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Morphometric Analysis And Geotechnical Zoning to Evaluate The Allowable Bearing Capacity of Iranshahr City, Eastern Iran

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Abstract: In the last few decades, tremendous progress has been made in the way of designing and implementing engineering structures. The main obstacle to the full realization of these ambitions is finding a suitable place where the desired structure can be placed with confidence. Therefore, "land" and "geological environment" have become the subject of civil engineering and geological studies. This research was conducted to create a relationship between the analysis of morphotectonic and geotechnical indicators to prepare a geotechnical zoning map of Iranshahr City, with an emphasis on the allowable bearing capacity of the foundation. Accordingly, the information on 26 boreholes related to projects inside the city was used. In these studies, the asymmetry ratio index of the drainage basin (Af), the sinuosity of the mountain front (Smf), the longitudinal slope of the river (SL), the width of the valley floor to its height (Vf), the hypsometric integral (Hi), the average slope index The axis of the channel (MASC) were calculated in different points of along the main faults of the study area. So, the results of these investigations indicate relatively active tectonics in the region. Furthermore, the mechanical properties of the soil were determined according to the results of direct shear, shear wave tests, and the SPT number, and then the bearing capacity was calculated for the strip foundation with a width of 2 and 1 meters and a depth of 1.5 and 1 meters and a map of the allowable bearing capacity of the foundation was prepared. The mentioned maps show that, in general, the allowable bearing capacity of the foundation in Iranshahr city, except for the northern and southern parts of the city, is high. Also, from the center to the southwest, with the decrease in the size of the particles and the increase in the percentage of natural soil moisture, the bearing capacity has decreased. Therefore, according to The relatively active tectonics of the region and the results of geotechnical parameters and further changes in the soil texture in different parts should be considered as necessary measures in the design of foundations for future structures and retrofitting in the current structure by performing deeper and wider geotechnical operations to increase the safety factor.

Keywords: *Morphometric indices, geotechnical zoning, strip foundation, allowable bearing capacity, Iranshahr city*

1. Introduction

Due to the occurrence of natural disasters caused by tectonic activities and related phenomena, conducting tectonic and geotechnical studies in the region is inevitable. The purpose of this study is to investigate the geological and geotechnical situation of the region so that the results of these studies can be taken into account in the implementation of development plans in the region and to prevent the occurrence of life and economic losses in the region in the future. The mutual and continuous action of tectonic processes as the factor of creating topography and surface processes as the eroding factor of unevenness forms the basis of tectonics. In the science of geology, terra construction examines the factors that create buildings and the relationships and forces governing them. Regarding morphometric studies, many types of research have been done by researchers. For example, the following research can be mentioned:

Bull and McFadden [1] divided the mountain front into categories 1 to 3 by combining the sinuosity index of the mountain front (Smf) and the width of the valley floor to its height (Vf). Wells et al., [2] studied a number of geological parameters for the analysis of regional tectonics and the results of the study of these parameters showed significant changes in the amount of tectonic activity that was determined by field and seismological data. The existing ones were also proven. Also, Silva et al., [3] investigated the relative tectonic activity of the mountain front by calculating the Smf and Vf indices, but they did not use the geographic information system (GIS). El Hamduni et al., [4] have used six geomorphological indexes to evaluate the active geostructural relative and by calculating and classifying the mentioned indexes and obtaining the average S/N index in the format of the Iat model has introduced four geo-structural categories from very active to relatively low activity. Dehbozorgi et al., [5] conducted the geomorphological indicators in the central Alborz Sarostan region and classified this area in terms of geostructural activities and also the results of the index study. Have been considered compatible with field surveys. Bagha et al., [6] in the Tehran region (Central Alborz) using pairwise comparison matrices by Analytical Hierarchy (AHP) method, concluded that most of the drainage basins that have the highest level of geo-structural activity they show that they coincide with the main faults of the southern edge of Central Alborz. Partabian et al., [7] have studied the effect of active tectonics on the tectonic processes in the Makran mountain range in the southeast of Iran by using the spatial analysis of tectonic indicators. The result of these studies shows a decrease in geological activities has been from north to south in this area. Jami et al., [8] surveyed the tectonic activity in the Taftan volcano area and its surroundings using morphometric indicators. Based on these studies, the high numerical value of the indices in the volcanic cone is mostly influenced by magmatic processes and the role of tectonic activities in the volcanic cone is very small. Furthermore, Alizadeh et al., [9] has been conducted the Evaluation of active tectonic using morphometric indices for the Tabriz area, NW of Iran. The results of these investigations revealed that the rate of the active tectonic ranged from moderate to high in the areas around Tabriz. Also, based on the evaluation of tectonic activity in the region and geological features it can be stated that the tectonic activities in the basins of the north and east are affected by the North Tabriz fault (NTF). Finally, another important study has been worked recently by Shvarev et al., [10] with titled Morphotectonics, Deformations of Loose Sediments, and Stages of Tectonic Activation of the Sambian (Kaliningrad) Peninsula in the Late Pleistocene and Holocene.

Geotechnical zoning maps are important and necessary factors for the realization of sustainable urban development. Reducing damages in construction projects and events such as land subsidence, slope movements, etc. requires the preparation of accurate geotechnical zoning maps. By providing detailed information on the physical and mechanical characteristics of the substrate, these maps, in addition to providing a kind of foreknowledge regarding the conditions of different areas of the region, can also give a perspective of the potential points for the implementation of specific construction projects. In fact, with the help of these maps, it is possible to check the conditions of all kinds of urban constructions in different places and take the best form of urban development according to the conditions of the soil layers. In the preliminary studies phase of the design of a construction project, detailed information on the type and resistance of the soil, slope, topography, underground water level, construction site, etc. is required. Furthermore, the use of the spatial information system in collecting this information and finally, preparing zoning maps Resistance parameters for the simultaneous use of different data reduces the cost of conducting studies.

