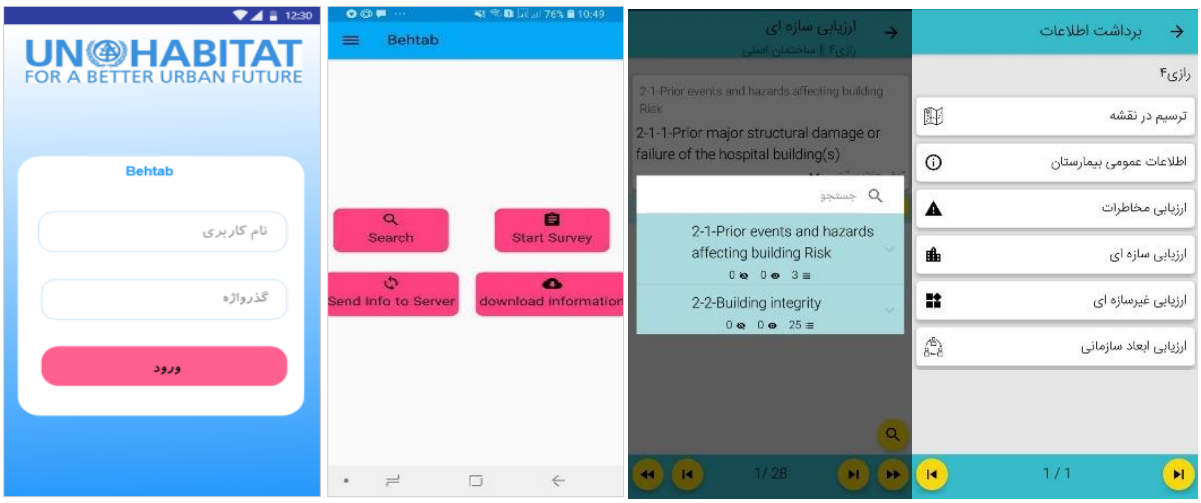


Figure 1. Snapshots of BEHTAB mobile software working in Android environment
top: entry screens, bottom: settings and options

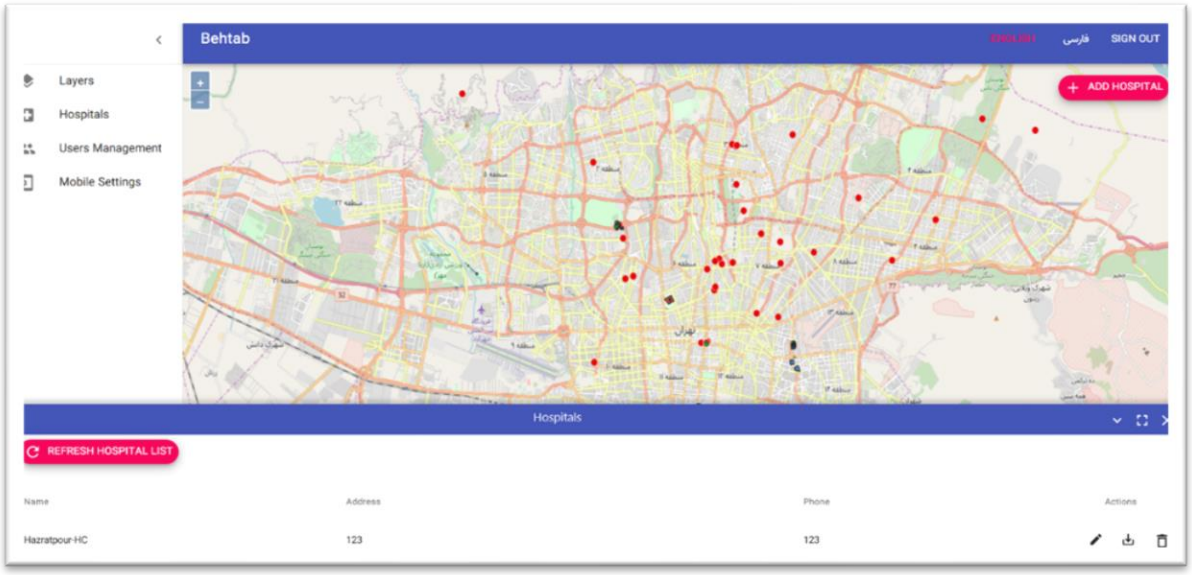


Figure 2 Web-based GIS module working on the MS Windows platform

The software has been tested and improved on several occasions:

- Two simulation tests were conducted in the UN-Habitat office to check the basic functionality of the application. These tests were conducted by BEHTAB team as well as a small sample of five users. The users were previously trained in RVA concepts and methodology.
- Moreover, two other pilot tests have been carried out at Shahr-e-Ghods and Nirougah hospitals in collaboration with Tehran Medical University and Ministry of Health and Medical Education. In these tests, 15 evaluators who were previously trained, conducted a real RVA using the BEHTAB application. Problems, issues, and areas of improvements were reported by the evaluators and subsequent actions to rectify problems have been undertaken.

