Hammer Design for Drilled Shaft Testing
Two Case Studies

by

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Introduction

Hussein et al. 1996 described a procedure for designing a dynamic loading system when drilled shaft testing is required. That proposed system is based on wave equation simulations and primarily deals with the ram size and cushion selection. However, theoretical considerations are one thing, actual performance another one. This paper will describe two projects where GRL either specified or actually supplied a driving system.

In the past, GRL has recommended that the ram weight should be at least 1%, better 1.5% of the proof load to be generated. That rule is based on experience. The higher value would be appropriate for piles with significant end bearing in a cohesionless material where large sets are necessary to activate the shaft's bearing capacity. For shafts in cohesive materials, lower ram weights are often satisfactory. The greater the ram weight the lower the stresses (and therefore likelihood of shaft damage) at the same activated capacity, since greater ram weights allow for lower drop heights. Particularly for end bearing piles which require a large set to activate resistance, tension stresses may be a problem.

Case 1: Auger Cast Pile Test

One hundred foot long auger cast piles of 16 inch diameter had to be tested to an ultimate capacity of 400 kips (1,780 kN). Soil consisted of fills and then silts and clays. Ordinarily a 2-ton ram should therefore be satisfactory. GRL, however, purchased an old open-ended diesel hammer whose ram weight is 3.3 tons (29 kN) and used its cylinder as the guide. The hammer was prepared for the test by removing the piston and impact block rings, the fuel pump and grease nipples. In that way it was assured that there would be minimal obstruction of the falling ram due to compressing air. The hammer was also generously lubricated. A helmet was prepared.

The crane needed two lines: one to handle the cylinder weight and maintain the cylinder's vertical position. The second one to lift the ram and drop it. A free release device was also available, however, there was no system in place to transfer the ram weight from the crane to the cylinder, prior to releasing the ram. With a relatively small crane of only 30 ton capacity it was therefore unsafe to free-release the ram. Instead the crane operator dropped the ram by releasing the winch. The ram was lifted by a hook in the center of the ram top. Thus, the system was well balanced and a very well guided impact resulted.

For testing, the pile tops were extended by a 4-ft cased section. For gage attachment, windows were cut into these casings. Four strain transducers and four accelerometers were installed. In general, this produced very consistent strain records. In one case, however, the strain on one location was extremely high (Figure 1) and it was not accompanied by a complementary low strain on the other side. Such an unusually high strain record must be attributed to a defect in the pile material. Indeed, closer inspection showed in the anchor holes of the affected strain transducer red brick material. Imagine what would have resulted if only two strain transducers had been used, one of them on the poor material location.

Figures 2a through 2f show the records obtained on one particular pile for a series of 5 consecutive blows. Energy transferred was typically 50% of the available energy. For example, for the five records enclosed, the drop heights were 3, 4, 5, 6 and 6.5 ft; the associated potential energies therefore were 19.8, 26.4, 33, 39.6, and 42.9 kip-ft. Transferred energies were 7.1 or 35%, 10.3 (39%), 10.8 (32%), 17.2 (52%), 19.6 (49%), and 20 kip-ft (46%). The transferred energies were actually better than expected; the variability of the transfer efficiency or energy transfer ratio (ETR) is attributable either to crane operator effects (early catching of the ram) or to alignment problems.

The records show some high resistance effects near the top that were lost during the test. However, the activated capacities of the pile increased with blow number to 413 kips (RMX with J = 0.8). On other similar piles capacities in excess of 500 kips were activated.

Case 2: Rock socketed shaft

These 42-inch diameter shafts, typically 50 to 60 ft long with 4 to 5 ft long 36-inch diameter rock socket, had to be tested with a 4000 kip (17800 kN) proof load. According to the GRL rule of thumb, a 60 ton ram was requested; both contractor and GRL attempted to find a quick and cheap solution for a hammer. Among the solutions considered was a drop weight composed of several rams (Pileco in Houston, TX has a 10 ton ram composed of 2 sections and would have available rams from other scrap hammers), a pipe filled with concrete, a pipe filled with lead ingots, a pipe filled with steel scraps. Transport cost was one reason why the steel scrap solution was adopted by the contractor who located steel scrap in a plant near the site. The contractor also had available: 42 inch casing, 46 inch casing, a vibratory hammer, welders, 3 inch steel plate and a 150 ton crane.

The hammer actually constructed (Figure 3) consisted of a 42 inch guide tube, approximately 14 inch long, closed at the bottom with a 2-3/4 inch plate, and filled with steel scrap that consisting primarily of washers. This ram was guided by an outer tube of

46 inch diameter of a length approximately equal to that of the ram. The guide tube was also closed at the bottom by a 3 inch plate which serve as a helmet. Initially, plywood cushioning was placed between the bottom of the ram and the top of the helmet plate. Additional cushioning was placed on top of the pile, underneath the helmet plate.

A cross beam was attached to the top of the ram: it could be engaged by the hydraulic jaws of a vibratory hammer. The hydraulic hammer (and thus the ram) could then be raised by the crane. After having been raised sufficiently, vertical posts of approximately 6 inch diameter, attached to the vibratory hammer and sliding inside 8-inch tubes, attached to the main guiding tube, were pinned to the smaller guiding tube pair. In this way, ram and vibratory weight could be transferred from crane to guiding tube and pile. Ram release was accomplished by operating the hydraulics of the vibratory hammer.

As is now standard in GRL practice for drilled shaft testing, pile instrumentation included four strain transducers and four accelerometers. They were attached to a shaft top extension which was contained in a 3/8 inch casing. Windows were cut into the casing for gage attachment.

