Application of Underwater MASW and Acoustic Methods in the Assessment of Sub-seabed Conditions Prior to Construction of the Manifa Causeway, Saudi Arabia

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Summary

In order to accurately assess the presence of voids or weak zones below caprock in the construction of the Manifa cause way (KSA) a combination of traditional acoustic geophysical methods and underwater MASW was executed. This paper describes the methodology and results of this survey.

Introduction

The offshore Gulf Region is known to have caprock layer within the first 0-5m of ground below the seabed. It varies in thickness from a few centimetres to two or three metres in thickness. Caprock is predominantly a Gulf regional phenomenon forming in shallow coastal areas where there are small tidal movements and water circulation. It is typically a cemented Limestone anhydrite with a matrix of small shells and calcarenite.

There are frequent voids found immediately below the caprock as the loose sands below naturally compact. The concern for the design engineers is the load bearing capacity of the causeway structure.

The pressure exerted by the Manifa causeway (Fig.1) unto and below the seabed may force the caprock layer to break and thus undermine the causeway structure. The purpose of the underwater MASW survey was to provide stiffness values of the materials below the caprock layer to assess the integrity of the design parameters.

Fig. 1: Manifa causeway (after google maps)

The acoustic survey was to be utilized to map the caprock layer over the causeway footprint and the larger sand borrow area. The sand deposits over the borrow area were to be defined and prioritized by silt content. The sand would then be dredged in the caprock areas by the suction method for used in the construction of the thirty two kilometer causeway. This strategy was proposed to save costs of indiscriminate use of a cutter dredger that would break the caprock layer before dredging the sand as is normal practice.

The site had been investigated with sixty five boreholes and these were to be used to correlate the acoustic data by silt content. The areas where there was no caprock were to be identified for suction dredging and priorities by sit content. Water depth over the survey area was between 3m to 18m. The causeway is twenty two kilometers long with twenty four 'island' pads used for drilling into the Manifa oil reserves. This manmade offshore dredging and construction is of similar magnitude to the Palm islands off the Dubai coast.

Underwater MASW

Multi-channel Analysis of Surface Waves (MASW) is not widely used in an offshore environment due to the difficulty of receiving surface waves originating from the sea bed. It is essential to use reliable seabed detectors and source mechanisms very close to the seabed. The continued expansion of shear wave marine geophysics is to derive useful mechanisms and provide reliable and accurate data.

The following equipment was used to obtain shear wave data from the seabed.

- A 24 Channel hydrophone streamer
- Hemisphere Vector Pro DGPS
- Sercel Mini G 12inch air gun
- Airgun controller with air tanks recharger
- Seismograph

The hydrophone streamer was attached to the back of the airgun frame and deployed directly onto the seabed. The start and end of the hydrophone streamer had orange buoys attached to observe approximate location and orientation. The hydrophone streamer was weighted at the front with diving weight to keep the streamer on the seabed.

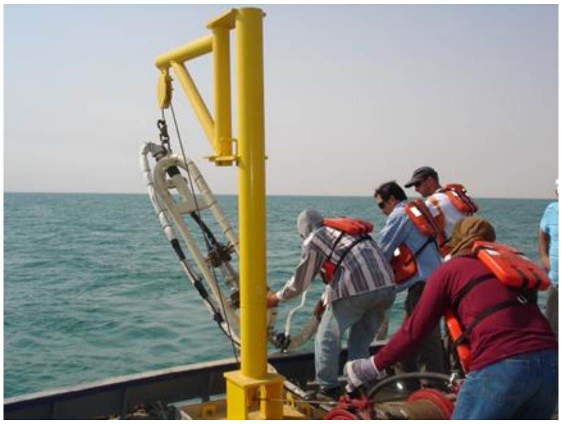

Fig. 2: System Deployment into Water

The marine DGPS was attached to the airgun controller and a bespoke triggering mechanism was fabricated so that the airgun was triggered by coordinates rather than time. The vessel moved along each survey line and the airgun was triggered every twenty five metres.

The data recorded was typically as shown in Fig. 3. The data exhibited clear first arrivals, clear reflectors and also surface waves.

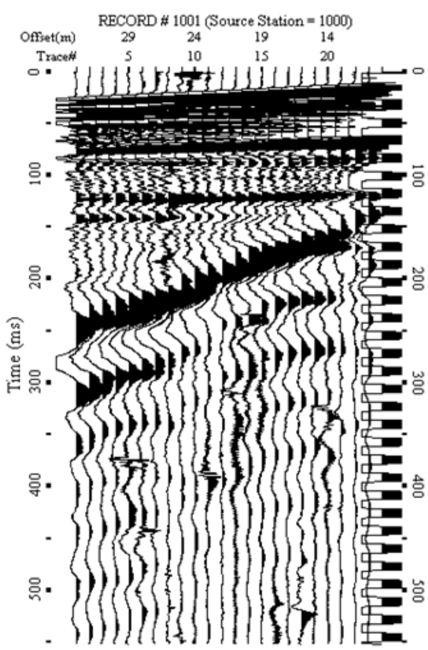

Fig. 3: Raw Data Example

The data was processed using SurfSeis and clean dispersions were produced

The high quality data enabled the processing of the p-wave data also, so seabed hardness plots were produced to further assist the dredging contractor in their activities.