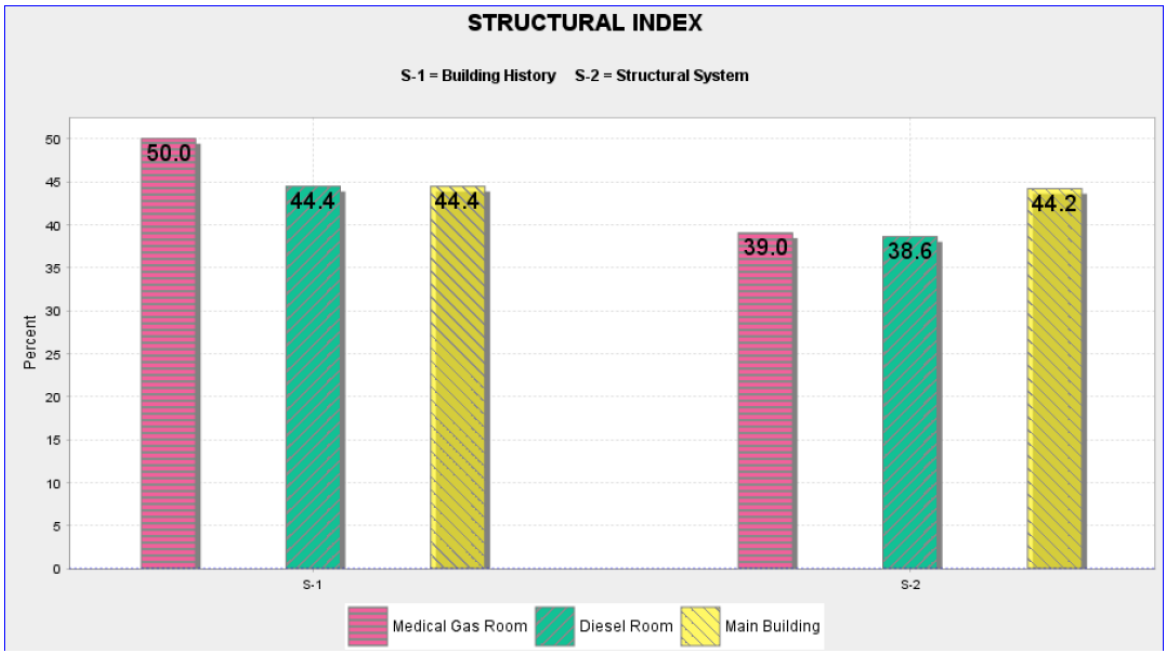


Figure 3 A sample of outputs of RVA, automated developed by App.

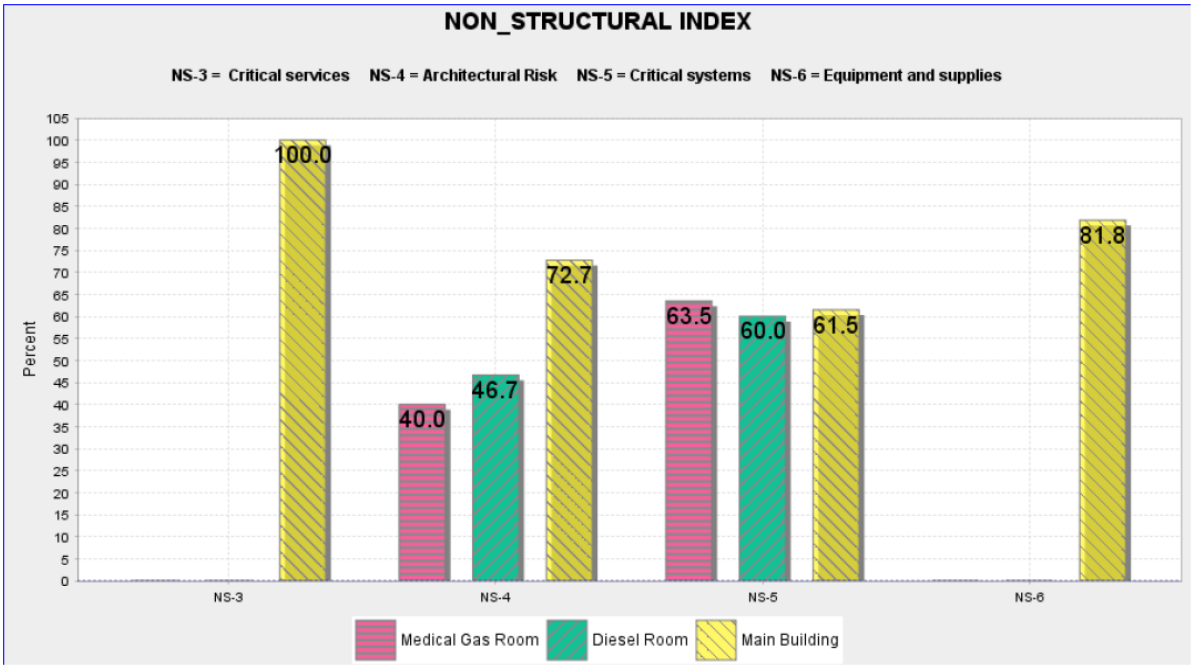


Figure 4 A sample of outputs of RVA, automated developed by App.

