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Changes in Bed Morphology of Mosul Dam Reservoir

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ABSTRACT

Mosul dam is one of the biggest hydraulic structures in Iraq. It was constructed on the Tigris River in the north of Iraq for multiple purposes: irrigation, flood control and power generation. The initial storage capacity and water surface area of its reservoir reach 11.11 km^3 and 380 km^2 respectively at the maximum operation level 330 m.a.s.l. The dam was operated in 1986. Since that time no survey has been conducted to determining the characteristics of sedimentation in the reservoir. Blockage of the intakes of the pump station for North Al-Jazira Irrigation Project in Mosul dam reservoir has highlighted the importance of sedimentation problems within the reservoir.

Sediment distribution was studied within the reservoir. A comparison was made between the conditions at the start of the dam operation and a recent bathymetric survey conducted in 2011.The former was achieved using a topographic map scale 1: 50000 dated 1983 which was converted to a triangular irregular network (TIN) format using the Arc/GIS program. The results of the bathymetric survey were also converted to the TIN map format using the above program. Comparison of the two maps shows that the sedimentation magnitude in the upper zone of the reservoir, where the River Tigris enters, was highest and gradually reduced toward Mosul dam site. Maximum deposition thickness within the reservoir was 17.6 m. The thalweg bed slope of the River Tigris within reservoir area changed from 0.65 $m.km^{-1}$ before dam construction to 0.71 $m.km^{-1}$ on the 2011 survey. Zones within the middle and lower parts of the reservoir were exposed to erosion which amounted to 9.6 m deep.

***Key words:* Mosul dam, Reservoir bottom morphology, Iraq, Reservoirs sedimentation, Bathymetric survey.**

1. Introduction

The dams are usually constructed for the development and management of water resources such as water storage, hydropower generation, flood control, navigational, municipal water supply and environmental purposes. Impounding water after construction of the dam will form a reservoir upstream from the dam site and changes the flow regime of the river due to backwater flow effects. Subsequently, sediments are deposited. Coarse particles, such as gravel and coarse sand, are the first to settle forming a delta (topset) at the point where the back water effect ends. The second zones are foreset beds which are the advancing face of the delta deposit in the reservoir. The foreset beds are different from the topset beds by an increase of the slope and the decrease in their grain size. Fine sediment particles enter the reservoir and are transported by turbid density currents or non-stratified flow forming bottomset beds. The bottomset beds are typically deposited beyond the delta near the dam away from the inflow point (Grade and Ranga Raju, 1985; Morris and Fan, 1998). The pattern of sediment deposition depends on factors, such as the quantity of moving sediment and stream flow, the nature and physical properties of the sediment and the operations mode of the reservoir (USBR, 1987).

Accumulation of sediment within the reservoirs directly affects the operation of hydraulic structures. Therefore, the study of sediment distribution within reservoirs is of major importance for the designers and planners of hydraulic structures and those interested in flushing of reservoirs. There are several techniques to study the sediment distribution within the reservoir, but the analysis of bathymetric survey can provides a direct method for determining both sediment distributions and bed profile (Morris and Fan, 1998; Ferrari and Collins, 2006).

The Mosul Dam is one of the most important and strategic projects in Iraq. It is a multipurpose project. One of its functions is to provide water at a rate of 48 $m^3.s^{-1}$ for a huge irrigation project known as *“North Al-Jazira Irrigation project”* that covers an area of 625 km^2. This station is located in the upper zone of Mosul reservoir dam. In 1991 and 2005, the station stopped for several days due to sediment accumulated at the inlets (Mohammed, 2001; ECB, 2010). Furthermore, no bathymetric survey was been conducted since the dam operation in 1986. Simple study was conducted on the sediment distribution on the bed of the reservoir by Al-Taiee (2005). In view of the above, a bathymetric survey was conducted using an echo sounder sonar viewer to develop a new topographic map for the reservoir in TIN format and a pre-construction topographic map converted to a digital map in the TIN format using the Arc/GIS program that was used for comparison purposes with the new bathymetric map constructed in 2011.

