Evaluating different guardian structures in making subway stations and introducing optimal method by using Analytic hierarchy process (AHP) (Case Study: Ahvaz subway)

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Abstract: One of the most important subjects of implementation is the plan of guardian structure of box` parapets for subway stations. Depth of parapets for Ahvaz subway station is up to 15 meters. Some factors such as drift soil, soil pressure and especially depth of underground water are about 1 to 1.5 meter below the ground surface in city of Ahvaz, cause drift parapets of stations box. First, strot (reciprocal anchorage) was used in order to prevent drift and movement of parapets. Then, strots because of time consuming and high costs were removed and other methods were adopted. For this subject, it was suggested that bodies will be connected to their backside soil by nailing and anchoring systems. In urban subway projects, which are currently being implemented in Iran, they generally use pile dig system and sheet piling for stations implementations and they hold bodies, then they perform main structure within this body, after excavation. In this project, the selected method couldn't provide major goals of the projects, because of nonuse of a classic research to determine the most appropriate guardian structure. In this article with taking advantage of AHP, different types of plans for guardian structures are examines and are analyzed, then criterions and priorities that allocated to the plans are analyzed by software Expert Choice, so the final result will be the most appropriate plan of guardian structure.[1,2]

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1. Introduction

Subways and specially their stations are the most important urban transport network infrastructures in big cities these days. Constructing these kinds of infrastructures in developed countries and achieving favorable results by using the mentioned constructions in order to reduce problems of urban transportation, makes it inevitable to necessity of widespread use of these constructions in developing countries.

By the way, implementation of such huge projects that require significant cost for constructing them in my country, It may be always, involved with challenges. Some of the most important challenges correspond to implementation phase and also sometimes lead to lots of financial losses and fatality in case of ignorance (to safety tips). For example, it will help to reduce the problems in constructing subway, by investigating different types of guardian structures in term below the groundwater followed by choosing the best ways in urban specially in City of Ahvaz.[3]

2- materials and methods

2-1- analytic hierarchical process

Analytic hierarchical process is one of the most comprehensive designed systems for decision making with multiple criterions. This technique provides possibility to formulate the subject as a hierarchal and also possibility to consider the various quantitative and qualitative criterions. This process uses various choices to decision and also has possibility of sensitivity analysis on criterions and sub criterions. This process facilitates judgments and calculations since it is based on paired comparison. It expresses compatibility and incompatibility of the decision and it can be said it is outstanding advantage of this technique in multiple criterions decision making. This method has a strong theoretical basis and is based on axioms. [4]

2-2-creation of hierarchical:

First step in analytic hierarchical process is creating a graphical representation about the subject that in which goal, criterions and options are shown.

According to questionnaire 6 major criterions among the implementation criterions were selected to compare and evaluate that include:

1- Constructions costs include implementation costs and preparation of materials,

2- Ease of implementation,

3- Safety,
4- Availability of construction technology,
5- Speed of implementing structure
6- And Enough space for implementing of guardian structure.
Also 6 main choices are considered for guardian structures, which are as follow:

1- Diaphragm wall,
2- Nailing,
3- Reciprocal anchorage,
4- Piling method,
5- Sheet piling method,
6- And Truss method [3,5]