Preliminary Engineering Analysis (PEA)

Health facilities in Iran are designed similar to other buildings such as residentials and commercials. Although some design factors and parameters such as Importance Factor lead to more resistant structure, further provision is yet required to guarantee hospital performance during and after disaster. For this reason, Performance Based Design (PBD) approach was selected as the basis of studies methodology. To prepare the methodology different tasks were conducted, including:

- Reviewing and comparing various guidelines, codes and standards for design of HFs;
- Determining differences between force-based and performance-based design and result on HFs;
- Performing gap analysis on result of code differences;
- Determining different performance objectives to evaluate the structure of heath facilities,
- Introducing various evaluation levels based on structural analysis method to identify vulnerability status,
- Providing conclusion table to determine the vulnerability state,
- Developing retrofit strategies, solutions, and techniques for different structural systems of health facilities,
- Determining procedure of retrofitting design including technical and financial aspects, and
- Developing formats and framework to prepare retrofitting detail drawing, cost estimation and implementation documents.

Having methodology to conduct the studies, a number of hospitals were designated, and technical documents and other requirements were gathered. The technical information

submitted to the consultant to conduct the studies for each heal facilities. The list of hospitals and health centers for which PEA studies were implemented, is as tables below:

Table 3 List of hospitals for PEA

NO.	Medical University of	CITY	NAME OF Hospital
1	Az-east	Tabriz	Emam Reza
2	Az-east	Maraghe	Bou Ali Sina Maraghe
3	AZ-west	Oroumie	Saratan Emam
4	Esfahan	Najaf abad	Najaf abad
5	Esfahan	Esfahan	Feyz
6	Esfahan	Kashan	Emam Hasan Mojtaba
7	Esfahan	Esfahan	Trauma Ayatolah Kashani
8	Tehran	Shahr e Ghods	Shahr e Ghods
9	Fars	Fasa	Emam Hosein
10	Ghom	Qom	Nirougah
11	Mazandaran	Tonekabon	Emam

It should be noted that activities of both stages two and four were conducted for the list above and based on the integrated methodology with related outputs. For each hospital, different stages of evaluation based on the mentioned methodology was conducted in accordance with the credible design references such as ASCE41-17. Throughout the procedure, structural analyses were conducted through mathematical 3D modelling of the structure using developed version of design software as well as complicated calculations. Different aspects of structural element and its behavior were assessed and evaluated, and appropriate retrofitting details were proposed to satisfy acceptance criteria.

