Geoelectrical Detection of Subsurface Channel at the downstream side of Mosul dam

N.H. Al-Saigh[1] , S.I. Khattab[2] , Z.S. Mohammed[3]
[1.] *Dams and Water Resources Research Center, Mosul University , Mosul , Iraq*
[2.] *Dept. of Geology, College of Science, Mosul University , Mosul , Iraq*
3. *Dept. of Civil Engineering, College of Engineering, Mosul University , Mosul , Iraq*
(**Received:** 31 / 1 / 2011 ---- **Accepted:** 26 / 11 / 2011)

Abstract
The causes of formation and continuous growth of several sinkholes within the service building areas of Mosul dam have been investigated using electrical resistivity method. The survey was conducted on the downstream - side of the western part of Mosul dam area and it was successful in detecting and delineating subsurface flowing water (channel). The calculated width of the channel is about 240m lying at a depth of about 10m. The channel probably has its intake from the main reservoir and then flow behind the western end of the dam body to discharge at the downstream side forming many sinkholes in the area.
Key words: Resistivity, subsurface channel, sinkhole

Introduction
The formation of sinkholes involves a complex interaction of rock, soil and groundwater that must be understood and considered in the site investigation. Sinkholes have been classified generally by the processes that cause them. Generally there are two different processes; the movement of material downward along solutionally enlarged channels or the collapse of a rock or soil roof (Frank and Beck, 1991). Mosul dam is located at about 40 km to the north of Mosul city, in the northern part of Iraq. The dam has suffered many geotechnical problems since establishment in 1985. From that year until now a daily routine grouting is being carried out. In the dam area several sinkholes have occurred, especially in the downstream side of the dam , causing subsidence and collapse of some buildings (Fig. 1). The continuous growth of these sinkholes necessitates the study of the causes behind the development of these sinkholes. Questions arose whether these sinkholes have occurred as a result of fluctuation of the river elevation which may cause the removal of some subsurface soil and consequently the occurrence of sinkholes or due to subsurface flowing water (channel) coming from the main reservoir (lake) or from the Dair Al-Maleh aquifer which is present within the Butmah East anticline. During construction of the dam large quantities of water had been discharged from the Dair Al-Maleh aquifer (Ameen, 1985). Another possibility is that the subsurface channel is an extension of the surface drainage present to the south of Mosul Directory Office Buildings (Fig.1). To answer these questions an electrical resistivity survey was conducted in the area. The measurement of earth resistivity is a possible means of detecting ground water flow where such flow usually is accompanied by changes in electrical resistivity from the surrounding media. A major reason for interest in developing electrical resistivity as a method of detecting and tracing ground water flow is that electrical resistivity surveys can conceivably provide subsurface data at a relatively low cost when compared with drilling. Success of the method has also been reported in tracing contaminated water (Ebraheem, et al. 1990, Abu-Zeid, 1994, De Lima, et. al. 1995).

Geology of the area
Mosul dam is bounded by two major anticlines; Butmah East anticline and Tira anticline (Fig.2). Tira anticline is located on the eastern side of Tigris River while Butmah East anticline lies on the western side of the river. Butmah East anticline is a double plunging asymmetrical anticline trending E-W and it is about 12km long and 3.5km wide (Tawfiq, and Domas, 1977). Al-Ansari, et al. (1984 and 1985) indicated that structural lineation, i.e. faults, joints and lineaments in the area are trending mainly NE-SW and NW-SE. They also indicated that faults and sinkholes are common in the northern part of Butmah East anticline within the Fat'ha Formation. The area shown in figure (1) represents the western side of the dam area. The lower marl series (Middle Miocene) forms the main exposed rocks. The area within 500m from the river is mainly composed of river terraces. Fig.2 shows geological cross-sections A-A' and B-B' nearby the study area. The sections show that the rocks from top to bottom are belonging to the Fat'ha Formation (Lower Marl Series), Jeribe Limestone Formation, which is underlain by Jaddala/Sinjar Formation. The lower marl series is composed mostly of different types of clayey marls, brecciated marls, marly limestone, chalky limestone, limestones as well as gypsum and anhydrite. Section A-A' indicates that the beds dipping towards SSW.

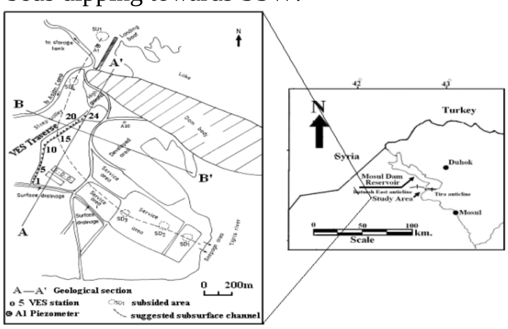

Fig.1 Plan view of the study area showing the positions of VES stations, the geological cross sections A-A', B-B' and, the suggested subsurface channel. (Modified from Modacom, 1984).