Different studies have been done so far regarding zoning methods, types of zoning maps, interpolation methods in geotechnical and geological engineering, and the best method for interpolation in different subjects. For example, Azadi et al., [11] have conducted the Geological, geotechnical, and geophysical characteristics of the Tus fault located north of Mashhad, north-eastern Iran. These studies have shown that the change of path streams in the valleys of Mashhad is correlated with the Tus fault trend. Ghiasi et al [12] have surveyed the subway station seismic consideration based on a geotechnical study: A case study approach. This research is a concise case study that highlights the important soil parameters for designing deep and shallow tunnels and substations. One of the objectives of this paper is to define the seismic modeling of tunnels. Specifying the differences in seismic modeling using two software, PlAXIS and FLAC is another aim of this paper. Ghobadi and Babazadeh [13] have studied engineering geological investigations along the Tabriz subway extension focusing on ground surface settlement, in northwestern Iran. The purpose of this paper is to assess the engineering geological characteristics of soil and rock, and to predict ground surface settlement due to tunneling in the main part of Tabriz subway line 2 which has a length of 12 km. Also, Qanawati et al.

[14] have investigated the Evaluation of geotechnical studies in the Settlement of Structures with an emphasis on the geomorphology of the Mashhad metropolis. Prepared maps are shown that the central part of the city, which is geomorphologically similar to the alluvial plain, and the southwest part of the city, geomorphologically landforms of pediment and alluvial fan and mountain and fault are extremely complex in each other, have The highest probability of occurrence of the risk and the northwest and west section is suitable for very low-risk physical development. Mahouti et al. [15] conducted the classification of carbonate soils from the point of view of geotechnical engineering (case study: marly soil of Tabriz city). This study tries to specify some characteristics of various parameters of marls by conducting several tests to introduce the marl of Tabriz more and determine its position in the general definition of marl in the world. Furthermore, Javadanian et al. [16], have discussed the Geotechnical Earthquake Zonation of Semnan Region Based on Geophysical Tests Results. In this study, based on a wide range of geophysical test results in Semnan City, iso-velocity maps of shear wave and iso-depth maps of shear wave velocity were provided using the ArcGIS program. Eventually, another study has been conducted recently by Alizadeh et al., [17] with titled Engineering Geology and geotechnical characterization of Tabriz Metro Line 2, Iran. These studies were performed to determine the engineering geology and geotechnical details of soils and rocks along Tabriz metro line 2(TML2) by using the information and raw data which were acquired by borehole drilling and all field and laboratory tests in the study area. Finally, important studies have also been conducted at the global level in this regard. Such as: ELmay et al. [18] have studied the analysis of geotechnical, morphotectonic, and engineering geological data in the direction of urban development and planning. Cueto et al. [19] have studied the engineering geological assessment using geochemical, mineralogical, and petrographic analysis along the Riyadh Metro Line 3 (Saudi Arabia). Eventually, Marshalko et al., have investigated the engineering-geological comparative analysis of four cases studies of waste landfills.
All the mentioned studies and researches show the importance of conducting tectonic and geotechnical studies in the civil projects. Despite the studies conducted in the study area, evaluating morphotectonic analysis and geotechnical zoning less attention has been paid. So, the Present study with the title "Morphotectonic analysis and geotechnical zoning to evaluate the allowable bearing capacity of Iranshahr City, Eastern Iran" was performed in this regard.

2. Area of study

The city of Iranshahr is geographically located at 60 degrees and 41 minutes east longitude and 27 degrees and 12 minutes north latitude in the central part of Sistan and Baluchistan province in Iranshahr city. Iranshahr is bounded by Zahedan in the north, Bampur in the west, Mehrestan in the east, and Chabahar in the south and at the end of the eastern part, it borders Pakistan. The city of Iranshahr is located 333 kilometers south-west of Zahedan and on the Zahedan-Bandar Chabahar road. This city is located at an altitude of 571 meters above sea level. Bampur River flows from 4 kilometers south of the city and after 130 kilometers it flows into Jazmurian Hamoon. According to the latest census (2015), the population of the city is 11,3750 people, and with the growing population, attention to infrastructure and implementation of engineering projects is of great importance. In Fig. 1, the location map of Iranshahr city is shown.

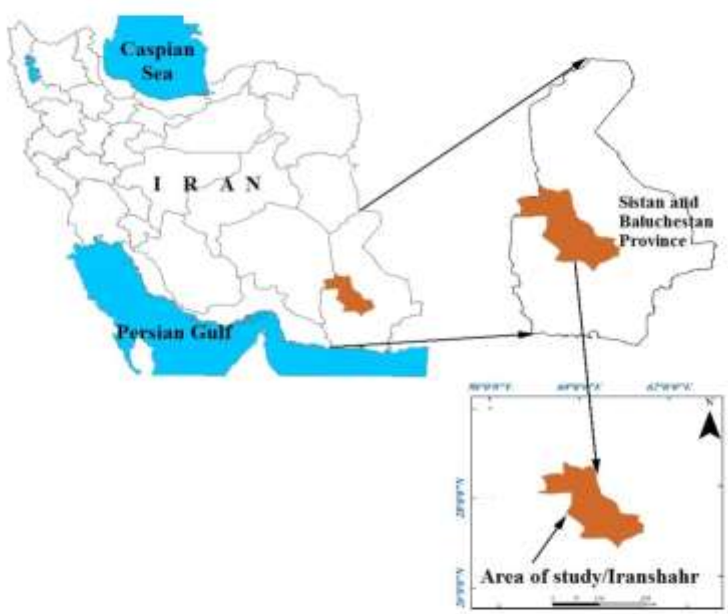

Fig 1. Location map of Iranshahr city (authors, 2022)

3. Geology Setting

The geology of the Iran region is divided into four regions, Zagros, Central Iran, Kope Dagh, and Makran, according to Stocklin and Nabavi [20]. The studied area is located at the end of the sedimentary zone of eastern Iran and at the intersection with the Natanz-Bazman zone. This zone is bounded from the east to Afghanistan, from the west to the Nehbandan fault, and from the south to the Makran zone, which is limited by the Beshagard fault. The Upper Cretaceous facies is of flysch type mixed with volcanic rocks and with weak metamorphism. The rock units are severely crushed under the stress of the movement of Lut and Afghan blocks. The old alluvial sediments include conglomerates that are located on green marls on different slopes. Young sediments include river and flood sediments. The engineering geology of the region has been examined from 4 viewpoints of lithology, geological morphology, hydrogeology, and morphology:

- Lithology: sediments including sand and sediments located on old conglomerate sediments. The conglomerate sediments are coarse-grained and have calcareous interference, and in some places, they are accompanied by chalk and salt. In the western areas of Iranshahr, under the conglomerates, green shale units are observed.
- Geological pattern: thrust faults and folds (reversed alluviums) are observed in conglomerate sediments in the north of Iranshahr. The studied area is covered with young river sediments. In the fault map of Iran [21], the active faults of Nehbandan and Beshagard can be seen in the region. Earthquakes in Saravan with a magnitude of 8, Sarvaz 5.5, and Sarjangal 3 to 4.5 on the Richter scale have been reported in the studied area in recent years.
- Hydrogeological: The sedimentary units of the studied area have high permeability. The underground water level depends on the amount of annual rainfall and urban sewage, and the water level has not been observed up to a depth of 10 meters.
- Morphology: This region is part of the alluvial cone and plain border regions. Basically, the water channels have a dendritic shape and depend on the type and size of the grain. In Fig. 2, the Geological map of the studied area is shown.

