Imaging Shallow Subsurface of Dead Sea Area by Common Shot Point Stacking and Diffraction Method Using Weighted Multipath Summation (Case Study)

Shemer Keydar, Benny Medvedev, Michael Ezersky, Leonid Sobolevsky

Geophysical Institute of Israel, Israel

shemer@gii.co.il

***Abstract*- A new methodology for imaging shallow subsurface is presented. This methodology combines several recently developed imaging techniques, namely zero-offset Common Shot Point (CSP) stacking, diffraction imaging technique and weighted multipath summation. We will show how employing the CSP stacking and diffraction method using weighted multipath summation makes possible to obtain a better image than using the conventional CMP method. Application of the new approach is illustrated by a real data-set from the Mineral beach at the Dead Sea area.**

***Keywords*- Shallow Subsurface Imaging; Common Shot Point (CSP) Stacking; Diffraction Imaging; Multipath Summation; Dead Sea Area**

I. INTRODUCTION

A new methodology for imaging shallow subsurface is presented. This methodology combines several, recently developed imaging techniques. The first one is zero offset Common Shot Point (CSP) stacking [3]. The heart of this technique is a new NMO travel time correction formula as a function of reference velocity and wavefront parameters namely radius of curvature of the common shot wavefront and angle of entry of the arriving wavefront. The other one is a diffraction imaging technique [6, 7], that utilizes diffracted waves in order to detect inhomogeneous objects such as faults, sinkholes, cavities, caves, tunnels. The diffraction travel time correction curve is defined as function of velocity of diffracted waves. The CSP stacking and diffraction imaging formulae can be extracted provided the model of the medium is known. However, in reality, the model of the medium is unknown; therefore, some kind of inverse problem must be solved in order to construct these parameters. This is done, like in the conventional CMP stacking procedure, by finding a maximum of a chosen coherence measure. But unlike in conventional CMP stacking one optimal parameter (V_{nmo}) have to be estimated, in case of CSP stacking there are three unknown optimal parameters. These parameters are estimated by a time-consuming procedure of optimization problem involving visual examination.

In our new approach we use an alternative, a more formal recently proposed multipath summation with proper weights [4, 5, 9, 10]. The multipath summation is performed by stacking the target waves along all possible time surfaces having a common apex at the given point. This approach does not require any explicit information on parameters since the involved multipath summation is performed for all possible parameters values within a wide specified range. We will show how using the CSP stacking and diffraction method using weighted multipath summation makes possible obtain a better image than using conventional CMP method. Application of the new approach is illustrated by a real data-set from the Mineral beach at the Dead Sea area.

In this paper we give a short description of CSP stacking, diffraction imaging and multipath weighted summation. For a more comprehensively discussion of the methods one can read in the relevant papers.

II. THE COMMON SHOT POINT STACKING METHOD

The Common Shot Point (CSP) stacking of reflection waves [3] is a special case of a Homeomorphic Imaging approach [1, 2]. This approach is based on the fundamental principle of topological equivalence of a reflector and its image as constructed from the stack parameters. The basis of the zero offset Common Shot point stacking method is a new normal moveout (NMO) time correction formula.

In order to get the time correction formula let us assume a source located at point Ao and receivers located at points Aκ (Fig. 1). A wavefront, with a centre of curvature denoted by C_o*, generated by this source and reaches the receivers Aκ. The ray AoCoAo is a normal ray. For an arbitrary set of receivers Aκ and sources Ao on the surface, from simple geometrical consideration the following expression of common shot time curve is obtained:

$$T_{sr}^{csp} = \frac{(x^2 + 2\cdot\sin\beta\cdot x\cdot R + R^2)^{0.5}}{V_0} \qquad (1)$$

where R is radius of curvature of the common shot wavefront, β is angle of entry of the arriving wavefront, x-distance between shot Ao and receiver Aκ and Vo is reference velocity at the subsurface. CSP imaging of subsurface usually can be performed by a spatial summation of the wavefield along time curves defined by Formula (1) as function of optimal parameters, namely radius of curvature R, angle of entry of the arriving wavefront and reference velocity of the subsurface Vo. Note that the Formula (1) is, unlike conventional CMP stacking, stretch free. This property makes possible to get a better reflection image of the shallow subsurface than by using the conventional CMP stacking. The optimal parameters β, R and Vo. are estimated in [3] using optimization problem which consists of finding parameters which maximize some correlation functional. Still now the estimation of these parameters is a very challenging problem. In our new methodology we use an alternative approach, so called weighted multipath summation. This approach replaces the complex optimization problem of estimating NMO parameters by stacking along all possible trajectories that are created from small variations of those parameters. In the following we give a short description of weighted multipath summation.

