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(उपभोक्ता मामले, खाद्य एवं सार्वजनिक वितरण मंत्रालय, भारत सरकार)
BUREAU OF INDIAN STANDARDS
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मानक: पथप्रदर्शक:

मानक भवन, 9, बहादुर शाह ज़फर मार्ग, नई दिल्ली – 110002
Manak Bhawan, 9, Bahadur Shah Zafar Marg, New Delhi – 110002
Phones: 23230131 / 2323375 / 23239402
Website: www.bis.gov.in

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हमारा संदर्भ : सीईडी 43/टी-64 **27 अगस्त 2024**

तकनीकी समिति : मृदा एवं नींव इंजीनियरिंग अनुभागीय समिति 43

प्राप्तकर्ता :

1. **सिविल अभियांत्रिकी विभाग परिषद, सीईडीसी के सभी सदस्य**
2. **मृदा एवं नींव इंजीनियरिंग अनुभागीय समिति 43 और इसकी उपसमितियों के सभी सदस्य**
3. **रुचि रखने वाले अन्य निकाय।**

महोदय/महोदया,

निम्नलिखित मानक का मसौदा संलग्न हैं:

प्रलेख संख्या	शीर्षक
सीईडी 43 (26427)	भारतीय मानक मसौदा मशीन फाउंडेशन का डिजाइन और निर्माण — रीति संहिता: भाग 4 हथौड़ों और प्रेस के लिए नींव [*आई एस 2974 भाग 1 से 5 का पुनरीक्षण*] *[आईसीएस 93.020]*

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सम्मतियाँ भेजने की अंतिम तिथि: 27 सितंबर 2024

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यह प्रालेख भारतीय मानक ब्यूरो की वेबसाइट **www.bis.gov.in** पर भी उपलब्ध हैं।

धन्यवाद।

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द्वैपायन भद्र
वैज्ञानिक ई एवं प्रमुख
सिविल अभियांत्रिकी विभाग
ई-मेल: ced43@bis.gov.in
फोन: +91-11 2323 5529

संलग्न: उपरलिखित

मानक भवन, 9, बहादुर शाह ज़फर मार्ग, नई दिल्ली – 110002
Manak Bhawan, 9, Bahadur Shah Zafar Marg, New Delhi – 110002
Phones: 23230131 / 2323375 / 23239402
Website: www.bis.gov.in

WIDE CIRCULATION DRAFT

Our Reference: CED 43/T-64 **27 August 2024**

TECHNICAL COMMITTEE: Soil and Foundation Engineering Sectional Committee, CED 43

ADDRESSED TO:

1. All Members of Civil Engineering Division Council, CEDC
2. All Members of Soil and Foundation Engineering Sectional Committee, CED 43 and its Subcommittees
3. All others interested.

Dear Sir/Madam,

Please find enclosed the following draft:

Doc No.	4. Title
CED 43(26427)	Design and Construction of Machine Foundations — Code of Practice: Part 4 Foundations for Hammers and Presses [*Revision of IS 2974 Parts 1 to 5*] [ICS: 93.020]

Kindly examine the attached draft and forward your views stating any difficulties which you are likely to experience in your business or profession, if this is finally adopted as National Standard.

Last Date for comments: 27 September 2024

Comments if any, may please be made in the enclosed format and emailed at ced43@bis.gov.in or sent at the above address. Additionally, comments may be sent online through the BIS e-governance portal, www.manakonline.in.

In case no comments are received or comments received are of editorial nature, kindly permit us to presume your approval for the above document as finalized. However, in case comments, technical in nature are received, then it may be finalized either in consultation with the Chairman, Sectional Committee or referred to the Sectional Committee for further necessary action if so desired by the Chairman, Sectional Committee.

The document is also hosted on BIS website www.bis.gov.in.

Thanking you,

Yours faithfully,

Sd/-

Dwaipayan Bhadra
Scientist ‘E’ & Head
Civil Engineering Department
Email: ced43@bis.gov.in
Phone: +91-11 2323 5529

Encl: As above

FORMAT FOR SENDING COMMENTS ON THE DOCUMENT

[Please use A4 size sheet of paper only and type within fields indicated. Comments on each clause/sub-clause/ table/figure, etc, be stated on a fresh row. Information/comments should include reasons for comments, technical references and suggestions for modified wordings of the clause. **Comments through e-mail to ced43@bis.gov.in shall be appreciated**.]

Doc. No.: CED 43(26427)

BIS Letter Ref: CED 43/T-64

Title: Design and Construction of Machine Foundations — Code of Practice: Part 4 Foundations for Hammers and Presses [*Revision of IS 2974 Parts 1 to 5*]

[ICS: 93.020]

Last date of comments: **27 September 2024**

Name of the Commentator/ Organization: ______________________________________

Sl No.	Clause/ Para/ Table/ Figure No. commented	Type of Comment (General/ Technical/ Editorial)	Comments/ Modified Wordings	Justification of Proposed Change
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NOTE- Kindly insert more rows as necessary for each clause/table, etc.

BUREAU OF INDIAN STANDARDS

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Draft Indian Standard

DESIGN AND CONSTRUCTION OFMACHINE FOUNDATIONS — CODE OF PRACTICE

PART 4 FOUNDATIONS FOR HAMMERS AND PRESSES SECTION 1 GENERAL

[Revision of IS 2974 Parts 1 to 5]

ICS 93.020

Soil and Foundation Engineering Sectional Committee, CED 43	Last date for Comment: **27 September 2024**

FOREWORD

This Indian Standard (Second Revision) was adopted by the Bureau of Indian Standards, after the draft finalized by the Soil and Foundation Engineering Sectional Committee had been approved by the Civil Engineering Division Council.

Installation of heavy machinery has assumed increased importance in the wake of the vast programme of industrial development in the country. While many of the special features relating to the design and construction of such machine foundations will have to be as advised by the manufacturers of these machines, still a large part of the details will have to be according to certain general principles of design covering machine foundations. It was also well realized that the dynamic soil parameters underneath the foundations play a significant role in achieving the said objective. It is to serve this purpose that, IS 2974 'Code of practice for design and construction of machine foundations' was published in five parts covering foundations for host of machines, thereby meeting development needs of the country. The various parts of the standard were published and revised as per the details given below:

Parts of IS 2974	*Title*	*First published in*	*Subsequently revised in*
Part 1	Foundations for reciprocating type machines`	1964	1969 and then in 1982

Part 2	Foundations for impact type machines	1966	1980
Part 3	Foundations for rotary type machines (Medium and high frequency)	1967	1975 and then in 1992
Part 4	Foundations for rotary type machines of low frequency	1968	1979
Part 5	Foundations for impact machines other than hammer (Forging and stamping press, pig-breaker, drop crusher and jolter)	1970	1987

Over the years, improvement in manufacturing technology has provided machines of higher ratings with better tolerances and controlled behaviour. The increased dependence of society provides no room for failure and demands equipment and systems with higher performance reliability. To ensure satisfactory performance of machines and to minimize machine downtime on account of malfunction/unsatisfactory performance, foundations for these machines must be specially designed taking into consideration the impact of vibration on the foundations as well as on the adjoining structures. Thus, for satisfactory performance, every machine, be it small or large, does require detailed vibration analysis providing insight into the dynamic behaviour of machine-foundation system including their associated components.

Further, failure data collected over the years from field tests on wide variety of machines and their foundations, provides clear indicator that the existing design philosophy needs a relook and suggests host of changes to be incorporated in the standards covering various design and construction aspects of the foundations. In view of the above as well as the recent developments reported globally on this subject, it is felt that the provisions regarding the design and construction of machine foundations should be further revised.

To cater to these objectives, it was decided to revise and restructure all the existing standards to meet the current demand of satisfactory performance of machines with no room for failure. While restructuring these standards, it was decided to address the standard, foundation wise, rather than machine wise, except foundations for impact and impulsive load machines, that is, hammers and presses, where it is necessarily to be machine wise. This would also avoid any overlapping of the provisions between different standards for similar foundation types and bring better clarity in design and construction of the foundation. Accordingly, the revised standard is being brought out in following eight parts, first five have been published in the first phase, and the remaining three parts would be brought out in subsequent phase:

Part 1 General provisions
Part 2 Block foundations
Part 3 Frame foundations
Part 4 Foundations for hammers and presses
Part 5 Foundation for machines (excluding hammers and presses) supported on vibration isolation system
Part 6 Machines supported on superstructures

Part 7 Machines supported on strip footings
Part 8 Machines supported on common mat/raft

This Part 4 deals with design and construction of hammer foundation subjected to stray and repeated impacts and where the ratio of mass of anvil to foundation is high. This Part also deals with design and construction of block type foundation of reinforced concrete for the installation of the machines like forging, sheet metal, stamping presses, scrap breakers or pig breakers and jolters. For the general provisions, Part 1 of the standard which is a necessary adjunct to this part of the standard, shall be referred.

Further, in the design and construction of foundations for all the machines, a proper coordination between the different branches of engineering, including those dealing with erection and commissioning is essential. Coordinated efforts by the different branches would result in satisfactory performance, convenience of operation, economy, and a good general appearance of the complete unit.

The main unit with all its auxiliaries and adjacent piping shall be provided for, when making the foundation plans and all the details should be well worked out, before going ahead with the design.

Due weightage has been given to international coordination among the standards and practices prevailing in different countries in addition to relating it to the practices in the field in the country.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis shall be rounded off in accordance with IS 2: 2022 'Rules for rounding off numerical values (*second revision*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

BUREAU OF INDIAN STANDARDS

DRAFT FOR COMMENT ONLY

Draft Indian Standard

DESIGN AND CONSTRUCTION OFMACHINE FOUNDATIONS — CODE OF PRACTICE

PART 4 FOUNDATIONS FOR HAMMERS AND PRESSES SECTION 1 GENERAL

[Revision of IS 2974 Parts 1 to 5]

ICS 93.020

Soil and Foundation Engineering Sectional Committee, CED 43	Last date for Comment: **27 September 2024**

SECTION 1

GENERAL

1 SCOPE

1.1 This standard (Part 4) covers design and construction of hammer foundations subjected to repeated impacts and press foundations subjected to impulsive loading. Foundations for the following machines are covered by this standard:

a) Hammers:

1) Single action and counter blow hammers;
2) High energy rate machines and impactors; and
3) Ring rolling mills hammers.

b) Presses:

1) Hydraulic and mechanical presses;
2) Presses with supported mandrel; and
3) Multiple ram presses.

1.2 IS 2974 (Part 1) is a necessary adjunct to this standard.

2 REFERENCES

The Indian Standards given in Annex A contain provisions which through reference in this text, constitute provision of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below.

IS No.	*Title*
IS 456:2000	Plain and reinforced concrete – Code of practice (*fourth revision*)
IS 875	Code of practice for design loads (other than earthquake) for buildings and structures
(Part 1):1987	Dead loads - Unit weights of building materials and stored materials (*second revision*)
(Part 2):1987	Imposed loads (*second revision*)
(Part 3):2015	Wind loads (*third revision*)
(Part 4):2021	Snow loads (*third revision*)
(Part 5):1987	Special load and combinations (*second revision*)
IS 1892:2021	Subsurface investigation for foundations – Code of Practice(*second revision*)
IS 1893 (Part 1):2016	Criteria for earthquake resistant design of structures: Part 1 General provisions and buildings (*sixth revision*)
IS 2809:1972	Glossary of terms and symbols relating to soil engineering (*first revision*)
IS 2810:1979	Glossary of terms relating to soil dynamics (*first revision*)
IS 2974 (Part 1): 2022	Design and construction of machine foundations – Code of practice: Part 1 General provisions.
IS 5249:1992	Determination of dynamic properties of soil – Method of test (*second revision*)
IS 6403:1981	Code of practice for determination of bearing capacity of shallow foundations (*first revision*)
IS 3370	Concrete structures for retaining aqueous liquids – Code of practice
(Part 1):2021	General requirements (*second revision*)
(Part 2):2021	Plain and reinforced concrete (*second revision*)

3 TERMINOLOGY

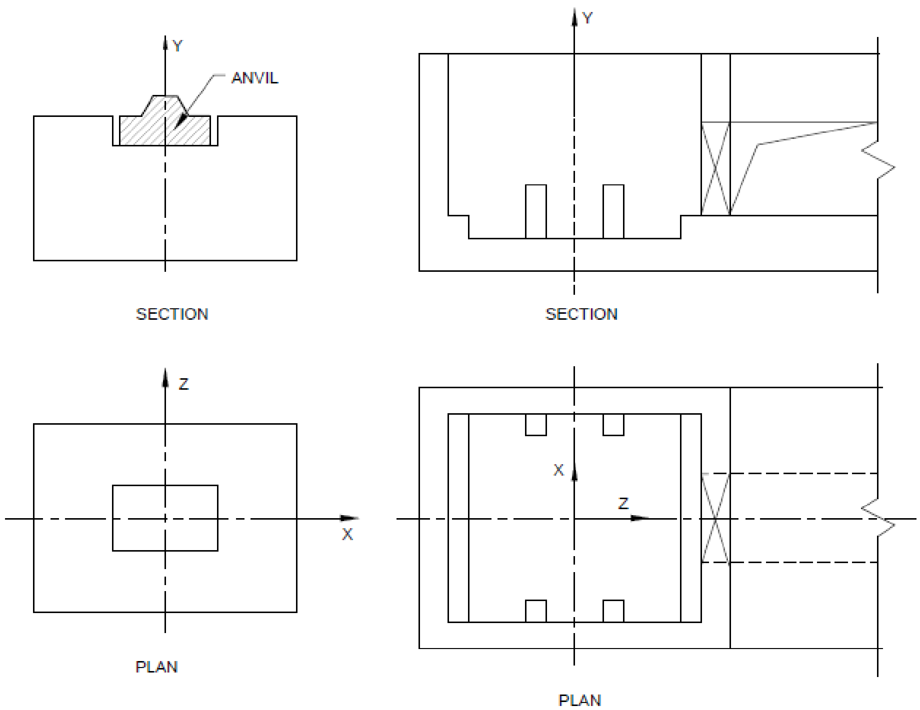
For the purpose of this standard, the following terms and definitions shall apply in addition to those given in IS 2974 (Part 1), IS 2809, IS 2810 and IS 875 (Parts 1 to 5).

3.1 Attenuation – Decay or reduction of amplitude or change in wave-form due to energy dissipation with distance and time.

3.2 Axis System

3.2.1 *Axis System for Hammer* – X- axis is along the axis of the anvil, and the motion along the X- axis is defined as motion in longitudinal direction; Y- axis is along the vertical axis, and the motion along the Y- axis is defined as vertical motion; and Z- axis is the axis transverse to the axis of the anvil, and the motion along the Z- axis is defined as transverse motion (*see* Fig. 1A).