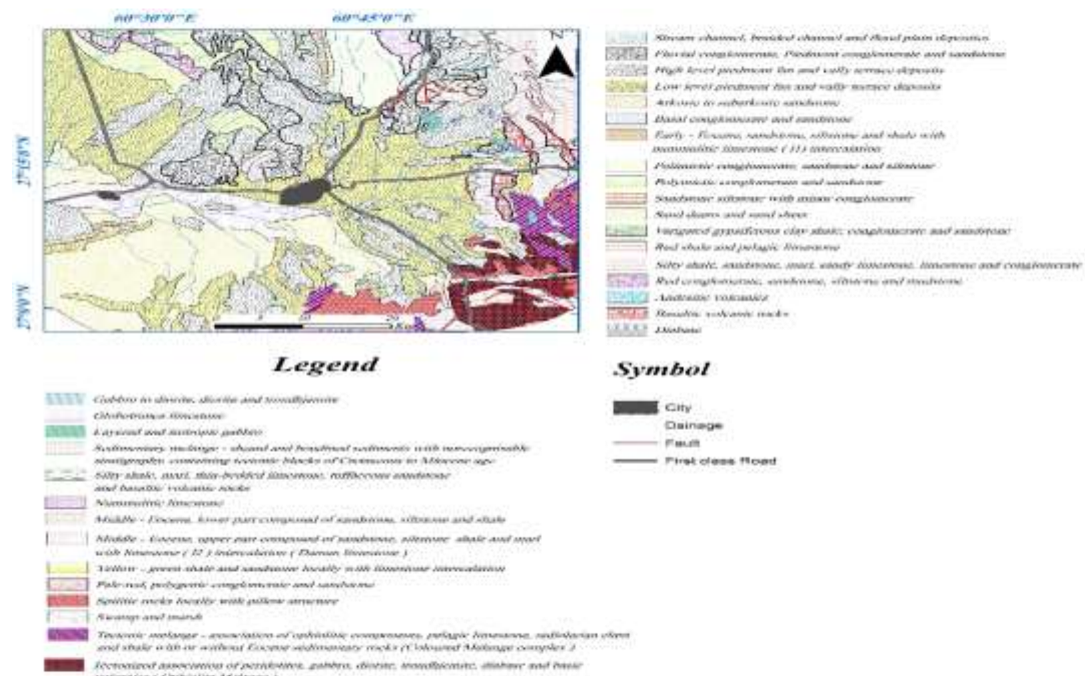

Fig. 2 Geological map of the studied area (authors, 2022).

4. Materials and methods

In the present study, the topographic map of the Iranshahr area, scale 1:250,000 [NATIONAL CARTOGRAPHIC CENTRAL OF IRAN, 2011] was utilized to measure morphometric indices. Further, the geological map of the Iranshahr area, scale 1:100,000 [GEOLOGICAL SURVEY OF IRAN, 2016] was used for obtaining the needed information about the geology and geological structures of the study area. Also, the indices of Asymmetry factor (AF) [22], Mean channel axial slope index (MASC) [23], Mountain-front sinuosity index (Smf) [24], length index - river gradient (SL) [25], Valley floor width-to-height ratio (Vf) [26], and hypsometric integral index(Hi) [27] were utilized for calculating the tectonic activity in the study area. In this study, an attempt was made to consider the basins as small as possible so that an accurate interpretation of the tectonic activity in the region can be obtained. Finally, for determining soil bearing capacity are adhesion (C) and internal friction angle (ϕ) of soil, which are performed by laboratory tests on intact specimens, used the Terzaghi equation [28].

5. Data

5. 1. Morhometric Indices

Geomorphological processes and interactions related to landscape evolution can be theoretically calculated in different geostructural environments with formulas related to each index. Examining these processes with reference to the changes in the course of the rivers, and even investigating the effects of earth-building activities on the changes and displacements, using various types of indicators, has a relatively long history. The results obtained from the study of several indicators can be combined and by adding to other information such as the elevation rate, determine the level of geotechnical activity, these levels indicate the relative level of activity in an area. In this research, to measure morphometric indices different basins and areas in the northern, eastern, southeastern, and southern parts of Iranshahr City are investigated. Therefore, in this regard, morphometric indices such as AF [29], (MASC) [30], Smf [31], SL [31], Vf [33], and Hi were utilized to measure tectonic activities in the region.

5. 2. Asymmetry of the drainage basin (AF)

Using the asymmetry factor, a tectonic tilt of the basin can be demonstrated [34]. The asymmetry index named (AF) is calculated by the following equation:

$$AF=100\ (Ar/At) \tag{1}$$

In this equation, we have: (Ar): Basin area in the right side of the basin (square kilometers) (the view is in the direction of flow) (At): Shows the total area of the basin (square kilometer).

For most of the drainage networks related to waterways that have been created and still flow in them and the state of symmetry governs them, (AF) should be around 50%. Numerical values greater than 50 and less than 50 indicate the erosion performance on the right and left sides of the main waterway, respectively.

In the study area, the AF index was calculated for 30 basins. The studied sections in the region have uniform lithology on both sides of the waterway and the changes in the measured value of this index in these basins are caused by the vertical movements of faults and active structures in the region. The basins of the northeast and east of the study area flow towards the south and southwest, and the basins of the northwest, south, and center of the region flow towards the south. The evaluation of the symmetry of the drainage basins using the transverse topography symmetry factor shows skewness in most parts of the basins. The basins of the east, and north-northwest parts of the region are tilted towards the west, east and southeast, respectively. Surveys showed that 22.25% of these basins have high tectonic activity, 47.74% have medium tectonic activity, and 27.02% have low tectonic activity.

