भारतीय मानक ब्यूरो
BUREAU OF INDIAN STANDARDS

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व्यापक परिचालन मसौदे

हमारा संदर्भ : सीईडी 43 /टी–61, टी-62 & टी-63 **17 अगस्त 2020**

तकनीकी समिति : मृदा एवं नींव इंजीनियरी विषय समिति, सीईडी 43

प्राप्तकर्ता :

1 सिविल इंजीनियरी विभाग परिषद् के रूचि रखने वाले सदस्य

2 मृदा एवं नींव इंजीनियरी विषय समिति, सीईडी 43 एवं आईएस 2974 (भाग 1 से 5) के पुनरीक्षण के लिए मसौदे तैयार करने के लिए तदर्थ पैनल, सीईडी 43:P8 के सभी सदस्य

3 रूचि रखने वाले अन्य निकाय

महोदय/महोदया,

निम्नलिखित मसौदे संलग्न है :

प्रलेख संख्या	शीर्षक
सीईडी 43 (12408)WC	**मशीनों की नींव का डिज़ाइन एवं निर्माण - रीति संहिता: भाग 1 सामान्य प्रावधान का भारतीय मानक मसौदा [IS 2974 (भाग 1 से 5) का पुनरीक्षण] (आई सी एस संख्या: 93.020)**
सीईडी 43 (13116)WC	**मशीनों की नींव का डिज़ाइन एवं निर्माण - रीति संहिता: भाग 2 ब्लॉक नींव का भारतीय मानक मसौदा [IS 2974 (भाग 1 से 5) का पुनरीक्षण] (आई सी एस संख्या: 93.020)**
सीईडी 43 (13264)WC	**मशीनों की नींव का डिज़ाइन एवं निर्माण - रीति संहिता: भाग 3 फ्रेम नींव का भारतीय मानक मसौदा [IS 2974 (भाग 1 से 5) का पुनरीक्षण] (आई सी एस संख्या: 93.020)**

कृपया इन मानक के मसौदों का अवलोकन करें और अपनी सम्मतियाँ यह बताते हुए भेजें कि यदि ये मानक के रूप में प्रकाशित हो तो इन पर अमल करने में आपके व्यवसाय अथवा कारोबार में क्या कठिनाइयाँ आ सकती हैं ।

सम्मतियाँ भेजने की अंतिम तिथि: **15 अक्टूबर 2020**.

सम्मति यदि कोई हो तो कृपया **ईमेल आईडी, madhurima@bis.gov.in** पर संलग्न फोर्मेट में भेजें।

यदि कोई सम्मति प्राप्त नहीं होती है अथवा सम्मति में केवल भाषा संबंधी त्रुटि हुई तो उपरोक्त प्रलेखों को यथावत अंतिम रूप दिया जाएगा । यदि सम्मति तकनीकी प्रकृति की हुई तो विषय समिति के अध्यक्ष के परामर्श से अथवा उनकी इच्छा पर आगे की कार्यवाही के लिए विषय समिति को भेजे जाने के बाद प्रलेखों को अंतिम रूप दे दिया जाएगा ।

ये प्रलेख भारतीय मानक ब्यूरो की वैबसाइट **www.bis.gov.in** पर भी उपलब्ध है

धन्यवाद ।

भवदीय,

(संजय पंत)

संलग्न : उपरिलखित **प्रमुख (सिविल इंजीनियरी)**

भारतीय मानक ब्यूरो
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DRAFTS IN WIDE CIRCULATION

DOCUMENT DESPATCH ADVICE

Reference	Date
CED 43/T- 61, T- 62 &T- 63	17 August 2020

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 the Adhoc Panel for Preparation of Drafts for Revision of IS 2974 (Parts 1 to 5), CED 43:P8
3. All other interests

Dear Sir/Madam,

Please find enclosed the following drafts:

Doc No.	Title
CED 43 (12408)WC	**Draft Indian Standard Design and Construction of Machine Foundations — Code of Practice: Part 1 General Provisions [Revision of IS 2974 (Parts 1 to 5)]** **(ICS No. 93.020)**
CED 43 (13116)WC	**Draft Indian Standard Design and Construction of Machine Foundations — Code of Practice: Part 2 Block Foundations [Revision of IS 2974 (Parts 1 to 5)]** **(ICS No. 93.020)**
CED 43 (13264)WC	**Draft Indian Standard Design and Construction of Machine Foundations — Code of Practice: Part 3 Frame Foundations [Revision of IS 2974 (Parts 1 to 5)]** **(ICS No. 93.020)**

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

Last Date for comments: 15 October 2020.

Comments if any, may please be made in the format as given overleaf and mailed to the email id, **madhurima@bis.gov.in**.

In case no comments are received or comments received are of editorial nature, you will kindly permit us to presume your approval for the above document as finalized. However, in case comments of technical 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 documents are also hosted on BIS website, **www.bis.gov.in**.

Thanking you,

Yours faithfully,

(Sanjay Pant)
Head (Civil Engg.)