The first test blow was done with a 3.5 ft fall height (potential energy 210 kip-ft). It generated a dynamic maximum force of 1160 kips and a transferred energy of 8 kip-ft!!! A perceived transfer efficiency of 8/210 = 4%. A second blow with 5.5 ft drop produced 1500 kips force and 13 kip-ft transferred energy (again 4%). A series of 8.5 ft drops generated at most 27 kip-ft (5%) with 2300 kips force. Fortunately, the rock was so stiff that the mobilized capacity reached approximately 120% of the maximum pile top force.

Variations in the ETR were caused by friction between ram and tube depending on alignment, cushion property changes (the upper cushion was completely removed, the lower one reduced to 3/4 inch thickness) and most importantly, due to chips falling out of the ram top and forming a non-uniform impact surface on the helmet plate.

It was decided that the hammer efficiency had to be improved. Thus, wave equation analyses were made, first to model the existing hammer and then to model certain improvements. To model the existing ram, an estimate of the actual ram weight was attempted. It was found that not all of the steel scrap filling had fitted into the ram tube. In fact, a pile of approximately ½ to 1/3 of the total scrap material was found at the site. It was therefore estimated that the actual ram weight was probably only 40 kips (that would make the ETR values 6 to 7%). Reducing the weight of the ram and setting the hammer efficiency to 0.5 could in no way explain the poor performance of the ram. For an approximate match of observed and measured quantities it was necessary to reduce the ram stiffness by a factor 10, relative to the empty tube. This was done in the GRLWEAP program using the non-uniform ram option with 6 ram segments, of which the last (bottom) one was modeled with a somewhat higher mass and stiffness to reflect the concentrated stiffness and mass effect of the bottom plate.

It was then decided to add as much 3-inch plate as would be necessary to obtain a computed pile top force of 3200 kips, *i.e.* 20% below the desired 4000 kip mobilized capacity. Repetitive trial analyses with additional plate weight and stiffness added to the bottom ram segment showed that additional weight of 6 kips should yield satisfactory results.

The modified hammer was adequate for the test. Unfortunately, welds failed several times and caused delays in testing. In all, 15 shafts were tested. Once the hammer was in a good working order, seven shafts were tested in one day. On the average, with a 12.5 ft drop height, 60 kip-ft of energy were transferred or 11% of the perceived potential energy. Compression forces/stresses reached 4800 kips/3.24 ksi; capacities of up to 5200 kips were mobilized; no noticeable shaft damage occurred. A sample record showing a 71 kip-ft energy transfer is shown in Figure 4.

In summary, poor energy transfer was due to friction (guide tube, load transfer tubes), imperfect impact surfaces and most of all, a soft, energy absorbing steel scrap filling. Additional energy losses are attributed to the connection of the 46 inch guide tube to the helmet plate. Practically, this created an additional pile in tension. Testing was made easy by a stiff rock response.