The chalky beds are highly pervious and contain open cracks and small cavities , while the gypsum brecciated marls (GB beds) created many problems during construction of the dam (Ameen , 1985). The rocks of the lower marl series had suffered karstification which forms the main characteristic feature of Mosul dam area (Ameen, 1985). Karstification leads to the formation of open cavities and channels , and consequently leads to subsidence.

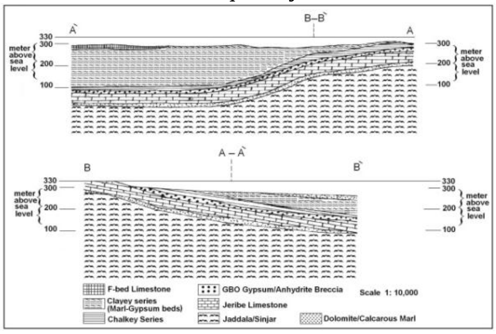

Fig.2 Geological cross-sections nearby of the studied area (Modacom, 1984)

Field procedure

The resistivity survey carried out using Schlumberger electrode arrangement with a maximum electrode spacing AB 600m. The survey traverse was located near the western end of the dam body at about 1150m from the river, as far away as possible from the sinkholes, and extended perpendicular to the imaginary line joining them. Twenty-four VES readings were conducted along the traverse with a total length of 720m, (Fig. 1). The distance between the VES readings was 30m. The level of the traverse was ranging between 288-315m a.s.l. The water level at the river was at 253m a.s.l., i.e. the VES measuring points were ranging between 35-52m above the water level in the river.The sounding points were located as far away as possible from pipes, power lines, and buildings.

Results and their interpretation

Two types of interpretation have been approached, qualitative and quantitative. Qualitative interpretation has been done through drawing resistivity profile, while quantitative interpretation through calculation of layering parameters and drawing geoelectrical section.

Qualitative interpretation

The apparent resistivity values at different electrode spacing were plotted against the position of VES station to obtain a set of apparent resistivity profiles at different depths Fig. 3 clearly shows that there is a systematic increase of resistivity with the increase of electrode spacing in the area between VES 12 and VES 18 with peaks at VES 15. The anomaly takes the shape of a letter W. As indicated by Dutta, et al. (1970) and Kumar (1973) this type of anomaly most probably represents channel like structure.It is very interesting to note that the resistivity values at VES 15 become progressively higher as the electrode spacing AB/2 increases beyond 70m. However the resistivity values at VES 15 are lower than the resistivity values at adjacent stations (i.e. VES 14 and 16) for the electrode spacing AB/2 20m-60m. This most probably indicates that the channel is wider at the top and become narrower at depth (V like shape). The V shape structure of the channel geologically is very acceptable.

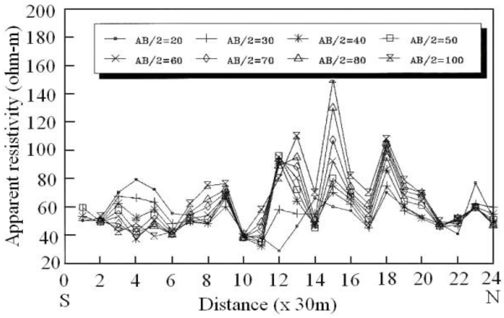

Fig.3 Apparent resistivity profiles at different electrode spacing

Quantitative interpretation

Fig.4 shows some of the obtained resistivity curves. In general the curves reveal significantly low resistivity values of less than 100 Ωm. The curves represent three, four and five layer case. Type of the curves differs widely from QH to HKH which reflects the subsurface geology.The layering parameters (resistivities and thicknesses) for the obtained vertical electrical soundings were calculated by the classical method of partial curve matching (Orellana and Mooney, 1966). As well as a computer program for forward modeling of VES data has been used (Ghosh, 1971). These parameters were then used to construct a geo-electric cross section in order to show stratigraphy and structures along the traverse. Statistical study of the calculated depths in the area indicated that the average depth of penetration was about 0.3 of electrode spacing AB/2.Resistivity and thickness rarely can be resolved independently without calibration with borehole information or some other geologic information. Due to the lack of borehole information in this part of the study area, the available geological cross-sections in the area (Fig.2) have been used to constrain our interpretation.Fig.5 shows the geoelectrical cross-section along the resistivity traverse. It can be seen that there are in general three and four subsurface layers. The resistivity of the top first layer ranges between 20 Ωm and 200 Ωm and thickness ranges between few centimeters to about 5m representing the resistivity of the top soil surface layer with different degree of compaction and cementation.The resistivity of the middle layers ranges between 25Ωm and 65Ωm and thickness ranges between 10 and 70m. These resistivities most probably represent clayey-layers with different degree of compaction and calcareous content. The lower resistivities could be due to clay content. Thickness of this layer increases in the southern part of the profile. The resistivity of this layer becomes in the range of 64 and 92 Ωm in the middle part of the line between VES12 and VES18 representing most probably admixture of marly sand silt layer. The resistivity of the last deeper layer ranges between 110 Ωm to more than 240 Ωm. This layer most probably represents the marly limestone beds within the clayey series that is shown along the geological cross-sections. The depth of this layer ranges between 22m to more than 65m below the surface. The depth of this layer increases in the southern part of the section. The figure also shows the presence of a fault between VES 22 and VES 23. This fault has a throw of about 13 m. The depth of water table in the area is about 50m from the surface. However, the resistivity measurements failed to clearly define the zone of water table. This is because the units above and below the water table probably possessed identical electrical properties.