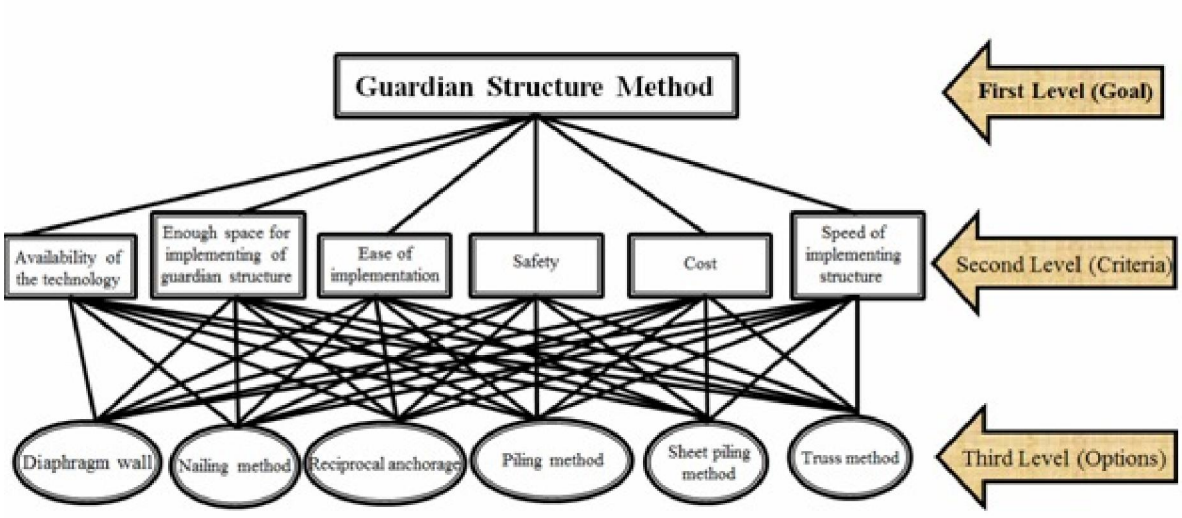

Figure 1. Tree hierarchical

2-3- weight calculation:

In ingredients analytic hierarchical process, each level is compared toward its element in higher level as pairs, then its weight is calculated.

In these comparisons, decision makers will use verbal judgments, so that if element i is compared with element j, decision maker will say that importance of i over j is one of the status in table 1. [5]

Table1- Quantification of decision making

Preferences (verbal judgment)	numerical value
fully favorable	9
Very strong favorable	7
strong favorable	5
a little more favorable	3
Same favorable	1
preferences between above intervals	2,4,6,8

The weight of each criterion in this analysis was achieved by using a questionnaire, through 20 Chief Executives who are supervisor of subway stations in city of Ahvaz, they mostly have more than 15 years of executive experience in guardian structure and constructing underground stations.

In tables 2 to 7, the results of comparison of choices are represented based on every criterion and in term of paired that are obtained through questionnaire by inputting data to the software, are shown.

Table2- paired comparison of choices based on costs

Methods	Diaphragm wall	Nailing	Reciprocal anchorage	Piling method	Sheet piling	Truss method
Diaphragm wall	1	4	3	2	1.5	6
Nailing	0.25	1	0.75	0.5	0.334	2
Reciprocal anchorage	0.334	1.334	1	0.75	0.5	3
Piling method	0.5	2	1.334	1	0.75	4
Sheet piling	0.667	3	2	1.334	1	5
Truss method	0.167	0.5	0.334	0.25	0.2	1

Table3- paired comparison of choices based on safety

Methods	Diaphragm wall	Nailing	Reciprocal anchorage	Pile implementation	Hitting sheet	Truss method
Diaphragm wall	1	4	5	2	3	6
Nailing	0.25	1	1.5	0.5	0.75	2
Reciprocal anchorage	0.2	0.667	1	0.334	0.5	1.5
Piling method	0.5	2	3	1	1.5	4
Sheet piling	0.334	1.334	2	0.667	1	3
Truss method	0.167	0.5	0.667	0.25	0.334	1

Table4- paired comparison of choices based on ease of implementation

Methods	Diaphragm wall	Nailing	Reciprocal anchorage	Piling method	Sheet piling	Truss method
Diaphragm wall	1	4	3	4	2	2
Nailing	0.25	1	0.75	1	0.5	0.5
Reciprocal anchorage	0.334	1.334	1	1.5	0.75	0.75
Piling method	0.25	1	0.667	1	0.5	0.5
Sheet piling	0.5	2	1.334	2	1	2
Truss method	0.5	2	1.334	2	0.5	1

Table5- paired comparison of choices based on Speed of implementing structure

Methods	Diaphragm wall	Nailing	Reciprocal anchorage	Piling method	Sheet piling	Truss method
Diaphragm wall	1	5	2	3	2	4
Nailing	0.2	1	0.334	0.5	0.334	0.75
Reciprocal anchorage	0.5	3	1	1.5	1	2
Piling method	0.334	2	0.667	1	0.75	1.5
Sheet piling	0.5	3	1	1.334	1	2
Truss method	0.25	1.334	0.5	0.667	0.5	1