Traditional Survey Techniques

The Acoustic method clearly identified the cap rock layer and with careful correlation with the borehole logs, it was possible to identify areas with higher silt content (Fig.4)

At the time of the survey a total of sixty five boreholes in the area were made available, which were used for calibrating the seismic and acoustic data and aiding in the interpretation of the geophysical data. These sixty five boreholes were summarized by their main geological descriptors:

1. In cap rock areas, little or no penetration through the cap rock of sonar waves was observed, though reflections, some 2-4m through the caprock can be seen.

2. In areas with clay layers at the surface of the sea bed, penetration of signal was a maximum of 10m, whereas in areas with sand at the surface, penetration was approximately 5m.

3. Visible structures are identifiable to only until the first multiple reflection (-> low penetration in shallow areas)

Characterization:

The four main units could be distinguished according to comparison with the available drill holes: cap rock, possible cap rock, sand and clay. Potential gas pockets/seepages have been also been marked on the images.

C**aprock**
Cap rock was mapped where a sonically hard reflector showed up below a layer of soft sediments.

Sand
Sand was mapped where cross bedding or layering structures was identified. When cap rock was immediately at the sea bottom, it could not be seen as a separated hard reflector.In this case possible caprock was recorded.

Soft Sediments

Soft sediment were characterized until either caprock, potential caprock or the first multiple reflection was observed. Where the boundary between surficial clay and sand is not seen, both units have been combined together as “soft sediment“.

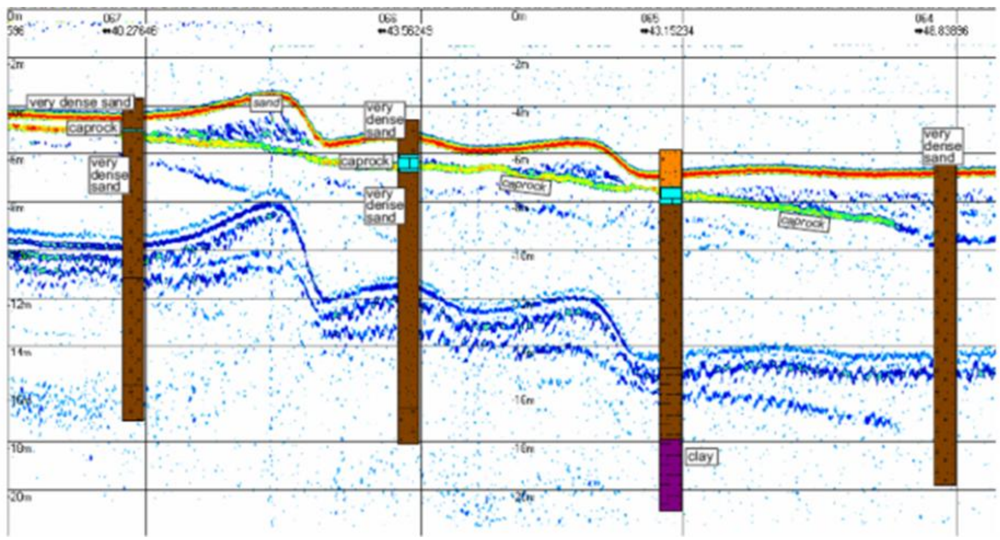

Fig.4: Combined Interpretation Borehole and Acoustic Data

Results

This method proved excellent for confirming data horizons and classification of large areas became a much simpler process. The seismic date were processed and placed directly below the acoustic data for a direct comparison.

A very close comparison can be made as both systems were geo-referenced with global coordinates.

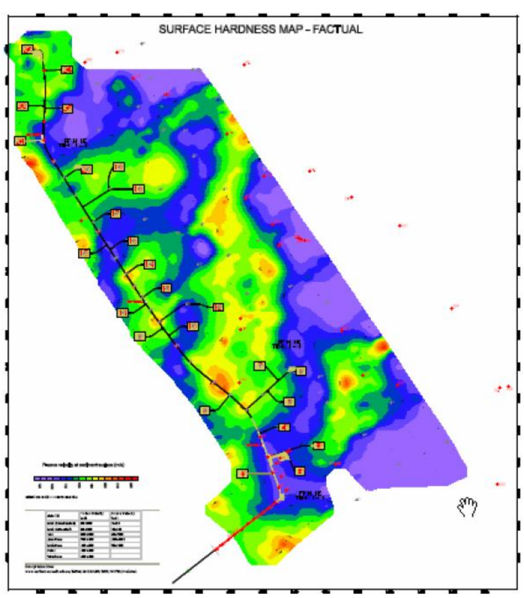

Fig. 5: Seabed Hardiness

The seabed hardness plot (Fig.5) was derived from the p-wave data obtained from analysis of the first arrival times. It indicates the areas (in blue) that are the softest and would be targets for suction dredging.

