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Laboratory based elastic & mechanical properties estimations and Geomechanical modeling for optimum hydraulic fracturing in Bokaro East CBM wells: A case study

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Abstract

Commercial production of coalbed methane (CBM) requires effective hydro-fracturing and successive de-watering in view of low permeability and depressurization of coal seams. Optimized hydro-fracturing planning needs precise knowledge of stresses and rock elastic properties data. In this view, Tri-axial geomechanical laboratory testing of sandstone, shale and coal from coal seams and underlying/overlying formations were carried out on the conventional cores recovered from wells BK-1A, BK-2B and BK-4C at Geomechanical Rock Testing Facility of ONGC and one dimensional Geomechanical model is prepared to determine in-situ stresses (minimum horizontal stress primarily). Estimated minimum horizontal stress is calibrated and cross validated with fracture closure pressure data acquired during hydraulic fracturing and pre-frack jobs in model wells.

Introduction

Coalbed Methane (CBM), an unconventional source of natural gas is now considered as an alternative source for augmenting India's energy resource. The Gondwana sediments of eastern India, host the bulk of India's coal reserves and all the current CBM producing blocks. The vast majority of the best prospective areas for CBM development are in eastern India, situated in Damodar Koel valley and Son valley (Fig.1). India has the fifth largest proven coal reserves in the world and thus holds significant prospects for exploration and exploitation of CBM. ONGC has focused on exploration strategies in CBM blocks to commence commercial gas production. Bokaro is one of the important coal field for exploitation in Damodar-Koel valley. In this regard, current study is carried out to precise estimation of rock elastic & mechanical properties along with in-situ stresses for optimum hydraulic fracturing modeling.

The Bokaro Coal block (Fig. 2)consists of three disconnected sectors viz Patch-A, Patch-B & Patch-C pertaining to Central patch, Western patch & Eastern patch respectively. Total 50 wells have been drilled in Bokaro consisting of both exploratory and development wells. About 10 corehole wells have been drilled for exclusive core studies. Workable coal seams are present only in Barakar Formation of lower Permian age. In East Bokaro wells, 24-26 major coal seams have been identified with total thickness of 100-150 m. The wells drilled in the West Bokaro, have 12-13 major coal seams with their total thickness about 80-100 m. The gas accumulation in coalbed methane is in adsorbed state on the free surfaces of coal matrix. The cleats are natural fractures in coals and the interconnected cleats serve as the path/conduits for CBM gas and water to flow from the coal seam to the well bore, and they determine the effective permeability of a given CBM play. Many of the drilled wells have been tested with gas break observed in some wells and dewatering stage in few wells. Hydro-fracturing has been carried out for enhancing the flow potential. The production testing in most of the wells is through commingled completion in different coal seams encountered.

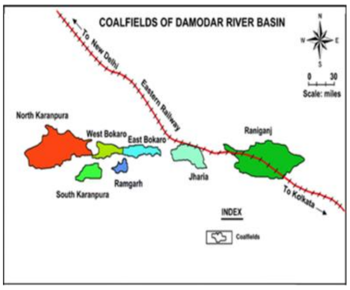


Figure 1 : Damodar valley coalfields.

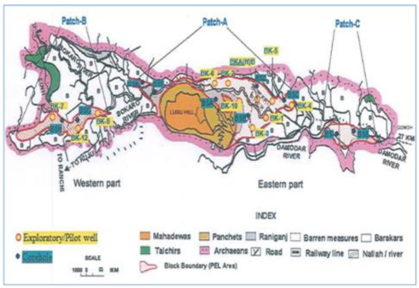


Figure 2 : Location map of East Bokaro CBM Block.

Study Methodology

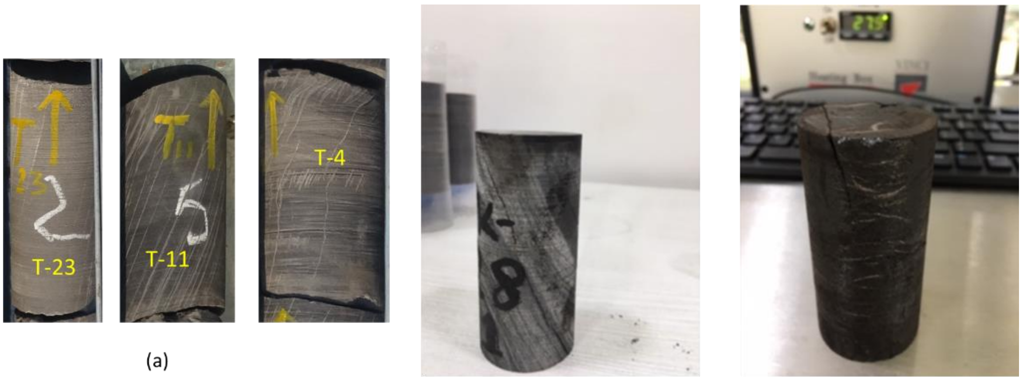
The study is carried out in three steps as follows;

1. Geomechanical Laboratery Studies of Core Samples

To build the geomechanical model rock mechanical properties (unconfined compressive strength, tensile strength, Young modulus, Poisson ratio, friction angle and cohesion) are essential. Dynamic elastic properties can be computed using well logs whereas static elastic properties required for 1-D geomechanical modelling. The static rock properties can be calculated using empirical relations, numerous empirical relations to convert dynamic Young's modulus to static Young's modulus have been published for different rock types. Log-derived dynamic rock properties should whenever possible be calibrated to core-derived static rock properties. To generate core derived static elastic properties, geomechannical core studies were carried out on core samples recovered from wells BK-1A, BK-2B and BK-4C.