Table6- paired comparison of choices based on availability of technology

Methods	Diaphragm wall	Nailing	Reciprocal anchorage	Piling method	Sheet piling	Truss method
Diaphragm wall	1	0.5	0.167	0.334	0.25	0.143
Nailing	2	1	0.25	0.75	0.5	0.2
Reciprocal anchorage	6	4	1	3	2	0.75
Piling method	3	1.334	0.334	1	0.75	0.25
Sheet piling	4	2	0.5	1.334	1	0.334
Truss method	7	5	1.334	4	3	1

Table7- paired comparison of choices based on enough space for implementing of guardian structure

Methods	Diaphragm wall	Nailing	Reciprocal anchorage	Piling method	Sheet piling	Truss method
Diaphragm wall	1	1.5	5	3	1.5	6
Nailing	0.667	1	4	2	1	5
Reciprocal anchorage	0.2	0.25	1	0.5	0.25	1.5
Piling method	0.334	0.5	2	1	0.5	3
Sheet piling	0.667	1	4	2	1	5
Truss method	0.167	0.2	0.667	0.334	0.2	1

2-4-calculating the weight of each matrix through arithmetic mean method

First step: summation of values in each column.

Second step: each element in the matrix of paired comparison must be divided by sum of its column in order to normalized the matrix of paired comparison.

Third step: organizing matrix preference.[5]

In tables 8 to 13 normalized comparisons matrix that are as follows:

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Table8- weighted percent of choices comparison based on costs

Normalized	Diaphragm wall	Nailing	Reciprocal anchorage	Piling method	Sheet piling	Truss method	Relative importance of alternative
Diaphragm wall	0.343	0.338	0.356	0.345	0.35	0.286	0.337
Nailing	0.086	0.085	0.089	0.086	0.078	0.095	0.0865
Reciprocal anchorage	0.114	0.112	0.119	0.128	0.117	0.143	0.122
Piling method	0.171	0.169	0.158	0.171	0.175	0.19	0.172
Sheet piling	0.229	0.254	0.238	0.228	0.233	0.238	0.237
Truss method	0.057	0.042	0.04	0.042	0.047	0.048	0.046
sum of columns	1	1	1	1	1	1	1

Table9- weighted percent of choices comparison based on safety

Normalized	Diaphragm wall	Nailing	Reciprocal anchorage	Piling method	Sheet piling	Truss method	Relative importance of alternative
Diaphragm wall	0.408	0.421	0.38	0.422	0.423	0.343	0.3995
Nailing	0.102	0.105	0.114	0.105	0.106	0.114	0.108
Reciprocal anchorage	0.082	0.07	0.076	0.07	0.071	0.086	0.0759
Piling method	0.204	0.211	0.228	0.21	0.212	0.229	0.216
Sheet piling	0.136	0.14	0.152	0.14	0.141	0.171	0.147
Truss method	0.068	0.053	0.05	0.053	0.047	0.057	0.055
sum of columns	1	1	1	1	1	1	1

Table10- weighted percent of choices comparison based on ease of implementation

Normalized	Diaphragm wall	Nailing	Reciprocal anchorage	Piling method	Sheet piling	Truss method	Relative importance of alternative
Diaphragm wall	0.353	0.354	0.371	0.348	0.382	0.297	0.351
Nailing	0.089	0.088	0.093	0.087	0.095	0.074	0.0877
Reciprocal anchorage	0.118	0.118	0.124	0.13	0.143	0.111	0.124
Piling method	0.088	0.088	0.082	0.087	0.095	0.074	0.086
Sheet piling	0.176	0.176	0.165	0.174	0.19	0.296	0.196
Truss method	0.176	0.176	0.165	0.174	0.095	0.148	0.156
sum of columns	1	1	1	1	1	1	1

Table11- weighted percent of choices comparison based on Speed of implementing structure

Normalized	Diaphragm wall	Nailing	Reciprocal anchorage	Piling method	Sheet piling	Truss method	Relative importance of alternative
Diaphragm wall	0.359	0.326	0.363	0.375	0.358	0.356	0.356
Nailing	0.071	0.065	0.061	0.062	0.06	0.067	0.064
Reciprocal anchorage	0.18	0.196	0.182	0.188	0.179	0.177	0.184
Piling method	0.12	0.13	0.121	0.125	0.134	0.133	0.127
Sheet piling	0.18	0.196	0.182	0.167	0.179	0.178	0.180
Truss method	0.09	0.087	0.091	0.083	0.09	0.089	0.088
sum of columns	1	1	1	1	1	1	1

