Research Article

Simulation of VSP data based on DSI data and estimation of shear wave velocity and elastic Moduli for a well case study

Abstract

The purpose of this article was to generate and compare seismic modeling results with real vertical seismic profiling data (VSP data) based on Dipole Shear Imager (DSI) data in the reservoir zone (Kangan and upper Dalan Formations) of a well in South Pars gas field. Estimation of shear wave velocity (V_s) and density for layers above the reservoir zone, for which; DSI data did not exist, was also done by the applied modeling method to estimate elastic parameters of the layers. In this method, modeling for X-component of the VSP survey was run by utilizing the DSI data set of reservoir zone and the VSP survey report of the studied well with high precision. Computed results for the proposed modeling method led to achieving highly accurate, close to the reality of VSP model around the studied well. According to compression wave velocity (V_p) attained from VSP survey reports of the well and V_p/V_s ratio obtained from Dipole Shear Imager (DSI), modeling was done. Afterward, shear wave velocity (V_s) for upper layers of reservoir zone estimated with high precision, then density and elastic moduli for the above layers and the reservoir zone were calculated.

Keywords: vsp modeling, dsi data, shear wave velocity (vs) estimation, density log, elastic moduli, kangan, dalan

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Abbreviations: VSP, vertical seismic profiling; DSI, dipole shear imager; V_s, shear wave velocity; V_p, compression wave velocity; NRM, natural resource management

Introduction

Compression and shear wave velocities are the most practical and functional data considered for determination and estimation of oil and gas reservoir characteristics including lithology, fluid characterization, geo-mechanical characterizations, petro-physical parameters, elastic moduli, and hydrocarbon reservoir evaluation. Compression and shear wave velocities can be obtained directly from laboratory measurements (by core analysis on core plugs), seismic surveys such as vertical seismic profiling (VSP), or utilizing Dipole Shear Sonic Imager. Laboratory measurements in which P and S wave velocities can be measured are time-consuming and in need of high expenditure. These velocities can also be determined directly by DSI tool from sides of a wellbore precisely; however, as DSI log is a very expensive log, it cannot be utilized for the whole length of a well or sometimes it is not possible to run in all wells of a field due to economic restrictions, thus this log is used only in zone of interest (reservoir zone) for determining reservoir characterizations and evaluations. Vertical seismic profiling survey (VSP) is of the most accurate seismic methods in petroleum explorations.[1,2] VSP data usually provides a higher resolution seismic image than surface seismic data.[3]

Compression wave velocity (V_p) can be obtained directly from seismic survey data,[4] but shear wave velocity (V_s) determination in reservoir zone, due to high sensitivity of shear waves to the changes

of rocks and reservoir saturation, is difficult.[1,5] Because of that, the discernment of P and S wave arrivals and their reflections on the seismic profiles are impossible without seismic modeling and simulation. Compression and shear wave velocities coupled with density and petro-physical parameters are always declared as the most essential and considered data for reservoir evaluations and characterizations. Although in recent years numerous mathematical and numerical simulations in the field of vertical seismic profiling (VSP) and sonic data have been proposed and run, but VSP modeling based on DSI data has never been done and utilized for more resolution of VSP model and simulate the arrival times of compression and shear waves and their reflections. In this study, by utilizing VSP data (raw data) coupled with DSI data, a VSP modeling method applied successfully to generalize the reservoir seismic model and then extended to the whole vertical seismic profile achieved from well reports. Besides, shear wave velocity (V_S) and density values for layers above the reservoir zone (Kangan and upper Dalan Formations) for which DSI log did not exist, are estimated with high accuracy based on Ghassem-Alaskari et al.[5] Finally, the physical moduli for all formations above the reservoir zone are estimated and discussed.

Methodology

In this research article, the raw VSP data for this case study were available and the inline vertical seismic profile (x-component) is exploited in (Figure 1). Also, sonic wave velocities are obtained from DSI log data in the reservoir formations (Kangan and upper Dalan). In this modeling method, the best match of the model to reality governed by all the parameters under which the seismic survey (VSP) had been done (mentioned in the well reports), including offset, seismic

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bin underwater, geophone intervals, polarizations of seismic waves diffused from seismic spring and reservoir fractures[6] are considered and applied.