Encl: as above

FORMAT FOR SENDING COMMENTS ON BIS DOCUMENTS

(Please use A4 size sheet of paper only and type within fields indicated. Comments on each clause/subclause/table/fig etc. be started on a fresh box. Information in column 5 should include reasons for the comments, and those in column 4 should include suggestions for modified wording of the clauses when the existing text is found not acceptable. Adherence to this format facilitates Secretariat's work) {Please e-mail your comments to **madhurima@bis.gov.in** }

DOC. NO.	**Doc: CED 43 (12408)**
TITLE	**Draft Indian Standard Design and Construction of Machine Foundatio — Code of Practice: Part 1 General Provisions [Revision of IS 2974 (Parts 1 to 5)] (ICS No. 93.020)**
LAST DATE OF COMMENTS	**15 October 2020**
NAME OF THE COMMENTATOR/ ORGANIZATION	______________________________

Sl. No. (1)	**Clause/Sub-clause/Para No. (2)**	**Comments/Suggestions (3)**	**Modified Wording of the Clause (4)**	**Reasons/ Justifications for the Proposed Changes (5)**

Doc: CED 43 (12408)
August 2020

BUREAU OF INDIAN STANDARDS

DRAFT FOR COMMENTS ONLY

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Draft Indian Standard

DESIGN AND CONSTRUCTION OF MACHINE FOUNDATIONS ─ CODE OF PRACTICE

PART 1 GENERAL PROVISIONS

[*Revision of* IS 2974 (Parts 1 to 5)]

ICS 93.020

Soil and Foundation Engineering Sectional Committee, CED 43	Last date for Comment: **15 October 2020**

FOREWORD

(*Formal clauses to be added later*)

Installation of heavy machinery has assumed increased importance in the wake of the vast programme of industrial development in the country. The overall foundation design of such machines shall have to be in accordance with the dynamic requirements of machine, and foundation and soil, besides special requirements of the machine as laid down by machine manufacturer. It was 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 Code were published and revised as per the details given below:

	Various Parts	*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	1967	1975 and

	(Medium and high frequency)		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	1970 and then in 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 have to 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 re-look and suggests host of changes to be incorporated in the codes 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 has been 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 various Parts of IS 2974 to meet the current demand of satisfactory performance of machines with no room for failure. While restructuring these, it was decided to address the code foundation-wise rather than machine-wise except foundations for impact and impulsive load machines, that is, hammers and presses, where it necessarily has to be machine-wise. This would also avoid any overlapping of the provisions between different Parts of the standard for similar foundation types and bring clarity in design and construction of the foundation. Accordingly, the revised standard is being brought out in following eight parts, first five being brought out in the first phase and remaining three parts in subsequent phase:

Part 1 General provisions
Part 2 Block foundations
Part 3 Frame foundations Part 4 Foundations for hammers and presses
Part 5 Foundations for machines (excluding hammers and presses) supported on vibration isolation system
Part 6 Machines supported on super structures
Part 7 Machines supported on strip footings
Part 8 Machines supported on common mat/raft.

This standard (Part 1) deals with general provisions applicable to all types of machine foundations, such as general terminology, machine types, foundation types, load data, general load combinations, soil dynamics investigation outlines, geotechnical data, machine parameters/data, general construction requirements, observations after commissioning of the equipment, permissible amplitude of vibrations, etc.

The provisions in Parts 2 to 8 are to be read in conjunction with the general provisions laid down in Part 1.

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 must be provided for, when making the foundation plans and all the details should be well worked out, before going ahead with the design.

In the preparation of this standard, 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 of this 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 2:1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Doc: CED 43 (12408)
August 2020

BUREAU OF INDIAN STANDARDS

DRAFT FOR COMMENTS ONLY

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Draft Indian Standard

DESIGN AND CONSTRUCTION OF MACHINE FOUNDATIONS — CODE OF PRACTICE

PART 1 GENERAL PROVISIONS

[*Revision of* IS 2974 (Parts 1 to 5)]

ICS 93.020

Soil and Foundation Engineering Sectional Committee, CED 43	Last date for Comment: **15 October 2020**

1 SCOPE

1.1 This standard (Part 1) deals with the design criteria and construction of foundations and structures supporting variety of rotary, reciprocating, impact and other machines associated with the following industries:

a) Power plants;
b) Process industries;
c) Petroleum, fertilizers and petro-chemical industries;
d) Steel, copper, zinc and aluminium plants;
e) Pharmaceutical plants;
f) Cement industry;
g) Automobile industry;
h) Sugar and alcohol industries;
j) Glass and ceramic industries;
k) Textile industry;
m) Foundries;
n) Electrical and electronic industries;
p) Consumer product industries;
q) Structures for sewage and water treatment plants and pump houses;
r) Leather industry;
s) Telephone exchanges;
t) Water and waste water treatment facilities; and
u) Paper plants.

1.2 This standard shall be considered applicable to all industries unless exclusively mentioned otherwise.

2 REFERENCES

The Indian Standards given below 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.

