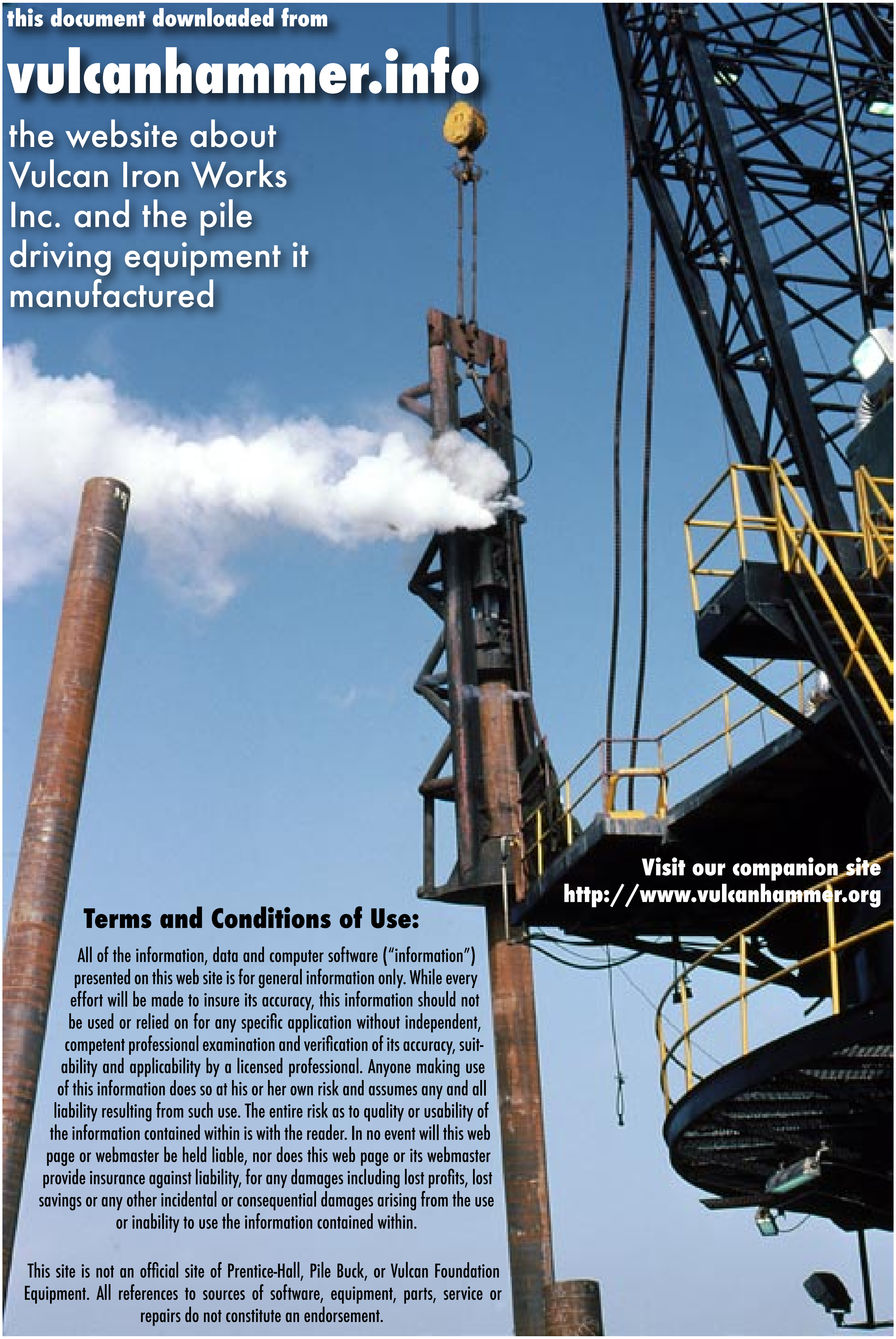

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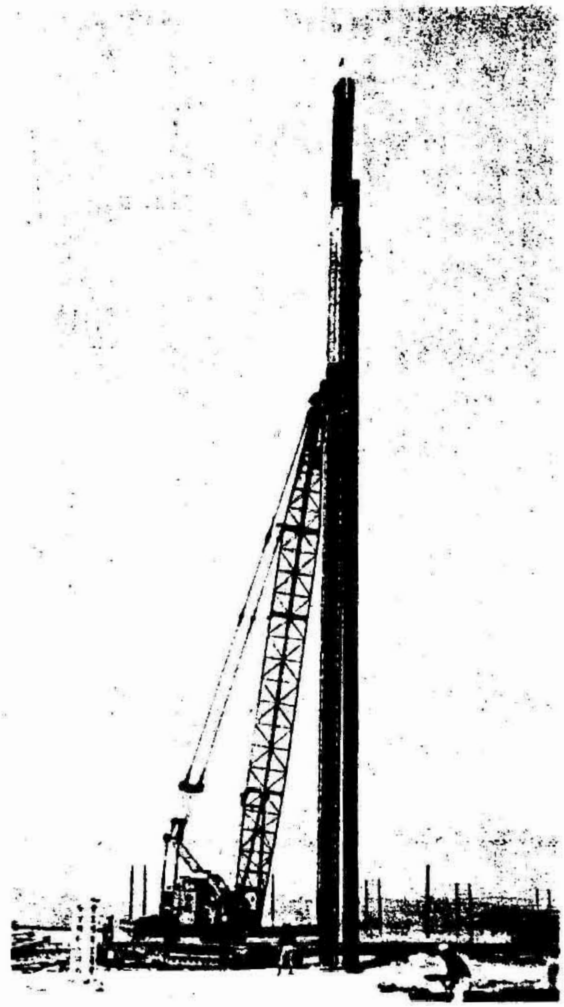


KOBE DIESEL PILE HAMMER

1. Introduction

We pioneered in the domestic pile hammer industry when we introduced our Diesel Pile Hammer No. 1 in 1954, and have established a high reputation in this field. At present we have diesel pile hammer models K13, K22, K32, and K42 in production, the fruit of our wide experience as well as of the ingenious application of data obtained from various tests, and we are proud of the markedly high standard of quality and performance of our products.

The following introduction to our diesel pile hammers is intended for easy understanding by those who are learning about the diesel pile hammer for the first time, and at the same time to furnish professionals with information by including technical data.

Results of research conducted by our engineering staff that have not been disclosed previously are also included.

2. Specifications

Specifications of the various models of diesel pile hammers are given below :

Model		K 13	KB 13	K 22	KB 22	K 32	KB 32	K 42	KB 42
Overall length	mm	3,850	4,500	4,070	4,720	4,150	4,800	4,420	5,070
Total weight of hammer	kg	2,900	2,990	4,800	4,920	7,000	7,190	10,000	10,220
Permissible angle for batter piling	degree	30°	45°	30°	45°	30°	45°	30°	45°
Weight of ram	kg	1,300		2,200		3,200		4,200	
Number of blow per minute	blow/min	45 - 60		45 - 60		45 - 60		45 - 60	
Energy output per blow	kg·m	3,380		6,150		7,800		11,000	
Max. ram stroke	mm	2,500		2,500		2,500		2,500	
Explosion pressure on pile	ton	45		72		100		127	
Fuel consumption (light oil)	ℓ/h	3 ~ 8		9 ~ 12		12 ~ 16		17 ~ 21	
Lubricant consumption	ℓ/h	1		1.5		2		2.5	
Fuel tank capacity	ℓ	40		40		48		65	
Lubricant reservoir capacity	ℓ	5		7		9.5		12.5	
Cooling water tank capacity	ℓ	70		70		130		150	
Lubricant for ram		Motor oil SAE 40 ~ 50		Motor oil SAE 40 ~ 50		Motor oil SAE 40 ~ 50		Motor oil SAE 40 ~ 50	
Lubricant for anvil		Superheated steam cylinder oil		Superheated steam cylinder oil		Superheated steam cylinder oil		Superheated steam cylinder oil	
Bearing capacity of piles driven by this hammer (permanent)	ton	20 ~ 50		30 ~ 100		50 ~ 150		65 ~ 200	

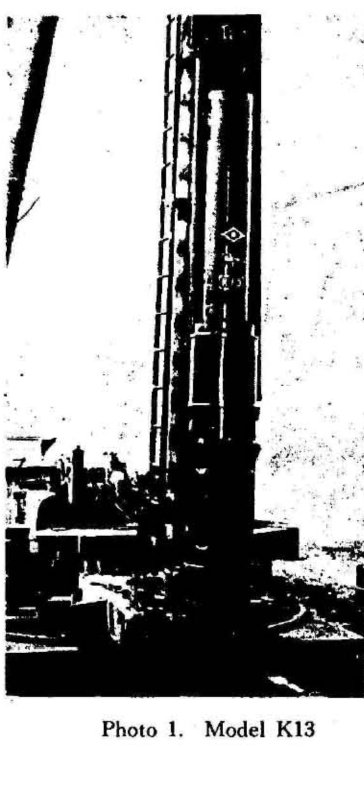
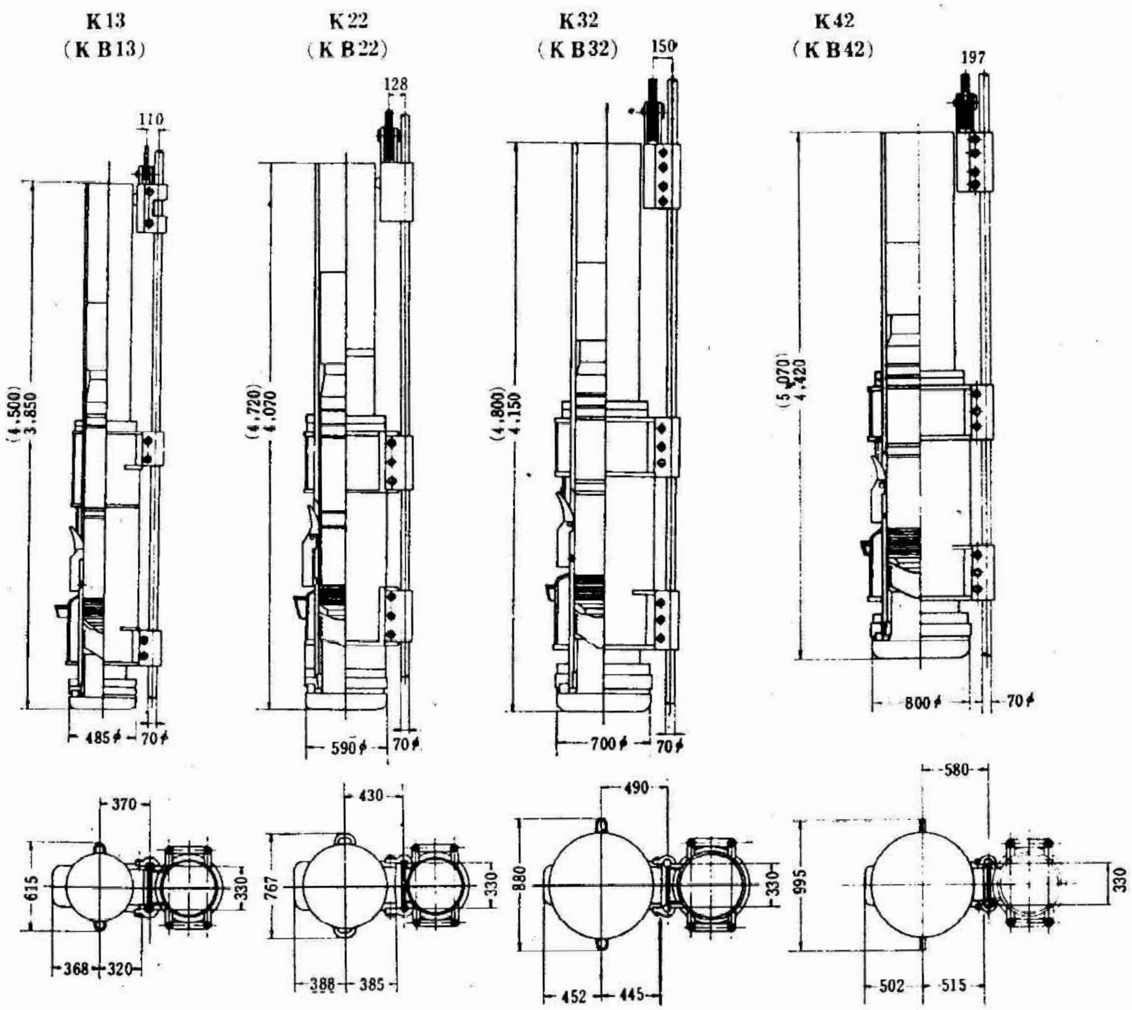


Photo 1. Model K13

Photo 2. Model K22

Photo 3. Model K32



*( ) indicates dimensions of Model KB

Fig. 1 Outside dimensions of Kobe Diesel Pile Hammers.

3. Construction

The diesel pile hammer consists of a vertical cylinder comprised of upper and lower sections, a ram that moves up and down in the cylinder, an anvil at the lower end of the cylinder, a fuel pump and a tripping device, and is equipped with a fuel tank, and a water tank for cooling the cylinder.

The cylinder is lubricated in two parts, the ram and anvil separately. The ram lubricant is fed by the up-and-down motions of the ram from the ram oil chamber at the top of the ram. The anvil lubricant is supplied at 4 grease nipples located around the lower cylinder.

The fuel pump is driven by the up-and-down motions of the ram by means of a cam. When the falling ram reaches the cam, it pushes aside the cam, and the motion is transmitted to a plunger by means of a push-rod, to inject the fuel from the fuel chamber at the bottom of the plunger. (Fig. 2, Fig. 3)

After the explosion, the ram rises and passes the cam which is then returned to its original position by the action of a spring in the fuel pump, and fuel flows from the fuel tank to the fuel chamber.

The throttle bolt regulates the amount of fuel injected. When it is shut, all the fuel forced out by the plunger is injected, bringing the injected fuel amount to a maximum. When the throttle bolt is opened, the back flow of fuel into the fuel chamber increases, thus gradually reducing the

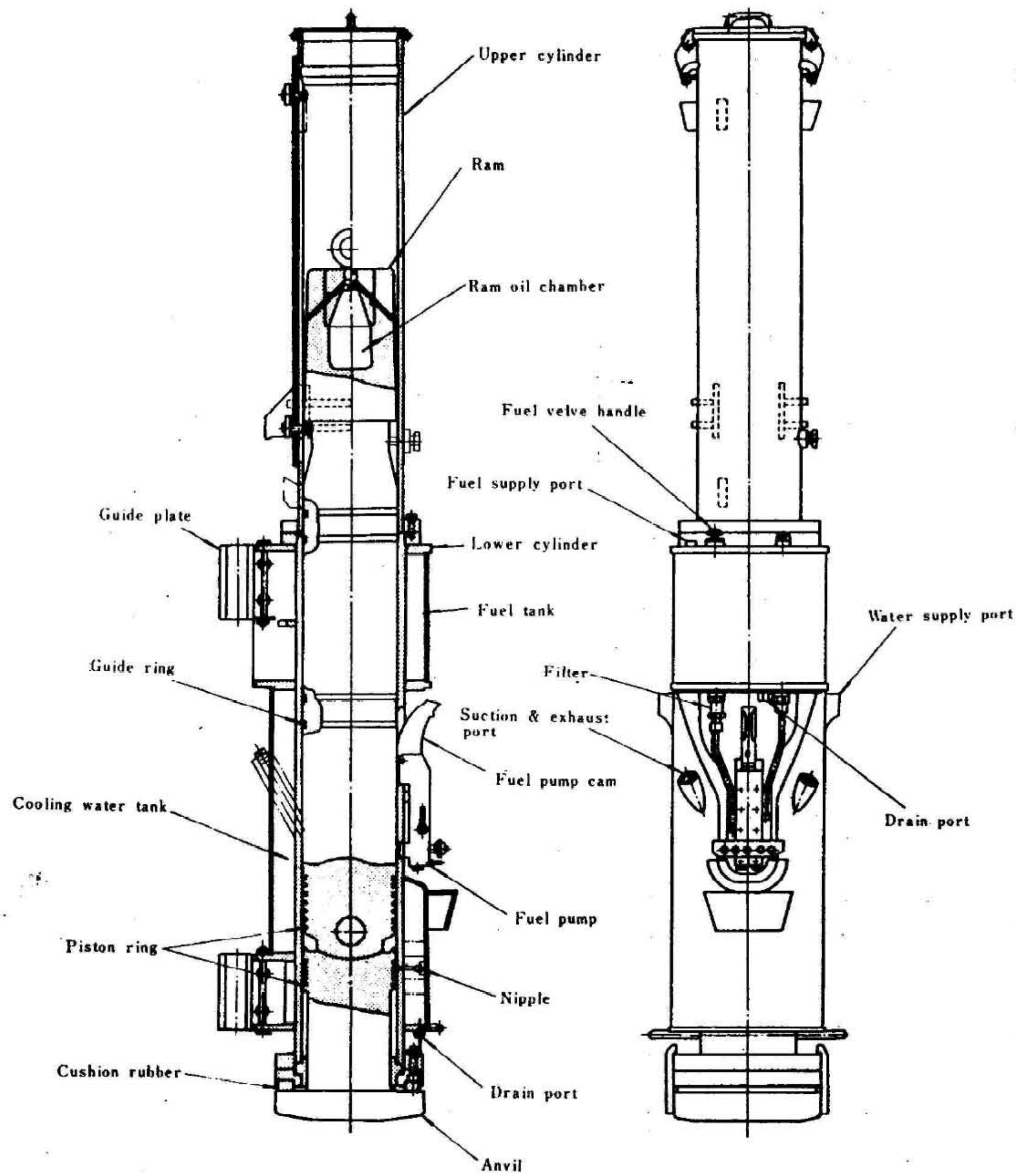


Fig. 2 Construction of diesel pile hammer.

amount of fuel in the injection. The above adjustment is performed by the fuel adjusting lever.

The check valve tip, for preventing fuel from flowing down from the fuel chamber, is opened by oil-pressure at the time the fuel is injected and closes upon being pressed against the valve seat by the action of a spring at the end of the injection. (Fig. 6)

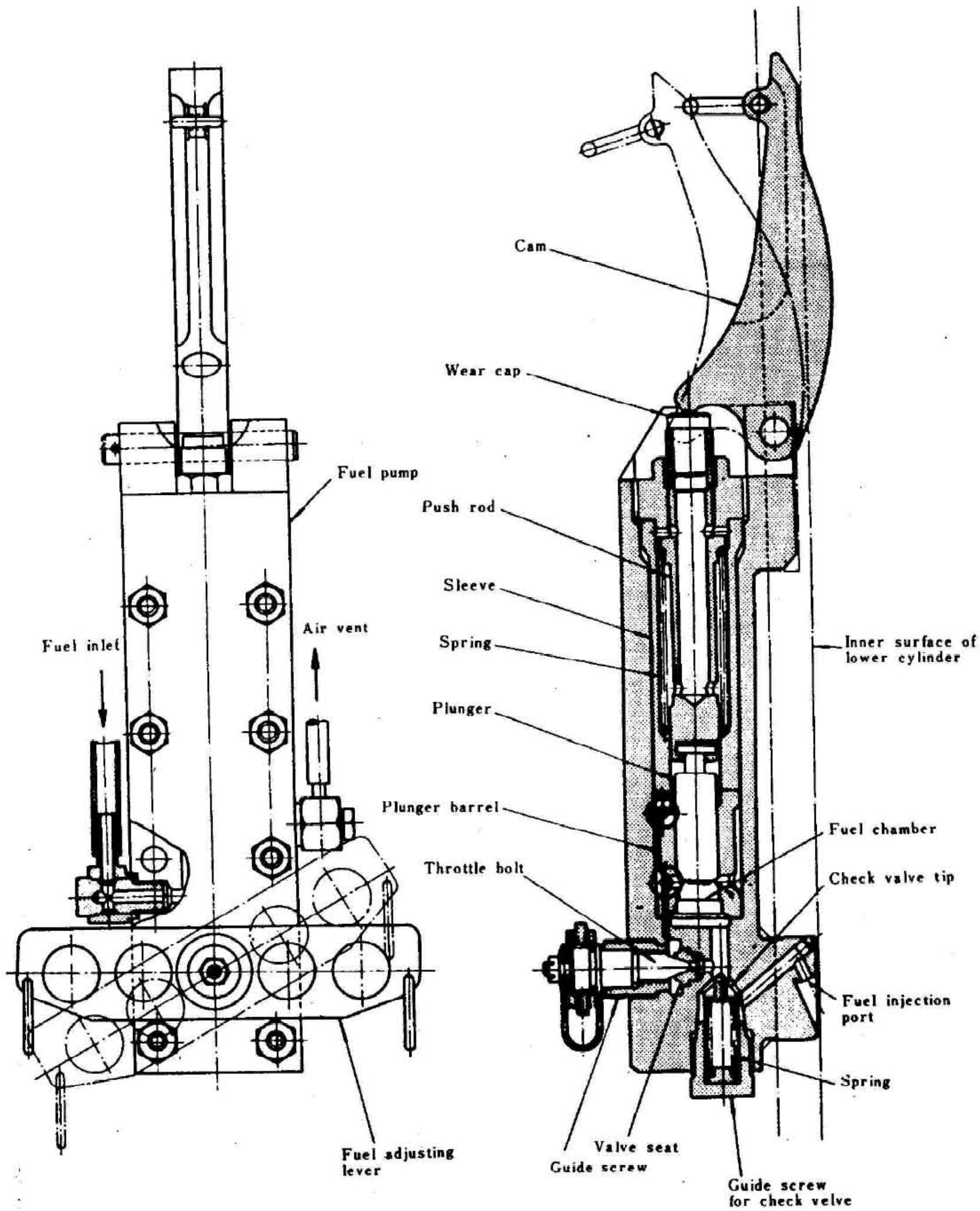


Fig. 3 Construction of fuel pump.

The tripping device consists of two parts, i.e., one for actuating the ram lifting hook and the other for actuating the left and right hammer lifting hooks. (Figs. 4 & 5)

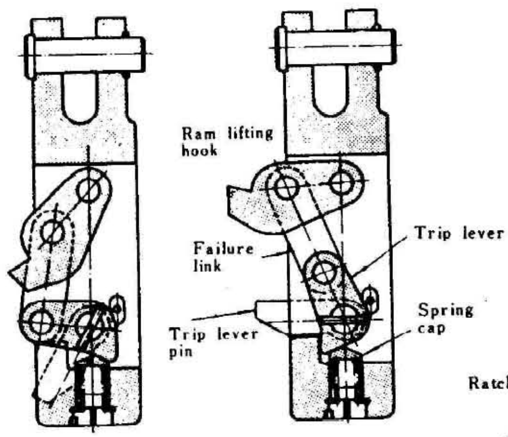


Fig. 4 Function of ram lifting hook.

