Introduction

The study area lies in the Krishna Godavari basin in the east coast of India. The area is shown in Fig. 1. It experiences very high sedimentation rates from the Krishna and Godavari Rivers. The huge volumes of sediment are accommodated by a major growth fault with subsidiary splay growth faults and an extensional area with antithetic normal faulting to the South of the growth fault. Flowing water with sediments and some gas in the wells were encountered in the area at shallow depths. Highly promising Miocene roll structure exist beneath the shallow hazard zones.

The wells A & B as shown in the Fig. 1 encountered high pressures at shallow depths. The other wells available (C, D & E) are far off and are in a different geological setup.

The standard procedure for carrying out pre drill Pore Pressure analysis consist of

- Carrying out post drill analysis of nearby wells within similar geologic setup and using the results in the target location after applying appropriate corrections.
- Using the seismic velocities at the target location. However, a scalar multiplier is required to scale down the seismic interval velocities to match the velocities obtained from sonic log.

Firstly, the study area has only few wells drilled
nearby. The logs in these wells are of limited extent and are missing in the shallow level which is zone of interest for the present study. Also the geologic setup of the wells is different from the area of interest. Secondly, the seismic velocities obtained from the processing center often lack the vertical resolution required for carrying out pore pressure studies. Also the derivation of an appropriate scalar for scaling down the interval velocities is subjective considering the fact that the extent of the recorded logs are limited and the drilled wells are not in a similar geological setup. Therefore carrying out only pore pressure prediction studies using the standard procedures may not be a logical solution for achieving the objective. This necessitated looking for an alternative/innovative method for achieving the objective.

**Alternative Plan/Methodology**

The alternative plan to the standard procedure of pore pressure prediction adopted for shallow hazard study is as follows:

- To carry out fresh velocity analysis at CEC-OG, using pre-stack gather with best possible resolution and then to carry out pore pressure prediction from seismic velocities freshly picked at these selected locations.
- To carry out post stack inversion: Calibrating inversion results with anomalous zone encountered at well locations and demarcating the areal extent of the hazardous anomaly. Then looking for similar anomalies spread over in other places in the area of interest.

**1D-Pore Pressure Prediction**

1D pore pressure analysis was carried out at 35 locations in and around the area of interest.

For the same fresh velocity analysis was carried out at these 35 locations at CEC-OG.

**Fresh Velocity Analysis**

The seismic gathers (CMP gathers) were loaded in OpenDTect software for carrying out the fresh velocity analysis. The gathers were Pre Stack Time Migrated (PSTM) gathers without NMO correction obtained from the basin. As it is clear from figure, picking of velocities was difficult as the semblance could not provide a viable velocity trend. Therefore, the CMP gathers were conditioned with the limited available processing module in the software. Super gathers were formed to improve the signal to noise ratio by attenuating the random noise. Automatic Gain Control (AGC) was applied that could enhance the signal at deeper level, thereby providing a reasonably good semblance for velocity picking. Moreover, only those portion of the data were used which had good Signal to Noise ratio for the purpose of velocity analysis. This was achieved by designing suitable inner and outer mutes. A representative gather along with
velocity semblance/trend after pre-processing are shown in Fig. 2.

The velocity analysis parameters were also tuned to enhance the quality of the semblance/velocity analysis. The confidence level of picking velocity even up to a deeper depth (Two Way Time) was quite good. Representative gathers with picked velocity before and after NMO correction is shown in Fig. 3.

An attempt was also made to derive the scalar multiplier for interval velocity at target locations using the data of wells C and E. Interval velocity was derived at these well locations through fresh velocity analysis. A comparison was made between the actual sonic log and the sonic log derived from the interval velocities at both the well locations. The comparison at C suggest that no scalar multiplier is required whereas at E, a scalar of .88 has to be applied to scale down the interval velocities to match the trend of the sonic. No conclusive scalar could be drawn out from the comparison at both the wells. It may be due to the limited extent of recorded sonic log.
Therefore, it was decided to carry out pore pressure prediction at target locations without a scalar multiplier which can be studied in a relative term.

Pore pressure analysis on the basis of new velocity was carried out using the following workflow:

- The picked/fresh RMS velocity at well location was converted to interval velocity in depth.
- Density log was calculated using the interval velocity.
- Overburden Gradient (OBG) was calculated using density dataset.
- Normal Compaction Trend (NCT) was computed.
- Calculated Pore Pressure Gradient (PPG).
- Fracture Gradient (FG) was calculated.

Using the above workflow pore pressure analysis was carried out for all the 35 locations and also at well locations A & B. A representative 1D pore pressure prediction result is shown in Fig. 4.

In 1D pore pressure velocity gradient changes are observed which may be qualitative indication of high pressure but the pore pressure derived is not conclusive. Therefore the results obtained were not able to satisfactorily explain the zones of shallow hazard.