IS No.	*Title*
IS 432 (Part 1):1982	Specification for mild steel and medium tensile steel bars and hard-drawn steel wire for concrete reinforcement: Part 1 Mild steel and medium tensile steel bars (*third revision*)
IS 456:2000	plain and reinforced concrete — Code of practice (*fourth revision*)
IS 800:2007	General construction in steel — Code of practice (*third revision*)
IS 1786:2008	High strength deformed steel bars and wires for concrete reinforcement — Specification (*fourth revision*)
IS 1892:1979	Code of practice for subsurface investigation for foundations (*first revision*)
IS 1893	Criteria for earthquake resistant design of structures
(Part 1):2016	Part 1 General provisions and buildings (*sixth revision*)
(Part 4):2015	Part 4 Industrial structures including stack-like structures (*first revision*)
IS 2062:2011	Hot rolled medium and high tensile structural steel — Specification (*seventh revision*)
IS 2911 (Parts 1 to 4):2010	Design and construction of pile foundations — Code of practice
IS 2974	Design and construction of machine foundations — Code of practice
Part 2:****	Part 2 Block foundations (*under preparation*)
Part 3:****	Part 3 Frame foundations (*under preparation*)
Part 4:****	Part 4 Foundations for hammers and presses (*under preparation*)
Part 5:****	Part 5 Foundations on vibration isolation system (*under preparation*)
IS 4926:2003	Ready-mixed concrete —Code of practice (*second revision*)
IS 5249:1992	Determination of dynamic properties of soil —Method of test (*second revision*)
IS 7861	Code of practice for extreme weather concreting
Part I:1975	Part I Recommended practice for hot weather concreting
Part II:1981	Part II Recommended practice for cold weather concreting
IS 9716:1981	Guide for lateral dynamic load test on piles
IS/ISO 21940-11:2016	Mechanical vibration – Rotor balancing: Part 11 Procedures and tolerances for rotors with rigid behaviour

Part 1:2003	Part 1 Specification and verification of balance tolerances
Part 2:1997	Part 2 Balance errors
IS/ISO 11342:1998	Mechanical vibration – Methods and criteria for the mechanical balancing of flexible rotors
IS/ISO 20816-1:2016	Mechanical vibration – Measurement and evaluation of machine vibration - Part 1: General guidelines
ISO 20816-2:2017	Mechanical vibration – Measurement and evaluation of machine vibration - Part 2: Land-based gas turbines, steam turbines and generators in excess of 40 MW, with fluid-film bearings and rated speeds of 1 500 r/min, 1 800 r/min, 3 000 r/min and 3 600 r/min
IS 14817(Part 3): 2017/ISO 10816-3: 2009	Mechanical vibration – Evaluation of machine vibration by measurements on non-rotating parts - Part 3: Industrial machines with nominal power above 15 kW and nominal speeds between 120 r/min and 15 000 r/min when measured in-situ (*first revision*)
ISO 20816-4:2018	Mechanical vibration – Measurement and evaluation of machine vibration - Part 4: Gas turbines in excess of 3 MW, with fluid-film bearings
ISO 20816-5:2018	Mechanical vibration – Measurement and evaluation of machine vibration - Part 5: Machine sets in hydraulic power generating and pump-storage plants
IS 14817(Part 6):2004/ ISO 10816-6:1995	Mechanical vibration – Evaluation of machine vibration by measurements on non-rotating parts – Part 6: Reciprocating machines with power rating above 100 kW
ISO 10816-7:2009	Mechanical vibration – Evaluation of machine vibration by measurements on non-rotating parts – Part 6: Rotodynamic pumps for industrial applications, including measurements on rotating shafts
ISO 20816-8:2018	Mechanical vibration – Measurement and evaluation of machine vibration – Part 8: Reciprocating compressor systems

3 TERMINOLOGY

For the purpose of this standard, the definitions of the following terms shall apply.

3.1 Acceleration — Rate of change of velocity with time, expressed in metres/square second (m/s^2). Acceleration is a physical vector quantity; both magnitude and direction are needed to define it.

3.1.1 *Angular Acceleration or Rotational Acceleration* — A quantitative expression of the change in angular velocity that a spinning object undergoes per unit time. It is a vector quantity, consisting of a magnitude component and the axis about which the object is rotating. It is measured in radians per second squared (rad/s^2).

3.2 Amplitude — Maximum value of an oscillating quantity measured from the position or level of equilibrium for one period (zero-to-peak value) is called half amplitude or peak amplitude, and peak-to-peak is taken as double the peak amplitude. Amplitude may be expressed in terms of displacement, velocity, acceleration with respect to time.

3.3 Axis System

Translation along longitudinal direction is the X-axis; translation along vertical direction is the Y-axis; and translation along lateral direction is the Z-axis. For horizontally mounted machines, axis along the shaft is to be considered as the longitudinal axis as shown in Fig. 1.

Rotation about X-axis is rocking; rotation about Y-axis is Yawing (torsion); and rotation about Z-axis is pitching.