3.2.2 *Axis System for Press* – X- axis is along the axis of the cross-head, and the motion along the X- axis is defined as motion in longitudinal direction; Y- axis is along the vertical axis, and the motion along the Y- axis is defined as vertical motion; and Z- axis is the axis transverse to the axis of the cross-head, and the motion along the Z- axis is defined as transverse motion (*see* Fig. 1B).



1A HAMMER FOUNDATION 1B PRESS FOUNDATON

FIG. 1 COORDINATE SYSTEM FOR HAMMER AND PRESS FOUNDATION

3.3 Anvil – A base-block for a hammer on which material is forged into shape by repeated striking of the tup

3.4 Base Block – The concrete block that supports machine and/or inertia block through vibration isolators. This base block is in turn supported on soil or pile groups.

3.5 Bolster Plate – The part which is used to mount the die assembly.

3.6 Capacity of Hammer – Expressed as the mass of the falling tup.

3.7 Coefficient of Restitution (*e*) – A coefficient that defines type of impact (fully elastic impact to fully plastic impact). It is used to determine the velocity of the anvil/foundation after impact. This coefficient is governed by the condition $0 < e < 1$. For design purposes, it's average value for steel-to-steel impact, may be considered as 0.6. For impact between two specific materials, it's value may be taken as per specific technical literature available.

3.8 Column – Main structure to which press head is mounted.

3.9 Cross Head – A stiff beam, mounted on the press frame that can be raised and lowered to the desired height with respect to the supporting columns.

3.10 Cylinder – The part which creates a mechanical movement and exert pushing or pulling efforts.

3.11 Damper – A device that dissipates energy.

3.12 Die – Tools required for precise forgings. These are made up of upper and lower parts, in which there are cavities for forgings.

3.13 Double Acting Drop Hammers – Hammers in which, steam or compressed air acts on the tup not only during lift, but also during its drop.

3.14 Eccentricity – Distance between centre of mass and centre of stiffness.

3.14.1 *Anvil Eccentricity* – Eccentricity between centre of mass of anvil and centre of stiffness of isolators below the anvil.

3.14.2 *Inertia Block Eccentricity* – Eccentricity between combined centre of mass of anvil and inertia block and centre of stiffness of isolators provided below the inertia block.

3.14.3 *RCC Chamber Eccentricity* – Eccentricity between combined centre of mass of anvil + inertia block + RCC chamber, and centre of stiffness of soil/pile system provided below the chamber.

3.15 Efficiency of Drop – A factor that is related to the drop process and influences impact velocity of the tup. In the absence of its value provided by the manufacturer, it may be taken as 0.65.

3.16 Elastomeric Pad – An elastic cushioning of suitable material having stiffness and damping characteristics provided between the anvil and the foundation (inertia block) to prevent bouncing of anvil as well as preventing damage to the top surface of the concrete of the foundation.

3.17 Foundation Block – A reinforced cement concrete block which supports the anvil and houses the inertia block. It comprises, (a) RCC inertia block; and (b) RCC chamber.

3.17.1 *Inertia Block* – A reinforced cement concrete (RCC) block that supports the anvil. It also supports the frame in case the same is not connected to anvil.

3.17.2 *RCC Chamber* – A RCC chamber that supports the inertia block. It in turn rests on soil/rock or group of piles.

3.18 Frame – Two types of frame arrangements are used, (a) frame supported on the anvil, or (b) frame supported on inertia block that supports anvil.

3.19 Frequency of Blow – Rate at which the tup strike to the specimen on anvil (number of blows per second).

3.20 Impact Force (*F*) – The force produced when the falling tup strikes the material being forged on the anvil.

3.21 Impulse – Integral with respect to time of a force taken over the time during which the force is applied.

NOTES:

1 In shock usage, the time interval is relatively short.
2 For a constant force, it is the product of the force and the time during which the force is applied.
3 Excitation due to an instant force is referred to as impulse excitation.

3.21.1 *Half-Sine Pulse* – Pulse for which the time-history curve has the shape of the positive (or negative) section of one cycle of a sine wave.

3.21.2 *Rectangular Pulse* – Pulse for which the motion rises instantaneously to a given value, remains constant for the duration of the pulse, then instantaneously drop to zero.

3.21.3 *Triangular Pulse* – Pulse for which the time-history curve has the shape of an isosceles triangle.

3.22 Isolation Efficiency (η) – Percentage of vibration force or motion which is not transmitted from machine to foundation or from foundation to machine.

3.23 Magnification Factor – Ratio of the dynamic amplitude to the static displacement.

3.24 Press Bed – The lower stationery part of press machine that bears all the load of press and to which the bolster is attached.

3.25 Pulse Loading

3.25.1 *Short Duration Impulse Loading* – Dynamic magnification depends upon ratio of frequency of impact to natural frequency.

3.25.2 *Long Duration Pulse Loading* – Dynamic magnification factor depends upon ratio of pulse duration to natural time period of foundation.

3.26 Short-stroke and Full-Stroke – Short-stroke is characterized by higher stroke rate with minimum contact times during collision and full-stroke is characterized by lesser stroke rate with longer contact times during collision.

3.27 Single Acting Drop Hammers – Single acting hammers operated by steam or compressed air, which lifts the tup and then allows it to fall by gravity.

3.28 Slide or Ram – The press member that reciprocates linearly, guided in the press frame to which the upper die is fastened.

3.29 Spring – A device that stores energy when deflected and returns the same amount of energy when released (like steel springs)

3.30 Tup – A weighted block of mass, m_0, that strikes the material being forged on the anvil.

3.31 Vibration Isolation – The process of reduction in transmission of vibration from machine to foundation or from foundation to machine.

3.32 Vibration Isolator – A device comprising spring(s) with or without damper(s).

4 SYMBOLS AND NOTATIONS

For the symbols and notations given below, the descriptions and units as given below shall apply, unless specified otherwise.

Symbols	Unit	Description
Tup/Ram and Die		
m_0	t	Total mass of tup/ram including mass of upper die
h	m	Height of fall of tup
Blows/Frequency of Repeated Pulse		
N	Blows per minute or Repeated pulse per minute	Blow speed
l	mm	Blow stroke (full)
τ_h	s	Time interval between two hammer strikes or time interval between two impulses = $^{60}/_{N}$
F_p	N	Force magnitude of pulse or impulse
t_p	s	Pulse duration (time) for short impulse or pulse
Anvil		
m_a	t	Total mass of anvil (including mass of lower die and SOW block) + Mass of frame (if connected to anvil)

L_a	m	Base length
B_a	m	Base width
A_a	m^2	Base area
Foundation		
a) *Inertia Block*		
m_b	t	Mass of inertia block + Mass of frame (if connected to inertia block)
L_b	m	Base length
B_b	m	Base width
A_b	m^2	Base area
D_p	m	Depth of pit for anvil
D_b	m	Depth below anvil pit
b) *Chamber* (*RCC*)		
m_c	t	Mass of RCC chamber
L_c	m	Base length
B_c	m	Base width
A_c	m^2	Base area
t_w	m	Thickness of chamber wall (free standing)
t_r	m	Thickness of base raft
Coefficients		
e	–	Coefficient of restitution (recommended value is 0.6)
η	–	Efficiency of drop (recommended value is 0.65)
Permissible Amplitudes		
δ_a	mm	Amplitude of anvil when anvil is supported over inertia block through VIS as in Fig. 3A
δ_b	mm	Amplitude of inertia block when inertia block is supported over RCC chamber through VIS as in Fig. 3A
δ_{ab} ($\delta_{ab} = \delta_b$)	mm	Amplitude of inertia block when Anvil is bolted directly to Inertia Block and Inertia Block is supported over RCC Chamber through VIS as in Fig. 3B
δ_c	mm	Amplitude of RCC chamber (when anvil is bolted to inertia block and inertia block is supported over RCC chamber through VIS as in Fig. 3B
Stiffness		
k_a	kN/m	Stiffness of VIS unit provided under anvil as in Fig 3A
k_b	kN/m	Stiffness of VIS unit provided under inertia block
k_c	kN/m	Stiffness of soil or group of piles under RCC chamber
Energy		
E_I	kN m	Impact energy due to fall of tup
E_{TB}	kN m	a) Energy transferred from anvil to inertia block
E_{TC}	kN m	b) Energy transferred from inertia block to RCC chamber
Velocity and Frequency		
v_0	m/s	Velocity of tup before impact
v_a	m/s	Velocity of anvil after impact
v_{ab}	m/s	Velocity of inertia block + anvil after tup impact

ω_a	rad/s	Limiting frequency of anvil
ω_b	rad/s	Limiting frequency of inertia block
ω_n	rad/s	Undamped natural frequency of the hammer/press foundation system
$\omega_{n,d}$	rad/s	Damped natural frequency of the hammer/press foundation system
Damping		
c_a	kN s/m	Damping of VIS unit provided under anvil
c_b	kN s/m	Damping of VIS unit provided under inertia block
c_c	kN s/m	Damping associated with soil/rock or group of piles
ζ_a	-	Damping constant of VIS under anvil
ζ_b	-	Damping constant of VIS under inertia block
ζ_c	-	Damping constant of soil under RCC chamber
Amplitudes		
$y_{a,1}$ *and* $y_{a,2}$ $y_{b,1}$ *and* $y_{b,2}$	m	Amplitude of the respective mass (m_a, m_b, m_{ab}, m_c) corresponding to 1st *and* 2nd vibration mode. Model as per Fig 3A
$y_{ab,1}$ *and* $y_{ab,2}$ $y_{c,1}$ *and* $y_{c,2}$	m	Amplitude of the respective mass (m_a, m_b, m_{ab}, m_c) corresponding to 1st *and* 2nd vibration mode Model as per Fig 3B
y_a	m	Total amplitude of anvil = Sum of anvil amplitudes in modes 1 and 2 given by, $\lvert y_a \rvert = \lvert y_{a,1} \rvert + \lvert y_{a,2} \rvert$
y_f	m	Total amplitude of foundation
Other Symbols		
λ_a	-	Ratio of mass of anvil to mass of tup $\{m_a / m_0\}$
m_{ab}	m	Mass of anvil (including mass of lower die, SOW block) + Mass of frame + Mass of inertia block
λ_{ab}	-	Ratio of mass of inertia block + mass of anvil to mass of tup $\{m_{ab} / m_0\}$

SECTION 2

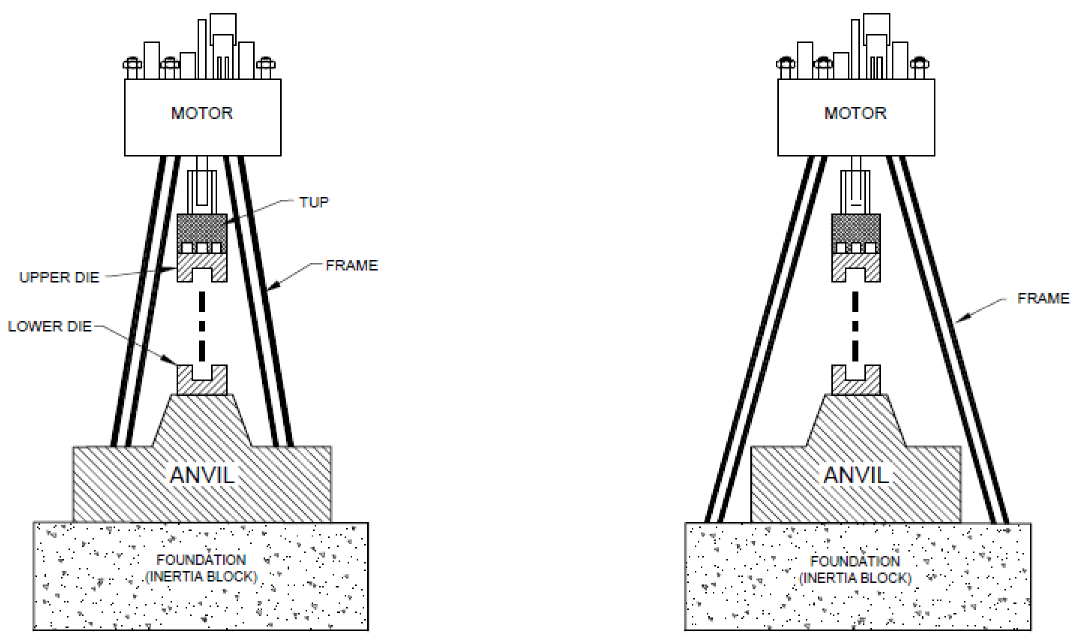
FOUNDATIONS FOR IMPACT TYPE MACHINES (HAMMER FOUNDATIONS)

5 GENERAL DESIGN REQUIREMENTS FOR HAMMER FOUNDATIONS

Machines producing repeated impacts are, (a) forge hammers, and(b)drop hammers. In the forging process (for both these hammers), a tup falls from a specified height and strikes the material to be forged placed on the anvil. In this process, the tup imparts initial velocity to the anvil, that causes anvil to vibrate, which in turn induces vibrations of the foundation. The entire process is repeated with next impact of the tup to the anvil after a short time interval.

5.1 Hammer-Frame Support Arrangements

Hammer-frame support arrangement depends upon hammer type that varies from manufacturer to manufacturer, and it also depends upon hammer capacity. Two types of hammer-frame arrangements, generally encountered in practice, are (a) where frame is attached to anvil and (b) where frame is supported on the foundation. Typical hammer-frame support arrangement is shown in Fig. 2. Schematic arrangement for hammer where frame is attached to anvil is shown in Fig. 2A, and that where frame is supported on foundation is shown in Fig. 2B.



2A FRAME ATTACHED TO ANVIL 2B FRAME SUPPORTED ON FOUNDATION

FIG. 2 SCHEMATIC ARRANGEMENTS SHOWING HAMMER SUPPORTED ON THE FOUNDATION

5.2 Hammer Foundation

5.2.1 Hammer foundation comprises of, (a) RCC inertia block that supports anvil, and (b) RCC chamber that houses inertia block. Two types of frame arrangements generally encountered in practice are given below:

a) Frame attached to anvil; and
b) Frame supported on inertia block.

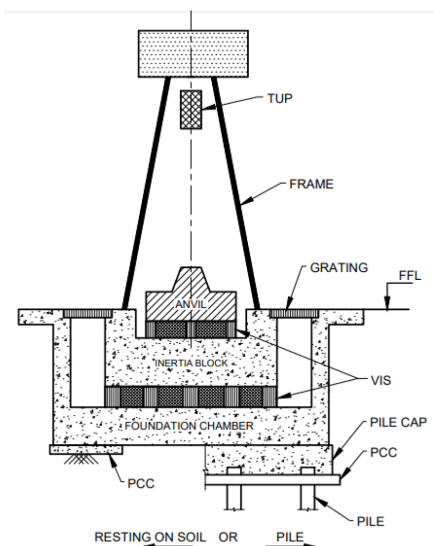
5.2.2 In view of the severity of the transmitted vibrations to other structures, inertia block is necessarily placed inside a RCC chamber that in turn is supported on soil/rock or group of piles.