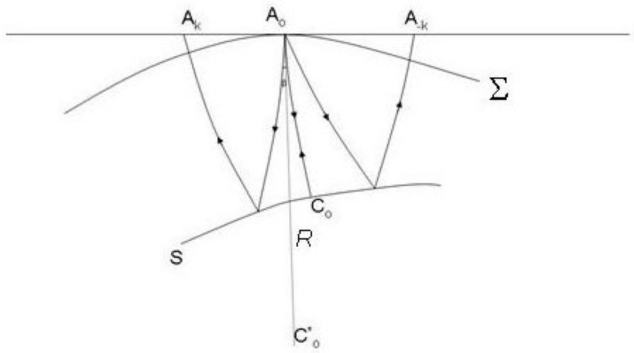

Fig. 1 Schematic description of the ray path from reflector S

III. DIFFRACTION IMAGING TECHNIQUE

The imaging algorithm for the detection of underground anomalies should emphasize scattering objects such as voids and faults and not be too sensitive to the presence of continuous and smooth interfaces, which generate reflected/or refracted waves. For example, it is clear that so-called stacked section, conventionally used in seismic reflection imaging, cannot be employed for faults and facies changes detection, since the stacking procedure emphasizes reflected waves and tends to eliminate diffraction/scattering events generated by faults and facies changes. For the detection of scattering objects, it was proposed to use so-called diffraction imaging algorithm [7], which is based on the phase correlation of the diffraction signals on the observed records. The data are analyzed along different diffraction curves to find the curve closest to the travel time curve of the signal.

Assume a diffractor located at a point (X_D, Z_D) (Fig. 2). Then for a set of shot points (X_o, 0) and receiver points (X_k, 0) located at the surface, the kinematic response of the diffractor (diffraction time curve) can be defined as follows:

$$T_{SR}^{DIFF} = \sqrt{(\xi_{SD}/V)^2 + T_D^{\ 2}} + \sqrt{(\xi_{DR}/V)^2 + T_D^{\ 2}} \qquad (2)$$

where $\xi_{SD} = \sqrt{(X_D - X_o)^2}$ is the horizontal source-to-diffractor distance, $\xi_{DR} = \sqrt{(X_K - X_D)^2}$ is the horizontal diffractor-to-receiver distance, V is the velocity in the medium and $T_D = Z_D/V$ is the vertical time above the diffractor. The velocity term V defines the shape of the diffraction time curve, whereas the time T_D defines its apex. For various values of V and a fixed value of T_D, Expression (2) defines a family of diffraction curves with different shapes and with a common apex at time $2T_D$. The unknown parameter V is estimated [6], [7] using the wave correlation procedure which consists of finding of optimal parameter V which maximizes the coherency functional. In this study we use a weighted multipath summation that replaces the wave correlation procedure. This technique has been successfully used for the detection of and locating karst cavities and man-made tunnels [6].