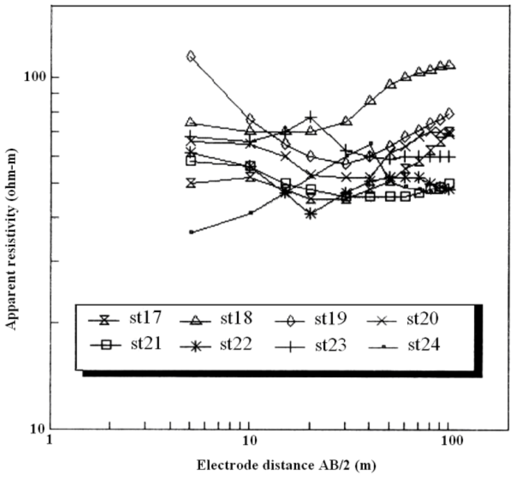

Fig.4 Some of the field resistivity (VES) curves

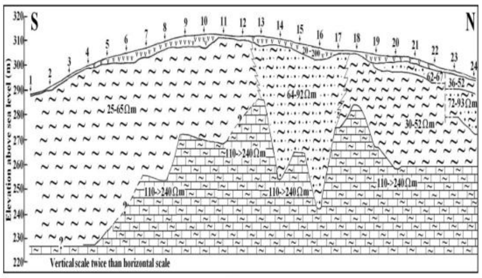

Fig.5 Geo-electrical cross-section along the traverse

Discussion And Conclusions

The data obtained from the resistivity survey ruled out the possibility of flowing water in the southern part of the traverse, specifically the area between VES 1 and VES 12 in spite of the presence of a surface drainage in the area. This is due to the presence of thick impervious marl (Fig.2). For the same reason resistivity survey also indicates the absence of flowing water in the northern part between VES 20 and VES 24 in spite of the presence of a fault in this area. Profiling technique suggests the presence of a subsurface channel in the area between VES 12 and VES 18. The deepest part of the channel is located at VES 16. Geoelectric - cross-section (Fig. 5) indicates the presence of a channel like structure between VES 12 and VES 18.According to Kumar's theoretical calculations, width of the channel is about 240m considering that the resistivity values at VES 12 and 18 as subsidiary peaks. The channel lies at a depth of about 10m below the surface. This is due to the fact that the shape of the channel starts to appear at electrode spacing AB/2 of 30m. A seismic refraction survey conducted along the same traverse by Al-Juraisy (1992) suggested the presence of two faults in the area between VES12 and VES 20 forming a channel like structure with a width of 220m and filled with weathered clayey layer. In the resistivity survey the position of these faults appeared as changes in lithology between VES 19 and VES 20, and between VES12 and VES13 as shown in figure 5. The channel probably extends from VES 15 and then extends to the five subsided areas to make a curve line discharge at the river, as shown in figure 1. At the western end of the dam on its upstream side (Landing boat), an area has been fractured and subsided (SU1) causing the collapse of a concrete fence in the area. An observation borehole in the area (piezometer A1) shows very fast fluctuation of water level, during impounding or discharging of the lake, as compared with other piezometers in the nearby areas. This probably suggests that the source of this channel comes from the main reservoir and then flow behind the right bank of the dam body towards the river. Al-Ansari et. al. (1984 and 1985) indicated that the main fracture patterns in the area are NE-SW, NW-SE as well as wide spread sinkholes. These two patterns represent weakness for flowing water. Intersection of these two patterns probably makes the two sections of the channel, as indicated by the dashed line in figure (1) . One section is represented by the NE pattern of weakness makes the source of the channel from the main reservoir with subsided area (SU1) as its intake. The other pattern is the SE makes the discharge channel that is extended in the downstream side to discharge in the river. This situation could be augmented by the fact that the eastern plunge of the Butmah East anticline is located at the western end of the dam body or slightly north of it. In this area the beds are dipping towards the southeast. Consequently the dissolution of gypsiferous and calcareous layers present within the lower marl series will be easier along the bedding plane. This situation probably represents an ideal situation for water seepage from the main reservoir towards the downstream.