2. Study Area

The Mosul dam is one of the biggest hydraulic structures in Iraq was built on the Tigris River in the north of Iraq approximately 60 km northwest Mosul city (Fig.1). The dam is an earth fill dam was operated on July 7^{th}, 1986 for multipurpose irrigation, flood control and hydropower generation (Iraqi Ministry of Water Resources, 2012). The main dam is 113 m high, 3650 m long with its spillway, 10 m top width and the crest level is 341m.a.s.l. The water surface area of its reservoir is 380 km^2 with a storage capacity of 11.11 km^3 at maximum operation level 330 m.a.s.l including 8.16 km^3 live storage and 2.95 km^3 dead storage (Iraqi Ministry of Water Resources, 2012). The main source of the water and sediment entering the reservoir flows from the River Tigris. Ten seasonal valleys feeding the reservoir, 7 from eastern side and 3 from the western side. These valleys contribute water and sediment during rain events that are less than 2% (Muhammad and Hbdul-Baki, 2005; Ezz-Aldeen et al., 2012 a,b,c and 2013). The catchment area of the River Tigris estimated above the Mosul dam is about 54900 km^2 shared by Turkey, Syria and Iraq (Swiss Consultants, 1979; Saleh, 2010; Al-Ansari and Knutsson, 2011). The reservoir area is composed of alternating beds of limestone, marls and gypsum (Al-Ansari et al., 1984; Al-Sinjari, 2007).

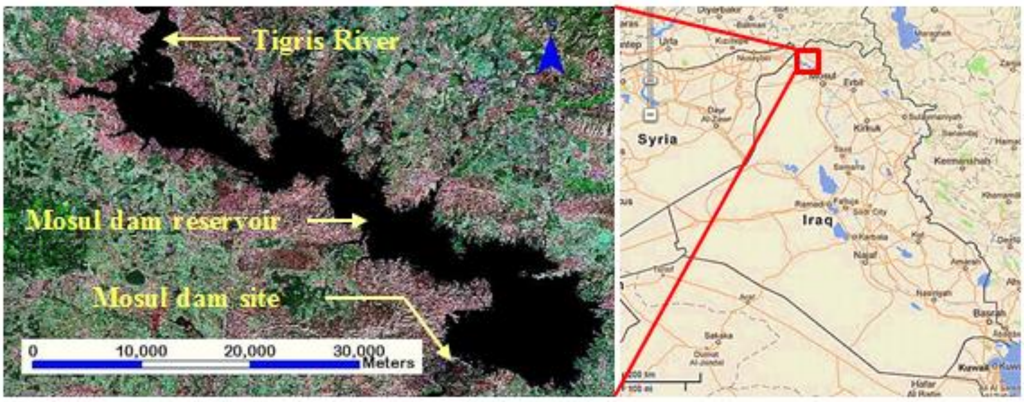

Fig. 1 Location of Mosul Dam

3. Methods

3.1 1983 survey

A pre-impoundment topographic map scale 1: 50000 with contour interval 5 m dated 1983 was used for comparison with bathymetric survey. The map was obtained from the Remote Sensing Center at Mosul University. This map was used to establish digital topographic map in TIN format using Arc/GIS software. The topographic map was scanned and projected onto a satellite image and georeferenced to the Universal Transverse Mercator (UTM) projection, *"WGS-1984, Zone 38N"* using Arc/GIS software (ESRI, 2012) (Fig. 2).

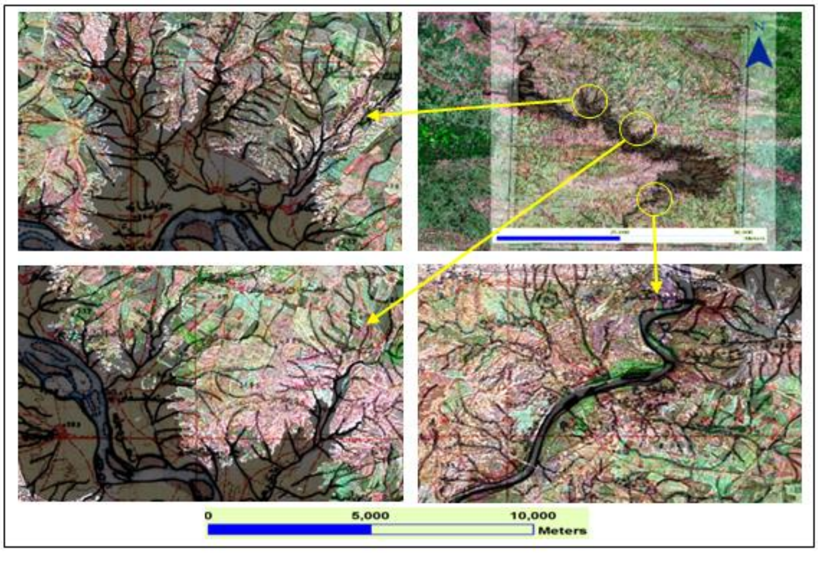

Fig. 2 Projection of Mosul reservoir1983 topographic map on the 2009 satellite image