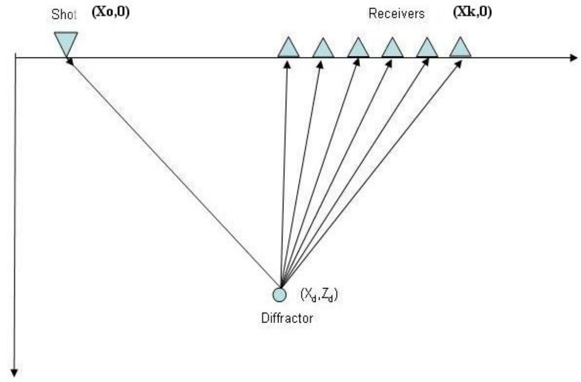

Fig. 2 Schematic description of the ray path from diffractor X_d, Z_d

IV. MULTIPATH SUMMATION

The summation of CSP imaging and diffraction imaging a performed along time curves is defined by Formula (1) and (2), respectively. The summation can be implemented using either of the two approaches. In the first, conventional, approach which was implemented in [3, 6, 7] the target waves are stacked along the time surfaces defined by some optimal parameters such as velocity in case of diffraction imaging or wavefront parameters and velocity in case of CSP imaging. These optimal parameters usually are estimated using optimization problem which consists of finding parameters which maximize some correlation functional. We use an alternative, a more formal recently proposed multipath summation with a proper weighting [4, 5, 8, 9]. The weighted multipath summation allows us to replace the complex optimization problem of estimating the optimal parameters, by summation along all possible trajectories that are created from small variations of those parameters. The weighted multipath summation (WMPS) can be described by the following expressions:

$$I_{WMPS} = \sum_P I_P W(I_P) / \sum_P W(I_P)$$
$$I_P = \sum_P U_{SR}(T_{SR}(P)) \qquad (3)$$

U_{sr} is the amplitude of receiver R and shot S, $W(I_p) = exp(\lambda I_P)$ is an optimal weighting function, λ is an undimensional large number. I_p is the image obtained for a fixed radius of curvature, velocity in case of CSP imaging and fixed velocity value in case of diffraction imaging using Expressions (1) and (2), respectively. The Summation (3) with the proper weight $W(I_p)$ is performed for all possible parameter values within a specified range. The imaging defined by I_p means that, for every point to be imaged, seismic amplitudes are stacked together along all possible time curves defined by Expression (1) or (2). The constructive and destructive interference of the amplitudes contributed by each time curve produces an image close to that obtained by stacking with the "correct" parameter [9].

V. REAL EXAMPLE

Mineral Beach (also called 'Shalem-2') study site is located at Dead Sea shoreline. The area, covering ~1 km^2, is located at the western coast of the central part of the northern Dead Sea basin (Fig. 3). Around Mineral Beach, sinkholes develop in both mudflat (south) and alluvial fan (north) areas along line. To specify the structural geological conditions of the site, a 345m multi channel reflection survey have been acquired. Field parameters of this survey included 71 shot points with 5m interval and 48 receivers for each shot with 2.5m interval between the receivers. As a source, it was used an accelerated weightdrop (‘DigiPulse’). The data was recorded using 0.5msec sample rate and 0.5 sec record length. Typical common shot gathers seen on Fig. 4. The time sections, obtained using conventional CMP (Fig. 5) and CSP methods (Fig. 6), reveal a complex structure at subsurface that can be interpreted as two blocks separated by a normal fault at ~ sp 30. Both sections were processed using the same flow including bandpass filter, gain and static correction. The CMP stacked section include 269 traces with 1.25m interval and can be divided to three zones, till sp 30, sp 30-45 and 45 to the end (sp71). The first zone includes a clear coherent reflector at time 125-155msec with a dominant frequency of 40Hz. On the second zone data quality is poor and the reflector disappears and can be seen again at the third zone till sp 65. The CSP section includes 71 traces with 5m interval. In general this section is similar to the CMP stacked section but it is different in details. A reflector is clearly seen and unlike in the CMP stacked section this reflector is continuous along all the line (sp-1-65). The dominant reflector has a similar character but with lower frequency contain. The main event appears on the conventional CMP stacked section at time ~140ms the same event appears on CSP section at time ~110ms. One of the possible explanations is that in case of CSP stacking the NMO time correction is stretch free and therefore it allows imaging the first arrivals of the event. In case of CMP stack the NMO time correction is not stretch free and the stacking along NMO curve destroy the first arrivals of the event and only the later phase of the event appears on the CMP stacked section.

In addition, a diffraction imaging was applied in order to detect the fault. The strong anomalies on the diffraction image located between shots 22-30 (Fig. 7) are consistent with the discontinuities of the reflector on both the CSP and the CMP time sections.

