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# SOIL INVESTIGATIONS AND DESIGN OF A FORGING HAMMER FOUNDATION

**Shamsher Prakash* and D.C. Gupta****

**Synopsis**

The paper describes soil investigations at the site of a forging hammer foundation proposed to be installed by M/s Forging Private Limited, Faridabad. The design of the hammer foundation is given along with the working drawings.

## Introduction

Soil investigations required for the design of forging hammer foundations at any site are similar to those required for slow speed reciprocating machines but differ considerably as compared to those for conventional foundations subjected to static weight and moment only. For machine foundation design, these investigations usually comprise of determining the dynamic properties of soil at site such as co-efficient of elastic uniform compression of soil. The usual tests carried out to determine the same are the static cyclic plate load test on 30 cm square plate and dynamic vertical and horizontal tests on an R.C.C. Block 1.5 m × 0.75 m × 0.7 m.† The damping of soil being small, is usually neglected in the design of forging hammer foundations. The co-efficient of elastic uniform compression at site, so obtained, helps in estimating the maximum amplitudes of the foundation block and anvil due to the impact of the tup on the forge piece and also the maximum stress on the pad below anvil. The estimated amplitudes and maximum stress on the pad are then compared with the permissible values.

The paper describes the investigation of soil at the site of forging hammer foundation proposed to be installed by M/s Forgings Private Limited, Faridabad. The design of the hammer foundation is given along with working drawings.

## Subsoil Conditions at Site

Auger boring was done to depth of 7m below ground level at the centre of the proposed site as shown in Figure 1. Soil samples were obtained at every 1.5 m depth and where there was a change of stratum. Standard Penetration Tests were carried out and N values obtained at various depths for different soil stratum. Figure 2. shows the boring log and N values observed at various depths.

The tests carried out at site to determine the co-efficient of elastic uniform compression are :

( i ) Cyclic plate load test,

(i i) Vertical dynamic test, and

(iii) Horizontal dynamic test.

## Cyclic Plate Load Test

Cyclic plate load test on 30 cm square plate was carried out at a depth of 2.44 m below ground level to determine the co-efficient of Elastic Uniform Compression, (Cu) at

* Professor of Soil Dyhamics, School of Research and Training in Earthquake Engineering, University of Roorkee, Roorkee.

** Lecturer in Soil Dynamics, School of Research and Training in Earthquake Engineering, University of Roorkee, Roorkee.

† Dimensions proposed in I.S. Methods of Tests for the Determination of In situ Dynamic Properties of soils

