Weak cementation effect on velocities of sands

De-hua Han, *Unocal*

ABSTRACT

P- and S-wave velocities and porosity reduction were measured on brine saturated, weak- and un-cemented sands samples. The measured data reveal that a weak cementation causes more than 100% increase of S-wave velocity and less than 20% increase of P-wave velocity due to a large increase of shear modulus, but a decrease of bulk modulus. Consequently, Vp/Vs and Poisson's ratio of weak-cemented sands is much lower than those of un-cemented sands. The result suggests that S-wave velocity may be needed to estimate weak-cementation and rock strength.

INTRODUCTION

Weak-Cemented Sands Reservoir

Mechanical strength of reservoir rocks is an important parameter for hydrocarbon production. Weak-cemented formations are often associated with abnormally high formation pressure andhydrocarbon reservoirs. For a deep, weak-cemented formation, drilling through it, completing for it, and producing from it often cause severe difficulties, extremely high cost, even risk to lose the well. If a weak-cemented formation can be predicted seismically, drilling into a over-pressured, weak-cemented zone may be avoidable, or if it cannot be avoided, operator can be informed and prepared before the drilling.

However, velocities of weak-cemented sands are rarely investigated. Most cores . drilled from weak-cemented sands are either blended, or collapsed during drilling. Therefore, velocities of weak-cemented formation may have to be estimated from velocity data measured on loose sands.

Model of Granular Media

Mechanism of grain contact effect on strength and velocities of granular media had been thoroughly investigated experimentally and theoretically for many years. Many of these works are reviewed and discussed by Stoll (1989). Only recently, few works have been focused on the effect of cementation on strength of porous media. Bernabe et al. (1992) found that a small amount of cement around grain contacts can significantly increase the strength of granular material. Yin et al. (1992) conduct a similar experiment in which compressional and shear velocities in epoxy-cemented glass beads were measured at varying epoxy saturations. The experimental result shows that the velocity increase with saturation is very large between 0% and 10% saturation and negligible between 50% and 100% saturation. An analytical model is developed to describe the effective elastic properties of cemented granular material by Dvorkin et. al. (1993). The model solution indicates that the amount of cement has larger effect on the stiffness of a granular assembly than the stiffness of the cement.

Weak-Cemented Sands

Most of the models are based on assumption of elastic spherical grains and cementation layers between them. The test samples are made of precompacted spherical glass beads, or Ottawa sands with artificial cement injected into pore space. However, for weak-cemented sands, rock frame and weak cement are far different from the models. They are not elastic. Therefore, the model and test results may not be relevant to the weak-cemented sands. The cementation effect on velocities of weak-cemented sands have to be examined on real rocks.

In this paper, measured velocities and porosity reduction on weak-cemented sands are presented. Both of samples Ai and A are from the same core (depth about 10000 ft). Sample Ai is an intact sample. Petrographic analyses suggest that sample Ai is weak-cemented and under-compacted. Grain fractures are common. Thus, the rock retain much of its original intergranular porosity. Sample Ai fall apart easily with a mechanical disturbance. Sample A is made of packed loose sands. They were recovered to surface as disaggregated.

In comparison of the data measured on the loose sands and the intact sample, the weak cementation effects on velocities was discussed.

MEASUREMENT PROCEDURES

Loose sand sample A was dried in a vacuum oven at 80° C for two days. Then, grain density was measured using a helium porosimeter. The sand grains were weighed before packing into a pressure vessel. Volume of sand grains was calculated using the sample weight and grain density. Sample A was sealed and pressed by a hydraulic piston in the pressure vessel. Sample A was vacuumed, then saturated with brine at pressure of 144 Psi.

Initial length of sample A was measured as the piston contacted firmly with the sample. The pore fluid pressure was maintained as a constant (144 Psi). The sample length reduction and volume of expelled pore fluid were monitored with increasing the piston pressure. Thus, porosity reduction can be measured in two ways: either from the sample bulk volume reduction(Por1), or from the volume of expelled brine(Por2).

Velocities of the intact sample Ai with water saturation was measured conventionally. Porosity reduction with elevated pressure was measured using volume of expelled brine from pores.

MEASURED DATA

Compaction

Grain density of sample A and Ai is 2.60 gm/cc. Porosity reduction, Por1 and Por2 of sample A are consistent as shown in FIGURES 1. Initial porosity of sample A is around 36% then reduce to 23.6% at the piston pressure of 5790 Psi. When the pressure released, porosity of sample A recovered to 24.4%. A large hysteresis of porosity for sample A was observed due to the permanent compaction. For the intact sample Ai, initial porosity is 27.8%, then porosity is compressed to 24.4% at effective pressure of 6120 Psi. The porosity reduction measured on sample Ai is relatively small, but still significantly over 10%.