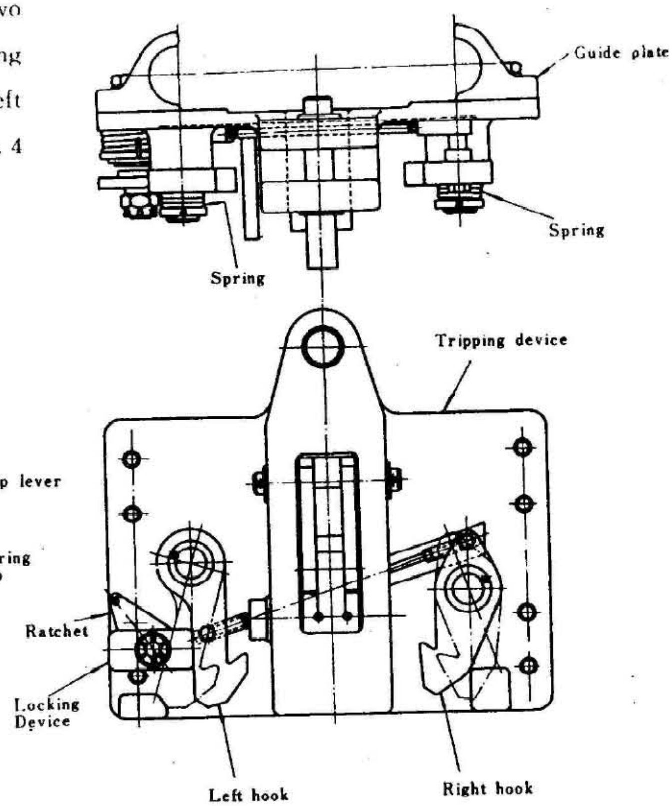


Fig. 5 Function of hammer lifting hook.

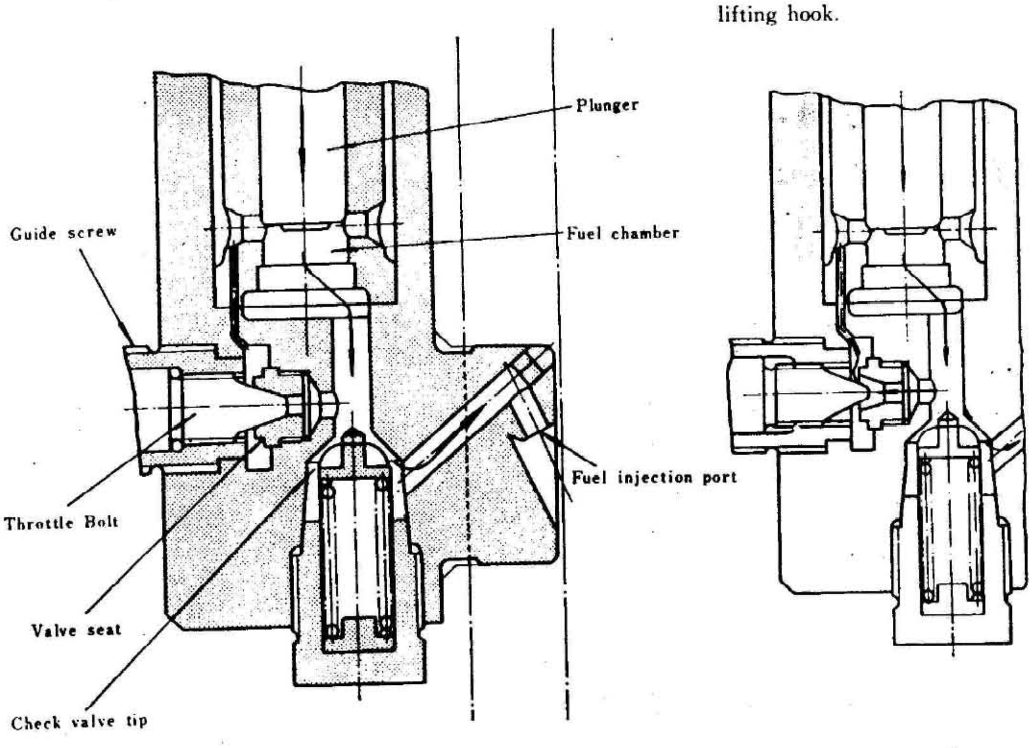


Fig. 6 Diagrams showing the construction of throttle valve & check valve.

4. Starting operation

(1) Lowering of tripping device (Fig. 7)

When a pile is erected in position, the hammer is put on the pile and the tripping device is lowered.

(2) Operation of tripping device (Fig. 8)

When the tripping device is lowered, the lower part of the trip lever pin comes into contact with the upper surface of the stopper of the upper cylinder and the lever is turned until it is horizontal, and at the same time the ram lifting hook enters the cylinder, passes along the grooves in the upper cylinder, and hooks the shoulder of the ram.

(3) Lifting of ram (Fig. 9)

When the tripping device is lifted, the ram, being held by the lifting hook, is raised.

(4) Gravity fall (Fig. 10)

When the tripping device reaches the predetermined height, the upper part of the trip lever pin contacts the lower part of the stopper of the upper cylinder to trip the starting lever, and the ram lifting hook is thrown open at the same time, and the ram begins to fall.

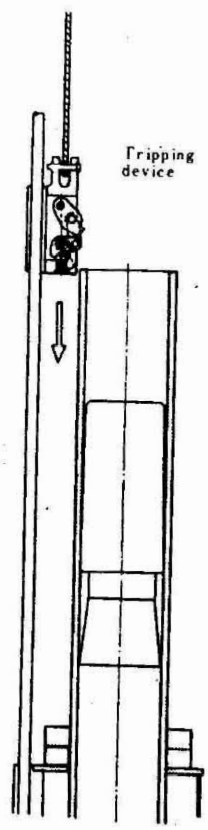


Fig. 7 Lowering tripping device.

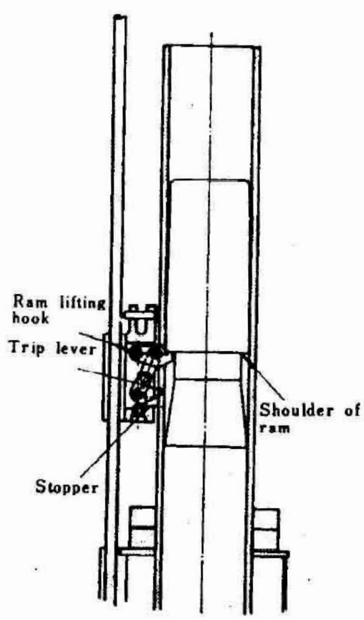


Fig. 8 Tripping device in action and ram being lifted.

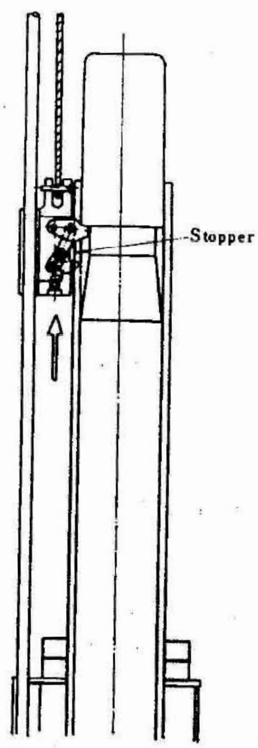


Fig. 9 Ram just before falling.

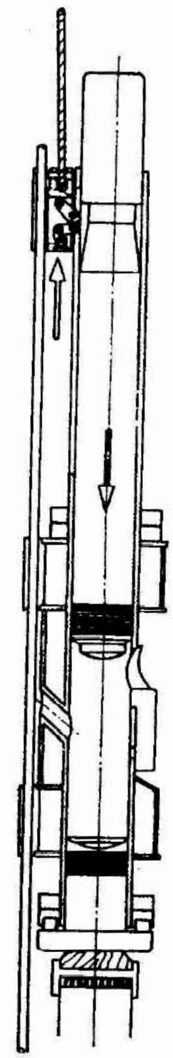


Fig. 10 Gravity fall.

5. Lifting of pile hammer

The pile hammer is also lifted by means of the tripping device. The tripping device is lowered with the hooks open, and when it has passed the rib for lifting the upper cylinder, a ratchet is operated to rotate the stopper which closes the left and right hooks. When the tripping device is lifted in this state, the entire hammer is lifted with it, the upper cylinder being supported by the left and right hooks.

For the tripping operation, the ratchet is operated again to open the hooks.

6. Working principle

The working principle of the diesel pile hammer is described by the diagrams in Fig. 11–17.

(1) **Fuel injection (Fig. 11)**

When the ram is lifted by the tripping device to a predetermined position, it is automatically released and in its fall actuates the fuel pump cam so as to inject a measured amount of diesel oil

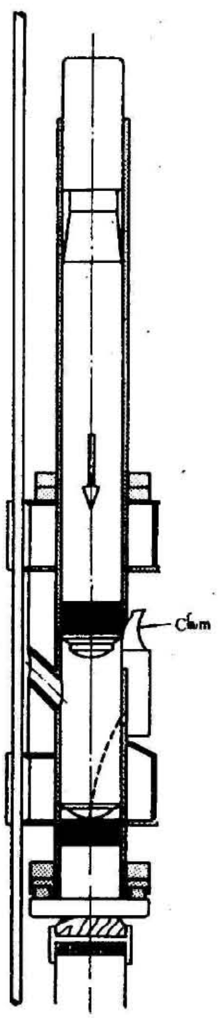


Fig. 11
Fuel injection.

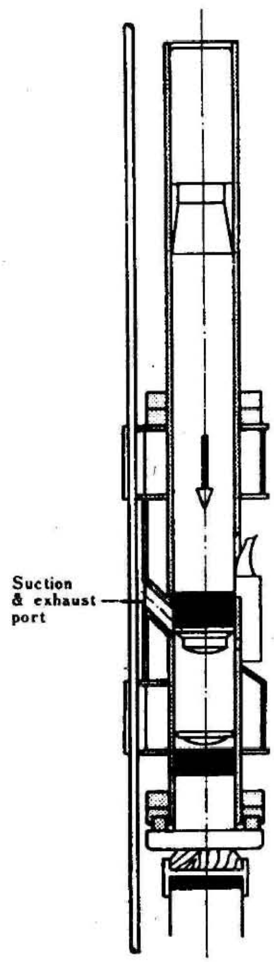


Fig. 12
Air compression.

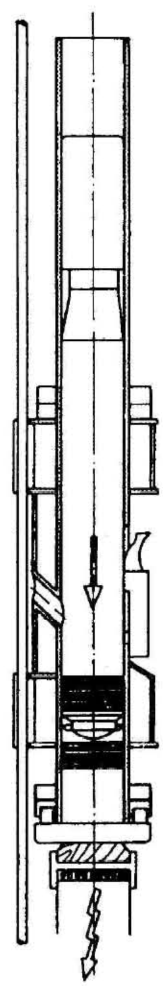


Fig. 13
Impact.

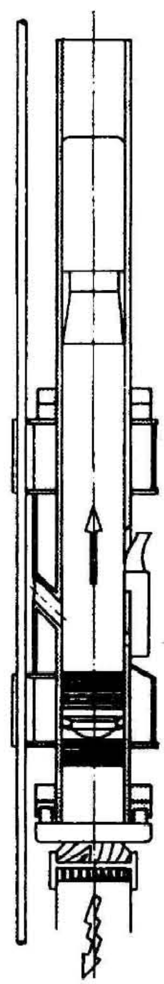


Fig. 14
Explosion.

onto the concave ball pan of the anvil under about 1.5 atmospheric pressure.

(2) **Air compression** (Fig. 12)

The ram, continuing its fall past the suction and exhaust ports compresses the air in the cylinder.

(3) **Impact explosion (Fig. 13 & 14)**

The ram finally strikes the anvil and delivers its impact energy to the pile and simultaneously atomizes the fuel on the top of the anvil, which is then ignited by the compressed hot air. The resultant explosive force drives the pile further into the ground, and propels the ram upward at the same time.

(4) **Exhaust (Fig. 15)**

The gas expanding in the cylinder is discharged when the rising ram passes the suction and exhaust ports.

(5) **Suction (Fig. 16)**

As the ram rises past the suction and exhaust ports, the pressure in the cylinder becomes negative, and fresh air is drawn in through the said ports. The fuel pump cam returns to its original position to be ready for the injection of fuel for the next stroke.

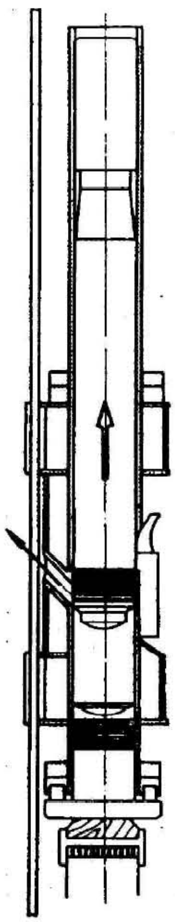


Fig. 15
Exhaust.

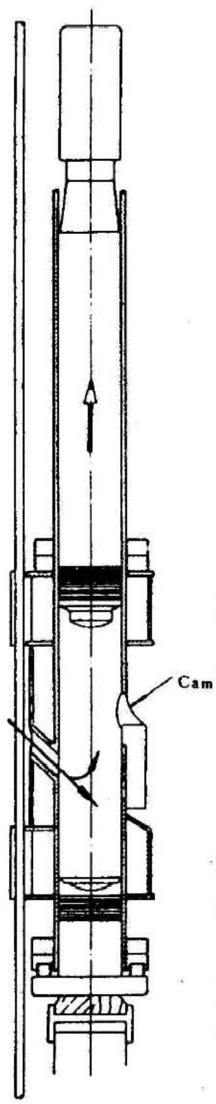


Fig. 16
Suction.

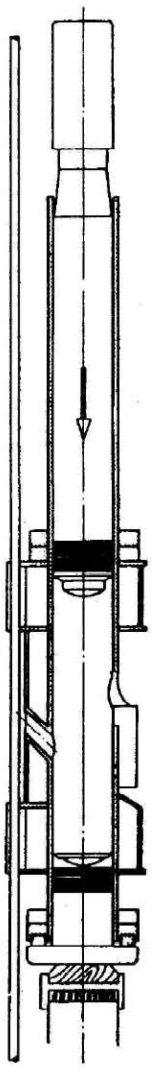


Fig. 17
Gravity fall.

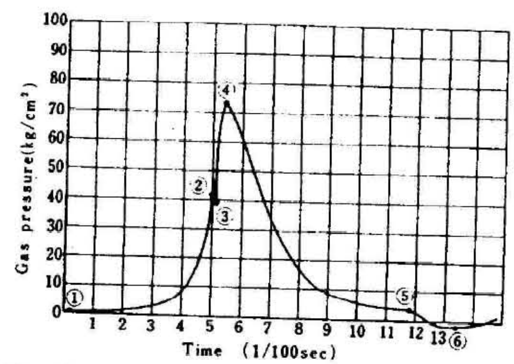


Fig. 18 Schematic diagram showing gas pressure.

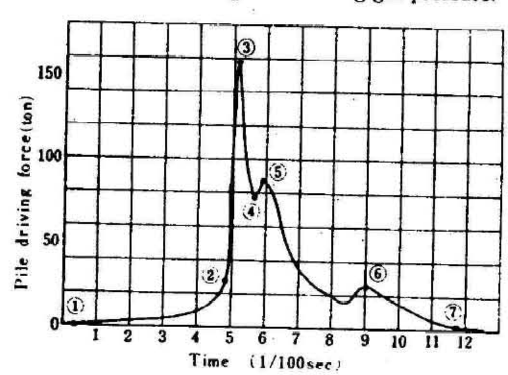


Fig. 19 Schematic diagram showing pile driving force.

(6) **Gravity fall (Fig. 17)**

The ram, having attained the full height of its stroke, begins falling again, expelling exhaust gas, and thus the cycle of fuel injection, compression, impact and explosion is repeated automatically.

(7) **Stopping**

The diesel pile hammer is stopped by disengaging the fuel pump cam for a while to shut off the flow of fuel. Further description will be given of the above function with reference to data on gas pressure in the cylinder, pile-driving forces, displacement of pile, etc. that were obtained during operating tests of the pile hammers.

(a) Variation of gas pressure in cylinder. **(Fig. 18)**

(1) shows the point at which the ram begins compressing air upon closing the suction and exhaust ports; (1)—(2) shows the compression stroke; (2) shows the time the ram strikes the anvil and the pressure is at the maximum; (2)—(3) shows the time lag between the formation of mixed gas of the compressed air and the atomized fuel by the blow of the ram and combustion; (3)—(4) shows combustion; (4) shows the point at which the explosive force reaches its maximum; (4)—(5) shows the expansion of gas in combustion; (5) shows the suction and exhaust ports open; (5)—(6) shows the discharge of exhaust and the point where negative pressure prevails in the cylinder and fresh air is drawn in.

(b) Variation of pile driving force. **(Fig. 19)**

(1)—(2) shows the ram entering compression stroke, and with the compression pressure increase, the driving force increasing; (2) shows the moment the ram strikes the anvil; between (2)—(3) a strong impact energy, maximum at point (3), is delivered to the pile; between (3)—(4) the impact energy decreases due to the fact that the energy delivered to the pile is consumed by the penetration of the pile into the ground; at (4)—(5), pushing force is created by the combustion following the impact, this energy being less than the impact energy, about 1/2 as shown in the diagram. In other words, the limit of the driving capacity of a diesel pile hammer depends on the impact energy, while the force generated by combustion is a factor concerned with impulse which governs the pile driving efficiency. Therefore, to obtain a large driving force with the diesel pile hammer, its ram stroke has to be large. (5)—(7) shows the expansion of the gas. The pile driving force decreases with the decrease of gas pressure; (6) shows a brief rise in impact energy at this point is due to the delayed fall of the cylinder behind the penetration of the pile to strike the anvil.

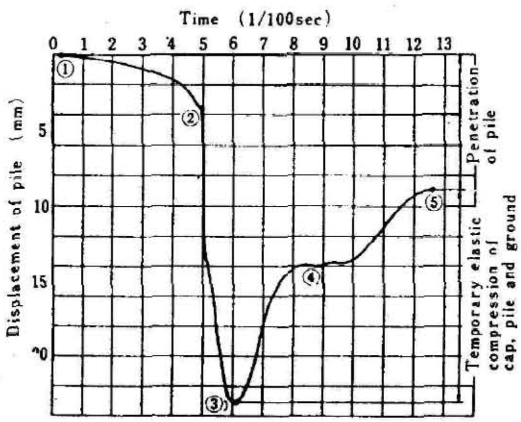


Fig. 20 Displacement of pile.

(c) Displacement of pile. (**Fig. 20**)

(1)—(2) shows the point at which the elastic resistance of the ground is overcome by the force of the compressed air in the cylinder and the pile begins a rigid movement ; (2) shows the point of impact between the ram and anvil ; (2)—(3) the pile is driven down strongly by the impact energy and explosion energy ; (3) the point of maximum displacement of the pile when the penetration stops ; (3)—(5) shows the point at which the pile rises due to the resilience of the pile and ground, and then comes to a stop ; (4) a stop of the rising curve is due to the pile receiving a downward push as it is struck by the cylinder ; (1)—(5) shows vertical distance of the penetration of the pile and (3) - (5) shows the amount of temporary elastic compression of the cap, pile and ground.

7. Equilibrium of generated energy

The diesel pile hammer operates in a cycle of two phases. The first phase is the downward stroke of the ram and the second is its upward stroke. The first phase is performed by the fall of the ram by gravity, and the second phase by the rise of the ram propelled by the gas expansion in the combustion chamber, when the energy for the first phase is generated.

The equilibrium of energy for the two-phased operation of the diesel pile hammer is as follows :

The 1st cycle :

$L_{p1}=L_c+L_f+L_{d1}+L_{s1}+L_{s2}+L_{fp}$ ....(1)

Where :

L_{p1} ; WH ....kg·m

L_{p1} ; Potential energy ....kg·m

W ; Weight of ram .... kg

H ; Stroke of ram .... m

L_c ; Energy consumed for compression of air in the cylinder..............................kg·m

L_f ; Energy consumed by friction and air resistance at the time of the ram's falling ....kg·m

L_{d1} ; Impact energy absorbed by the resilience of the striking part of the hammer and the elastic deformation of the pile and soil ....kg·m

L_{s1} ; Energy utilized for sinking of the pile during the compression stroke in the cylinder..............................kg·m

L_{s2} ; Energy utilized for sinking the pile by impact ....kg·m

L_{fp} ; Energy consumed for jetting of the fuel ....kg·m

The 2nd cycle :

$L_{p2}=L_c-L_f'-L_{s3}-L_{d2}+L_p'$..............................(2)

Where :

L_{ps} ; Potential energy ....kg·m

L_e ; Energy delivered by the expansion of gas in the cylinder ....kg·m

L_f' ; Energy consumed by friction and air resistance in the ram's upward movement ....kg·m

L_{s3} ; Explosive energy of the fuel utilized for the sinking of the pile ....kg·m

L_{d2} ; Explosive energy absorbed by the resilience of the striking part of the hammer and the elastic deformation of the pile and soil ....kg·m

L_p' ; Energy given back to the ram by the Elastic restitution (Restitution at the impact and elastic recovery of the pile and soil) (coefficient of Restitution >0)..kg·m

From the above equations (1) and (2):

$$L_{p2}-L_{p1}=(L_e-L_c)-(L_{s1}+L_{s2}+L_{s3})-(L_{d1}+L_{d2}-L_p')-(L_f+L_f'+L_{fp}) \quad \text{............(3)}$$

Where:

$L_e-L_c=FP_{ime}S$

F ; Sectional area of the cylinder...m^2

P_{ime}; Indicated mean effective pressure ....kg·m^2

S ; Operating stroke of ram ....m

The equation (3) can be expressed as follows:

Energy to vary the ram stroke=(energy generated in the cylinder)—(effective striking energy)—(energy loss due to elastic deformation)—(mechanical energy loss) ....(4)

=(energy generated in the cylinder)—(energy released)......................................(5)

In the above equation (4), the first item, i.e., the magnitude of the energy generated in the cylinder, is related to the magnitude of impact energy of the diesel pile hammer, and whether this thermodynamic process is rational or not constitutes a decisive factor in determining the various elements in hammer designing.

The two energy losses mentioned in the 3rd and 4th items in the same equation (4) are those occuring in the hammer itself and the pile system including the hammer, and constitute an important factor in the manufacture of hammers, and the selection of a suitable hammer for the kind of piles to be driven.

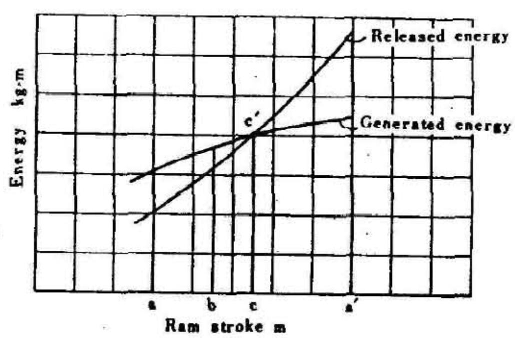


Fig. 21 Relationship between ram stroke and energies generated and released.

(1) When the penetration resistance is constant

Assuming the penetration resistance to be constant, the relationship between equation (1) and (2) can be plotted as shown in Fig. 21, wherein, if the operating cycle of the diesel pile hammer starts at a given ram stroke, for example, at point a, the energy generated is greater than the energy released and because of the relationship shown in equation (5), the ram stroke at the initial stage of the next cycle moves to point b.

The ram stroke thus successively increases up to point c. And even if the operating cycle commences at point a′, the ram stroke reaches point c through an entirely reversed process. Point c′, which corresponds to point c, is a point of equilibrium of energies generated and released as is apparent in the diagram, and the pile hammer repeats the operating cycle at a constant ram stroke at point c.