To check the accuracy of work done, the map was superimposed on the satellite image. It was noticed that the courses of the River Tigris and the side valleys were 98% coinciding on the two maps (Fig. 2).

Contour lines and spot locations of elevation (benchmarks and high water marks) within the reservoir area on the map were manually digitized to compute (x,y,z) data. Furthermore, stream path lines representing the River Tigris within the reservoir area were also digitized. The River Tigris digitization within reservoir area was carried out depending on contour lines on the map and the 0.65 $m.km^{-1}$ water surface slope of River Tigris at that time (Swiss Consultants, 1979; Najib, 1980). The total number of the digitized points was 6029 within the reservoir area (Fig. 3)

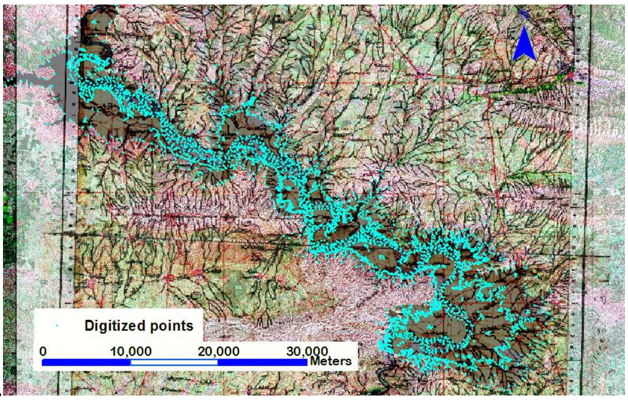

Fig. 3 Location of digitized points on Mosul reservoir topographic map

All digitized points from the 1983 map were used to develop a TIN for the reservoir area before the construction of the dam by Arc/map program (Fig. 4).

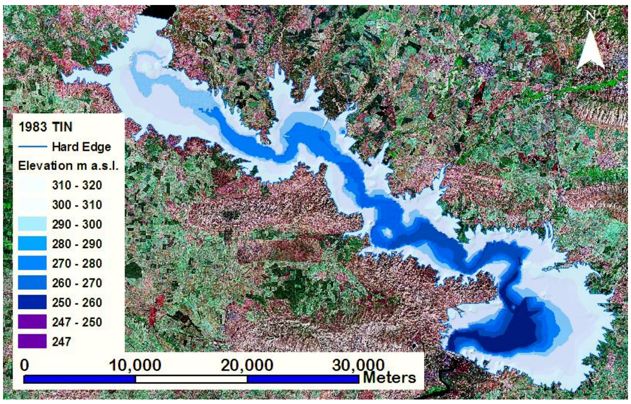

Fig. 4 Mosul reservoir a TIN surface model generated using 1983 topographic map

3.2 Bathymetric survey

This section presents the methodology and data processing methods that were used in the bathymetric survey for Mosul reservoir. The survey was conducted in May 2011 using an echo sounder sonar viewer and the Arc/GIS software to develop a new topographic map for determining the sediment distribution within the reservoir.

3.2.1 Equipment and survey procedures

The bathymetric survey of the Mosul reservoir was conducted using an echo sounder with accessories, a Jet Ski boat, (12v DC) echo sounding power unit and a variety of auxiliary equipment. The data were collected using *"200-kHz single-beam echo sounder sonar viewer type Sea Charter 480DF"* linked to a global positioning system (GPS/WAAS;) which were working together to define the absolute x, y, z coordinates of the reservoir bottom during the traverses. The GPS receivers monitor the horizontal position of the survey boat while the echo sounder measured water depth (Eagle Electronics, 2003).