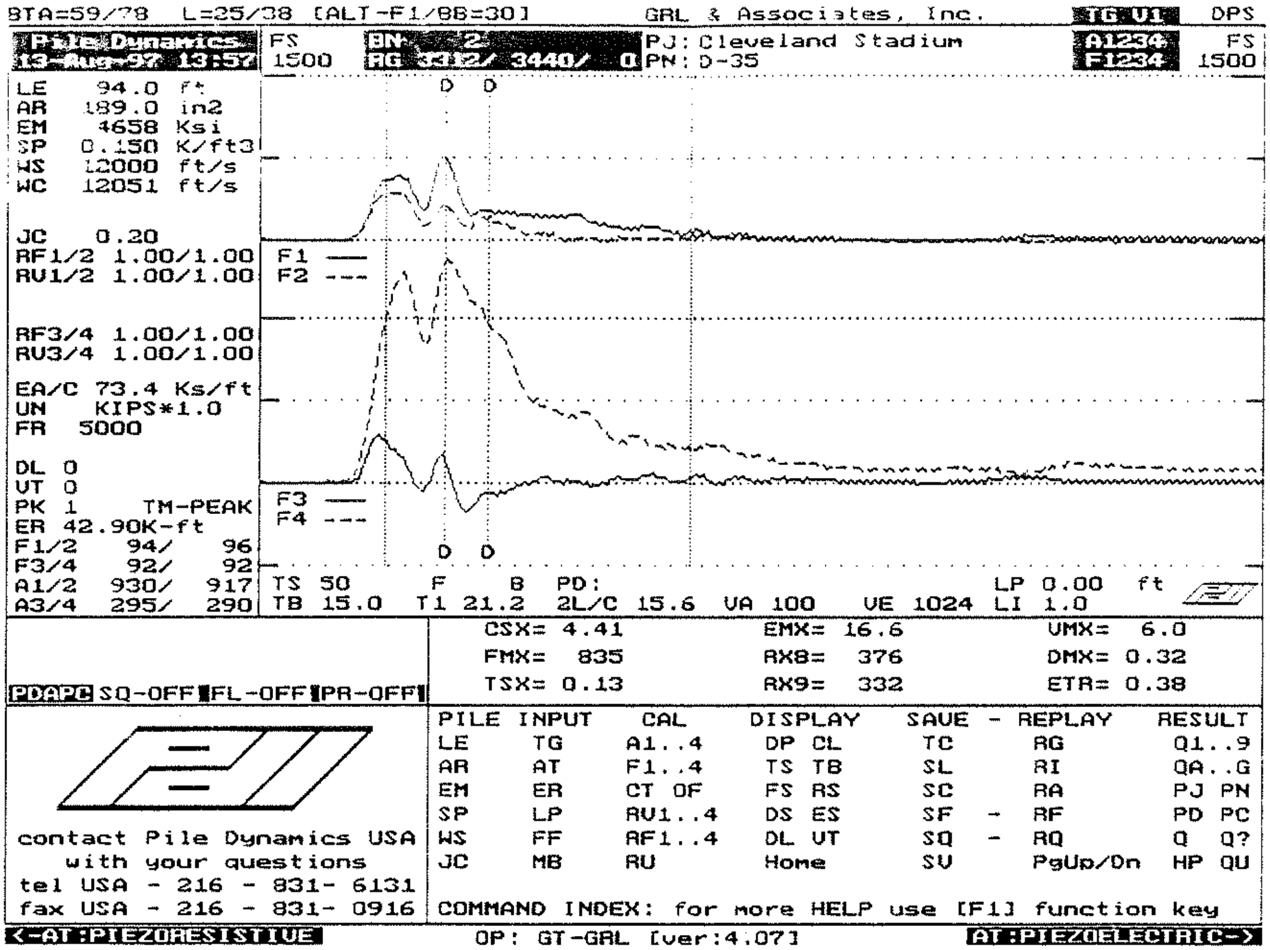

Fig 1:
Strain Records Showing one unusual record at point of poor material properties