(2) When the penetration resistance is varied

In an ordinary piling operation, the penetration resistance is not constant, but tends to increase as the penetration progresses, and the effect of variation of penetration resistance on the ram stroke can be explained as follows:

As shown in Fig. 22, the energy generated by the hammer tends to increase with the increase

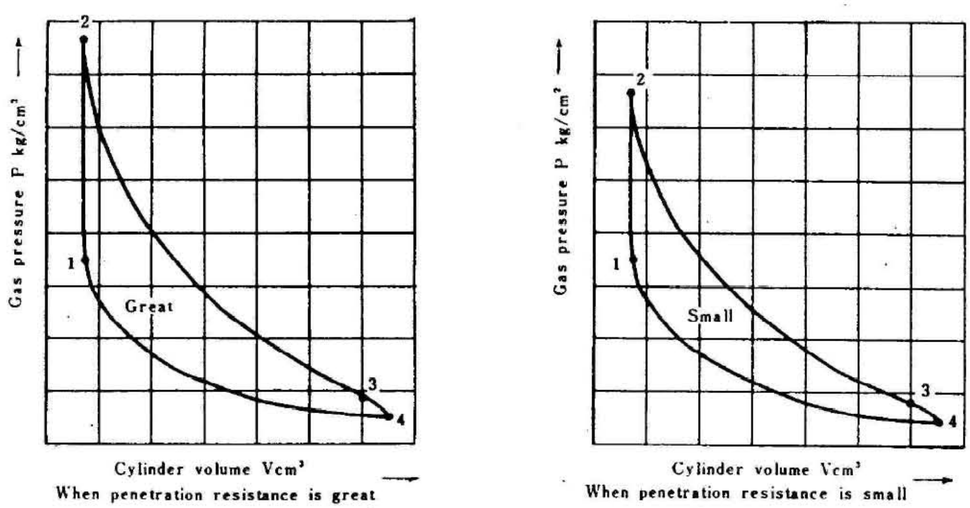


Fig. 22 Relationship between generated energy and penetration resistance.
(Generated energy E—Area 1-2-3-4-1)

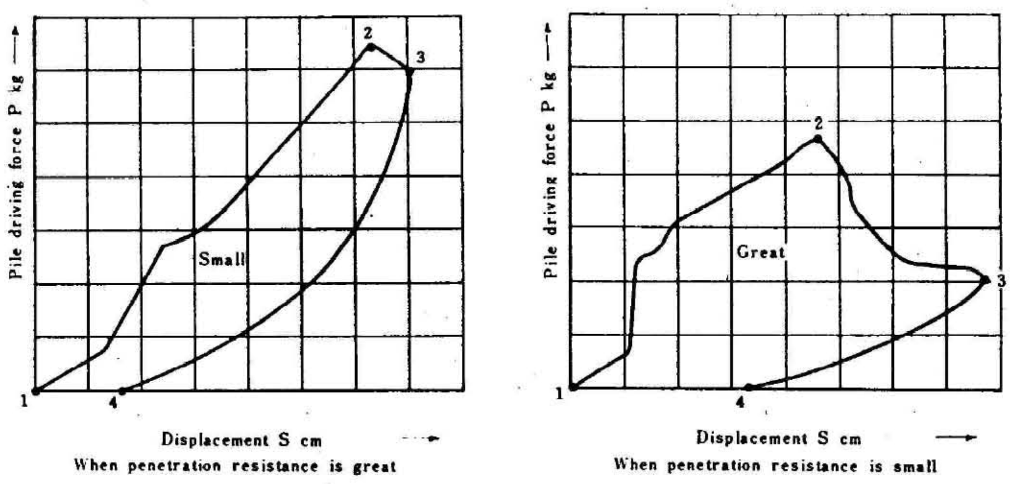


Fig. 23 Relationship between released energy and penetration resistance
(Released energy E'—Area 1-2-3-4-1)

of the penetration resistance of the pile. This is considered to be due to the fact that the atomization of the fuel becomes finer with the increase of penetration resistance, and that the increased penetration resistance facilitates scavenging of the exhaust, resulting in more efficient combustion.

As is shown in Fig. 23, the released energy tends to decrease as the penetration resistance of the pile increases. This is considered to be due to the fact that the amount of work done on the pile decreases with the increase of penetration resistance and that more of the impact energy is returned to the ram.

The relationship between equations (1) and (2) is shown here again in Fig. 24.

As is shown in Fig. 24, when the penetration resistance is great, the equilibrium point of the energies generated and released moves to the right, contrasted with the case in which the penetration resistance is small, and as a result the pile hammer operates with a larger ram strokes.

In actual piling operations, the ram stroke of the diesel pile hammer is small at the initial stage of driving, and increases with the advance of the penetration of the pile, and this phenomenon is

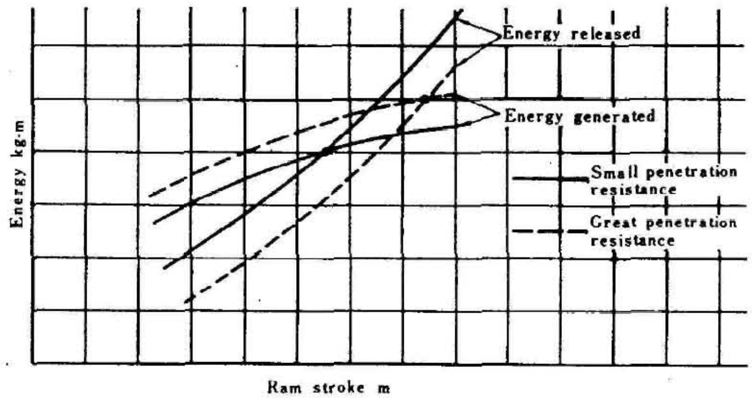


Fig. 24 Relationship between ram stroke and energies generated and released.

believed to be due to the above reasons. Thus, the greater the penetration resistance becomes, the stronger the striking force becomes, and this is one of the advantages of the diesel pile hammer.

8. Impact atomizing mechanism

There are two fuel atomizing methods used for the diesel pile hammers: the high-pressure jet atomizing method and the impact atomizing method. The hammers used in Japan generally adopt the latter method, in which the fuel is not atomized by a high-pressure jet pump as in the case of the diesel engine, but is sprayed into the concave ball pan of the anvil and is atomized by the impact of the ram. This is the method unique to pile hammers.

The impact atomizing method can be described as follows:

The ram point is convex and the head of the anvil is concave so that they fit together. When it is assumed that a viscous fluid is present between these two surfaces (See Fig. 25 & 26), that the ram and anvil are perfectly rigid bodies, and that the viscosity of the fluid is not changed by pressure or temperature, the maximum pressure on the viscous fluid at the center of impact between these two surfaces and the maximum velocity of the viscous fluid jetted are as follows:

$$P_{max} = \frac{0.154\ (R^2 - r^2)}{R^2}\sqrt{\frac{M^3 V_o^5}{\eta}} \quad \cdots\cdots(6)$$

$$\bar{C}_{max} = \frac{0.125r}{R^2}\sqrt{\frac{M V_o^3}{\eta}} \quad \cdots\cdots(7)$$

Where:

M ; Mass of ram .... kg·s²/cm

V_o ; Initial velocity of ram .... cm/s

h ; Thickness of viscous membrane during ram's striking .... cm

p ; Pressure on viscous membrane .... kg/cm²

Z ; Coordinate tangent to axial line of ram, and extending in axial direction of ram from the center of the thickness of viscous membrane .... cm

η ; Viscosity of viscous substance .... kg·s/cm²

$\bar{C}$; Average flow velocity in radial direction relative to axial line of ram .... cm/s

The above equations (6) and (7) respectively give pressure distribution in radial direction from the center of the impact of the ram when P_{max} is produced, and velocity distribution when $\bar{C}_{max}$ is produced.

Now as for the size of the atomized particles, when fuel is jetted from a nozzle, the diameter of the atomized particles is proportional to the diameter of the nozzle but inversely proportional to the jet velocity of fuel according to the experimental equation of Prof. Tanazawa, and by applying this theory to the impact atomizing of the diesel pile hammer, the diameter of the nozzle is relative to the positions of the ram and anvil during the fuel jet, and the jet velocity is considered to be $\bar{C}_{max}$ sought by presuming $r = R$ (outside radius of the impact surface) in the equation (7). Now the relative positions of the ram and anvil become closer with the decrease of oil pressure created on the impact surface, that is, the relative positions of the ram and anvil in an atomizing condition creating excessively high oil pressure are considered to be inversely proportional to the oil pressure created on the impact surface. When the equations (6) and (7) are considered again with this idea in mind, the factors that affect the size of the atomized fuel particles are these two:

(1) The area of the impact surface of the ram and anvil.

(2) The collision velocity between the ram and anvil.

To secure stabilized combustion of fuel in the diesel pile hammer, it is essential that the fuel be atomized in as small particle as possible. For this reason the effects of the above two factors should be thoroughly taken into consideration in the selection of design requirements. Other important factors are the distance the atomized particles travel and the shape of the combustion chamber,

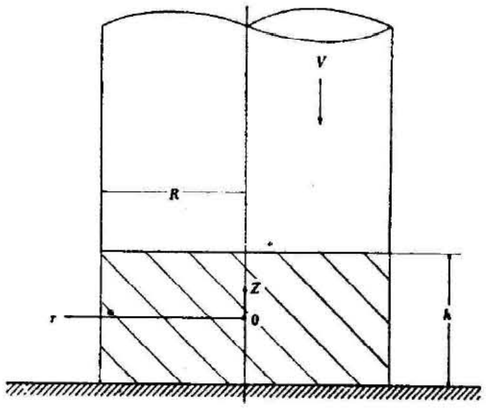


Fig. 25 Diagram showing the impact of rigid bodies with viscous membrane between them.

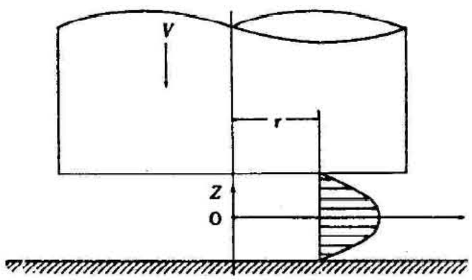


Fig. 26 Daigram showing velocity distribution of viscous fluid in axial direction.

that takes into consideration the quantitative distributional state of the fuel in relation to the jet direction.

The factors impairing the impact atomizing process during piling operation are :

(a) Faulty ignition on soft ground.

When the penetration resistance of the pile is small because the ground is extremely soft, the sectional area of the pile is small, or the pile is too light, repeated explosions cannot occur, hence continued operation is not possible. If the starting performance is unsatisfactory, it is necessary to repeat it, which lowers operational efficiency. When the diesel pile hammer operates on soft ground, the anvil sinks with the pile before the ram strikes, lowering the impact velocity of the ram, and for this reason the atomized particles are large and their distribution in the combustion chamber is poor, causing faulty ignition and stoppage.

(b) Preignition.

When the cylinder becomes overheated, preignition occurs, with inefficient atomizing. A detailed explanation of this will be given in part 2 of item 9.

(c) Batter piling.

When the angle of inclination of the hammer becomes large, it is difficult to hold the

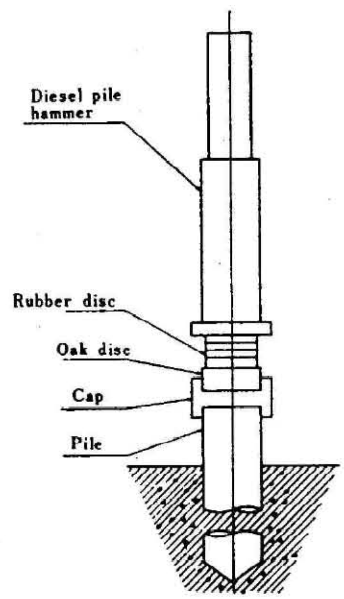


Fig. 27 Rig used in testing the diesel pile hammer.

Photo 4 Rubber discs used for starting performance tests

fuel in the ball pan of the anvil, so that this angle is limited. The maximum angle of batter piling was about 30° with conventional hammers. However, hammers with a maximum allowable inclination of 45° have recently been developed.

9. Special features

9—1 Performance

The shapes of the ram point, ball pan of the anvil and combustion chamber are of our own design, insuring optimum atomization and distribution of the fuel for most efficient combustion. The shapes of the suction and exhaust ports are designed to insure best dynamic effects at the ports (suction inertia effect and exhaust blowout effect) so that the residual gas at the bottom of the combustion chamber can be thoroughly scavenged.

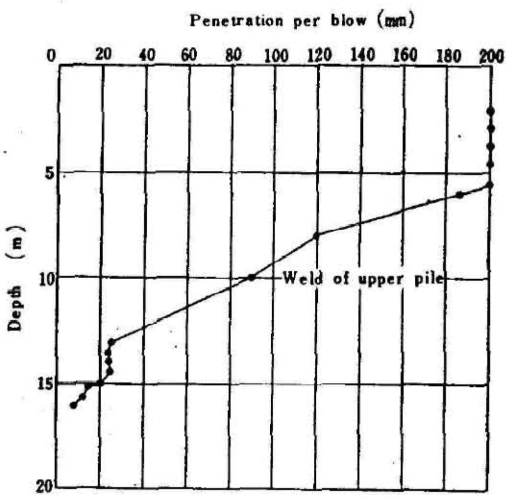
(1) Fine starting performance

Starting performance of the Kobe Diesel Pile Hammer is revolutionary, eliminating the greatest drawback of the conventional diesel pile hammer, faulty ignition on soft ground, with the result that in ordinary operation just a single starting is sufficient. Even on ground so soft that the pile sinks several meters only when the hammer is lowered onto it, continuous operation is possible after a few cold blows.

In tests of starting performance conducted at our factory, a number of rubber discs were stacked on a rigid foundation to simulate soft ground. The test rig used is shown in Fig. 27 and the manner of stacking the rubber discs in Photo 4.

The starting performance data obtained through the tests were as follows:

Model K13 18 discs (number of rubber discs that were stacked at the point of critical starting)
Model K22 16 discs (number of rubber discs that were stacked at the point of critical starting)
Model K32 16 discs (number of rubber discs that were stacked at the point of critical starting)
Model K42 12 discs (number of rubber discs that were stacked at the point of critical starting)
Other maker 7～8 discs (number of rubber discs that were stacked at the point of critical starting)



Sinking effected by the dead weight of the hammer............2 m
Hammering without fuel......Amount of sinking ... 800 mm
Hammering without fuel......Amount of sinking ... 800 mm
Hammering without fuel......Amount of sinking ...1,000 mm
Hammering without fuel......Amount of sinking ...1,000 mm

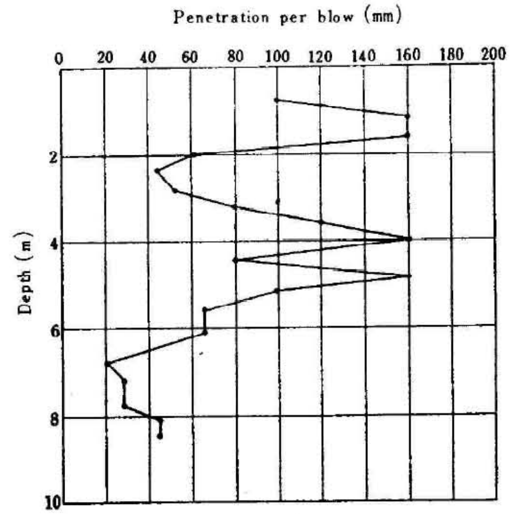
At this point the driving resistance increased and the fuel starting operation was done. Continued operation began immediately.

Pile used: 241/257×10m Upper pile (steel pipe pile)
241/250×10m Lower pile (steel pipe pile)

Date: December 9, 1963

Site: Tokai Iron Works Compound (Nagoya) Reclaimed ground.

Fig. 28 Chart showing results of driving by Diesel Pile Hammer Model K13.



At the first starting operation, repeated explosions began, and continuous operation was maintained.

Pile used: 350$\phi \times$9 m concrete pile
Time required for driviing: About 3 min.
Number of piles driven: 70/day
Date: December 10, 1963
Site: Nabeta reclaimed land, Nagoya

Fig. 29 Diagram showing results of driving by Diesel Pile Hammer Model K13

The starting performance data confirmed by actual employment in the field is as follows:

Model K13 160~200 mm (sinking of pile per blow at the point of critical starting)
Model K22 150~200 mm (sinking of pile per blow at the point of critical starting)
Model K32 150~200 mm (sinking of pile per blow at the point of critical starting)
Model K42 150~200 mm (sinking of pile per blow at the point of critical starting)
Other maker 70~ 80 mm (sinking of pile per blow at the point of critical starting)

Fig. 28 and Fig. 29 show the results of operating tests on soft ground in the Nagoya district and Photo 5 shows the scene of the tests.

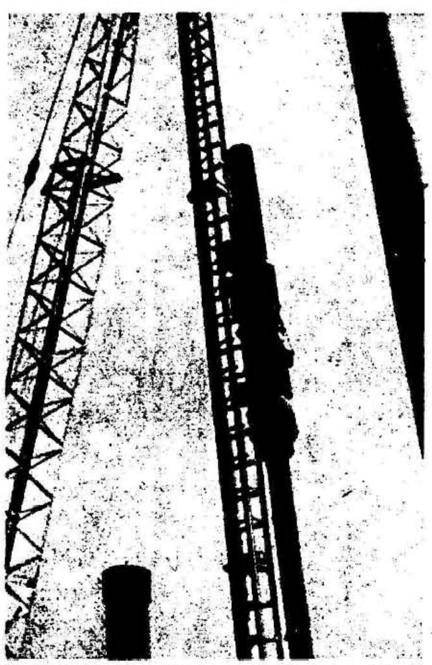


Photo 5 Driving 250 mm steel pipe with diesel pile hammer Model K13 (Nogoya Tokai Iron Works Compound)

Photo 6 Testing a diesel pile hammer

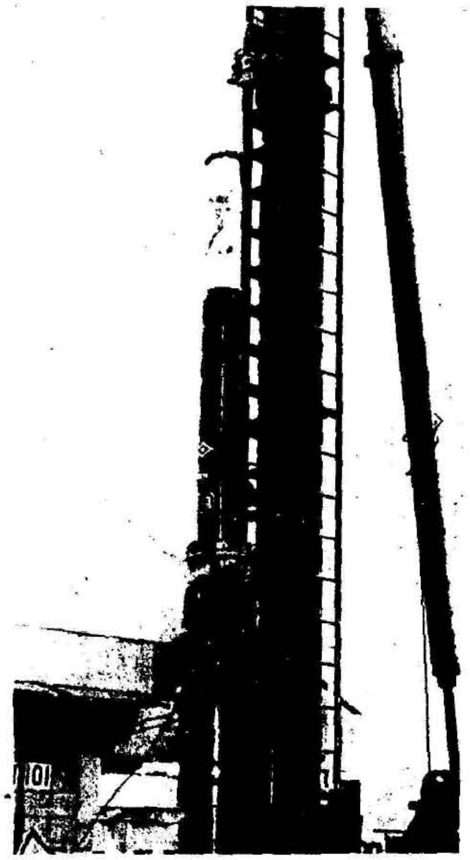


Photo 7. Diesel pile hammer Model K13 in action

(2) Powerful driving force

The Kobe Diesel Pile Hammer has a ram stroke as long as 2.500mm at a point near the end of the driving of a pile (when sinking of the pile per blow is 0.5 mm).

This stroke is longer by 300 to 400 mm than that of the hammers manufactured by other makers in Japan, and produces a striking force and pile bearing capacity some 15～20% greater than conventional hammers of this type. Photo 6 shows a hammer equipped with instruments for measuring striking force, gas pressure, etc., and Photo 7 shows the Model K13 exhibitting the power.

9—2 Construction and materials

(1) Water-cooled system

Diesel pile hammers are cooled either by water or by air, and the former method is employed in the Kobe hammers. In the diesel pile hammer, the cooling system deserves particular attention because of the close relationship it has with the performance of the hammer. The merits and faults of the two systems will be explained using the results of comparative tests performed by our engineers.

These tests were conducted with a view to find the differences in performance during continuous operation of water-cooled and air-cooled hammers, and inner-wall temperature of the cylinder, gas pressure and striking force were measured.

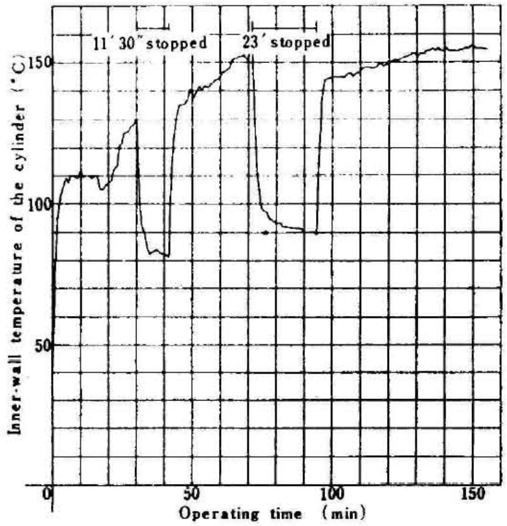
To measure the inner-wall temperature of the cylinder, an adaptor containing a thermocouple was inserted in the scavenging port of the cylinder and the variation of temperature was recorded on an electronic self balancing type recorder.

To measure the gas pressure, a plug for mounting a pressure indicator was made and attached to the scavenging port and the variation of gas pressure was measured with an electromagnetic oscilloscope.

To measure the striking force, a load cell equipped with a dynamic strain meter was made and placed under the hammer and recording was done by means of an electromagnetic oscillograph.

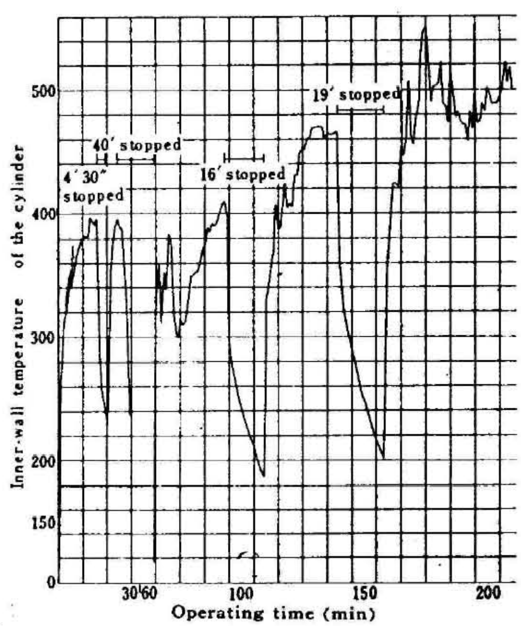
For the tests, two Model K13 water-cooled hammers of identical design were used, one with its water tank detached.

To insure uniformity in the testing conditions, same fuel pump was used and the throttle was



Date: May 22, 1964
Site: Okubo Plant compound
Air temperature: 29°C.

Fig. 30 Test results of water-cooled diesel pile hammer Model K13.



Date: May 23, 1964
Site: Okubo Plant compound
Air temperature: 28°C.

Fig. 31 Test results of air-cooled diesel pile hammer Model K13.

opened to the same extent so as to feed the same amount of fuel constantly.

To avoid variations in the load conditions, both hammers were tested on stands that were perfectly free from penetration.