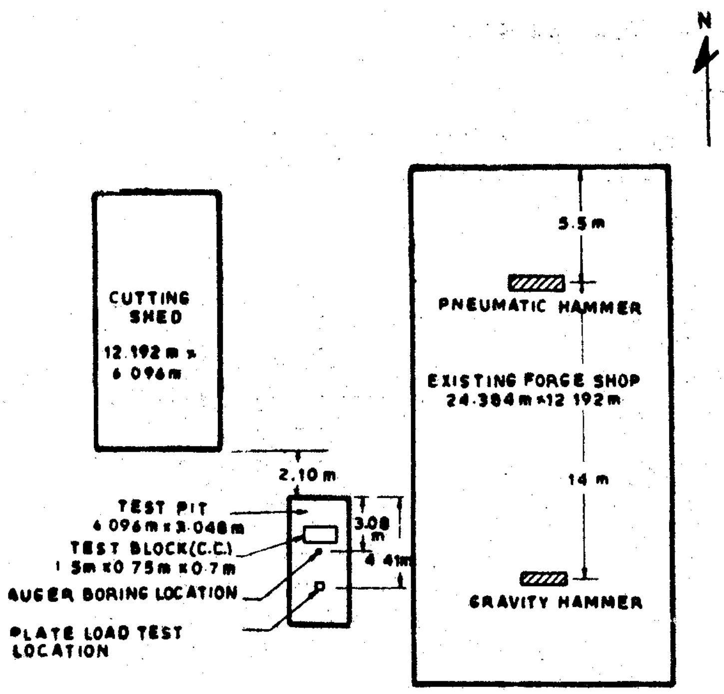



FIG 1 _LOCATION OF FIELD TESTS

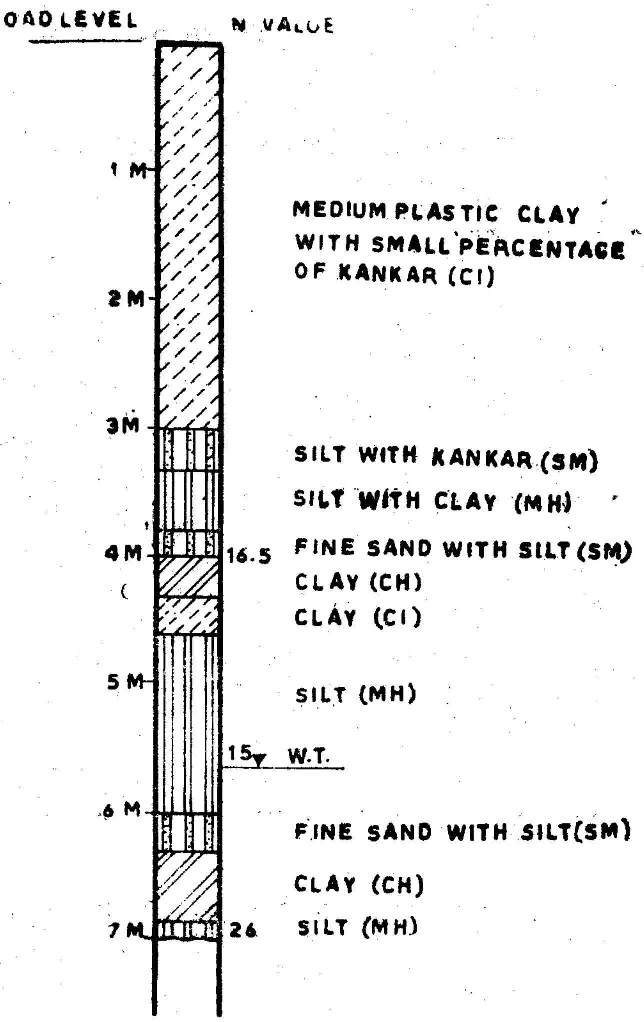



Fig. 2. Boring Log at Site

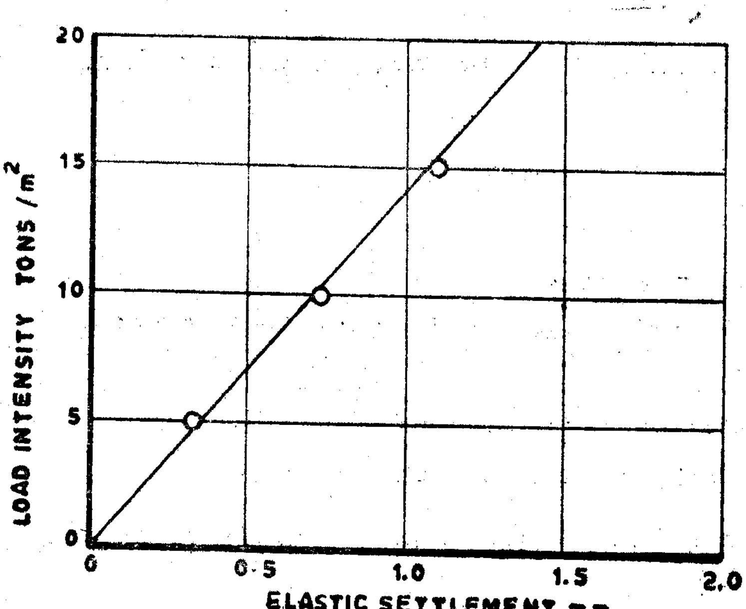



Fig 3. Load Intensity VS Elastic Settlement

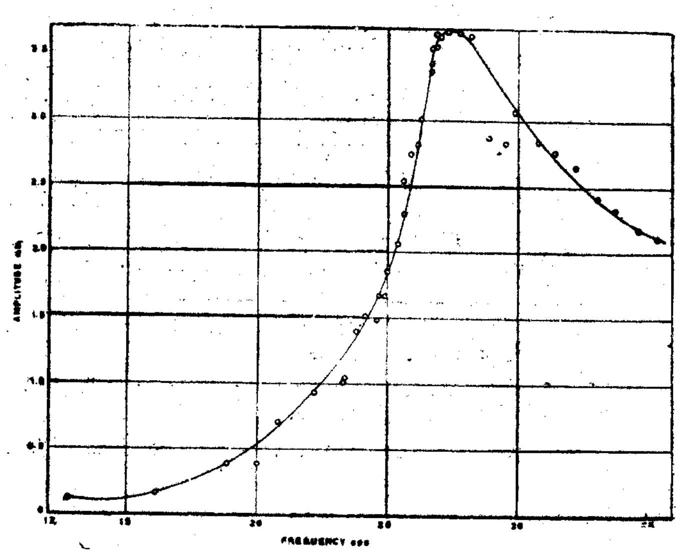


FIG 4 _ AMPLITUDE VS FREQUENCY - VERTICAL VIBRATIONS site. The test was performed at the location shown in Figure 1. Load vs elastic settlement was ploted with the help of the load settlement curve obtained from this test and is shown in Figure 3. The value of Cu, which is the slope of the line in Figure 3 is $15.16 \times 10^3$ tons/m³ for the test plate having an area of 0.0929 m².

Deducing for foundation area of 10 m²,

$$u = 15.16 \sqrt{\frac{0.0929}{10}} \times 10^3 = 1.465 \times 10^3 \text{ t/m}^3.$$

### Vertical Dynamic Test on Model Block Foundation

Model block foundation of plain cement concrete measuring 1.5 m × 0.75 m × 0.7 m high was constructed with its bottom at 2.44 m depth below the ground level. The test was carried out by mounting a Lazan type oscillator on the top surface of the block. The block was vibrated in the vertical direction. The vibration of the foundation were picked up at the top surface of the block by means of Miller accelerometer. The signal of the accelerometer was amplified by means of a "Brush Universal Amplifier" and recorded on the "Brush Direct Writing Oscillograph".