5. 3. Mean channel axial slope index (MASC)

This index indicates a balance between tectonic activity and erosion. Rivers near the mouth have more digging power than farther distances, which causes the basin to be cut without increasing the length of the river, so the overall slope of the river increases. This index is defined as the following relationship [35]:

$$MASC= (H\_max- H\_min)/LS\times 100 \tag{2}$$

In this regard: MASC is the axial slope of the canal, H max is the highest point of the basin, H min is the lowest point of the basin and Ls is the length of the canal parallel to the main drainage line.

In the areas with maximum roughness where cut valleys are located and the length of the valleys is short, this ratio increases, while in the areas with low roughness and plain and flat surfaces where the valleys are longer. The value of this index decreases, and its lowest value is associated with smooth surfaces [36]. Based on the level of earth-building activity, this index was divided into three categories. The results of the MASC index revealed that 15.13 percent of the basins in the northwest and northeast of the region have high tectonic activity, 39.63 percent have moderate tectonic activity, and 22.25 percent of the basins have construction activity is low. The index values of the average axial slope of the MASC channel in the region have decreased mainly from north to south.

5. 4. Mountain-front sinuosity index

The Smf is an index that reflects the balance between erosive and tectonic forces. Low sinuosity is usually seen on a straight and flat mountain front with an active boundary fault. If the erosive processes have a greater effect on the mountain front due to the reduction of tectonic activities in the region, the sinuosity value will increase. The sinuosity index of the mountain front is obtained from equation 3.

$$Smf = Lmf/Ls \quad (3)$$

Lmf: the length of the mountain front at the foot of the mountain (where the slope changes and breaks with the slope).
Ls: straight line between two points at the place of change of slope
Smf: mountain front meander index
The rate of uplift causes different amounts of twisting of the mountain front. The twisting index of mountain fronts with high activity is usually less than 1.5, mountain fronts with moderate activity between 1.5 and 3, and inactive fronts show values greater than 3.
The measured points are at 1-15 stations in the southern part and 15-30 points in the eastern and northeastern parts of the region. Figure 3 shows the location of a number of stations measured from the border of the mountain front with the plain. The calculations obtained from this study are presented in the figure 4. In the eastern and northeastern parts of the region, which have been affected by many faults and moved, in this part, the sinuosity activity rate is 1.1. The southern part of the region is higher than the eastern part and consists of Cretaceous rock units, and the average sinuosity activity rate for this part is calculated as 1.2. In a general view, the activity rate of mountain sinuosity for the entire studied area is 1.15, which indicates the activity of young faults in the area.

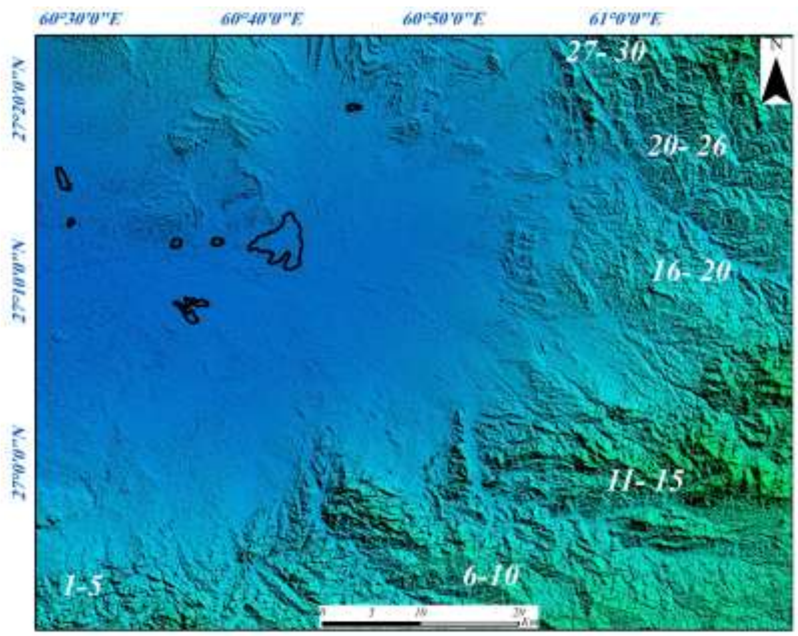

Fig. 3 The location of the measured points from the mountain fronts in the study area (authors, 2022).

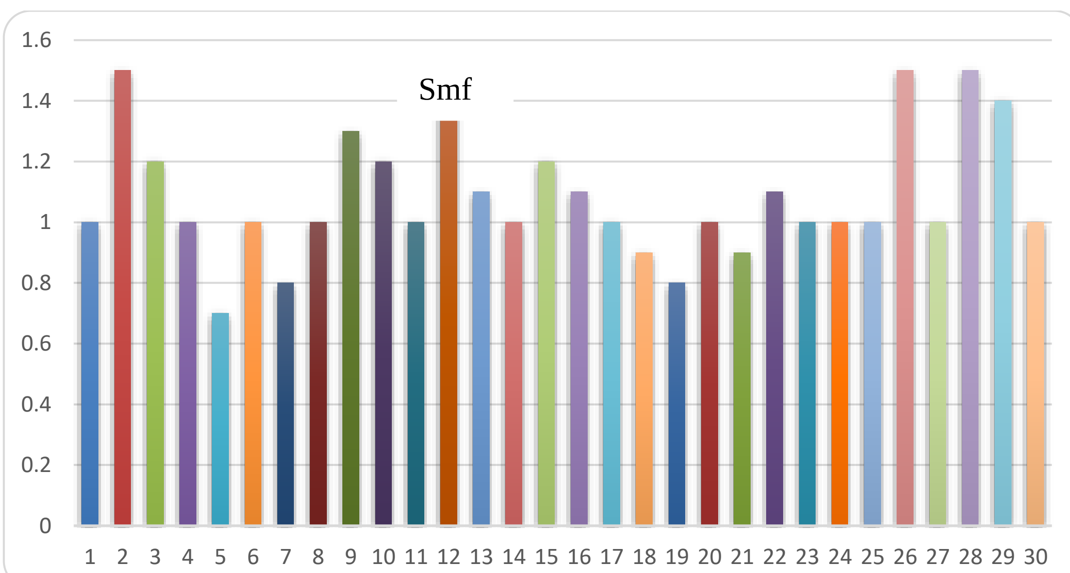

Fig. 4 Measured values of the mountain forehead sinuosity in the studied area (authors, 2022).