When the hammers were operated continuously with a constant feed of fuel and under constant load conditions, it was apparent that the changes in the operating conditions of the water-cooled and air-cooled hammers were caused only by the rise of temperature.

(a) Inner-wall temperature of cylinder

With the water-cooled hammer, the inner-wall temperature of the cylinder became stabilized after about 30 minutes of operation, and thereafter the rise of temperature was very slow, and at the end of the tests it was about 150°C. The curve of temperature rise indicates that the peak is about 150°C., and that no further temperature rise takes place during continuous operation. (See Fig. 30)

This is because the heat generated by the cylinder is absorbed by the evaporation heat of the water.

With the air-cooled hammer, however, the temperature rise was considerable, going as high as 500°C. (Fig. 31)

Since the air-cooled system depends greatly upon the convection of the surrounding

Table 1. Results of comparative tests of air-cooled and water-cooled diesel pile hammrs.

Type		Air-cooled	Water cooled
Temperature of cylinder inner-wall (°C)	At beginning of operation	28	29
	After about 2 hours of operation	500	150
Maximum gas pressure (kg/cm²)	At beginnig of operation: p	90.8	91.3
	After about 2 hours of operation: p′	53	83.5
	p′/p %	9.35	91
Striking force (ton)	At beginning of operation: P	150	152
	After about 2 hours operation: P′	80.5	137
	P′/P %	54	90

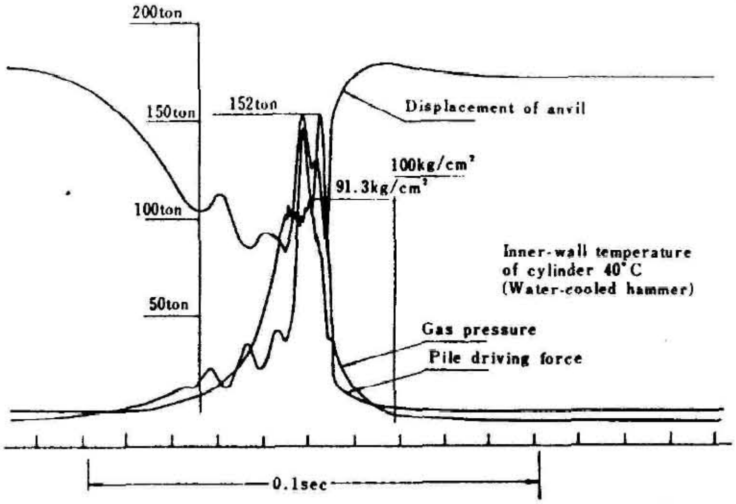


Fig. 32 Performance curve of water-cooled hammer.

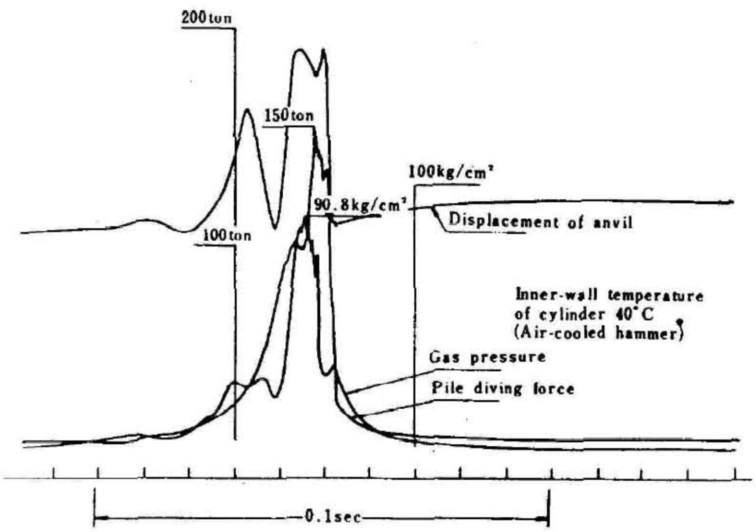


Fig. 33 Performance curve of air-cooled hammer.

air, there is a strong tendency for the cylinder to become overheated.

Under such a condition, lubricants may burn or lose viscosity, and as a result the lubrication of the inside of the cylinder becomes unsatisfactory.

Overheating of the cylinder not only impairs lubrication, but also causes preignition, thus adversely affecting the performance of the hammer.

(b) Gas pressure

While variation in gas pressure is seldom observed in a water-cooled hammer, the maximum gas pressure in the air-cooled hammer dropped to 59% or so after 2 hours of operation (Table 1).

The decrease of gas pressure means a decrease in generated horse power, and reduced striking force, which can render the hammer unworkable.

(c) Striking force

With the water-cooled hammer the decrease in striking force was almost unobservable, but in

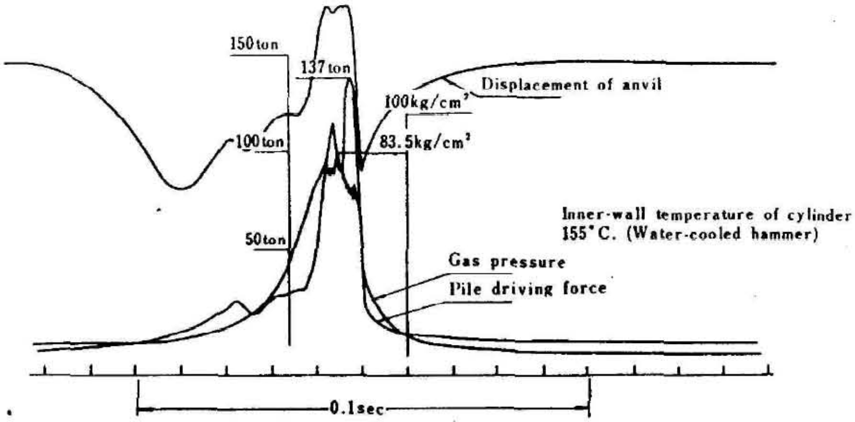


Fig. 34 Performance diagram of water-cooled hammer.

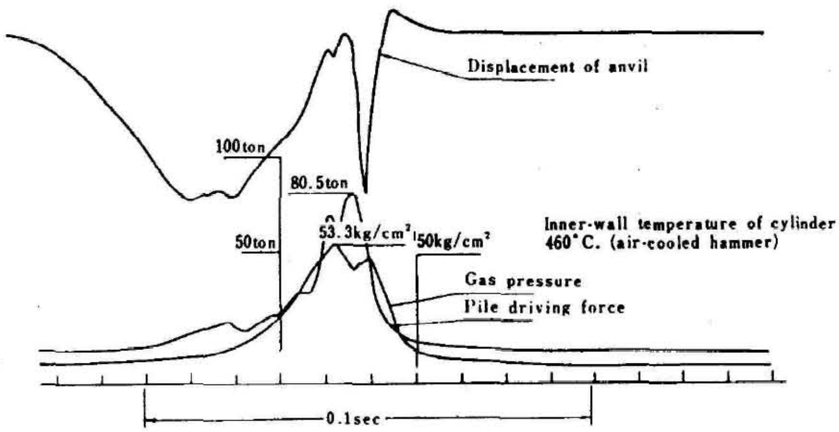


Fig. 35 Performance diagram of air-cooled hammer.

the case of the air-cooled hammer the striking force dropped to about 54% (Table 1).

The striking force determines the driving capacity, and the extreme decrease in striking force of the air-cooled hammer is a serious drawback of this type.

(d) Cause of deterioration of performance

The deterioration of performance in the air-cooled diesel pile hammer can be explained by comparing the diagrams of gas pressures at the beginning of operation (normal condition) and after continuous operation (overheated condition).

Fig. 32 and Fig. 33 show gas pressure at the beginning of operation, and, as explained earlier, they clearly show the normal generation of combustion energy, while Fig. 34 and Fig. 35 show the gas pressure after a long period of operation. In Fig. 35 the maximum compression pressure and ignition lag are not clear, and the beginning of compression and the maximum gas pressure are connected by a steady curve, and when compared with Fig. 33, the characteristics of the chart are varied. The absolute value of the maximum gas pressure is also reduced.

This phenomenon can be explained as being casued by the overheating of the cylinder, which leads to imperfect combustion of the fuel in the ball pan of the anvil. Pre-ignition takes place due to the high temperature before the fuel is atomized sufficiently, decreasing the striking force,a characteristic peculiar to diesel pile hammer.

(2) **Guide ring**

The Kobe Pile Hammer has an annular guide ring made of anti-friction alloy around the ram, by means of which the ram is kept aligned with the cylinder. The air-tightness of the piston ring is positively maintained and the curved surface of the ram point and ball pan of the anvil are kept accurately fitted, assuring the most efficient atomization and combustion. As the axial line of the ram is kept correct, the circumferential surface of the ram except for the sliding guide does not come into contact with the cylinder wall, protecting the wall from wear and damage.

(3) **Cylinder**

The upper and lower cylinders which constitute the most vital part of the hammer are welded by a technic of the highest standard. The lower cylinder is made of nickel--chrome-molybdenum steel to insure long service life.

(4) **Ram and anvil**

The ram and anvil are made of forged high-carbon steel and manganese steel to give them sufficient strength to bear the powerful driving force of the Kobe hammer as well as to prevent wear of the lifting shoulder of ram and the convex and concave ball pan.

(5) **Fuel pump system**

The cam of the fuel pump is so shaped as to reduce its surface pressure against the ram as much as possible and thus to minimize wear of the ram and cam. The working surface of the cam is given hard facing to insure long, dependable service.

For the fuel line, heat- and oil-resistant rubber hose is used that effectively absorb shock and prevent breakdown of the fuel system.

9—3 Comparison with drop hammer and steam hammer

Besides diesel hammers, steam hammers and drop hammers are used for pile driving. These, however, have become things of the past in Japan, having been replaced by diesel pile hammers.

This is because the diesel pile hammer has the following advantages over conventional drop hammers and steam hammers (Table 2).

(1) **Savings in expenses and easy mobility**

(a) Auxiliary external source of power is eliminated.

The diesel pile hammer is a kind of 2-cycle diesel engine in which the fuel itself perform the work, and thus the energy can be utilized most effectively with great fuel economy.

Table 2. Comparison of performance of various pile hammers.

Item \ Model	Kobe diesel pile hammer				McKiernan-Terry (single-action) steam hammer		
	K13	K22	K32	K42	S5	S8	S14
Energy output per blow FT LBS	3,380 24400	6,150 44500	7,800 56500	11,000 79600	1,360	3,600	5,200
Weight of ram #	1,300 2870	2,200 4850	3,200 7060	4,200 9260	1,240	3,620	6,350
Total weight	2,900	4,800	7,000	10,000	4,100	8,300	14,400
Number of blows per minute	45~60	45~60	45~60	45~60	65	55	60

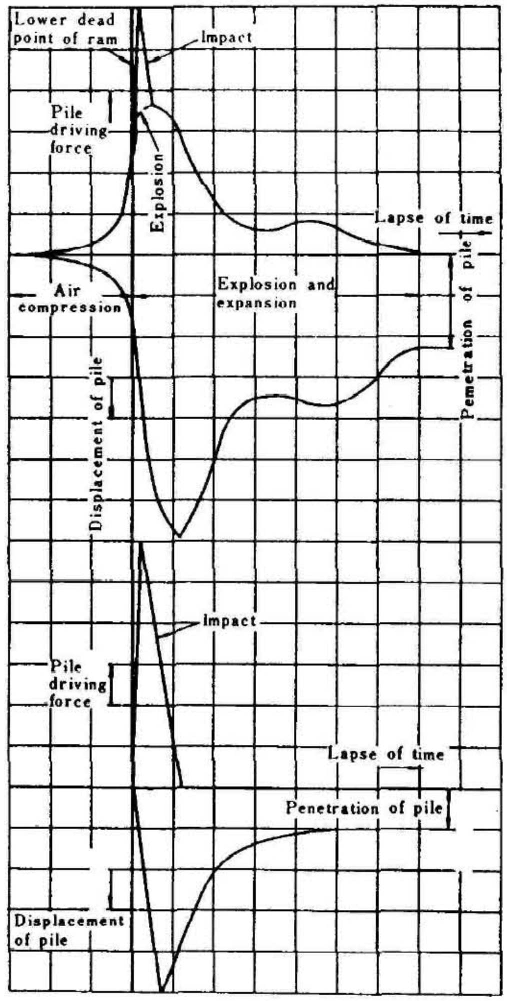


Fig. 36 (upper) Diagram showing the performance of diesel pile hammer.

Fig. 37 (lower) Diagram showing the performance of drop hammer or steam hammer.

Since no ancillary equipment such as a boiler is required, as in the case of a steam hammer, the initial cost of the equipment is low, and assembly, disassembly and transportation of the hammer are simple.

(b) Light weight

The weight of a diesel pile hammer is about 1/2 to 1/3 that of a steam hammer having the same driving energy.

Because of the diesel pile hammer's high impact energy in spite of its light weight, the capacity of a crane or pile driver using it can be small, reducing the investment for equipment considerably. This helps make it easy to assemble, disassemble and transport the entire rig.

(2) **Promotion of working efficiency**

(a) Fast starting

This hammer, being self-contained, can start instantly at any time, without complicated preparations, and gives no trouble in cold weather.

(b) Powerful driving force (Fig. 36 & Fig. 37)

As pile driving work is carried out in the 3 steps of air compression in the cylinder by the ram, the blow of the ram and the subsequent explosion, the diesel pile hammer has much greater driving force than other types of hammers which depend solely on impact energy. The energy created by compressive force, impact and explosion in succession combine to achieve strong driving effects.

(c) Effective for driving into hard ground

As the diesel pile hammer has the characteristic that the ram stroke is proportional to the penetration resistance, the greater the resistance is, the more powerful the impact energy will become.

(d) Automatic operation

Because of the larger number of blows delivered per minute and its automatic operation, the diesel pile hammer can work about three times more efficiently than the drop hammer.

(3) **No damage to pile head**

Since the pile is driven in the three-step operation of air compression, ram impact and explosion, forces acting upon the pile are less violent. As a result the pile head is not damaged.

As the hammer and the pile are connected together, working energy is always imparted to the center and the pile is driven straight.

10. Ancillary equipment

10-1 Pile driver

The pile driver is a mechanism intended for erecting the pile, lifting the hammer and maintaining the alignment of the pile and hammer. The performance of the pile driver greatly affects the efficiency of piling work, so in planning piling work, the hammer to be used, the kinds of piles, amount of work, method of operation and the site of operation should be carefully studied. There are various types of pile drivers but they can be be roughly divided into the pile driving tower and the crane equipped with a leader.

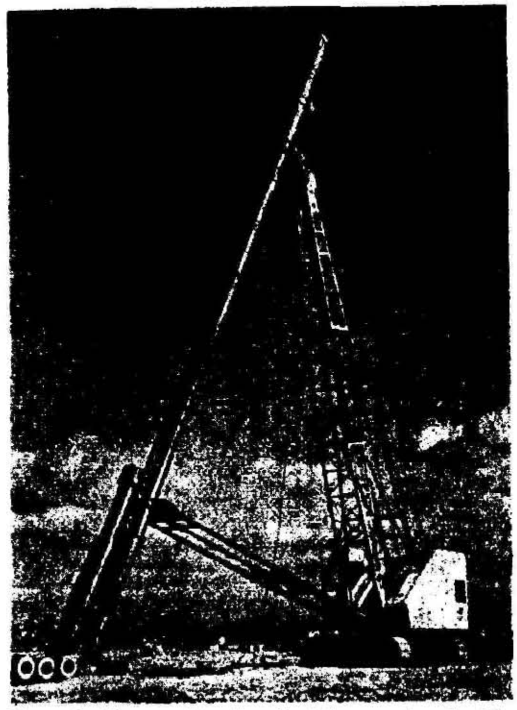


Photo 8 Batter piling by pile driver equipped with P & H type LA leader

(1) Pile driving tower

This type consists of a rotary frame, traveling frame, leader, stays, etc., with a winch and an electric motor mounted on the rotary frame. The winch is used for lifting the mammer and pile. For traveling, rotation, slanting movement and sliding of the leader, a hydraulic or mechanical method is employed. The slant of the leader is controlled by either tightening or slacking the stays, and the angle of slant is generally limited to about 15°.

In batter driving, usually the pile is first erected vertically, and then slanted as desired together with the leader, but there is another method in which a jib boom is attached to the upper part of the leader and with the leader in slanted position, the pile is lifted from the jib boom.

(2) Crane equipped with a leader

This is a crawler crane or a truck crane to which a leader is attached and used as a pile driver, permitting greater mobility and easier operation with more efficiency than pile drivers of the rail traveling pile driving tower. For these reasons this type of pile driver has come to be used more widely in recent years.

The crane type pile drivers are classified as follows according to the leaders used,

(2)-1 Suspension type

(a) Outline

Dimension \ Type of Crane	315	320H	330
A	3,020	3,350	3,350
·B	2,840	3,340	3,340

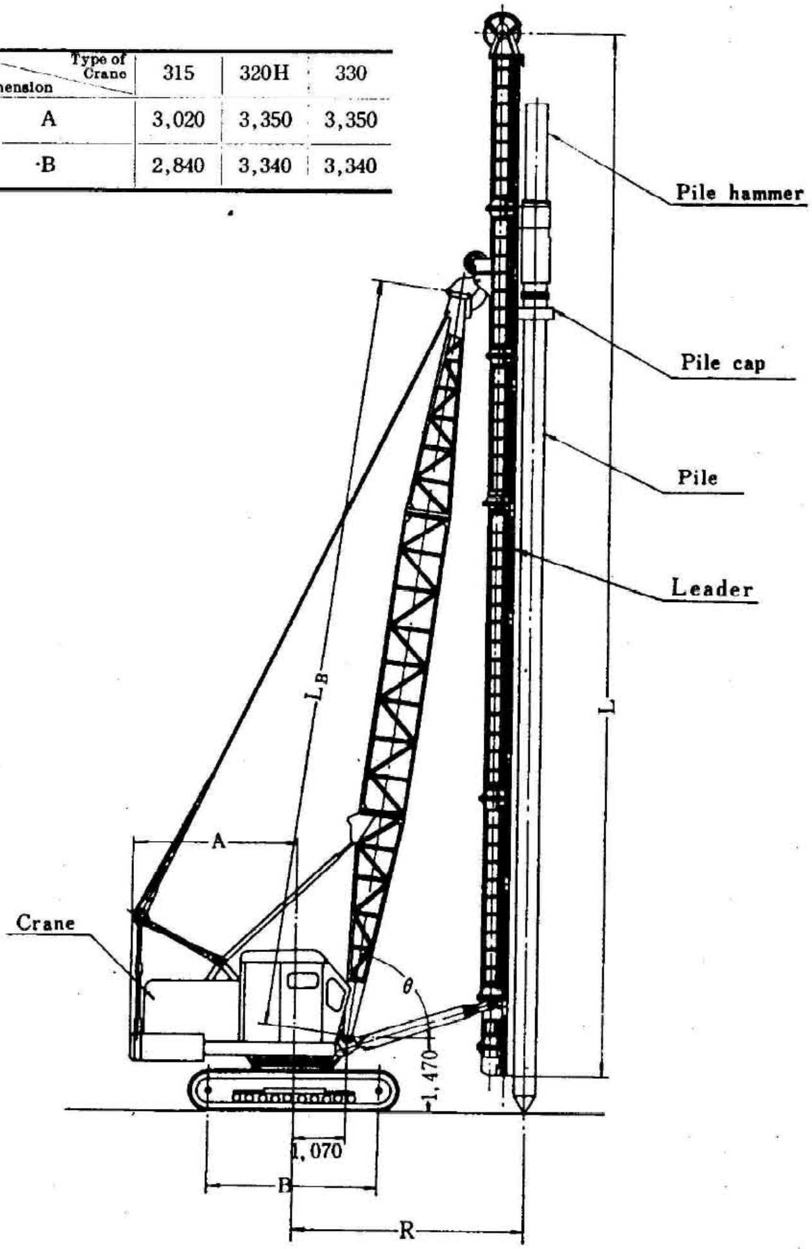


Fig. 38 Overall view of pile driver equipped with type LA leader.

This type is constructed by attaching the leader to the upper end of the crane-boom and connecting the lower end of the leader to the crane body by catch-fork. The lifting of the hammer and pile is performed by the hoisting mechanism of the crane, and the slanting of the leader is controlled by adjusting the boom angle and the length of the catch-fork. At our plant this type of leader is classfied as type LA, and the entire pile driving rig as a pile driver. Specifications of this type are shown in Table 3 (page 29) and the entire rig is shown in Fig. 38. Photo 8 shown an example of batter piling by type LA.

(b) Special features

Type of Crane	320H-LH 330-LH		320H-LH 330-LH	
Type of leader	LH 22		LH 42	
Dimension mm / Hammer used	K13	K22	K32	K42
A	21,250		21,300	
B	6,340		6,390	
C	21,000		21,050	
D	2,990		3,040	
E	290		340	
F	450		500	
G	370	430	490	580
H	3,260	3,420	3,530	3,620

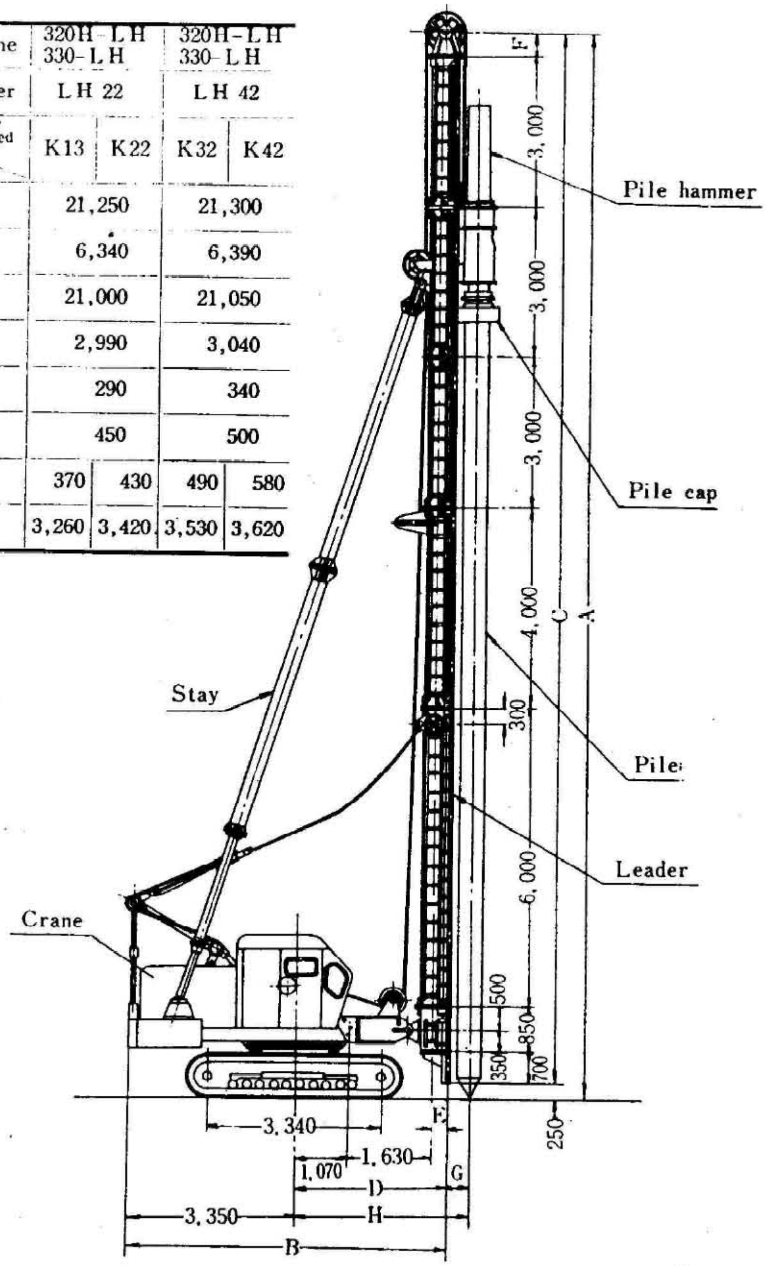


Fig. 39 Overall view of type LH pile driver (3-point supporting type).