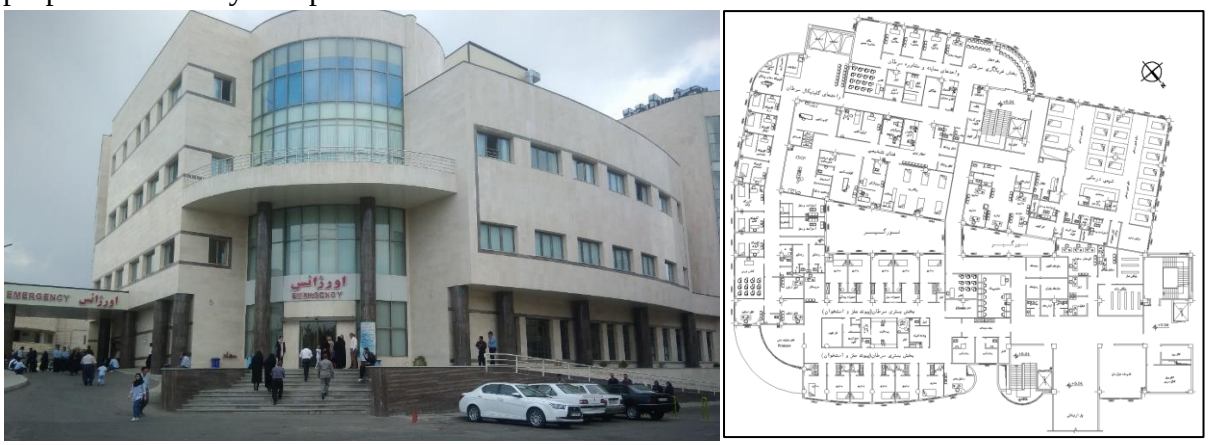


Figure 5: a sample of hospitals and drawings for PEA

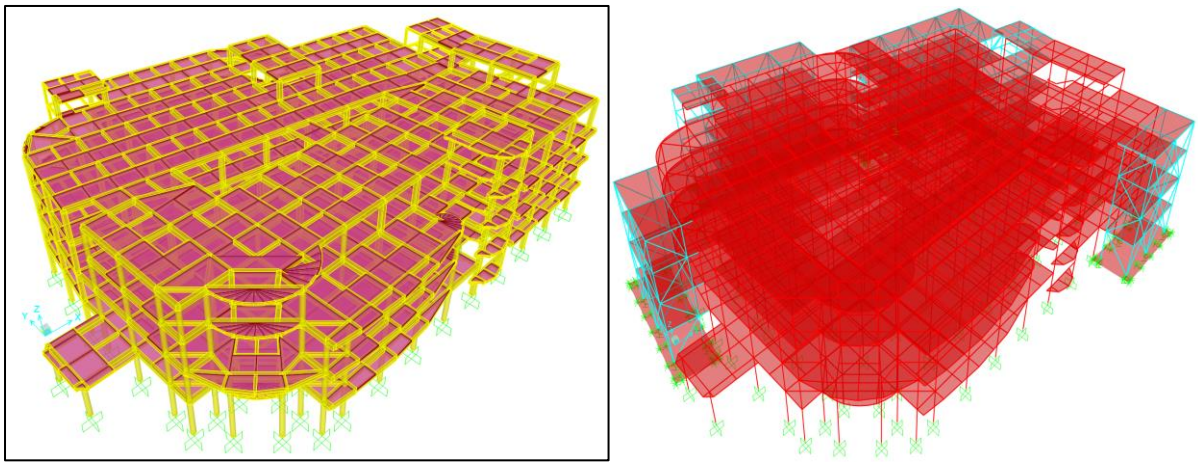


Figure 6: Structural 3D modelling and analysis for PEA

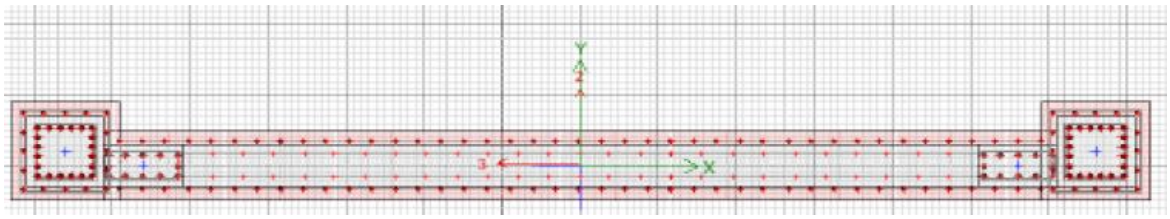


Figure 7: Structural element (shear walls) modelling for PEA

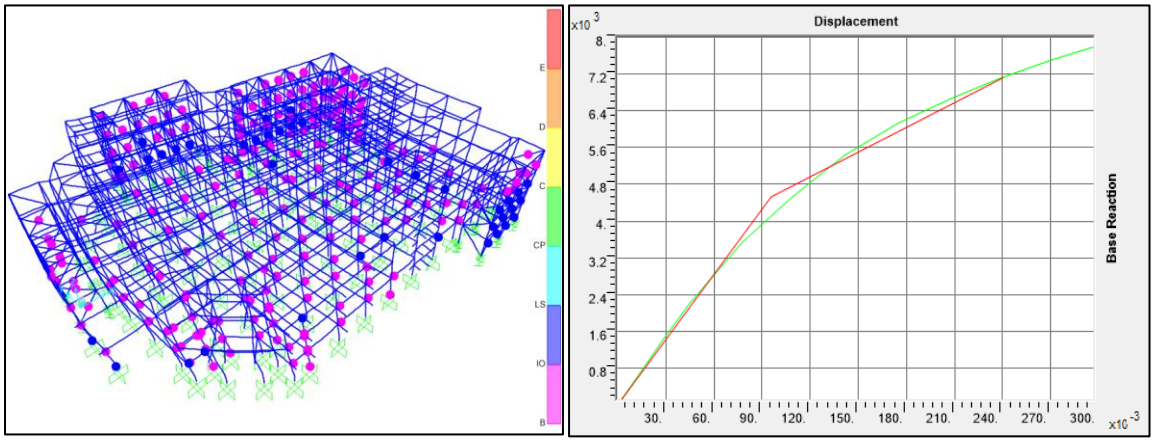


Figure 8: Structural non-linear analysis and result for PEA

To make sure that results are reliable, all stages of PEA studies were reviewed and checked by BEHTAB team and also a number of university professors as consultants of peer-reviewing.

Output Analysis : 2800 -v4		
Element Type	**Total Number**	**Unsatisfied Elements**
Column	318	61
Beam	867	0
Shear Walls	110	20

Output Analysis Asce -level 1 - 475		
Element Type	**Total Number**	**Unsatisfied Elements**
Column	318	7
Beam	867	26
Shear Walls	110	3

Output Analysis Asce -level 2 - 2475		
Element Type	**Total Number**	**Unsatisfied Elements**
Column	318	0
Beam	867	44
Shear Walls	110	5