As it is shown in Figure 1, P-wave arrivals which are received directly from seismic spring by located geophones inside the well are effortlessly recognizable and are marked by a red line. However, since shear waves have less frequency than compression waves, recognition of shear waves and their changing trend on the seismic record is relatively difficult. Besides, since the shear wave is by far more sensitive than compression wave to reservoir fluid, locating the shear wave arrivals and their reflections without relative seismic modeling is impossible. In the current study, in order to make a model of compression and shear waves on the vertical seismic profile in reservoir zone, VP, VS, and VP/VS obtained from existed DSI log from reservoir zone of the well, had been exploited to determine the VS for the layers above the reservoir zone, for which DSI log was not existed, with high accuracy.

Finally, using the estimated shear wave velocity (V_s), all elastic moduli for the layers above the reservoir zone can be calculated. In this article, NRM and VSP seismic modeling utilizing x-component vertical seismic profile (Figure 1) based on DSI log data, with two different seismic methods of Ghassem-Alaskari[1,2] was done and the results were compared with the real seismic data. Modeling for the studied well , which from the surface to the end of the reservoir zone is consist of 16 layers (water, Fars, Asmari and Jahrom, Ahmadi, Maudud, Kazhdomi, Dariyan, Gadvan, Fahliyan, Hith, Surmeh, Neyriz, Dashtak, Aghar Shale, Kangan, and Dalan Formations respectively), was accomplished with two models of 16-layers and 19-layers.
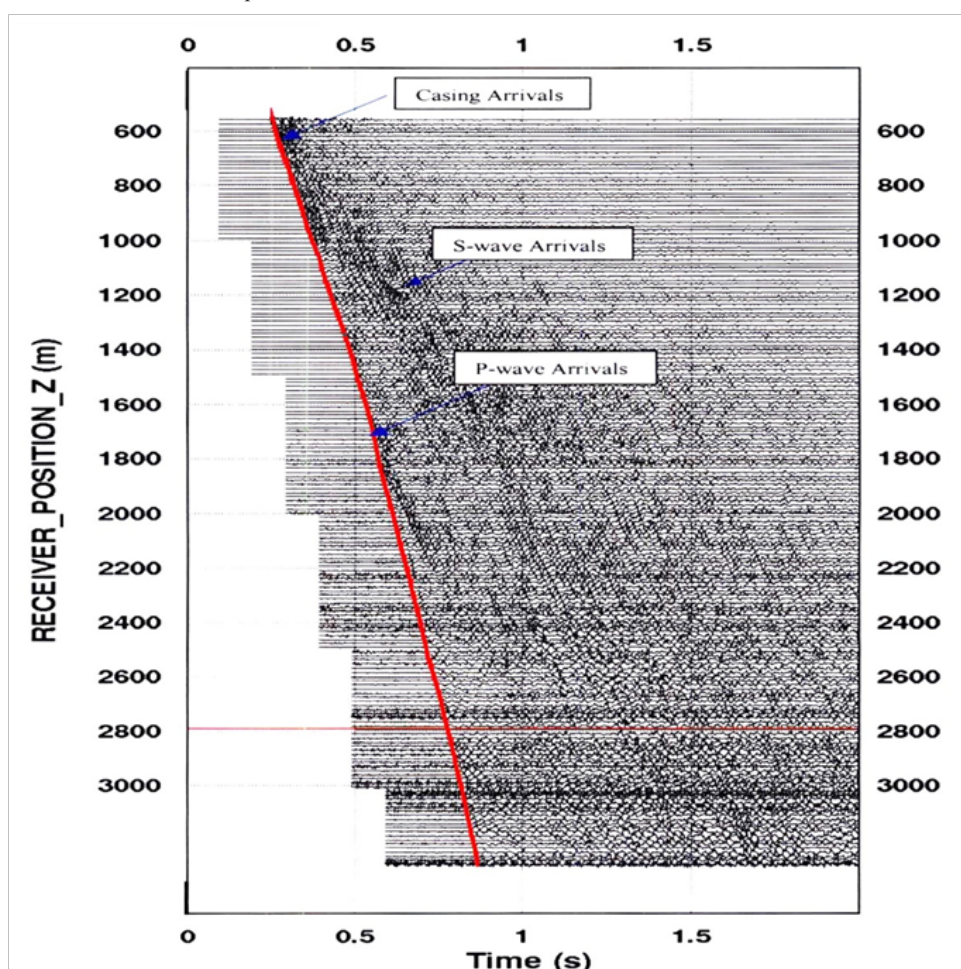