References

1. Abu-Zeid, N. (1994). Investigation of channel seepage areas at the existing Kaffrein Dam site (Jordan) using electrical resistivity measurements. Journal of Applied Geophysics, V.32, Issue 2-3, pp.163-175.
2. Al-Ansari, N. H.; Barznji, A.; Al-Jabbari, M. H. and Gayara, A. D. (1984). Geological investigation of Mosul dam site. Internal Report, Ministry of Irregation , Baghdad.
3. Al-Ansari, N. H.; Barznji, A.; Al-Jabbari, M. H. and Gayara, A. D. (1985). Geology of Saddam Dam area. Internal Report (in arabic), Directorate of Saddam Dam Project. Ministry of Irrigation
4. Al-Juraisy, B. A. M. (1992). A seismic refraction study of some parts of the Saddam dam area. Unpublished M.Sc. Thesis, Department of Geology, Mosul University, 98pp.
5. Ameen, M. K. (1985). General geological report of Saddam dam area. Internal Report (in arabic), Directorate of Saddam dam Project.
6. De Lima, O. A. L., Sato H. K. and Porsani M. J. (1995). Imaging industrial contaminant plumes with resistivity techniques. Journal of Applied Geophysics, V. 34, Issue 2, pp 93-108
7. Dutta, N. P.; Bose, R. N. and Saikia, B. C. (1970). Detection of solution channels in limestone by electrical resistivity method. Geophysical Prospecting, V.18, pp.405-417.
8. Ebraheem, A. M.; Hamburger, M. W.; Bayless, E. R. and Korthe, N. C. (1990). A study of acid mine drainage using earth resistivity measurements. Ground Water, V.28, No.3, pp.361-368.
9. Frank E. F. and Beck B. F. (1991). An analysis of the cause of subsidence damage in the Dunedin, Florida, area 1990/1991: Florida Sinkhole Research Institute Report 90-91-2. Orlando: University of Central Florida. 59 pp
10. Ghosh, G. P. (1971). Inverse filter coefficients for the computation of apparent resistivity standard curves for a horizontally stratified earth. Geophysical Prospecting, V.19, pp.769-775.
11. Kumar, R. (1973). Resistivity type curves over outcropping vertical dyke. Geophysical Prospecting, v.21, pp.615-625.
12. Modacom 1984. Geological Map –Left and Right Banks-Main Scheme area, Internal Report, Directorate of Saddam Dam Project, Ministry of Irrigation
13. Orellana, E. and Mooney, H. M. (1966). Master tables and curves for vertical electrical sounding over layered structure. Madrid, Interciencia, 193pp.
16. Tawfiq , J. M . and Domas, J. , 1977. The regional geological mapping of Dohuk - Ainzalah area. Unpublished Report. State Organization of Mineral Library, Baghdad, Report no. 837.

التحري الجيوكهربائي لقناة تحت سطحية في جهة أسفل الجريان لسد الموصل

[١] نبيل حميد الصائغ[١] ، سهيل إدريس خطاب[٢] ، زهير شيت محمد[٣]

[١] *مركز بحوث السدود والموارد المائية ، جامعة الموصل ، الموصل ، العراق*

[٢] *قسم المدني ، كلية الهندسة ، جامعة الموصل ، الموصل ، العراق*

[٣] *قسم الجيولوجي ، كلية العلوم ، جامعة الموصل ، الموصل ، العراق*

(**تاريخ الاستلام:** ٣١ / ١ / ٢٠١١ ---- **تاريخ القبول:** ٢٦ / ١٠ / ٢٠١١)

الملخص

تم التحري عن سبب تكون وتطور عدد من التخسفات ضمن منطقة الخدمات من الجانب الأسفل للجهة الغربية لسد الموصل وذلك باستخدام طريقة المقاومة النوعية الكهربائية. كان التحري ناجحاً في كشف وتحديد قناة مائية تحت سطحية. العرض المحسوب لهذه القناة هو بحدود 240 متراً وبعمق ١٠ متر. المأخذ المائي لهذه القناة هو على الأغلب من البحيرة الرئيسية ومن ثم تجري خلف الجهة الغربية من نهاية جسم السد لتصب في أسفل النهر مكونة عدداً من الخسفات في المنطقة.