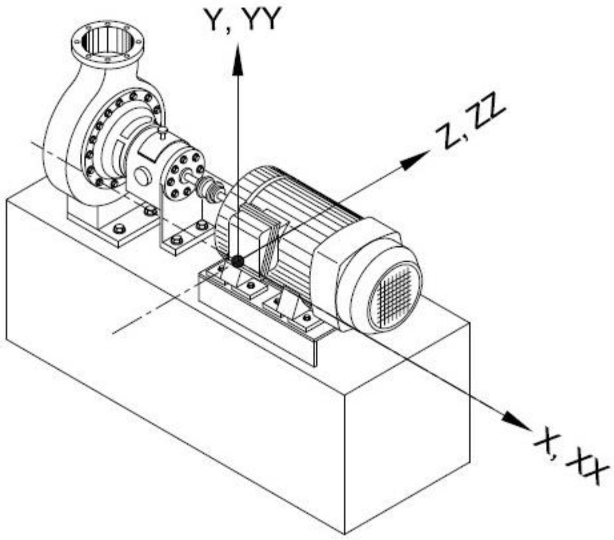


Fig. 1 Coordinate Axes

3.3.1 *Degrees of Freedom* — The degree of freedom is defined as the number of independent coordinates required to describe the displaced position.

3.4 Centre of Mass — Combined centre of mass of the machine and foundation.

3.5 Centre of Stiffness — Centre of stiffness of the soil / pile group

3.6 Damping — Damping is associated with reduction in the amplitude of an oscillation or vibration as a result of energy being dissipated.

3.6.1 *Damping Constant* (*C*) — The ratio between the damping force and the system velocity. For viscously damped systems, the ratio is constant (independent of frequency) (N-s/m).

3.6.2 *Critical Damping* (C_c) —The minimum amount of damping that results in a displaced system returning to its original position without any oscillation.

3.6.3 *Damping Ratio* (ζ *- zeta*) — The ratio of the actual system damping (*C*) to the system's critical damping (C_c).

3.6.4 *Viscous Damping* — Damping force directly proportional to the velocity of the system.

3.7 Displacement — A vector quantity that specifies the position of a body in motion with respect to a position at rest or equilibrium, expressed in metres (m).

3.7.1 *Angular Displacement* — The angle through which a point or line of a body has been rotated in a specified sense about a specified axis. It is measured in radians (degrees, revolutions).

3.8 Dynamic/Excitation Force and Couples — Time dependent force/couples produced by machine.

3.8.1 *Reciprocating Force* — In reciprocating machine, the unbalanced part of the periodic inertia force is caused by the acceleration and deceleration of reciprocating *parts.*

3.8.2 *Centrifugal/Rotating/Unbalanced Dynamic Force* — The rotating machine rotor produces unbalanced dynamic force (centrifugal) due to the unbalance left in the rotor after balancing. The unbalanced dynamic force generated by the machine is a function of rotor mass, rotor speed and its eccentricity.

3.9 Foundation Eccentricity — The distance between centre of mass and centre of stiffness.

3.10 Foundation Base Area — Area of the foundation base (horizontal) in contact with the soil.

3.11 Dynamic Analysis — A general term for analysis of a vibratory system for evaluating its natural frequencies, mode shapes and responses to excitation.

3.11.1 *Modal Analysis* — Method for analysing the response of linear dynamic system. Modal analysis is used to determine the undamped free vibration mode shapes and frequencies of the system, which provide an excellent insight into the behaviour of the structure.

a) Mode of Vibration — It is a characteristic deflection shape of a structure corresponding to a specific natural frequency of the system. A mode of vibration is characterized by a modal frequency and a mode shape.

b) Mode shape — A mode shape is a specific pattern of vibration of a system at a specific natural frequency. Different mode shapes will be associated with different natural frequencies.

3.11.2 *Harmonic Analysis* — The dynamic analysis of a vibratory system subjected to sinusoidal-type of excitation.

3.11.3 *Time History Analysis* — Dynamic analysis in which the response of a vibratory system is evaluated based on a set of specified time-varying excitation parameter such as force, acceleration or displacement. Time history analysis is also known as transient response analysis.

3.12 Free Vibration Analysis — Analysis of the system for its response without any external dynamic excitation.

3.13 Forced Vibration Analysis — It is a part of dynamic analysis carried out to evaluate the response of a vibratory system subjected to excitation.

3.14 Frequency (*f*) — Number of times a periodic oscillation completes its oscillation per unit time. It may be expressed in terms of frequency (cps or Hz) or circular frequency (rad/s).

3.14.1 *Natural Frequency* (f_n) —The frequency of vibration of a vibratory system not disturbed by an outside force or damping. Each degree of freedom of an object has its own natural frequency.

3.14.2 *Disturbing Frequency/Excitation Frequency* (f_e)*/Operating Speed/Operating Frequency* — The frequency of the source of vibration. The rotating speed of the main drive of the periodic force acting on the system.

3.14.3 *Fundamental Frequency* — The lowest natural frequency of the vibratory system. This term is to be used in a direction dependent manner so that the vertical fundamental frequency may differ from a lateral fundamental frequency.

3.14.4 *Frequency Ratio* — The ratio of excitation frequency to the natural frequency of the system.

3.15 Machine Foundations — Special types of foundations required for supporting machines which have wide range of speeds, loads and operating conditions.