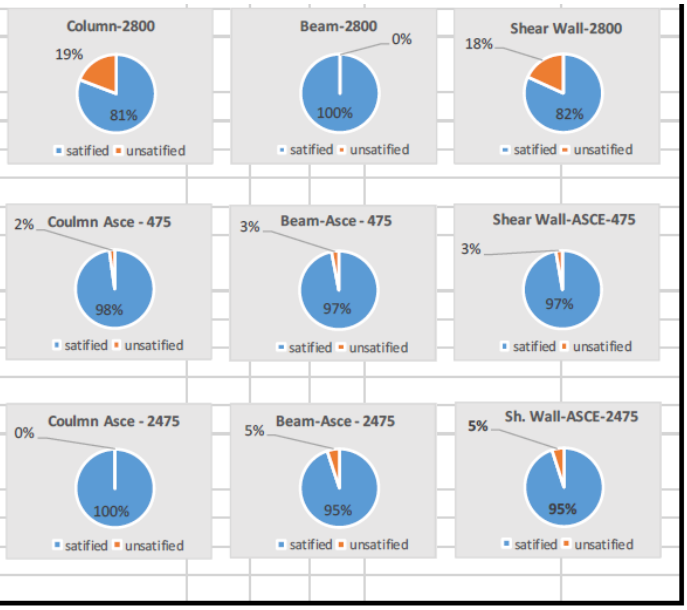
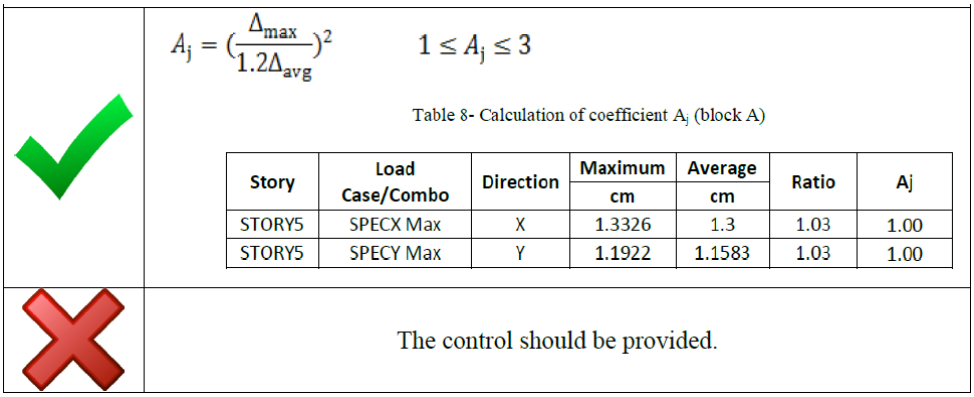


Figure 9 Output of analysis of PEA studies



$$A_j = \left(\frac{\Delta_{max}}{1.2\Delta_{avg}}\right)^2 \qquad 1 \le A_j \le 3$$

Table 8- Calculation of coefficient A_j (block A)

Story	Load Case/Combo	Direction	Maximum cm	Average cm	Ratio	Aj
STORY5	SPECX Max	X	1.3326	1.3	1.03	1.00
STORY5	SPECY Max	Y	1.1922	1.1583	1.03	1.00

The control should be provided.

Figure 10 Methodology of peer-reviewing of PEA studies

ASSESSMENT BASED ON ASCE41-L1		
Properties of Material	✓	
Knowledge Factor	✗	
Linear Dynamic Procedure Requirements	✗	
Multidirectional Seismic Effects	✗	The load combinations are not clear
Vertical Seismic Effects	✗	Description is not complete
Modification of Forces and Deformations for LDP	✓	
Torsion	✗	he Calculation for parameter A is not give
Elements Checking (k=0.75)	✓	
Elements Checking (k=1)	✗	
Force Control Parameters Checking	✓	
ASSESSMENT BASED ON ASCE41-L2		
Nonlinear Static Analysis Procedure Requirements	✗	
Determination of fundamental period	✓	
Target displacement	✓	
Elements Checking (k=0.75)	✓	
Elements Checking (k=1)	✗	
Force Control Parameters Checking	✓	

Figure 11 Result of peer-reviewing of PEA studies

Non-structural hazard mitigation

The main objective of non-structural analyses is defining procedures that lead to safeguarding non-load bearing building components, mechanical and electrical installations, as well as functional and institutional elements. The proposed methodology for this study was completed by the respective sub-committees in March and April 2019. Based on the mentioned methodology a number of hospitals and health care centers were evaluated from non-structural point of view. The finalized methodology is comprised of the following steps:

- A general inventory is developed for strategic equipment indicating their main characteristics, such as size, weight, shape, cost, and importance for an interrupted function of hospital services during the disaster.
- A non-structural mitigation programme is prepared by establishing a systematic and thorough inspection of HFs to evaluate existing hazards.
- A list of more than 150 items for such an investigation has been collected. These were tested in the first pilot training activity and put to use by the consultant.
- Based on the assessment of individual components of respective systems, the critical systems and medical facilities are examined to identify possible risks. Mitigation options for each system will then be identified and critically evaluated in terms of feasibility, cost, and expected efficiency.
- A systematic review is then conducted, taking into account the fluid movement of staff, equipment, and supplies in an unexpected situation during a disaster. This underscores the critical nature and interdependence of the various processes, buildings, and equipment. Deficiencies in any of these areas can plunge a hospital into a crisis.
- In hospital design, emphasis must be placed on the optimal use of space and the configuration of the services provided, so that the different departments and activities can mesh together with the greatest possible efficiency and the lowest vulnerability. Many facilities have suffered a functional collapse because of simple omissions during their design, which could have been easily corrected or addressed at a marginal cost during construction or retrofitting.
- In terms of Institutional aspects, the list of important factors affecting the functionality of hospitals are gathered and a questionnaire is developed to determine the weight of each factor based on its effect in the final index. To this end, the Analytical Hierarchical Process is used as an efficient methodology with reasonable accuracy.