(1) Being of the crawler crane type, the unit has excellent mobility and is ideal for work requiring frequent work-site shifting.

(2) The assembling and disassembling of this rig require no additional equipment.

(3) Because of its simple construction, it is easy to transport the unit from one job site to another.

(4) This leader can be mounted on the standard P&H crane without any modifications, making it versatile.

(2)-2 3-point supporting type

(a) Outline

This rig supports the leader with stays and leader holders, and the hammer and pile are lifted by hoisting mechanism of the crane as in the case of the suspension type. The slanting movement of the leader is controlled by changing the length of the stays.

At our plant this type of leader is called type LH and the entire rig is called the type LH pile driver. The specifications of type LH are given in Table 4, and the overall view of the pile driver in Fig. 39, and the overall appearance in photo 9. Fig. 40 shows the sectional dimensions of the leader.

(b) Special features

(1) The angle of the leader is adjusted by means of hydraulic cylinder, making it easy to operate.

(2) For batter piling this system is far more efficient than the suspension type.

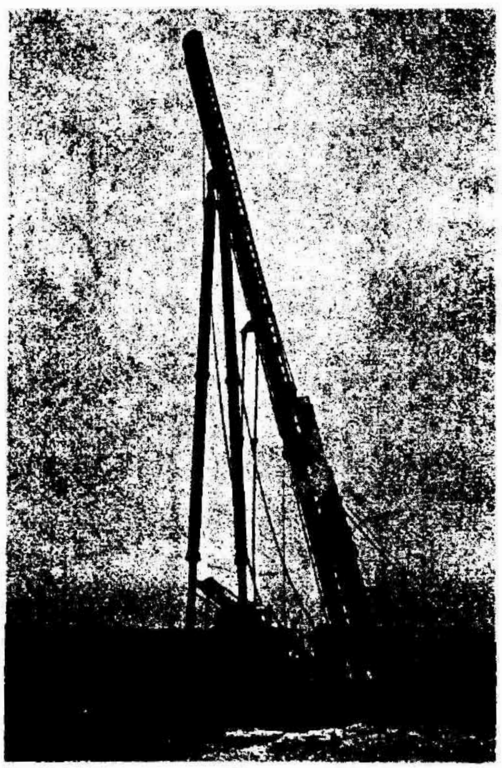
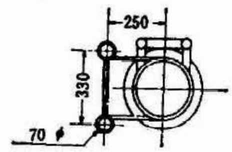


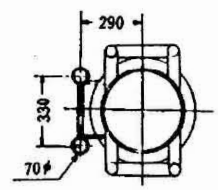
Photo 9

(3) As the leader can be held close to the body of the crane, it is convenient for working in confined areas. The unit is very stable and can be used in combination with a large hammer such as our K42 diesel pile hammer.

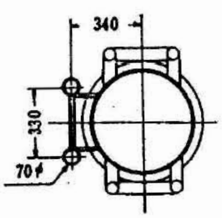
(4) The leader is so constructed that its angle can be adjusted into either side, and it can



Sectional view of Model 13 Leader



Sectional view of Model 22 Leader



Sectional view of Model 42 Leader

Fig. 40 Sectional dimensions of leaders.

Suitable combinations of hammers and leaders.

Model of leader	Suitable hammer
Modle 13	K13
Model 22	K13 K22
Model 42	K13 K22 K32 K42

be easily erected vertically even on ground that is not level.

(5) This rig can be assembled or disasembled without the use of auxiliary devices.

(6) Because it is easily set up or taken down, the rig can be transported from one work-site to another with ease.

(7) This leader can be combined with standard cranes such as P&H Model 320H or Model 330 without major modifications.

Table 3. Specifications for suspension type pile driver.

(Table 3-1) (See Fig. 38)

Item \ Model of Crane (Model of Leader)	Pile driver 315 (LA13)	Pile driver 320OH (LA22)	Pile driver 330 (LA42)
Diesel pile hammer	K13	K13 K22	K22 K32
Length of boom : LB (m)	12.19	12.19 ~ 18.29	12.19 ~ 18.29
Length of leader : L (m)	18	18 ~ 24	18 ~ 24
Maximum length of pile (m)	13	13 ~ 19	13 ~ 19
Traveling speed (km/h)	1.9 (high speed) 1.2 (low speed)		
Rotating speed (rpm)	5.1 (high speed) 3.2 (low speed)		
Speed of hammer lifting rope m/min	51 (high speed) 31 (low speed)		
Speed of pile lifting rope m/min	51 (high speed) 31 (low speed)		
Hammer lifting wire rope	20φ 2 ropes	20φ 2 ropes	20φ 2 ropes (K22) 3 ropes (K32)
Pile lifting wire rope	20φ	20φ	20φ
Ground pressure (kg/cm^2)	0.70	0.61 ~ 0.71 (760mm shoe) 0.77 ~ 0.89 (590mm shoe)	0.68 ~ 0.79

Pile driver 315 (with leader LA13) equipped with pile hammer Model K13

(Table 3 - 2) (See Fig. 38)

Length of boom LB (m)	12.2
Length of leader L (m)	18
Maximum length of pile (m)	13

Boom angle ($\theta°$)	Working radius R (m)	Weight of pile W (t)
82	4.2	4.8
81	4.4	4.1
80	4.7	3.4
79	4.9	2.8
78	5.1	2.3
77	5.3	1.9
76	5.5	1.5
75	5.7	1.1
74	—	—
73	—	—
72	—	—
71	—	—
70	—	—

Pile driver 320H (with leader LA22 & 760 mm shoes) equipped with diesel pile hammer Model K13
Table 3 - 3 (See Fig. 38)

	With standard counterweight						With 2,100 kg extra countweight					
Length of boom LB (m)	12.2		15.2		18.3		12.2		15.2		18.3	
Length of leader L (m)	18		21		24		18		21		24	
Maximum length of pile (m)	13		16		19		13		16		19	
Boom angle ($\theta°$)	Working radius R (m) Weight of pile to be lifted W (t)											
	R	W	R	W	R	W	R	W	R	W	R	W
82	4.1	8.4	4.6	6.0	5.0	4.0	4.1	10.7	4.6	8.0	5.0	5.8
81	4.4	7.3	4.8	4.9	5.3	3.0	4.4	9.4	4.8	6.8	5.3	4.7
80	4.6	6.3	5.1	4.0	5.6	2.1	4.6	8.3	5.1	5.8	5.6	3.7
79	4.8	5.5	5.4	3.2	6.0	1.4	4.8	7.4	5.4	4.9	6.0	2.9
78	5.0	4.7	5.6	2.5	—	—	5.0	6.5	5.6	4.1	6.3	2.1
77	5.2	4.1	5.9	1.9	—	—	5.2	5.8	5.9	3.4	6.6	1.5
76	5.4	3.5	6.2	1.4	—	—	5.4	5.1	6.2	2.8	—	—
75	5.6	2.9	—	—	—	—	5.6	4.5	6.4	2.2	—	—
74	5.8	2.5	—	—	—	—	5.8	3.9	6.7	1.7	—	—
73	6.0	2.0	—	—	—	—	6.0	3.4	6.9	1.3	—	—
72	6.3	1.6	—	—	—	—	6.3	3.0	—	—	—	—
71	6.5	1.1	—	—	—	—	6.5	2.4	—	—	—	—
70	—	—	—	—	—	—	6.7	2.2	—	—	—	—

Pile driver 320H (with leader LA22 & 760mm shoe) equipped with diesel pile hammer Model K22.
(Table 3 - 4) (See Fig. 38)

	With standard counterweight						With 2,100 kg extra counterweight					
Length of boom LB (m)	12.2		15.2		18.3		12.2		15.2		18.3	
Length of leader L (m)	18		21		24		18		21		24	
Maximum length of pile (m)	13		16		19		13		16		19	
Boom angle ($\theta°$)	Working radius R (m) Weight of pile to be lifted W (t)											
	R	W	R	W	R	W	R	W	R	W	R	W
82	4.2	6.1	4.6	3.8	5.1	1.9	4.2	8.4	4.6	5.8	5.1	3.7
81	4.4	5.1	4.9	2.8	—	—	4.4	7.2	4.9	4.6	5.4	2.5
80	4.6	4.1	5.2	1.9	—	—	4.6	6.1	5.2	3.6	5.7	1.6
79	4.8	3.3	5.4	1.1	—	—	4.8	5.2	5.4	2.8	—	—
78	5.1	2.6	—	—	—	—	5.1	4.4	5.7	2.0	—	—
77	5.3	2.0	—	—	—	—	5.3	3.6	6.0	1.3	—	—
76	5.5	1.4	—	—	—	—	5.5	3.0	—	—	—	—
75	—	—	—	—	—	—	5.7	2.4	—	—	—	—
74	—	—	—	—	—	—	5.9	1.9	—	—	—	—
73	—	—	—	—	—	—	6.1	1.4	—	—	—	—
72	—	—	—	—	—	—	—	—	—	—	—	—
71	—	—	—	—	—	—	—	—	—	—	—	—
70	—	—	—	—	—	—	—	—	—	—	—	—

Pile driver 330 (with leader LA22) equipped with diesel pile hammer Model K22.
(Table 3 - 5) (See Fig. 38)

	With standard counterweight				With 2,100 kg extra counter weight			
Length of boom LB (m)	15.2		18.3		15.2		18.3	
Length of leader L (m)	21		24		21		24	
Maximum length of pile (m)	16		19		16		19	
Boom angle (θ°)	Working radius R (m)				Weight of pile to be lifted W (t)			
	R	W	R	W	R	W	R	W
82	4.6	7.2	5.1	4.8	4.6	9.6	5.1	6.9
81	4.9	5.9	5.4	3.5	4.9	8.0	5.4	5.4
80	5.2	4.7	5.7	2.4	5.2	6.7	5.7	4.2
79	5.4	3.7	6.0	1.5	5.4	5.6	6.0	3.1
78	5.7	2.8	—	—	5.7	4.6	6.3	2.2
77	6.0	2.1	—	—	6.0	3.7	6.6	1.4
76	6.2	1.4	—	—	6.2	2.9	—	—
75	—	—	—	—	6.5	2.2	—	—
74	—	—	—	—	6.7	2.0	—	—
73	—	—	—	—	7.0	1.1	—	—
72	—	—	—	—	—	—	—	—
71	—	—	—	—	—	—	—	—
70	—	—	—	—	—	—	—	—

Pile driver 330 (with leader LA42) equipped with diesel pile hammer K32
(Table 3 — 6) (See Fig. 38)

	With standard counterweight						With 2,100 kg extra counter-weight					
Length of boom LB (m)	12.2		15.2		18.3		12.2		15.2		18.2	
Length of leader L (m)	18		21		24		18		21		24	
Maximum length of pile (m)	13		16		19		13		16		19	
Boom angle (θ°)	Working radius R (m) Weight of pile to be lifted W (t)											
	R	W	R	W	R	W	R	W	R	W	R	W
82	4.4	6.4	4.8	3.5	5.2	1.1	4.4	8.9	4.8	5.7	5.2	3.0
81	4.6	5.1	5.0	2.2	—	—	4.6	7.4	5.0	4.2	5.5	1.7
80	4.8	3.9	5.3	1.1	—	—	4.8	6.1	5.3	3.0	—	—
79	5.0	2.9	—	—	—	—	5.0	4.9	5.6	1.9	—	—
78	5.2	1.9	—	—	—	—	5.2	3.9	5.8	1.0	—	—
77	5.4	1.1	—	—	—	—	5.4	3.0	—	—	—	—
76	—	—	—	—	—	—	5.6	2.2	—	—	—	—
75	—	—	—	—	—	—	5.8	1.5	—	—	—	—
74	—	—	—	—	—	—	—	—	—	—	—	—
73	—	—	—	—	—	—	—	—	—	—	—	—

Note: The weights of the piles mentioned in the above tables show the vertical loads at the center of the hammer on firm level with the Kobe leader mounted.
The 760 mm shoe is recommended for pile driver 320H.
When the standard shoe is attached, the weights of the piles should be 300 kg less than the values mentioned in the above tables.
The attaching and detaching of the extra counterweight should be carried out with the boom mounted.

10-2 Marine pile driver

For underwater piling, a marine pile driver is used. It may be equipped with the upper structure of a crawler crane or have a winch and other equipment mounted on it. To reduce the rocking of the marine by wire ropes stretched leading to anchors or land mooring. Photo 10 shows an example of using a marine pile driver.

10-3 Pile cap .

When driving a pile, a cap is placed between the hammer and the pile to protect the pile head from damage and at the same time to keep the pile aligned. If the pile is struck directly by the hammer, the pile head receives a strong impact that damages the head. To avoid this a cap is used to absorb the impact energy. The cap is held in position by the lead of the leader so as to drive the pile parallel to the leader without slanting. The cap should be made of cast steel rather than welded steel plate. This is because it receives tremendous impact energy that can crack welds.

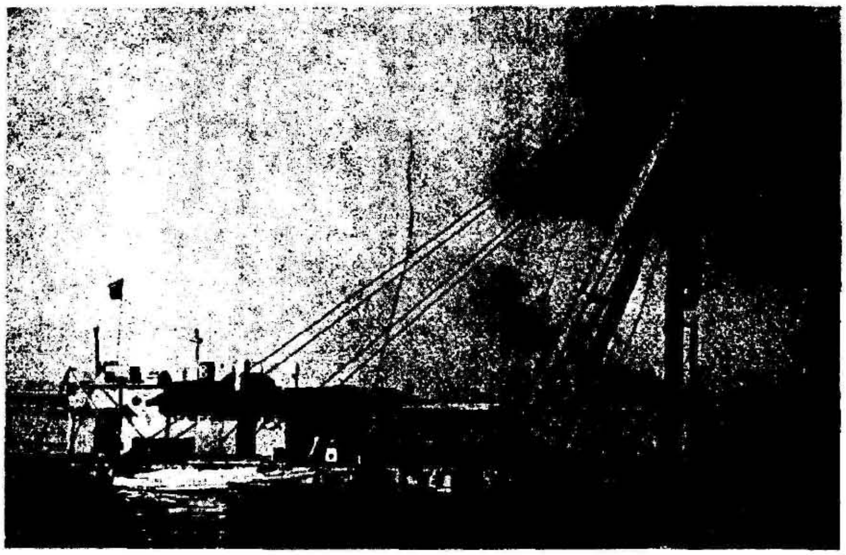


Photo 10 Work with a marine pile driver.

A cushion of hard wood is placed on top of the cap to avoid the direct impact of the hammer on the cap. The rate of absorption of impact energy is in direct proportion to the size of the cushion material. When the cushion becomes worn, the impact stress on the cap becomes greater. The cushion should be replaced occasionally for it wears out comparatively easily. Fig. 41 and Fig. 42 show caps for sheet piles.

10-4 Follower

When pit excavation work is to be done, the follower is used to drive the pile head down to a predetermined position below the ground level. The follower is often used in the construction of foundation of bridge piers. When the pile head is even with the ground surface, the cap is removed and the follower is placed on the pile head and, with the upper end of follower being struck by the hammer, the pile is driven to the predetermined depth, and then the follower is lifted out by wire rope. The follower should be so constructed that it fits the pile head snugly to transmit all the

Table 4. Specifications for pile driver type LH (3-point supporting type)

(Table 4 — 1)

Item / Model of crane (Model of leader)		320H - LH Pile driver (LH22)	320H - LH Pile driver (LH42)	330 - LH Pile driver (LH22)	330 - LH Pile driver (LH42)
Diesel pile hammer		K13 K22	K32 K42	K13 K22	K32 K42
Length of leader	(m)	18 ~ 27	18 ~ 24	18 ~ 27	18 ~ 24
Maximum length of pile	(m)	13 ~ 22	13 ~ 19	13 ~ 22	13 ~ 19

Note : For items other than those mentioned above, the specifications in Table 3—1 apply.

Table of working capacity of pile driver 320H-LH.

(Table 4 — 2)

Leader		Hammer used	Maximum batter angle (degree)		Pile	
Model	Length (m)		Backward	Forward	Max. Length (m)	Max. Weight (ton)
LH22	18	K13	20	5	13	4
	21		20	5	16	4
	24		15	5	19	4
	27		0	0	22	4
	18	K22	20	5	13	4
	21		*20	5	16	4
	24		15	5	19	4
	27		0	0	22	4
LH42	18	K32	20	5	13	4
	21		15	5	16	4
	24		15	0	19	4
	18	K42	20	0	13	4
	21		15	0	16	4
	24		15	0	19	4

*Avoid lifting the hammer while the leader is in the position for batter piling.

Table of working capacity of pile driver 330-LH.

(Table 4 — 3)

Leader		Hammer used	Maximum batter angle (degree)		Pile	
Model	Length (m)		Backward	Forward	Max. length (m)	Max. weight (ton)
LH22	18	K13	20	5	13	4
	21		20	5	16	4
	24		20	5	19	4
	27		0	0	22	4
	18	K22	20	5	13	4
	21		20	5	16	4
	24		20	5	19	4
	27		0	0	22	4
LH42	18	K32	20	5	13	4
	21		20	5	16	4
	24		15	5	19	4
	18	K42	20	5	13	4
	21		20	5	16	4
	24		15	0	19	4

impact energy of the hammer to the pile. It is essential to have an accurate alignment between the axial centers of follower and the pile in order to avoid eccentric driving. The follower is usually made of steel pipe, and its diameter of middle part is slightly smaller than the diameter of the pile so as to minimize the contact between it and the sides of the pile hole, and to facilitate the drawing out of the follower. When a long follower is driven into clayey soil, it may not be easy to pull it out because of the adhesive property of the soil. The pile driven in such a case should be strong enough to overcome such a tensile force.

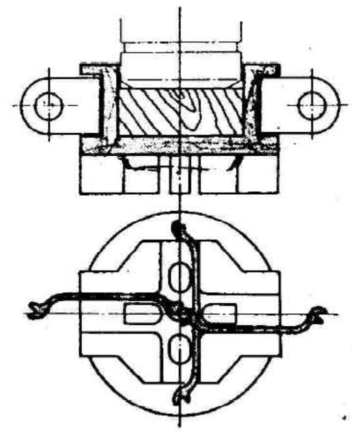


Fig. 41 Cap for sheet pile.

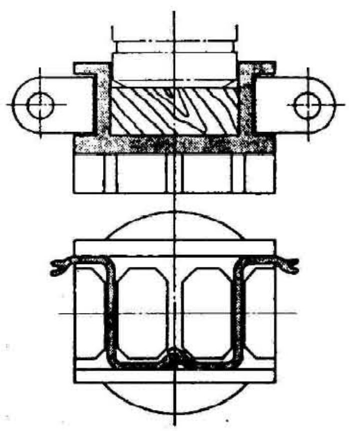


Fig. 42 Cap for sheet pile.

11. Selection of hammer capacity

The hammer to be employed should be selected by taking into consideration the bearing capacity of the pile desired, economy, efficiency and the strength of the pile.

It is expected that greater impact energy raises the efficiency of operation. However, when a hammer of large capacity is used, a large pile driver is required, and if the striking force is too great, and the stress the pile receives becomes too strong, then the pile head is liable to be damaged. If, on the other hand, the impact energy is too small, it can not overcome the penetration resistance and elastic resistance and not satisfy the work requirements. The critical point of the driving operation can be considered to be a penetration of 0.5 mm per blow. When the penetration per blow is less than 0.5 mm, the driving operation is unduely slow and the hammer becomes overloaded.

The heavier the pile becomes in relation to the weight of the ram, the larger the rate of loss of the striking energy becomes, and the lower the driving efficiency. The energy transmitted from the hammer to the pile can be described as follows:

$$Ep = Eh \cdot \frac{W+n^2P}{W+P} \quad \cdots\cdots\cdots\cdots(8)$$

Where:

Ep = Energy transmitted from hammer to pile .... ton•cm

Eh = Impact energy of hammer .... ton•cm

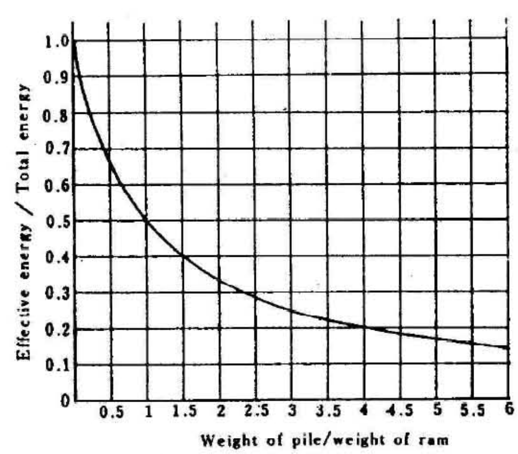


Fig. 43 Weight ratio and reduced values of impact energy.

W = Weight of ram ....ton

P = Weight of pile ....ton

n = Repulsive coefficient

In equation 8, the reduced values of impact energy were sought relative to the weight ratio between the ram and pile, ignoring the effects of elasticity.

Generally speaking, it is not advisable to use a hammer whose ram is less than 1/3 the weight of a pile.

11-1 Bearing capacity formula and N value

A hammer should have sufficient impact energy to utilize the designed bearing capacity of the pile and to easily overcome the penetratiion resistance and elastic resistance.

To select a hammer adequate for the designed bearing capacity of a pile, it is best to calculate the penetration resistance of the ground by Meyeroff's formula (Equation 17), and the driving capacity of the hammer by Hiley's formula (Equation 20) when the diameter and length of the pile, N value and $\overline{\mathrm{N}}$ value of the standard penetration tests are known, and determine the capacity of the hammer by comparing the two values thus obtained.

11-2 Strength of pile at the time of driving

The pile is subjected to an extremely large dynamic compressive force or tensile force at the time of driving, and this also must be considered.

(1) Dynamic compressive force on pile head

To calculate the component of force created in the pile body by the hammer impact while the pile is being driven, there are two methods, i.e., either by the equilibrium of impact energy or by impact wave equation. The following is an impact wave equation that is often employed because it is said to correspondent with values obtained by actual operation.