**Post Stack Inversion**

To carry out model based post stack inversion sufficient well control is required for derivation of low frequency model and also to calibrate inversion result at these locations. Due to the limitations/insufficiency of well data in the area an innovative/alternate approach was adopted of creating pseudo wells using freshly picked velocities for carrying out model based post stack inversion. Model based Post Stack Inversion requires low frequency model using the well logs. The velocity analysis carried out by the authors had sufficient resolution to give this low frequency required for the model. For creating pseudo wells velocity analysis was carried out using OpenDTeect software at 16 locations as shown in map Fig. 5.

As already discussed above the seismic gathers (CMP gathers without NMO correction) were loaded in OpenDTeect software for carrying out the fresh velocity analysis. These gathers were conditioned with the limited available processing module in the software. The confidence level of picking velocity even up to a deeper depth (Two Way Time) was quite good. In model based inversion only the low frequency part is taken from the well logs. As the level of confidence in picking of the velocities is reasonably good, therefore it was thought the velocity trends obtained would suffice the requirement for providing the desired low frequency trend.

The seismic velocities obtained at the 16 locations were then used for creating pseudo wells and logs. The RMS velocities were converted to interval velocity in depth and then to sonic log. Using the Gardner’s transformation the sonic log was converted to density log. These logs were used as an input to post stack inversion.

The following data were used for carrying out post stack inversion:

![Fig. 4: 1D Pore Pressure Prediction at well location A](image1.png)

![Fig. 5: Map showing the pseudo well locations (W1-W14) used for carrying out Post Stack Inversion](image2.png)
Fig. 6: Inline and Xline respectively along the inverted (above) and seismic (below) volume passing through well A. Low impedance zone marked in inverted volume correspond to bright amplitude anomaly in seismic.

Fig. 7: Inline and Xline respectively along the inverted (above) and seismic (below) volume passing through well B. Low impedance zone marked in inverted volume correspond to bright amplitude anomaly in seismic.
Fig. 8: Extension of the low impedance anomaly (high pressure zones) observed at well A and B

Fig. 9: Two Way Time map of the extent of anomaly at well A
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Fig. 10: Two Way Time map of the extent of anomaly at well B

Fig. 11: Extension of Low impedance anomalies in area around well A and B interpreted as high pressure zones
1. Density and sonic logs of limited extent from wells C and E
2. Water bottom and Below Pliocene Unit horizon
3. Q marine stack volume
4. Pseudo logs created using the seismic velocities picked using fresh velocity analysis.

The post stack inversion results were calibrated at the well locations where shallow high pressure was encountered. High pressure zones corresponding to the drilled wells were seen as low impedance zones at the well A and B. Inline and xline passing through the wells A and B pertaining to seismic and inverted volume are shown in Figs. 6 and 7.

As observed from the above figures the shallow hazard zones correspond low impedance in the inverted volume.

This inversion volume was then analyzed in Geo Probe to find the extension of the low impedance anomalies observed at well A and Band also to identify and delineate similar anomalies in the area of interest.

The extension of the low impedance anomaly observed at well A and B is shown in Fig. 8.

The map view of the extent of the anomalies at A and B is shown in Figs. 9 and 10 respectively.

Similar Geo anomalies at different levels were tracked and identified till 1000ms TWT with different permutation and combination and a tentative area of anomalous zone was identified as shown in Fig. 11.

**Analysis of the Results**

**Pore Pressure Study**

In 1D pore pressure velocity gradient changes are observed which may be qualitative indication of high pressure but the pore pressure derived is not conclusive.

**Post Stack Inversion Study**

The post stack inversion volume shows anomalous low impedance zones in the shallow region which are indicative of the high pore pressure zones in the region. The same is validated through the observation at well A & B. The Geo anomalies obtained through tracking the extension of the low impedance anomalies at the wells A and B, and similar anomalies in the nearby areas may indicate the zone of the Shallow hazard/high pore pressure.

The demarcation of probable high pressure zones indicates suitable locations towards the north east of the area.

The study results also indicate solution for side tracking for tapping the zone of interest i.e., Miocene rotated structure.

**Conclusion**

The entire area has lot of drilling complications owing to the presence of shallow hazards. Different agencies have worked on this area but were unable to demarcate the zones of shallow hazards. In an area where well logs were not available, an innovative approach of generating pseudo logs from seismic velocity was adopted. Model based Post Stack Inversion requires low freqeucy model using the well logs. The velocity analysis carried out by the authors had sufficient resolution to give this low frequency required for the model. The inversion results thus obtained are able to demarcate the anomalous (low impedance) zones which may be attributed to high pressure as calibrated at A and B.

The methodology adopted in the study is not a standard workflow. The workflow adopted for carrying out the work has not been attempted by any other agency. This innovative approach adopted for carrying out Post stack seismic Inversion has been able to achieve the objective. Such studies have provided a way to look into the extension of such hazardous zones and tap the reserves beneath.

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