Conventional cores recovered from wells are 4” dia and length varies from few inches to feet. Rock mechanical testing facility available at ONGC Vadodara has capability to handle samples of 1” & 1.5” diameter and length twice of diameter of samples i.e. if 1” diameter sample is being used then its length must be at least 2”. Biggest challenge were to make core samples of desired size(diameter and length) from coal cores because of its fragile nature and presence of natural fractures/cleats, samples were breaking(Fig. 3) while making plugs. Desired number of core plugs samples 1.5” diameter were prepared from representative samples of sandstone, shale and coal triaxial geomechanical laboratory testing (Fig. 4).

Figure 3: Coal sample breaking during sample preparation



(a) (b) (C)

Figure 4: (a) Conventional core 4" dia segments, (b) 1.5" dia plug sample of shale (c) 1.5" dia coal sample

Geomechanical laboratory testing on a total 9 core plug samples were carried out at in house Triaxial laboratory of ONGC Vadodara, strain vs stress curve is given in figure-5. Experimental results are tabulated below in table-1.

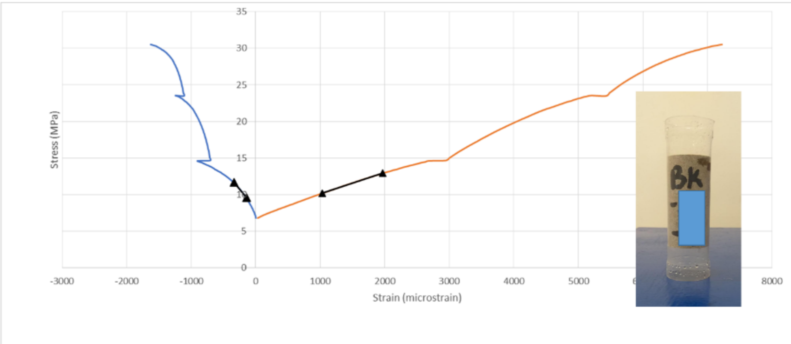


Figure 5: Strain vs stress curve of one core plus sample.

Table-1

Well No	Plug id	Plug Depth	Young Modulus (Gpa)	Poisson Ratio	Cohesion coefficient (Mpa)	Angle of internal friction (degree)	UCS (psi)	Remark
BK-1A	BK-A	X44.1	33.525	0.111	-	-	-	Failed at first confining
	BK-B	X44.06	29.068	0.093	-	-	-	Failed at first confining
	BK-C	X40.681	26.074	0.082	-	-	-	Type-I only done
	BK-D	X40.611	23.96	0.134	-	-	-	Failed at first confining
BK-2B	BK-E	Y59.38	20.487	0.203	-	-	-	Sample Broken at first test; UCS not determined
	BK-F	Y61.16	22.756	0.217	NA	NA	NA	Sample Broken at first test; UCS not determined
	BK-G	Y61.2	21.59	0.136	17.69	32.93	65.19	Complete experiment
	BK-H	Y61.24	23.737	0.138	-	-	-	Sample Break at first confining
BK-4C	BK-I	Z18	2.917	0.27	2.5	41.1	11.014	Complete experiment

2. Dynamic data to static data conversion and calibration with lab data

Elastic and mechanical properties were computed from density & sonic logs using standard equation given below.

$$\nu_{\text{poisson}} = \frac{0.5\,(t_s/t_c)^2 - 1}{(t_s/t_c)^2 - 1}$$

$$G_{\text{shear}} = a\,.\,\rho_b/t_s^2$$

$$E_{\text{young}} = 2\,G_{\text{shear}}(1 + \nu_{\text{poisson}})$$

UCS = A+B*YMOD_STATIC (in MPSI) A & B were taken 3 & 1 respectively in present case.

Elastic and mechanical properties computed from above equations are dynamic properties. Elastic and mechanical properties estimated in lab (table-1) are called static elastic properties; empirical relationships were used to convert dynamic into static properties and calibrated with lab derived static properties. By this means we get continuous static properties given in figure-6 below; lab determined properties are plotted point data.

