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Discussion: Observed increases in offshore pile driving resistance

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The paper gives useful guidance, which accounts for the effect of delays in driving, for the selection of hammer size for offshore piles driven into the soil types covered. However, a few practical considerations should be borne in mind.

Archival pile driving records from the North Sea, where steam hammers were used, have been reviewed in the paper. Today, however, it is much more common in the offshore environment, as elsewhere, to use hydraulic hammers, which are a lot more efficient.

Steam hammer performance, particularly in terms of stroke (ram fall height), will have been estimated visually by an observer, and the results of this are, in this discusser's experience, likely to have been somewhat subjective, and to vary from observer to observer. Steam hammers at initial start-up on a pile are generally not warmed up, and thus are not working at optimum efficiency. The timing may not be correct, which can also significantly affect the drivability. New cushion blocks may not have bedded in fully. Add-ons or followers will change the configuration, and may lead to greater energy losses, particularly for piles driven through raked (or 'battered') legs. Thus it is likely that part of the increase in blow counts experienced after a delay relates to the hammer performance and/or pile configuration, etc., and not to the soil. In terms of ensuring that a sufficiently large hammer is available offshore, many of these considerations regarding back-analysis of driving records will, of course, tend to make the hammer selection more robust.

Offshore piles are now more frequently driven vertically through relatively short sleeves, under water, with hydraulic hammers, and without the need for followers, thus reducing energy losses compared with steam hammers driving piles with followers through jacket legs on a batter.

Hydraulic hammers, in contrast to steam hammers, are typically instrumented, and data on impact energy are recorded automatically. Blow count recording does, however, still rely on personnel pressing a button at the exact moment that a 0·25 m mark on the pile passes some reference point. If the driving is performed under water, and the blow count is recorded done from an untethered, remotely operated vehicle, then there can still be some uncertainty, even in this seemingly simple task.

The authors of the paper wisely do not claim that the data can be used directly to estimate long-term axial pile capacity under static or quasi-static loading. Unlike onshore piling, offshore piles are not routinely load-tested to enable a reliable site-specific correlation between driving behaviour and measured axial capacity to be established and, as noted by the authors, the mechanism involved during driving of pipe piles (essentially unplugged) differs from that during quasi-static environmental loading (essentially plugged), notwithstanding any rate or time effects. Also, in this discusser's experience, there appears to be some scope for arriving at non-unique solutions from the back-analysis process.

Authors' reply

The authors thank Dr Hobbs for the comments and interest in our paper.

We agree with the point raised by the discusser that modern pile driving hydraulic hammers are efficient, and are often fitted with internal monitoring equipment. This equipment provides information on many aspects of the working of the hammer, including the ram energy at, or just before, impact. However, it is exactly the delays for add-ons and cushion changes with steam hammers that have given rise to the data on set-up during delays while using these hammers.

The discusser notes that there is a hammer warm-up and cushion bedding-in period that needs to be taken into consideration when back-analysing pile driving by steam hammers. The authors can confirm that this was taken into account when making estimates of SRD (static resistance at time of driving) after delays, in that SRD values were back-figured not from the initial blows after restart but typically from the blow count after a further 0·25 to 0·50 m of driving. Some inefficiency in energy transmission between followers, as noted by the discusser, was also assumed in the analysis when followers were added.

The authors agree that there can be uncertainties or subjectivity involved in obtaining information of pile driving data or soil parameters, which may lead to non-uniqueness of the specific conclusions related to the percentage increase in SRD. However, the broad conclusions that can be drawn from the dataset are consistent with the theoretical expectations.

(*a*) Immediately after installation, the soil surrounding the pile is severely disturbed, owing to undrained shearing and remoulding. For soft clay, the contractant behaviour tends to result in positive pore pressures developing. On the other hand, in very stiff clay, dilatant shearing may lead to negative excess pore pressures. This difference may explain the relatively higher SRD increase for shallower pile penetrations or softer clays.

(*b*) The mechanisms related to the dissipation of excess pore water are highly non-linear, and the rate of dissipation of excess pore water pressure is also not constant. It is interesting to note that there is generally a higher degree of scatter in the initial 7 – 10 h.

The authors can confirm that offshore observations indicate that most large-diameter steel pipe piles drive unplugged over most or all of their penetration. This is considered to be due, in part, to the inertia of the soil plug, which encourages slippage to occur between the pile wall and the soil plug.