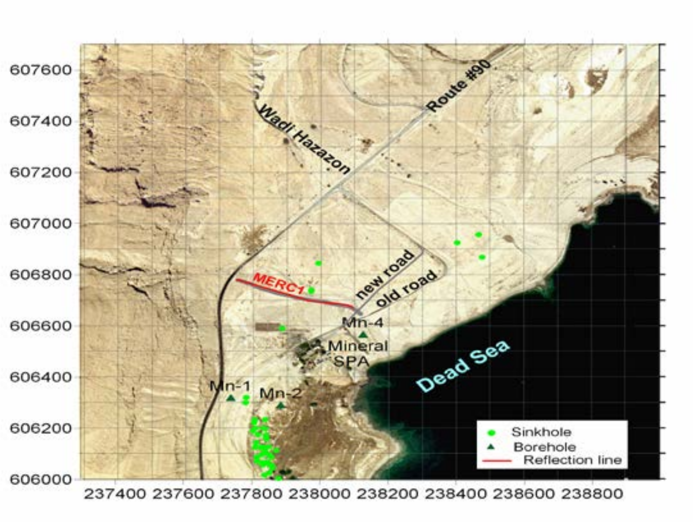

Fig. 3 Mineral Beach (Shalem-2) sinkhole development area with location of the MERC1 seismic reflection line