5. 5. length index - river gradient (SL)

The hydraulic gradient length index of the river in a specific area or region is expressed as follows [37]:

$$SL = (\Delta H/\Delta L).L \quad (4)$$

In this equation (SL) is stream length to river's slope and ΔH / ΔL is gradient and (L) is the total length of the channel from the branching point to the middle point in which the index is calculated. In areas with tectonic activity or in the investigation of large areas or areas, this index can be used as a useful tool to determine tectonic movements [38]. When rivers and waterways flow in areas with a high uplift rate, the amount of (SL) increases, but when the river flows parallel to structures such as valleys resulting from the Rastalghaz fault, the amount of SL) decreases [39].

According to the calculation of the SL index in the entire studied area, the value of the SL index is high in basins 3, 4, 8, 14, 15, 17, 20, 26 and 28, the high SL index in the sections North-west and west of the region due to the presence of hard lithology and in the eastern part due to the presence of active and young geological structure at that point, the rest of the basins of the studied area have second and third class SL index values. In the parts where the index category is low (third category), the reason can be pointed to the absence of resistant lithology or active and young structures in that area. The lowest values of the indicators are related to the basins of the western part of the region, which mainly include alluvial sediments of the present age. The low resistance of these rocks can be a reason for the low SL index in this sub-basin. The high SL index in sub-basins 3, 4, etc. (numbers are mentioned above) and in sub-basin 7 indicates that the high latitudes of the studied area are active.

5. 6. The ratio of the width of the valley floor to the depth of the valley (VF)

The ratio of the width of the valley floor to its height is another geomorphological index that has been used to investigate the activity of tectonic forces in the region. The ratio of the width of the valley to its height is usually measured at a certain distance from the mountain front (usually one kilometer from the mountain front to the upstream side of the river). This indicator can be obtained by the following equation:

$$SL = (\Delta H/\Delta L).L \quad (5)$$

According to the above equation

(Vfw) is the width of the valley floor, (Eld) is left- valley height, (Erd) is right-valley height and (Esc) is the height of the valley floor. The ratio of the width of the valley floor to the depth of the valley is one of the most useful ratios in identifying active areas, which are very sensitive to the tectonic activities of the late Quaternary. In very active mountain areas, Vf varies between 0.05 and 0.5. In the studied area, 26 valleys were investigated and the necessary indicators were measured (See Fig. 5.). The values obtained for the above index in the studied area are not the same in terms of activity, which can be attributed to the type of sediments in the area and their resistance to erosive factors. According to Table 1, it can be seen that the lowest measured VF index was related to Valley No. 17, which has a numerical value of 0.16, and the highest numerical value was 2.83 related to Valley No. 14. The average ratio of the width of the valley floor to the depth of the valley was calculated as 0.94, which indicates active tectonics in the region.

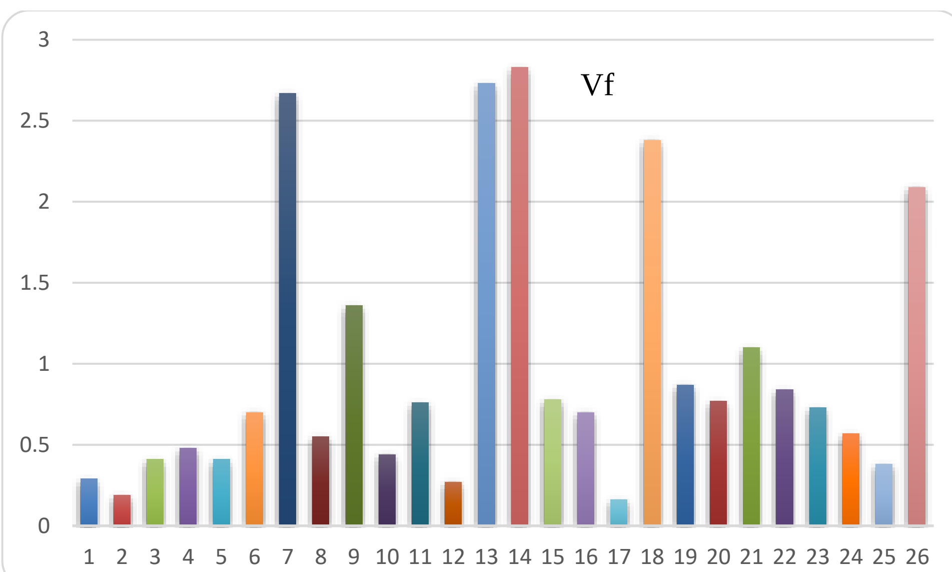

Fig. 5 Values of the ratio of valley floor width to valley depth (Vf) for the number of 26 valleys in the study area (authors, 2022).

5. 7. hypermetric Integral (HI)

The altimetric curve shows the height distribution in a region of the earth, from a drainage basin to a whole planet [40]. Equal to the total area of the basin (relative area) will be obtained, which indicates the topographical curve in a drainage basin located on a uniform slope. The said drainage basin consists of 8 horizontal lines; the total area (A) is actually the sum of the area between the horizontal lines. Area a is the surface area of the basin above a certain height line (h). The value of the relative area (A/a) always changes from one at the lowest point in the basin (h/H=0) to zero at the highest (h/H=1). One of the useful features of topography is that drainage basins of different sizes can be compared with each other. The method of calculating the parametric curve index is presented below [41]:

Hi= (average height - minimum height)/(maximum height - minimum height) (6)

Therefore, only three values are required to calculate this integral, two of them (minimum height and maximum height) can be easily obtained from the topographical map. The minimum and maximum heights can be read directly from the topographic map, the average height by sampling (on a grid) the height of the minimum (50) points in the basin and calculating their average using the model A digital height is doable and can be calculated. High values of this integral indicate active and young tectonic areas, but low values of this integral are associated with areas with low tectonic activity and erosion [42]. (The maximum and minimum altimeter integral fluctuates between 1 and 0). It should be noted that the convex curve indicates high tectonic activity in the region. The (convex) curve indicates the activity of fault structures and vertical movements related to folding, in the Quaternary period or for various other reasons, but the concave curve will indicate the decrease of tectonic activity in the study area.

The results of the Hi index show that the basins in the western, northern, and northeastern parts of the region have a value of Hi above 0.50.

