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UNDERWATER PILEDRIVING.
TODAY'S EXPERIENCES AND WHAT IS ABOUT TO COME

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Summary

In late 1974 the first offshore pile was driven underwater in the Gulf of Mexico in 92 m water depth. A 0.6 m O.D. pile was given its 76 m penetration into the seabed. It was the very first real underwater hammer, seated immediately on top of a pile without any intermediate follower.

Driving took place completely submerged and full remote controllability was proven. It was a Hydroblok hammer that set this world record.

Subsequently in 1977 the heavy 190 m long 2.13 m O.D. piles for Shell Oil's Cognac Deepwater Production Platform were very successfully driven in record time to their 152 m penetration in 320 m deep water of the Gulf. Pile and hammer-handling were of a highly sophisticated nature.

At about the same time another Hydroblok hammer drove 1.22 m O.D. piles in the 37 m deep South China Sea. Handling here was simplified as much as possible.

The projects, given here as practical illustrations of two very different set-ups had one thing in common; there already was a structure on the seafloor prior to driving that provided laterally stability.

Is it possible at all to drive a pile underwater without such a template? The answer is 'Puppet'-system; this contribution deals with this system in particular. In late 1978 the first laterally unsupported free standing piles were driven in the North Sea; their purpose is to serve as subsea anchor piles.

Looking into the immediate future, the scene shows quite a number of interesting new developments such as driving conductor piles in early production systems, batter platform piles not requiring followers, nor guide bells, anchor piles in waterdepths of 1000 meter or more.
Although this contribution focuses on underwater piledriving, a good understanding of its prior development is thought to be useful. Publications in the past contain most of this knowledge already in some scattered form. Here, however, an effort will be made to show how logical the developments really were that have ultimately led to our abilities today. It could very well be that corresponding logic may as well stretch further into the future.

Driving piles is a very old technique. Dropping the ramweight on top of a pile has two major aspects;

- the top of the pile experiences a force (tons) during impact, and
- energy of the ramweight (meter.tons) is transferred into the pile to be converted into pile penetration.

Pile penetration means that the soil near the pile toe must be given plastic deformation. Dimensions and material of the pile also have their specific influence on the driving result. It is evidently not only the hammer that governs the process, it is the interaction between hammer, pile and soil immediately following the moment of impact. Decreasing the dropweight of a drophammer not only reduces the energy of the hammer, but also results in a reduced impact force, so energy and force are interdependent in that case.

Research of these phenomena has given birth to the Hydroblok-principle, where a specially designed pretensioned member is interposed between the ramweight and the pile (ref. 1 and 2). This member can either be built in the ram or in the anvil. The patented Hydroblok buffer can be remotely controlled between a minimum and a maximum force, the force being available immediately at moment of impact. It is called the "impact force" and its value in tons or kips can be read or recorded on the control panel of the operator. It is this Hydroblok buffer that makes energy and force independent of each other, with the effect that the impact force-value can be changed while the impact energy level remains constant. The lower the impact force is chosen, the longer the period of time will be that this force remains active on the pile. And it has been found that in many cases it is the longer duration that leads to greater penetration. This is the clue which explains the short driving times of Hydroblok hammers. (ref. 3 and 4). In addition the larger number of blows per minute when compared with other hammers also adds to the high performance.

Table I shows the calculated results made for a particular case. For a given pile in a certain soil condition, the penetration result was analysed for various impact forces, all with the same impact energy. It is interesting to see that it is not always the highest impact force that must render maximum penetration.

Fig. 1 shows the calculated impact-force-time-diagrams and also the measured impact-force-time-diagrams. The calculations were performed for the Hydroblok HBM 4000 in the design stage before the hammer was built. The measurements were taken later during testing of one of these hammers on a pile of 2.13 m diameter, 32 mm wall thickness as part of the commission-procedure to the client. Comparison of the diagrams shows that the mechanical model that is adopted for the design of hammers is close to reality. This proves that hammers can be designed to serve a particular well-defined purpose. In the case of the HBM 4000 the design diagrams have been sent to a number of non-partial representatives of oil companies and certifying organizations, who sponsored part of the tests, before these hammers were built and prior to the actual tests. Fig. 2 shows the HBM 4000 on a 1:5 batter pile.
WHY HAS UNDERWATER PILEDRIVING BECOME POSSIBLE?