Figure 1 Vertical seismic profile (X-component) of a well in south pars field.

In 16-layers model, the measured VP of the layers achieved from the VSP survey reports, is considered in the modeling calculations (Table 1), and the average V_p/V_s ratio obtained from DSI log (Table 2) is considered for the amount of V_p/V_s ratio of the reservoir zone (Kangan and upper Dalan Formations) calculations.

In 19-layers model, all the layers above the reservoir formations (Kangan and Dalan) are assumed as one layer by the geometrical averaging technique and the average P-wave velocity of these layers calculated from (Table 1) and applied into the modeling process. For Kangan and Dalan Formations, which based on lithology and according to DSI reports, are divided to 18 sub-layers, the amount of V_p, V_s and V_p/V_s ratio obtained from DSI log of these sub-layers (Table 3) applied in the related modeling calculations. Thereafter, the achieved 16-layers and 19-layers models were utilized to accomplish seismic modeling and simulation for the whole length of the well by NRM and VSP programs, which will be mentioned in the next section.

Table 1 measured compression wave velocity by VSP survey in a well of south pars field.

Formation name	Measured depth (m)	Interval velocity (P) (Km/s)
RKB	28	1524
Water	92	1524
Fars	580	2384
Asmari/ Jahrom	1085	3307
Ahmadi	1174	4384
Maudud	1203	3625
Kazhdomi	1262	3734
Dariyan	1302	2837
Gadvan	1411	3825
Fahliyan	1488	4140
Hith	1654	4160
Surmeh	1718	5872
Neyriz	2357	4787
Dashtak	2384	4500
Aghar shale	2780	4877
Kangan	2805	4307
Dalan	2993	5194
TD	3284	5588

Table 2 Average V_P/V_S ratio achieved from DSI log in Kangan and Dalan Formations in a well of south pars field.

Formation name	V_P/V_s
Kangan	1.8
Dalan	1.79

Table 3 Average $V_P V_s$ and V_P/V_s ratio obtained from DSI log for 18 sub-layers of Kangan and Dalan Formations in a well of south pars field.

Kangan and Dalan sub-layers	Depth (m)	P-wave velocity (Km/s)	S-wave velocity (Km/s)	V_P/V_s
K1Z1a	2837	5.523649	3.089961	1.794301
K1Z1b	2871.5	5.340584	2.959426	1.803883
K1Z2a	2889	5.47332	3.029984	1.803874
K1Z2b	2911.5	6.013158	3.356498	1.791313
K1Z3	2934.1	6.204202	3.377801	1.837512
K2Z1a	2949.5	4.960449	2.832009	1.752084
K2Z1b	2965.5	5.050296	2.80328	1.801143
K2Z2	2985	5.973231	3.195274	1.869495
K3Z1a	2992	5.182257	2.950808	1.754172
K3Z1b	3006.5	6.119642	3.420445	1.789703
K3Z2	3030	6.315257	3.482058	1.814741
K3Z3	3049	6.36988	3.532898	1.803739
K3Z4a	3090	6.194875	3.468932	1.786017
K3Z4b	3104.2	5.936195	3.34482	1.773923
K4Z1	3115	5.308415	3.044804	1.742577
K4Z2	3132	4.395417	2.504526	1.755293
K4Z3	3170	4.953431	2.760627	1.792916
K4Z4	3178.8	4.79621	2.732737	1.754918
K4Z5	3216	6.072566	3.397375	1.786671

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i. Modeling and simulation

Two sets of NRM and VSP models are applied and compared with the VSP Data.