Accordingly, this basin shows a geo-structural active state or the maturity stage of the Davis model of the basins. The intermediate value indicates that the tectonic processes in the basins of the mentioned parts are in a state of balance. In the southern parts the tectonic inactive state or in other words the stage shows the aging of the Davis pattern. Because the values of Hi are much less than 0.50 and this indicates the reduction of the erosion capacity of the river in these sub-basins. The active parts of the region (east, northeast, north and west of the region) are in the young stage of the Davis model and show the relatively high tectonic activity in this sub-basin. Erodible lithology is observed in the study area and the density of seams and cracks decreases from north to south and from east to the center and south of the range. The roughness differences in the mentioned parts cause the credibility of those parts and due to dynamic processes; they face a large amount of destruction in the erosion cycle. Finally, after examining and calculating several mentioned indices, based on the values calculated from the Hi index, 35.13 percent have high geo-structural activity, 28.82 percent have medium geo-structural activity and 36.03 percent of the basins have a construction activity low.

6. Analysis of geotechnical indicators for zoning the permitted carrying capacity in the region

6. 1. Bearing capacity of surface foundations

The main parameters for determining soil bearing capacity are adhesion (C) and internal friction angle (ϕ) of soil, which are performed by laboratory tests on intact specimens. Terzaghi [43] proposed the ultimate bearing capacity qf of surface foundations with depth D, width B, and length L as follows:

$$\frac{D_f}{B} < 1 \qquad \frac{D_f}{B} < (3-4)B \qquad q_u = CNc + qNq + 0.5 \quad BN\gamma S\gamma \tag{7}$$

In this research, by correcting the existing 1:250,000 map in the area using aerial photos and field survey, preparing a topographic map using existing topographic maps and required surveys from different parts of the city, followed by preparing a slope map and classifying the slope. Geological and topographical mapping and identification of rock outcrops, waterways, channels, sedimentary deposits, flood plains, etc. were done on it. The topographical map of the studied area is shown in Fig. 6.

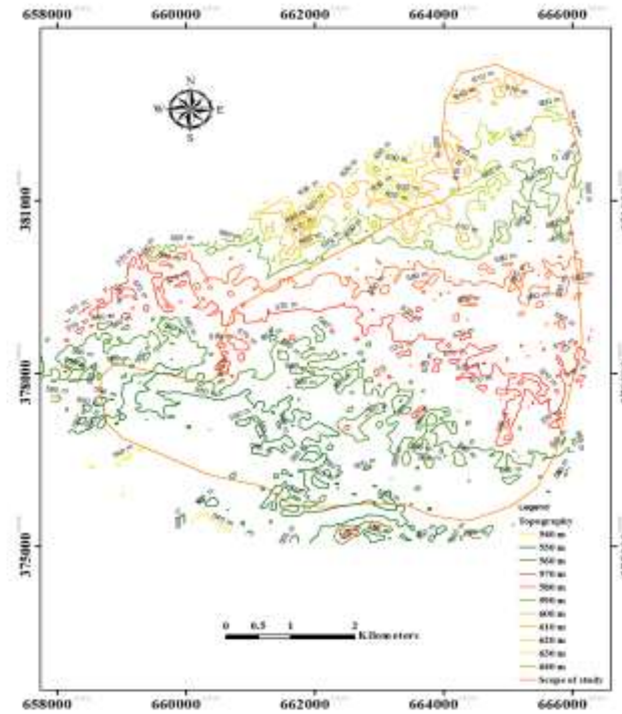

Fig. 6 Topographical map of the studied area (authors, 2022).

Next, to prepare the initial map of the sedimentary environment using aerial photographs and field observations, the initial map of the sedimentary environment was formed and geotechnical information was used to complete it in the urban area.

By collecting and studying the geotechnical reports and soil mechanics research of the projects carried out in different parts of the city to design and form the geotechnical information bank of Iranshahr city, by applying the geotechnical and morphotectonic information on the geological map, an initial map of the soil texture was prepared. Completing geotechnical information by preparing a preliminary map of soil texture, areas with a lack of specific information, and using trenches to cover these parts of the city. Figures 7 and 8 show the Soil type map and location map of data collected in the study area, respectively.

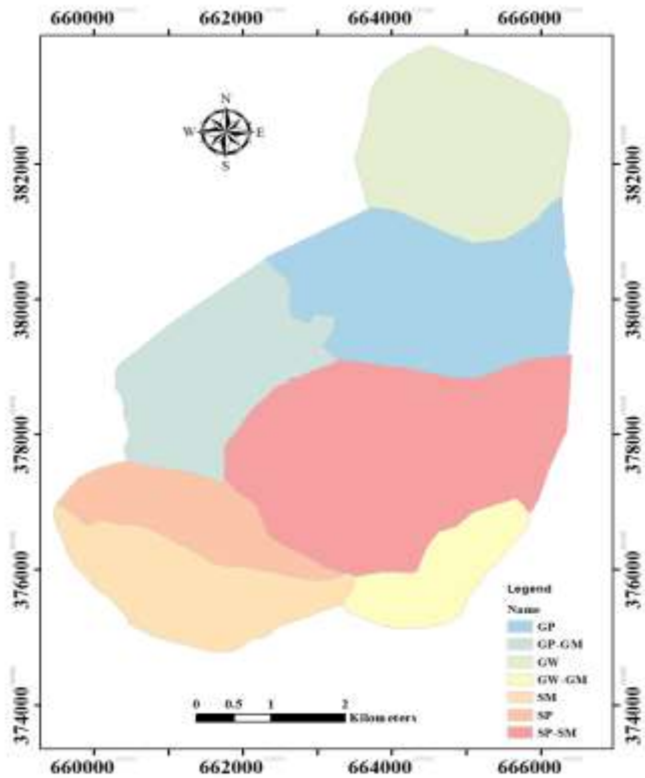

Fig. 7 Soil type map in the study area (authors, 2022).