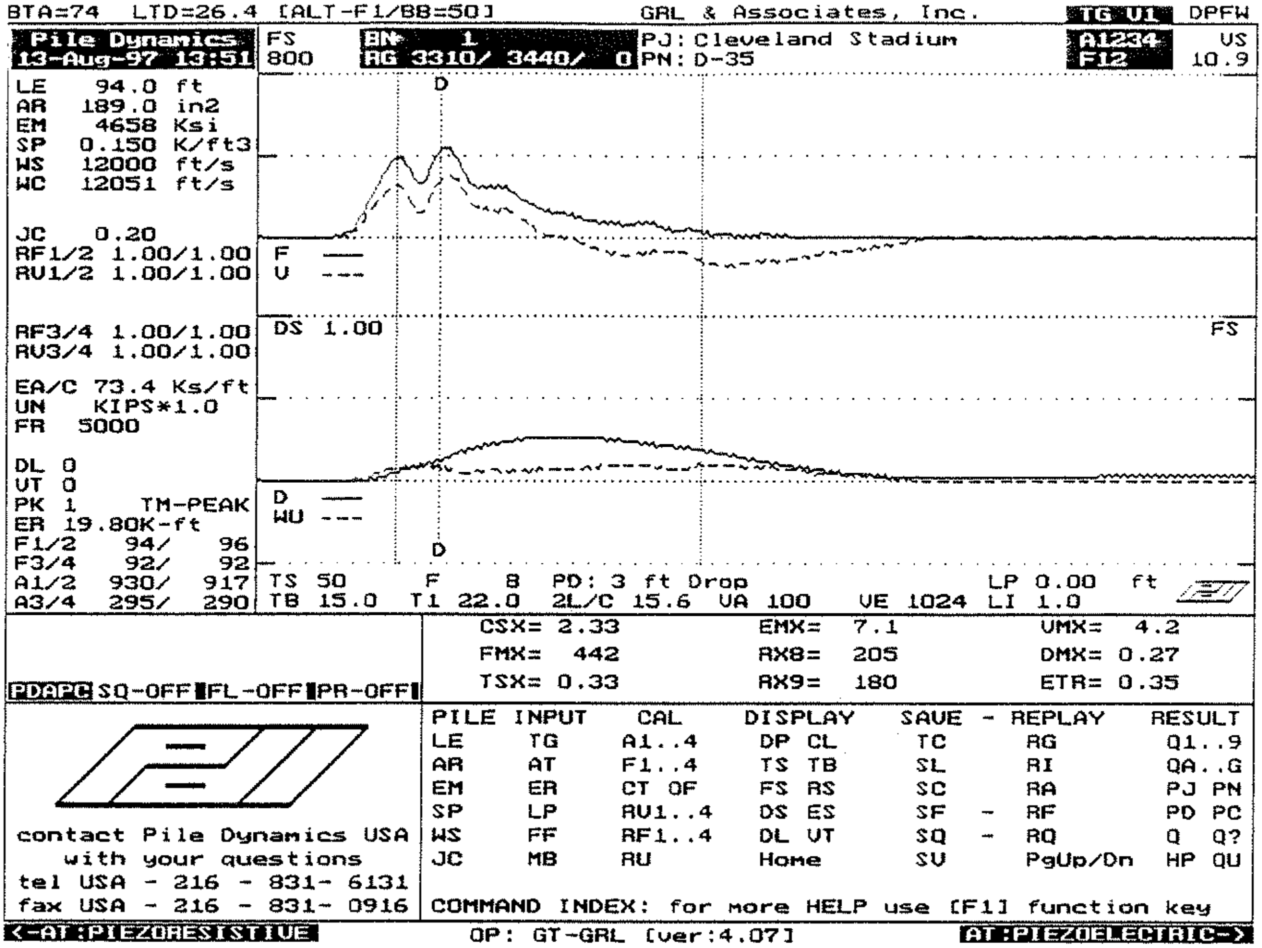

Fig 2a: Auger Cast Pile Test
1st Blow: 3ft drop

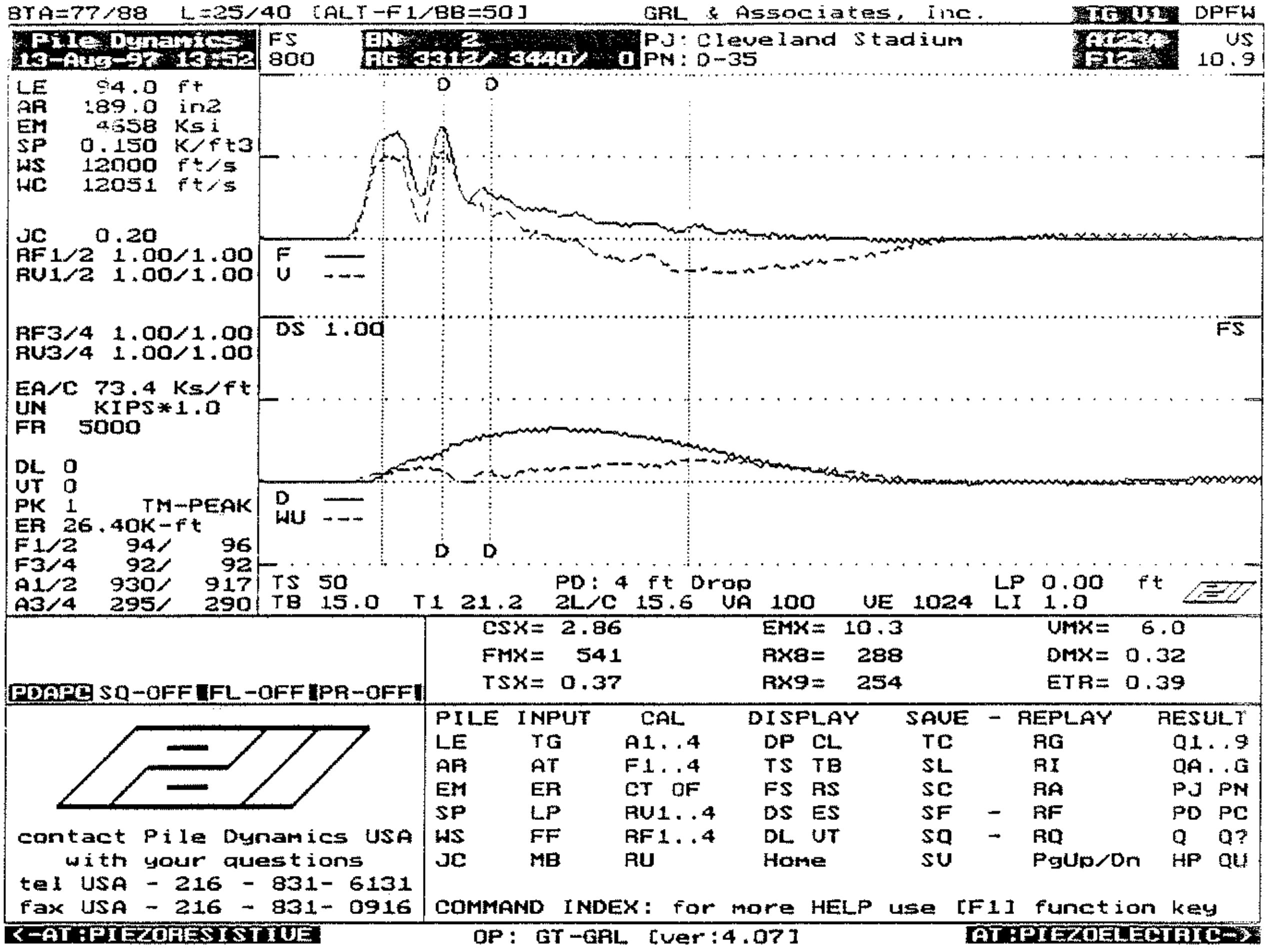