16-Layers model

(Figure 2) demonstrates the achieved 16-layers NRM model.
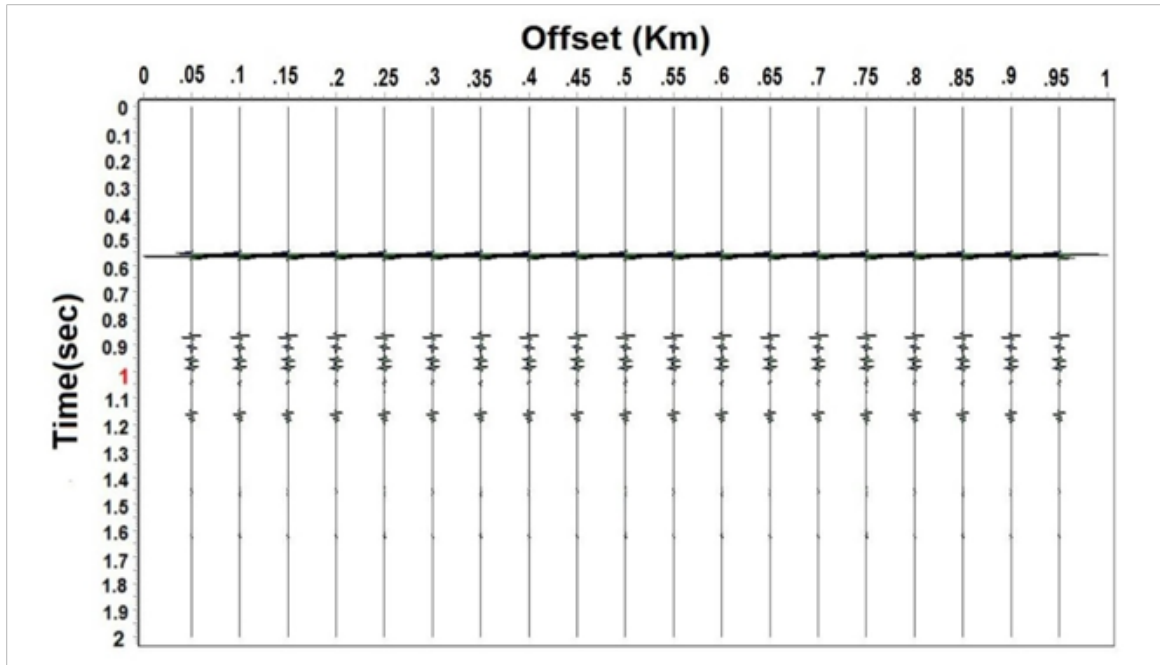
ii. NRM modeling

Figure 2 achieved 16-layers model by NRM modeler around the studied well.

19-Layers model

(Figure 3) demonstrates the achieved 19 -layers NRM model.