5.2.3 Hammer foundation shall be provided with **Vibration Isolation System** (VIS) at two levels as given below (as shown in Fig. 3A):

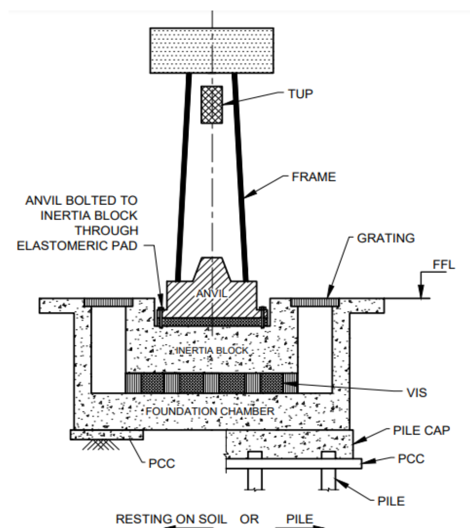
a) VIS at base of anvil (between Anvil & Inertia Block); and
b) VIS at base of inertia block (between Inertia Block and RCC Chamber).

For hammers with capacity of 1.0 t or less, isolation (VIS) below anvil shall be replaced by an Elastomeric Pads to absorb the impact and to prevent bouncing of anvil as well as preventing damage to the top surface of the concrete of the foundation. VIS shall be provided only at base of inertia block (between Inertia Block and RCC Chamber) as shown in Fig. 3B.

A typical hammer foundation with both these arrangements is shown in Fig. 3.



3A FOR LARGE SIZE HAMMERS – ANVIL SUPPORTED ON INERTIA BLOCK THROUGH VIS AND INERTIA BLOCK SUPPORTED ON THE FOUNDATION CHAMBER THROUGH VIS



3B FOR SMALL SIZE HAMMERS – ANVIL BOLTED TO INERTIA BLOCK THROUGH ELASTOMERIC PADS AND INERTIA BLOCK SUPPORTED ON THE FOUNDATION CHAMBER THROUGH VIS

FIG. 3 TYPICAL HAMMER FOUNDATION (INERTIA BLOCK) PLACED INSIDE RCC CHAMBER

5.2.4 RCC chamber shall be isolated from adjoining building/structures as well as from their foundations. The base level of RCC chamber shall be kept below the building/ structure foundation level.

5.2.5 *Foundation Material*

RCC foundation block shall be provided with minimum concrete grade of M25 for both inertia block and RCC chamber. The materials shall comply with the requirements given in IS 2974 (Part1). RCC chamber shall be designed as uncracked section as per the provisions of IS 3370 (Part 1) and (Part 2).

5.2.6 In case piles are required to be provided, RCC chamber shall be placed on the top of the pile cap.

5.2.7 The bearing pressure on soil/permissible load on the heaviest loaded pile, under equivalent static loading, shall be restricted to 80 percent of the net allowable bearing capacity.

5.2.8 Foundation shall be dimensioned and designed in such a way that dynamic performance requirements, as specified by the manufacturer and codal provisions, are met.

5.2.9 In a typical forging operation, about 65 percent of the impact energy is consumed for forging and around 33percent of the energy is consumed causing tup to rebound. Only about 2 to 3 percent of the impact energy is consumed in generating vibrations of the anvil and the foundation, that propagates and gets transmitted to adjoining building/structures. Foundation design for the hammer shall ensure that vibration transmission to adjoining Structures is well within permissible levels.

5.2.10 The foundation shall be designed such that integrity of foundation is maintained under all operating conditions.

6 SYSTEM DATA

6.1 Hammer Data

In addition to the general machine data as specified in **7** of IS 2974 (Part 1), the following data shall be obtained from the machine supplier/customer/machine manufacturer, for design of hammer foundation.

a) Capacity of hammer;
b) Tup;
   1) Mass of tup, and
   2) Height of drop;
c) Die;
   1) Mass of upper die,
   2) Mass of lower die, and

3) Mass of SOW block;

d) Anvil;
   1) Mass of anvil
   2) Geometrical details (Base area in plan and anvil height), and
   3) Bolt layout and bolt sizes;

e) Frame (including motor drive arrangement);
   1) Mass of frame and
   2) Height;

f) Total height of machine (hammer with frame);

g) Dynamic parameters of drive Motor;
   1) Motor horsepower,
   2) Motor rating (frequency/volts/rpm), and
   3) Full blow energy;

h) Number of blows (per minute);
   1) Short stroke - number of blows, and
   2) Full stroke- number of blows;

j) Minimum time between two impact strikes;

k) Level of anvil base with respect to finished floor level of shop floor; and

m) Allowable amplitudes at anvil.

6.2 Foundation Data

6.2.1 Foundation layout showing anvil base plan and bolt locations shall be obtained from the supplier. In case the frame is supported over the inertia block, its layout (including bolt sizes and bolt locations) shall also be obtained from the supplier.

6.2.2 Dimensional details of cavity or depression to be provided in the foundation to accommodate anvil, shall be obtained from the customer/hammer supplier. The space all around the anvil shall be adequate for maintenance of isolation device provided below anvil and in no case, it shall be less than 600 mm or as recommended by the manufacturer.

6.2.3 *Material Properties and Permissible Stresses*

Material properties and permissible stresses in the concrete and reinforcement bars shall be in accordance with the provisions given in **8** of IS 2974 (Part 1). Permissible stresses in the vibration isolation system shall be in accordance with the properties of selected isolation device. This shall be obtained from the supplier of isolation pads.

6.3 Geotechnical Data

The following soil/pile data, required for design of foundation, shall be obtained.

a) Soil profile and soil characteristics up to a depth at least 3 times the mean plan dimensions of the foundation (which can be taken as the square root of the expected area) or hard strata, whichever is less;

b) Soil investigation to the extent necessary in accordance with IS 1892 and for determination of dynamic properties of the soil in accordance with IS 5249;
c) The relative position of the water table below ground at different times of the year; and
d) The soil dynamic parameters or pile design parameters including vertical and lateral stiffness, as well as total permissible settlement, required for the analysis of foundation shall be considered asper **4** of IS 2974 (Part 1).

6.4 Vibration Isolation System Data

6.4.1 *Isolation Pad (Elastomeric pads)*

The following data shall be obtained:

a) Material;
b) Elastic modulus;
c) Variation of elastic modulus with deflection;
d) Maximum allowable deformation/deflection under the load; and
e) Allowable stress intensity.

6.4.2 *Spring-Damper Unit*

The following data shall be obtained:

a) Maximum allowable spring deflections for normal working as well as for extreme conditions and also for static loads as well as for dynamic loads;
b) Stiffness of springs;
c) Damping characteristics of damper units;
d) Base plate size, bolt size and bolt locations;
e) Top plate size, bolt size and bolt locations; and
f) Height of the unit.

7 PERMISSIBLE AMPLITUDES

7.1 The permissible amplitudes, which depend upon the mass of the tup shall be as follows:

	Mass of Tup		
	Up to 3 t	3 to 5 t	More than 5 t
For inertia block (δ_b)	1.0 mm	1.5 mm	2.0 mm
For anvil (δ_a)	1.2 mm	2.0 mm	3.0 to 4.0 mm

7.2 Wherever any important structure exists near the foundation, the foundation should be so designed such that the velocity of the vibrations at these structures does not exceed 2.0 mm/s.

8 DESIGN CRITERIA

Three main governing criterions for hammer foundation design are:

a) After each impact and before taking up the next strike, both anvil and the foundation shall return to their normal position at rest;
b) Amplitudes of the anvil and the foundation shall be within prescribed limits, both for initial velocity conditions as well as steady state response under applied dynamic loading; and
c) Effective attenuation of vibration from the source to adjoining areas shall also be ensured during the entire forging process.

8.1 Design Considerations/Requirements

The hammer foundation shall satisfy the requirements given in **8.1.1** to **8.1.7**.

8.1.1 *Centre of Mass*

Foundation shall be sized such that the combined centre of gravity (centre of mass) of the anvil, the frame, the foundation (inertia block) and the RCC chamber coincides with the line of fall of the hammer tup.

8.1.2 *Eccentricity*

Centre of stiffness of vibration isolation system provided under anvil and under the foundation bock, as well as centre of stiffness of soil, shall lie in one vertical line.

8.1.2.1 Anvil eccentricity shall preferably be zero and in no case, it shall exceed 2 percent.

8.1.2.2 Inertia block eccentricity shall preferably be zero and in no case, it shall exceed 2 percent.

8.1.2.3 RCC chamber eccentricity shall preferably be zero and in no case, it shall exceed 5 percent. Piles provided below RCC chamber shall be placed such that centre of pile stiffness shall match with centre of gravity of chamber base area.

8.1.3 *Frequency Separation*

For hammers having continuous impacts, the vertical natural frequency of the foundation system shall be 100 percent away from blow speed. Wherever it is not possible to get the desired frequency separation, the criteria that the amplitude of the anvil and the foundation are within permissible limits, shall be the governing criteria.

8.1.4 *VIS Parameters* (*Stiffness and Damping*)

Vibration isolation system (VIS) parameters shall be selected such that the anvil and the foundation (inertia block and RCC chamber), when set into vibrating mode after first impact, shall return to position at rest before the second impact strike of the tup. This is necessary for achieving good forge quality.

8.1.5 *Anvil and Foundation Amplitudes*

Vibration isolation system (VIS) parameters shall be selected such that the amplitudes of the anvil and the inertia block shall be within permissible limits as specified in **7.1**.

8.1.6 *Minimum Thickness of Inertia Block*

Minimum thickness of the Inertia block (below the anvil) shall be as under:

Sl No.	*Mass of Tup* t	*Thickness (Depth) of Foundation Block, Min* m
i)	Up to 1.0	1.00
ii)	1.0 to 2.0	1.25
iii)	2.0 to 4.0	1.75
iv)	4.0 to 6.0	2.25
v)	Over 6.0	2.50

8.1.7 *Foundation Mass*

8.1.7.1 *Inertia block*

In case frame is attached to anvil, mass of the inertia block shall be at least 3 times the sum of the mass of the anvil and the mass of the frame. In case frame is attached to inertia block, the mass of the inertia block shall be at least 3 times the mass of the anvil.

8.1.7.2 *RCC chamber*

There is no minimum mass criterion applicable to RCC chamber. However, the following considerations shall be adhered to while designing RCC chamber:

a) RCC chamber shall be designed as uncracked section as per the provisions of IS 3370 (Part 1) and (Part 2) to prevent entry of ground water into the chamber so as to avoid damage to Vibration isolation system;
b) Base thickness of RCC chamber – Thickness provided shall be as per design but shall not be less than 800 mm. It shall also be ensured that it is safe in one-way shear, punching shear and bending, under all operational conditions including jacking

loads required for VIS during initial placing or/repair and maintenance of isolators. It shall be uniform all over the base area.

c) For foundations resting on stiff clays or compact sandy deposits, the thickness of base of the chamber shall be minimum 800 mm. Natural frequency of the base slab under applied loads from inertia block including machine loads, shall be 50 percent away from the blow frequency.

d) Side walls shall be designed for external soil pressure including effect of sub-soil water (ground water table) as per IS 3370 (Part 1) and IS 3370 (Part 2). Its thickness shall not be less than 300 mm. Natural frequency of the walls (free standing) without any influence of soil shall be 50 percent away from the blow frequency.

e) *Vibration transmission to adjoining structures/foundations* – No part of the hammer foundation shall be allowed to have a rigid contact with parts of adjoining structures. For best isolation, a gap is recommended between parts of the foundation and adjacent structures.

9 DESIGN OF FOUNDATION

Foundation shall be designed to comply with the design philosophy and design requirements as per **8**.

9.1 Machine Parameters

The machine parameters that govern the design are given in Table 1. Symbols and units for these parameters shall be as per **4**.

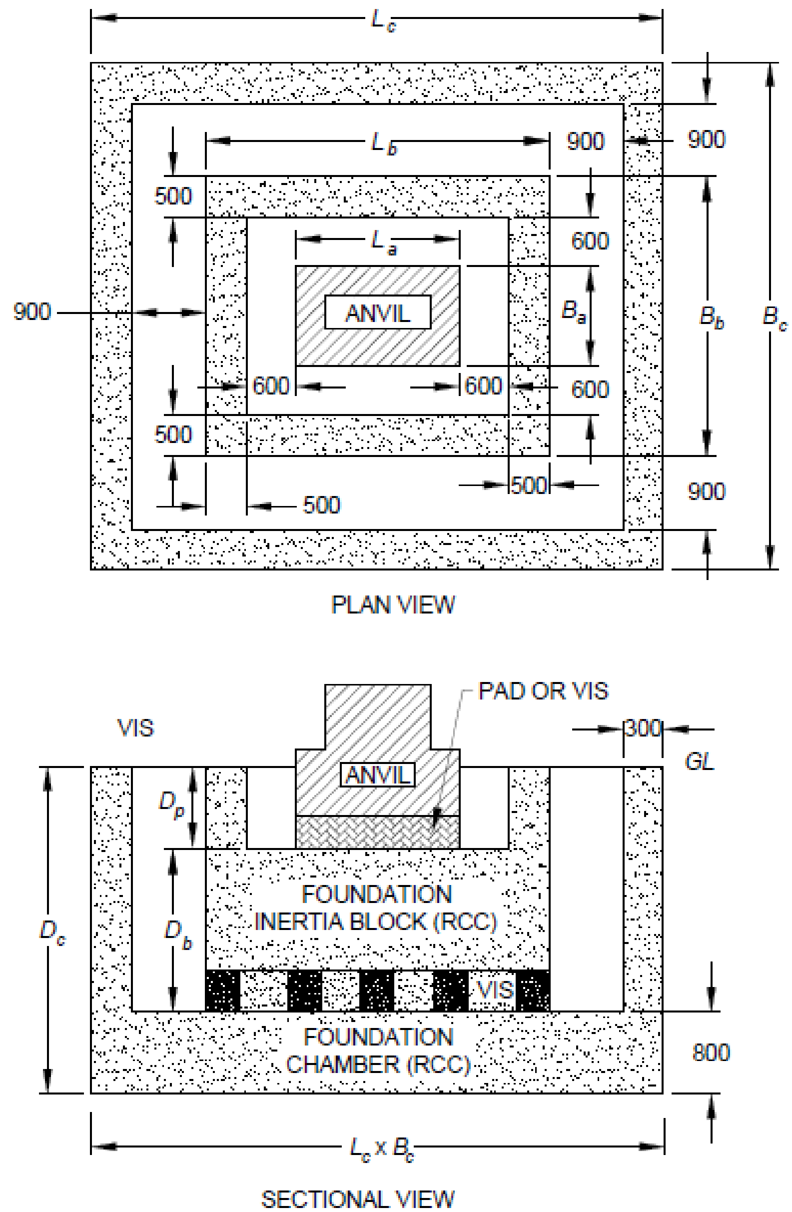
Table 1 Machine Parameters for Design of Hammer Foundation
(*Clause* 9.1)

Sl No.	Machine Data	Description
(1)	(2)	(3)
i)	Tup and die	Mass of tup Mass of upper die Height of fall
ii)	Blow	Blow speed higher Blow stroke (full) Time gap between two strokes
iii)	Anvil	Mass of anvil Mass of lower die + SOW block Base length Base width Base area

iv)	Coefficients	Coefficient of restitution (recommended value is 0.6) Efficiency of drop (recommended value is 0.65)
v)	Permissible Amplitudes	Anvil Foundation (inertia block), and RCC chamber

9.2. Foundation Sizing

Foundation sizing shall be done as per design keeping in view the requirements of the customer and the machine (as dictated by the hammer manufacturer). Typical foundation details are shown in Fig. 4. Dimensions and clearances, as shown are the minimum. Actual dimensions shall be as per design (dynamic analysis and strength design).