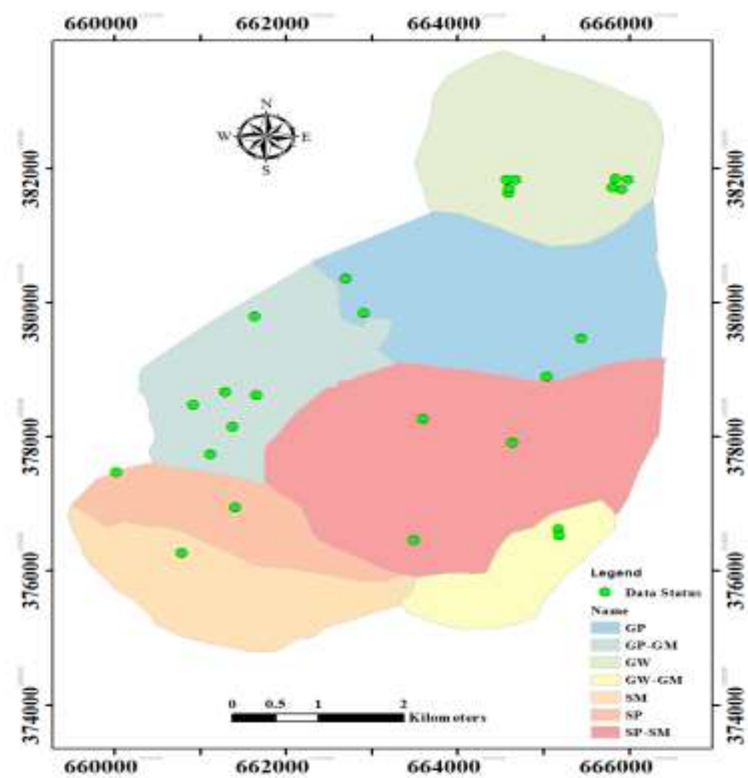

Fig. 8 Location map of data collected in the study area (authors, 2022).

Evaluation of the physical and mechanical properties of the soil and its zoning in the studied area, using the results of tests of direct cutting, granulation, triaxial cutting, sand cone, etc. In the following, the leveling of the layers and the preparation of the geotechnical and geological zoning map of Iranshahr City will be prepared according to the morphotectonic conditions of the region. To prepare the zoning map of the carrying capacity of Iranshahr city, the information from more than 65 exploratory boreholes dug in the city was examined and among them, 26 boreholes with more accurate information were selected. The values of adhesion and internal friction angle of the soil at a depth of 2 meters from the ground, the results of direct shear tests, the results of standard penetration and shear waves were used to estimate the above parameters. Then, the bearing capacity in the 26 investigated points has been determined assuming strip foundations with a width of 2 and a depth of 1.5 meters and a width of 1 and a depth of 1 meter. Tables (1) and (2) show the mechanical characteristics of different soils at the desired depth. By obtaining the carrying capacity in 26 points of the city and with the help of the map, surface soil texture, and classification of Ladira table (3), the carrying capacity in the area of Iranshahr city has been obtained.

Table 1. Physical and mechanical characteristics of soil types in Iranshahr city with 1-meter foundation dimensions and 1-meter depth (authors, 2022)

soil pattern	Adhesion (kg/cm3)	Internal friction angle (degrees)	density (g/cm3)	SPT	Permitted carrying capacity(Kpa)
GW-GM	0.11	39	1.90	30-50	237
GP	0.09	48	1.90	30-50	306
GP-GM	0.12	49	1.95	30-50	365
GW	0.17	46	1.95	30-50	281
SM	0.08	48	2.00	30-50	274
SP	0.11	47	2.00	30-50	221
SP-SM	0.06	48	2.10	30-50	378

Table 2. Physical and mechanical characteristics of soil types in Iranshahr city with 2-meterfoundation dimensions and 1.5 meter depth (authors, 2022)

soil pattern	Adhesion (kg/cm3)	Internal friction angle (degrees)	density (g/cm3)	SPT	Permitted carrying capacity(Kpa)
GW-GM	0.11	39	1.9	30-50	403
GP	0.09	48	1.9	30-50	514
GP-GM	0.12	49	1.95	30-50	606
GW	0.17	46	1.95	30-50	471
SM	0.08	48	2	30-50	422
SP	0.11	47	2	30-50	377
SP-SM	0.06	48	2.1	30-50	554

Table 3. The classification proposed by Ladira [1994] for the allowable bearing capacity and their description of Land classification.

Qa(Kpa)	Description	Land classification
0-50	Infinitely low	Soft silty or silty clay organic soils
50-100	very little	Silty or silty soft clay soils - clayey or loose sandy soils
100-200	Low	Clay-silty or silty clay soils with medium strength or sandy soils with medium
200-300	medium	Hard soils and well-compacted sandy soils, well-compacted sands and gravels
300-500	Much	Very hard soils and very dense sandy soils, very good dense sands and gravels
500-800	very much	Extremely hardened soils and extremely dense sandy soils and gravels
800 <	Infinitely much	Extremely dense soft rocks and non-stick soils

7. Assessing the accuracy of information

The accuracy of the present study is a function of two parameters, the degree of soil homogeneity and the dispersion of the used boreholes. Changes in soil texture and resistance are relatively high in the north of the city, while the western, eastern, and northern parts have more homogeneous conditions. It can be seen that the concentration of data around the north, northwest, and west is less in the south, southeast and east parts of the city. According to the degree of soil homogeneity, the results of the study are less for the south, the city center, the east, etc. The results and interpretation of the carrying capacity are done in Tables (4) and (5). Figures 9 and 10 show the map of the permissible bearing capacity with the dimensions of the foundation of 1 meter at a depth of 1 meter and 2 meters at a depth of 1.5 meters, respectively.

Table 4. Description of soil based on the value of bearing capacity for foundations with dimensions of 1 meter and depth of 1 meter (authors, 2022).

Soil type	Permitted bearing capacity (Qa) with dimensions 1 in depth 1	Description of soil
GW-GM	237	medium
GP	306	Much
GP-GM	365	Much
GW	281	medium
SM	274	medium
SP	221	medium
SP-SM	378	Much

Table 5. Description of soil based on the value of bearing capacity for foundations with dimensions of 2 meters and a depth of 1.5 meters (authors, 2022).