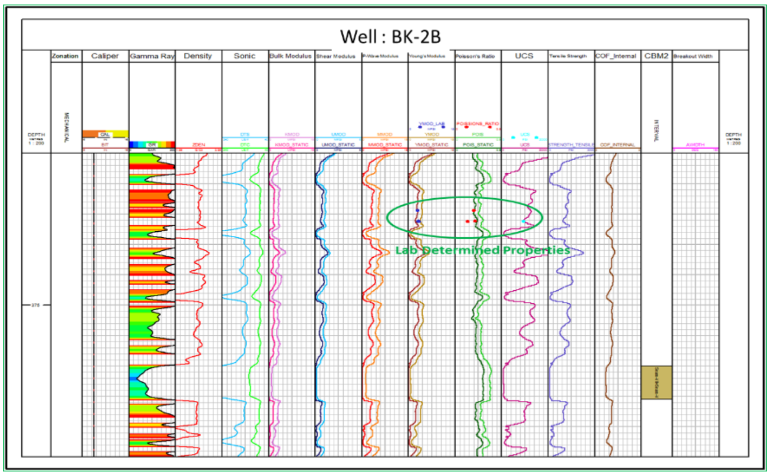


Figure 6: Dynamic to static elastic properties with calibration from lab estimated data.

3. 1-D Geomechanical Modeling

Overburden stress is estimated integrating density log over depth interval, pore pressure is taken normal hydrostatic as inferred from drilling pressure data and other drilling events. The Minimum horizontal stress were estimated using Poro-elastic equation given below;

$$\sigma_h = \frac{v_s}{1 - v_s}(\sigma_v - \alpha P_p) + \alpha P_p + \frac{v_s E_s}{1 - v_s^2}\varepsilon_x + \frac{E_s}{1 - v_s^2}\varepsilon_y$$

εx and εy are tectonic strains in maximum and minimum horizontal stresses directions, respectively. In absence of breakout on image logs, Shmin is calibrated with closure pressure data. Closure Pressure data was recorded in wells BK-2B and BK-4D which are located in Patch-B(Western Sector) and Patch-A(Eastern sector) respectively. Closure pressure gradient in these two wells are entirely different, BK-27 has closure pressure gradient of 0.58 psi/ft and BK-4D has closure pressure gradient of 1.046 psi/ft. Closure pressure data of these two wells indicate that different tectonic strain acting in Patch-A and B. Patch-B seems to be relaxed and there is high tectonic strain in Patch-A, this indication is from closure pressure data of two wells only and cannot be concluded. Using same calibrated correlations and tectonic strains, geomechanical modelling of other wells in the area were carried out.

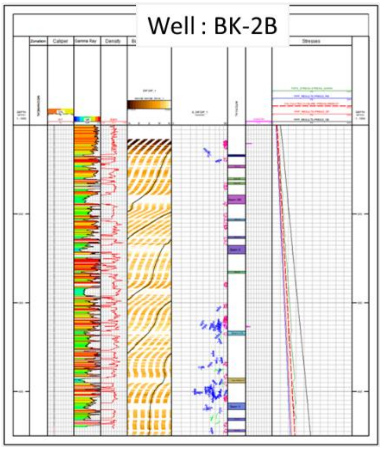


Figure 7: Geomechanical model of well BK-2B.

Conclusion

Direction of maximum horizontal stress is 45-50 deg N in Bokaro field as seen from resistivity image logs. BK-1A samples are shale-sand and shale-sand-coal mixture, Poisson's ratio and Young's modulus determined are in the range 0.08-0.13 and 23.96-33.52 Gpa respectively. Core samples from BK-2B are mostly sandstone; UCS, Cohesion and Friction angle for one plug from sandstone sample could be determined which came out as 65.19 Mpa, 17.69 Mpa and 32.93 degree respectively; Poisson's ratio and Young's modulus are in the range 0.13-0.21 and 20.48-23.73 Gpa respectively. Core samples from BK-4C are pure coal; Young's modulus, Poisson's ratio, Cohesion, Friction angle and UCS determined are 2.917 Gpa, 0.27, 2.5 Mpa, 41.1 degree and 11.014 Mpa respectively. Coal seam wise estimated closure pressure and breakdown pressure data from 1-D geomechanical model of well BK-2B is below in table-2;

Table-2

Sl. No.	Coal Seam	Closure Pressure (psi)	Breakdown Pressure (psi)	Young's Modulus (MPSI)	Poisson's Ratio
1.	Seam-XVI	280-297	380-690	0.12	0.26-0.32
2.	Seam-XV	292-304	414-1033	0.18	0.23-0.28
3.	Seam-XIV	316-345	463-812	0.20	0.24-0.30
4.	Seam-XIII	372-397	491-1211	0.14	0.23-0.30
5.	Seam-XII	413-446	573-1513	0.22	0.23-0.30
6.	Seam-XI	451-483	591-1353	0.18	0.24-0.29
7.	Seam-X	497-509	706-1450	0.39	0.24-0.29
8.	Seam-IX	568-586	688-1841	0.16	0.22-0.31
9.	Seam-VIII	691-729	852-1977	0.21	0.22-0.30
10.	Seam-VI+VII	778-842	942-1725	0.16	0.23-0.30
11.	Seam-V	800-883	1045-2161	0.31	0.21-0.29
12.	Seam-IV	836-917	1124-1810	0.42	0.22-0.29

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