Though the objective of the Hydroblok research has originally been the achievement of a better piledriving performance, its side-effects have been many, some evidently opening wide perspectives to its future use underwater (ref. 5 and 6).

In this respect the following aspects should be mentioned here.

- Because of the built-in buffer (Fig. 3) an all-steel anvil could be introduced to transfer the energy and the force in a steel-to-steel manner from the ram into the pile, not requiring any capfilling material. Apart from considerable losses in such material which have a negative effect on performance, its replacement at regular intervals prevents such a hammer being used as an underwater tool.

- The built-in buffer protects the hammer from excessive stress and strain. At the moment of impact shock-waves start to travel not only in the pile, but also in the hammer. Now peakforces are controlled by the buffer and consequently kept within acceptable limits. This makes it possible to design the various hammer parts properly for fatigue. Extensive stress and strain calculations have been performed, both statically and dynamically, the latter being based on known impact speeds of the various colliding hammer parts.

- Extensive test measurements during actual piledriving have proved that these complex calculations correctly assess what happens in practice. Only after this research-phase is over can it be expected that the hammer is designed as a reliable tool, suitable to be used underwater during longer periods.

- The built-in buffer can be remotely controlled, its force being constantly indicated or recorded. Kinetic energy of each blow at the moment of impact is also automatically measured, displayed and recorded. Any type of operation that takes place out of sight or sound can only be mastered when certain key values that change during the operation are numerically known. This also applies to driving piles underwater.

- Another indispensable item in the underwater piledriving development is the pilesleeve, located in the lower part of the hammer (Fig. 3). In the topsection of the pilesleeve the flat-bottom anvil is captively held, the bottom generally serves as an open conical guide-bell, which continues into a cylindrical part that serves the purpose of guide onto the pile. In this way the Hydroblok hammer can be guided on the upper part of a pile, thereby securing a perfect square in-line transmission of the driving force from the ram into the pile. Also raked piles with a batter of 1:5 that have sufficient lateral support from themselves can be driven in this way; the hammer does not require any additional support or guide.

- Being seated on top of the pile the hammer can be started to drive. Built-in safety devices automatically stop the ram-movement immediately at the moment that a "no-go" situation occurs which could damage the pile-hammer system, as for instance when the pile starts to run. As soon however as the "go" situation restores, the driving of the hammer restarts automatically or can be restarted manually if preferred.

- The pilesleeve has also provided the possibility of lowering the pile with the hammer on top as one unit in one simple operation. Certain provisions prevent the hammer from losing the pile during their mutual descent. Shortly after the driving has started the temporary connection between the hammer and the pile is disconnected allowing the hammer to be retrieved. These provisions have been used for instance in the North Sea Piper Field, where heavy subsea anchor piles have been driven.

Not before all the mentioned aspects were satisfactorily solved, could one think of driving piles in greater waterdepths; this phase was reached in 1974.
FIRST REAL UNDERWATER PILEDREADING

Confidence in 1974 was such that the moment neared for the Hydroblok to be baptised. On September 17, 1974 for the first time a pile was really driven underwater; an HBM 500 type Hydroblok hammer, operating underwater, made a 0.6 m diameter pile penetrate 76 m into the seabed in the Gulf of Mexico. The water depth was 92 m. For nine hours the hammer remained underwater, of which 5 hours actually driving, twice interrupted to remove a temporary support. Driving was terminated with 305 blows per foot (Fig. 4). This successful test operation proved that all "technical philosophies" and their materialisation were correct so far and that the underwater piledriving process could be remotely controlled. At that time all parties, amongst which were the Shell Oil Company and McDermott, were convinced that this type of hydraulic hammer was the appropriate tool to secure the largest platform ever built to the seafloor. At the same time it also became evident that much consideration still had to be given to handling procedures for so large an operation as Cognac (Fig. 5).

PILES IN SHELL OIL'S COGNAC PLATFORM

190 m long piles in one length were to be driven 150 m deep into the seabed to render ultimately more than 6500 tons safe bearing capacity each; the HBM 3000 A type Hydroblok hammer was chosen for the purpose. We will not repeat here what has already been published in many periodicals and technical papers about this extremely interesting project, where so many new as well as sophisticated techniques were used. The piledriving turned out to be a highly successful operation, performed in record time; the last 18 out of a total of 24 of these giant piles took 21 days.