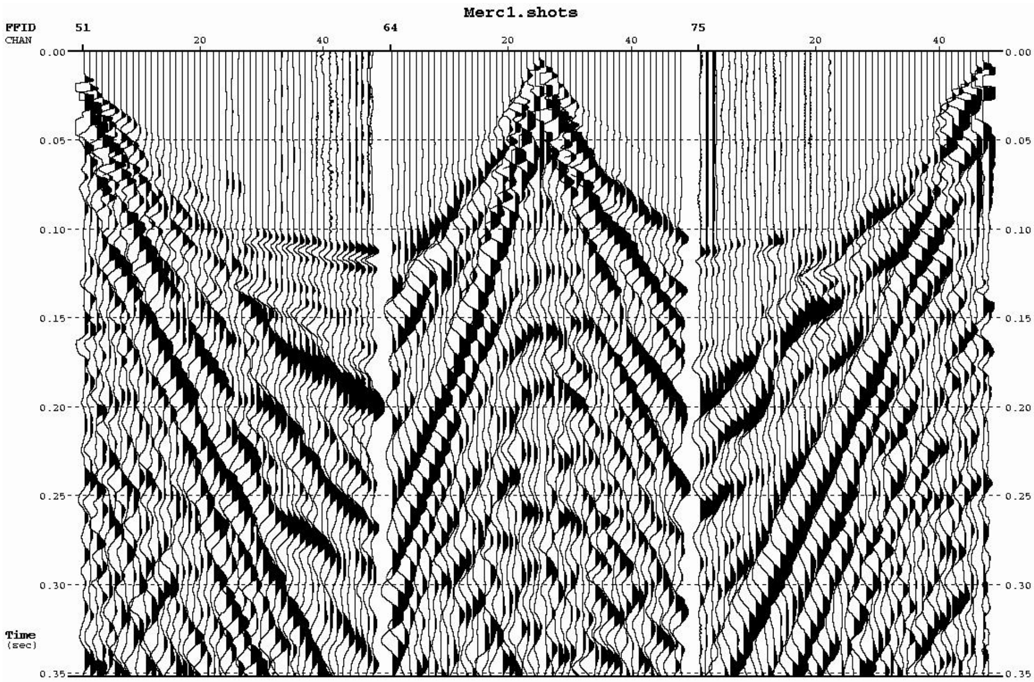

Fig. 4 Example of three common shot gathers

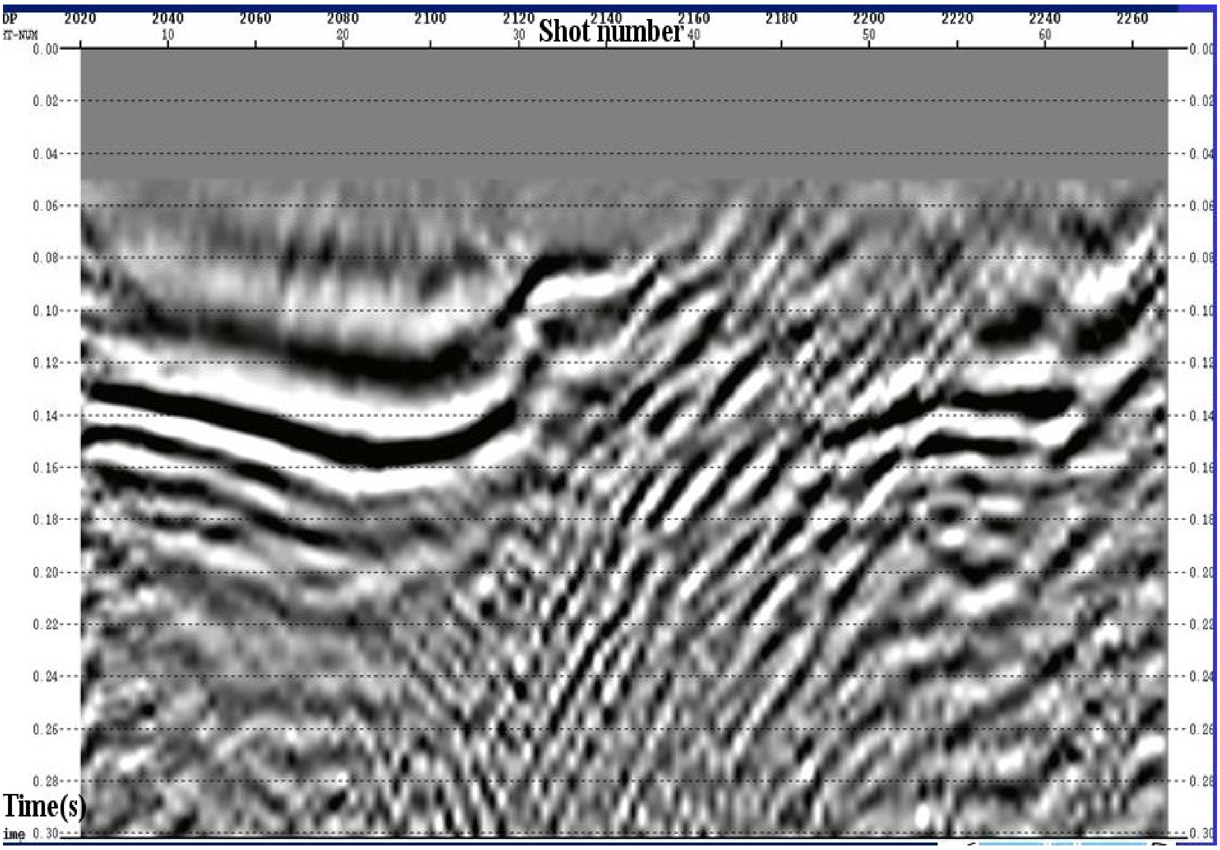

Fig. 5 CMP stacked section obtained using conventional processing

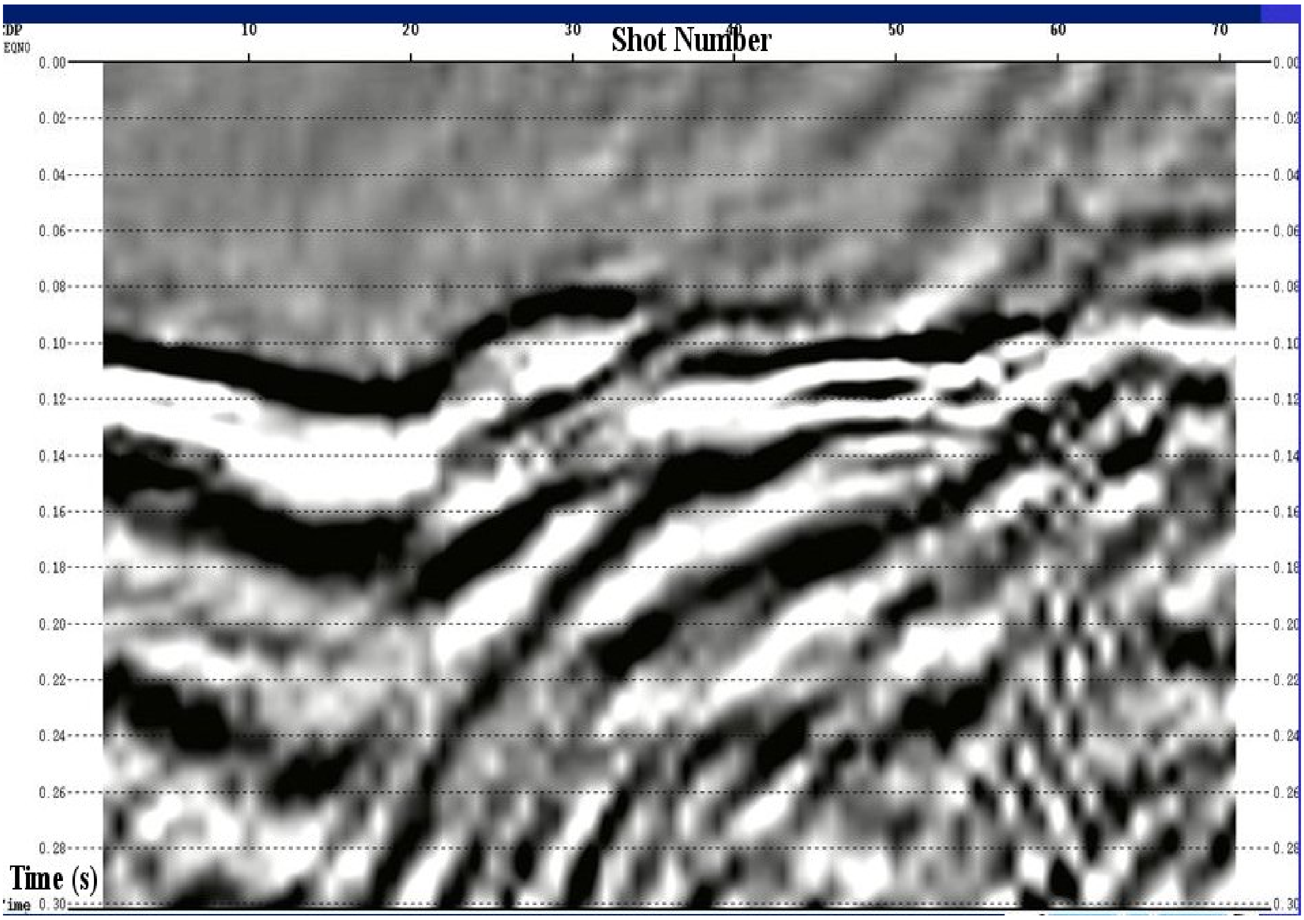

Fig. 6 CSP time section obtained using the weighted multipath summation

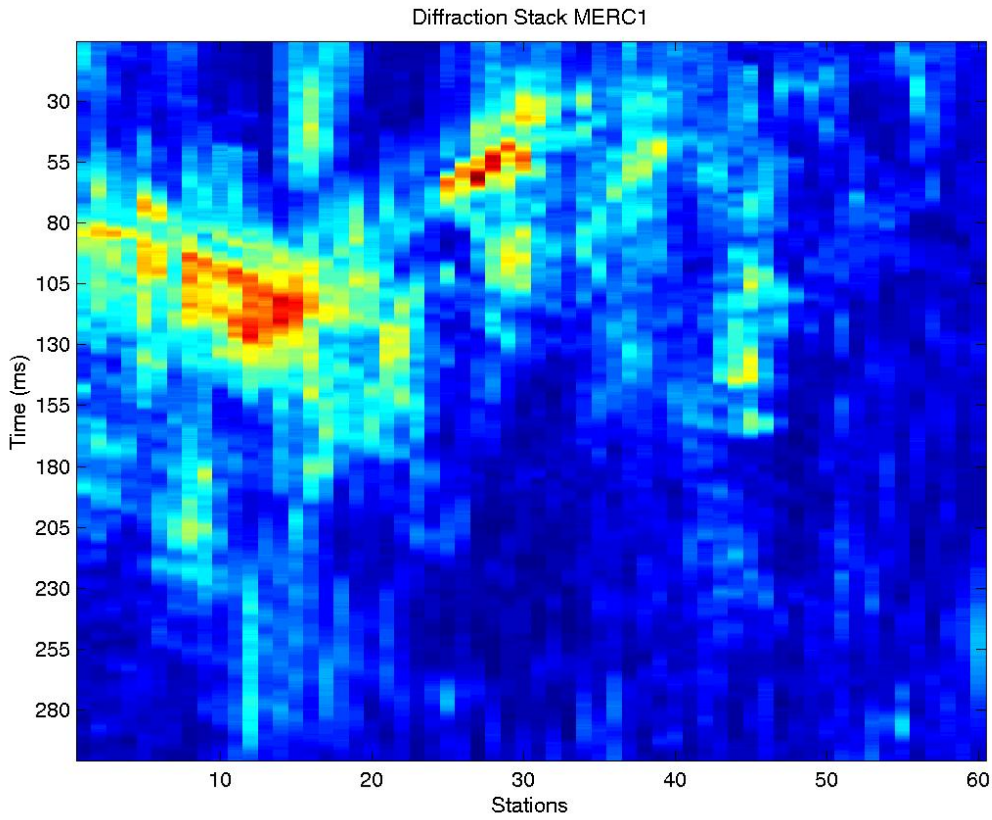

Fig. 7 Diffraction image obtained by diffraction method using weighted multipath summation

VI. CONCLUSIONS

We have presented a new approach for imaging shallow subsurface. The proposed approach includes recently developed imaging techniques namely CSP stacking, diffraction imaging and multipath summation. The resulting time section, obtained using CSP free stretch stacking, is superior to the time section that obtained by the CMP method. The diffraction image produces a clear image of subsurface heterogeneities such as faults, sinkholes, cavities, caves, tunnels or voids. This approach does not require any information about the subsurface, since the multipath summation is performed for all possible parameters values within a wide specified range.