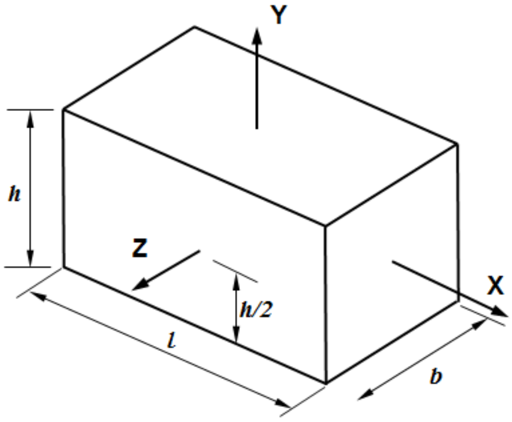
3.15.1 *Flexible Foundation* — Foundation whose structural own natural frequencies are much lower than operating frequency of the machine.

3.15.2 *Rigid Foundation* — Foundation whose structural own natural frequencies are much higher compared to operating frequency of the machine.

3.15.3 *Over Tuned Foundation* — A foundation system, whose vertical natural frequency is above the operating frequency of the machine.

3.15.4 *Under Tuned foundation* — A foundation system, whose vertical natural frequency is below the operating frequency of the machine.

3.16 Mass Moments of Inertia — The resistance of a mass to rotation. It is equal to the mass times the radius of gyration squared. The rectangular prism values for the same are $I_{\theta x}$,$I_{\theta y}$,$I_{\theta z}$ (*see* Fig. 2).



About CG:

$$I_{\theta x} = \frac{m}{12}\left(b^2 + h^2\right)$$

$$I_{\theta y} = \frac{m}{12}\left(b^2 + l^2\right)$$

$$I_{\theta z} = \frac{m}{12}\left(l^2 + h^2\right)$$

About base:

$$I_{\theta x'} = I_{\theta x} + m\left(\frac{h}{2}\right)^2$$

$$I_{\theta z'} = I_{\theta z} + m\left(\frac{h}{2}\right)^2$$

Fig. 2 Mass Moment of Inertia of Rectangular Prism

3.17 Resonance — A state in which the frequency of excitation coincides with any one of the natural frequencies of the system.

3.18 Response — The physical response of a structure to a load. If load is static in nature, the response is static in nature (static response). If load is dynamic in nature, the response is dynamic in nature (dynamic response). The response can be mathematically described in terms of displacement, velocity, acceleration, or other parameters.

3.19 Rotor Balancing

3.19.1 *Eccentricity* (*e*) — The distance between the centre of rotation and the centre of mass (gravity). In Fig. 3, 'O' is the centre of rotation of the disc and 'A' is the centre of mass (gravity) of the rotor.

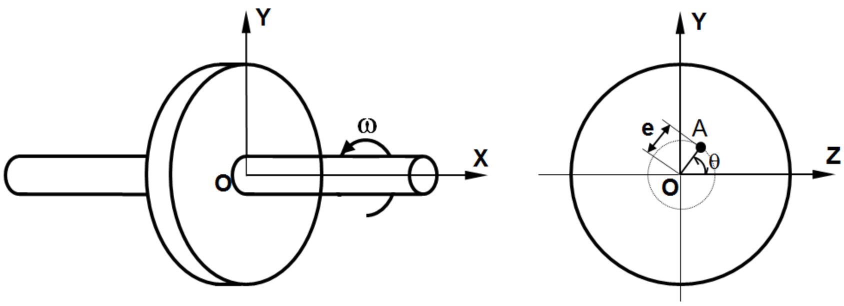


Fig. 3 Unbalance in Single Plane

3.19.2 *Unbalance* — When a rotor is manufactured/assembled with a total mass, *m*, unbalance in a rotor is the result of an uneven distribution of mass, which causes the rotor to vibrate. The unbalance in the rotor is defined as,

$$U = me$$

where, *U* is the unbalance, in kg-m or g-mm.

To reduce the design unbalance force to a permissible residual unbalance, U_{per}, rotors are balanced to a Balance Quality Grade (G) (*see* **3.13.4**), by achieving an improved permissible eccentricity, e_{per}.

3.19.3 *Unbalance Force* (*F*) — If the rotor is rotating at an angular speed, *ω*, the unbalance force will be,

$$F = m_r e \omega^2$$

where

m_r = rotor mass, in kg;
e = eccentricity, in m;
ω = angular speed of rotation, in rad/s; and
F = unbalance force, in N.

3.19.4 *Balance Quality Grade* (*G*) — The product of eccentricity and the angular velocity of the rotor at maximum operating speed and is a constant for rotors of the same type. It is expressed in mm/s.

$$G = e\,\omega = \text{constant}$$

NOTE — This is based on the fact that geometrically similar rotors running at the same speed will have similar stresses in the rotor and its bearings. Balance quality grades are separated by a factor of 2.5. However, *G* numbers of intermediate value may be used to satisfy special requirements. For more information, relevant Indian Standards on rotor balancing may be referred to.