Not yet published before are the basic keys to this successful underwater piledriving in over 320 m water depth. Within the framework of this contribution only a few of these technical philosophies that have formed the basis of the chosen technical solutions for the various handling aspects, will be mentioned.

DESIGN PHILOSOPHY

The first step in tackling any technical problem involved is to analyse the problem in order to isolate and identify more or less self-contained partialities or sub-problems (problem areas). Maybe it is more fashionable to speak of "system-analysis" and "sub-systems". At their interfaces, the sub-systems are linked, and combined they form the complete system (which on its term always can be perceived as a sub-system of another even bigger system).

At this stage it is of crucial importance to identify clearly the one or two most critical problem areas. These must be solved first and in general little or no compromise can be accepted here. They provide the boundary conditions which will govern the solutions of the remaining problems.

Piledriving, and specially so under water, proves to be a sub-system which cannot be tackled as a self-contained problem. One has to look at the links at the interfaces of adjacent problem areas.

Let us examine Shell's Cognac Platform. The main problem, though in itself not to be underestimated, is not how a 190 m pile should be driven to a penetration of 150 m. Nor is in itself the main problem, how this should be done under water. No, on the contrary, driving heavy piles and doing so under water were problems that, in principle, were solved at that time.
The real critical problems were "How do you get the pile and hammer down?", "How do you retrieve equipment?", "How do you control and monitor the operation?". In one word HANDLING and MONITORING; the components were there, but there was no SYSTEM.

Table II shows the problem areas and the solutions that were adopted in this particular application; one or two of these solutions will be highlighted in the following. They may serve as an illustration of the application of the adopted design philosophy.

THE DESIGN PHILOSOPHY APPLIED ON COGNAC

Figs.6a and 6b show one such example. To avoid misalignment problems and bending effects of the extremely slender piles the elevator-idea of Fig. 6b was introduced. Fig. 7 shows the principle of the elevator, in this case carried by 4 cables. The elevator-lines, first used to lower the pile, serve a second purpose after the pile has been stabbed and slipped into the guidepile of the base structure; the 4 elevator lines allow the hammer to be travelled down in a fully guided fashion with a guaranteed failsafe landing on top of the pile. The earlier mentioned pile-sleeve of the hammer provides a perfect seating of the hammer. The next step is to slip the elevator down along the pile, thus allowing the driving to be started. Notice that in case of a hammer failure the hammer is easily retrievable; after repair and/or replacement it can be sent down safely again.

Introduction of the yoke frame (Fig.8) is another example of the systems analysis outcome. During operation the hydraulic hoses, the airhose and the electric cable will run from their hose/cable-drums vertically down through the water to the yoke frame thereby being kept automatically under constant tension by the weight of the yoke frame. From the top of the yoke frame the hoses and the cable are loopwise connected to the hammer (see Figs. 9b and 9c). The 6 m stroke of the yoke frame not only compensated a certain vertical barge movement (heave) but it also gave the operator a certain stretch to drive the pile without the need to unreel constantly; he had a yoke frame indicator on his control desk that showed him the position of the hammer in relation to the yoke frame. Having consumed most of the stroke the operator could unreel another 6 m for the next stretch. This chosen solution resulted not only in a simple operation that could be controlled quickly, but the hoses hanging a hundred and more meters down in the water, kept under a constant tension force, were in this way only subjected to the relatively slow vertical barge movements; they were given the most ideal position at all times during every phase of the operations. Figs. 9a, b and c depict the way how in an early stage the above described "technical philosophy" was developed. Fig. 10 is a picture of what the philosophy really looked like, after it had been fully engineered.

I have described in detail a few items with their background philosophy because they illustrate how we tackled the complexity when faced for the first time with COGNAK Platform underwater piledriving. How we stripped reality as much as possible from all technical complications in order that only the basic problems would remain. It is definitely not a matter of oversimplification but this technique makes the engineer focus on basic problem areas, before real technical details make him nearly drown in the engineering problems.
THE PUPPET SYSTEMS

It was the above type of technique that also rendered the Puppet Systems which make it possible to drive piles under water without any physical support of whatever nature on the seafloor. It has been a desire for many years to be able to drive heavy anchor piles into the seabed without the help of a template to keep the pile upright at the moment of touch-down of the pile toe and during the first hammer blows.

