Execution and results of a sonar survey in a horizontal leached cavern

by

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Abstract

The surveillance of horizontal caverns which are developed using a vertical and a deviated well is limited when using conventional sonar probes. Difficulties in sonar surveying are encountered particularly when areas of the cavern can be measured only from parts of the deviated well that are almost horizontal.

By referring to a real-life example, it is shown how it was possible by adapting the existing tool technique to monitor the cavern shape from a part of the well with an inclination to the horizontal of only 10 degrees. The difficulties that occurred with surveying on site are expounded and it is shown how they were solved.

In conclusion the final cavern geometry, which was constructed from the survey results of the vertical and deviated well, is presented in a 3D display.

1. Design of the cavern

The vertical B-1 well with a depth of 3000 ft and the deviated B-2 well were drilled in order to construct a horizontal cavern in a bedded salt structure. The B-2 well is vertical down to a depth of 2500 ft. At a depth between 2500 ft and 3000 ft the well is deviated 80° to the vertical around a radius of curvature of 360 ft. Down to the final depth of 3265 ft the well has a constant inclination of 80°. The horizontal distance between the starting point at the surface and the final depth point of the well is 556 ft. The location of the starting points of the wells and also the projection of the courses of the wells are shown in Fig. 1.

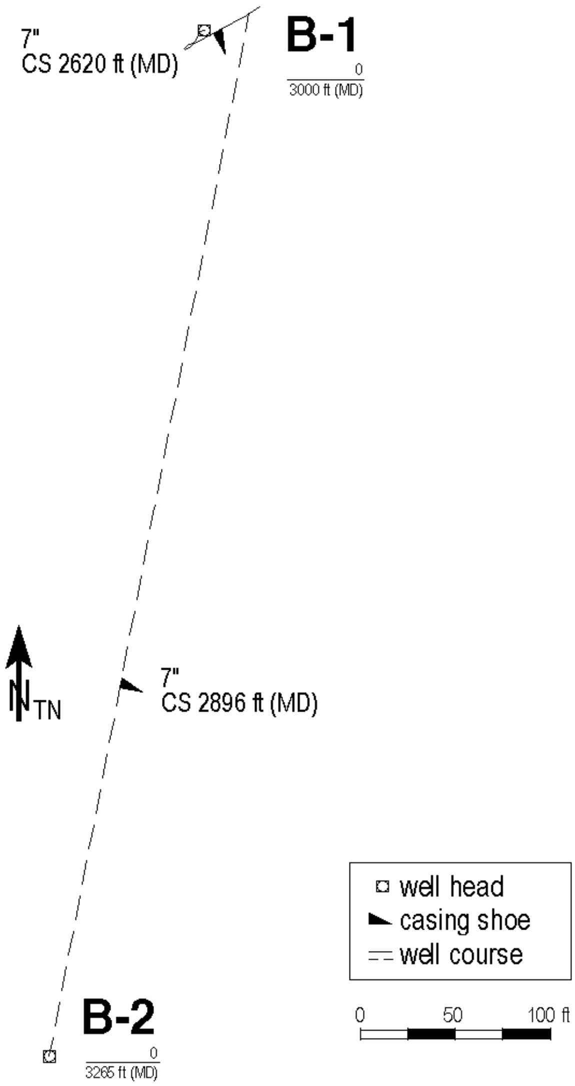

Fig. 1: Location map and course of the B-2 well

Surveillance of the geometry of the resulting void is really quite a special case. In order to survey the void in its entirety, it must be possible to survey with an echo tool not only from the vertical well but also from the deviated well.

2. Sonar survey of the horizontal cavern

2.1 Measuring from the vertical well

So as to be able to gain an idea of how the cavern was developing, surveying was started from the vertical B-1 well. At the time of surveying the cavern was uncased so that measurements could be made in the open void. The 7" casing string was first pulled out of the hole up to a depth of 2620 ft.

Sonar surveying from the vertical well was carried out under normal operating conditions; nothing unusual was observed in the first place considering the survey technique applied. The BSE echo tool was used for the survey [1].

The survey results indicate a still relatively small cavern with a volume of approximately 10,000 barrels. As could be expected the cavern was relatively regular, with the exception of the connecting tunnel to the B-2 well (Fig. 2).