3.20 Velocity — Rate of change of displacement with time, expressed in metres/second (m/s). It is a physical vector quantity; both magnitude and direction are needed to define it. The scalar absolute value (magnitude) of velocity is speed.

3.20.1 *Angular Velocity or Rotational Velocity* — A quantitative expression of the amount of rotation that a spinning object undergoes per unit time. It is a vector quantity that specifies the angular speed (rotational speed) of an object and the axis about which the object is rotating. It is measured in radians per second (rad/s, rpm, Hz).

3.21 Vibration — Mechanical oscillation about equilibrium position.

3.21.1 *Free Vibration* — Oscillations about a system's equilibrium position that occur in the absence of an external excitation.

3.21.2 *Forced Vibration* — Vibration process of a system which is caused by external time-varying loads acting on it.

4 GEOTECHNICAL DATA

4.1 The site shall be subjected to a careful and thorough soil exploration as per IS 1892 and IS 5249, in such a manner that all relevant information pertaining to the proper design and construction of the foundation are available.

4.2 Soil/Pile parameters, generally required for the analysis and design of the foundation, shall be considered as listed below:

a) Coefficient of elastic uniform compression (C_u);
b) Dynamic shear modulus;
c) Shear wave velocity;
d) Poisson's ratio;
e) Bearing capacity;
f) Subgrade reaction;
g) Density of soil;
h) Permissible settlement;
j) Pile capacity-Vertical Compression/Lateral/Pull-Out;
k) Dynamic pile stiffness-Vertical/Lateral;
m) Group Effect on piles; and
n) Ground water table.

4.3 Soil Parameters

The following soil data shall be obtained:

a) In case of open foundation, sub-soil profile and soil characteristics up to a depth, for 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 later, below the expected founding level.

b) In case of pile foundation, sub-soil profile and soil characteristics up to a depth of one and half times the width of structure from the toe of pile.

4.3.1 Dynamic properties of sub-strata shall be determined by conducting necessary test in accordance with IS 5249 or by conducting cross hole shear test as per IS 13372 (Part 1) or downhole shear test as per IS 13372 (Part 2), etc. Guidance for choosing design parameters from in-situ tests may be taken from IS 5249.

4.3.2 The elastic modulus (E_s) and shear modulus (G_s) of the soil medium may be calculated from the following relations:

$$G_s = V_s^2 \rho_s$$

$$E_s = 2G_s(1+\nu_s)$$

where

E_s = Elastic modulus of soil, in kN/m^2;

G_s = Shear modulus of soil, in kN/m^2;
ρ_s = Mass density of soil, in T/m^3 (kN-s^2/m^4);
V_s = Shear wave velocity of soil, in m/s; and
ν_s = Poisson's ratio of soil.

4.3.3 The values of coefficient of elastic uniform compression of soil, C_u, in kN/m^3 shall be obtained using the following relationship:

$$C_u = \frac{1.13 E_s}{\left(1-\nu_s^2\right)\sqrt{A}}$$

where,

A = area of foundation in contact with soil,in m^2.

NOTE — This relation between C_u and E_s is based upon the assumption that E_s remains constant with depth.

From the value of C_u obtained for the test block of contact area A, the value of C_{u1}, for the foundation having contact area A_1, may be obtained from the equation:

$$C_{u1} = C_u \sqrt{\frac{A}{A_1}}$$

NOTE — This relation is valid for small variations in base area of the foundations and may be used for area up to 10 m^2. For actual foundation areas larger than 10 m^2, the value of C_{u1}, obtained for 10 m^2 may be used.

4.3.4 Coefficient of elastic uniform compression, C_u, Coefficient of elastic uniform Shear, C_τ, coefficients of elastic non-uniform compression, C_θ *or* C_ϕ (C_θ about X-axis and C_ϕ about Z-axis) and the coefficient of elastic non-uniform shear, C_ψ about Y-axis are related to each other. These are obtained using the following correlations:

$C_\tau = 0.5\, C_u$;
$C_\phi = C_\theta = 2.0\, C_u$; and
$C_\psi = 1.5\, C_\tau$.

4.3.5 Where foundations of such machines are required to be located close to a building or other foundation, care shall be taken to protect it from non-uniform stresses imposed by adjacent foundations. In view of this, a minimum distance of 500 mm to any building foundation in the vicinity of the rotary machine foundation is recommended.

4.3.6 *Dynamic Soil Stiffness*

For a foundation base in contact with the soil, dynamic soil stiffness properties shall be evaluated as under:

$$k_x = C_\tau \times A; \qquad k_y = C_u \times A; \qquad k_z = C_\tau \times A$$

$$k_\theta = C_\theta \times I_{xx}; \qquad k_\psi = C_\psi \times I_{yy}; \qquad k_\phi = C_\phi \times I_{zz}$$

where

A = Base area of the foundation in contact with soil;
I_{xx} = Moment of inertia of base area about X-X axis;
I_{yy} = Moment of inertia of base area about Y-Y axis; and
I_{zz} = Polar moment of inertia of base area = $I_{xx} + I_{yy}$.

Soil damping of 8 percent shall be considered for computing response.