During two years of research, from a variety of methods two were selected for application in practice (Fig. 11):

1. A method where only lateral soil resistance is used to stabilize pile and hammer.

2. A method where a mass, the Puppet Weight, provides self-stabilization to both pile and hammer; this method works independently of soil properties.

Both methods were recently described in detail (ref. 7 and 8); a short outline will be given here.

In a Puppet System piledriving operation the pile and the hammer are temporarily connected for easy lowering of both as one unit. Several well-proven temporary connector systems are available today which do not need any diver assistance.

Puppet System method number 1 can only be employed if soil conditions are suitable. Its principle is very simple; the pile penetrates the soil by selfweight of pile and hammer and lateral soil resistance keeps pile and hammer upright. Theoretically, a pile could be stabbed exactly vertically using this method. In practice, however, deviations from the vertical will occur due to currents and position changes of the vessel during the pile stabbing operation. An analysis method has been developed (ref. 7) to assess the largest possible pile deviation from the vertical after stabbing. Fig. 12 shows one calculated result for Occidental's North Sea Piper field, showing that method number 1 is acceptable. The result is the worst extreme under conditions according to table III. The graph (Fig. 12) shows that even in the worst case pile deviation from the vertical will be less than 4 degrees after stabbing. A further increase of the pile deviation during the first hammer blows may be neglected.

The soil independent Puppet System method number 2 requires two guidelines, running down from the vessel, through the puppet-eyes to the Puppet Weight (Fig. 11). The latter is simply a mass, loosely slipped around the pile and located at a low level, producing a constant tension force in the puppet-weight-guidelines. Once the weight of pile and hammer rests on the seafloor, the force in the puppet-weight-guidelines acts partly on the puppet-eyes thus stabilizing pile and hammer. The self-stabilizing capacity of this mechanical system can be clarified from the graph in Fig. 13 showing the moment of all forces on the system versus the pile's deviation from the vertical.

As long as \( \frac{dM}{d\alpha} < 0 \), the system will be self-stabilizing (moment \( M_\alpha \) and pile angle \( \alpha \) acting in the same direction). This criterion holds as long as pile angle \( \alpha \) remains between the two Re-Stabbing points \( RS \), then the system will always automatically return to the Equilibrium Position \( EP \). Fig. 13 represents the worst case under conditions according to table IV. Fig. 14 shows the two area's to be noticed in practice: the self-stabilizing working area and the re-stab area's. If for some reason (e.g. an unexpected large position change of the vessel) the pile angle \( \alpha \) would come into a re-stab area, the pile and hammer must be hoisted and be re-stabbed again. The example analyzed here shows that a Puppet Weight of 85 ton provides sufficient capacities to stabilize a 168 ton pile plus the piledriving hammer IBM 1500's weight of 78 ton.
FIRST APPLICATION (1978) OF THE PUPPET SYSTEM

In August and September 1978 eight anchor piles were driven into the seabed (Fig. 15) in Occidental's North Sea Piper Field. The nature of the soil at this location was as given in table III. The project was the first of this type and was conducted from the Sedco 445 drillship which is dynamically positioned. Only minor adaptations to the ship's installations were required.

Regular 5-in O.D. drillstring was used as hoist and bumpersubs providing 6.4 m total stroke allowed the regular HBM 1500 hammer to drive the pile without introducing shocks into the drillstring. Remote control of the piledriving operation proved to be an important feature. Adverse weather in the North Sea at this time of the year caused numerous interruptions to operations. The Sedco 445 is not capable of operating in waveheights in excess of 2.5 m and windforces over Beaufort 5-6. An HBM 1500 Hydroblok hammer was aboard and an identical hammer provided a backup. A standard self-supporting skid-mounted powerpack was also aboard. Two hydraulically powered reels completed the system. At the halfway point the heavy anchor chain was preconnected to the pile and some 60 ton of chain was lowered simultaneously with the hammer and the pile.

A complication was the requirement that the pile top had to be well below the mudline after driving. A short "follower" which remained connected to the hammer was re-used on all anchor piles. This solution proved to work well. Specially designed shearpins connected the anchor pile to the follower, allowing the combination of hammer, follower and anchor pile (including chain) to be lowered to the seafloor as a single unit. The shearpin connection was safely broken during the first hammer blows. Before the driving could begin two additional conditions were to be met:

- The connection of chain to pile required correct orientation; the Eastman Whipstock System solved this problem satisfactorily.
- Verticality of the pile had to be checked; the Regan Bubble System proved to be a good tool for the purpose.