Fig. 2b: 4 ft drop

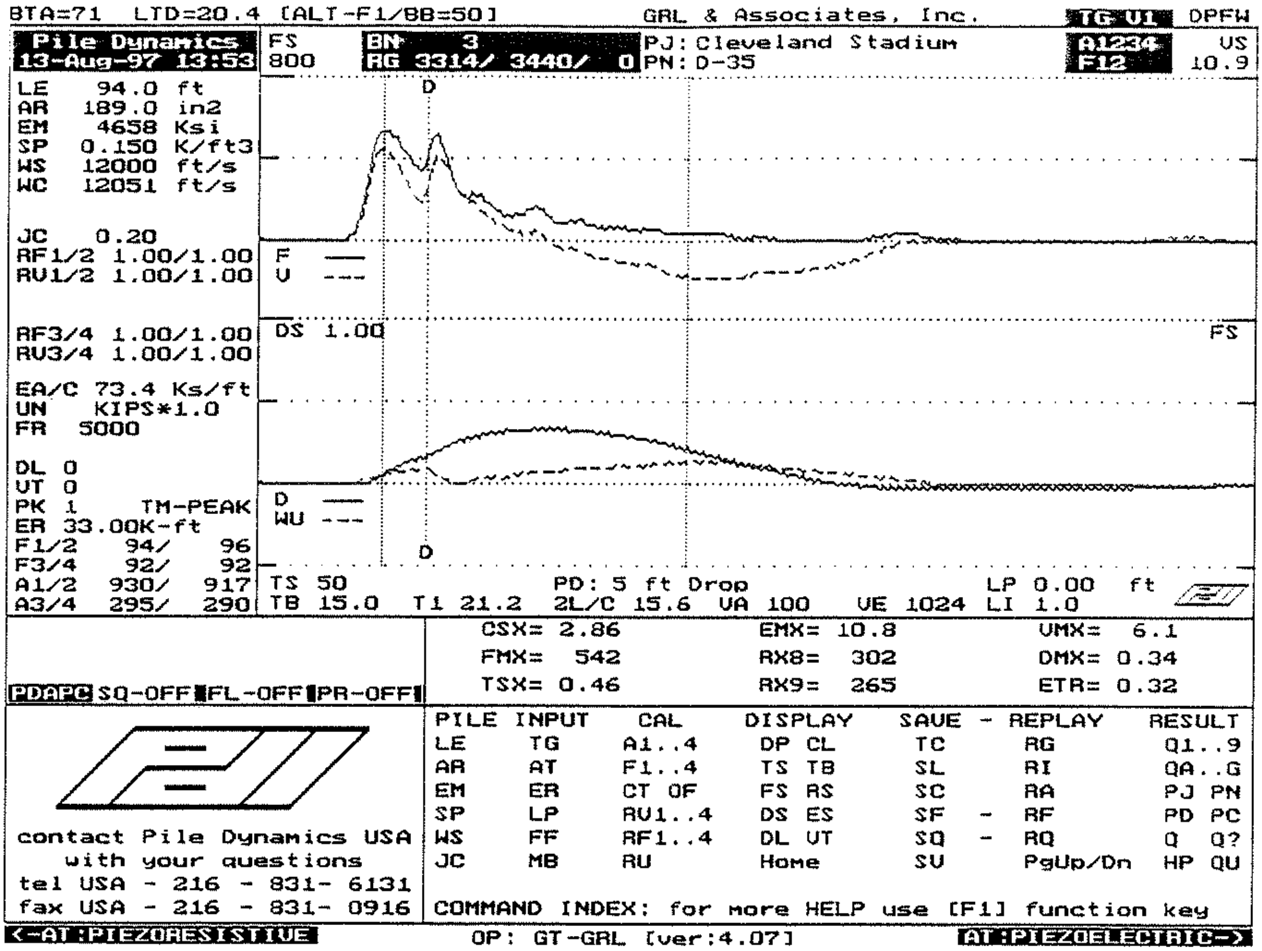

Fig 2c: 5 ft drop

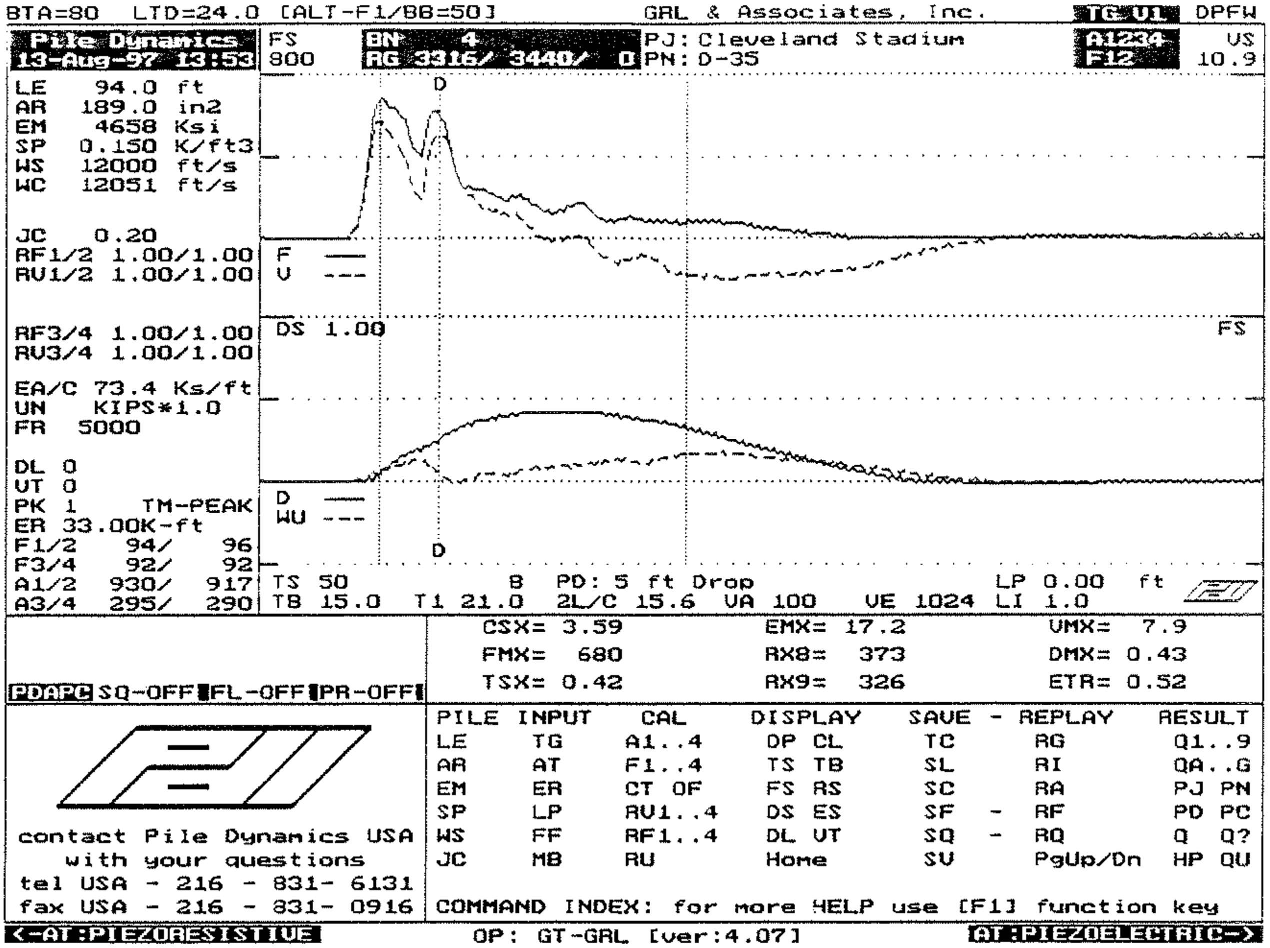