All Dimensions are in mm

NOTES

1 Indicated dimensions as shown are minimum.
2 For description of various symbols used and their units, refer **4**.

FIG. 4 TYPICAL HAMMER FOUNDATION ARRANGEMENT - ANVIL PLACED OVER INERTIA BLOCK THROUGH PAD/ VIS AND INERTIA BLOCK PLACED INSIDE RCC CHAMBER THROUGH VIS

9.3 Initial Velocity of Anvil and Energy Transmission from Anvil to the Foundation

9.3.1 *Anvil is supported over Inertia Block through VIS* (*see* Fig.3A)

Impact of the Tup on Anvil: The initial velocity of anvil (mass,m_a) subjected to impact of the tup (falling mass,m_0) shall be computed by the following equation:

$$v_a = v_0 \times \frac{(1+e)}{(1+\lambda_a)}$$

where,

v_a = Initial velocity of Anvil after impact, in m/s;

$v_0 = \eta\sqrt{2gh}$ = Velocity of tup before impact, in m/s;

h = Height of fall of mass,m_0 (tup+ upper die), in m;

η = Efficiency of drop (recommended value is 0.65);

$\lambda_a = \frac{m_a}{m_0}$ = Mass ratio (ratio of mass of anvil to mass of tup);

m_0 = Total mass of falling object (mass of tup + upper die), in t;

m_a = Total mass of anvil + lower die + SOW block + frame (if connected to anvil), in t;

e = Coefficient of restitution as provided by manufacturer (in the absence of provided data it shall be taken as 0.6)

Impact energy (due to fall of tup) =$E_I = \frac{1}{2}m_0v_0^2$; in kNm

Energy transferred from anvil to the inertia block = $E_{\mathrm{Tb}} = \frac{1}{2}m_{\mathrm{a}}v_{\mathrm{a}}^2$; in kNm

Ratio of E_{Tb} to E_{I} = $E_{\mathrm{R}} = \frac{E_{\mathrm{Tb}}}{E_{\mathrm{I}}}$

$$E_R = \frac{m_a}{m_0}\times\frac{v_a^2}{v_0^2} = \lambda_a\times\frac{v_a^2}{v_0^2} = \lambda_a\times\left[\eta\frac{(1+e)}{(1+\lambda_a)}\right]^2 = \frac{\lambda_a}{(1+\lambda_a)^2}\times\eta^2\times(1+e)^2$$

$$E_R = \frac{\lambda_a}{(1+\lambda_a)^2}\times\eta^2\times(1+e)^2$$

For $e = 0.6\ and\ \eta = 0.65,\ E_R = 1.08\ \frac{\lambda_a}{(1+\lambda_a)^2}$

Plot of energy transmitted from the anvil to the inertia block (foundation) is shown in Fig. 5A. It is seen that energy transmitted to foundation decreases with increase in mass ratio of anvil to tup, that is, higher the mass ratio, lower shall be the energy transmitted to the foundation. For example, for mass ratio of 35, transmitted energy from anvil to foundation is only 3 percent.

9.3.2 *Anvil is Bolted to Inertia Block and the Block is Supported on RCC Chamber through VIS* (*see* Fig. 3B)

Impact of the Tup on Anvil: Since anvil is rigidly connected to the inertia block, the impact will cause initial velocity of anvil + inertia block subjected to impact of the tup (falling mass m_0) shall be computed by the following equation:

$$v_{\mathrm{ab}} = v_0 \times \frac{(1+e)}{(1+\lambda_{\mathrm{ab}})}$$

where,

v_{ab} = initial velocity of anvil & inertia block after impact

$\lambda_{ab} = \frac{m_{\mathrm{ab}}}{m_0}$ = mass ratio (mass of Inertia Block + Anvil to mass of Tup)

m_{ab} = total mass of inertia block + anvil + lower die + SOW block + frame

Energy transferred from inertia block to the RCC chamber = $E_{Tc} = \frac{1}{2} m_{ab} v_{ab}^2$

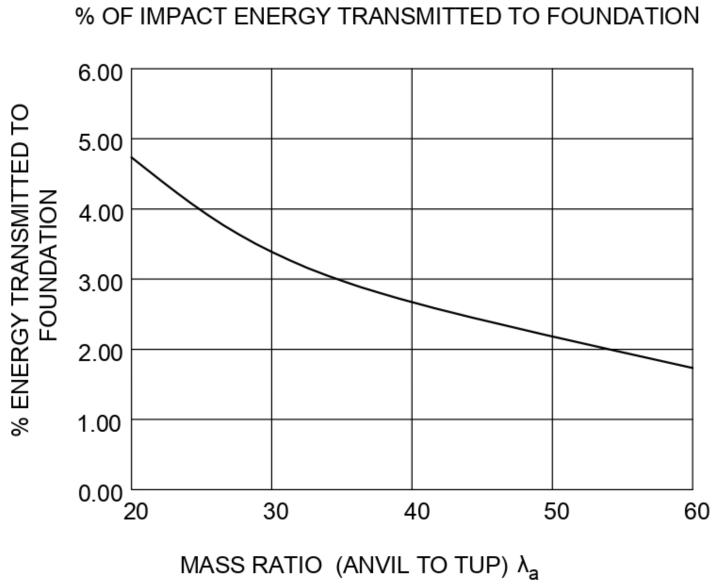
Ratio of E_{Tc} to E_I = $E_R = \frac{E_{TC}}{E_I}$

$$E_R = \frac{m_{ab}}{m_0} \times \frac{v_{ab}^2}{v_0^2} = \lambda_{ab} \times \frac{v_{ab}^2}{v_0^2} = \lambda_{ab} \times \left[\eta \frac{(1+e)}{(1+\lambda_{ab})}\right]^2 = \frac{\lambda_{ab}}{(1+\lambda_{ab})^2} \times \eta^2 \times (1+e)^2$$

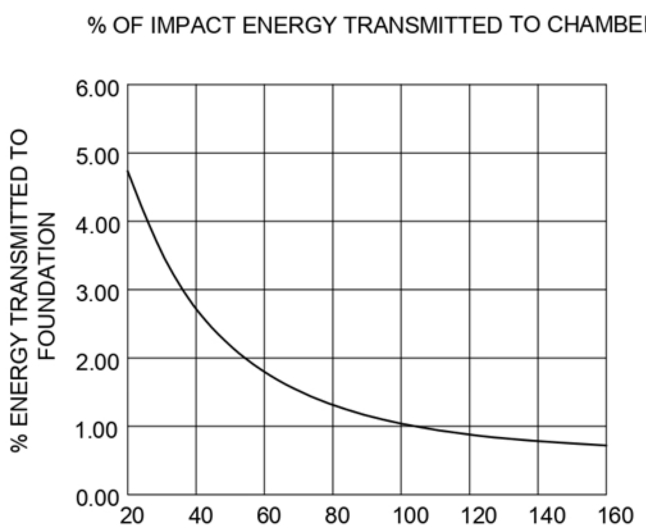
$$E_R = \frac{\lambda_{ab}}{(1+\lambda_{ab})^2} \times \eta^2 \times (1+e)^2$$

For $e = 0.6 \; and \; \eta = 0.65, E_R = 1.08 \frac{\lambda_{ab}}{(1+\lambda_{ab})^2}$

Plot of energy transmitted to foundation is shown in Fig. 5B. It is seen that energy transmitted to chamber decreases with increase in mass ratio of block + anvil to tup. For mass ratio of greater than 100, the transmitted energy is less than 1 percent.



5A MASS RATIO (ANVIL TO TUP) λ_a



5B MASS RATIO (INERTIA BLOCK + ANVIL TO TUP), λ_{ab}

FIG. 5 RATIO OF IMPACT ENERGY (PERCENT) TRANSFERRED FROM INERTIA BLOCK TO THE FOUNDATION (RCC CHAMBER)

9.4 Selection of VIS Parameters

Isolation parameters, that is, stiffness and damping shall be selected to meet the design criteria as per **8**. Whereas the stiffness of VIS controls vibration amplitudes, the damping controls the stability in bringing back the system to position of rest before anvil takes up next strike of the tup. It also contributes to reducing amplitude values.

9.4.1 *Stiffness*

Initial stiffness estimates of VIS depend upon permissible amplitudes of, (a) anvil, and (b) inertia block.

9.4.1.1 *Anvil is supported on inertia block through VIS* (*see* Fig.3A)

a) Stiffness of VIS provided between anvil and inertia block

Permissible anvil amplitude = δ_a; in mm

First estimate of VIS stiffness, $k_a = m_a \times \text{g} \times (1000/\,\delta_a)$; in kN/m

where, g is acceleration due to gravity = 9.81 m/s^2

b) Stiffness of VIS provided between inertia block and RCC chamber

Permissible inertia block amplitude = δ_b; in mm

First estimate of VIS stiffness, $k_b = (m_a + m_b) \times \text{g} \times (1000/\,\delta_b)$; in kN/m

9.4.1.2 *Anvil is bolted to inertia block and the block is supported on the RCC Chamber through VIS* (*see* Fig. 3B)

Permissible amplitude = δ_b ; in mm

First estimate of VIS stiffness, $k_b = m_{ab} \times \text{g} \times (1000/\,\delta_b)$; in kN/m

where, m_{ab} = total mass of inertia block + anvil + lower die + SOW block + frame

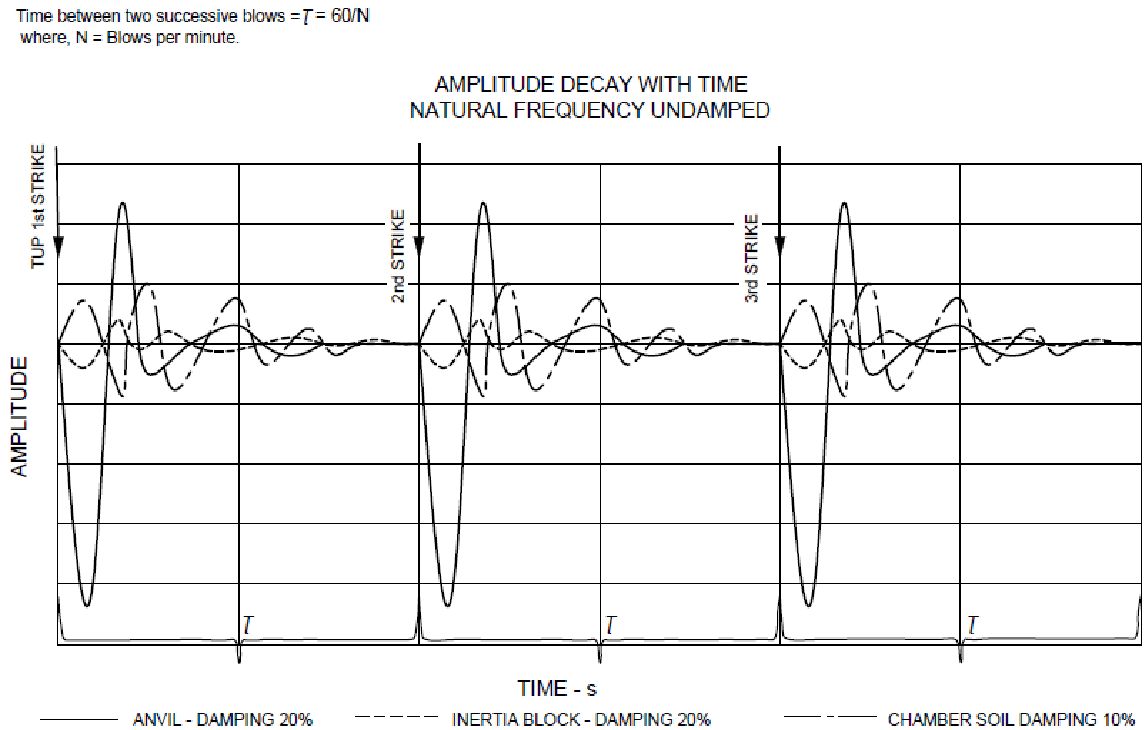
9.4.2 *Damping*

Role of damping is very important and significant for hammer foundation design. To achieve good forge quality, it is essential that after the strike of the tup to the anvil, both anvil and the foundation shall resume their position at rest before taking the next strike of the tup. This is made possible only by introducing the required damping while designing isolation system for the foundation.

For foundation arrangements shown in Fig. 3A, minimum damping for VIS between anvil and inertia block as well as that for VIS between inertia block and RCC chamber shall be 20 percent.

For foundation arrangements shown in Fig. 3B, no consideration need to be given for damping of elastomeric pads as anvil is directly bolted to the inertia block. However, minimum damping for VIS between inertia block and RCC chamber shall be 20 percent.

9.4.3 Both stiffness and damping values suggested above are minimum recommended values. Actual values shall be finalized after conducting dynamic analysis and ensuring that amplitudes for anvil and foundation are within permissible limits. Further, it shall also be ensured that the anvil and the block resume position at rest after each strike of the tup, that is, before next tup strike, as shown in Fig. 6.



AMPLITUDE DECAY WITH TIME — ANVIL; INERTIA BLOCK & RCC CHAMBER

NOTE – Anvil, inertia block and RCC chamber come to rest at the end of each strike (before start of next strike).

