Investigation of Stress and Possible Subsidence of Bridge Foundations Utilizing Seismic and Geoelectrical Tomography

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Extended Abstract

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Summary

In this research seismic, electrical sounding and geoelectrical tomography methods are used to assess the distribution of strength of foundations, the earth's natural period (T_0), layering conditions and petrophysical characteristics of the underlying soil. The bridge is built on alluvial sediments of the Haraz river in Mazandaran province. The bridge consists of two lateral and three intermediate bases. The Haraz river passes through the eastern and adjacent intermediate base. This research indicates that: 1- based on seismic studies, the average shear wave velocity to a depth of 30 meters at the eastern base of the bridge is significantly more than that of the western base. Therefore, the stiffness and loading capability in both bases of the bridge are different, 2- geoelectrical sounding shows that the eastern side of the bridge, most likely composed of silt and clay and there is a possibility of subsidence at the east side of the bridge, 3- electrical resistivity tomography maps in E-W section is asymmetric and shows lateral changes of soil structures along bridge. In other words, distribution of stress on eastern and middle basis of the bridge with considering mentioned reasons is stirred with probably subsidence in the last few decades utilization and appearing of defects in the body of the bridge.

Introduction

Many factors such as floods, earthquakes, hurricanes, tsunamis, improper exploitation conditions and other factors have threatened historic buildings and urban infrastructure. Iran is one of the active seismic areas of the world and unfortunately many of the historical monuments have been damaged or completely destroyed during different earthquakes. Bam citadel, the largest mud structure in the world, is an example of a cultural heritage which was completely destroyed in deadly earthquake of January 2003. In many large cities of the world such as Tehran, more than hundred bridges have been constructed to solve the traffic jam. Insecure and improper utilization may threat the strength of bridges and decrease their longevity. Today, the soil behavior under loading cycles and dynamic condition is very important in urban active seismic areas. In most cases the physical properties of soil are obtained by laboratory tests and in situ methods including refraction seismic method, reflection seismic method, SASW method, well logging, cross-hole and also geo-electrical and other geophysical methods. The relation between seismic wave velocities and stress in soils and mineral materials are to the interest of seismologist and seismic specialists. Today in exploration seismic the relation between stress and velocity of seismic waves can be used in AVO analysis and also to predicting and monitoring the hydrocarbon and thermal fields of reservoirs in 4D exploration seismic. There are many researches in this subject and established some experimental relationships between stress and elastic modulus of rocks with wave velocities. The aim of this research was to identify the seismic characteristics and geological conditions of soil beneath foundations of bridge in north of Iran mainly for investigating possibilities for strengthening the city historical oldest bridge. In this study we used simultaneously refraction seismic, electrical sounding and geoelectrical tomography methods. Seismic method used to estimate the stiffness of soil, average shear wave velocity of upper 30 m and determination of site classes. Electrical sounding and geoelectrical tomography have used to identify subsurface geology, differentiation and identifying electrical resistivity of soil profile and distribution of electrical resistivity in tomography section for understanding distribution of stress in soil. The bridge is built on alluvial sediments of the Haraz River. Mazandaran-Khazar fault is located 7 km south of study area in east-west direction. The bridge consists of two lateral and three intermediate bases. The Haraz River passes through the eastern and adjacent intermediate base.

Field surveying

Several seismic profiles surveyed in this are and five of them used in current research. Linear array are employed with P-wave and S-wave. Distance between geophones is 2 m respectively. The lengths of profiles were different due to space constrains. Length of profiles considering offsets was up to 86 m. Impulse impact is transmitted to the soil by sledge hammer equipped with a trigger element. For P- wave profiles, vertical hit on steel plate and for S-eave profiles, horizontal hit on special I-beam steel were used. In order to improve the signal to noise ratio (S/N), an average of ten hammer blows were stacked for each record. Length of records is one second with sampling interval one millisecond. The first arrival times of refraction seismic data were interpreted with considering characteristic of first arrivals in layered condition and continuous medium. The results of average shear wave velocities to the depth of 30 m in the five profiles (S1 to S5) were 774 m/s, 629 m/s, 540 m/s, 581m/s, and 563 m/s consequently.