The bathymetric survey was conducted over 12 days starting on May 15^{th} and ending on June 3^{rd}, 2011. The survey was conducted according to U.S. Army Corps of Engineers standards for distances between transverse sections, boat types and calibration (USACE, 2004). Installation and Calibration of the echo sounder was performed before the bathymetric survey.

The calibration was performed by a marked rod (bar check calibration) over the side of the boat in calm water according to the methods described in Eagle Electronics (2003) and Ferrari and Collins (2006). The error values of water depth measurements were ±4 cm when water depth ranging 0.5-50 m within the reservoir. The water temperature during the survey ranged from 28-30 °C during the whole survey period. Since the temperature was almost constant, then the effect of temperature on sound velocity was neglected. Transducers face depth (draft) during the survey was 0.35 m below the water surface. The draft depth was used to correct the water depth recorded by an echo sounder. The bathymetric survey was performed in calm water to avoid the errors in water depth measurement due to waves. The water surface elevations during the survey were recorded at the hydropower generation station at the dam site and at the pumping station of North Al-Jazira project in the upper zone of Mosul Reservoir. The recorded readings were between 319.75 and 319.96 m.a.s.l. These elevations were used to convert the acoustic depth measurements to reservoir bottom elevations during data processing. Figure 5 shows the details of the transect lines during the bathymetric survey.

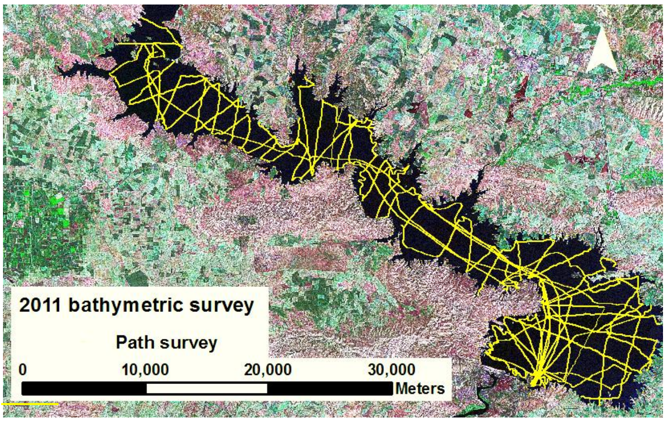

Fig. 5 Boat path of bathymetric survey for Mosul reservoir

3.2.2 Data Processing

The echo sounding survey system produces data files in (*slg) format containing acoustic data and GPS data in a Universal Transverse Mercator (UTM) system. Each (*slg) file was converted to (x,y,z) (*csv) excel file format by the Sonar Viewer 2.1.2 program. The water depth values in (*csv) file was adjusted with respect to transducer depth.The value of bed-elevation = water surface elevation – adjusted depth. The water surface elevation for each survey date was used for each data set collected on that date. It should be mentioned however, that the survey was conducted during calm period where the wave's heights were less than 10 cm. For this reason the effect of waves on the water depth measurement was neglected. The bathymetric survey data were used to develop the TIN of the 2011 survey using the same previous method as used in 1983 survey (Fig. 6).

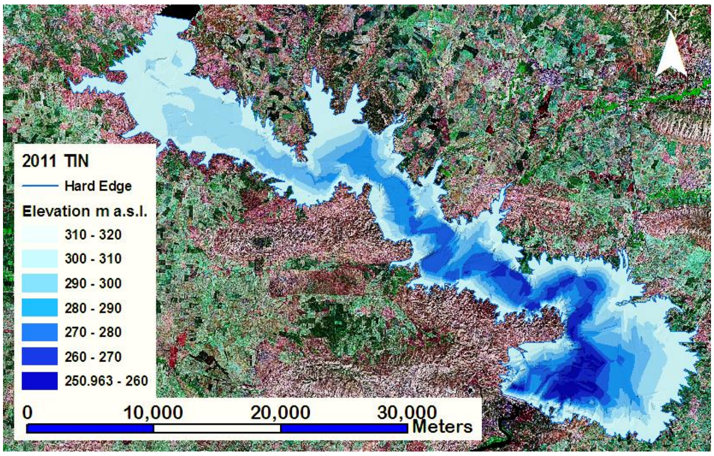

Fig. 6 Mosul reservoir a TIN surface model generated using 2011 bathymetric survey

4. Results and Discussion

To illustrate the sediment distribution within the Mosul reservoir, longitudinal profiles were plotted along the thalweg of River Tigris within the reservoir area for both the 1983 and 2011 surveys (Fig. 7).