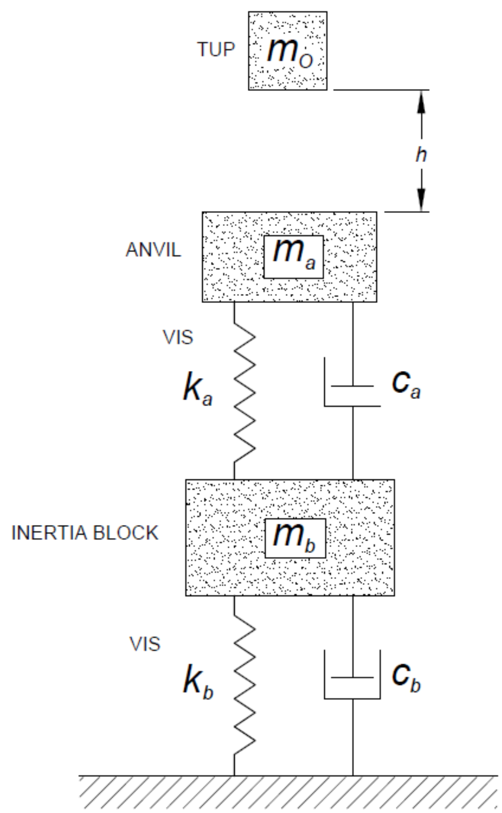
FIG. 6 AMPLITUDE DECAY WITH TIME BETWEEN 1ST STRIKE, 2ND STRIKE AND SUBSEQUENT STRIKES OF TUP

10 VIBRATION ANALYSIS

10.1 Anvil is Supported on Inertia Block through VIS and Inertia Block is Supported on RCC Chamber through VIS (*see* Fig. 3A)

For manual computation (hand calculations), two spring mass system is considered good enough for frequency and amplitude computations. RCC chamber is considered fixed, that is, the stiffness and damping of soil/pile system are not considered in the dynamic analysis.

The foundation system is idealized as two spring mass damped system [two degrees of freedom (DOF) system] and is shown in Fig. 7. Mathematical formulations (with derivation) for computation of natural frequencies and amplitudes are given in **10.1.1** and **10.1.2**.



Key

m_o = Mass of tup + upper die, in t;
m_a = Mass of anvil + lower die + SOW block + frame (if attached to anvil); in t;
m_b = Mass of inertia block + frame (if not attached to anvil but attached to foundation), in t;
For other symbols, *see* **4**

FIG. 7 MATHEMATICAL MODEL OF FOUNDATION SYSTEM SHOWN IN FIG. 3A 2 - SPRING MASS DAMPED SYSTEM COMPRISING OF ANVIL AND INERTIA BLOCK

10.1.1 *Natural Frequencies*

The two natural frequencies, ω_{n1} and ω_{n2} are given by,

$$\omega_{n1} = \sqrt{\frac{1}{2}\left\{(\omega_a{}^2(1+\alpha) + \omega_b{}^2) - \sqrt{(\omega_a{}^2(1+\alpha) + \omega_b{}^2)^2 - 4(\omega_a{}^2\omega_b{}^2)}\right\}}$$

$$\omega_{n2} = \sqrt{\frac{1}{2}\left\{(\omega_a{}^2(1+\alpha) + \omega_b{}^2) + \sqrt{(\omega_a{}^2(1+\alpha) + \omega_b{}^2)^2 - 4(\omega_a{}^2\omega_b{}^2)}\right\}}$$

where, $\omega_a = \sqrt{\frac{k_a}{m_a}}$; $\omega_b = \sqrt{\frac{k_b}{m_b}}$; $\alpha = \frac{m_a}{m_b}$

Damped natural frequencies $\omega_{n1,d}$ and $\omega_{n2,d}$ of the system are given by,

$$\omega_{n1,d} = \omega_{n1}\sqrt{1-\zeta_a{}^2}; \qquad \omega_{n2,d} = \omega_{n2}\sqrt{1-\zeta_b{}^2} \ ;$$

where, $\zeta_a = \frac{c_a}{2\sqrt{k_a m_a}}$; $\zeta_b = \frac{c_b}{2\sqrt{k_b(m_a+m_b)}}$

10.1.2 *Amplitudes*

Initial velocity of anvil (due to impact of tup)

$$v_a = v_0 \times \frac{(1+e)}{(1+\lambda_a)}; \qquad v_0 = \eta\sqrt{2gh} \ ; \qquad \lambda_a = \frac{m_a}{m_0}$$

a) Amplitude (dynamic displacement response) of mass, m_a, that is, anvil

$$y_a(t) = y_{a,1}e^{-(\zeta_b\omega_{n1}t)}\, sin(\,\omega_{n1,d}t) + y_{a,2}e^{-(\zeta_a\omega_{n2}t)}\, sin\big(\omega_{n2,d}t\big)$$

where, $y_{a,1} = \frac{v_a}{\omega_{n1}}\left(\frac{\omega_{n2}^2-\omega_a^2}{\omega_{n2}^2-\omega_{n1}^2}\right)$

$$y_{a,2} = \frac{v_a}{\omega_{n2}}\left(\frac{\omega_a^2-\omega_{n1}^2}{\omega_{n2}^2-\omega_{n1}^2}\right)$$

$$y_{a\_max} = |y_{a,1}| + |y_{a,2}|$$

b) Amplitude (dynamic displacement response) of mass, m_b, that is, inertia block

$$y_b(t) = y_{b,1}e^{-(\zeta_b\omega_{n1}t)}\,\sin(\,\omega_{n1,d}t) + y_{b,2}e^{-(\zeta_a\omega_{n2}t)}\,\sin\big(\omega_{n2,d}t\big)$$

Where, $y_{b,1} = y_{a,1}\left(1 - \frac{\omega_{n1}^2}{\omega_a^2}\right)$; and $y_{b,2} = y_{b,1}\left(\frac{\omega_{n1}}{\omega_{n2}}\right)$;

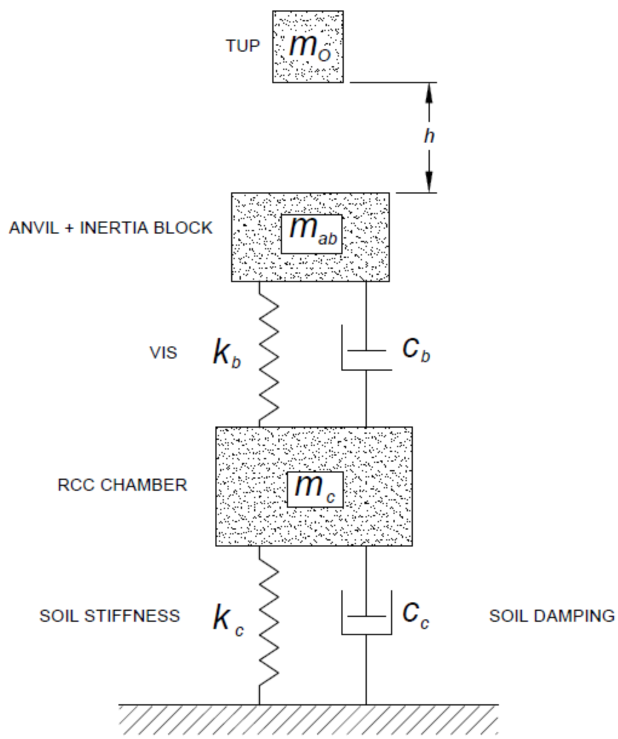
$$y_{b\_max} = |y_{b,1}| + |y_{b,2}|$$

c) Velocity of mass, m_b, that is, inertia block

$$\dot{y}_b(t) = y_{b,1}e^{-(\zeta_b\omega_{n1}t)}\left[\omega_{n1,d}\cos(\omega_{n1,d}t) - \zeta_b\omega_{n1}\sin(\omega_{n1,d}t)\right] + y_{b,2}e^{-(\zeta_a\omega_{n2}t)}\left[\omega_{n2,d}\cos(\omega_{n2,d}t) - \zeta_a\omega_{n2}\sin(\omega_{n2,d}t)\right]$$

10.2 Anvil is Bolted to Inertia Block through Elastomeric Pads and the Block in turn Rests on the RCC Chamber through VIS (*see* Fig. 3B)

The foundation system is idealized as two spring mass damped system [two degrees of freedom (DOF) system] and is shown in Fig. 8. Mathematical formulations (with derivation) for computation of natural frequencies and amplitudes are given in **10.2.1** and **10.2.2**.



Key

m_o = Mass of tup + upper die, in t;
m_{ab} = Mass of inertia block + anvil + lower die + SOW block + frame, in t; and
m_c = Mass of RCC chamber, in t.

For other symbols, *see* **4**

FIG. 8 MATHEMATICAL MODEL OF FOUNDATION SYSTEM SHOWN IN FIG. 3B:
2 - SPRING MASS DAMPED SYSTEM COMPRISING OF ANVIL AND INERTIA BLOCK (RIGIDLY CONNECTED) AND SUPPORTED ON RCC CHAMBER THROUGH VIS

10.2.1 *Natural Frequency*

The two natural frequencies, ω_{n1} and ω_{n2} are given by,

$$\omega_{n1} = \sqrt{\frac{1}{2}\left\{(\omega_{ab}{}^2(1+\alpha)+\omega_c{}^2) - \sqrt{(\omega_{ab}{}^2(1+\alpha)+\omega_c{}^2)^2 - 4(\omega_c{}^2\omega_{ab}{}^2)}\right\}}$$

$$\omega_{n2} = \sqrt{\frac{1}{2}\left\{(\omega_{ab}{}^2(1+\alpha)+\omega_c{}^2) + \sqrt{(\omega_{ab}{}^2(1+\alpha)+\omega_c{}^2)^2 - 4(\omega_c{}^2\omega_{ab}{}^2)}\right\}}$$

where,

$$\omega_{ab} = \sqrt{\frac{k_b}{m_{ab}}}; \quad \omega_c = \sqrt{\frac{k_c}{m_c}}; \quad \alpha = \frac{m_{ab}}{m_c}$$

Damped natural frequencies, $\omega_{n1,d}$ and $\omega_{n2,d}$ of the system are given by,

$$\omega_{n1,d} = \omega_{n1}\sqrt{1-\zeta_b{}^2} \qquad ; \qquad \omega_{n2,d} = \omega_{n2}\sqrt{1-\zeta_c{}^2}$$

where, $\zeta_b = \frac{c_b}{2\sqrt{k_b m_{ab}}}$ and $\zeta_c = \frac{c_c}{2\sqrt{k_c(m_{ab}+m_c)}}$

10.2.2 *Amplitudes*

Initial velocity of block (anvil + Inertia Block) due to impact of tup

$$v_{ab} = v_0 \times \frac{(1+e)}{(1+\lambda_{ab})};$$

where,

$v_0 = \eta\sqrt{2gh}$; and

$\lambda_{ab} = \frac{m_{ab}}{m_0}$

Amplitude of Inertia Block (Anvil bolted to Inertia Block):

Amplitude (dynamic displacement response) of mass m_{ab}, that is, anvil + inertia block

$$y_{ab}(t) = y_{ab,1}e^{-(\zeta_c\omega_{n1}t)}\,sin(\omega_{n1,d}t) + y_{ab,2}e^{-(\zeta_b\omega_{n2}t)}\,sin(\omega_{n2,d}t)$$

Maximum amplitude of block (anvil + block) = $y_{ab\_max} = |y_{ab,1}| + |y_{ab,2}|$

where,

$$y_{ab,1} = \frac{v_{ab}}{\omega_{n1}}\left(\frac{\omega_{n2}^2-\omega_{ab}^2}{\omega_{n2}^2-\omega_{n1}^2}\right)$$

$$y_{ab,2} = \frac{v_{ab}}{\omega_{n2}}\left(\frac{\omega_{ab}^2-\omega_{n1}^2}{\omega_{n2}^2-\omega_{n1}^2}\right)$$

Maximum Amplitude of Inertia Block = $y_{ab\_max} = |y_{ab,1}| + |y_{ab,2}|$

Amplitude of RCC Chamber:

Amplitude (dynamic displacement response) of mass m_c, that is, RCC chamber

$$y_c(t) = y_{c,1}e^{-(\zeta_c\omega_{n1}t)}\, sin(\,\omega_{n1,d}t) + y_{c,2}e^{-(\zeta_b\omega_{n2}t)}\, sin\big(\omega_{n2,d}t\big)$$

where,

$$y_{c,1} = y_{ab,1}\left(1 - \frac{\omega_{n1}^2}{\omega_{ab}^2}\right)$$

$$y_{c,2} = y_{c,1}\left(\frac{\omega_{n1}}{\omega_{n2}}\right)$$

Maximum Amplitude of RCC Chamber = $y_{c\_max} = |y_{c,1}| + |y_{c,2}|$

Velocity of mass, m_c , that is, RCC chamber,

$$\begin{aligned}\dot{y}_c(t) \;&= y_{c,1}e^{-(\zeta_c\omega_{n1}t)}\left[\omega_{n1,d}\cos(\omega_{n1,d}t) - \zeta_c\omega_{n1}\sin(\omega_{n1,d}t)\right]\\ &\quad + \; y_{c,2}e^{-(\zeta_b\omega_{n2}t)}\left[\omega_{n2,d}\cos(\omega_{n2,d}t) - \zeta_b\omega_{n2}\sin(\omega_{n2,d}t)\right]\end{aligned}$$

11 STRENGTH DESIGN

11.1 Inertia Block

It shall be designed for all operational loads as given below:

a) Impact loads due to tup;
b) Jacking loads; and
c) Handling loads (as dictated by the process).

An impact factor of minimum 1.5 shall be considered for design. Minimum grade of concrete shall be M 25 and reinforcement shall be provided as per design. Minimum steel shall not be less 50 kg/m^3 of concrete.

11.2 RCC Chamber

It shall be designed for all operational loads including jacking loads and the following shall also be complied with.

a) An impact factor of minimum 1.5 shall be considered for design;
b) Minimum grade of concrete shall be M 25;

c) RCC chamber shall be watertight such that ground water does not enter the chamber. Hence, it shall be designed as per provisions of IS 3370 (Part 1) and IS 3370 (Part 2); and
d) Reinforcement shall be provided as per design. Minimum steel shall also be in accordance with IS 3370 (Part 1) and IS 3370 (Part 2).