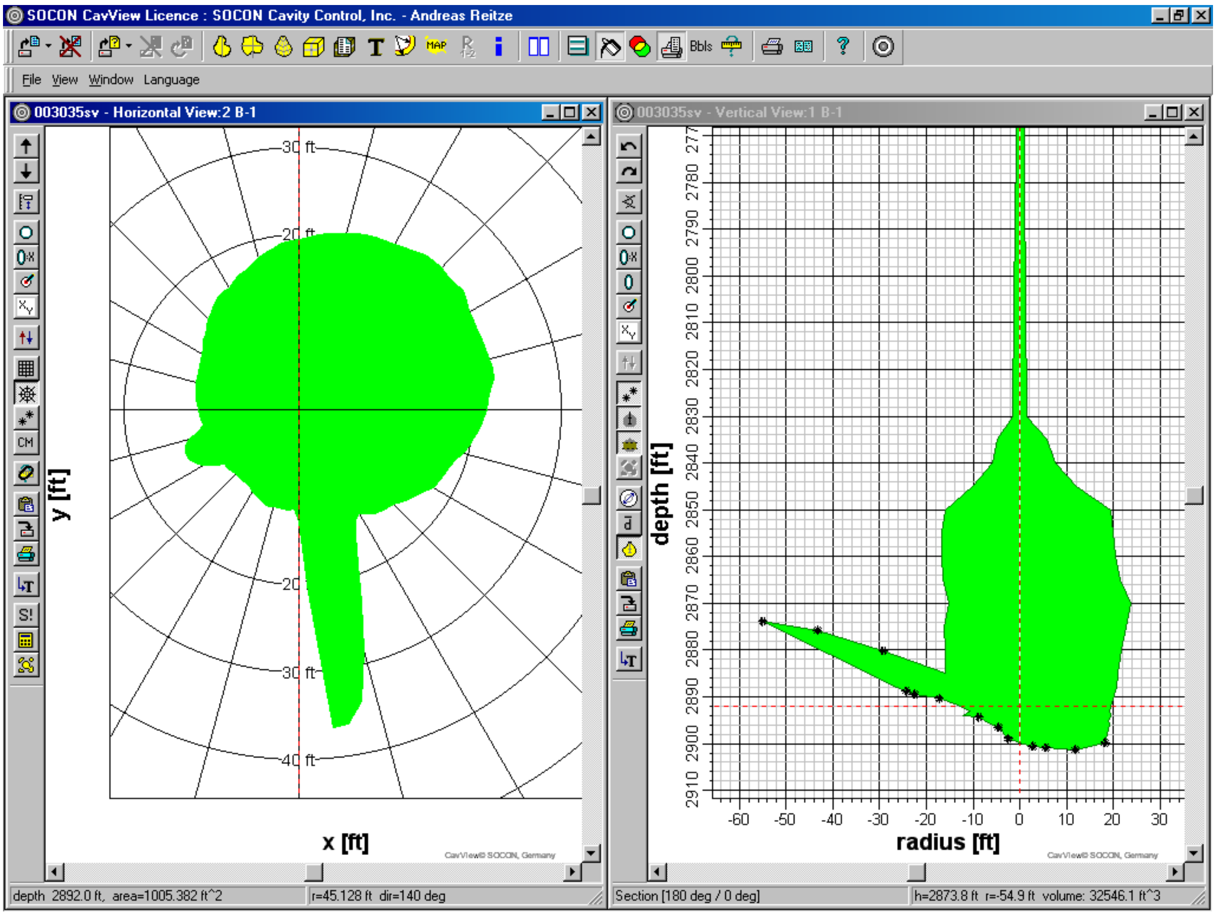

Fig. 2: Horizontal and vertical view of the B-1 cavern in Cav*View*®

In the south the first signs of the connecting tunnel can be seen very well. In this area targeted tilted measurements were made so as to obtain a particularly high survey point density in the vicinity around the tunnel. This was made possible because the survey equipment used allowed the cavern shape to be graphically displayed on site in the survey truck while the tool was still in the hole. Based on this procedure the optimal depth and inclination for the targeted measurements going into the tunnel could be determined together with the cavern operator. However, as the tunnel height was still very low (approximately 10 ft), it was not possible to measure more than a distance of 70 ft into the tunnel.
As expected the precise geometrical shape of the tunnel could not be determined from the survey made from the vertical well, nevertheless the survey showed beyond doubt that a connection in the form of a tunnel had been leached in the direction of the deviated well.