Non-structural components are divided to architectural elements, mechanical and electrical elements, medical equipment, thus, assessment of each component were done via specific method. The lists of hospitals and health centers for which NST studies was implemented, are as tables below:

Table 4 List of hospitals for NST

NO.	Medical UNIVERSITY of	CITY	NAME OF Hospitals
1	Az-east	Maraghe	Bou Ali Sina Maraghe
2	AZ-west	Oroumie	Takmil e Khoy
3	AZ-west	Oroumie	2nd Wing Mian doab

4	AZ-west	Oroumie	Saratan Emam
5	Ardebil	Pars abad	Pars abad
6	Esfahan	Esfahan	Trauma Ayatolah Kashani
7	Esfahan	Esfahan	Almahdi nour & Ali asghar
8	Alborz	Karaj	Bahonar
9	Tehran	Tehran	Amir Alam
10	Shahid Beheshti	Gharchak Varamin	Gharchak Varamin
11	Ghom	Qom	Nirougah
12	Semnan	Shahroud	Fatemiye
13	tavanbakhshi	Tehran	Nezam Mafi

Table 5 List of Health centers for NST

NO.	Medical UNIVERSITY of	CITY	NAME OF HEALTH CENTER
1	Az-east	Tabriz	Sardardoud
2	Az-east	Tabriz	Yousef abad
3	Az-east	Tabriz	Shahid Motahari
4	Az-east	Tabriz	Satarkhan
5	Az-east	Tabriz	Ghataran
6	Az-east	Tabriz	Ostad Jafari
7	Az-east	Tabriz	Marzadaran (Ana khatoon)
8	Esfahan	Esfahan	Khorasgan no.1
9	Alborz	Karaj	Shahid Esmail Rousanezhad
10	Alborz	Karaj	Hesarak
11	Alborz	Karaj	Khoramdasht
12	Alborz	Savojbolagh	Ghasem abad
13	Alborz	Savojbolagh	Shahr e Jadid Savojbolagh
14	Tehran	Eslam shahr	Shahrak e Golha
15	Tehran	Eslam shahr	Mehr Vavan
16	Tehran	Eslam shahr	Mehr Zia abad
17	Tehran	Eslam shahr	Bagh e feyz
18	Tehran	Eslam shahr	Ghasem abad
19	Tehran	Tehran	Sheykh Ahmad Kafi
20	Tehran	Tehran	Dolat Khan
21	Tehran	Tehran	Shahid Ahmadi
22	Tehran	Tehran	Meysam
23	Tehran	Tehran	Hakim Etemad
24	Tehran	Tehran	Javadie
25	Tehran	Tehran	Shahid Vahedi jonoub
26	Shahid Beheshti	Gharchak	Ziba shahr 1
27	Shahid Beheshti	Pakdasht	Khatoun abad
28	Ghom	Ghom	Isar
29	Ghom	Ghom	Imam Sadegh

30	Ghom	Ghom	Zarei
31	Ghom	Ghom	Imam reza Pardisan

Figure 12. samples of architectural and mechanical elements in Non-Structural assessment

Figure 13medical equipment in Non-Structural assessment

Figure 14 mechanical equipment in Non-Structural assessment

Resilience of HFs in urban grid

According to the overall goal of BEHTAB project in enhancing the disaster resilience of hospitals, the project adopts a multi-dimensional approach to study and analyze the resilience of HFs' grid within the cities. Studying such various dimensions is required to obtain necessary knowledge to assess health care facilities' capacity to prepare, respond and recover from all shocks and stresses. BEHTAB project follows three major steps including:

- Data collection and diagnosis;
- Determining the vulnerability index of healthcare facilities in urban context;
  - Scaling
  - Weighted rating
  - Calculating the vulnerability index
- Identifying actions to improve the resilience of HFs at the urban scale.

To this end, two hospitals of more important health facilities in Tehran with the approximated area of 70000 square meters are selected to study of urban resiliency; Shohadaye Tajrish and also AmirAalam. The studies of both two hospitals were done successfully and lots of maps and features were developed for them as well as filling checklists for vulnerability index which some are demonstrated below:

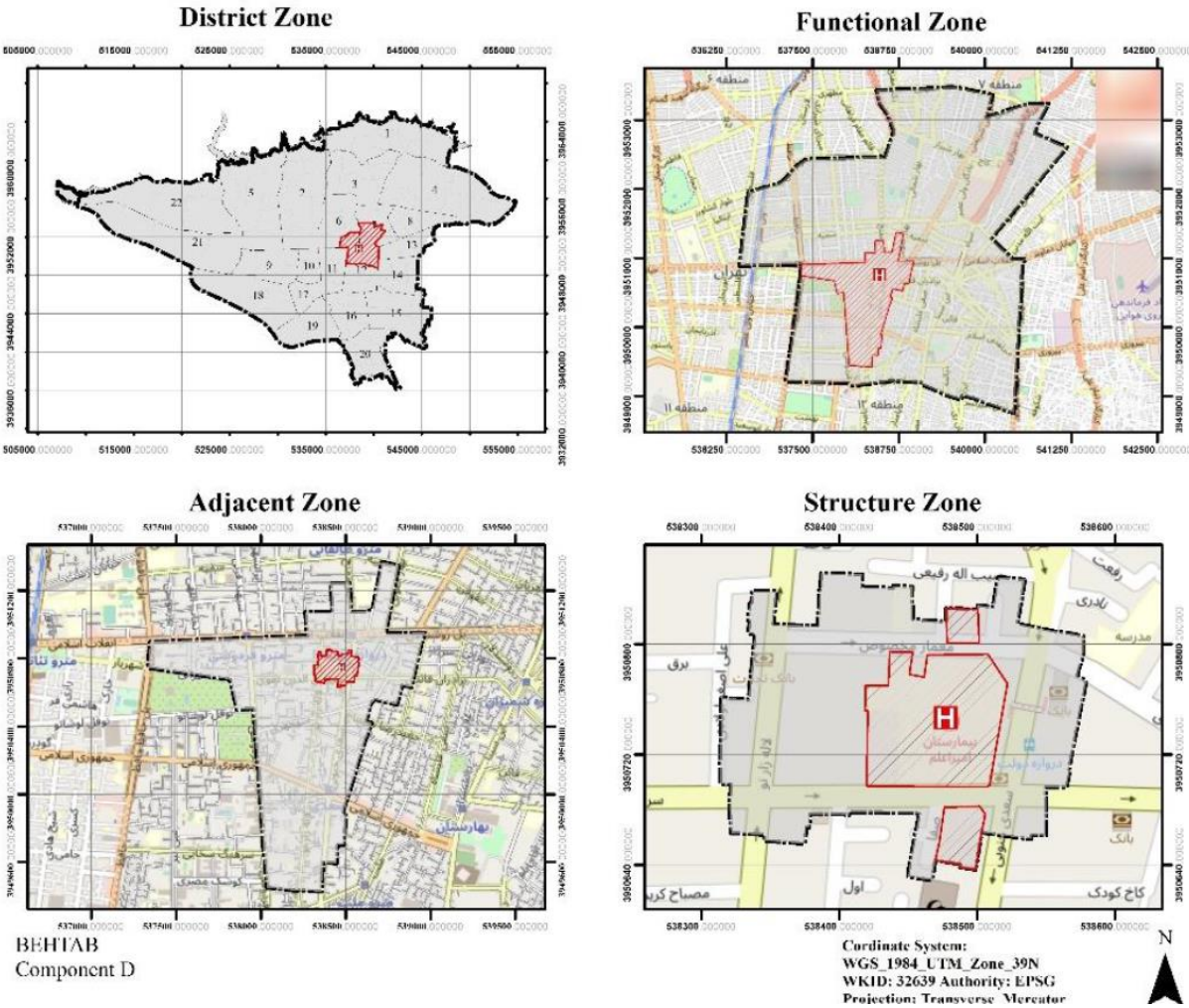


Figure 15 Different borders for AmirAalam hospital

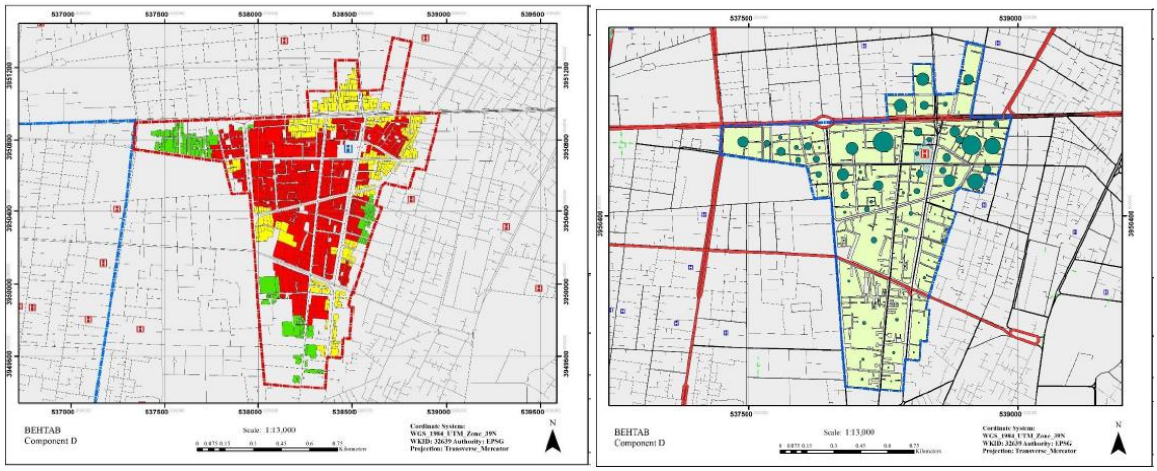


Figure 16 functional boundary based on closest walking and vehicle routes - Population distribution