Figure 4. shows a plot of amplitude of vibration vs frequency of excitation. The natural frequency of the oscillator–foundation–soil system is seen to be 27.3 cps. Assuming soil to be mass-less elastic spring and using expressions developed by Barkan (1962), the value of Cu is computed as follows :

$$Cu = \frac{4 \pi^2 f^2_{nz} m}{A}$$

$$= 5040 \text{ T/m}^2 \text{ for } 1.125 \text{ m}^2 \text{ base area} \qquad (1)$$

For 10 m² area,

$$Cu = 5040 \sqrt{\frac{1.125}{10}} = 1.69 \times 10^3 \text{ T/m}^3.$$

### Horizontal Dynamic Test

In this test, the concrete block was vibrated in the longitudinal direction. The vibration of the foundation were picked up at three heights of the block. The unbalanced force of the Oscillator at a height of 50 cm above the c.g. of the block caused the footing to translate in the longitudinal direction as well as to have pitching about the transverse axis of the block. The system, thus, constituted a two degress of freedom system.

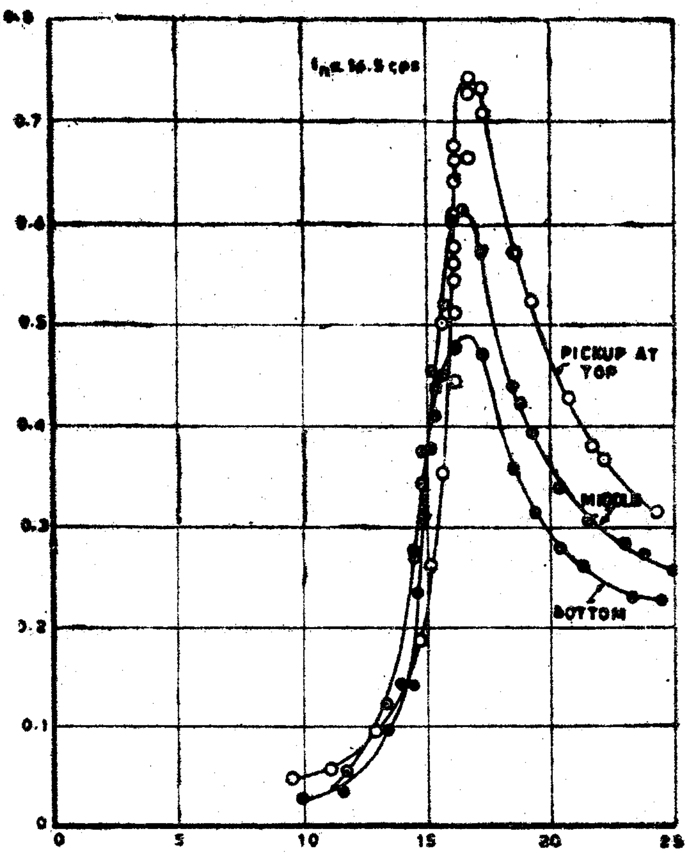
Figure 5. shows the records of amplitude of vibration vs frequency of excitation at top, mid height and bottom of the block. The first natural frequency is observed to be 16.5 cps. Assuming soil to be mass-less elastic spring and using expressions developed by Barkan (1962) the values of $C_\tau$ and $C_u$ of soil have been computed as follows :

### Computations of $C_\tau$ and $C_u$

**Moment of Inertia of the Foundation Block :**

The moment of inertia I of the foundation contact area with respect to the axis passing through its centre of gravity perpendicular to the plane of vibration is

$$I = \frac{0.75 \times (1.5)^3}{12} = 0.211 \text{ m}^4$$




Frequncy cps

Fig. 5. Amplitude vs Frequency of Vibrations

**Mass M.I. about an axis passing through C.G. of the System :**

The moment of inertia of the foundation block with respect to the axis passing through the centre of gravity of the whole system perpendicular to the plane of vibration is

$$M_m = \frac{m}{12}(a_y^2 + a_z^2) = \frac{1.77}{9.81 \times 12}(2.25 + 0.49)$$

$$= 0.0412 \text{ tons} \times \text{m} \times \text{sec}^2$$

where $a_y$ = length of the block = 1.5 m

and $a_z$ = height of the block = 0.7 m

**Mass M.I. about an axis passing through the C.G. of the base area :**

$$M_{mo} = M_m + m\left(\frac{a_z}{2}\right)^2 = 0.0412 + \frac{1.77}{9.81} \times 0.1225$$

$$= 0.0633 \text{ tons} \times \text{m} \times \text{sec}^2$$

The ratio between the two mass moments of inertia is

$$\gamma = \frac{0.0412}{0.0633} = 0.65$$

Assuming the following relationship between coefficients of Elastic non-Uniform Compression ($C_\phi$) and Uniform Shear ($C_\tau$)

$$C_\phi = 3.46\ C_\tau$$

The following expression is obtained for the natural frequencies (Prakash and Gupta, 1967) ;

$$\omega^2_{n1,2} = \frac{1}{2\gamma}\left[\left(\frac{A}{m} + \frac{3.46I}{M_{mo}}\right) \pm \sqrt{\left(\frac{A}{m} + \frac{3.46I}{M_{mo}}\right)^2 - \frac{13.84\gamma AI}{m\ M_{mo}}}\right] \times C_\tau \qquad (2)$$