Fig 2d: 5 ft drop repeated

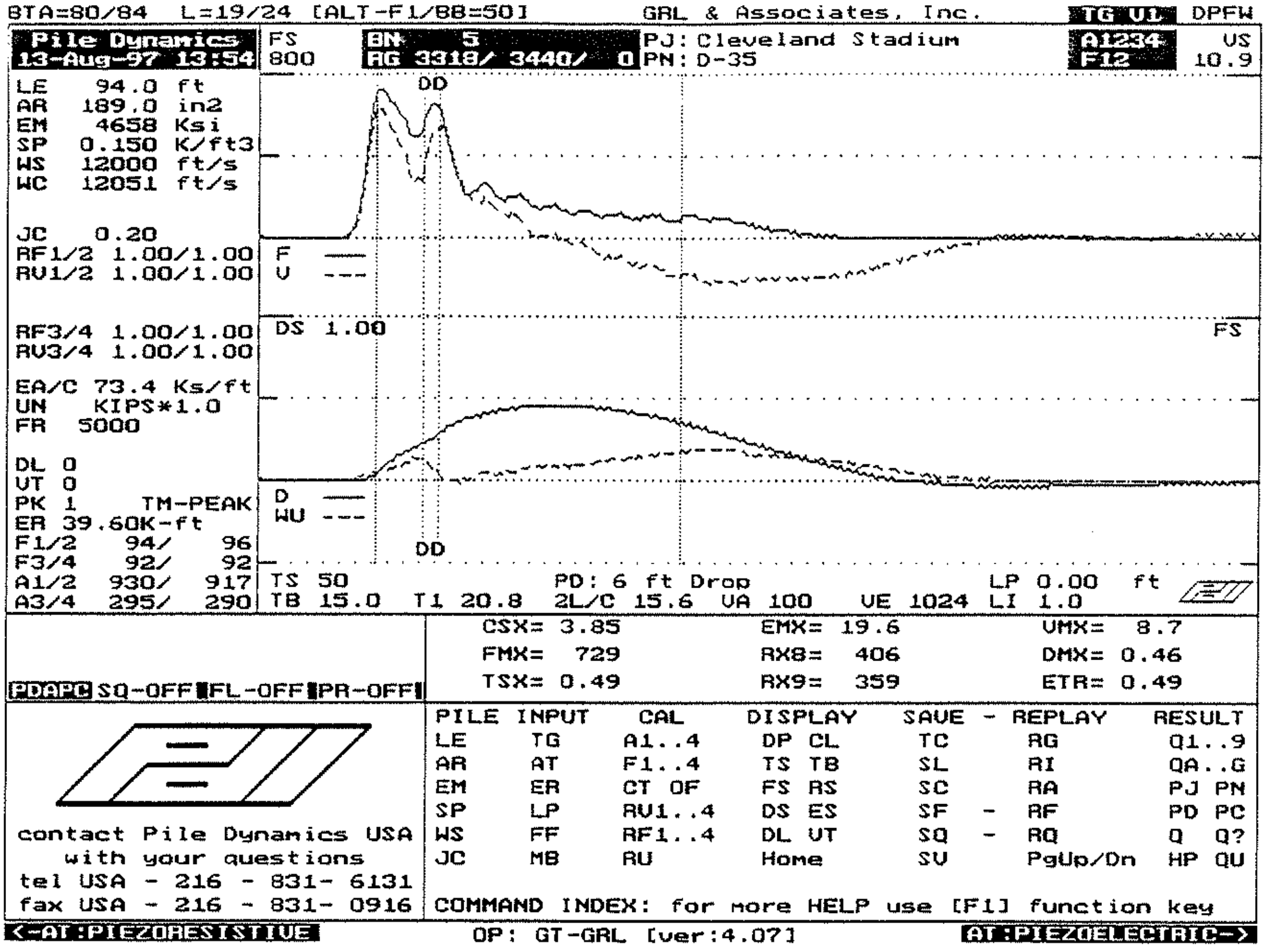

Fig 2e: 6 ft drop

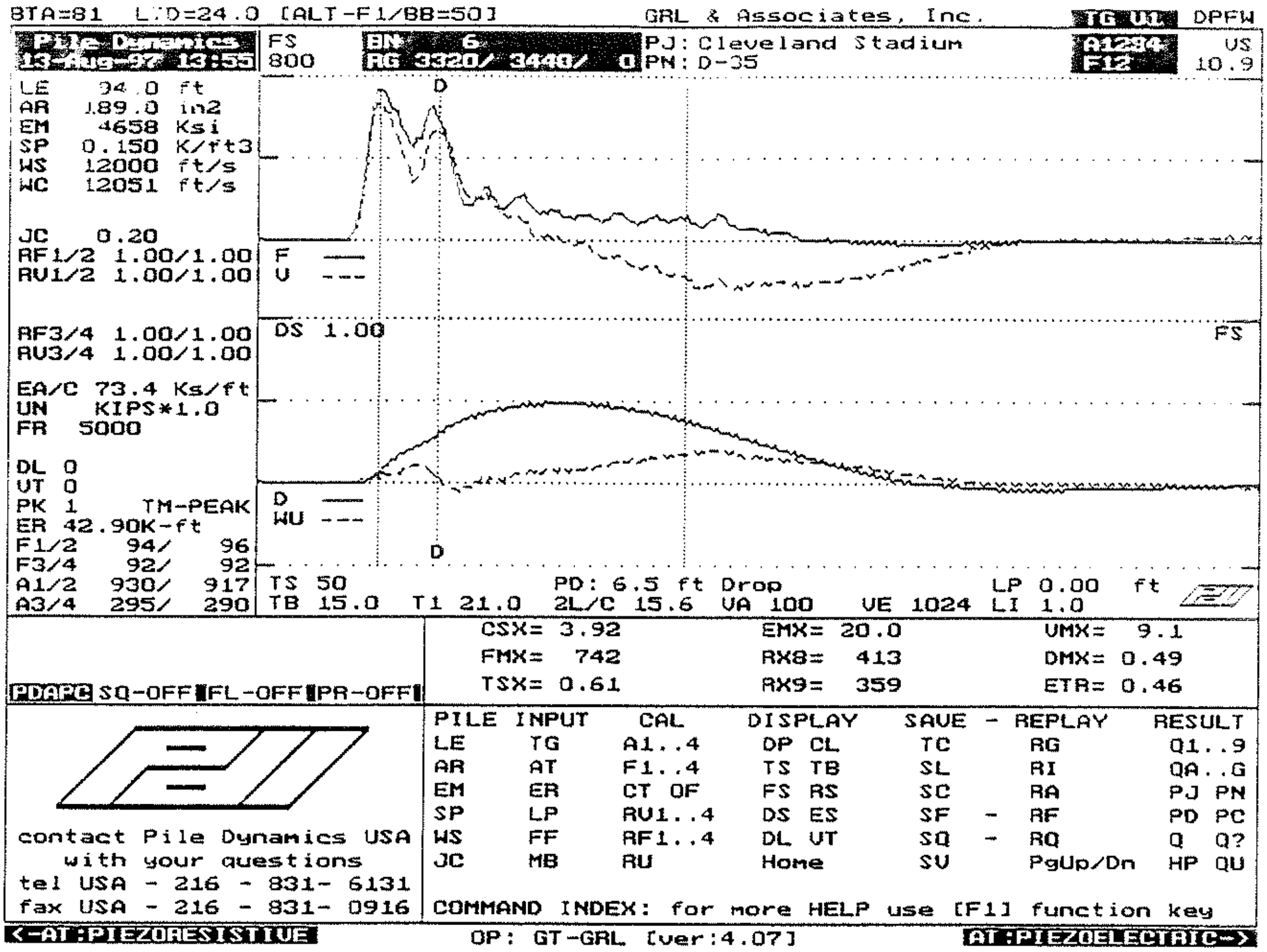

Fig 2 f: 6.5 ft drop