In (Figure 4) the NRM seismic model achieved from both 16-layers and 19-layers models around the studied well in comparison with the raw seismic profile (time(s)-offset (km)), which is obtained from well reports.
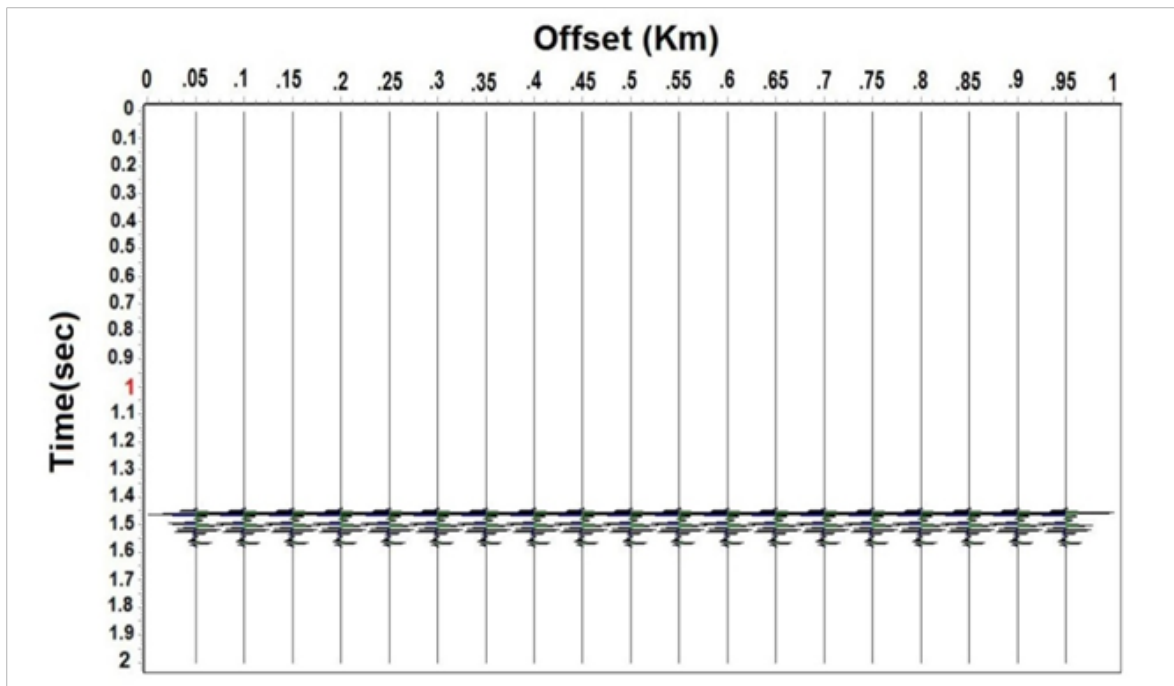

Figure 3 achieved 19-layers model by NRM modeler around the studied well.

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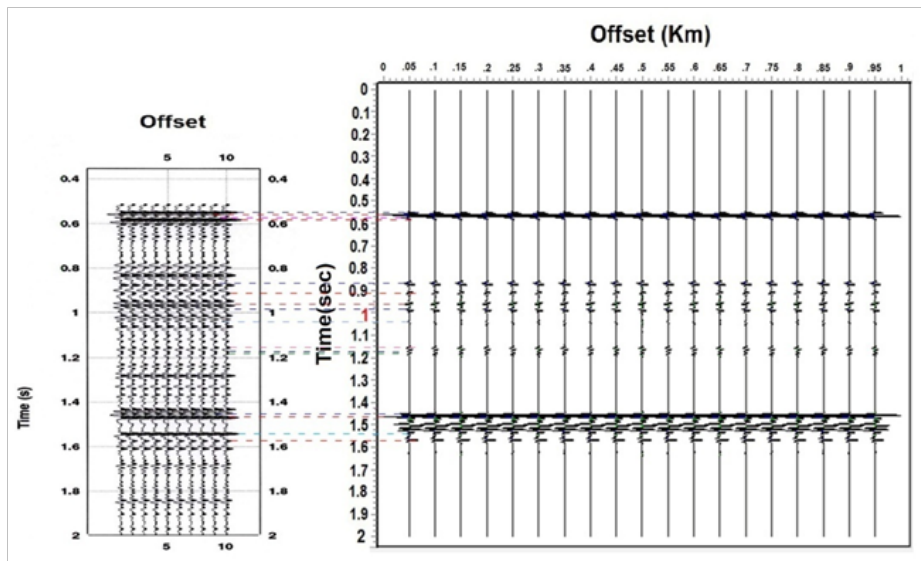
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Figure 4 achieved seismic model by NRM modeler around the studied well (right) in comparison with the raw seismic profile obtained from well reports (left).

iii. VSP modeling

To perform P and S waves VSP modeling, the x-component of vertical seismic profile obtained from VSP survey reports (Figure 1), and the VP, Vs and V_p/V_s ratio achieved from DSI log of reservoir zone of the studied well were used to locate P and S waves (arrivals and their reflections) on the studied vertical seismic profile (Figure 1) with high accuracy. Afterward, by the use of the velocities (V_p, V_s and V_p/V_s ratio) which were determined by DSI tool precisely, the S-wave velocity of the layers above the reservoir zone, where the DSI log was not run, can be determined. The modeling was accomplished and compared with the real seismic data based on 16-layers and 19-layers methods mentioned above.