4.3.7 While determining the bearing capacity of the foundation, the total permissible settlement shall be taken as below for calculating the net allowable bearing pressure:

a) 25 mm in case of soil and 12 mm in case of rock; or
b) as specified by the machine manufacturer; whichever is lower.

4.4 Pile Parameters

Design of piles shall be carried out as per relevant parts of IS 2911. Design working load for the piles shall be considered 20 percent more than required to withstand all static loads of machine and foundation. Safe load on piles shall be ascertained in accordance with IS 2911 (Part 4).

4.4.1 *Dynamic Pile Stiffness*

The dynamic pile stiffness in vertical direction, k_{pv} and lateral direction, k_{ph} shall be evaluated as per the procedure given in Annex B.

4.4.1.1 *Influence of Pile Group*

For a pile-supported foundation, having pile diameter, d, pile length, l, number of piles, n and pile spacing, s, the effective vertical pile stiffness, k_v and effective lateral pile stiffness, k_h of each pile is evaluated such that the combined stiffness for a group of n piles is the linear summation of effective pile stiffness of each pile in the pile group in respective direction.

Effective pile stiffness shall be evaluated as under:

Effective vertical stiffness of each pile, $k_v = a_{eff} \times k_{pv}$; and
Effective lateral stiffness of each pile, $k_h = a_{eff} \times k_{ph}$.

where,

a_{eff} = influence coefficient as given in Table 1;
k_{pv} = vertical pile stiffness obtained from test pile; and
k_{ph} = lateral pile stiffness obtained from test pile.

For determination of k_{pv} and k_{ph}, reference shall be made to Annex B.

Table 1 Influence Coefficient, α_{eff}
(*Clause* 4.4.1.1)

Sl No.	$\frac{\text{Pile Spacing}}{\text{Pile Diameter}}, \left(\frac{s}{d}\right)$	Influence Coefficient, α_{eff}
(1)	(2)	(3)
i)	3.0	0.43
ii)	4.0	0.52
iii)	4.5	0.56
iv)	5.0	0.60
v)	6.0	0.68
vi)	10.0	0.95

The combined vertical stiffness of group of 'n' piles shall be the linear summation of effective pile stiffness of each pile in the pile group, as given below:

Total vertical stiffness of group of '*n'* piles, $K_V = n \times k_v$; and
Total lateral stiffness of group of '*n'* piles, $K_H = n \times k_h$.

A constant value of 5 percent damping for pile-supported foundations shall be considered for response computation.

4.5 Embedment Effect

There are no simplified expressions providing effect of foundation embedment on the machine foundation response. Since the embedment effect will lead to increased damping, which in turn result in reduced vibration amplitudes, it is suggested to ignore this effect in foundation response computation.

4.6 Influence of Ground Water Table

Influence of ground water table in the vicinity of machine foundation is reported on the machine response. Enhanced influence of this is specifically noticed for hammer foundations. Since, there is no explicit literature available on this aspect, it is recommended to keep higher frequency margins of foundation natural frequencies from machine operating speed to counter the effect of variation in ground water table.

5 MACHINE TYPES

5.1 Machine

A machine is an apparatus/device, using mechanical or electrical power and having several parts, fixed/stationary and moving/rotating parts, each with a definite function and together performing a particular task/work.

5.1.1 *Drive Machine and Driven Machine*

Between two elements of a machine, the one which drives the other is called drive machine and the other which gets driven is called driven machine. For example, in case of turbo generator, turbine is called drive machine and generator is called driven machine, and in case of motor fan unit, the motor is a drive machine and fan is a driven machine.

5.1.2 Machines are categorized based on type of motion or speed of operation, as given in **5.2.1.1** and **5.2.1.2**.

5.2.1.1 *Machine categorization based on type of motion*

Machines are categorized based on their type of motion as below:

a) *Rotary machines* — A machine having a rotating member operating with this motion is called rotating machine. This category includes machines such as turbines, pumps, compressors, fans, motors, centrifuges, etc. These machines are characterized by the rotating motion of impellers/rotors.

b) *Reciprocating machines* — Reciprocating motion, also called reciprocation, is a repetitive up-and-down or back-and-forth linear motion. The two opposite motions that comprise a single reciprocation cycle are called strokes. A machine operating with this motion is called reciprocating machine. This category includes machines that convert rotating motion into translatory motion and vice-versa, such as compressors and diesel engines.

c) *Impact machines* — An impact is a high force or shock applied over a short time period when two or more bodies collide. Such a force or acceleration usually has a greater effect than a lower force applied over a proportionally longer period. The effect depends critically on the relative velocity of the bodies to one another. These machines operate with regulated impacts or shocks between different parts of the machines. This shock loading is often transmitted to the foundation system. This category includes machines such as forging hammers.

d) *Impulsive machines* — These machines operate with kinematic energy applied to the system which is transmitted to foundation. This category of machine includes presses.

e) *Other miscellaneous machines* — Other machinery generating dynamic forces include vibratory screens, rock crushers, metal shredders, etc.