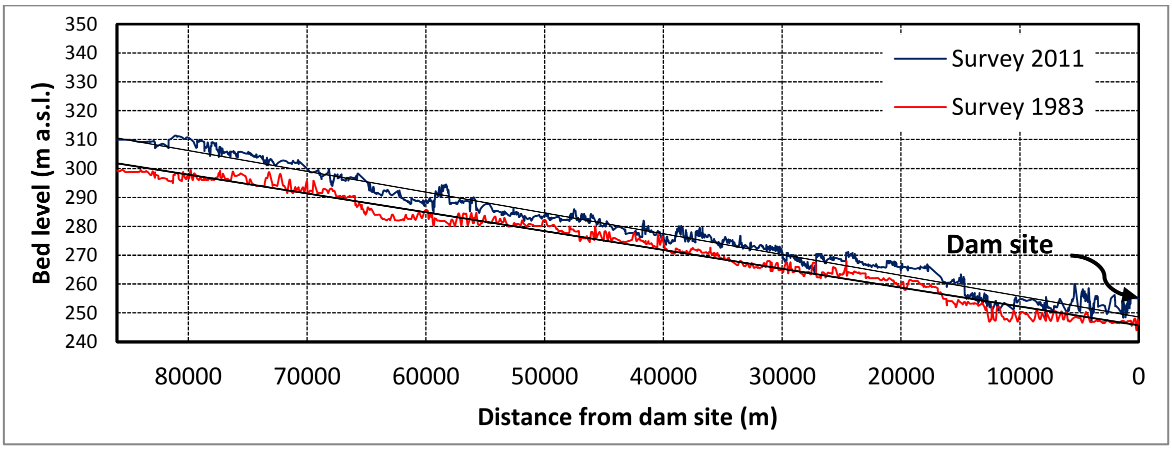

Fig. 7 Comparison of thalweg longitudinal profiles for two surveys 1983 and 2011

The longitudinal profiles were established using 1983 topographic map, satellite image and TINs of the two survey figures (4 and 6). The difference between the 1983 survey and 2011 survey represents the sediment deposited into the reservoir during this period. These longitudinal profiles represent the deepest part of the reservoir bottom along the central portion for 1983 survey. The drawing shows that the greatest volume of sediment was deposited within the upper zone of the reservoir where the River Tigris enters the reservoir. The overall bed slope changed from 0.65 m.km-1 to 0.71 m.km-1.

In addition to this, the reservoir area was divided by the Arc/map program into three zones; upper, middle and lower zones to show the sedimentation rates within each (Fig. 8). These divisions were based on the shape of the reservoir. The two bends within the general shape of the reservoir were used to designate the borders between these zones.

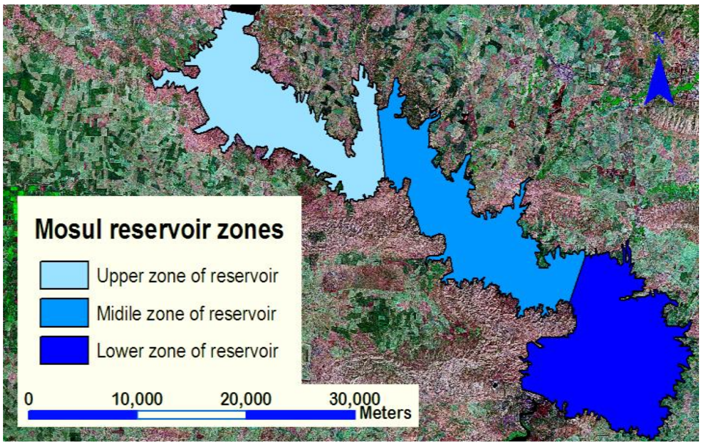

Fig. 8 The Zones of the Mosul reservoir polygon

The storage capacities for these zones for each of the two surveys were computed by Arc/GIS software and then sedimentation rate were computed (Table 1). This table indicates that the sedimentation rate was relatively high in the area where the River Tigris enters the reservoir. Generally, rate of sedimentation gradually diminishes toward Mosul dam. This sequence is very logical in reservoirs (Fan and Morris, 1992).