2.2 Measuring from the deviated well

2.2.1 Running the tool into the well

In a second step the leached void was surveyed from the deviated B-2 well. Immediately prior to carrying out the survey a 5" casing string was installed down to a depth (MD) of 3219 ft through which the tool could be run down into the horizontal part of the cavern. Before the tool was run into the hole it had been calculated that the BSE echo tool with a length of almost 6 metres and with an 8° knuckle joint fitted would be able to pass by the curvature in the well. Surveying through the casing in this part of the cavern was possible only because a new casing string had been installed that was obviously not yet covered by insoluble deposits.

The running of the tool into the hole presented an element of uncertainty even prior to performing the survey. Irrespective of the radius of curvature, it was uncertain whether it would be at all possible to run the tool past the curved part of the hole and into the section which was inclined just 10° to the horizontal. Initially it was attempted to advance the tool to the final depth of 3200 ft by pumping water down the hole. After this attempt proved unsuccessful, 2 7/8“ swab cups were positioned above the tool but this led only to a partial success. Finally a 4" swab cup was used and this enabled the tool to be run down to the final depth.

2.2.2 Specific features of the survey

Tool orientation methods applied when surveying conventional caverns could not be used for orientating the tool and the ultrasonic transducers in the well which was inclined at 80° to the vertical. The magnetic compass, which normally determines the rotation around the vertical and the orientation of the tool referred to north, could not be applied under the given conditions.

After running the tool into the cavern the tunnel shaped cavity was surveyed section-wise from the bottom of the well (Fig. 3). In this case the rotation of the tool head no longer represented a horizontal section, but rather a diagonal section through the cavity; we can refer to this as a whirled slice.