On one pile the hammer had to be retrieved before final penetration was achieved. Relanding at a later stage was not a problem using standard equipment and the pile was easily installed. Total time for the first pile was approximately 100 hr, of which actual driving required less than 30 minutes. The last pile took less than 30 hr after crews became acquainted with the operation which had never before been attempted from a drillship. Actual driving times varied from 5 to 30 minutes, with the number of blows varying from 300 to 1800 at an average rate of 60 blows/min. Maximum bufferforce (impact-force) was 15,000 kN, maximum blowcount approximately 300. All driven piles have a final verticality of less than +1 degree.

DRIVING PILES IN VERY DEEP WATER

A logical question that can be asked is whether the Puppet System could be used in "any depth"? After the experience in the 146 m North Sea depth and the prior experience in 320 m Gulf of Mexico the answer can be in the affirmative. In depths up to 400-500 m the presently available equipment and the systems that were used make us believe that such an operation does not pose new problems. For greater depths exceeding 500 m the energy supply in the present form with hoses will become prohibitive, if not from a technical point of view, economics will hardly be acceptable. An underwater powerpack, driven electrically, fed through an umbilical is a possibility that should be engineered, in case of sufficient interest. The Hydroblok hammer itself has all potentialities already at this stage to be submerged to very great depth. Its controllability remains the same.
Underwater piledriving experience is limited as yet; are its prospects promising? As far as the hammer is concerned, the Hydroblok hammer has proved to be an appropriate tool. Performance, reliability, remote controllability, all match the purpose. The underwater operations, done in various parts of the world, were very instructive.

One promising aspect in particular has strongly attracted our attention; it is the behaviour in water of a heavy mass such as a pile or a hammer, or the combination of both hanging from a cable or from a drillstring. We got used to rather uncontrolled, rather rapid movements of large masses in air. Once completely submerged, even influenced by currents up to 2 knots, the behaviour becomes surprisingly calm. Calm in the sense that the movement of the mass (say the piletip) is nearly nil, when the hoistable (crane boom) is kept in place and secondly a horizontal change of the crane boom position results in a very smooth and slow corresponding movement of the piletip: there are no wild movements at all!

The first few meters down from the watersurface in the situation at sea, however, is just the contrary; a mass hanging in this area is often brought in violent movement because of wave action. The forces resulting from such movements are notoriously high and for this reason one tends to think that such behaviour exists all the way down. This has clearly been proved not to be the case. Based on this knowledge, a number of "technical philosophies" were developed that can be fruitfully applied when designing handling systems for a particular offshore situation. With respect to the watersurface area that the pile and hammer must pass, there are basically two principles. The one is, that the energy transferred from the wave action into the mass is accepted as well as the movement resulting therefrom. Such is the case when the mass can be lowered freely through this area without any lateral support, for instance with an offshore crane on sufficient boom-radius, where movements of the mass are acceptable, not causing damage. After being lowered deeper in the water, the mass is automatically calmed down. When working through the moonpool of a drillship, however, only limited movements of the mass can be accepted: a certain guide-system must be designed, that allows all the masses to be vertically transported in a guided sense until they have been lowered deep enough underwater to continue without guide. The guided portion can either be rigid or partly elastic allowing only a certain controlled lateral movement. For applications other than with a drillship a more universal system has been designed; the "Juggler"-system (Fig. 16).

Another problem is, how to land the pile into its pilesleeve, for instance in a cluster of pilesleeves, as is common for skirtpiles of North Sea type platforms. Usually, as long as the driving takes place from above water, the pile and the followers are run down through pileguides connected around the platformleg at regular intervals. After the piles have been driven these pileguides have no function anymore and are often a nuisance.

It has been proposed to design a slim type underwater hammer, its length matching the pileguide spacing. On first sight this looks attractive, except for the handling of the hosebundle, which must pass through the guides as well, which certainly involves unacceptable risks. And there are more aspects that make such an approach less attractive and moreover in the end of such an operation the pileguides are still there, still being a nuisance.