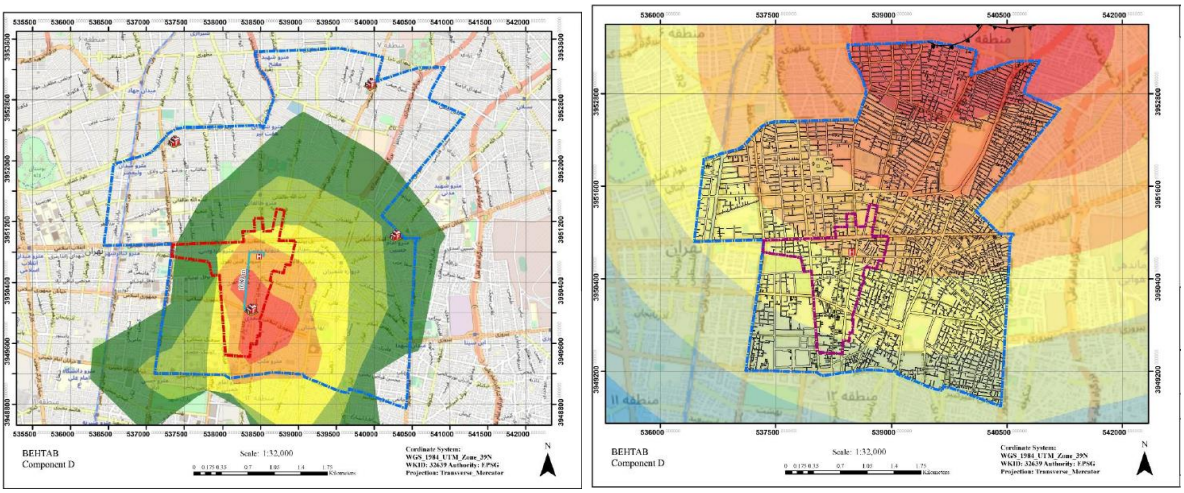


Figure 17 Proximity to the fire station - Distance from the fault line

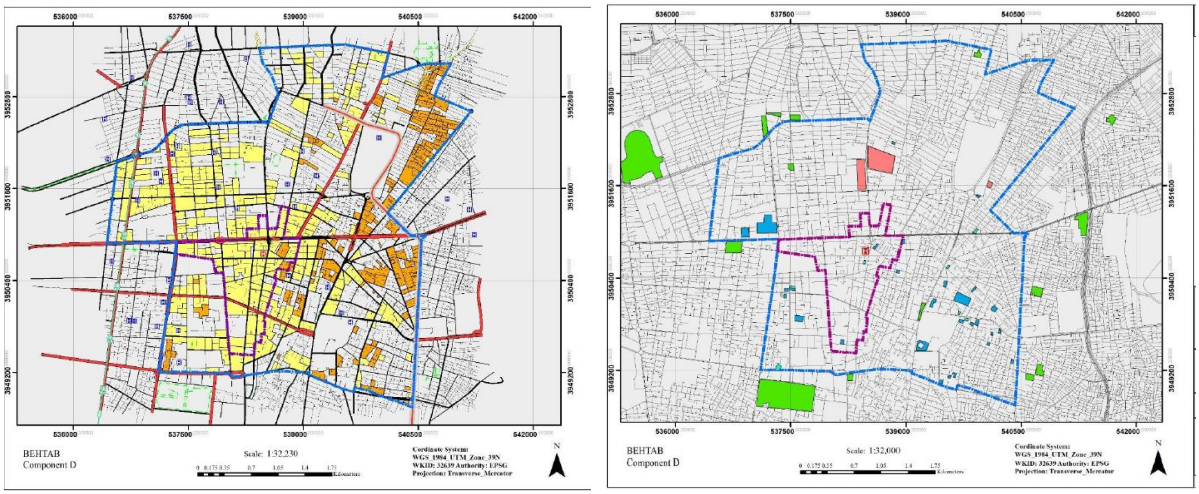


Figure 18 Deteriorated area - Supportive land use for Hospital

Table 6 Urban Resiliency index

	Dimension	Index	Indicator Score	Component weight	Component Score	Percentage
Physical Attributes	Site Plan	Open space	0	25	6	24
		Space expansion	0			
	Hard Infrastructure	Underground sewage disposal system	2			
		Electricity network coverage	2			
		Number of Bridge	0			
		Adequate lighting in and around the building	2			
	Built-up Environment	Built-up area ratio	0			
		Average of Building Density (zoning)	0			
Functional Attributes	Land-use zoning	Gravity (to analyze primary and Trip attractive Building)	2	30	20.55	68
		Supporting Land-uses in adjacent zone	1.5			
		Dangerous Building	2			
	Socio-Economic	Population Density	4			
		Vulnerable group (women, disabled people, age group upper than 65 and lower than 5)	1.3			
		Literacy	1.5			
		Social responsibility	1			
	Transportation	Public transportation system	2			
		Parking	2			
		Traffic Flow ratio	1			
		Has well-paved access roads	1			
		Obstructions on the roads leading to the hospital	0			
		Road inundation	1.25			
Spatial attributes	Accessibility	Number of Entrance	1	30	13.73	46
		Proximity to open spaces and green spaces	0			
		Depth	0.5			
		Proximity to main roads	2			
		Straightness	0.5			
		Proximity to public transportation	2			
		Betweenness	0			
		Integration	1			
		Connectivity	0			
		Reach	1			
		The type of access road (width)	1			
	Proximity	Supporting Land-uses in Functional zone	1			
		Dangerous Land uses	2			
		Fire station	0.4			
		Proximity to fault	1.33			
		Distance from adjacent buildings	0			
		Are there trees and/or towers too close to the building that may fall on it during high wind/cyclone?	0			
	Development Plans	Paying attention on Resiliency	0			
		Paying attention on Hospital needs	0			
		Decayed area	0			
Organizational attributes	Institutional structure	Role of Hospital management in local governance	0	10	4	40
	Serviceability of Hospital	Number of beds	3			
	Hospital levels	Functional Scale	1			
		Distance to city center	0			
Dynamic attribute	Time trend	Role changing	5	5	5	100
	Total		49.28	100	49.28	_