Table12- weighted percent of choices comparison based on availability of technology

Normalized	Diaphragm wall	Nailing	Reciprocal anchorage	Piling method	Sheet piling	Truss method	Relative importance of alternative
Diaphragm wall	0.044	0.036	0.046	0.032	0.033	0.053	0.041
Nailing	0.087	0.072	0.07	0.072	0.067	0.075	0.0738
Reciprocal anchorage	0.261	0.289	0.279	0.288	0.267	0.28	0.277
Piling method	0.13	0.097	0.093	0.096	0.1	0.093	0.102
Sheet piling	0.174	0.145	0.14	0.128	0.133	0.125	0.141
Truss method	0.304	0.361	0.372	0.384	0.4	0.374	0.366
sum of columns	1	1	1	1	1	1	1

Table13- weighted percent of choices comparison based on enough space for implementing of guardian structure

Normalized	Diaphragm wall	Nailing	Reciprocal anchorage	Piling method	Sheet piling	Truss method	Relative importance of alternative
Diaphragm wall	0.329	0.337	0.3	0.34	0.337	0.279	0.320
Nailing	0.22	0.225	0.24	0.226	0.225	0.232	0.228
Reciprocal anchorage	0.066	0.056	0.06	0.057	0.056	0.07	0.061
Piling method	0.11	0.112	0.12	0.113	0.112	0.139	0.118
Sheet piling	0.22	0.225	0.24	0.226	0.225	0.233	0.228
Truss method	0.055	0.045	0.04	0.038	0.045	0.047	0.045
sum of columns	1	1	1	1	1	1	1

In first step (in matrix of weight), all of the choices are compared with each criterion in pairs, and relative weight value is given to each of them. In second step, the matrix is normalized and is computed by using the weight arithmetic mean of each choice corresponding to specified criterions. Questionnaire and also opinion of experts is used for other choices. All of the choices are compared with each criterion in pairs and table 14 represents summary of steps one and two for guardian structure method. [5, 6, 7]

Table14- summary of normalized weights

No.	Method\Criteria	Speed of implementing structure	Cost	Safety	ease of implementation	Enough space for implementing of guardian structure	availability of the technology
1	Diaphragm wall	0.356	0.336	0.4	0.351	0.32	0.041
2	Nailing	0.064	0.087	0.108	0.088	0.228	0.074
3	Reciprocal anchorage	0.184	0.122	0.076	0.124	0.061	0.277
4	Piling method	0.127	0.172	0.216	0.086	0.118	0.102
5	Sheet piling	0.18	0.237	0.147	0.196	0.228	0.141
6	Truss method	0.088	0.046	0.055	0.156	0.045	0.366
sum of columns		1	1	1	1	1	1

2-5- paired comparison of criterions

In third step, criterions are compared in pairs in the same method. In this step, comparison is made more widely and checks different viewpoints in order to provide appropriate strategies. In other words, it is considered in each scenario that superiority of one criterion is tangible than other criterions in order to decision making will be done due to the requirements and factors (tables 15 and 16) Also, in diagram 1, relative importance of criterions is shown in percentage. [5,7]

Table15- paired comparison of criterions-determining preference of criterions

Criteria	Speed of implementing structure	Cost	Safety	ease of implementation	Enough space for implementing of guardian structure	availability of the technology
Speed of implementing structure	1	9	4	6	9	0.167
Cost	0.112	1	7	8	5	6
Safety	0.25	0.143	1	5	6	0.334
Ease of implementation	0.167	0.125	0.2	1	0.334	0.112
Enough space for guardian structure implementation	0.112	0.2	0.167	3	1	0.125
Availability of the technology	6	0.167	3	9	8	1

Table16- normalizing weights of criterions preference

Normalized	Speed of implementing structure	Cost	Safety	Ease of implementation	Enough space for implementing of guardian structure	Availability of the technology	Relative importance of alternative
Speed of implementing structure	0.131	0.846	0.261	0.188	0.307	0.023	0.293
Cost	0.015	0.094	0.455	0.25	0.17	0.775	0.293
Safety	0.033	0.013	0.065	0.156	0.205	0.043	0.086
Ease of implementation	0.022	0.012	0.013	0.031	0.011	0.014	0.0172
Enough space for implementing of guardian structure	0.015	0.019	0.011	0.094	0.034	0.016	0.032
Availability of the technology	0.784	0.016	0.195	0.281	0.273	0.129	0.28
Sum of columns	1	1	1	1	1	1	1