Substituting the values of $A, m, I, M_{mo}$ and $\gamma$ for the block under investigation, Equation (2) reduces to,

$$\omega^2_{n1,2} = 4.96\ C_\tau \text{ and } 22.35\ C_\tau\ \text{sec}^{-2}$$

$f_{n_1}$ has been measured for the foundation block as 16.5 cps. $C_\tau$ can be computed from the relationship :

$$C_\tau = \frac{\omega_{n_1}{}^2}{4.96}\ \text{t/m}^3$$

$$= \frac{(16.5 \times 2\,\pi)^2}{4.96} = 2.17 \times 10^3\ \text{t/m}^3.$$

The value of $C_u$ for the soil is obtained by the empirical relation :

$$C_u = 2\ C_\tau$$

$$= 2 \times 2.17 \times 10^3\ \text{t/m}^3 \text{ for } 1.125\ \text{m}^2$$

$$= 4.34 \times 10^3\ \text{t/m}^3$$

and $C_u$ for 10 $m^2$ foundation area

$$= 4.34\sqrt{\frac{1.125}{10}} \times 10^3\ \text{t/m}^3$$

$$C_u = 1.455 \times 10^3\ \text{t/m}^3$$

A comparison of the values of $C_u$ obtained from cyclic plate load test, vertical dynamic test and Longitudinal dynamic test has been made in Table 1.

The minimum value of $C_u$ equal to $1.455 \times 10^3$ t/$m^3$ for an area of 10 $m^2$ has been taken for design purpose.

Table 1

Value of $C_u$ From Various Tests

| Type of Test | $C_u$ |
|---|---|
| Cyclic Plate Load Test | $1.465\times10^3$ t/$m^3$ |
| Vertical Dynamic Test | $1.69 \times 10^3$ t/$m^3$ |
| Longitudinal Dynamic Test | $1.455\times10^3$ t/$m^3$ |

### Design Data

The hammer has the following specifications :

| | | |
|---|---|---|
| Tup weight without die | : | 1150 kg |
| Maximum tup stroke, h | : | 900 mm |
| Supply steam pressure, p | : | 100 psi $= 70$ t/m$^2$ |
| Anvil block weight | : | 22.5 tons |
| Total weight of hammer | : | 34.3 tons |
| Bearing area of anvil | : | $2.1 \times 1.3 = 2.73$ m$^2$ |

Soil at site consists of silty clay of medium plasticity mixed with Kankar and intermitant layers of fine silty sand of medium relative density. The water table is at a depth of about 5.65 m below ground level. The coefficient of elastic uniform compression of soil, $C_u$ is equal to $1.455 \times 10^3$ t/m$^3$ for an area of 10 m$^2$ as determined by tests at site.

### Data Assumed

For design purposes, the following data was assumed :

1. Material of pad below anvil—Teak heart wood
2. Modulus of Elasticity of pad—$5 \times 10^4$ t/m$^2$
3. Thickness of pad below anvil—0.61 m
4. Dimensions of the foundation blok—$6.50 \text{ m} \times 5.70 \text{ m} \times 1.75$ m
5. Dimensions of R. C. C. walls—$0.50 \times 1.34$ m all around anvil as shown in Figure 6.