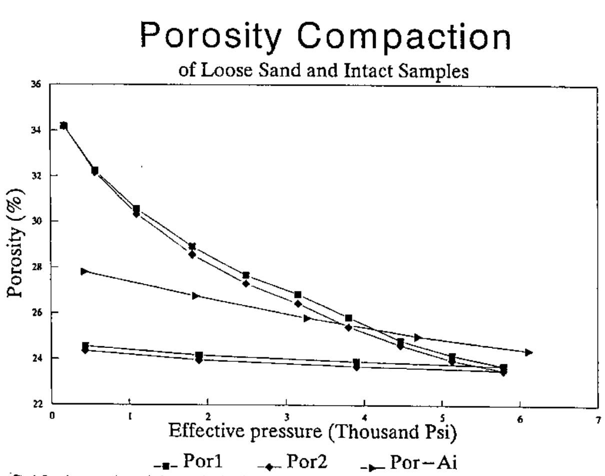

Fig. 1. Porosity compaction on the loose sand and the intact samples.

Velocities

Both P- and S-wave velocities of sample A were measured as shown in FIGURE 2. The measured Vp on the intact sample Ai is 0.42 to 0.46 km/s (17 to 20%) higher than the Vp of sample A (FIGURE 2). The Vs of sample Ai is 0.98 km/s (120%) higherthanthe Vs of sample A at effective pressure of 1900 Psi. Hysteresis of the velocities in a pressure cycle is caused by the permanent compaction of the sample. Clearly, a weak cementation results in a large increase of the Vs and a moderate increase of the Vp.

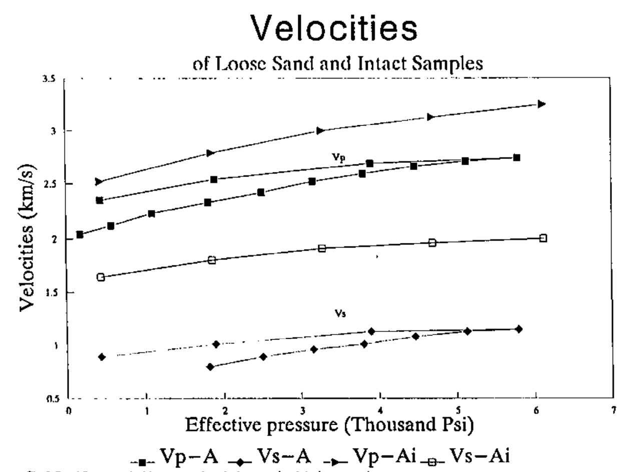

Fig. 2. P and S-wave velocities measured on the loose sand and the intact samples.

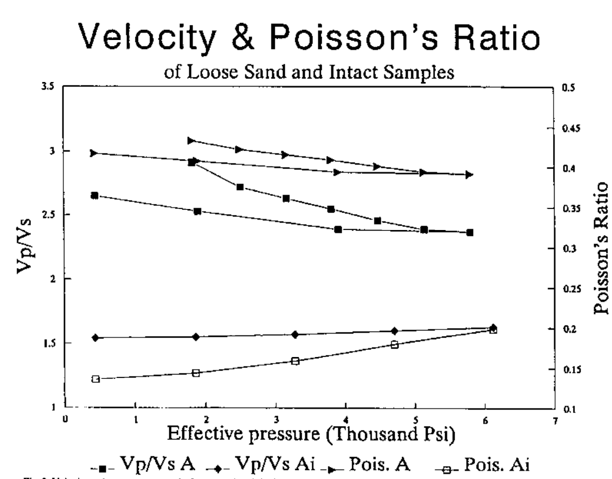

Fig. 3. Velocity ratios measured on the loose sand and the intact samples.

Consequently, for un-cemented sample A, Vp/Vs ratio ranged from 2.91 to 2.37, and Poisson's ratio ranged from 0.43 to 0.39 are much higher than 1.63 and 0.20 for intact sample Ai (FIGURE 3). Vp/Vs ratio of sand grains is 1.5. Clearly, Vp/Vs ratio of un-cemented sands matrix has no relation to the Vp/Vs ratio of sand grains.

Modulus

Dynamic bulk and shear moduliof samples A and Ai are calculated from velocity data as shown in FIGURE 4 . For weak-cemented sample Ai, the shear moduli are 3 to 4 times higher than those of un-cemented sample A, while the bulk moduli of sample Ai are lower than those of sample A. This result suggests that rigidity of brine saturated, weak-cemented sands is very sensitive to their cementation, but not elastic moduli of sand grains.