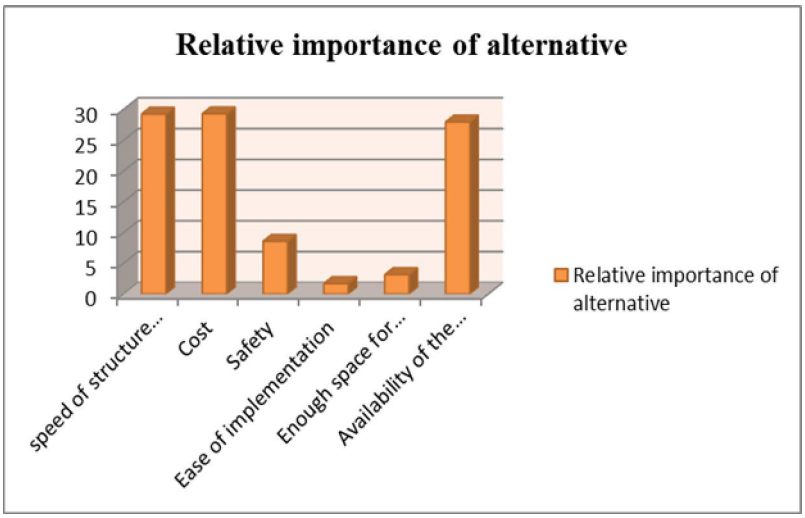

Diagram1- relative importance of criterions in digging method (in percentage)

For facilitating decision making and also for achieving true weights of criterions, sensitivity analysis was done, that in each scenario, superior choice was determined. It can be seen in table 17, summary of suggested scenarios with superiority of choices. In table 17, suggested choices are compared with each other in pairs, by several basic factors. In first scenario, with considering 5 superior criterions (speed of implementation, cost, safety, ease of implementation, enough space) that these 5 were evaluated with higher percentage than the other criterions. Finally, first choice was selected as a superior plan. Scenario 6 is second suggested plan because easily accessible of technology. Also, in diagram 2, comparisons of guardian structure based on criterions (in percentage) are shown.[5,6]

Table17-various scenarios about selecting superior choice and percentage of each criterion

No.	Method\Criteria	Speed of structure implementation	Cost	Safety	Ease of implementation	Enough space for guardian structure implementation	Availability of the technology
1	Diaphragm wall	35.6	33.6	40	35.1	32	4.1
2	Nailing	6.4	8.7	10.8	8.8	22.8	7.4
3	Reciprocal anchorage	18.4	12.2	7.6	12.4	6.1	27.7
4	Pile implementation	12.7	17.2	21.6	8.6	11.8	10.2
5	Hitting sheet	18	23.7	14.7	19.6	22.8	14.1
6	Truss method	8.8	4.6	5.5	15.6	4.5	36.6
The sum of columns (percent)		100	100	100	100	100	100