Table 1 Storage capacity and sedimentation rate of all zones for Mosul reservoir dam for two surveys.

Location	Storage Capacity [km^3] at 1986	Storage Capacity [km^3] at 2011	Accumulated sediment [km^3]	Sedimentation rate [$km^3\ yr^{-1}$]
Upper zone	1.538	0.938	0.600	0.024
Middle zone	2.85	2.55	0.300	0.012
Lower zone	3.361	3.12	0.241	0.00964
Total	7.749	6.606	1.143	0.04572

To show the changes in the reservoir bottom morphology with time due to erosion and sedimentation processes, a TINs difference command within Arc/map program was used to develop an erosion and sedimentation map for reservoir (Fig. 9). The TIN difference map shows that the maximum deposition took place in the upper zone was 17.6 m. This pattern is very logical for this is where the River Tigris transports 99.79 % of the sediments entering the reservoir while 0.21 % of the sediment are contributed from the side valleys (Ezz-Aldeen et al., 2012 a,b,c and 2013).

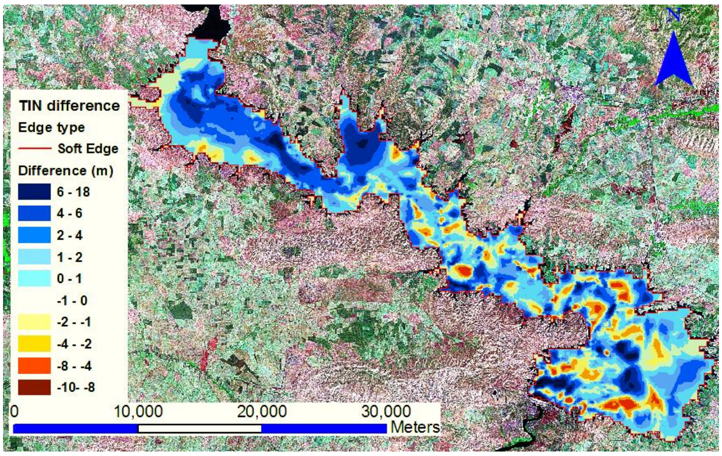

Fig. 9 Differences between two TINs for survey 2011 and 1983 of Mosul reservoir

The map highlights the areas of erosion, deposition and unchanged areas. Generally, erosional areas are restricted mainly in the middle and lower zones of the reservoir where the maximum depth was 9.6 m. They are believed to represent sinkholes and gypsum dissolved areas (Tamplin and McGee 2005; Kelley et al., 2007; Wakeley et al., 2007). Some of these sinkholes are about 15 m in diameter and more 15 m in depth (WII/BV, 2005). In addition, flash flood from side valleys during rainy seasons can cause some erosion in places and deposition in other places when it enters the reservoir. In the upper zone of the reservoir, the erosional areas are mainly confined near the shore due to wave erosion or dissolved gypsum. Field observation and data in figure 9 indicates that it is due to the huge accumulation of sediment in the northern and middle parts of the reservoir in that area converting the main flow to the south causing erosion near the banks. As previously stated, most of the sediment are deposited in the upper zone of the reservoir and at the confluences of the side tributaries (Fig. 9). In addition, deep areas are also characterized by accumulation of thick sediment.

Conclusion

Bathymetric surveys are the direct method for assessment of the sediment distribution within the reservoir. In this study the bathymetric survey was conducted using echo sounder sonar viewer. Two triangular irregular networks were established from the 2011 bathymetric survey and 1983 topographic map. After 25 years of the dam operation following; the thalweg bed slope of the River Tigris was changed from 0.65 $m.km^{-1}$ before dam construction to 0.71 $m.km^{-1}$ during the 2011 survey. The sedimentation rate in the upper section of the reservoir where the River Tigris enters the reservoir was greatest and gradually decreased toward the Mosul dam site. The greatest deposition thickness was 17.6 m in the upper zone of the reservoir. Furthermore, there are many areas in the middle and lower zones of the reservoir that are exposed to erosion. This is believed to be due to the dissolution of gypsum and limestones forming sinkholes that might reach about 20 m in diameter and 9.6 m in depth.

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