The problem, however, can be looked upon in a different way, utilizing as much as possible the experiences of prior underwater piledriving and the ways their handling problems were satisfactorily solved. Within the scope of this contribution only two points will be described.
Based on well proven techniques, mainly underwater acoustics and underwater television (RCV), a pile can rather easily be lowered in a purely controlled sense. The last few meters are controlled by television. The principle here is not, as is common practice for other applications, to stab concentrically with the sleeve-pile. The lowering of the pile is done eccentrically, well away from the platform leg, until its tip has reached a level, only a few feet above the top of the sleeve-pile; this can be controlled by television (control in z-direction). Then the pile is slowly moved in, thereby controlled in x and y direction. For this purpose x, y and z markings are painted on the horseshoe type catch. The catch is mounted on top of the sleevepile and it is open to one side for easy reception of the pile-tip. The system is applicable for batter skirtpiles as well (Fig. 17).

The second point that I would like to raise is a question. The Cognac Platform (Fig. 5) is always referred to as a 3-part platform. Of course this is correct, because there are 3 parts. But shouldn't it be looked upon rather as a 2-part platform, built on a solid foundation? In conformity with sound engineering principles, as is common practice on land, the first thing one does, is to build a solid foundation, before the structure is erected. I believe that since the availability of a reliable underwater offshore hammer such sound engineering should become common practice in offshore engineering as well. Shouldn't we consider Fig. 5b as such a solid foundation for Cognac's 2-part platform? The question is, whether this is the most economical "solid foundation"? The author, not being a platform-designer by profession, may be excused for leaving this question unanswered here. Would further research in this direction perhaps lead to safer and cheaper subsea foundation techniques, where steel and concrete perhaps may prove to match well?

EARLY PRODUCTION SYSTEMS

Driving conductor pipes in early production systems can be an attractive technique. Conductor pipes with their usual top part configuration can easily be driven with a Hydroblok hammer without being damaged; to prevent a maximum stresslevel being exceeded during driving the maximum allowable bufferforce can be calculated in advance. Accurate verticality is not a problem; all anchor piles in Piper Field (1978) were driven vertically with a tolerance less than ± 1 degree. Driving times are short. A simple template, landed on the seafloor, can be leveled towards its first 3 or 4 cornerpiles, subsequently serving as a guide for all the other piles (or conductor pipes). There is no danger of any disturbance or washout of the soil. No grouting of the conductor into the soil is needed. Because the conductors are driven by a Hydroblok hammer, the soilconsultant is given pertinent soil-information, derived directly from the driving, that enables him to judge the holding capacity of the conductor pipe in the soil. The driving can be done from a drilling vessel (Fig. 18). All piles and conductors being driven, the drilling operation can be started from the same vessel.

PILED FOUNDATIONS FOR TENSION LEG PLATFORMS

Tension Leg Platforms are being studied by many. All have in common that they require a very stable and reliable foundation in/on the seabed, generally in deep water, where inspection is hardly possible. Elaborate studies are well under way to gain knowledge of the behaviour of foundations under cyclic loading. The same applies to piled foundations. Other contributions will highlight these phenomena. They are beyond the scope of this contribution.
There are two contributions, however, that I would like to offer here in relation to TLP-foundations.

Important in this respect is to recall once more, that during Hydroblok-driving a great deal of (dynamic) soil information can be derived. Other recent publications have reported on this subject and there are more to follow, partly based on test-results as they were derived from recent HBM 4000 drivings on an 2.13 m pile on a testsite in the Netherlands.

The other contribution is a system to equally distribute the load over a number of piles (1, 2 or 3). Fig. 19 shows the principle of the PAP-system. The base frame primarily serves the purpose of stabilizing the anchor piles before they are driven. The anchor plate carries the anchorcable(s); the anchorcable-connection can be carefully checked and the cable is coiled before submersion. The anchor piles are driven, and a certain difference in the levels of the gimbals is acceptable. Pulling the anchorcable(s) makes the anchorplate match all gimbals, evenly distributing the anchorforce to all (maximum 3) piles. The baseframe from this moment on has no function anymore, as far as vertical anchorforces are concerned. Pinning the baseframe firmly to the seafloor with separate piles makes horizontal components of the anchorforce not work any more on the vertical anchorpiles. Because of the nature in which TLP-anchorpiles are cyclically loaded, separation of horizontal and vertical force components can be advantageous.