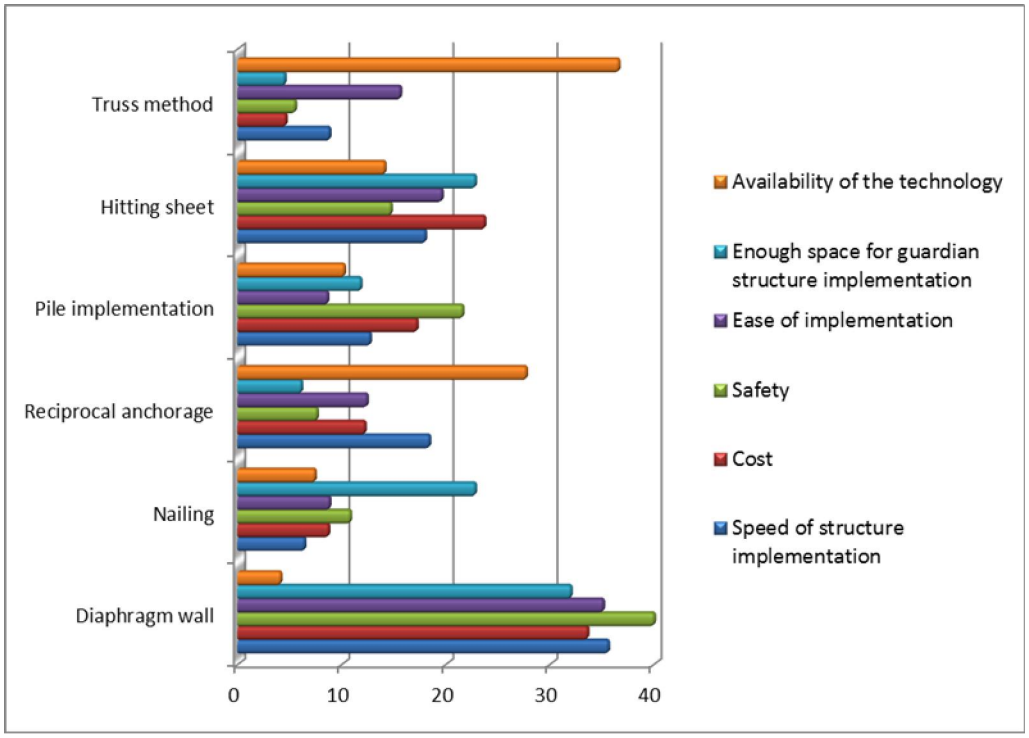

Diagram2- comparison of guardian structure method based on criterions in percentage

2-6- evaluation`s results of guardian structure method with use of analytical hierarchy process in Expert Choice method.

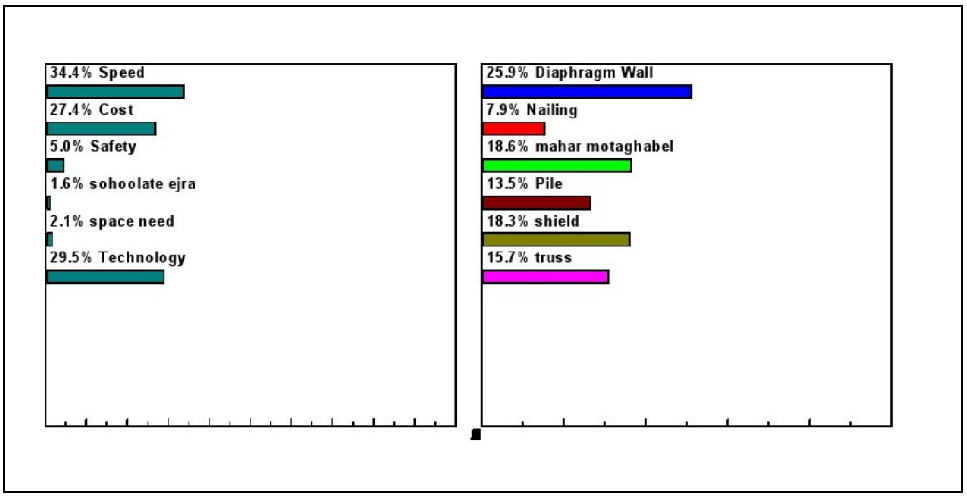

Diagram3 - dynamic sensitivity for each option

Diagram 3 shows the final weights for options and criterion in percentage separately in bar graph. Among criterions, speed of structure implementation is the most important with 34.4% and also among the options Diaphragm wall method achieved heaviest weight that is 25.9%.

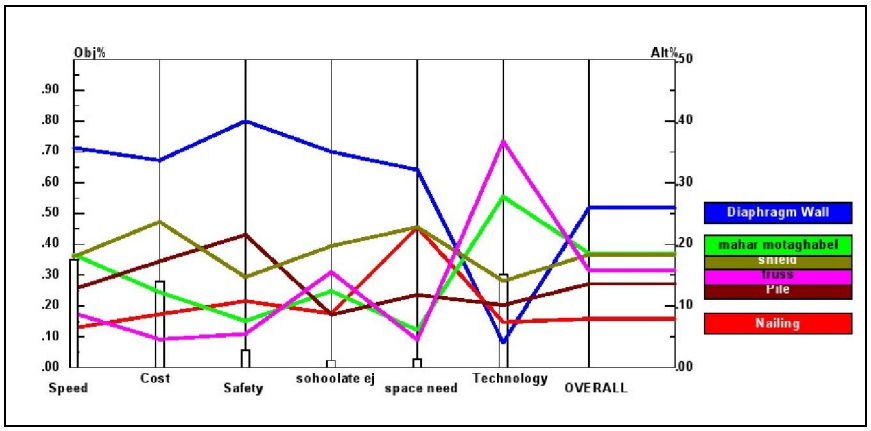

Diagram4 - sensitivity of performance for each option

In Diagram 4 final percentage of choices weights was determined that superior choice is use of Diaphragm wall with the maximum weight. [5]