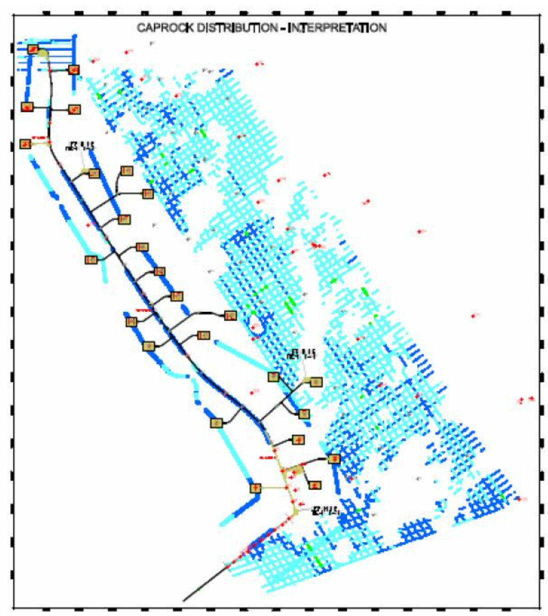

Fig. 6: Caprock Distribution

The caprock distribution plot (Fig.6) indicates where dredging using suction dredging must be avoided.

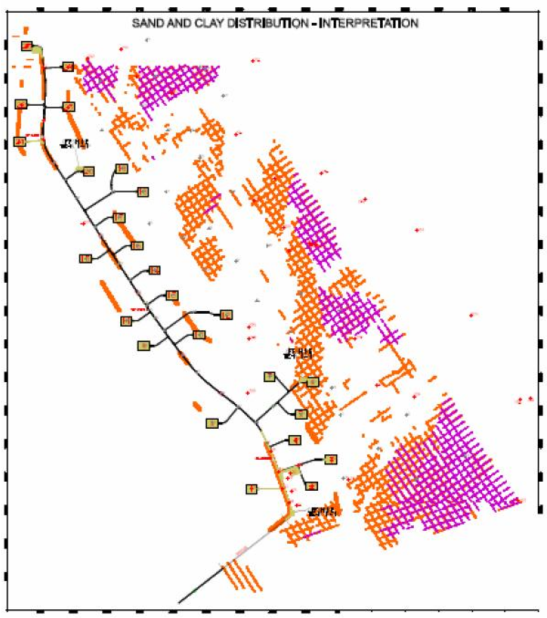

Fig. 7: Sand/Clay Distribution

The sand and clay distribution plot (Fig.7) shows the locations where the dredging company can use suction dredging to a minimum of ten metres depth.

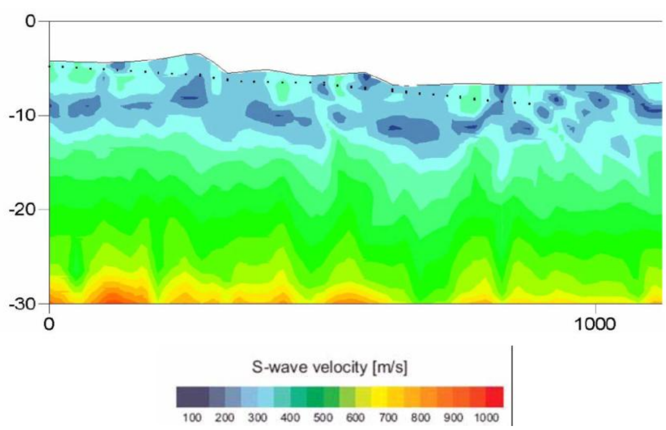

Fig. 8: Combined Acoustic & MASW 2D profile

Figure 8 shows an example of an MASW profile. The dotted line at the near surface of the seismic data indicates where the cap rock layer exists, confirmed by the acoustic and borehole data. It was not possible to image the very thin caprock layer with the MASW method as a relatively low frequency energy source was used. The underwater MASW data has shown there to be a weak (less stiff) zone extending to 10-15m below the seabed. The velocity values are very low in terrestrial terms and would be comparable with loose sand.

Conclusions

Based on the results of this survey the client redesigned the causeway structure to further spread the load of the construction due to the low stiffness values as indicated in the survey.

References

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