Dynamic compressive force of diesel pile hammer

$$\sigma_P = 2 \cdot \frac{A_H \sqrt{E_H \rho_H}}{A_H \sqrt{E_H \rho_H} + A_O \sqrt{E_O \rho_O}} \cdot \frac{A_O \sqrt{E_O \rho_O}}{A_D \sqrt{E_O \rho_C} + A_P \sqrt{E_P \rho_P}} \cdot \sqrt{2eE_P \rho_P H} \quad \text{..........(12)}$$

σ_P — Dynamic compressive force on pile head ....ton/cm^2

A — Sectional area .... cm^2

E — Young's modulus..ton/cm^2

ρ — Specific gravity ....ton/cm^3

e — Efficiency .... ≑ 0.8

H — Ram stroke .... cm

Additive symbol$_H$ — Hammer

Additive symbol$_O$ — Cap

Additive symbol$_P$ — Pile

For centrifugal reinforced concrete piles and steel piles, the above equation can be replaced by the assumed constants as follows:

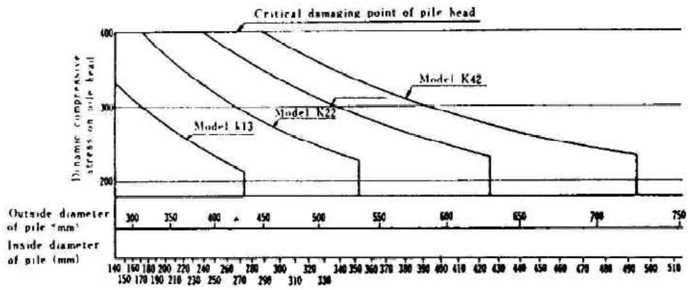


Fig. 44 Selection of adequate hammer according to dynamic compressive component of force on pile head (concrete pile).

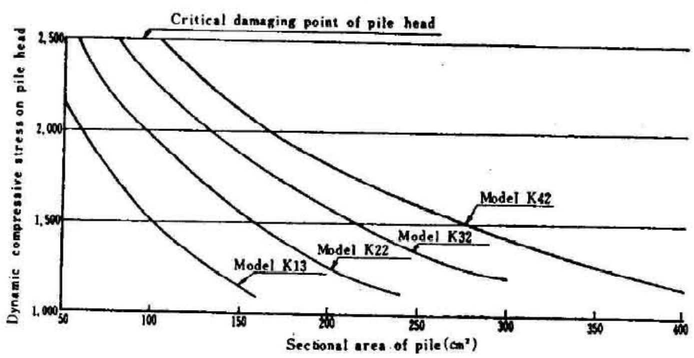


Fig. 45 Selection of adequate hammer according to dynamic compressive force on pile head (steel pile).

(a) Centrifugal reinforced concrete pile

$E_H = 2{,}100\ \mathrm{t/cm^2}$

$E_P = 350\ \mathrm{t/cm^2}$

$E_C = 100\ \mathrm{t/cm^2}$

$\rho_H = 7.85\times10^{-6}\ \mathrm{t/cm^3}$

$\rho_P = 2.4\times10^{-6}\ \mathrm{t/cm^3}$

$\rho_C = 1.0\times10^{-6}\ \mathrm{t/cm^3}$

$$\sigma_P = \frac{0.0733\sqrt{H}}{\left(1+0.0778\frac{A_O}{A_H}\right)\left(1+2.90\frac{A_P}{A_O}\right)} \quad \cdots\cdots(13)$$

(b) Steel pile

$E_H = E_P = 2{,}100\ \mathrm{t/cm^2}$

$E_O = 100\ \mathrm{t/cm^2}$

$\rho_H = \rho_P = 7.85\times10^{-6}\ \mathrm{t/cm^3}$

$\rho_O = 1.0\times10^{-6}\ \mathrm{t/cm^3}$

$$\sigma_P = \frac{0.324\sqrt{H}}{\left(1+0.0778\frac{A_O}{A_H}\right)\left(1+12.86\frac{A_P}{A_O}\right)} \quad \cdots\cdots(14)$$

From the above equations (12), (13) and (14), it can be said that the length of the fall, rather than the weight of the hammer, and the use of a hammer whose sectional area is larger than that of a pile create forces that can damage the pile head.

Now in equations (13), (14), assuming

$H = 180\ \mathrm{cm}$

$A_O/A_H = 1.0$

the following equation can be obtained:

(a) In the case of centrifugal reinforced concrete pile

$$\sigma_P = \frac{0.912}{1+2.90\frac{A_P}{A_H}} \quad \cdots\cdots(15)$$

(b) In the case of steel pile

$$\sigma_P = \frac{4.03}{1+12.86\frac{A_P}{A_H}} \quad \cdots\cdots(16)$$

Fig. 44 & Fig. 45 show the selection of adequate hammers, considering the dynamic compressive forces on the pile head.

The strength of a pile can be expressed relative to the N value of the standard penetration tests, and the limit of the hardness of ground that can be penetrated by piles is roughly $N=30$ for the concrete pile and $N=50\sim70$ for the steel pile.

Table 5. Typical combinations of piles and Kobe Diesel Pile Hammers.

	Type of pile	Hammer model	K 13									
Ordinary ground	H pile	Height × Width mm	300 × 300		350 × 350		400 × 400					
		Thickness mm	12	16	13	16	12.5	16				
		Weight kg/m	84.1	103	106	131	115	137				
	Pipe pile	Out dia. mm	318.5	355.6	406.4							
		Thickness mm	6.0	6.4	6.4	9.5	12.7					
		Weight kg/m	46.2	55.1	63.1	93.0	123					
	Sheet pile	Type	Ⅲ	Ⅳ	Ⅴ	Z-38	Z-45					
		Thickness mm	13	15.5	22	17.2/11.4	21.5/12.6					
		Number of piles	Single pile									
		Weight per pile kg/m	60	76.4	105	96	116					
	Concrete pile	Out. dia. mm	250	300			350			400		
		Thickness mm	50	60	70	80	60	70	80	70	80	90
		Weight kg/m	82	120	130	140	140	160	180	190	210	230
	Wood pile	Lower end mm	2 5 0 over									
Weight of pile		ton	1. 0 ~ 2. 5									
Bearing capacity		ton	2 0 ~ 5 0									

	Type of pile	Hammer model	K 22														
Ordinary ground	H pile	Height × Width mm	300 × 300		350 × 350		400 × 400										
		Thickness mm	12	16	13	16	12.5	16									
		Weight kg/m	84.1	103	106	131	115	137									
	Pipe pile	Out dia. mm	406.4			508.0			609.6								
		Thickness mm	6.4	9.5	127	6.4	9.5	12.7	9.5	12.7	16.9						
		Weight kg/m	63.1	93.0	123	79.2	117	155	141	187	234						
	Sheet pile	Type	Ⅲ	Ⅳ	Ⅴ	Z-38	Z-45										
		Thickness mm	13	15.5	22	17.2/11.4	21.5/12.6										
		Number of piles	Double pile														
		Weight per pile kg/m	60	76.4	105	96	116										
	Concrete pile	Out. dia. mm	300			350			400			450			500		
		Thickness mm	60	70	80	60	70	80	70	80	90	70	80	90	80	90	100
		Weight kg/m	120	130	140	140	160	180	190	210	230	220	240	260	280	300	330
	Wood pile	Lower end mm															
Weight of pile		ton	1. 5 ~ 4. 5														
Bearing capacity		ton	3 0 ~ 100														

	Type of pile	Hammer model	K 32											
Ordinary ground	H pile	Height × Width mm	300 × 300		350 × 350		400 × 400							
		Thickness mm	12	16	13	16	12.5	16						
		Weight kg/m	84.1	103	106	131	115	137						
	Pipe pile	Out. dia. mm	508.0			609.6			711.2			812.8		
		Thickness mm	6.4	9.5	12.7	9.5	12.7	16.9	9.5	12.7	16.0	9.5	12.7	16.0
		Weight kg/m	79.2	117	155	141	187	234	164	219	274	188	251	314
	Sheet pile	Type	Ⅲ	Ⅳ	Ⅴ	Z-38	Z-45							
		Thickness mm	13	15.5	22	17.2/11.4	21.5/12.6							
		Number of piles	Triple pile											
		Weight per pile kg/m	60	76.4	105	96	116							
	Concrete pile	Out. dia. mm	400			450			500			600		
		Thickness mm	70	80	90	70	80	90	80	90	100	90	100	110
		Weight kg/m	190	210	230	220	240	260	280	300	330	380	410	440
	Wood pile	Lower end mm												
Weight of pile		ton	2. 5 ~ 6. 5											
Bearing capacity		ton	5 0 ~ 150											

	Type of pile	Hammer model	K 42											
Ordinary ground	H pile	Height × Width mm	350 × 350		400 × 400									
		Thickness mm	13	16	12.5	16								
		Weight kg/m	106	131	115	137								
	Pipe pile	Out. dia. mm	609.6			711.2			812.8			914.4		
		Thickness mm	9.5	12.7	16.9	9.5	12.7	16.0	9.5	12.7	16.0	9.5	12.7	16
		Weight kg/m	141	187	234	164	219	274	188	251	314	212	282	354
	Sheet pile	Type	Ⅲ	Ⅳ	Ⅴ	Z-38	Z 45							
		Thickness mm	13	15.5	22	17.2/11.4	21.5/12.6							
		Number of piles	Triple pile											
		Weight per pile kg/m	60	76.4	105	96	116							
	Concrete pile	Out. dia. mm	500			600			700			800		
		Thickness mm	80	90	100	90	100	110	100	110	120	110	120	130
		Weight kg/m	280	300	330	380	410	440	490	530	570	620	670	710
	Wood pile	Lower end mm												
Weight of pile		ton	3. 5 ~ 8. 5											
Bearing capacity		ton	6 5 ~ 200											

Table 6. Dimensions and performance of centrifugal reinforced concrete pile.

Dimensions			Natures of cross section			Designed bending moment		Reference weight kg/m
Out. dia. (mm)	In. dia. (mm)	Thickness (mm)	A cm^2	Z cm^3	1 cm^4	Crack kg/m	Rupture kg/m	
300	180	60	452	2,470	37,100	3,500	8,200	120
	160	70	506	2,600	39,100	3,700	8,400	130
	140	80	553	2,690	40,400	3,800	8,800	140
350	230	60	547	3,700	64,400	5,200	12,300	140
	210	70	616	3,900	68,600	5,600	12,800	160
	190	80	679	4,100	72,000	5,900	13,500	180
400	260	70	726	5,550	111,000	7,900	18,100	190
	240	80	804	5,860	117,000	8,500	19,600	210
	220	90	877	6,100	122,500	8,700	20,600	230
450	310	70	836	7,500	167,800	10,600	24,200	220
	290	80	930	7,960	179,000	11,100	25,800	240
	270	90	1,018	8,370	188,000	11,800	27,500	260
500	340	80	1,056	10,360	259,000	14,700	33,300	280
	320	90	1,159	10,960	273,900	15,400	35,500	300
	300	100	1,257	11,400	286,300	16,500	38,100	330
600	420	90	1,442	17,400	520,700	24,800	56,900	380
	400	100	1,571	18,300	549,300	26,000	59,600	410
	380	110	1,693	19,100	573,900	27,500	63,700	440
700	500	100	1,885	26,800	939,100	38,400	86,400	490
	480	110	2,039	28,200	988,600	39,900	91,100	530
	460	120	2,187	29,500	1,031,000	41,700	95,500	570
800	580	110	2,384	39,200	1,568,700	55,800	126,000	620
	560	120	2,564	41,100	1,646,500	59,200	132,000	670
	540	130	2,736	42,900	1,714,600	61,500	140,000	710
1,000	760	120	3,317	70,500	3,524,000	100,000	226,000	860
	740	130	3,553	74,000	3,702,000	105,000	338,000	920
	720	140	3,782	77,300	3,866,000	110,000	250,000	980
1,200	940	130	4,370	114,000	6,843,000	163,000	362,000	1,140
	920	140	4,662	119,700	7,183,000	170,000	382,000	1,210
	900	150	4,948	124,900	7,495,000	179,000	404,000	1,290

Table 7. Dimensions, Weight and sectional performance of steel pipe (JIS G3444, JIS A5525)

Dimensions of steel pile			Weight		Area			Sectional performance		
Out. dia. mm	Thick-ness mm	In dia. mm	kg/m	m/ton	Cross sectional area of steel material cm^2	Outside sectional area m^2	Outside surface area m^2/m	Section modulus cm^3	Geometrical moment of inertia cm^4	Radius of gyration of area cm
318.5	6.0	306.5	46.2	21.63	58.91	0.0797	1.00	451	719×10	11.0
	6.9	304.7	53.0	18.86	67.55			515	820×10	11.0
	8.0	302.5	61.3	16.33	78.04			591	940×10	11.0
	10.3	297.9	78.3	12.78	99.73			744	119×10^{2}	10.9
323.8	6.0	311.8	47.0	21.27	59.90	0.0824	1.02	467	756×10	11.2
	7.1	309.6	55.4	18.04	70.64			547	880×10	11.2
	7.9	308.0	61.5	16.25	78.40			604	978×10	11.2
	9.3	305.2	72.1	23.87	91.89			702	113×10^{2}	11.1
	11.1	301.6	85.6	11.68	109.04			824	133×10^{2}	11.0
355.6	6.4	342.8	55.1	18.15	70.21	0.0993	1.12	602	107×10^{2}	12.3
	7.1	341.4	61.0	16.39	77.73			664	118×10^{2}	12.3
	7.9	339.8	67.7	14.76	86.29			734	130×10^{2}	12.3
	9.3	337.0	79.4	12.59	101.2			853	150×10^{2}	12.2
	11.1	333.4	94.3	10.60	120.1			100×10	178×10^{2}	12.2
406.4	6.4	393.6	63.1	15.84	80.42	0.130	1.28	792	161×10^{2}	14.1
	7.9	390.6	77.6	12.88	98.90			967	196×10^{2}	14.1
	* 9.5	387.4	93.0	10.75	118.5			115×15	233×10^{2}	14.0
	*12.7	381.0	123	8.11	157.1			100×10	305×10^{2}	13.9
457.2	6.4	444.4	71.1	14.06	90.64	0.164	1.44	101×10	230×10^{2}	15.9
	* 9.5	438.2	105	9.54	113.6			147×10	335×10^{2}	15.8
	*12.7	431.8	139	7.18	177.3			192×10	438×10^{2}	15.7
508.0	6.4	495.2	79.2	12.63	100.9	0.203	1.60	125×10	317×10^{2}	17.7
	* 9.5	489.0	117	8.56	148.8			182×10	462×10^{2}	17.6
	*12.7	482.6	155	6.45	197.6			239×10	606×10^{2}	17.5
558.8	9.5	539.8	129	7.77	163.9	0.245	1.76	222×10	619×10^{2}	19.4
	*12.7	533.4	171	5.85	217.9			291×10	813×10^{2}	19.3
	*16.0	526.8	214	4.67	272.8			360×10	101×10^{2}	19.2
609.6	9.5	590.6	141	7.11	179.1	0.292	1.92	265×10	129×10^{2}	21.2
	*12.7	584.2	187	5.35	238.2			348×10	170×12^{2}	21.1
	*16.0	577.6	234	4.27	298.4			432×10	211×10^{2}	21.0
711.2	9.5	692.2	164	6.08	209.4	0.397	2.23	363×10	129×10^{3}	24.8
	*12.7	685.8	219	4.57	287.7			478×10	170×10^{3}	24.7
	*16.0	679.2	274	3.65	349.4			594×10	211×10^{3}	24.6
812.8	9.5	793.8	188	5.32	239.7	0.519	2.55	476×10	193×10^{3}	28.4
	12.7	787.4	251	3.99	319.2			629×10	256×10^{3}	26.3
	*16.0	780.8	314	3.18	400.5			782×10	318×10^{3}	28.2
914.4	9.5	895.4	212	4.72	270.1	0.657	2.87	605×10	271×10^{3}	32.0
	12.7	889.0	282	3.54	359.8			800×10	366×10^{3}	31.9
	*16.0	882.4	354	2.82	451.6			997×10	456×10^{3}	31.8
1,016.0	9.5	997.0	236	4.24	300.4	0.811	3.19	749×10	380×10^{3}	35.6
	12.7	990.6	314	3.18	400.3			992×10	504×10^{8}	35.5
	*16.0	984.0	395	2.53	502.7			124×10	268×10^{3}	35.4

Note: The above dimension conform to JIS A5525 steel pipe pile.

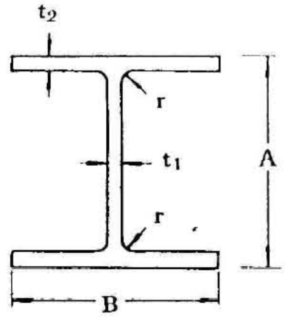


Fig. 46 H pile.

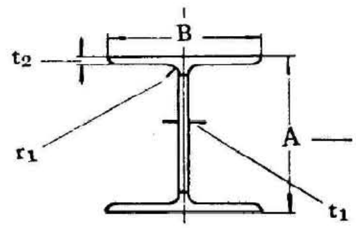


Fig. 47 H pile.

Table 8. Dimensions and sectional area performance of H pile. (See Fig. 48)

Dimensions mm					Sectional	Unit weight kg/m	Geometrical moment of inertia cm^4		Radius of gyration of area cm		Sectional modulus cm^3	
A	B	t_1	t_2	r	cm^2		Ix	Iy	ix	iy	Zx	Zy
200	204	12	12	13	71.53	56.2	4,980	1,700	8.35	4.88	498	167
244	252	11	11	16	82.06	64.4	8,790	2,940	10.3	5.98	720	233
250	255	14	14	16	104.7	82.2	11,500	3,880	10.3	6.09	919	304
294	302	12	12	18	107.7	84.5	16,900	5,520	12.5	7.16	1,150	365
300	305	15	15	18	134.8	106	21,500	7,100	12.6	7.26	1,440	466
338	351	13	13	20	135.3	106	28,200	9,380	14.4	8.33	1,670	534
344	354	16	16	20	166.6	131	35,300	11,800	14.6	8.43	2,050	669
350	357	19	19	20	198.4	156	42,800	14,400	14.7	8.53	2,450	809
388	402	15	15	22	178.5	140	49,000	16,300	16.6	9.54	2,520	809
394	405	18	18	22	214.4	168	59,700	20,000	16.7	9.65	3,030	985
400	408	21	21	22	250.7	197	70,900	23,800	16.8	9.75	3,540	1,170

Table 9. Dimensions and sectional area performance of H pile. (See Fig. 47)

Designation	Dimensions					Sectional area cm^2	Unit weight kg/m	Sectional area performance					
	A mm	C mm	t_1 mm	t_2 mm	r_1			Geometrical moment of inertia Ix cm^4	Iy cm^4	Sectional modulus Zx cm^3	Zy cm^3	Radius of gyration of area ix cm	iy cm
300×300×12	300	300	11	12	20	107.1	84.1	17,700	5,360	1,180	357	12.8	7.07
399×300×12	399	300	11	12	20	118.0	92.6	33,400	5,360	1,670	357	16.8	6.74
499×300×12	499	300	11	12	20	129.0	101	55,100	5,360	2,210	358	20.7	6.45
308×300×16	308	300	11	16	20	131.1	103	23,200	7,160	1,510	477	13.3	7.39
407×300×16	407	300	11	16	20	142.0	111	43,100	7,160	2,120	477	17.4	7.10
507×300×16	507	300	11	16	20	153.0	120	70,200	7,160	2,770	478	21.4	6.84
301×400×12.5	301	400	11	12.5	20	135.1	106	23,600	13,300	1,570	663	13.2	9.90
400×400×12.5	400	400	11	12.5	20	146.0	115	44,000	13,300	2,200	663	17.3	9.53
500×400×12.5	500	400	11	12.5	20	157.0	123	71,800	13,300	2,870	663	21.4	9.19
308×400×16	308	400	11	16	20	163.1	128	30,100	17,000	1,950	850	13.6	1.02
407×400×16	407	400	11	16	20	174.0	137	55,300	17,000	2,720	850	17.8	9.88
507×400×16	507	400	11	16	20	185.0	145	89,500	17,000	3,530	850	22.0	9.58

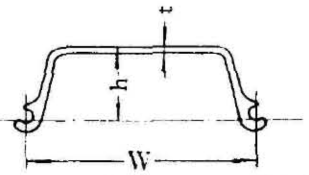


Fig. 48 U shape steel sheet pile.

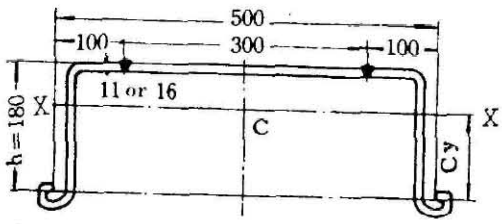


Fig. 49 U shape steel sheet pile.

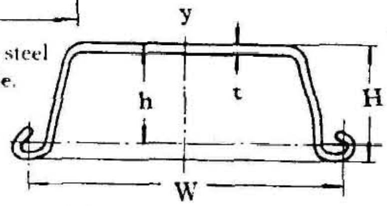


Fig. 50 U shape steels heet pile.

Table 10. Performance of U shape steel sheet pile. (See Fig. 48)

Type	Dimensions			Sectional area		Weight		Moment of inertia		Section modulus	
	W mm	h mm	t mm	Per sheet wall cm^2	Per width of wall cm^2	Per sheet kg/m	Per width of wall kg/m^2	Per sheet cm^4	Per width of wall cm^4	Per sheet cm^3	Per width of wall cm^3
YSP-Ⅰ	400	75	8.0	46.5	116	36.5	91.2	429	3,820	66.4	509
YSP-Ⅱ	400	100	10.5	61.2	153	48.0	120	986	8,690	121	869
YSPU-9	400	107.5	9.2	56.1	142	44.0	110	1,130	9,340	130	879
YSP-Ⅲ	400	125	13.0	76.4	191	60.0	150	1,920	16,400	196	1,310
YSPU-15	400	152.5	12.0	75.6	189	59.3	148	2,900	23,200	256	1,520
YSP-Ⅳ	400	155	15.5	97.4	243	76.4	191	3,690	31,900	311	2,060
YSPU-23	400	175.0	14.2	95.2	238	74.8	187	4,700	39,400	357	2,250
YSP-Ⅴ	400	175	22.0	134	319	105	250	5,950	55,200	433	3,150

Table 11. Performance of U shape steel sheet pile. (See Fig. 49)

Item	Dimensions			Per sheet of pile									Per meter of wall			
	Effective width	Height	Thickness of flat portion	Sectional area	Unit weight	Position of center of gravity	Geometrical moment of inertia		Section modulus		Radius of gyration		Sectional area	Unit weight	Geometrical moment of inertia	Section modulus
Unit / Type	B mm	h mm	t_f mm	A cm^2	W kg/m	Cy cm	Lx cm^4	Iy cm^4	Zx cm^3	Zy cm^3	ix cm	iy cm	A cm^2	W kg/m^2	Ix cm^4	Zx cm^3
NKK 4	500	180	11	96.81	76.0	11.6	5,214	34,040	374.8	1,270	7,34	18,8	193.6	152	36,520	2,030
NKK 5	500	180	16	130.4	102	12.4	5,876	43,000	399.6	1,605	6,71	18,2	260.8	204	51,860	2,882
NKK Special 4	600	180	11	107.8	84.6	12.2	5,552	53,120	382.8	1,671	7,18	22,2	179.7	141	35,783	2,002
NKK Special 5	600	180	16	146.4	115	12.9	6,207	67,890	407.6	2,135	6,51	21,5	244.9	192	51,117	2,840

Note: NKK Special 4 & NKK Special 5 are manufactured on order.