ACKNOWLEDGMENT

This study has been performed within the framework of MERC Project M27-050, fund sponsored by the USAID. Thanks to the support of the Israel Ministry of Infrastructure. The authors are also grateful to the Geophysical Institute of Israel for permission to publish this paper.

REFERENCES

[1] J. C. R Cruz, P. Hubral, M. Tygel, J. Schleicher, and G. Hocht, "The common reflecting element (CRE) method revisited", Geophysics, 65 (3), pp979-993, 2000.

[2] B. Gelchinsky, "Common reflecting element (CRE) method", *Exploration Geophysics*, 19, pp71-75, 1988.

[3] S. Keydar, B. Gelchinsky and A. Berkovitch, "Common shot-point stacking and imaging method", *Journal of Seismic Exploration* 5, 261-274, 1996.

[4] S. Keydar, "Homeomorphic imaging using path integrals", in *Expanded Abstract, 66th EAGE Conference & Exhibition, Paris*, P078, 2004.

[5] S. Keydar and V. Shtivelman, "Imaging zero-offset sections using multipath summation", *First Break*, 23 (September issue), pp21-24, 2005.

[6] S. Keydar, D. Pelman and M. Ezersky, "*Application of seismic diffraction imaging for detecting near-surface inhomogeneities in the Dead Sea area*", Journal of Applied Geophysics, 71, (2-3), pp47-52, 2010.

[7] E. Landa and S. Keydar, "Seismic monitoring of diffraction images for detection of local heterogeneties in the shallow subsurface", *Geophysics*, 63, 3, pp-423-471, 1998.

[8] E. Landa, S. Fomel and T. J. Moser, "Path-integral seismic imaging" *Geophysical Prospecting*, 54, pp491-50, 2006.

[9] V. Shtivelman, and S. Keydar, "Imaging shallow subsurface inhomogeneities 3D multipath diffraction summation", *First Break*, 23 (January issue), pp39-42, 2005.

[10] V. Shtivelaman, S. Keydar and M. Mikenberg, "Imaging near surface heterogeneties using weighted multipath summation", *Near Surface Geophysics*, Vol. 7, pp171-177, 2009.