Soil type	Permitted bearing capacity (Qa) with dimensions 2 in depth 1.5	Description of soil
GW-GM	403	Much
GP	514	very much
GP-GM	606	very much
GW	471	Much
SM	422	Much
SP	377	Much
SP-SM	554	very much

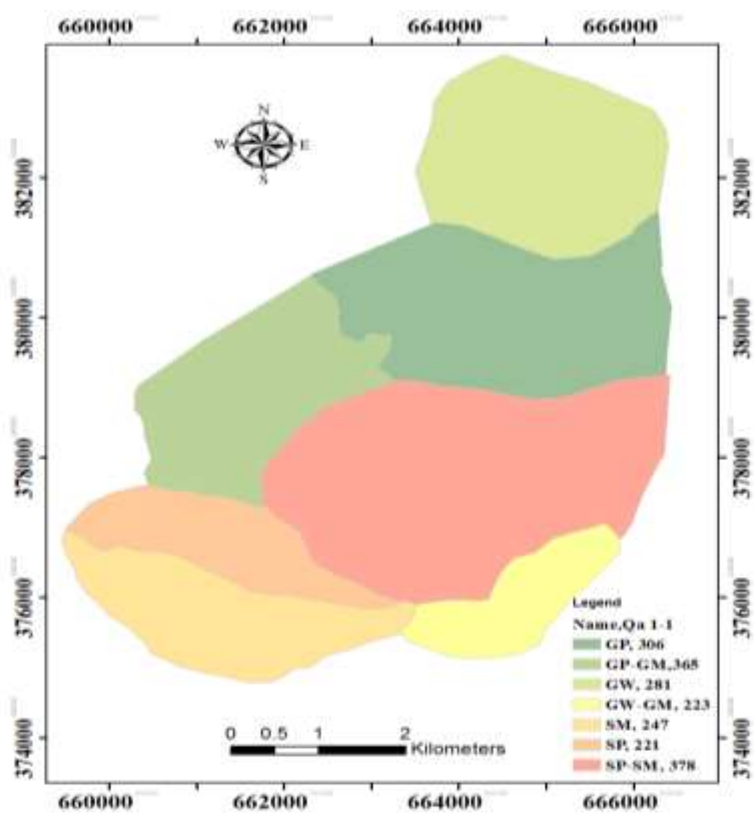

Fig.9 The map of the permissible bearing capacity with the dimensions of the foundation of 1 meter at a depth of 1 meter in the studied area (authors, 2022).

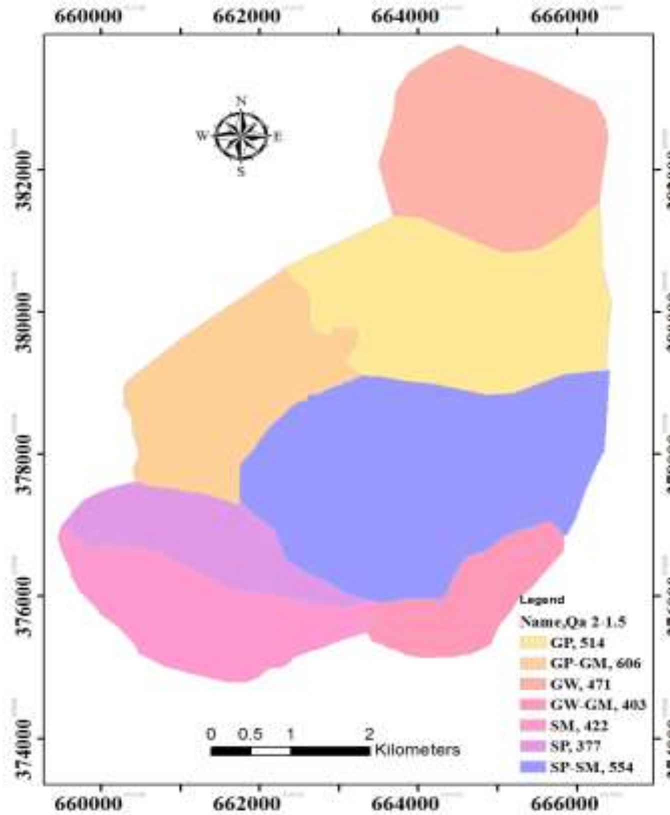

Fig. 10 The map of the permissible bearing capacity with the dimensions of the foundation of 2 meters at a depth of 1.5 meters in the studied area (Authors, 2022).

8. Discussion and conclusion

The present study was conducted in order to Morphotectonic analysis and geotechnical zoning to evaluate the allowable bearing capacity of Iranshahr City, Eastern Iran. Therefore, in this regard, the topographic map of the Iranshahr area, scale 1:250,000 [NATIONAL CARTOGRAPHIC CENTRAL OF IRAN, 2016], Further, the geological map of the Iranshahr area, scale 1:100,000 [22] were used. Also, the indices of AF [23], MASC [24], Smf [25], SL [26], Vf [27], and Hi [28] were utilized for calculating the tectonic activity in the study area. Finally, for determining soil bearing capacity are adhesion (C) and internal friction angle (ϕ) of soil, which are performed by laboratory tests on intact specimens, used the Terzaghi equation [29].

Establishing a relationship between geotechnical parameters and morphotectonic conditions in the region and generalizing it to similar cases in other places in order to create stable and optimal conditions for engineering structures in the direction of urban infrastructure development.

According to the survey of quantitative morphometric indices in the investigated area and the field studies that have been conducted in the area, the results of the values obtained from the calculation of the indices based on the relative active geostructural classification that was first published by El Hamdouni et al, [30], is presented together and the result obtained is presented. According to the presented model, four tectonic zones can be distinguished in the studied area: (Area with very high relative tectonic activity) this zone is located in the northwestern and northeastern parts of the region. (Area with relatively high tectonic activity) This area is only observed in the basins in the north-northeast and eastern parts of the region. (Area with moderate relative geo-structural activity) A large area of the studied area is located in this area. (Area with relatively low tectonic activity) This area was observed in the basins located in the center, west, and southwest. The basins located in the northern and eastern parts have a high rate of relative tectonic activity, which is mainly affected by the lithology, young movement of faults, and active tectonic structures in this basin. The results obtained from the examination of morphotectonic evidence provide a relative classification of tectonic activity that is useful for studies, identification, and preliminary investigations.

Evaluation and classification of soil bearing capacity for two types of foundations with a width and depth of 1 meter and a width of 2 and a depth of 1.5 meters in the city of Iranshahr shows on average that the dimensions of a foundation with a width and a depth of 1 meter in the north and south regions are in the capacity group. The average load and in the east, central, and northwest regions is in the high group. In the next case, with a width of 2 meters and a depth of 1.5 meters, they are placed in the high and very high groups in almost all areas.

When several indicators are used to investigate the tectonic activity in the region, they will have more justified results, and the integration of these results with geotechnical analysis and zoning in the studied area will have a general view of the implementation and forecasts needed for the projects under construction and in the future.
Also, due to relatively active tectonics in the region and more changes in soil texture in different parts, deeper and wider geotechnical operations should be carried out in important projects.

Compliance with ethical standards

Conflict of interest: The authors have no conflicts of interest.

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