- last blow

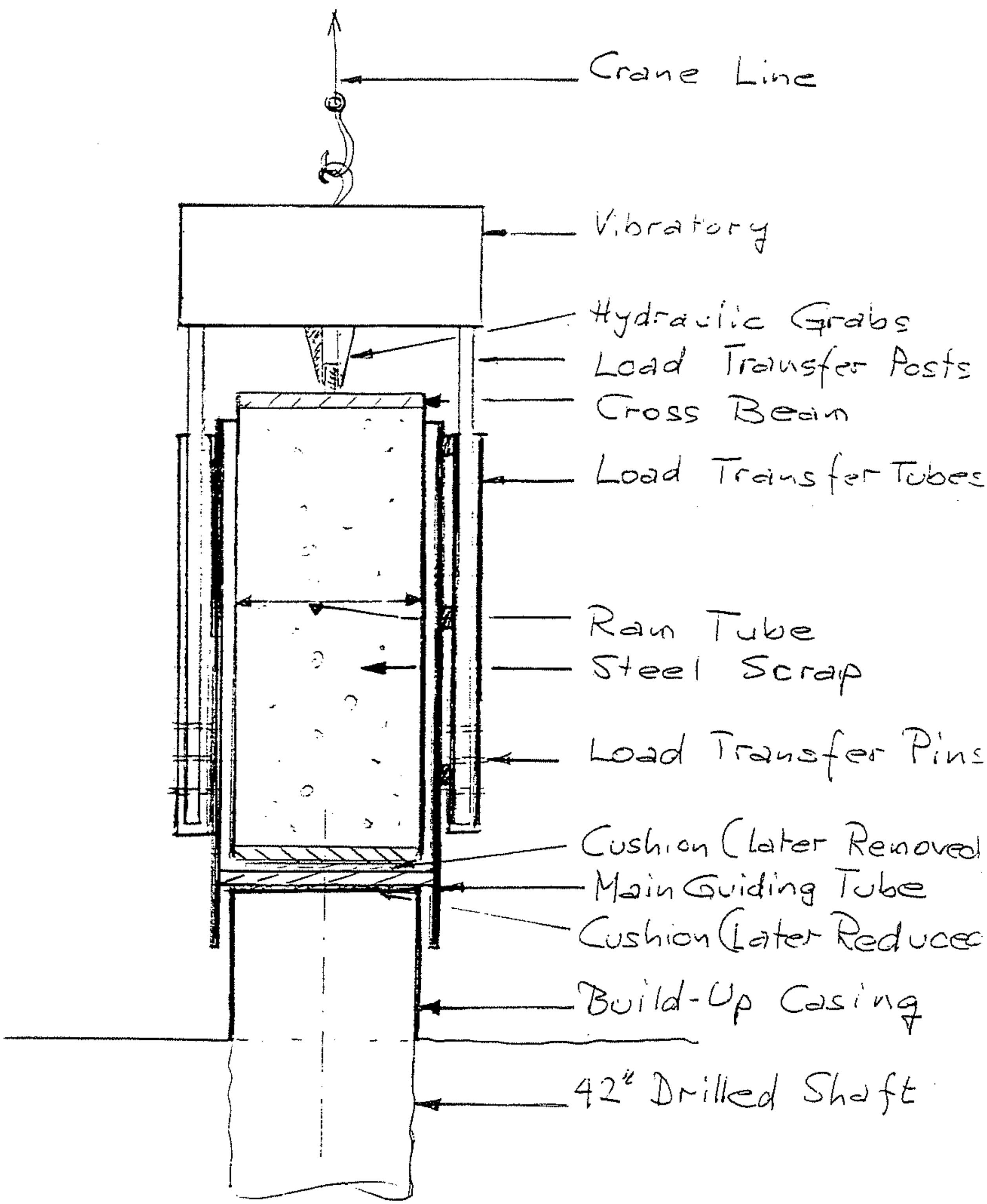

Figure 3: Dynamic Loading System for 42" Shaft

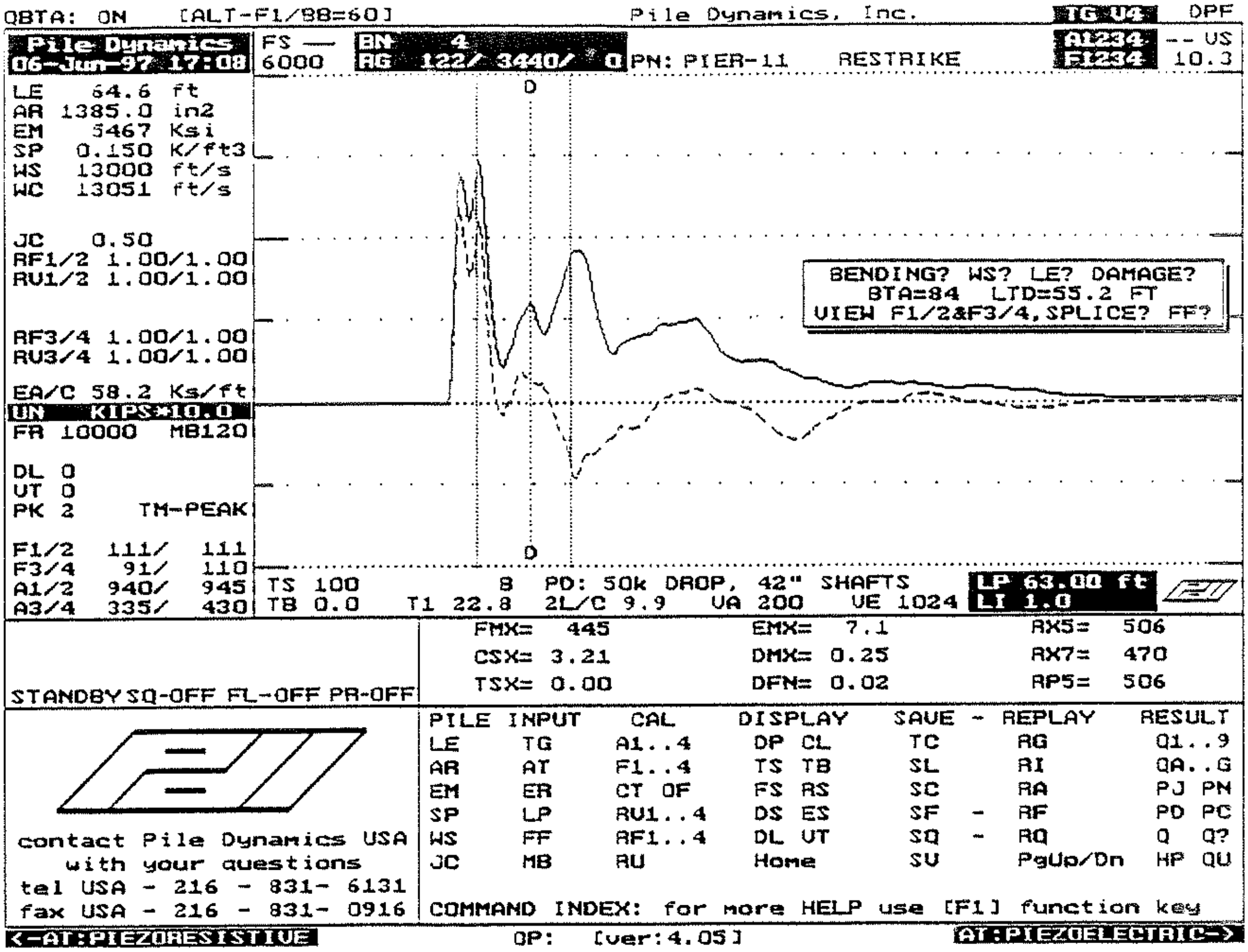

Figure 4: Typical 42" shaft record.
(Damage indicated rock socket)

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