REFERENCES

(1) JANSZ, J.W. "Underwater Piledriver for 1000-ft Depth" Ocean Engineering 1975, November 15, pp 68-76


(3) COX, B.E. and CHRISTY, W.W. "Underwater Pile Driving Test Offshore Louisiana" Offshore Technology Conference 1976, OTC 2478

(4) JANSZ, J.W. "North Sea Pile Driving Experience with a Hydraulic Hammer" Offshore Technology Conference 1977, OTC 2840

(5) HUSSEN, K. van "Submarine Piledriving for Deepwater Installations" Ocean Resources Engineering, September 1977, pp. 60-65

(6) JANSZ, J.W. "Subsea Piledriving: A Breakthrough" Petroleum Engineer, June 1978, pp. 76-86


(8) JANSZ, J.W. "The Puppet System"; A Simple Way to Drive Subsea Anchor Piles" Offshore Technology Conference 1979, OTC 3439
Table I: How variation of impact force with constant energy per blow affects penetration.

<table>
<thead>
<tr>
<th>Impact force in t</th>
<th>1200</th>
<th>2100</th>
<th>3000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portion of energy that pile is able to absorb: in m.ton (in % of net energy per blow)</td>
<td>65 (82%)</td>
<td>74 (94%)</td>
<td>54 (68%)</td>
</tr>
<tr>
<td>Penetration per blow in cm</td>
<td>0.1</td>
<td>2.2</td>
<td>1.4</td>
</tr>
<tr>
<td>Blowcount per ft</td>
<td>300</td>
<td>14</td>
<td>22</td>
</tr>
</tbody>
</table>

Schematic F-t diagrams

- $F_t = $ tons
- $t = $ milliseconds

Hydroblok Hammer, type HBM 3000.
Pile, 84-in O.D., 1.25-in. W.T.
Net energy per blow, constant 79 m.ton (produced by hammer).
Total driving resistance, constant 2100 ton.
Table II: System-Analysis for Shell Oil's Cognac Platform Piledriving.

<table>
<thead>
<tr>
<th>Problem Area</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Piledriving (6 500 ton bearing capacity)</td>
<td>Use hammer with sufficient capacity to be chosen from available types.</td>
</tr>
<tr>
<td>• Under water piledriving (6 500 ton bearing capacity)</td>
<td>Use HBM 3000 A.</td>
</tr>
<tr>
<td>• Lowering pile and hammer</td>
<td>Lower pile and hammer separately. (Not: pile + hammer; too heavy)</td>
</tr>
<tr>
<td>• Lowering pile</td>
<td>Use elevator near top of pile.</td>
</tr>
<tr>
<td>• Lowering hammer</td>
<td>Use elevator guidelines.</td>
</tr>
<tr>
<td>• Landing hammer in desired position</td>
<td>Make guidelines end near top of pile.</td>
</tr>
<tr>
<td>• Alignment of hammer on pile and lateral fixation</td>
<td>Use pilesleeve (Not: driving cage)</td>
</tr>
<tr>
<td>• Retrieve hammer during/after driving</td>
<td>Use elevator guidelines.</td>
</tr>
<tr>
<td>• Allowance for barge-heave</td>
<td>Use yoke frame</td>
</tr>
<tr>
<td>• Allowance for shock-wise movement of driving hammer</td>
<td>Use yoke frame (Not: bumpersubs)</td>
</tr>
<tr>
<td>• Monitor during driving</td>
<td>Use all facilities for remote control that Hydroblok can provide. Redundant. (Not: divers)</td>
</tr>
<tr>
<td>• Monitor during lowering hammer</td>
<td>Not required because of chosen elevator system. (Not: divers)</td>
</tr>
<tr>
<td>• Monitor during lowering pile</td>
<td>Use RCV television and camera at piletip. (Not: divers)</td>
</tr>
</tbody>
</table>
Table III: Data for Puppet System method number 1 as used in Occidental's North Sea Piper Field.

Sea: waterdepth 146 m (480 ft)
current at surface of the water 1.2 m/s (4 ft/s)

Vessel: dynamically positioned with possible position changes 3 m (9.8 ft)

Soil: soft clay; pile penetration by selfweight of pile and hammer: 15 m (49 ft)

Pile: O.D. 1.5 m (60-in)
W.T. 2½-in
length 36.5 m (120 ft)
weight (above water) 84 ton (185 000 lbs)

Hammer: HBM 1500
weight (above water) 78 ton (172 000 lbs)
water displacement 28 m³
magnitude of maximum total soil resistance 27 000 kN (6 000 kips)

Table IV: Data for calculated example of Puppet System method number 2 using the Puppet Weight

Sea: waterdepth 146 m (480 ft)
current at surface of the water 1.2 m/s (4 ft/s)

Vessel: dynamically positioned with possible position changes 1.5 m (5 ft)

Soil: no pile penetration by selfweight of pile and hammer is assumed.

