Stressed-out Concrete Piles

The Effect of Diesel Hammer Combustion Chamber Pressure on Tension Stresses in Concrete Piles

By George Goble and John White

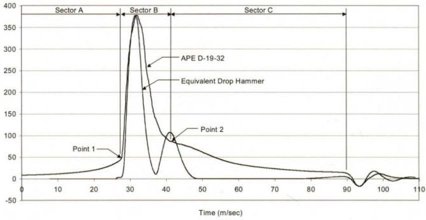

Figure 1: Force Records for APE-D-19-32 and an Equivalent Drop Hammer at the top of a 400 Foot Long

Some piling contractors and engineers have observed that diesel hammers seem to have fewer problems with tension cracking in concrete piles than similar external combustion hammers. Certainly this view is not held universally, but it caused us to consider why such an effect might be true. Routine Pile Driving Analyzer (PDA) measurements have indicated that the stress wave induced by a diesel hammer seems to decay more slowly than would be expected from a theoretical analysis. Since the difference between the two hammer types is primarily combustion chamber pressure, we asked the question, "What is the effect of the combustion chamber pressure on the stress wave immediately following impact?"

A small study was undertaken to investigate the stresses induced by the combustion chamber pressure immediately after impact. In the first phase, we sought to compare the induced stress wave from a diesel hammer and a comparable external combustion hammer. Due to the complexity of the problem the only means of examining the question was to use wave equation analysis. All of the analyses presented here were made using GRLWEAP 2002-1.

In order to easily separate the induced (downward traveling) wave from the reflected wave, a 400-foot long concrete pile was analyzed. Of course, such a long pile is unrealistic from a practical point of view, but it shows the input compression wave at the pile top without the effect of a reflected wave. A 12-inch square concrete pile section was used with an APE D-19-32 diesel hammer and an APE driving system with a three-inch-thick plywood pile cushion. The pile was embedded in the ground 20 feet with a total soil resistance of 100 kips. The rather large soil resistance was necessary to carry the total weight of the pile, hammer and driving system. Since only the downward traveling wave was of interest the characteristics of the reflected soil resistance was of no consequence so long as it was not reflected back to the pile top on top of the induced downward traveling wave.

The force induced at the pile top by the APE D-19-32 is shown by the solid line in Figure 1. The force during the time shown in Sector A is the pile top force due to the diesel hammer pre-compression force. The ram has moved past the exhaust ports and is compressing the air in the combustion chamber and exerting a force on the pile top. Impact occurs at Point 1 on the curve inducing a force that continues to Point 2. Sector B represents the force at the top of the pile from the time of impact to the time of ram separation. During this period pile penetration can be induced by the large force coming from ram impact. After about Point 2 the ram has separated from the impact block. Actually, the point where the ram and the impact block separate is not clearly defined in the force record. Sector C is the period from ram separation from the impact

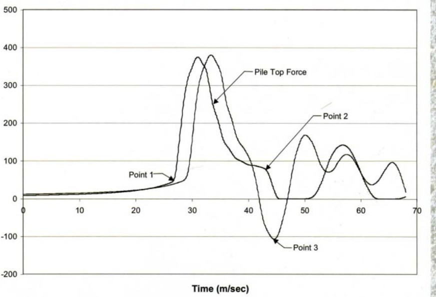

Figure 2: Force Records for the APE-D-19-32 Driving a 100 Foot Long Concrete Pile

block to the arrival of the reflection of the impact wave back from the toe of the pile. The force during this time comes from the combustion chamber pressure.

An equivalent drop hammer was created in GRLWEAP to compare with the diesel hammer results. The drop hammer ram was given the same geometry and weight as the ram and impact block of the APE D-19-32. This drop hammer was then dropped on the pile top using the same helmet and cushion as was used in the diesel hammer analysis described above. The stroke was adjusted to obtain the same peak impact force as was generated by the APE D-19-32. The force generated at the top of the pile by the drop hammer is shown in Figure 1 by the light line. The double-humped record at impact is probably due to the dynamic interaction of the ram, pile cushion and helmet. There is a slight similar effect at about the same time in the diesel hammer record in Figure 1, but almost all of the effect is probably smoothed by the combustion chamber pressure.

After the impact, the drop hammer force stays constant at zero until the arrival of the toe reflection. The slow decay of the induced force after the impact event for the diesel hammer provides a continuing downward compression force input that when superimposed on the upward reflected tension stresses results in a reduced magnitude of net tension stresses along the pile. This reduced net tension is directly attributed to the long extended downward traveling compression wave coming from the combusted gas in the chamber.

A more realistic example was then analyzed using the same two driving systems with the same 12-inch concrete pile, but with a length of 100 feet. The same soil

resistance was also used. The results of the analysis of the APE D-19-32 are shown in Figure 2. The solid line is the force at the pile top. Point 1 is the beginning of impact and Point 2 is at the time when the tension reflection first arrives back at the top, causing the force to go to zero.

The force records for each analysis element along the length of the pile were examined to locate the element with the largest tension stress. It was located about 30 feet from the top of the pile in element 10, and the record for that element is shown by the light line in Figure 2. The maximum tension force was 106 kips or 736 psi at Point 3. (Note: This tension is not a usual problem as usually the prestress is larger than this, so no true tension exists in the concrete itself.)

The last example analyzed used the equivalent drop hammer on the same 100-foot-long pile. The results of the analysis are shown in Figure 3. In this case, the maximum tension force occurred in Element 21, about 30 feet from the bottom of the pile as shown by Point 1 in Figure 3. The maximum tension

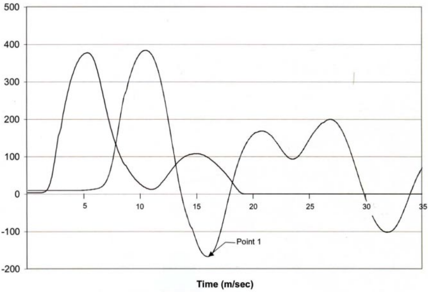

Figure 3: Force Records for the Equivalent Drop Hammer Driving a 100-Foot Long Concrete Pile

force was 166 kips or 1,150 psi, more than 50 percent larger than the same case driven by the diesel hammer.

This brief example showed the effect of the "stretching out" of the compression force in the stress wave by the normal operation of a diesel hammer. It can be expected that this effect can substantially reduce the possibility of tension

cracking and damage in concrete piles driven with diesel hammers when compared with a similar external combustion hammer. This effect is determined by the usual GRLWEAP analysis. This study shows that arbitrary limitations on pile-ram weight ratios often contained in pile driving specifications are not appropriate for diesel hammers. It is essential that a wave equation analysis must be made to evaluate possible tension stresses during the driving concrete piles.

George Goble is principal of George G. Goble Consulting Engineer, LLC, located in Boulder, Colo. He can be reached for questions or comments by phone at 303-494-0702, or by e-mail at goble@bridgetest.com.

John White is president of American Piledriving Equipment, located in Kent, Wash. He can be reached for questions or comments by phone at 253-872-0141, or by e-mail at johnw@apevibro.com. ▼