The average shear wave velocity in the upper 30 m was globally adopted after the National Earthquake Hazard Reduction Program (NEHPR) classification in the USA. Profile S1 is located near the western base of the bridge, profile S3 near the eastern base of the bridge, profiles S2 and S6 at the middle of bridge and profile S5 about 200 m of eastern base. The average sheer wave velocity in the upper 30 m of soil in western base (Vs30=774) is more than eastern base (Vs30=540). According to the average shear wave velocities, the type of underlying soil in western base falls to B class ($760<\overline{V}_{S30}<1500$) and in eastern base falls to C class ($360<\overline{V}_{S30}<760$). It means that the natural periods of soil and reflection coefficient of bridge in both sides are different.

Vertical electrical sounding is another geophysical method that used to separate the layers, thicknesses and electrical resistivities of underlying sediments at the eastern base of the bridge. The resistivity measurements carried out by injecting electrical current into the ground through the two current electrodes, and measuring the resulting voltage difference at two potential electrodes. We used symmetrical four electrode schlumberger array. The type of experimental sounding curve is AH. It means that soil profile under the eastern base of the bridge consists of 4 layers with interbedded low resistivity layer. Interpretation of geoelectrical curve shows that the first layer has a thickness of 4 m with resistivity of 800 ohm-m. Surface evidence indicates that this layer is composition of sand, gravel and conglomerate. The second layer has a thickness of 16 m with the resistivity of 334 ohm-m. This layer most probably is composition of saturated sand and conglomerate. The third layer has a thickness of 14 m with resistivity of 43 ohm-m. Low electrical resistivity shows that the grain size is fine and matches with silt and clay. The last layer as a basement starts from the depth of 34 m with electrical resistivity of more than 1000 ohm-m.

Geoelectrical tomography is another method that used to determine the lateral changes of electrical resistivity and identifying the pattern of distribution of stress in underlying soil at the middle of the bridge. Geoelectrical tomography profiles were in east-west direction. The distance between measuring points was 1 m. Electrical resistivity of sedimentary rocks and soils generally depends on porosity, mineral type, depth, stress, moisture content, structure and texture and temperature. Variation of electrical resistivity verses depth shows that the distribution of electrical resistivity of the subsurface material is not uniform and increase with depth. It also shows that the distribution of electrical resistivity in soil under the base is asymmetric in E-W direction.

Conclusions and result

Integrated geophysical studies were conducted in three stages with three different methods. The following conclusions are extracted based on study: According to seismic data the average shear wave velocity at the western side of the bridge ($\overline{V}s = 703$ m/s, $\overline{V}s30 = 770$ m/s) is more than the East ($\overline{V}s = 508$ m/s, $\overline{V}s30 = 540$ m/s) and middle of the bridge ($\overline{V}s = 458$ m/s, $\overline{V}s30 = 564$ m/s). The high velocity of S waves in the western side of the bridge shows that the stiffness of soil materials in the west side of the bridge is more than of the east side. According to NEHPR site classes, the type of underlying soil in western base falls to B class and in eastern base falls to C class. It means that the natural periods of soil and reflection coefficient of bridge in both sides are different. In other word the response of bridge respect to vibration of soil generating by traffic in both sides is different. The Haraz River passes through the eastern and adjacent intermediate base about 4 m under ground level of the middle bases. Geoelectrical sounding show that the eastern side of the bridge most likely composed of silt and clay. Therefore there is a possibility of subsidence at the east side of the bridge. This bridge connects the eastern side of the river to the western side and asphalted road passes through western base and intermediate base. It means that the vehicle traffics continuously compacts underlying soil in western base respect to eastern base. Electrical resistivity tomography map in E-W section is asymmetric and shows lateral changes of soil structures along bridge. In other words distribution of stress on eastern and middle basis of the bridge with considering mentioned reasons is stirred with probably subsidence in the last few decades of utilization and generation of lateral stress due to truck traffic impacts in eastern bases and underlying soil. The change of lateral or transverse stress changes the porosity of soil profile and change of porosity changes the electrical resistivity. Existing cracks in the beam of studied bridge agrees with the available results of research

Keywords: Bridge, Seismic method, Geoelectrical sounding, Electrical tomography, Subsidence

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