LIGO-T880036

23R

List of 3/15/89

REPORT ON SEISMIC ISOLATION AND SUSPENSION SYSTEMS

Comments on the Preliminary Seismic Survey of the Livingston Site Including Recommendation of Site Suitability

Yekta Gürsel Fred Raab Peter Saulson
Robert Spero

14.1 November, 1988

1 Comments on the Livingston Survey, Including Recommendations for Future Studies

We review the measurements and analysis presented in the report by Warren Johnson, Donald Stevenson and Kyle Clevenger summarizing the first seismic survey of the Livingston site. The authors of the Livingston report are to be commended for the thorough way in which they carried out and reported their measurements. The report is markedly superior to previous work done in a similar vein by the LIGO project. Our critical perspective arises from the concern that future studies cover all seismic considerations relevant to LIGO design and operation.

1.1 Calibration

It is good practice, even in the absence of calibration discrepancies such as those above 30 Hz noted in the report, to calibrate seismometers independently of the built-in calibration coil. One method is to use a calibrated accelerometer—such as a B & K Model 8305—mounted rigidly to the seismometer. The instruments are then accelerated together by a vibration exciter such as a B & K Model 4812. Suitable accelerometers and shakers are available at Caltech and MIT, and we recommend that future seismic surveys be conducted with seismometers so calibrated. The internal calibration coil can be used in the field to check the stability of the calibration.

1.2 Noise Floor of the Measurements

The best measurement of system noise would be to seismically isolate the seismometer in the lab, and to use the same amplifiers and gain settings used in the field. An isolation method that we have found successful down to 1 Hz is to suspend the seismometer by at least 2 meters of surgical tubing.

1.3 Ground Placement

The horizontal and the vertical seismometers appear to have been buried differently, with no explanation of the reason (we speculate that the difference was determined by convenience: the vertically oriented seismometer was placed in a hole made by a drill, no deeper than an arm can reach, and the horizontal seismometer was placed in a shallow hole dug with a shovel). It appears that soil is packed more tightly around the horizontal seismometer. These differences may account for the difference in responses to passing airplanes, which we hypothesize was not due to motion of the ground, as claimed in the report, but rather an artifact of direct acoustic pickup in the seismometers. A check of and guard against acoustic pickup is to fill the pits with sound absorbing foam.

Also, we would like to see data from seismometers in the same orientation buried at varying (and *recorded*) depths. Such data could provide guidance for civil engineering questions such as the optimum depth of foundations.

1.4 Data Acquisition; Variation

A time-domain analysis of the signals recorded on tape would complement the frequency-domain results presented in the report, and provide valuable information for LIGO receiver design. The following reductions of time-domain data are particularly relevant:

- The time-variation of background seismic noise, at least including diurnal, and preferably also seasonal, variations.
- An analysis of how frequently burst disturbances of various amplitudes occur.
- A measure of the correlation of seismic noise to wind and weather, as might be monitored by a portable weather station.

Such time-domain analyses have not been done on any of the sites so far surveyed, though we note that at Edwards the 1 Hz noise is a factor of four lower just before sunrise than it is around sunset. (This quiet time at Edwards is 80 times quieter at 1 Hz than the reported measurements at Livingston.)

1.5 Locations and Times

The are two creeks passing through the site. During rainy season the creeks might carry enough water flow to cause significant seismic noise.

Contrary to the claim in the report, vertical seismic motion may be at least as important as horizontal motion. The degree of coupling of vertical motion of the LIGO test masses into noise is not known, but all proposed designs have the masses hanging as pendula, providing much more horizontal isolation. We know there is a minimum coupling of vertical vibration into interferometer noise due to departures of the interferometer arms from horizontal. The relative importance of external vertical and horizontal seismic noise can be meaningfully evaluated only in the context of a specific suspension design.

1.6 Wind and Pipeline Noise

The report states that the high frequency wind noise was observed when the seismometers were placed directly under a tree vanished when the sensors were moved away from the tree. This was also observed by the British seismic survey team in an indirect way. They placed their sensors always away from the trees and did not see any effect due to the wind shaking the trees.

Another conclusion in this section is that the wind noise is not significant for a typical day at this site. This conclusion may be altered by the presence of LIGO buildings, which can couple wind noise to the ground.

The authors found that the active pipelines contributed excess noise. They did note, however, that at a sufficiently large distance this excess noise could not be discerned above the background. We believe that we should require that all LIGO instrumentation buildings be located outside the areas where the pipeline noise can be detected. We have not checked how much restriction this requirement puts on the LIGO alignment.

1.7 Remarks

The most interesting feature of this site is the observed large motion in the frequency range from 1 to 3 Hz. This excessive noise may be due to local wind induced ground motion, or to ocean waves crashing into the nearby coastline. Support for the importance of local conditions comes from the British seismic survey, which included an examination of a site with excessive motion at about 3 Hz. This was a clay filled buried valley and they conclude that it was the wind that was driving it. Excerpting from the British report:

> The effect of amplification of ground motion by deposits of unconsolidated materials is a well known phenomenon in earthquake seismology. Studies in the San Francisco Bay region (Borcherdt, et al, 1975) have indicated that the effects of amplified ground shaking are expected least for sites underlain by bedrock, intermediate for sites underlain by alluvium (largely silt, sand and gravel), and greatest for sites underlain by bay mud (largely clay and silt).

The authors state that the Livingston site is 10 times noisier than the other sites at 1 to 3 Hz. We note that the Edwards site, which is not the quietest available, is 80 times quieter than Livingston site at late hours of the night.

2 Conclusion and Recommendations

This report is more complete than anything we have on the Edwards and Cherryfield sites. We do not believe the seismic data from Livingston rule it out as a LIGO site.

However, as we outlined above we do have a number of technical concerns. One concern in particular is serious—the large noise level below 3 Hz, about five times higher than in the Caltech Laboratory. Although this is likely to be outside the signal band of the first (and maybe even all subsequent) LIGO receivers, the large amount of noise could cause difficult demands on the dynamic range of servos. Also, nonlinearities in the mechanical or optical systems could upconvert low frequency motion into the signal band.

This large motion can also directly interfere with low frequency gravitational wave searches through varying gravitational gradients driven directly by motion of the ground.

We do not yet know how to evaluate all of these effects, but we know enough to say that a site which has this much low frequency noise is substantially less attractive than a site without it. It is likely that the noise is tolerable for the first LIGO searches, but quite possible that it would seriously compromise future improvements, especially through the additional demands on servo performance.

We know that in the absence of such nonlinearities, Livingston would be quite acceptable as a LIGO site. It is quiet at high frequencies and the medium-frequency noise can be isolated with passive stacks.

Another issue which needs resolution is the effect of the noise imported to the site, since relatively tall buildings and vibration producing machinery will be installed. The wind noise coupling to the ground through the building might be an important noise source and it may be larger than the intrinsic seismic noise of the site.

We appreciate the urgency of resolving this question. We propose making a few measurements that will cover an extended period of time (perhaps one week) at the Caltech laboratory and at the JPL research facility at Edwards. These measurements should show the effect of wind coupling to the ground through buildings. The necessary equipment is in our possession.

We further suggest shipping this equipment to Maine to get a better idea of what that site is like. We expect that these measurements could be completed in a month.

In summary we do not know for sure that this site is any worse than any of the other sites since we do not yet know how to assess the importance of the low frequency noise. The measurements planned might be able to help us in resolving this issue in the near future.