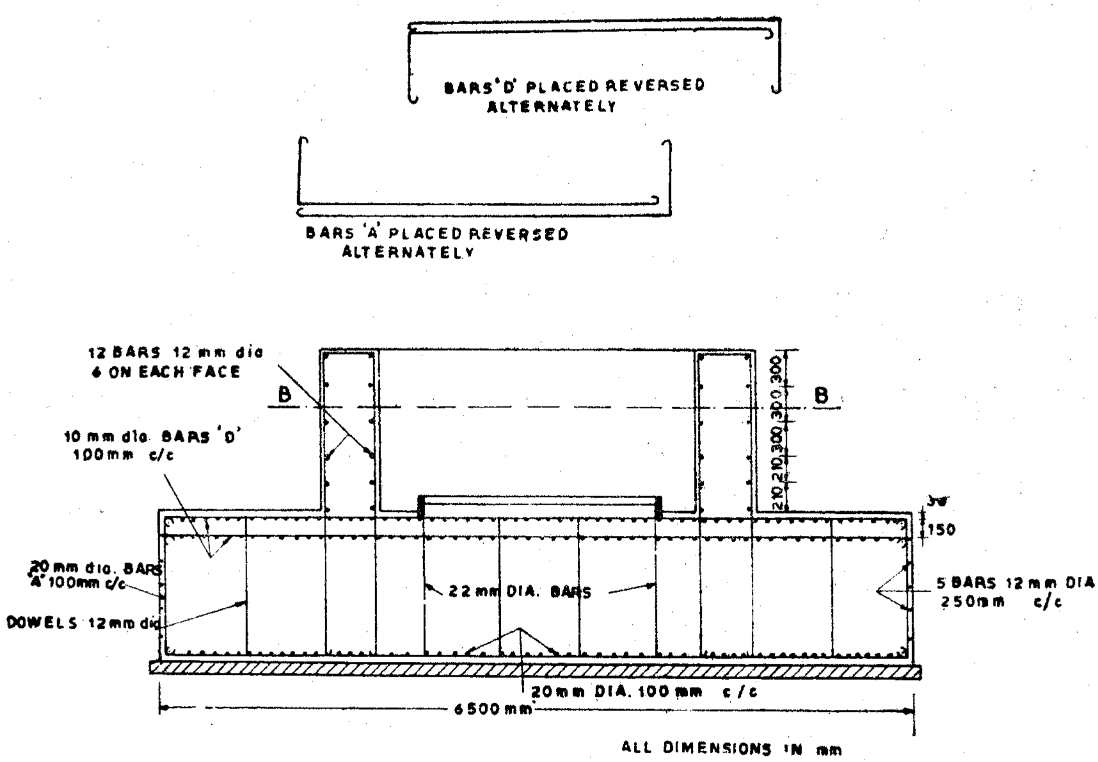



Fig. 6. Section of Hammer Foundation

6. Unit weight of R. C. C. = 2.4 t/m$^3$
7. Unit weight of backfill = 1.76 t/m$^3$
8. Modified coefficient of Elastic Uniform Compression for Impact loading $C_u' = 3.\ C_u$.
9. Coefficient of restitution, e = 0.5
10. Coefficient which takes into account counter-pressure and frictional forces, $\eta = 0.65$

## Requirements for Design

The following are the main requirements for satisfactory design of the foundation :

(a) The amplitudes of vibration of the foundation and anvil should be within allowable limits.

(b) The dynamic stress on the soil and pad should be within permissible limits.

According to Barkan (1962) and Indian Standard code af Practice 2974–1966, the following are the permissible limits for amplitudes of vibration :

$A_{foundation}$ = 1.0 to 1.2 mm

$A_{anvil}$ = 1.0 mm for 1 T hammer
and 2.0 mm for 2 T hammer

According to Indian Standard code IS : 883–1961 the allowable limit for stress on Teak heart wood loaded perpendicular to grains is as follows : $\sigma$ allowable = 400 t/m$^2$ in compression.

## Computations

Figures 6 and 7 show the assumed dimension of the foundation.

Foundation area in contact with soil = 6.50 × 5.70 = 37.05 m$^2$

Weight of foundation and backfill :

Volume of the Block = 6.50 × 5.70 × 1.75 = 64.8375 Cu m

Walls = 2×3.70×0.50×1.34 = 4.958 Cu m

2×1.90×0.50×1.34 = 2.546 Cu m

72.3415 Cu m

Weight of Concrete = 72.3415 × 2.40 = 173.62 tons.