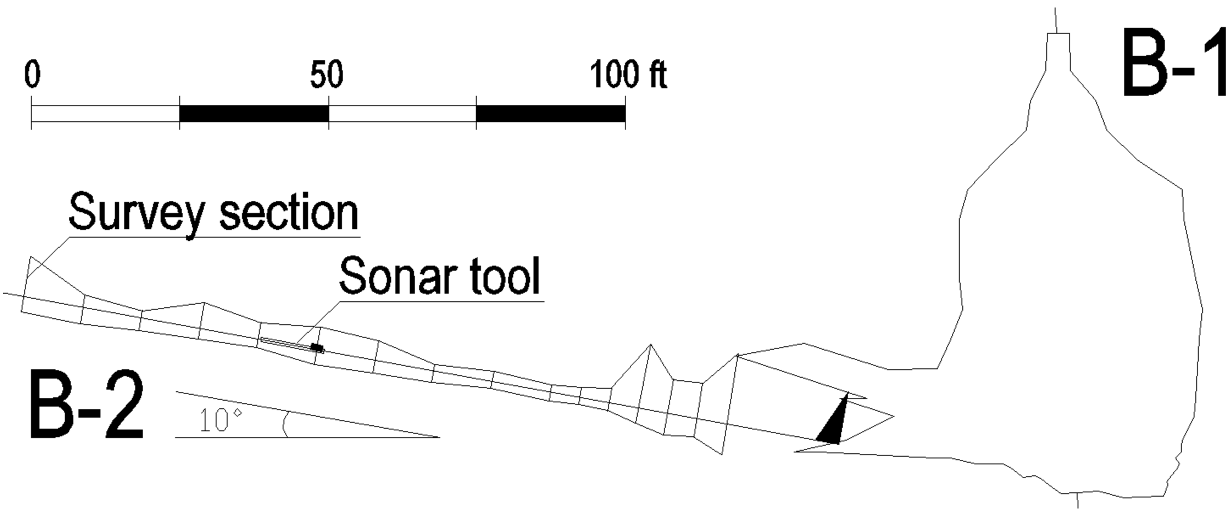

Fig. 3: Surveying from the inclined well

In order to obtain the spatial position of the survey points, the position of the tool head was initially determined based on the survey results of the course of the well. The data provided by the inclination sensor installed in the BSE tool were used to orientate the individual survey sections. Prior to the sections being measured an inclination profile was first recorded by rotating the tool head about its own axis while the tool was lying at an angle in the casing. By interpreting the inclination curve over a complete tool rotation a virtual reference direction could be determined for measuring the sections, and this direction is identical for each of the inclined sections. This virtual reference direction runs upwards and is perpendicular to the casing and tool axis. The position of the section referred to the inclined casing string is therefore unequivocally defined. Knowing the x, y and z coordinates of each measuring position and now knowing the relative spatial position of the section, it was possible to calculate the coordinates of every survey point.

The survey results revealed a tunnel shaped cavity (Fig. 4) with an average diameter of 10 ft in a depth range (MD) from 3080 ft to 3200 ft.

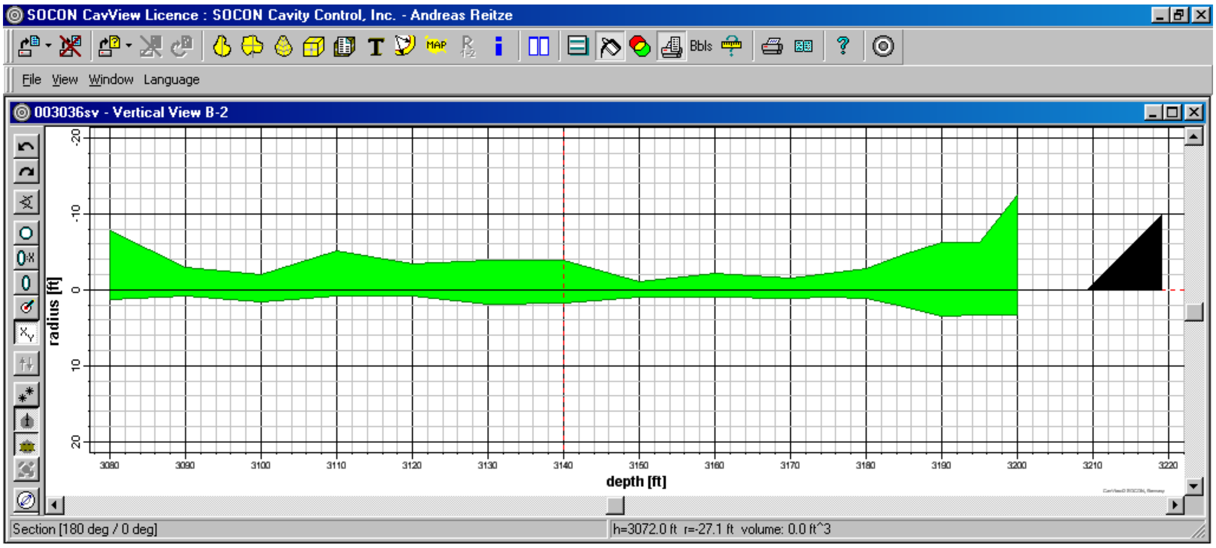

Fig. 4: Vertical view of the B-2 cavity in Cav*View*®

3. Joint interpretation and visualization of the cavern

To display the final cavern shape that was formed as well as to make a definitive plausibility check it was necessary to display both surveys together in a superordinate coordinate system. In the first place the survey in the vertical well, which was oriented to magnetic north, had to be adjusted to refer to geographic north. The results of the survey in the inclined well were already referred to geographic north owing to its orientation being based on the well course.

At the survey location the declination, i.e. the angle between geographic north and magnetic north, is approximately 10 degrees. After applying this directional correction the two surveys agreed with each other very well and indicated a plausible cavity geometry (Fig. 5).

A 3D model of the entire cavity was generated to enable the cavern volume to be determined and allow the cavern to be better visualized. The modelling and the calculations were performed with the KARISDAT CAD system [2], which is based on AutoCAD and was specially developed for displaying caverns.

