SEABED SEISMIC COUPLING – TESTING AND EVALUATION PROBLEMS

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Summary - Coupling of gravity deployed Ocean Bottom Seismometer multicomponent sensors has been an issue for at least 30 years, and remains largely an empirical art rather than a science. There are a number of reasons why it retains it elusive nature ;- the environment is generally hostile and all operations have to be conducted remotely, the nature of the seabed is highly variable from place to place, so that it is impossible to directly compare results from different sites, but largely because making detailed in-situ comparisons of a number of sensors accurately deployed in controlled deep sea conditions adjacent to each other is extremely costly. This paper considers some of these problems, and ways in which coupling can be evaluated in the laboratory, and the limitations that result. Variations of the internal sensor geometry also affect the sensor response in deployed sensors.

The history of multicomponent sensor packages for Seabed seismics has been marked by many designs that can be seen on a cursory inspection to offer poor coupling fidelity, and rather few designs that inspire much confidence. The basic reason for this poor design lies in a failure of designers to understand intuititively the properties of the seabed. This can largely be traced to the difference between the properties of seabed materials we observe when we handle them in the lab or in shallow water muds, and the mud properties as they affect seismic waves. Put simply, all our physical experience of mud is related to its properties ABOVE the yield point, whereas seismic signals received are invariably in the elastic range well below these levels. Because of this, designers have failed to take account of the seabed as a very springy undamped material. Once one accepts the intuitive idea that seabed mud behaves like a sheet of foam rubber, the true nature of the problem becomes evident.

I first became aware of the complexity of seabed coupling through an unplanned comparison of two cylindrical 3 component seismometers – one deployed on end and one on its side. Since the physical sensor difference was gross and there were several sensors of each type, it was not necessary to account for minor variations in the depth to which each sensor sank in the mud, or of local variations in mud properties within the area. Where intercomparisons are designed to investigate differences between several sensors that have been designed carefully for good coupling, these minor differences may well mask significant differences between different designs. Even if a good intercomparison can be made, and significant differences in sensor response are evident, these may well only apply on that particular seabed and with that deployment technique.

Planning a good comparison test in a real seismic environment requires either a large enough number of each sensor type to give statistically meaningful results, or some means of carefully controlling and monitoring the deployment and orientation of each sensor to ensure that it is deployed in its optimum way. Achieving this degree of control almost certainly requires a R.O.V. to deploy and check instruments and is thus very costly. Either way, a good intercomparison is real conditions is a complex and costly operation and yields information related to that particular environment only.

One alternative to 'real world' testing is to reproduce a piece of seabed in the laboratory and use this for tests. The first complication is that we are moving from a real environment where the seismic wavelength is small compared to the physical dimensions of our 'laboratory' to a situation where the test facility is a very small fraction of a seismic wavelength. This inevitably means that the interaction of our model seabed with its boundaries is of comparable complexity to the interactions of the sensor with the 'seabed'. We must then consider how we are to generate and apply our test excitation to simulate the seismic arrivals. This is not as easy as it might seem:- in the real world seismic signals of interest consist of 'pressure' (p) waves and 'shear' (s) waves that both arrive substantially vertically. In the laboratory model we have to substitute direct physical vibration in such a way so that we can control or compensate for spurious motions introduced by our simulated seismic wave. Assuming that we can impart a controlled, known motion to some external boundary of the 'seabed', we have to be able to measure the actual motion of the material surrounding the sensor. Some idea of the complexity of this problem can be gained by thinking of the complexity of the motion of a bowl of jelly (American: jello) when the bowl is shaken!

This complexity when using a simulated soft deep sea mud highlights one of the limitations of conventional geophones:- To describe completely the motion of a rigid body in 3 dimensional space requires 6 independent components – conventionally we chose the set of 3 translations and 3 rotations about orthogonal axes. A 'standard' geophone has only 3 components, orthogonal x and y horizontal components and z vertical component and so does not respond to rotations about these axes – i.e. when correctly positioned it measures translations corresponding to the principal directions of the (theoretically perfect) seismic signals and has minimal sensitivity to spurious rotations. A number of industry seismic geophones, however, use a Galperin configuration, which consists of a set of 3 orthogonal sensors oriented symmetrically about a vertical axis so that each inclines at 37.3 degrees to the horizontal. In this configuration the sensors respond to both xyz translations AND rotations about x and y axes but not about z. Furthermore the response to rotations depends upon whether the sensors in the Galperin configuration converge upward or downward.

These differences between sensor configurations, combined with the complexity of the expected motion within the test volume mean that we have to measure and record all 6 components of motion for as much of the system as we can – at least for the simulated seabed in the region in which the sensor is sited, and preferably also of the sensor itself, if necessary by adding small external sensors. When this is taken into consideration, it means that any recording system monitoring the experiment will need a minimum of 12 channels and probably 18 to 24 to stand a chance of capturing the expected motion.

An alternative to shaking the whole test volume is to put small shakers within the sensors and effectively measure the inverse coupling of the sensors. This approach has been used and does give some information about the coupling, but of course introduces a whole new set of complications.

So far we have assumed that we can find a material that will simulate deep sea mud. Conventionally it has been assumed that china clay can be mixed with water and settled and possibly subsequently de-watered to give the required strength to simulate a particular seabed mud. However, there is increasing evidence that first few metres of the seafloor owes its physical properties more to biological activity than to the inert materials it mostly consists of. Recent analysis of mud from offshore Angola, for instance, suggests that the top few meters of mud have all passed through the digestive tracts of seabed worms, and been packaged into protein wrapped bundles that retain their effective low strength properties until the gravitational load a few meters down overcomes the strength of the bundles. It is therefore doubtful whether lab tests can ever be reliable indicators of deep sea performance.

Taken together this represents a formidable challenge to any attempt to quantify the coupling of a seabed sensor package. Field tests are inevitably of limited validity, complex and expensive. Lab tests result in extremely complex motions and the analysis of large volumes of data. One possible solution is currently being investigated – a seismic test range on inter-tidal mud where a small source and reference geophones can be used to generate and monitor a simulated shear wave and a number of sensors can be compared, not necessarily at the same time.