Volume of the fill = 2×6.50×1.40×1.34 = 24.40

2×2.90×1.40×1.34 = 10.80

35.29 Cu m

Weight of back-fill = 35.29 × 1.76 = 62.20 tons

Total weight of foundation and backfill = 235.82 tons

$$\text{Total mass, m} = \frac{235.82}{9.81} = 24.0 \text{ t sec}^2/\text{m}$$

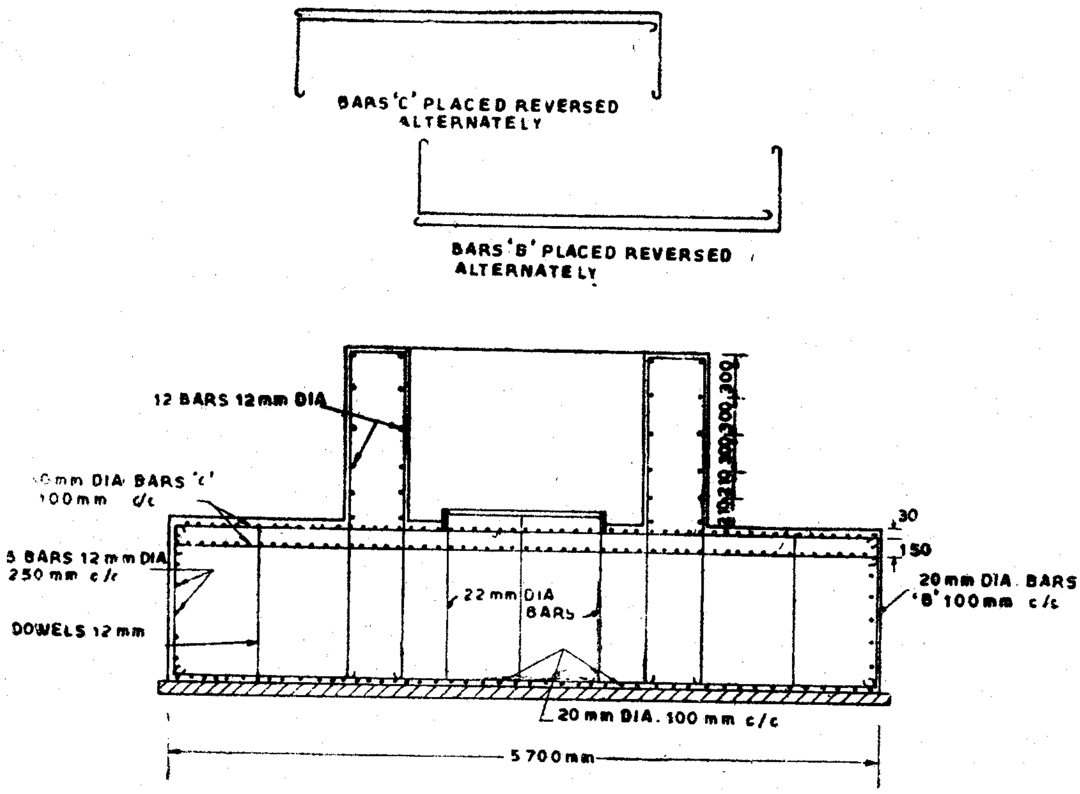



Fig. 7. Side View of Hammer Foundation

**Natural Frequencies of Foundation—Hammer System**

The modulus of elasticity of the pad, $E_2 = 5 \times 10^4$ t/m$^2$

Thickness of the pad, $b = 0.61$ m

Coefficient of rigidity of the pad, $k_2 = \frac{E_2 A_2}{t_2} = \frac{5 \times 10^4 \times 2.73}{0.61}$

$= 22.4 \times 10^4$ t/m.

The mass of the anvil and frame, $m_2 = \frac{34.3}{9.81} = 3.5$ t sec$^2$/m

The limiting natural frequency of anvil on pad is

$$\omega^2_{na} = \frac{k_2}{m_2} = \frac{22.4 \times 10^4}{3.5} = 6.4 \times 10^4 \text{ sec}^{-2}$$

now, $Cu = 1.455 \times 10^3$ t/m$^3$ for an area of 10 m$^2$

According to Barkan, if Cu is the coefficient of elastic uniform compression for an area A, then the coefficient of elastic uniform compression $Cu_1$ for an area $A_1$ is given by

$$Cu_1 = Cu \sqrt{\frac{A}{A_1}}$$

$Cu_1$ for an area of 37.05 $m^2$ is given by

$$Cu_1 = 1.455\times 10^3 \sqrt{\frac{10.0}{37.05}} = 0.755 \times 10^3 \ t/m^3$$

$$Cu' = 3.Cu_1 = 3 \times 0.755 \times 10^3 = 2.265 \times 10^3 \ t/m^3$$

Coefficient of rigidity of the soil, $k_1 = Cu' \times A_1 = 2.265 \times 10^3 \times 37.05$
$= 8.4 \times 10^4$ t/m

The limiting natural frequency of the whole system.

$$\omega_l^2 = \frac{k_1}{m_1+m_2} = \frac{8.4 \times 10^4}{3.5 + 24.0} = 0.305\times 10^4 \ sec^{-2} \text{ and}$$

$$\mu = \frac{m_2}{m_1} = \frac{3.5}{24.0} = 0.1458$$

The two natural frequencies of the combined system are given by

$$\omega^4{}_n - (\omega_l^2 + \omega^2{}_{na}) (1 + \mu) \omega^2{}_n + (1 + \mu) \omega_l^2 \omega^2{}_{na} = 0$$

$$\omega^4{}_n - (0.305 + 6.4) 1.1458 \times 10^4\omega^2{}_n + 1.1458 \times 0.305 \times 6.4 \times 10^8 = 0$$

$$\omega^4{}_n - 7.69 \times 10^4\omega^2{}_n + 2.24 \times 10^8 = 0$$

$$\omega^2{}_n = \tfrac{1}{2} [7.69 \pm \sqrt{(7.69)^2 - 4 \times 2.24}] \times 10^4$$

$$= \tfrac{1}{2} [7.69 \pm \sqrt{59 - 8.96}] \times 10^4$$

$$= \tfrac{1}{2} [7.69 \pm 7.10] \times 10^4$$

If $\omega_{n1} > \omega_{n2}$

$$\omega^2{}_{n1} = \tfrac{1}{2} \times 14.79 \times 10^4 = 7.395 \times 10^4 \ sec^{-2}$$

$$\omega^2{}_{n2} = \tfrac{1}{2} \times 0.59 \times 10^4 = 0.295 \times 10^4 \ sec^{-2}$$

$$\omega_{n2} = 54.3 \ sec^{-1}$$

Velocity of Dropping Parts at the beginning of impact

$$V = \eta \sqrt{\frac{2 g (W + A_c . p) h}{W}}$$

where $A_c$ = Area of Piston

$$\therefore \quad V = 0.65 \sqrt{\frac{2\times 9.81\times(1.55+0.129\times 70\times 0.9)}{1.55}} = 7.13 \text{ m/scs}$$