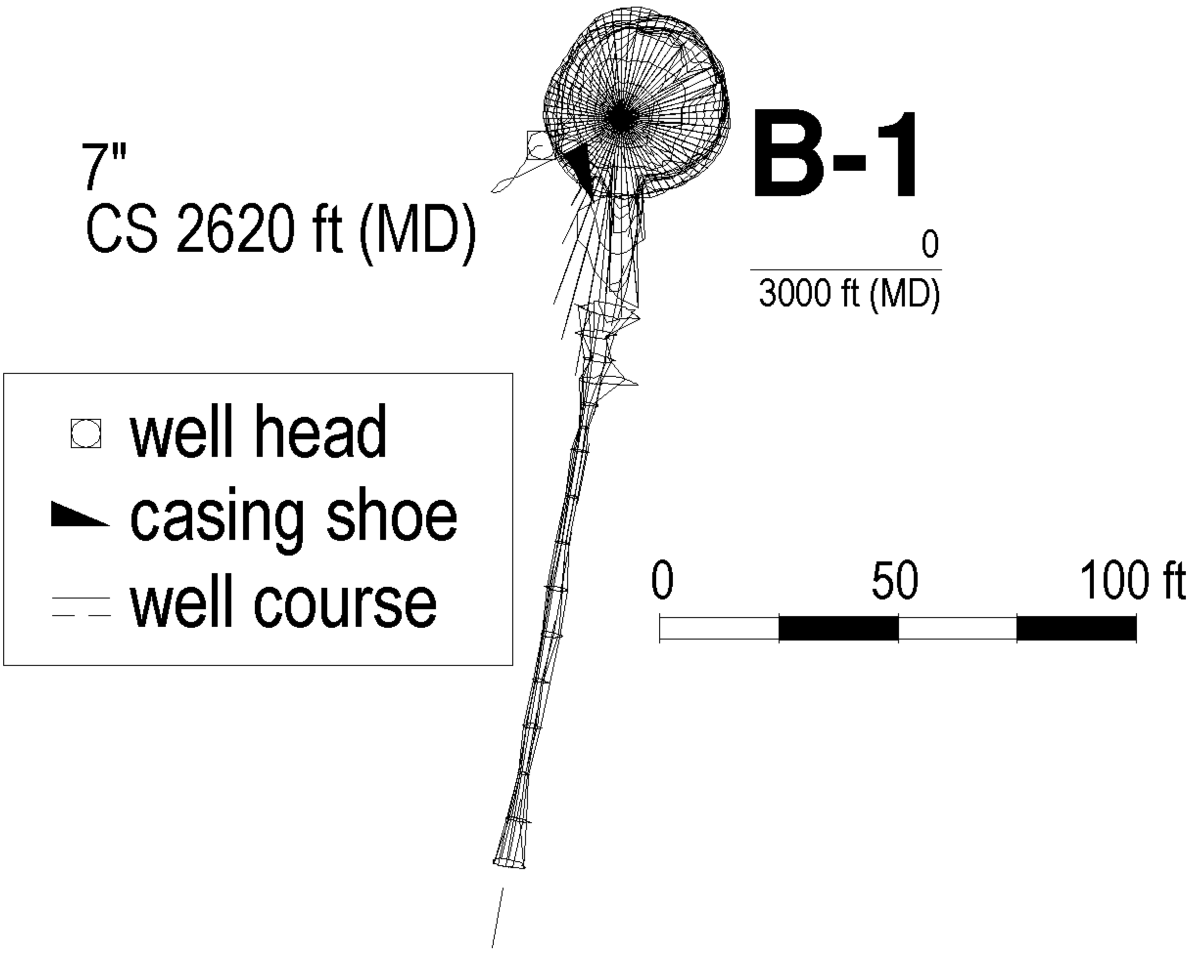

Fig. 5: Resulting cavern shape in plan view and section

4. References

[1] **REITZE A., VON TRYLLER H.:** *Techniques and practical use of the new tool generation for the echometric surveillance of cavities,* SMRI Spring meeting, 14.-17. April 1996, Houston, Texas, U.S.A. (1996).

[2] **MA, Z., REITZE A.,:** *Mapping of cavern fields using the PC-based information system KARISDAT®*, SOCON Sonar Control Kavernenvermessung GmbH, (2000).