iv. 16-Layers VSP model

This model applied based on the 16 layers method from the surface to the bottom of the reservoir zone. Figure 5 illustrates the applied VSP model for P-wave (green-colored) and S-wave (yellow-colored) in comparison with the vertical seismic profile obtained from seismic well reports (Figure 1).
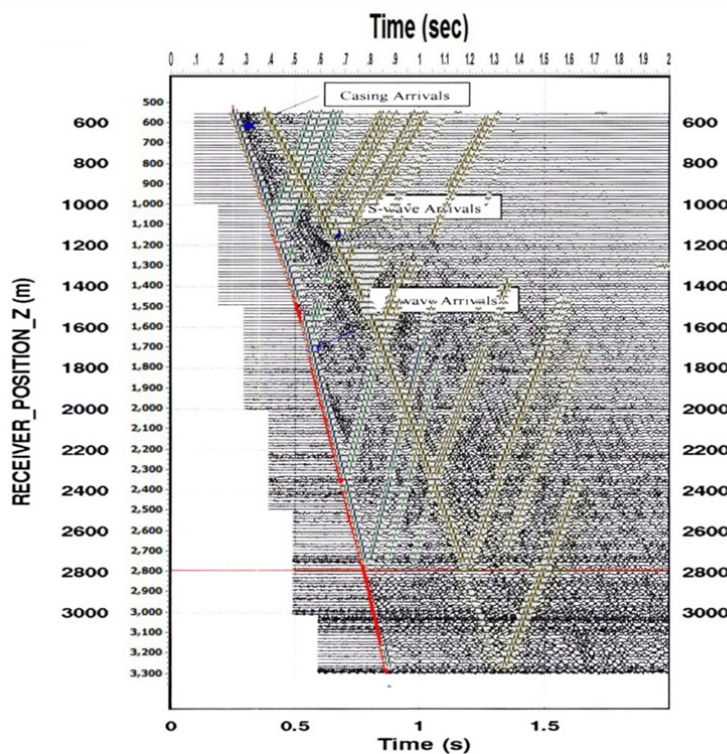

Figure 5 achieved VSP model based on 16-layers method for arrivals and reflections of P-wave (green-colored) and S-wave (yellow-colored) in comparison with the vertical seismic profile (Figure-1).

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v. 19-Layers VSP model

Figure 6 illustrates the applied VSP model for P-wave (green-colored) and S-wave (yellow-colored) based on the 19-layers method in comparison with the vertical seismic profile obtained from seismic well reports (Figure 1). Finally, in (Figure 7) the final results of the VSP model based on DSI data (achieved by DSI tool) for P-wave (green-colored) and S-wave (yellow-colored) in comparison with vertical seismic profile obtained from seismic well reports (Figure 1) are matched.
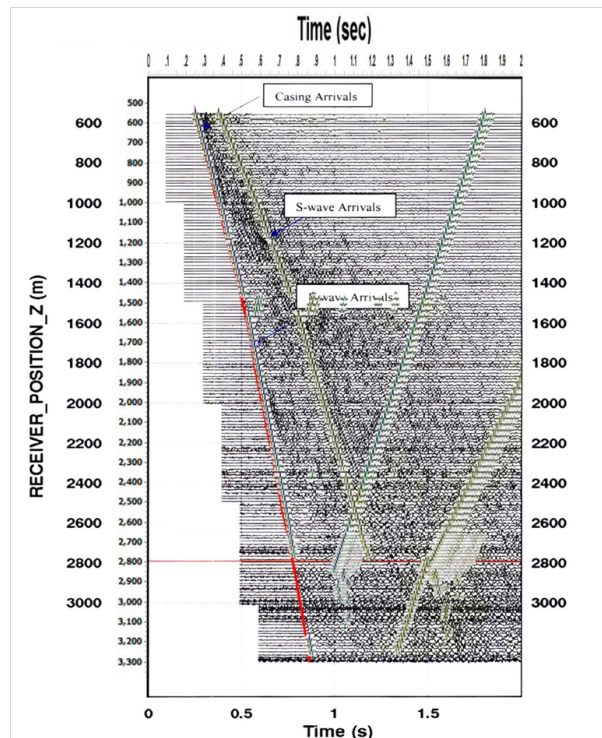