12 CONSTRUCTION

12.1 Inertia Block

a) It is strongly recommended that construction shall be done in single pour without any construction joint. Wherever, single pour construction does not become feasible due to site constraints, only one joint (in horizontal plane) shall be permitted as per direction of Engineer-in-charge. The joint shall be properly designed by providing water bar and shear dowels and shall also have the concurrence of design engineer that such a joint shall not influence dynamic performance requirement of the block.
b) It shall be cast as per provisions of IS 456 and 2974 (Part 1);
c) Reinforcement shall be arranged along all the three axes and also diagonally to prevent shear failures (*see* Fig. 9);
d) Additional reinforcement shall be provided at the top side of the foundation block to cater to impact loads. This additional reinforcement shall be in addition to minimum reinforcement. This may be provided in the form of layers of grills made of minimum 16 mm diameter bars spaced @ 200 mm c to c. Spacing shall be suitably adjusted to allow easy pouring of concrete;
e) Clear Cover to Reinforcement: Clear cover on all sides and bottom shall be minimum 50 mm. The topmost layers of reinforcement in anvil cavity (under anvil) shall be provided with additional layer of reinforcement (as in (d) above) having cover of minimum 50 mm
f) Special care shall be taken to provide accurate location of holes for anchor bolts (if any) cut out for anvil, frame, etc.;
g) The bearing surface for inertia block shall be strictly horizontal and no additional corrective pouring of concrete shall be permitted;
h) Necessary provisions shall be made to ensure protection of the elastomeric pads/ VIS between anvil and foundation block against water, oil scales, etc., and the material selected for such provisions should be able to withstand temperatures up to 100°C;
j) Recommended admixtures shall be used in the areas exposed to high temperature. Specialist literature shall be referred for specifications for this;
k) Air-gaps and spring elements provided for the purpose of reducing vibrations shall be accessible in order to remove scales and enable inspection of springs and their replacement, if necessary; and
m) Hammer foundations which are 'cut-in' by the anvil pits shall be made so deep that the parts which are weakened by the indent of 'cut-in' are of sufficient strength.

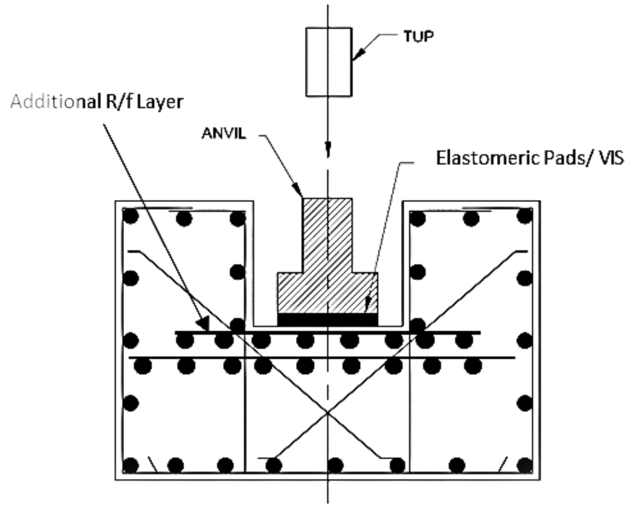


FIG. 9 TYPICAL REINFORCEMENT DETAIL FOR INERTIA BLOCK
(Additional R/f shown below the anvil)

12.2 RCC Chamber

a) Construction shall be done in single pour to avoid any construction joint;
b) Clear cover: Clear cover on all inner sides and top of the chamber shall be minimum 50 mm. The cover at bottom, as well as outer sides of the chamber (in contact with the soil) shall be minimum 75 mm (as per provisions of IS 3370).
c) Where single pour is not feasible, construction joints shall be provided as designed construction joints with provision of water bar all along the length of the construction joints.
d) Necessary provisions shall be made to ensure protection of the VIS between foundation block and RCC Chamber against water, oil scales, etc., and
e) Air-gaps and spring elements provided for the purpose of damping vibrations shall be accessible in order to remove scales and enable inspection of springs and their replacement, if necessary.

SECTION 3

FOUNDATIONS FOR IMPACT MACHINES OTHER THAN HAMMER (FORGING AND STAMPING PRESS)

13 GENERAL DESIGN REQUIREMENTS FOR PRESS FOUNDATIONS

13.1 Mechanical/Forging Press

Forging presses, commonly classified as mechanical or hydraulic presses, are a group of forging machines used in impression die forging, cold forging, open die forging and seamless rolled ring forging. Energy released by the forging presses is slower than those for forge hammers. Both, hot and cold forging processes are used by these presses. Heated billet is kept over the bottom half of the die, which is fixed to the bed plate/anvil and the top die undergoes repeated up and down motion and presses the billet repeatedly to shape it up to final product. In the process, the billet is pressed/squeezed in mechanical forging press. Since there are no impacts involved in the process, the life of the die becomes longer. The process being mechanical forging, the production rate of the forging press is higher than that for a drop forging hammer. The press comprises of,

a) Flywheel, connected to a drive unit through belt or gear drive, supplies power for the forging process;
b) Ram that is connected to the upper half of the die and performs vertical motion guided by lubricated shafts;
c) Die that is designed to give the final shape of the forged component, is split into two halves, the top half moves up and down with the ram, whereas the bottom half is kept fixed by the bedplate/anvil; and
d) Bed plate/anvil that rigidly holds the bottom half of the die.

13.2 Press Foundation – System Constituents

13.2.1 Press support arrangement varies from manufacturer to manufacturer. It depends upon the type of the press, its forging power/capacity, the type, and size of the end product. Two types of frame arrangements, generally encountered in practice, are, (a) where frame is attached to bed plate/anvil; and (b) where frame is supported on the foundation. Size of bed plate/anvil of the press is relatively large.

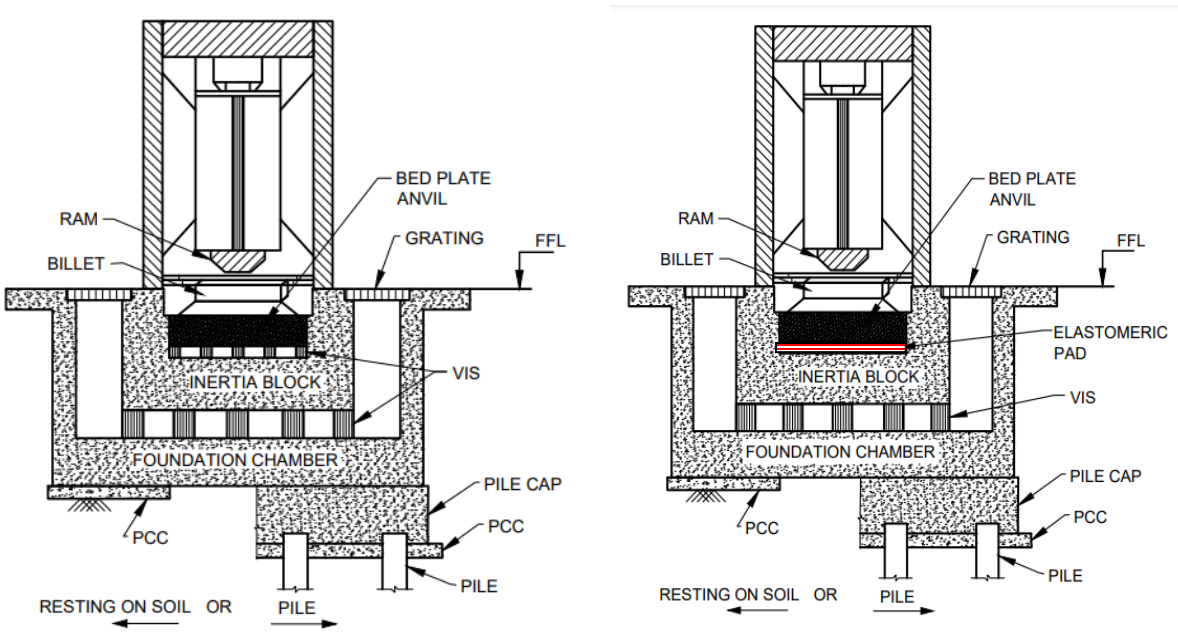
There is a wide variation in the press sizes that are currently being manufactured and are in use. Capacity variation ranges from 10 t to 60 000 t. With such a wide range in the forge capacity, the foundation arrangement and foundation sizes shall vary to a great extent. However, the design philosophy and design considerations remain the same irrespective of the press size.

In the forging operation, because of the high pulse loading, vibrations travel for a long distance. In view of the severity of the transmitted vibrations to other structures, inertia block is necessarily placed inside a RCC chamber that in turn is supported on soil/rock or group of piles. Hence, press foundation shall be provided with vibration isolation system (VIS) at two levels as shown in Fig 10 A.

a) VIS at base of anvil (between Anvil & Inertia Block); and
b) VIS at base of inertia block (between Inertia Block and RCC Chamber).

Wherever not feasible to provide VIS below Anvil, Elastomeric Pads shall be provided below Anvil to take the impact and prevent bouncing of anvil as well as preventing damage to the top surface of the concrete of the foundation. VIS shall be provided only at base of inertia block (between Inertia Block and RCC Chamber) as shown in Fig. 10 B.

Schematic foundation arrangement of a typical forge press is shown in Fig. 10.



10A ANVIL SUPPORTED ON INERTIA BLOCK THROUGH VIS, INERTIA BLOCK SUPPORTED ON RCC CHAMBER THROUGH VIS AND RCC CHAMBER SUPPORTED ON SOIL/ROCK OR GROUP OF PILES

10B ANVIL BOLTED TO INERTIA BLOCK THROUGH ELASTOMERIC PAD, INERTIA BLOCK SUPPORTED ON RCC CHAMBER THROUGH VIS AND RCC CHAMBER SUPPORTED ON SOIL/ROCK OR GROUP OF PILES

FIG. 10 TYPICAL FORGE PRESS FOUNDATION (INERTIA BLOCK) PLACED INSIDE RCC CHAMBER

13.2.2 *RCC Chamber*

RCC chamber shall be isolated from adjoining building/structures as well as from their foundations. The base level of RCC chamber shall be kept below the building/structure foundation level.

13.2.3 *Foundation Material*

RCC foundation block shall be provided with minimum concrete grade of M25 for both inertia block and RCC chamber. The materials shall comply with the requirements given in IS 2974 (Part1). RCC chamber shall be designed as uncracked section as per the provisions of IS 3370 (Part 1) and (Part 2).

13.2.4 In case piles are required to be provided, RCC chamber shall be placed on the top of the pile cap.

13.2.5 The bearing pressure on soil/permissible load on the heaviest loaded pile, under equivalent static loading, shall be restricted to 80 percent of the net allowable bearing capacity.

13.2.6 Foundation shall be dimensioned and designed in such a way that dynamic performance requirements, as specified by the manufacturer and codal provisions, are met.

13.2.7 The foundation shall be designed such that integrity of foundation is maintained under all operating conditions.

13.2.8 Selection of VIS underneath bed plate/anvil as well as that under inertia-block/foundation shall be such that the vibration amplitudes of anvil and the inertia block (foundation) are well within permissible limits and vibration amplitudes (transmitted vibrations) to adjoining structures are also well within permissible limits.

14 SYSTEM DATA

14.1 Press Data

In addition to general machine data as per **7** of 2974 (Part 1), the following data shall be obtained from the machine supplier/machine manufacturer/customer for design of press foundation:

a) Layout and outline drawing of the installation with details of anchor bolts and other embedded parts;
b) Load-time relationship of the pulse realized during the action of the forge press (*p versus t);*
c) Mass of machine, that is,
   1) Mass of the ram;
   2) Mass of upper die;
   3) Mass of frame (including masses of all mechanical components housed on the frame);
   4) Height and cross-section of steel columns/ bolsters;
   5) Frequency of repeated short pulses, that is, minimum time between two short pulses;
   6) Support arrangement of the frame with the anvil/ foundation;

7) Mass of the bed plate/ anvil;
8) Mass of lower die + SOW block;
9) Weight of material to be forged;
10) Level of anvil base with respect to finished floor level of shop floor; and
11) Allowable amplitudes at anvil.

14.2 Foundation Data

14.2.1 *Foundation Layout*

Layout and outline drawing of the installation with details of embedded parts showing anvil base plan and details of bolt sizes and bolt locations shall be obtained from the supplier. In case the frame is supported over the inertia block, its layout (including bolt sizes and bolt locations) shall be obtained from the supplier.

14.2.2 Dimensional details of cavity or depression to be provided in the foundation to accommodate anvil, shall be obtained from the customer/hammer supplier. The space all around the anvil shall be adequate for maintenance of isolation device provided below anvil and in no case, it shall be less than 600 mm or as recommended by the manufacturer.

14.2.3 *Material Properties and Permissible Stresses*

Material properties and permissible stresses in the concrete and reinforcement bars shall be in accordance with the provisions given in **8** of IS 2974 (Part 1). Permissible stresses in the VIS shall be in accordance with the properties of selected isolation device. This shall be obtained from the supplier of isolation pads.

14.3 Geotechnical Data

The following soil/pile data, required for design of foundation, shall be obtained.

a) Soil profile and soil characteristics up to a depth at least 3 times the mean plan dimensions of the foundation (which can be taken as the square root of the expected area) or hard strata, whichever is less.
b) Soil investigation to the extent necessary in accordance with IS 1892 and for determination of dynamic properties of the soil in accordance with IS 5249.
c) The relative position of the water table below ground at different times of the year.
d) The soil dynamic parameters or pile design parameters including vertical and lateral stiffness, as well as total permissible settlement, required for the analysis of foundation shall be considered asper of IS 2974 (Part 1).

14.4 Vibration Isolation System

14.4.1 Elastomeric Pads: Suitable Pads are provided between Anvil and Inertia Block to resist Impact and prevent bouncing of anvil as well as preventing damage to the top surface of the concrete of the foundation as shown in Fig. 10B

a) Material;
b) Elastic modulus;
c) Variation of elastic modulus with deflection;
d) Maximum allowable deformation/deflection under the load; and
e) Allowable stress intensity.

14.4.2 *Spring-Damper Unit*

a) Maximum allowable spring deflections for normal working as well as for extreme conditions and also for static loads as well as for dynamic loads;
b) Stiffness of springs;
c) Damping characteristics of damper unit:
d) Base plate size, bolt size and bolt locations;
e) Top plate size, bolt size and bolt locations; and
f) Height of the unit.

15 PERMISSIBLE AMPLITUDES

15.1 The permissible amplitudes shall be as recommended by the press manufacturer. In the absence of any such data from the manufacturer, permissible amplitudes shall be as follows:

Sl No.	*Component*	*Press Force Capacity*		
		Up to 100 t	100 to 1 000 t	More than 1 000 t
(1)	(2)	(3)	(4)	(5)
i)	For inertia block (δ_b)	1.0 mm	1.5 mm	2.5 mm
ii)	For bed plate/anvil (δ_a)	1.2 mm	2.0 mm	3.0 to 4.0 mm

15.2 Wherever any important structure exists near the foundation, the foundation should be so designed such that the velocity of the vibrations at these structures does not exceed 2.0 mm/s.

16 DESIGN CRITERIA

16.1 Design Considerations and Requirements

16.1.1 *Pulse Loading*

In the forging process, both short duration impulse loading as well as long duration pulse loading are applied by the forge press. Short duration impulse loading is applied at repeated interval. Amplitudes of the anvil, inertia block and the RCC chamber depend upon the stiffness and damping provided to the system.