Pile: O.D. 1.5 m (60-in)
W.T. 2½-in
length 73 m (240 ft)
weight (above water) 168 ton (370 000 lbs)

Hammer: HBM 1500
weight (above water) 78 ton (172 000 lbs)
water displacement 28 m³
magnitude of maximum total soil resistance 27 000 kN (6 000 kips)

Puppet weight: steel, weight (above water) 85 ton (187 000 lbs)
Figure 1: Impact Force-Time diagrams.

Hydrofoam HBM 4000; Pile 60 m, 84", O.D.; I.25" W.T.

Figure 1: Impact Force-Time diagrams.

-- measured during test
-- calculated case

No test results available for the exact calculated cases.
Figure 2: HBM 4000 type Hydrobloc hammer, sitting freely on top of the 1:5 batter testpile while driving.

Figure 3: Schematic cross-section of the Hydrobloc hammer showing the built-in buffer and the flat bottom anvil.
Figure 4: Piledriving record of first real underwater piledriving.
Date September 17, 1974.
Figure 5a: Overall dimensions.

Figure 5b: The bottom section to be secured into the seabed.

Figure 5: Shell Oil's Cognac Platform in the Gulf of Mexico, composed of 3 parts.
Figure 6a: WRONG: hammer guidelines leading to base structure create undesired misalignment of hammer downward travel when landing on pile.

Figure 6b: GOOD: elevator lines serving also as hammer guidelines results in small misalignment at pile top.

Figure 6: Design philosophy for elevator.
Figure 7: Elevator on 4 cables, suitable to carry the weight of the pile during its downward travel.

Figure 8: Picture of HBM 3000A on testpile with fully extended yoke frame.

NOTE: The loopwise hose connections between upper part of yoke frame and hammer are not yet connected here.
Figure 9a: Operations Analysis; Topview of hose drum assembly and hammer arrangement.
Figure 9b: Operations Analysis; Hammer on barge deck, hosedrum assembly away from side of the barge.

Figure 9c: Operations Analysis.
Hammer in line with operations §.
Hosedrum assembly ready to be shifted to barge side, allowing the hoses to hang vertically down.
Figure 11: The two basic Puppet System methods.

Method 1
- Hoist
- Puppet-Weight-Guidelines
- Puppet-Eyes
- Hammer
- Pile
- Puppet Weight

Method 2
- Hoist (kept slack)
- Puppet-Weight-Guidelines
- Puppet-Eyes
- Hammer
- Pile
- Puppet Weight

Pile penetrates soil by selfweight and lateral soil resistance keeps pile and hammer upright.

Figure 10: McDermott's barge US 16 rigged up with facilities to handle the pile and to drive them underwater.
pile angle \( \alpha \) in degrees
(measured from the vertical)

extreme condition: full upstream position change
full current

Figure 12: Analysis of Puppet System method number 1; the graph shows pile angle \( \alpha \) versus penetration depth during slackening of hoist for data according to table III.

moment \( M_\alpha \) in kN.m

EP = Equilibrium Position
RS = Re-Stab Position

extreme condition: full downstream position change.
full current.

Figure 13: Analysis of Puppet System method number 2; the graph shows moment \( M_\alpha \) versus pile angle \( \alpha \) for data according to table IV.
pile angle $\alpha$ in degrees

self-stabilizing working area

re-stab area

RS +10.4

EP -3.0

RS -9.4

re-stab area

seafloor

EP = Equilibrium Position
RS = Re-Stab position

Figure 16: Capacities of Puppet System method number 2 for data according to table IV.

Figure 15: Realisation of a subsea anchorpile (North Sea 1978)
Figure 16: JUGGLER-system.
Universal system to pass waterline in a fully guided way.
Figure 17: Open catch type sleevepile entrance.
Figure 18: Underwater driving of conductor pipe in early production systems.
Figure 19: Piled Anchor Point (PAP) System with self-equalizing force distribution for Tension Leg Platforms.