Figure 6 achieved VSP model based on 19-layers method for arrivals and reflections of P-wave (green-colored) and S-wave (yellow-colored) in comparison with the vertical seismic profile (Figure 1).
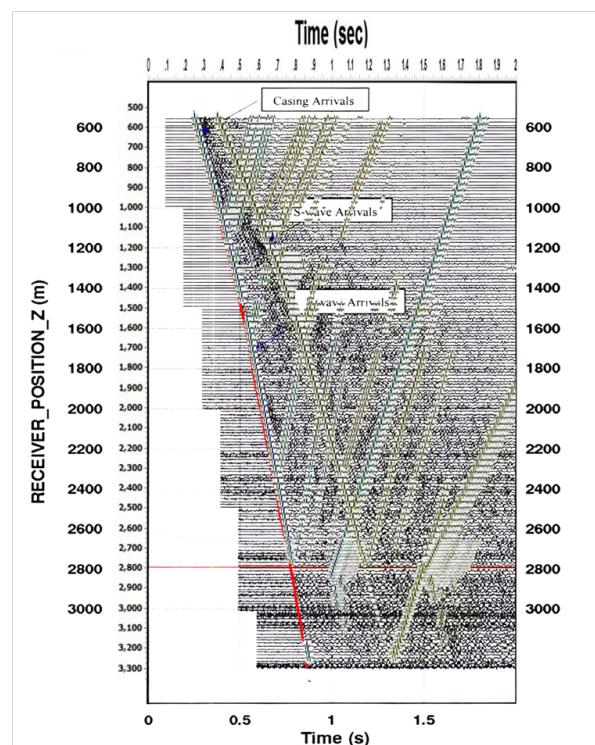

Figure 7 Final VSP model based on DSI data for arrivals and reflections of P-wave (green-colored) and S-wave (yellow-colored) in comparison with the vertical seismic profile (Figure 1).

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Discussion

As it is observable from the final match in the Figure 7, the simulated down-going P-wave has complete conformity with P-wave arrivals which are marked by a red line in the (Figure 1). Besides, the reflected P and S waves from each layer, which were not recognizable before on the vertical seismic profile data, especially inside the reservoir zone of Kangan and Dalan Formations, became distinguishable by the accomplished modeling method accurately. In the current study, the proposed VSP data, on the vertical seismic profile diagram (Figure1) obtained from well reports utilizing DSI data of the reservoir zone of the well, accomplished with high accuracy by modeling method. Regarding that, the VSP modeling accomplished by using the amounts of V_p, V_S, and V_p/V_S which were achieved by Dipole Shear Imager (DSI) tool precisely and generalized to the VSP data (VP) obtained from VSP survey reports, the velocity of shear wave (VS) is calculated for the upper layers of the reservoir zone, where the DSI data did not exist. The final shear wave velocities (VS) for the formations above the reservoir zone are shown in Table 4.

Table 4 determined shear wave velocities (V_s) for the layers above the reservoir zone (Kangan and Dalan Formations) in the studied well in south pars field.

Formation name	Interval velocity (s) (m/s)
Water	-----
Fars	1589
Asmari/ Jahrom	2204
Ahmadi	2922
Maudud	2416
Kazhdomi	2489
Dariyan	1891
Gadvan	2550
Fahliyan	2760
Hith	2773
Surmeh	3914
Neyriz	3191
Dashtak	3000
Aghar shale	3251

In order to calculate elastic moduli, in addition to accessibility of the amounts of V_p and V_S, the amount of density (ρ) of the layers is needed.[8] For the layers above the reservoir zone (Kangan and Dalan Formations), the compression wave velocity (V_p) was measured by VSP survey and obtained from related well reports (Table 1); also, shear wave velocity (V_S) for these layers determined by proposed VSP modeling method in this study. However, since the density log of these layers did not exist, the amount of density (ρ) is calculated by the Gardner equation[7] modified based on DSI data[5] and is shown in Table 5.

$$\rho = 1.7 + 0.23 V_p \tag{1}$$

Where, the unit of V_p is km/s and ρ is g/cc.