Typical impulsive loads used by forge presses are, (a) a rectangular pulse; (b) a triangular pulse; (c) a half sine pulse, etc. Pulse duration depends upon the forging process. These include both short duration pulses as well as long duration pulses. Pulse loading is shown in Fig. 11.

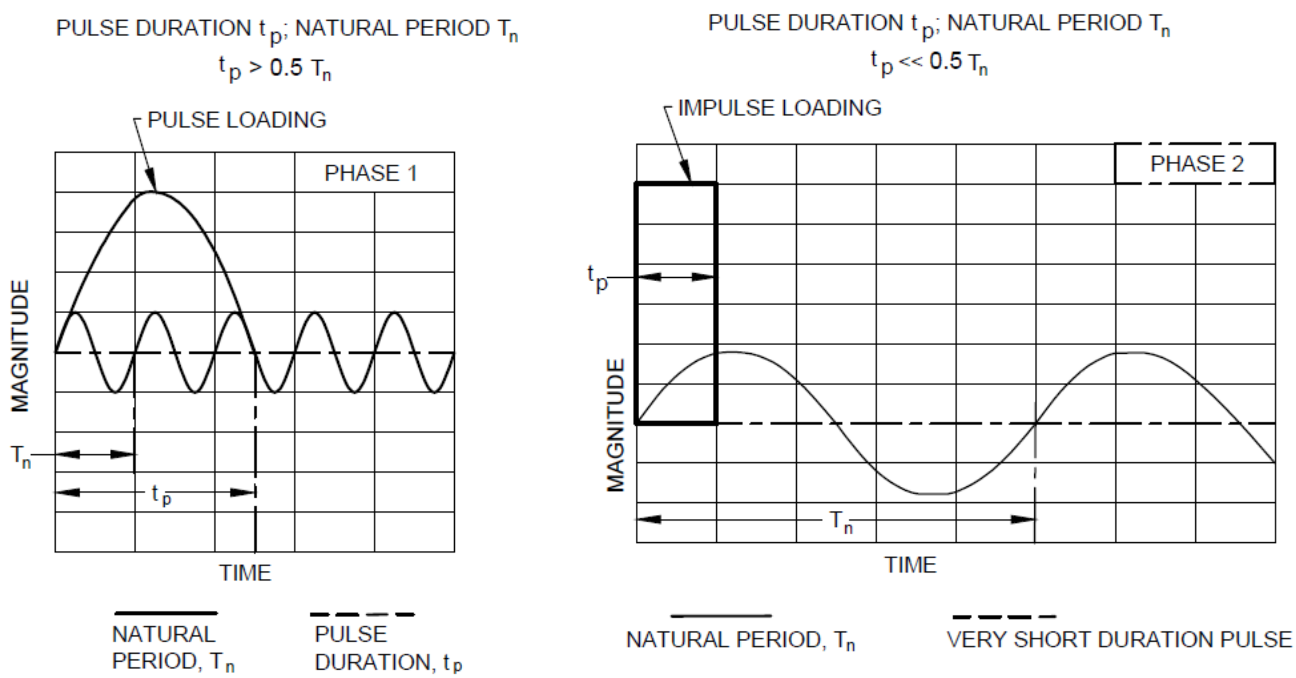


FIG. 11 PULSE AND IMPULSE LOADING WITH RESPECT TO NATURAL PERIOD

There are two phases of vibration response, (a) forced vibration and (b) free vibration response. For long duration pulse, the maximum response occurs in the first phase, that is, during forced vibration phase, whereas for short duration impulse, maximum amplitude occurs in the second phase, that is, during free vibration phase.

For a foundation system subjected to a pulse loading, maximum response depends upon ratio of pulse duration (t_p) to natural time period of the foundation (T_n).

a) For $t_p > 0.5\ T_n$, maximum response occurs in forced vibration phase, that is, phase 1 (*see* Fig. 12) within the pulse duration.

Maximum system response = $y_{max} = \frac{F_p}{k}\mu$

b) For $t_p < 0.5\ T_n$, maximum response occurs in free vibration phase, that is, phase 2 (after the pulse duration). Impulse imparts initial velocity to the system and system vibrates.

Maximum system response = $y_{max} = \frac{F_p \times t_p}{m\ \omega_n}$

Response magnification for pulse duration to natural period ratios is shown in Fig. 12.

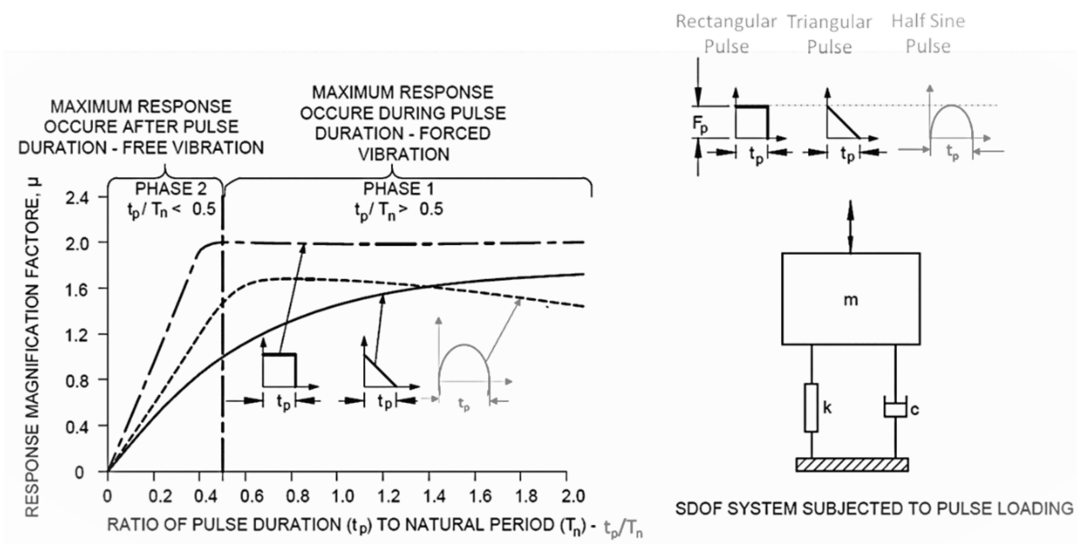


FIG. 12 SDOF SYSTEM – RESPONSE MAGNIFICATION FACTOR *VERSUS* RATIO OF PULSE DURATION TO NATURAL PERIOD

where,

F_p = pulse force magnitude;
t_p = pulse duration;
k = system stiffness;
c = system damping;
ζ = system damping constant (damping ratio);
m = mass of the system;
ω_n = undamped natural frequency of the system, $\omega_n = \sqrt{\frac{k}{m}}$;

$T_n = \frac{2\pi}{\omega_n}$ = Natural Time period of the system

μ = response magnification factor corresponding to $\frac{t_p}{T_n}$ (obtained from Fig. 12).

16.1.2 *Foundation*

The press foundation shall satisfy the requirements given in **16.1.2.1** to **16.1.3.4**.

16.1.2.1 *Inertia block*

Mass of the inertia block shall be at least 3 times the sum of the mass of the anvil and mass of the frame.

16.1.2.2 *RCC chamber*

There is no minimum mass criterion applicable to RCC chamber. However, the following considerations shall be adhered to while designing RCC chamber:

a) RCC chamber shall be designed as uncracked section as per the provisions of IS 3370 (Part 1) and (Part 2) to prevent entry of ground water into the chamber so as to avoid damage to Vibration Isolation System.

b) Base thickness of RCC chamber shall not be less than 800 mm. It shall also be ensured that it is safe both in punching shear and bending under all operational conditions including jacking loads required for VIS during initial placing or/repair and maintenance of isolators. It shall be uniform all over the base area. For foundations resting on stiff clays or compact sandy deposits, the thickness of base of the chamber shall be minimum 800 mm.

c) Side walls shall be designed for external soil pressure. Its thickness shall not be less than 300 mm. Natural frequency of the walls (free standing) without any influence of soil shall be 50 percent away from the repeated short impulse frequency.

16.1.2.3 *Centre of mass*

Foundation shall be sized such that the combined centre of gravity (centre of mass) of the anvil, the press, the foundation (inertia block) and the RCC chamber coincides with the centre line of the ram.

16.1.2.4 *Eccentricity*

Centre of stiffness of vibration isolation system provided under anvil and under the foundation bock, as well as centre of stiffness of soil, shall lie in one vertical line.

16.1.2.5 Anvil eccentricity shall preferably be zero and in no case, it shall exceed 2 percent.

16.1.2.6 Inertia block eccentricity shall preferably be zero and in no case, it shall exceed 2 percent.

16.1.2.7 RCC chamber eccentricity shall preferably be zero and in no case, it shall exceed 5 percent. Piles provided below RCC chamber shall be placed such that centre of pile stiffness shall match with centre of gravity of chamber base area.

16.1.3 *Vibration Parameters*

16.1.3.1 *Frequency separation*

For press foundations subjected to repeated impulse loading, the vertical natural frequency of the foundation system shall be 100 percent away from the frequency of repeated impulse loading. Wherever it is not possible to get the desired frequency separation, the criteria that the amplitude of the anvil and the foundation are within permissible limits, shall be the governing criteria.

16.1.3.2 *Anvil and foundation amplitudes*

VIS parameters shall be selected such that the amplitudes of the anvil and the inertia block are within specified permissible limits.

16.1.3.3 *VIS parameters* (*stiffness* and *damping*)

VIS parameters shall be selected such that the anvil and the foundation (inertia block and RCC chamber), when set into vibrating mode after first short pulse loading shall return to position at rest before the second impulse is applied. This is necessary for achieving good forge quality.

16.1.3.4 *Vibration transmission to adjoining structures/ foundations*

No part of the press foundation shall be allowed to have a rigid contact with parts of adjoining structures. For best isolation, a gap is recommended between parts of the press foundation and adjacent structures. Overhanging cantilever supports for walkways shall be avoided as far as possible. Where unavoidable, they shall be designed to ensure adequate rigidity against vibrations.

17 DESIGN OF FOUNDATION

Foundation shall be designed to comply with the design philosophy and design requirements as per **16**.

17.1 Machine Parameters

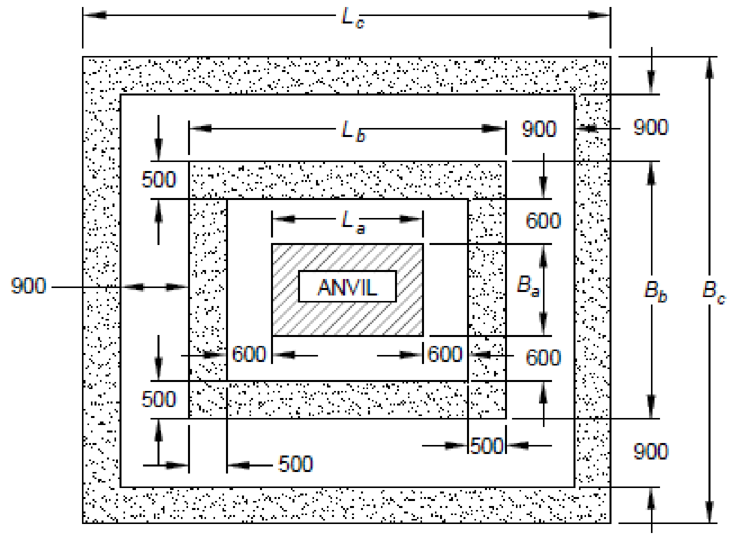
The machine parameters that govern the design are given in Table 2. The units and symbols for these parameters shall be as per **4**.

Table 2 Machine Parameters for Design of Press Foundation
(*Clause* 17.1)

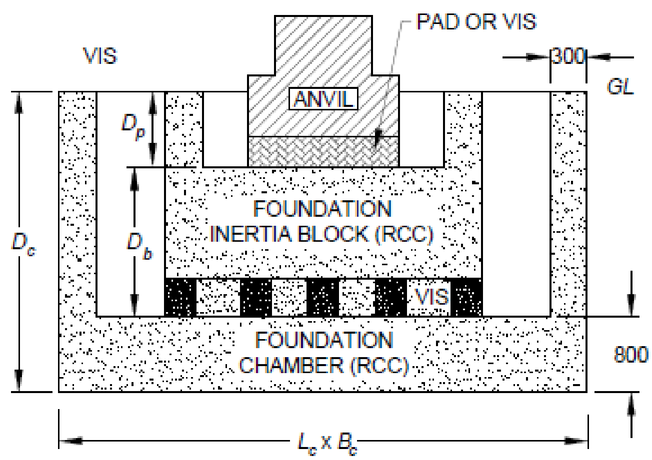
Sl No. (1)	Machine Data (2)	Description (3)	
i)	Ram	Mass of ram	
		Mass of upper die	
		Short impulse	Force magnitude Pulse duration (time) Frequency of repeated (pulse/per min) Time interval between two impulses
		Pulse	Force Magnitude Pulse duration (Time)
ii)	Bed plate/anvil	Mass of bed plate/anvil Mass of lower die + SOW block Base length Base width Base area	
iii)	Permissible amplitudes	Anvil Foundation (inertia block), and RCC chamber	

17.2 Foundation Sizing

Foundation sizing shall be done as per design keeping in view the requirements of the customer and the machine as dictated by the manufacturer. Typical foundation details are shown in Fig. 13. Dimensions and clearances, as shown are the minimum. Actual dimensions shall be as per design (dynamic analysis and strength design).



PLAN VIEW



SECTIONAL VIEW

All Dimensions are in mm

NOTES

1 Indicated dimensions as shown are minimum.
2 For description of various symbols used and their units, refer **4**.

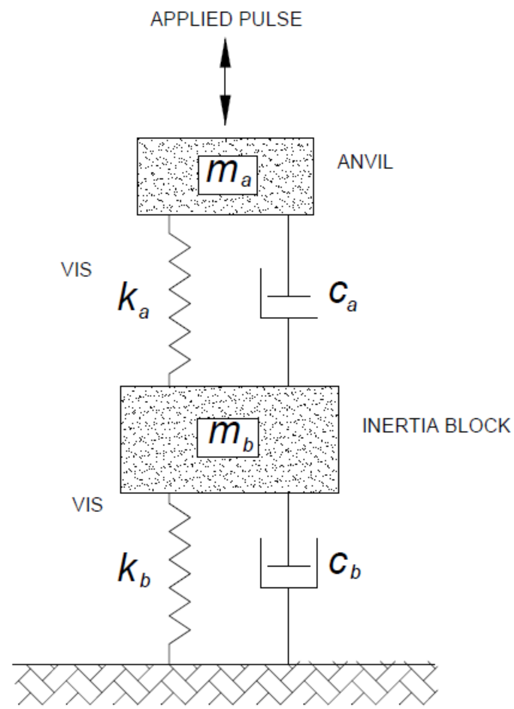
FIG. 13 TYPICAL PRESS FOUNDATION ARRANGEMENT - ANVIL PLACED OVER INERTIA BLOCK THROUGH VIS AND INERTIA BLOCK PLACED INSIDE RCC CHAMBER THROUGH VIS

17.3 Vibration Analysis

17.3.1 *VIS between* (a) *Anvil and Inertia Block*; and (b) *Inertia Block and RCC Chamber*

Anvil is supported on inertia block through VIS; inertia block is supported on RCC chamber through VIS and RCC chamber is supported on ground (soil/rock or pile) as shown in Fig. 10A with pulse applied to the anvil.