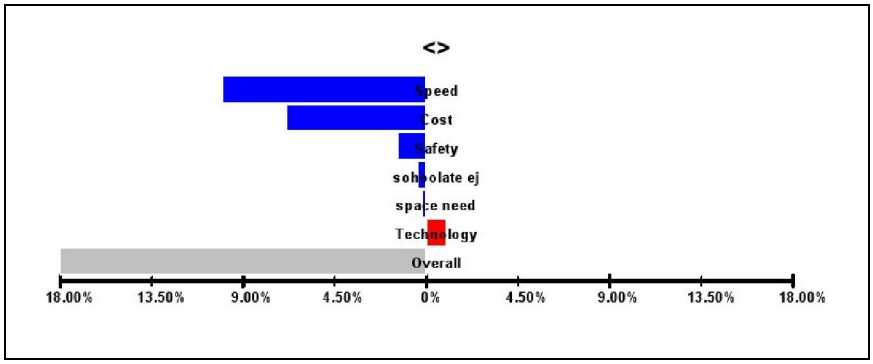

Diagram 5 - comparison in pairs between choices: Diaphragm wall and Nailing

In Diagram 5 the two choices Diaphragm wall and Nailing were compared in pairs based on all criterions.

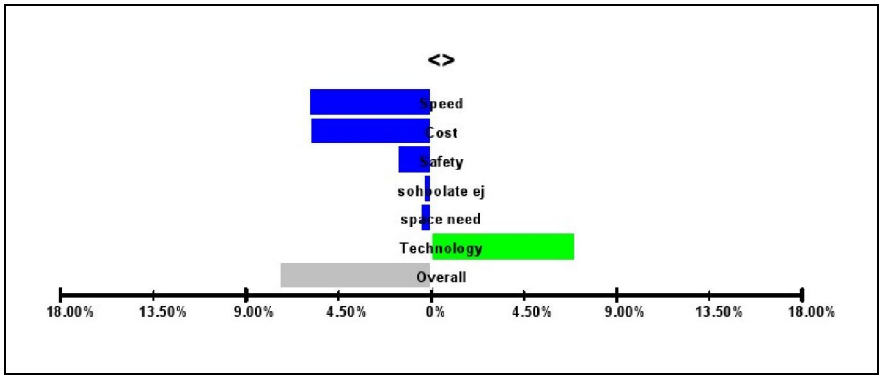

Diagram 6 - comparison in pairs between choices: Diaphragm wall and reciprocal anchorage

In Diagram 6 the two choices Diaphragm wall and reciprocal anchorage were compared in pairs based on all criterions.

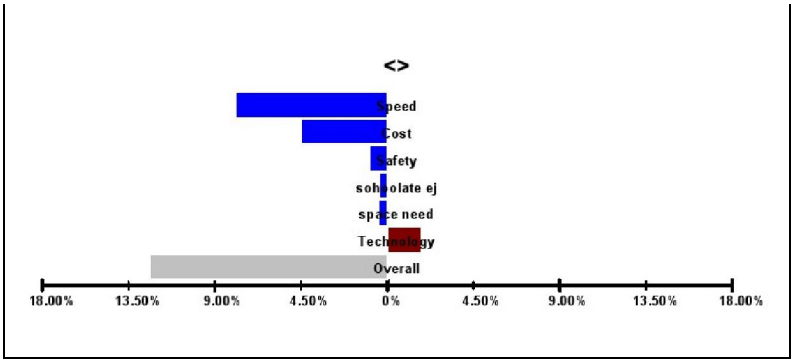

Diagram 7 - comparison in pairs between choices: Diaphragm wall and Piling method

In Diagram 7 the two choices: Diaphragm wall and Piling were compared in pairs based on all criterions.