In the next step, elastic moduli based on the amounts of three parameters involving density (ρ), V_p (Table 1) and V_S (Table 4) estimated for the layers above the reservoir zone and are shown in Table 6.

The average amounts of elastic moduli and Poisson ratio calculated from DSI data of Kangan and Dalan Formations, which are subdivided to K1, K2, K3, and K4 are based on lithology and are shown in Table 7.

Table 5 Calculated density (ρ) for the layers above the Kangan and Dalan Formations (reservoir zone).

Formation name	ρ (g/cc)
Fars	2.24832
Asmari/ Jahrom	2.46061
Ahmadi	2.70832
Maudud	2.53375
Kazhdomi	2.55882
Dariyan	2.35251
Gadvan	2.57975
Fahliyan	2.6522
Hith	2.6568
Surmeh	3.05056
Neyriz	2.80101
Dashtak	2.735
Aghar shale	2.82171

Table 6 Estimated young modulus (E), Balk modulus (K), Lame parameter (λ), Shear modulus (G) for formations above the reservoir zone in south pars field.

Formation name	G (Gpa)	λ (Gpa)	K (Gpa)	E (Gpa)
Fars	5.67683	1.424567	5.209121	12.49245
Asmari/ Jahrom	11.9527	3.004447	10.97291	26.30634
Ahmadi	23.12384	5.80471	21.22062	50.88768
Maudud	14.78964	3.715777	13.57554	32.54895
Kazhdomi	15.8522	3.972604	14.54074	34.88095
Dariyan	8.412296	2.109747	7.717945	18.51132
Gadvan	16.77482	4.193706	15.37692	36.90461
Fahliyan	20.2034	5.05085	18.51978	44.44748
Hith	20.42954	5.118437	18.73813	44.95206
Surmeh	46.73274	11.71901	42.87416	102.8349
Neyriz	28.52123	7.143716	26.15787	62.75529
Dashtak	24.615	6.15375	22.56375	54.153
Aghar shale	29.82266	7.469425	27.3512	65.61865

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Table 7 Young modulus (E), Balk modulus (K), Lame parameter (λ), Shear modulus (G) and Poisson ratio calculated based on DSI data for Kangan and Dalan Formations in south pars field.

Sub-layers	Depth (m)	Shear modulus (Gpa)	Lame parameter (Gpa)	Bulk modulus (Gpa)	Young modulus (Gpa)	Poisson ratio
K1	2837-2949	27.80046	37.20591	53.8171	71.0085	0.276222
K2	2949-2992	22.69751	29.41369	44.54536	58.07607	0.277029
K3	2992-3115	31.6779	38.18381	59.30241	80.57345	0.270626
K4	3115-3279	21.57296	24.52274	38.90471	54.54459	0.262851

Conclusion

According to the proposed VSP modeling method and DSI data results are as follows:

i. Since the shear wave appears in the reservoir zone with a lower frequency than the compression wave, due to the existence of fluid, distinguishing shear waves from other waves and noises on the seismic profile is impossible without modeling and simulation.

ii. This study illustrated that modeling of P and S waves can be done for the whole length of any well, by the availability of DSI data (sonic V_S and V_P) of the reservoir zone and the vertical seismic profile with high accuracy. The phase rotations of compression and shear waves on the seismic profile can also be distinguished.

iii. Computed results for the proposed modeling method led to achieving highly accurate, close to reality earth model around the well.

iv. Using compression wave velocity (V_P) obtained from VSP survey reports of the well and V_p/V_s ratio obtained from Dipole Shear Imager (DSI), the simulation was done correctly.

v. By estimating shear wave velocity (V_s) and density for upper layers of reservoir zone with high precision, elastic moduli for the above reservoir layers and the reservoir zone were calculated.

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Conflicts of interest

The author declares that there are no conflicts of interest.

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