Initial velocity of Anvil Motion

$$Va = \frac{1 + e}{1 + \mu_a} V = \frac{1 + 0.5}{1+ \frac{34.2}{1.55}} \times 7.13 = 0.463 \text{ m/sec}$$

Amplitude of Vibration of Foundation

$$A_z = \frac{(\omega^2{}_{na} - \omega^2{}_{n2}) \times (\omega^2{}_{na} - \omega^2{}_{n1})}{\omega^2{}_{na} (\omega^2{}_{n1} - \omega^2{}_{n2}) \omega_{n2}} V_a = 1.14 \text{ mm}$$

and that of anvil

$$A_a = \frac{(\omega^2{}_{na} - \omega^2{}_{n1}) \times V_a}{(\omega^2{}_{n1} - \omega^2{}_{n2}) \times \omega_{n2}} = 1.195 \text{ mm}$$

These are within permissible limits.

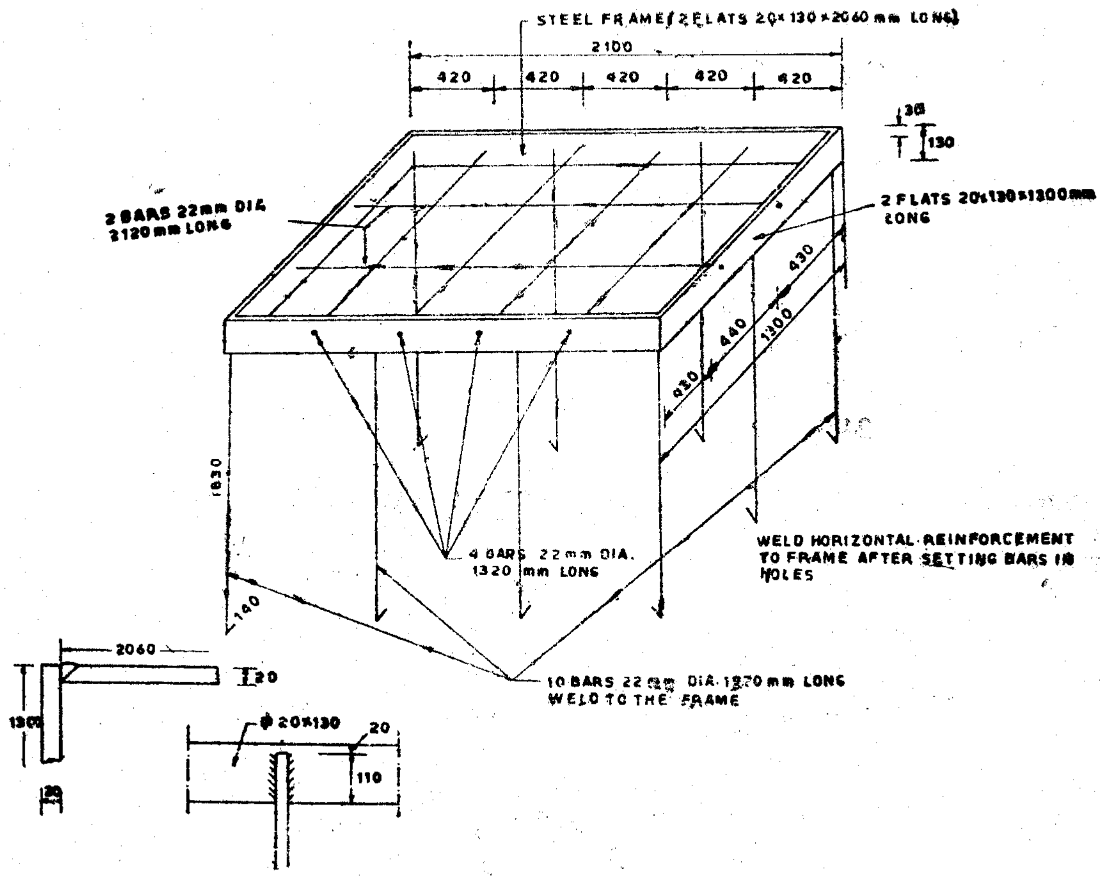



Fig. 8. Details of Reinforcement Under the Anvil

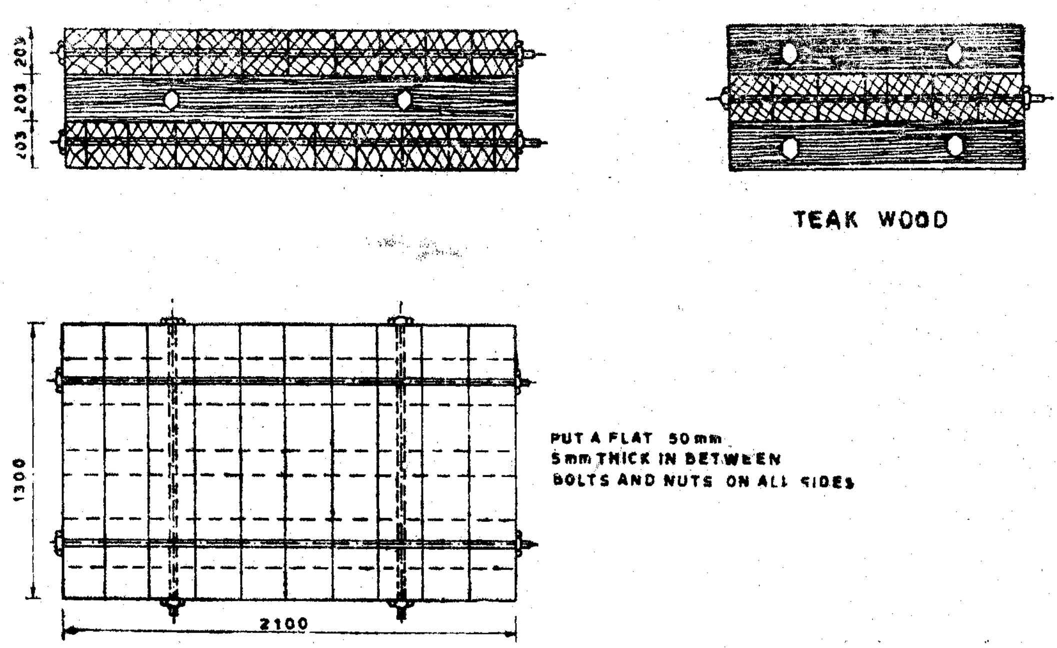



Fig. 9. Details of Pad

Dynamic Stress in pad

$$= \frac{k_2 (A_a - A_z)}{A_2} = \frac{22.4 \times 10^4 \ (1\text{-}14 + 1.195) \ 10^{-3}}{2.73} = 192 \ t/m^2$$

This is also within permissible limits.

The details of various dimensions and reinforcement are shown in Figures 6,7 and 8.

**Recommendations for the Material of the Foundation and Pad Under the Anvil**

Foundation block under the anvil snould be made of concrete type M 150 with coarse aggregate of hard rocks with a compressive strength of not less than 250 kg/cm$^2$. Normal portland cement should be used for concrete. The latter should be reinforced.

The pad under the anvil should be made of Teak heart wood. Timber of best quality, having a moisture content below 15 to 18 per cent should be used.

**Remarks on Construction Proceshre**

It should be ensured that no water penetrates the soil after the excavation of the pit to the required level. The soil should be properly compacted before the lean concrete is laid over it.

While installing the anvil, it should be ensured that the centre of gravities of the anvil and the foundation block coincide with the line of fall of the hammer tup and the impact of forging always remains central.