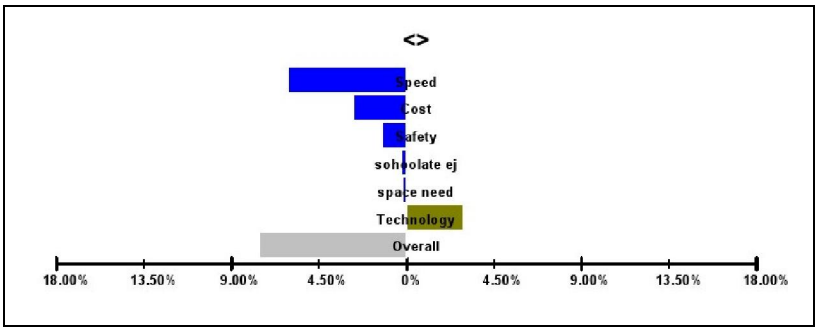

Diagram 8 - comparison in pairs between choices: Diaphragm wall and Sheet piling

In Diagram 8 the two choices: Diaphragm wall and Sheet piling were compared in pairs based on all criterions.

In final step, matrix of criterions weights is multiplied by matrix of choices weights to compute percentage of each choice to the total ones according to provided criterions. (Table 18 and Diagram 9)

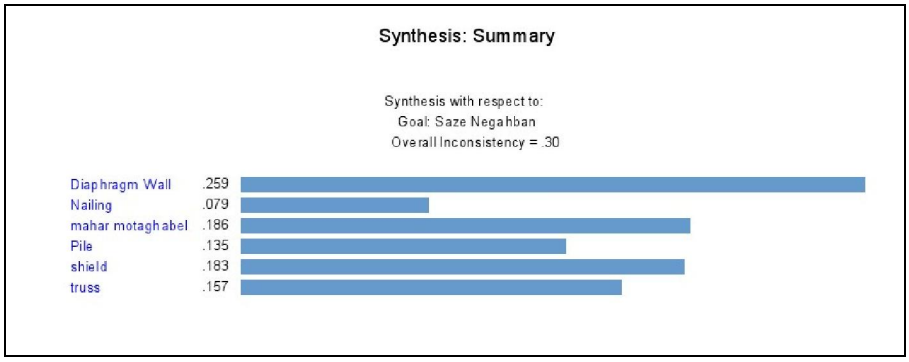

Diagram 9 - final results and choices weights in order to select the guardian structure method

In Diagram 9 final results and choices weights in order to select the guardian structure method are shown in bar graph.

Table18- priorities to select guardian structure method based on analytical hierarchy process

Method	Weighted rate	Priority
Diaphragm wall	0.259	1
Nailing	0.079	6
Reciprocal anchorage	0.186	2
Pile implementation	0.135	5
Hitting sheet	0.183	3
Truss method	0.157	4

3- conclusion:

According to greatness of box size in subways stations, using guardian structure is inevitable because of loose ground conditions (like ahvaz land). So, use of any type of mentioned methods in this research must be according to side effects, effects of digging on the ground surface, municipal facilities, and specially amount of subsidence in ground surface in short term and long term. Successful widespread using AHP in the world in projects, generally in urban areas, can provide potential use of this method in Iran and with the same favorable result. Considering high cost of subways stations construction, on one hand, and time consuming on the other hand, causes it important to choose the appropriate kind of structure that has a great impact on project progress.

For this purpose, in this study, different methods were examined and results were analyzed by software Expert Choice, then the results are as follow:

The best suggested choice that usable as guardian structure in constructing subways stations (The situation in of Ahvaz) is diaphragm wall, and its weighted rate is 0.265.

Weighted rate criterions in this choice are as followed:

Cost of using this method with weighted rate of 0.336

Speed of implementing structure with weighted rate of 0.356

Safety with weighted rate of 0.400

Ease of implementation with weighted rate of 0.351

Enough space for implementing of guardian structure with weighted rate of 0.320

Availability of technology with weighted rate of 0.041

And second suggested choice that usable as guardian structure method is hitting sheet, weighted rate of this parameter is 0.185, effective subparameters of using hitting sheet method are:

Cost of using this method with weighted rate of 0.237

Speed of implementing structure with weighted rate of 0.180

Safety with weighted rate of 0.147

Ease of implementation with weighted rate of 0.196

Enough space for implementing of guardian structure with weighted rate of 0.228

Availability of technology with weighted rate of 0.158

Note that it is not possible to use one procedure as a best way for all of the projects with different specifications, so according to specification of each project the best procedure must be selected.

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