Table 12. Performance of U shape steel sheet pile. (See Fig. 50)

Type	Dimensions			Sectional area	Weight		Moment of inertia		Section modulus	
	W mm	h mm	I mm	Per sheet cm^2	Per sheet kg/m	Width of wall (m) kg/m^2	Per sheet of pile cm^4	Per width of wall (m) cm^4	Per sheet of pile cm^3	Per width of wall (m) cm^3
ESP Ⅱ	400	100	10.5	61.2	48.0	120	1,240	8,740	152	874
ESP Ⅱ A	400	120	9.2	55.0	43.2	108	1,460	10,600	160	880
ESP Ⅲ	400	125	13.0	76.4	60.0	150	2,220	16,750	223	1,340
ESP Ⅲ A	400	150	13.1	74.4	58.4	146	2,790	22,800	250	1,520
ESP Ⅳ	400	170	15.5	96.9	76.1	190.25	4,670	38,641	362	2,273
ESP Ⅳ	400	185	16.1	94.2	74.0	185	5,300	41,600	400	2,250

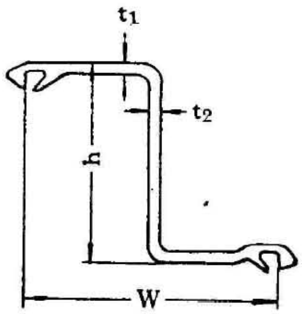


Fig. 51 Z shape steel sheet pile.

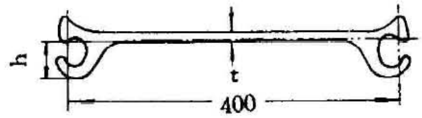


Fig. 52 Straight line steel sheet pile.

Table 13. Performance of Z shape steel sheet pile. (See Fig. 51)

Type	Dimensions				Sectional area		Weight		Moment of inertia		Section modulus	
	W mm	h mm	t_1 mm	t_2 mm	Per sheet cm^2	Per width of wall (m) cm^2	Per sheet kg/m	Per width of wall (m) kg/m^2	Per sheet cm^4	Per width of wall (m) cm^4	Per sheet cm^3	Per width of wall (m) cm^3
YSP Z-14	400	235	9.4	8.2	66.0	165	51.9	130	6,480	16,200	552	1,380
YSP Z-25	400	305	13.0	9.6	94.4	236	74.0	185	15,300	38,300	1,000	2,510
YSP Z-38	400	364	17.2	11.4	122	306	96.0	240	27,700	69,200	1,520	3,800
YSP Z-45	400	360	21.5	12.5	148	371	116	290	32,900	82,200	1,820	4,550

Table 14. Performance of straight line steel sheet pile. (See Fig. 52)

Type	Dimensions			Sectional area		Weight		Moment of inertia		Section modulus	
	W mm	h mm	t mm	Per sheet cm^2	Per width of wall (m) cm^2	Per sheet kg/m	Per width of wall (m) kg/m^2	Per sheet cm^4	Per width of wall (m) cm^4	Per sheet cm^3	Per width of wall (m) cm^3
Straight line type	400	45	9.5	69.1	173	54.2	136	190	525	47.8	120

(2) Dynamic tensile force created in the pile body by the blow of the hammer when the pile is driven into soft ground.

When a pile is driven into soft ground, it sinks quickly on the impact of the hammer and extremely large dynamic force may be created in the pile. The most important problem in this connecton is the jointing of piles, and special care should be taken to prevent the joints from being broken or damaged.

(3) Buckling of the portion protruding above the ground at the time of driving.

In driving a pile into hard ground, the part of the pile protruding above the ground is apt to buckle. When the pile and the hammer are not truly aligned, or when the striking point of the hammer deviates from the center of the pile, dynamic bending moment occurs besides static compressive force, so it is necessary to take these forces into consideration. An acceptable slant of the pile is generally considered to be 1/500 and the eccentricity of the hammer to be 1/20 of the diameter or width of the pile.

As described above, in the selection of hammer capacity, various factors have to be considered, and typical types of piles suitable for use with the Kobe Diesel Pile Hammer are shown in Table 5 (page 37). The shapes and performance of various piles are shown in Figs. 46~52 (page 40~42) and Tables 6~14 (page 38~42).

12. Bearing capacity formula

As a method to determine the bearing capacity of a pile, the pile load test i.e., placing a load on the pile and finding the bearing capacity from the relationship between the load and the sinking of the pile, is recommended as the most reliable one, and in all important projects this pile load test is conducted. But this test requires much time and expenditure. As a result, two methods which can easily be put to use have been developed to determine bearing capacity. One tries to find the bearing capacity of the pile from analysis of the soil and the other from the relationship between the amount of penetration of the pile and the hammer impact energy. The former is called a static bearing capacity formula and the latter a dynamic bearing capacity formula, and variations on these two have been presented by many scholars. Some of them will be described below.

The following method for determining the permanent allowable bearing capacity of a pile is given in the Structural Designing Standards for Foundations of Buildings.

The permanent bearing capacity of a pile should be determined as follows:

(1) The bearing capacity should be 1/2 the value of the yielding load in the load test of the pile, or 1/3 of the ultimate bearing capacity or the bearing capacity obtained by multiplying the allowable compressive stress unit of the pile material by its sectional area, whichever is the smallest. In case the load test is not carried out, a value smaller than one obtained by a pile driving test or other methods such as the static bearing capacity formula, or allowable bearing strength obtained from the allowable compressive stress unit of the pile material, whichever is the smallest, can be used.

If a jointed or composite pile is used the bearing capacity of the weaker pile should be taken.

(2) For a jointed pile, 20% should be deducted from the value of (1) above per joint. However, when a jointed steel pile is used, if it is considered to have sufficient strength, no deduction needs be made for the joint.

(3) With a pile whose length is more than 60 times its diameter, a percentage value obtained by deducting 60 from the figure obtained by dividing the length by the diameter of the pile is deducted from the value (1), and in the case of a steel pile the figure 60 referred to above should be changed to 120.

(4) When a end-bearing pile penetrates the ground which supposed decay, the effect of the frictional force acting on the circumference of the pile should be taken into consideration in determining permanent allowable bearing capacity."

12-1 Static formula

This formula supposes that the bearing capacity of a pile is the sum of the bearing capacity at the pile end and the frictional bearing capacity at the circumference of the pile.

There are many formulas for static bearing capacity, and the one shown below is Meyerhoff's formula, which seeks the bearing capacity formula by applying the theory of bearing capacity and the N value of the standard penetration test.

(a) Formula applicable to sandy ground

$$R_u = 40NA + \frac{\bar{N}L\varphi}{5} \quad \cdots\cdots (17)$$

Where:

R_u — Ultimate bearing capacity of pile .... ton

A — Area of pile end .... m^2

L — Length of pile .... m

φ — Circumferential length of pile .... m

N — N value of the ground at the pile end

$\bar{N}$ — Average N value of the ground around the pile

(b) Formula applicable to the composite ground of clayey and sandy strata

$$R_u = 40NA + \left(\frac{\bar{N}_s L_s}{5} + \frac{\bar{q}_u L_c}{2}\right)\varphi \quad \cdots\cdots (18)$$

Where:

L_s — The length of the portion of the pile in sandy stratum .... m

L_c — The length of the portion of the pile in clayey stratum .... m

$\bar{N}_s$ — Average N value of the sandy portion of the ground around the pile

$\bar{Q}_u$ — Average unconfined compressive of the clayey portion of the ground around the pile .... ton/m^2

or from the relation of substantially $q_u = \frac{N}{8}$ $(kg/cm^2) \doteqdot N\ t/m^2$

Between the unconfined compressive strength and the N value, thus

$$R_u = 40NA + \left(\frac{\bar{N}_s L_s}{5} + \frac{\bar{N}_c L_c}{2}\right)\varphi \quad \cdots\cdots (19)$$

With a pile of the open end type the effective area of the end portion which displays its end resistance is not the actual sectional area of the pile, it is said to be better to consider its closed area as the effective area as is shown in Fig. 53.

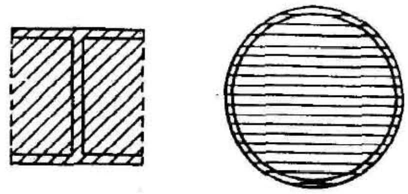


Fig. 53 Closed sectional area of pile.

The reason is this: As the pile penetrates, the interior of steel pile or the space between the flanges of an H-steel section becomes filled with soil, and when its inner friction becomes equal to the end resistance of the soil, there will be no further entry of soil, and thus the same effect as closing the open section is said to be displayed.

There is another problem of how far we should practically consider the N value of the ground at the pile end, one formula proposed in this connection being as follows:

$$\bar{N}=\frac{N+\bar{N}_2}{2} \quad (20)$$

Where:

$\bar{N}$ — N value of the ground at the pile end for design

N_1 — N value at the pile end position

$\bar{N}_2$ — Average N value within the range of 10B (B being the diameter or width of the pile) upward from the pile end

However, in such a case in which the N value tends to decrease with the depth downward from the pile end position, and average N value in the range of 2B downward from the pile end is taken as N_1.

Tables 15~17 below show various dimensions of piles with reference to the calculation of the above formulas. For steel pipe pile, see Table 6. (page 38)

12-2 Dynamic formulas

The bearing capacity of a pile driven by a diesel pile hammer can be obtained by the formula based on the theory that "the bearing capacity of a pile equals the driving resistance met at the end of driving."

While there are various formulas for the calculation, here is given an experimental one by Stuttgart University in Germany which is slightly modified version of Hiley's adopted in

Table 15. Dimensions of concrete pile.

Outside dia. (mm)	Circumferential length ψ(m)	Circumferential sectional area A (m^2)
200	0.628	0.0314
250	0.785	0.0491
300	0.942	0.0707
350	1,100	0.0962
400	1,260	0.1260
450	1,410	0.1590
500	1,570	0.1960

Table 16. Dimensions of H pile.

Designation	Circumferential length of closed section ψ (m)	Closed sectional area A (m^2)
200×204×12	0.808	0.0408
244×252×11	0.992	0.0615
250×255×14	1,010	0.0638
294×302×12	1,190	0.0888
300×305×15	1,210	0.0915
338×351×13	1,380	0.1190
334×354×16	1,380	0.1180
350×357×19	1,410	0.1250
388×402×15	1,580	0.1560
394×405×18	1,600	0.1600
400×408×21	1,620	0.1630
300×300×12	1,200	0.0900
399×300×12	1,400	0.1200
499×300×12	1,600	0.1500
308×300×16	1,220	0.0924
407×300×16	1,410	0.1220
507×300×16	1,610	0.1520
301×400×12.5	1,400	0.1200
400×400×12.5	1,600	0.1600
500×400×12.5	1,800	0.2000
308×400×16	1,420	0.1230
407×400×16	1,610	0.1630
507×400×16	1,810	0.2030

Table 17. Dimensions of steel sheet pile.

Division	Sub-division	Circumferential length of closed section ψ (m)	Closed sectional A (m^2)
Groove type	YSP Ⅰ	0.92	0.0347
	YSP Ⅱ ESP Ⅱ	0.97	0.0436
	YSPU-9 ESP Ⅱ A	0.99	0.0481
	YSP Ⅲ ESP Ⅲ	1.00	0.0518
	YSPU-15 ESP Ⅲ A	1.04	0.0578
	YSPIV ESPIV	1.10	0.0687
	YSPU-23 ESP Ⅳ A	1.09	0.0675
	YSPV	1.29	0.0868
	NKK 4	1.36	0.0900
	NKK 5	1.36	0.0900
	NKK 4 Special	1.56	0.1080
	NKK 5 Special	1.56	0.1080
Z type	YSPZ-14	1.02	0.0470
	YSPZ-25	1.13	0.0610
	YSPZ-38	1.23	0.0728
	YSPZ-45	1.22	0.0720
Straight line type	YSPF	0.85	

the Japan Institute of Architects Structural Standards for Foundations.

$$R=\frac{2WH}{S+K}\cdot\frac{W+n^2P}{W+P} \qquad (21)$$

Where :

R — Bearing capacity of pile .... ton

W — Weight of ram .... ton

H — Height of fall of ram .... cm

P — Weight of pile .... ton

S — Amount of penetration of pile at the end of driving .... cm

K — Amount of temporary elastic compression of cap, pile and ground .... cm

n — Repulsion factor (here n=o)

The above formula is intended to seek the penetration resistance of a pile more rationally by taking into consideration the energy loss due to the temporary elastic compression of the cap, pile and ground, and the effect of inertia due to the weight of the ram and pile. S is the best to take a value of 1/10 of the amount of sinking by the last 10 blows, and K indicates the actual amount of deformation during driving.

It is convenient to measure the amount of the final penetration and that of the elastic compression by the method shown in Fig. 54. First, a horizontal beam is set up a few centimeters apart from the pile. This beam is supported at a distance of several meters from the pile to avoid the vibration caused by the driving of the pile. A sheet of recording paper is attached to the side of the

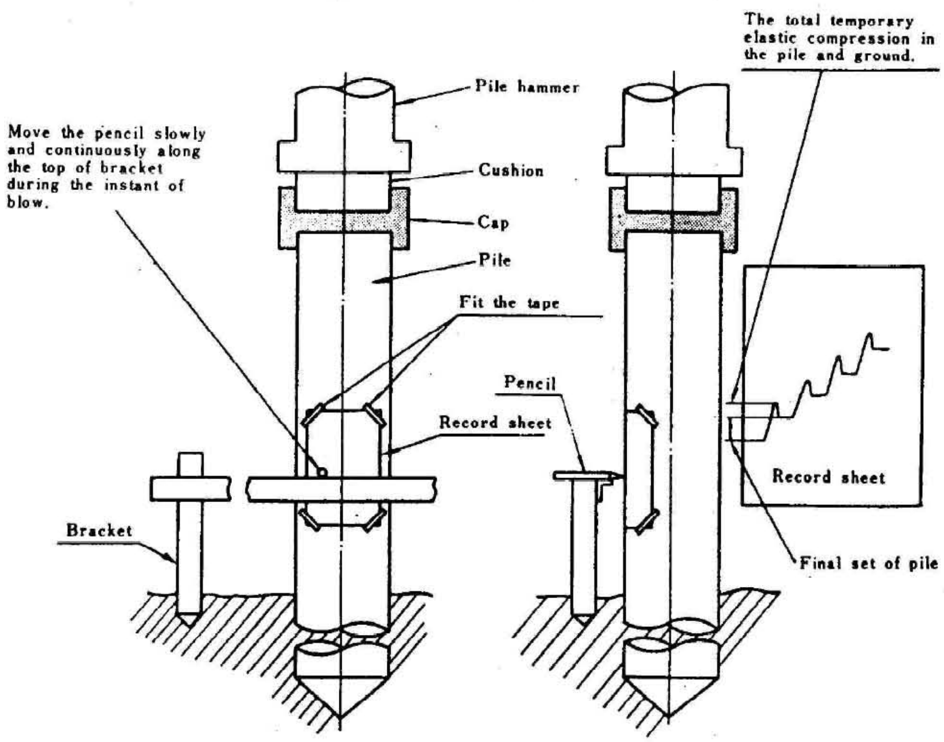


Fig. 54 Method of measuring the amount of penetration and the amount of temporary elastic compression.

pile, and a pencil is fastened to the beam in such a way that the point of the pencil will bear against the pile. During the driving operation, the pencil is moved slowly along the beam so that a stepped wave-line is recorded on the paper. The vertical distances between adjacent lines show the amount of penetration per blow, symbol S, and the height of the line rising from the left side of the horizontal line shows the amount of temporary elastic compression of the pile and ground.

Literatures dealing with temporary elastic compression are listed in the footnotes of Tables 10~21. However, the calculation of the bearing capacity should be based on the values obtained by actual measurement. The symbols used in Tables 18~21 represent the following:

$$K = C_1 + C_2 + C_3$$

Where:

C_1 = Amount of temporary elastic compression of the cap

C_2 = Amount of temporary elastic compression of the pile

C_3 = Amount of temporary elastic compression ofthe ground

Reference literature: Pile Foundation

Table 18. Tempotary Compression Allowance C_1 for Pile Head and Cap[a].

Material to which blow is applied	Easy driving, $p_1 = 500$ psi on cushion or pile butt if no cushion, in.	Medium driving, $p_1 = 1{,}000$ psi on head or cap, in.	Hard driving, $p_1 = 1{,}500$ psi on hrad or cap, in.	Very hard driving, $p_1 = 2{,}000$ psi on head or cap, in.
Head of timber pile	0.05	0.10	0.15	0.20
3--4-in. packing inside cap on head of precast concrete pile	0.05 + 0.07[b]	0.10 + 0.15[b]	0.15 + 0.22[b]	0.20 + 0.30[b]
½—1-in. mat pad only on head of precast concrete pile	0.025	0.05	0.075	0.10
Steel-covered cap, containing wood packing, for steel piling or pipe	0.04	0.08	0.12	0.16
3/16-in. red electrical-fiber disk between two 3/8-in. steel plates, for use with severe driving on Monotube pile......	0.02	0.04	0.06	0.08
Head of steel piling or pipe	0	0	0	0

[a]Largely from A. Hile, "Pile Driving Calculations with Notes on Driving Force and Ground Resistance," *The Structural Engineer*, vol. 8, July and August, 1930.[7] For a fuller discussion of the means of obtaining these values see this reference. For purpose of this article values represent average conditions and may be used.

[b]The first figure represents the compression of the cap and wood dolly or packing above the cap, whereas the second figure represents the compression of the wood packing between the cap and the pile head.

Note: Superior numbers (with or without letters) refer to the Bibliography, pp. 641*ff*., in which the material is organized by subject.

Table 19. Temporary Compression Values of C_2 for Piles.

Type of pile	Easy driving, $p_2 = 500$ psi for wood or concrete piles, 7,500 psi for steel, net section, in.	Medium driving, $p_2 = 1,000$ psi for wood or concrete piles, 15,000 psi for steel, net section, in.	Hard driving, $p_2 = 1,500$ psi for wood or concrete piles, 22,500 psi for steel, net section, in.	Very hard driving, $p_2 = 2,000$ psi for wood or concrete piles, 30,000 psi for steel, net section, in.
Timber pile, based on value of $E=$ 1,500,000.	$0.004 \times L^b$	$0.008 \times L^b$	$0.012 \times L^b$	$0.016 \times L^b$
Precast concrete pile ($E=3{,}000{,}000^{a,c}$)	$0.002 \times L$	$0.004 \times L$	$0.006 \times L$	$0.008 \times L$
Steel sheet piling, Simplex tube, pipe pile, Monotube shell, Raymond steel mandrel[d] ($E=30{,}000{,}000$)	$0.003 \times L$	$0.006 \times L$	$0.009 \times L$	$0.012 \times L$

[a] All other values in direct proportion to P_2 and inverse proportion to E.

[b] L should be considered as length to center of driving resistance, not necessarily full length of pile.

[c] May reach 6,000,000 for exceptionally good mix.

[d] When computing p_2 for a Raymond steel mandrel, it is suggested that the weight of the mandrel be divided by 3.4×length of pile in feet to obtain the average area.

Table 20. Temporary Compression or Quake of Ground Allowance C_3[a].

All values of p_3 to be taken on projected area of pile tips or driving points for end-bearing piles and piles of constant cross section; on gross area of pile at ground surface in case of tapered friction piles; and on bounding area under H piles.

	Easy driving, $p_3 = 500$ psi, in.	Medium driving, $p_3 = 1,000$ psi, in.	Hard driving, $p_3 = 1,500$ psi, in.	Very hard driving, $p_3 = 2,000$ psi, in.
For piles of constant cross section[b,c] ...	0 to 0.10	0.10	0.10	0.10

[a] Largely from A. Hiley, "Pile Driving Calculations with Notes on Driving Force and Ground Resistance," *The Structural Engineer*, vol. 8, July and August, 1930.[7] For a fuller discussion of the means of obtaining these values see this reference. For purpose of this article values represent average conditions and may be used.

[b] It is recognized that these values should probably be increased in the case of piles with battered faces, but insufficient test data are available at present time to cover this condition.

[c] If the strata immediately underlying the pile tips are very soft, it is possible that these values might be increased to as much as double those shown.

Reference literature : The Resistance of Piles to Penetration

Table 21. Temporary Compression Allowance C_c for Pile Head and Cap.

Material of Head of Pile.	Easy Driving, p = 500 lbs. per sq. in.	Medium Driving, p = 1,000 lbs. per sq. in.	Hard Driving, p = 1,500 lbs. per sq. in.	Very Hard Driving, p = 2,000 lbs. per sq. in.
Head of timber pile	.05″	.10″	.15″	.20″
Short dolly in helmet, 3″ to 4″ of highly compressed packing inside helmet on head of RC pile } Helmet and cap Packing	.05″ + .07″	.10″ + .15″	.15″ + .22″	.20″ + .30″
1″ to 1½″ mat pad only on head of RC pile	.03″	.05″	.075″	.10″

Temporary Compression Values of C_p per 10-Ft. Length of Piles.

Type of Pile	Easy Driving, p = 500 lbs. per sq. in.	Medium Driving, p = 1,000 lbs. per sq. in.	Hard Driving, p = 1,500 lbs. per sq. in. Very Hard	Very Hand Driving p = 2,000 lbs. per sq. in.
Timber pile	.04″	.08″	.12″	.16″
Reinforced concrete pile	.03″	.06″	.09″	.12″

Temporary Compression or Quake of Ground C_q for Average Cases where the Pile is Driven into Penetrable Ground.

	Easy Driving	Medium Driving	Hard Driving	Very Hard Driving
As above	.05″	.10″	.15″	.10″ to .20″

Note.—$C=C_e+C_p+C_q$.

These temporary compression values of C_p and C_q will vary with the quality of the concrete, period of curing, and nature of soil, and should be checked by actual observation with the pile set gauge.

Fig. 55 shows a diagram of the ram strokes by eye estimation, and Table 22 shows figures of the ram strokes by measurement.

A reasonable safety factor is considered as a usual practice to the bearing capacity R obtained from formula (21), and according to the Institute of Architects Standards for Foundations, the following values are to be considered :

For permanent load, Safety factor 4

For temporary load, Safety factor 2

and therefore these values are used here.

Figs. 56, 57, 58 and 59 (pages 51～54) are charts showing the bearing capacities of piles driven with Kobe Diesel Pile Hammers, K13, K22, K32 and K42, respectively, obtained from the above formula.

In the case of batter piling the rate of the loss of impact energy increases with the increase of the slant angle of the hammer.

The ram stroke should be considered as being perpendicular.

$H' = H(\cos\theta - \mu\sin\theta)$ ....(22)

H' = Effective ram stroke ....cm

H = Ram stroke measured in a slant direction ......cm

θ = Slant angle

μ = Coefficient of friction of ram and cylinder

Assuming η to be constant, the relation of H'/H against θ is shown in Fig. 60. (page)

15,400 FT LBS

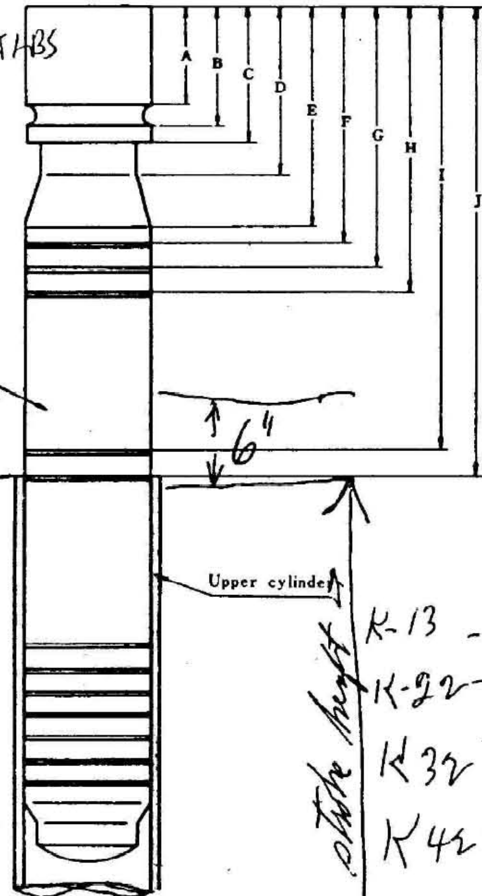


Table 22. Measurement of ram stroke of Kobe Diesel Pile Hammer.