Pads under the anvil should be made of square timbers 20.3 cm by 20.3 cm in cross section. Timber are to be laid flat in 3 rows one over the other, such that it is loaded perpendicular to grains only. The upper row of timbers is to be laid along the short side of the anvil base. The 3 layers of timber should be glued together. Each row is braced by transverse bolts as shown in Figure 9. To prevent decay resulting from moisture, it is advisable to impregnate timbers with wood preserving solutions.

**The mats must be strictly horizontal** and smoothly planed. Levels of the excavated pit and the mats should be checked by means of a sensitive water level.

The space between the pad and side walls may be filled with asphalt. In order to prevent the horizontal displacement of the anvil along the pad, four timbers are placed around it near the base, properly wedged.

A trench 3.5 m deep below floor level and minimum of 30 cm wide all around the foundation at a distance of about 1 m from the edges of the foundation base may be filled with saw dust mixed with bitumen or similar shock absorbing material. This is required primarily to cut down the noise level away from the foundation.

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## Notation

The following are the notations used in computing the amplitudes of vibration of the anvil and foundation block :

$W_o$ = Weight of dropping parts
h = Weight of drop
$W_2$ = Weight of hammer–Anvil
$A_2$ = Base area of anvil
b = Thickness of pad under anvil
p = Steam pressure
$A_c$ = Cylinder area
Cu = Coeff. of elastic uniform compression
V = Veolcity of dropping parts at the beginning of impact
$V_a$ = Initial velocity of motion of the anvil
$W_1$ = Weight of foundation and backfill
A = Foundation area in contact with the soil
$E_2$ = Modulus of elasticity of pad under anvil
$k_2$ = Coefficient of rigidity of pad
$m_2$ = Mass of hammer plus anvil
$\omega na$ = Limiting frequency of natural vibration of the anvil + hammer
$k_1$ = Coefficient of rigidity of base under foundation
$m_1$ = Mass of foundation plus bacafill
$\omega_l$ = Limiting natural frequency of the whole system
$\mu$ = $m_2/m_1$
$\omega_{n1,2}$ = Natural frequencies of vibrations of the foundation — hammer system
$A_z$&$A_a$= Amplitude of vibration of foundation and anvil respectively