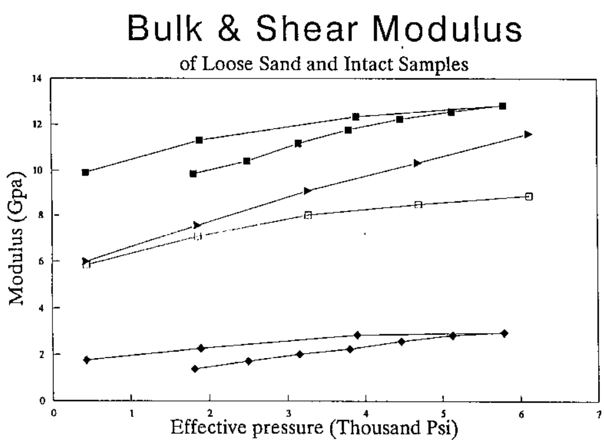

Fig. 4. Measured bulk and shear modulus on thc loose sand and the intact samples.

Compaction of loose sands is anelastic. However, apparent 'static' bulk modulican be calculatedusingpressure change andporosity reduction. With up-loading effective pressure, the 'static' bulk moduli of the loose sands and the intact samples range from 0.1 to 1.3 GPa, much less than dynamic bulk moduli as shown in FIGURE 5. For weak- and un-cemented sands, the dynamic modulimay not be used to refer the anelastic 'static' moduli.

DISCUSSION

For consolidated sandstones (Han, et al., 1986), P- and S-wave correlate with porosity and clay content as

$$Vp = 5.59 - 6.93 * \phi - 2.18 * C$$

$$Vs = 3.52 - 4.91 * \phi - 1.89 * C.$$

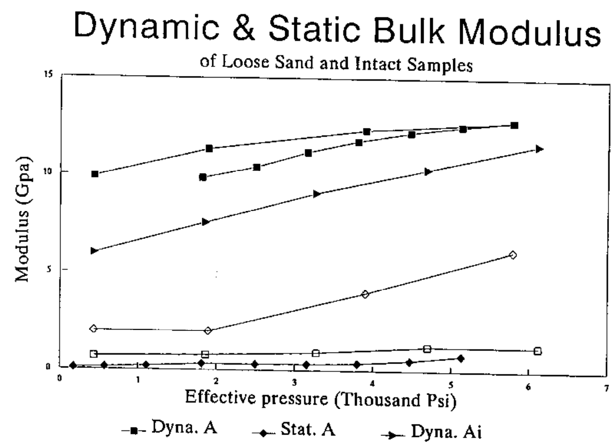

Fig. 5. Dynamic & Static bulk modulus on the loose sand and the intact samples.

where ϕ is porosity, and C is clay content. For a sample with 25% porosity, 5% clay (similar to sample Ai), high bounds of Vp and Vs can be calculated as 3.75 km/s and 2.2 km/s respectively. Thus, cementation effects on velocities can be estimated as

	High bound	low bound	Sample Ai
VP	3.75 km/s	2.74 km/s	3.25 km/s
vs	2.20 km/s	1.15 km/s	2.00 km/s.

Measuredvelocities on loose sands could provide low bounds and estimations of velocities for weak-cemented formations.

The procedure of the AVO analysis depends on Poisson's ratio. For brine saturated, weak-cemented sands, Vp/Vs and Poisson's ratio is very sensitive to the cementation, but not to sand grain moduli. Therefore, the weak-cementation effect on the AVO analysis need to be examined.

CONCLUSIONS

The above measured data reveal that for brine saturated, weak-cemented sands, a weak cementation results in a large increase of shear modulus, but a decrease of bulk modulus. Therefore, for weak-cemented sands, the cementation controls the elastic properties.

REFERENCE

Bernabe, Y., Fryer, D. T. and Hayes, J. A., 1992, The effect of cement on the strength of granular rocks, Geophys, Res, Let., 19, 1511-1514.

Dvorkin J., Nur. A. and Yin. H., 1993, Effective properties of cemented granular materials, SRB Project V53, Paper C.

Ian De-hua, A. Nur, and D. Morgan, 1986, Effects of porosity and clay content on wave velocities in sandstones: Geophysics, 51, 2093-2107.

Stoll, R. D., 1989, Sediment acoustics, Springer, Berlin.

Yin, H., Dvorkin, J. and Nur, A., 1992, Intergranular cementation: experimental study, abstract, AGU Annual Meeting, San Francisco.