K 13 2870 Ram?

Distance ram protrudes above the upper end of the cylinder		Ram stroke	
A	407 mm	1,312 mm	= 15,400
B	491 mm	1,396 mm	
C	524 mm	1.429 mm	
D	599 mm	1,504 mm	1710 approx
E	759 mm	1,664 mm	
F	809 mm	1,714 mm	
G	901 mm	1,806 mm	
H	—	—	
I	1,478 mm	2,383 mm	= 21,280
5' J	1,570 mm	2.475 mm	96 3/4"

8' stroke = @ 2800R = 22400 FT LBS E

K 22

Distance ram protrudes above the upper end of the cylinder		Ram stroke	
A	536 mm	1,403 mm	
B	629 mm	1,496 mm	
C	662 mm	1,529 mm	
D	782 mm	1,649 mm	
E	910 mm	1,777 mm	
F	1,000 mm	1,867 mm	
G	1,100 mm	1,967 mm	
H	1,200 mm	2,067 mm	
I	1.700 mm	2,567 mm	101 INCHES 103. MAX

4850 Ram Weight. 8'.5" STROKE = 40,837E approx

max —
@ 2500 mm = 86.7250000 inches = 7' = 33950 ENERGY.

Fig. 55 Eye estimation of the ram stroke of Kobe Diesel Pile Hammer.

ANVIL TOP OF RAM AT REST

Note: An excessively ~~large ram stroke is liable~~ to damage the ~~cylinder, ram and~~ anvil, so it should be controlled to within 2,500 mm by adjusting the amount of fuel fed.

K 32

Distance ram protrudes above the upper end of the cylinder		Ram stroke
A	516 mm	1,323 mm
B	614 mm	1,421 mm
C	647 mm	1,454 mm
D	797 mm	1,604 mm
E	947 mm	1,754 mm
F	982 mm	1,789 mm
G	1,082 mm	1,889 mm
H	1,182 mm	1,989 mm
I	1,652 mm	2,459 mm
J	1,752 mm	2,559 mm

8'4" STROKE = 59,093E

100 INCHES

K 42

Distance ram protrudes above the upper end of the cylinder		Ram stroke
A	448 mm	1,384 mm
B	555 mm	1,491 mm
C	588 mm	1,524 mm
D	763 mm	1,699 mm
E	938 mm	1,874 mm
F	993 mm	1,929 mm
G	1,093 mm	2,029 mm
H	1,193 mm	2,129 mm
I	1,593 mm	2,529 mm

99 INCHES

8' 3" STROKE @ 82,983E

Fig. 56 Chart of bearing capacity of pile driven by Diesel Pile Hammer K13.

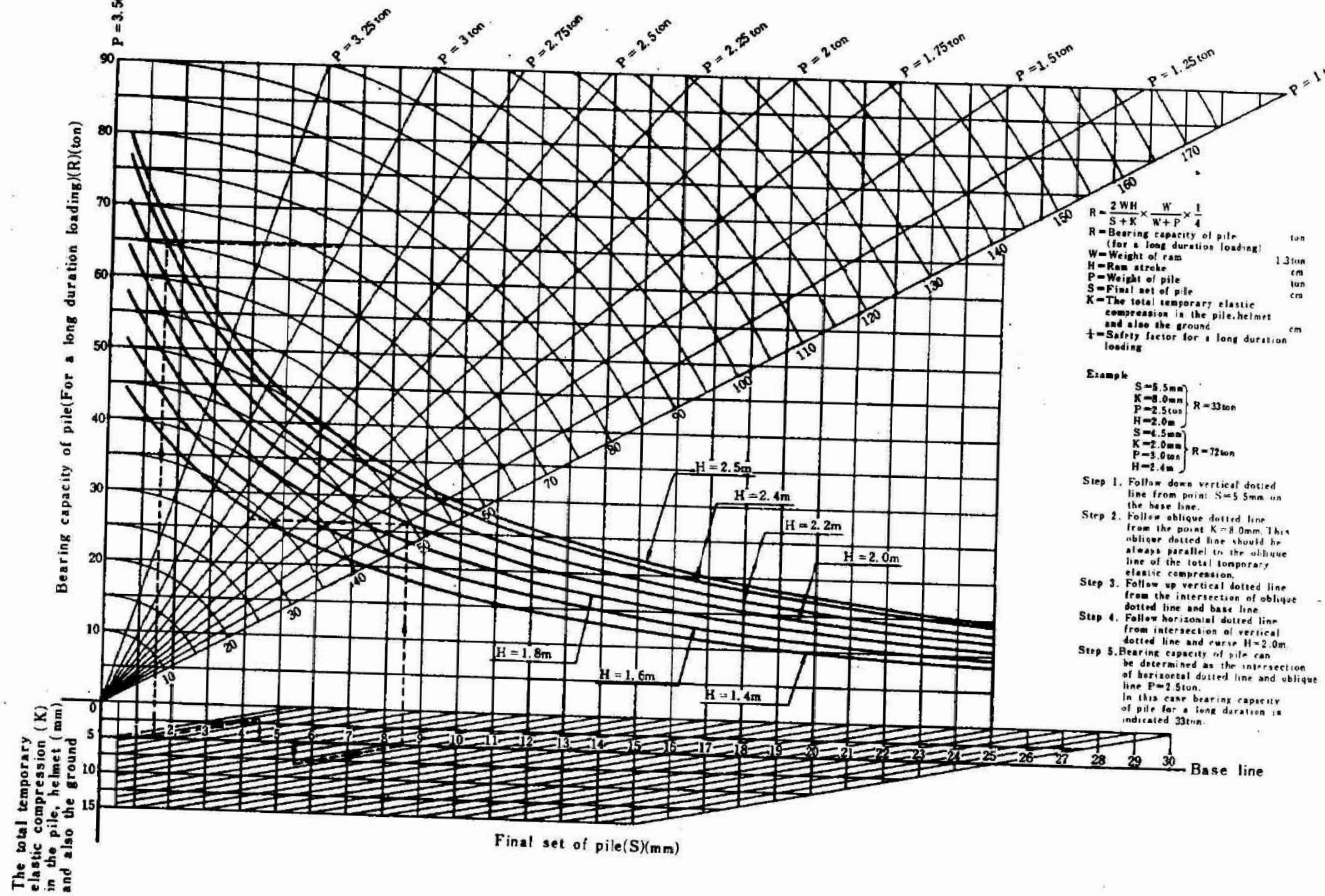
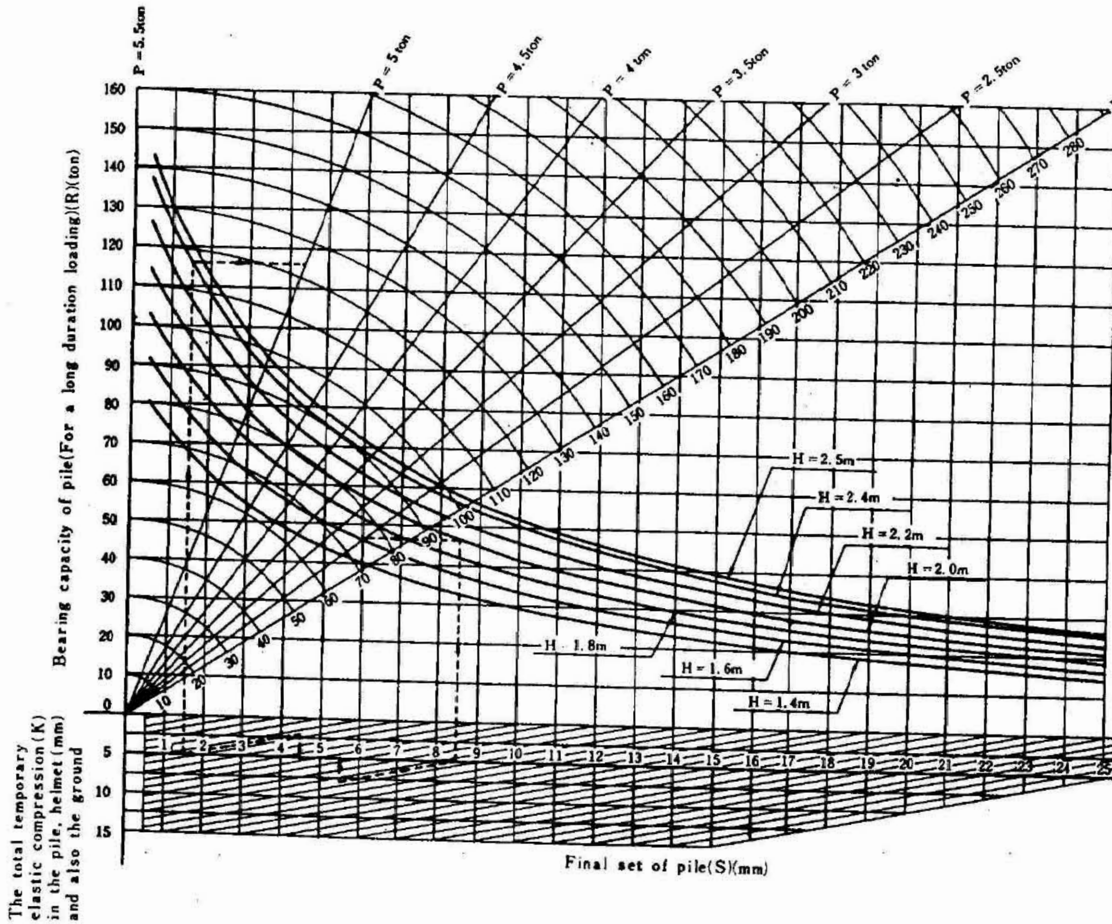


Fig. 57 Chart of bearing capacity of pile driven by Diesel Pile Hammer K22.



$$R = \frac{2WH}{S+K} \times \frac{W}{W+P} \times \frac{1}{4}$$

R =	Bearing capacity of pile (for a long duration loading)	ton
W =	Weight of ram	2.2ton
H =	Ram stroke	cm
P =	Weight of pile	ton
S =	Final set of pile	cm
K =	The total temporary elastic compression in the pile, helmet and also the ground	cm
$\frac{1}{4}$ =	Safety factor for a long duration loading	

Example

S = 5.5mm, K = 8.0mm, P = 2.5ton, H = 2.0m } R = 76ton

S = 4.5mm, K = 2.0mm, P = 3.0ton, H = 2.4m } R = 124ton

Step 1. Follow down vertical dotted line from point S = 5.5mm on the base line.

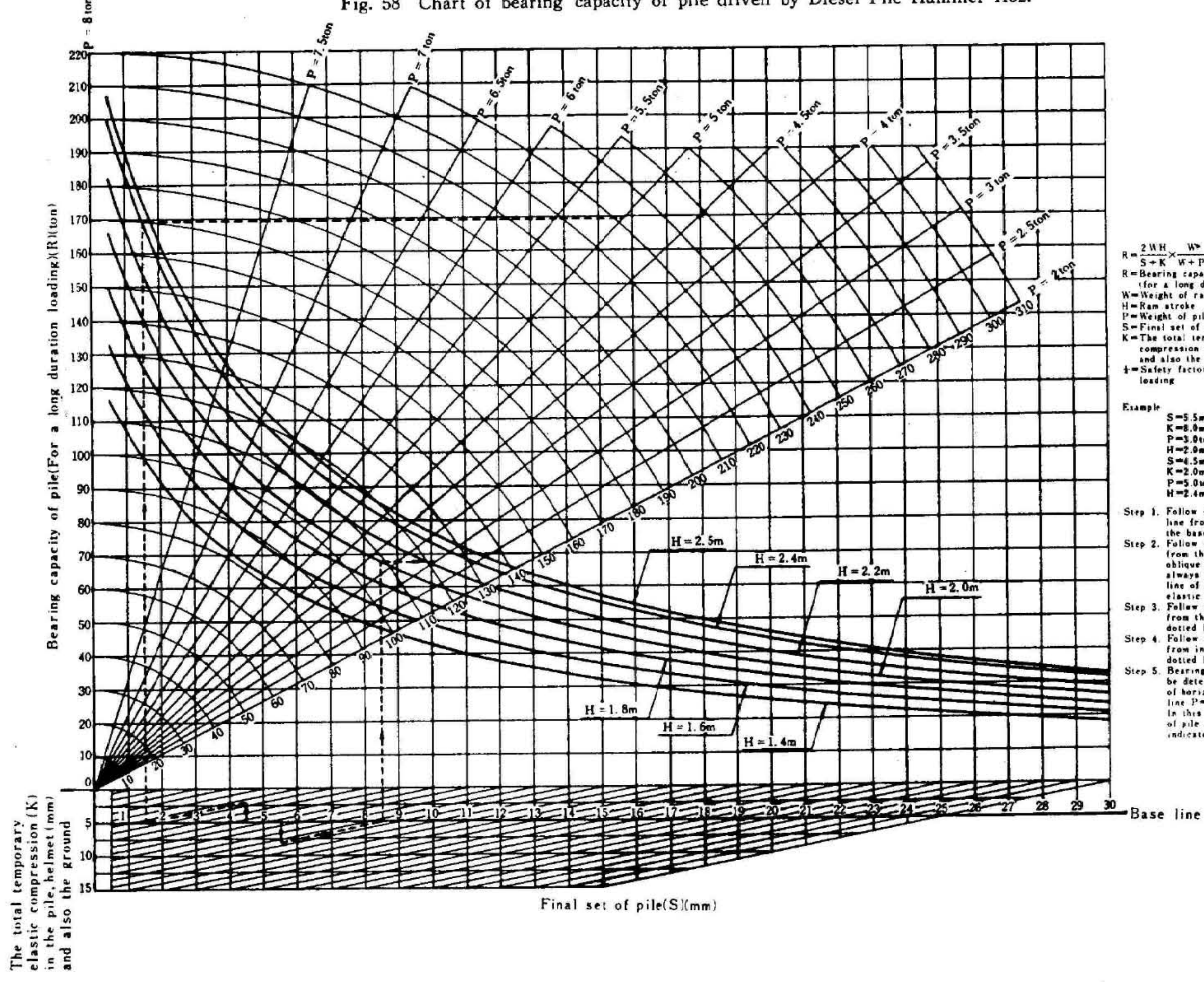
Step 2. Follow oblique dotted line from the point K = 8.0mm. This oblique dotted line should be always parallel to the oblique line of the total temporary elastic compression.

Step 3. Follow up vertical dotted line from the intersection of oblique dotted line and base line.

Step 4. Follow horizontal dotted line from intersection of vertical dotted line and curve H = 2.0m.

Step 5. Bearing capacity of pile can be determined as the intersection of horizontal dotted line and oblique line P = 2.5ton.
In this case bearing capacity of pile for a long duration is indicated 76ton.

Fig. 58 Chart of bearing capacity of pile driven by Diesel Plie Hammer K32.



$$R = \frac{2WH}{S+K} \times \frac{W}{W+P} \times \frac{1}{4}$$

R	= Bearing capacity of pile (for a long duration loading	ton
W	= Weight of ram	3.2ton
H	= Ram stroke	cm
P	= Weight of pile	ton
S	= Final set of pile	cm
K	= The total temporary elastic compression in the pile, helmet and also the ground	cm
$\frac{1}{4}$	= Safety factor for along duration loading	

Example

$S = 5.5mm$, $K = 8.0mm$, $P = 3.0ton$, $H = 2.0m$ } $R = 122ton$

$S = 4.5mm$, $K = 2.0mm$, $P = 5.0ton$, $H = 2.4m$ } $R = 232ton$

Step 1. Follow down vertical dotted line from point S = 5.5mm on the base line.

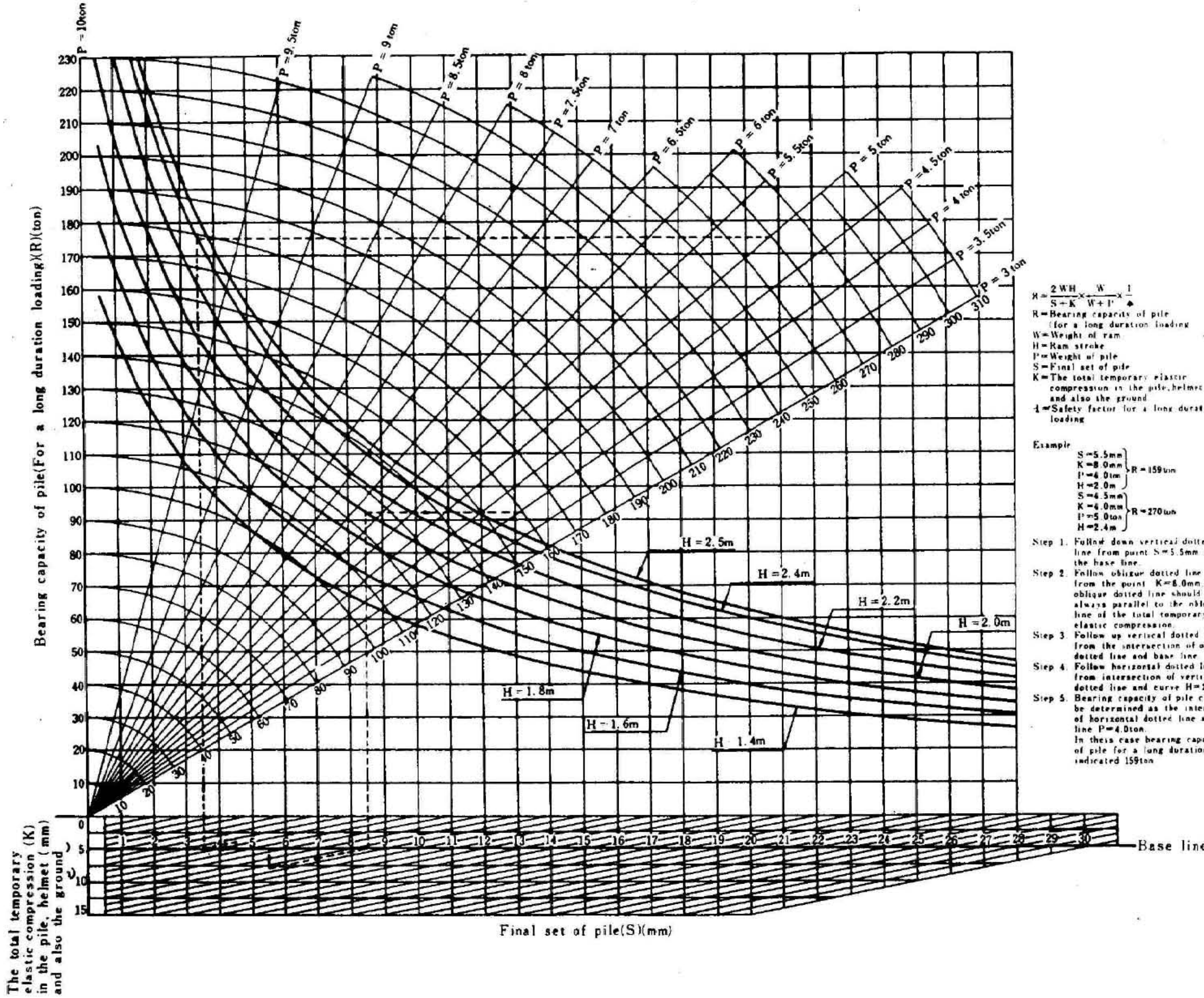
Step 2. Follow oblique dotted line from the point K = 8.0mm. This oblique dotted line should be always parallel to the oblique line of the total temporary elastic compression.

Step 3. Follow up vertical dotted line from the intersection of oblique dotted line and base line.

Step 4. Follow horizontal dotted line from intersection of vertical dotted line and curve H = 2.0m.

Step 5. Bearing capacity of pile can be determined as the intersection of horizontal dotted line and oblique line P = 3ton.
In this case bearing capacity of pile for a long duration is indicated 122ton

Fig. 59 Chart of bearing capacity of pile driven by Diesel Pile Hammer K42.



$$R = \frac{2WH}{S+K} \times \frac{W}{W+P} \times \frac{1}{4}$$

R = Bearing capacity of pile (for a long duration loading		ton
W = Weight of ram		4.2ton
H = Ram stroke		cm
P = Weight of pile		ton
S = Final set of pile		cm
K = The total temporary elastic compression in the pile, helmet and also the ground		cm
4 = Safety factor for a long duration loading		

Example

$\left.\begin{array}{l} S = 5.5mm \\ K = 8.0mm \\ P = 4.0ton \\ H = 2.0m \end{array}\right\} R = 159ton$

$\left.\begin{array}{l} S = 4.5mm \\ K = 4.0mm \\ P = 5.0ton \\ H = 2.4m \end{array}\right\} R = 270ton$

Step 1. Follow down vertical dotted line from point S = 5.5mm on the base line.

Step 2. Follow oblique dotted line from the point K = 8.0mm. This oblique dotted line should be always parallel to the oblique line of the total temporary elastic compression.

Step 3. Follow up vertical dotted line from the intersection of oblique dotted line and base line.

Step 4. Follow horizontal dotted line from intersection of vertical dotted line and curve H = 2.0m.

Step 5. Bearing capacity of pile can be determined as the intersectin of horizontal dotted line and oblique line P = 4.0ton.
In theis case bearing capacity of pile for a long duration is indicated 159ton.

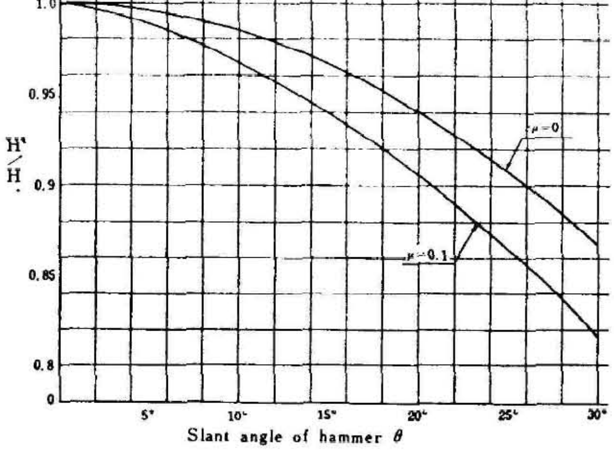


Fig. 60 Relationship between slant angle of hammer and decrease in impact energy.

13. Postcript

The merits of the diesel pile hammer are so outstanding that it has come to be considered indispensable for foundation work. We will be very happy if this booklet serves those who are in this field.

We would like to take this opportunity to invite your further investigation of our Kobe Diesel Pile Hammers K13, K22, K32 and K42, and to thank you for your interest.