Mathematical model (2 DOF system), considering anvil and inertia block with pulse applied to anvil is shown in Fig. 14. RCC Chamber is considered fixed, that is, the stiffness and damping of soil/pile system are not considered in the dynamic analysis.



Key

m_a = Mass of anvil + lower die + SOW block + frame, if attached to anvil; in t;

m_b = Mass of inertia block + frame, if not attached to anvil but attached to the foundation; in t;

k_a = Stiffness of VIS unit provided under anvil

k_b = Stiffness of VIS unit provided under inertia block

c_a = Damping of VIS unit provided under anvil

c_b = Damping of VIS unit provided under inertia block

FIG. 14 MATHEMATICAL MODEL OF FOUNDATIONS AS PER FIG. 10A

a) *Pulse Loading:*

F_p = Force applied (pulse force);

t_p = Pulse duration (of applied force F_p);

For $t_p > 0.5\ T_n$, response occurs in forced vibration phase, that is, phase 1 (within the pulse duration)

$$\omega_{n1}^2 = \frac{1}{2}\left\{\left(\omega_a^2(1+\alpha)+\omega_b^2\right) - \sqrt{\left(\omega_a^2(1+\alpha)+\omega_b^2\right)^2 - 4\left(\omega_b^2\omega_a^2\right)}\right\}$$

$$\omega_{n2}^2 = \frac{1}{2}\left\{\left(\omega_a^2(1+\alpha)+\omega_{Lb}^2\right) + \sqrt{\left(\omega_a^2(1+\alpha)+\omega_b^2\right)^2 - 4\left(\omega_b^2\omega_a^2\right)}\right\}$$

where,

$\omega_a = \sqrt{\frac{k_a}{m_a}}$; Limiting natural frequency of Anvil

$\omega_b = \sqrt{\frac{k_b}{m_b}}$; Limiting natural frequency of Inertia Block, and

$\alpha = \frac{m_a}{m_b}$; Mass ratio

β = Frequency ratio [= Excitation frequency/Natural frequency = ω_p/ω_n = $T_n/(2t_p)$].

where,

ω_p = Excitation frequency (frequency of pulse) = (π/t_p);

ω_n = System natural frequency (natural frequency of anvil);

T_n = System (Anvil) time period, in sec = ($2\pi/\omega_n$); and

t_p = Pulse duration.

Maximum Anvil Response = $y_{a\_max} = \frac{F_p}{k_a}\mu$

where,

μ = response magnification factor corresponding to $\frac{t_p}{T_n}$ (obtained from Fig. 12); and

T_n = time period corresponding to anvil's natural frequency.

Maximum Block (Inertia block) Response = $y_{b\_max} = \frac{F_p}{k_b}\mu$

where,

μ = response magnification factor corresponding to $\frac{t_p}{T_n}$ (obtained from Fig. 12) ; and

T_n = time period corresponding to block's natural frequency

b) *Impulse Loading*

For $t_p < 0.5\ T_n$, response occurs in free vibration phase, that is, phase 2 (after the pulse duration). Impulse repeats at frequency N blows per minute. Time between two successive impulses, $\tau = \frac{60}{N}\ s$

Initial velocity imparted to anvil, $v_a = \frac{F_p \times t_p}{m_a}$

Anvil amplitude, $y_a(t) = e^{-\omega_a \zeta_a t}\left(\frac{v_a}{\omega_{a\_d}}\ sin\ \omega_{a\_d}\ t\right)$

Maximum anvil amplitude = $y_{a\_max} = \frac{v_a}{\omega_{a\_d}}$

$$\omega_a = \sqrt{\frac{k_a}{m_a}} \quad ; \quad \omega_{a\_d} = \omega_a \sqrt{(1 - \zeta_a^2)};$$

where,

ω_a *and* ω_{a_d} are undamped and damped frequencies of anvil, respectively; and
ζ_a is damping constant of VIS provided below anvil.

Inertia Block amplitude, $y_b(t) = e^{-\omega_b \zeta_b t}\left(\frac{v_a}{\omega_{b\_d}}\ sin\ \omega_{b\_d}\ t\right)$

Maximum Inertia Block amplitude = $y_{b\_max} = \frac{v_a}{\omega_{b\_d}}$

$$\omega_b = \sqrt{\frac{k_b}{m_b}} \quad ; \quad \omega_{b\_d} = \omega_b \sqrt{(1 - \zeta_b^2)};$$

where,

ω_b *and* ω_{b_d} are undamped and damped frequencies of block, respectively; and
ζ_b is damping constant of VIS provided below the block.

VIS parameters to be selected such that the anvil, after impulse loading, resumes position at rest before the 2nd impulse strikes. Amplitude decay with time is shown in Fig. 15.

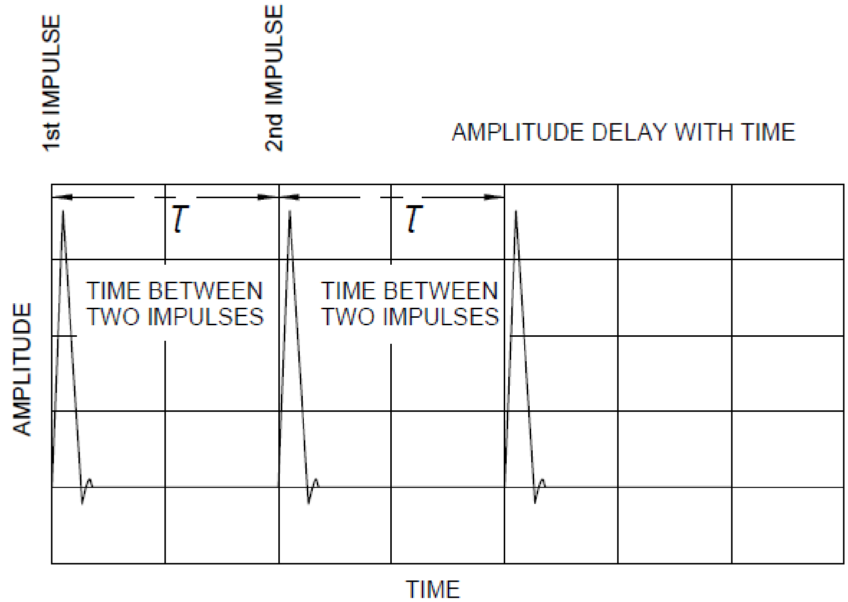


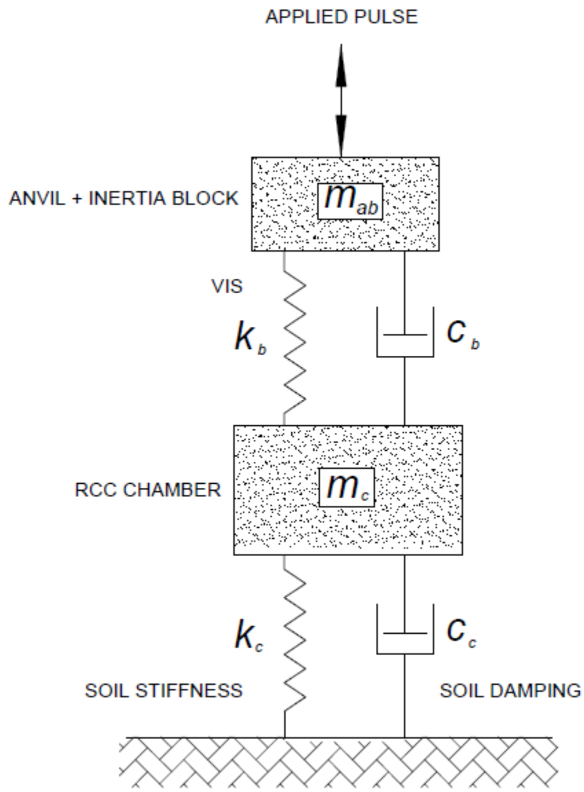
FIG. 15 AMPLITUDE DECAY FOR SUCCESSIVE IMPULSES

17.3.2 *Anvil Rigidly Connected to Inertia Block*

VIS provided between inertia block and RCC chamber and RCC chamber supported on ground (*soil/rock or pile*):

Anvil is rigidly connected to inertia block through elastomeric pad and inertia block is supported on RCC chamber through VIS and RCC chamber is supported on ground (soil/rock or pile) as shown in Fig. 10B.Pulse applied to the anvil.

Mathematical model as 2 DOF system, considering inertia block and RCC Chamber, with pulse load applied to the inertia block (through anvil), is shown in Fig. 16.



m_{ab} = Mass of inertia block + anvil + lower die + SOW block + frame, in t;
m_c = Mass of RCC Chamber

k_b = Stiffness of VIS unit provided under Inertia Block

k_c = Stiffness of Soil/ Pile system

c_b = Damping of VIS unit provided under inertia block

c_c = Damping associated with soil/rock or group of piles, in kN s/m;

FIG. 16 MATHEMATICAL MODEL OF FOUNDATIONS AS PER FIG. 10 B.

a) *Pulse Loading*

F_p = Force applied (pulse force);
t_p= Pulse duration;

For $t_p > 0.5\ T_n$, response occurs in forced vibration phase i.e., phase 1 (within the pulse duration).

$$\omega_{n1}^2 = \frac{1}{2}\left\{\left(\omega_b^2(1+\alpha)+\omega_c^2\right) - \sqrt{\left(\omega_b^2(1+\alpha)+\omega_c^2\right)^2 - 4\left(\omega_b^2\omega_c^2\right)}\right\}$$

$$\omega_{n2}^2 = \frac{1}{2}\left\{\left(\omega_b^2(1+\alpha)+\omega_c^2\right)+\sqrt{\left(\omega_b^2(1+\alpha)+\omega_c^2\right)^2-4\left(\omega_b^2\omega_c^2\right)}\right\}$$

where,

$$\omega_b = \sqrt{\frac{k_b}{m_{ab}}}; \quad \omega_c = \sqrt{\frac{k_c}{m_c}}; \quad \alpha = \frac{m_{ab}}{m_c}$$

Amplitude of Inertia Block (Anvil bolted to Inertia Block):

Pulse Duration = t_p

ω_p = Excitation frequency (frequency of pulse) = (π/t_p);
ω_n = System natural frequency (Natural frequency corresponding to that of inertia block);
T_n = System (Anvil + Inertia Block) time period, in sec = ($2\pi/\omega_n$).

β = Frequency ratio [= Excitation frequency/Natural frequency = ω_p/ω_n= $T_n/(2t_p)$].

Maximum amplitude of inertia block,

$$y_{b\_max} = \frac{F_p}{k_b}\mu$$

where,
μ = response magnification factor corresponding to $\frac{t_p}{T_n}$ (obtained from Fig. 12); and
T_n = time period corresponding to block natural frequency.

Amplitude of RCC Chamber:

ω_n = System natural frequency (Natural frequency corresponding to that of RCC Chamber);
T_n = System (RCC Chamber) time period, in sec = ($2\pi/\omega_n$); and

β = Frequency ratio [= Excitation frequency/Natural frequency = ω_p/ω_n= $T_n/(2t_p)$].

Maximum Amplitude of RCC chamber, $y_{c\_max} = \frac{F_p}{k_c}\mu$
where,
μ = response magnification factor corresponding to $\frac{t_p}{T_n}$ (obtained from Fig. 12); and
T_n = time period corresponding to chamber natural frequency.

b) *Impulse Loading*

For $t_p < 0.5\ T_n$, response occurs in free vibration phase, that is, phase 2 (after the pulse duration). Impulse repeats at frequency N blows per minute. Time between two successive impulses, $\tau = \frac{60}{N}\ s$

Initial velocity imparted to inertia block, $v_b = \frac{F_p \times t_p}{m_{ab}}$

Amplitude of Inertia Block (Anvil bolted to Inertia Block):

Inertia block amplitude, $y_{ab}(t) = e^{-\omega_b \zeta_b t}\left(\frac{v_b}{\omega_{b\_d}}\ sin\,\omega_{b\_d}\,t\right)$

Maximum block amplitude = $y_{ab\_max} = \frac{v_b}{\omega_{b\_d}}$

$$\omega_{\mathrm{b}} = \sqrt{\frac{k_{\mathrm{b}}}{m_{\mathrm{ab}}}};\qquad \omega_{\mathrm{b\_d}} = \omega_{\mathrm{b}}\sqrt{(1-\zeta_b^2)}$$

where,

ω_{b} *and* $\omega_{\mathrm{b\_d}}$ are undamped and damped Limiting frequencies of inertia block, respectively; and

ζ_{b} is damping constant of VIS provided below inertia block.

Amplitude of RCC Chamber

Amplitude (dynamic displacement response) of RCC chamber of mass m_c is given by,

RCC chamber amplitude, $y_c(t) = e^{-\omega_c \zeta_c t}\left(\frac{v_b}{\omega_{c\_d}}\ sin\,\omega_{c\_d}\,t\right)$

Maximum Amplitude of RCC Chamber = $y_{c\_max} = \frac{v_b}{\omega_{c\_d}}$

where,

$$\omega_{\mathrm{c}} = \sqrt{\frac{k_{\mathrm{c}}}{m_{\mathrm{c}}}};\qquad \omega_{\mathrm{c\_d}} = \omega_{\mathrm{c}}\sqrt{(1-\zeta_c^2)}$$

where,

ω_{c} *and* $\omega_{\mathrm{c\_d}}$ are undamped and damped Limiting frequencies of RCC Chamber respectively; and

ζ_{c} is damping constant of Soil/ Pile system below RCC Chamber.

VIS parameters shall be selected such that the inertia block, after impulse loading, resumes position at rest before the 2nd impulse strikes. Amplitude decay with time is same as shown in Fig. 15.

18 STRENGTH DESIGN

Design criteria for strength design of press foundation shall be the same as that of hammer foundation as given in **11**.

19 CONSTRUCTION

Construction aspects of press foundation shall be the same as that of hammer foundation as given in **12**.