5.2.1.2 *Machine categorization based on based on speed of operation*

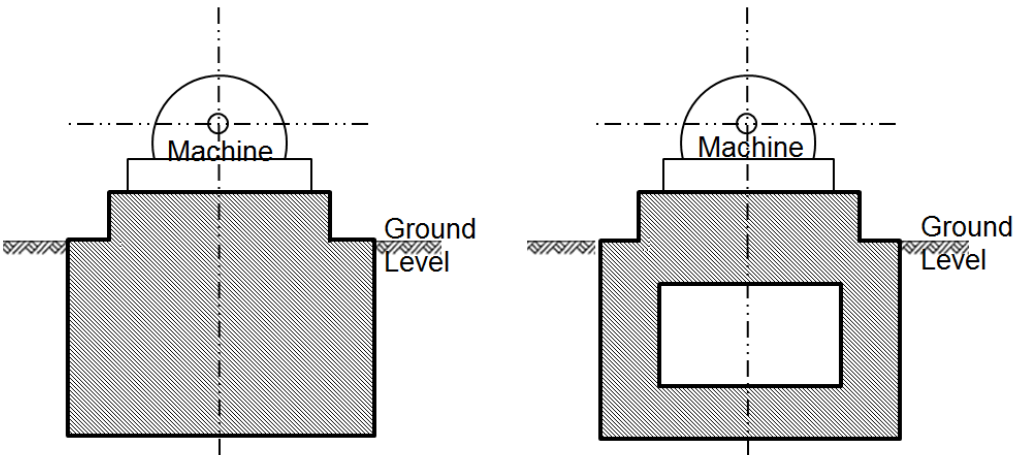
Machines are categorized based on their speed, s, as below:

a)	Low speed machines	:	100 < *s* < 1 500 rpm
b)	Medium speed machines	:	1 500 ≤ *s* < 3 000 rpm
c)	High speed machines	:	*s* ≥ 3 000rpm

6 FOUNDATION TYPES

The machine foundations are classified as below:

a) Block foundations — Machines located close to grade are generally supported on block type of foundation, both solid block and hollow block (*see* Fig. 4). Depending up on geotechnical parameters, such foundations are supported directly on the grade or through the group of piles. These foundations are rigid foundations because, for such foundations, structural own natural frequencies are much higher compared to those contributed by soil/pile system. For hollow block to behave rigid, it shall be ensured that natural frequency of each of its six sides are higher than machine operating speed. Extent to which a block is to be made hollow is controlled by the criteria that the natural frequency of each side (top, bottom and all 4 sides) of the hollow block is 30 percent more than the highest operating speed of the machine. For details, reference may be made to IS 2974 (Part 2).



4A Solid Block Type 4B Hollow Block (Box) Type

Fig. 4 Block Foundations

b) *Frame foundation* — Some machine requires elevated foundations to house various mechanical systems required for the machine performance (condensers for turbines, bus ducts for generators, piping, ducts, etc.). Elevated support consisting of base raft, columns and top deck form the frame type foundation (*see*Fig.5). Depending up on the geotechnical parameters, such foundations are supported directly on the grade or through the group of piles. These foundations are flexible foundations. For such foundations, structural own natural frequencies are much lower than operating speeds and these are comparable to those contributed by soil/pile support system.

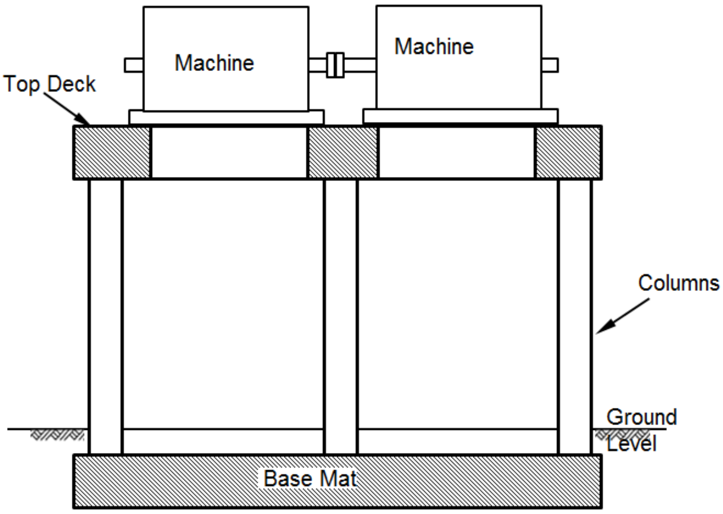


Fig.5 Frame Foundation (Typical)

c) *Slab foundation on elastic support* — Foundation in the form of flexible concrete slab which supports machines is considered as slab foundation (see Fig.6). Machine such as Gas Turbine Generator (GTG) close to grade require flexible foundation whose length to thickness ratio is high (more than 8). These foundations will behave like beam/slab on elastic foundation and can be treated as slab foundation. Depending upon geotechnical parameters, such foundations are supported directly on the grade or through the group of piles. These foundations are also flexible foundations. For such foundations, structural own natural frequencies are much lower than operating speeds and these are comparable to those contributed by soil/pile support system.

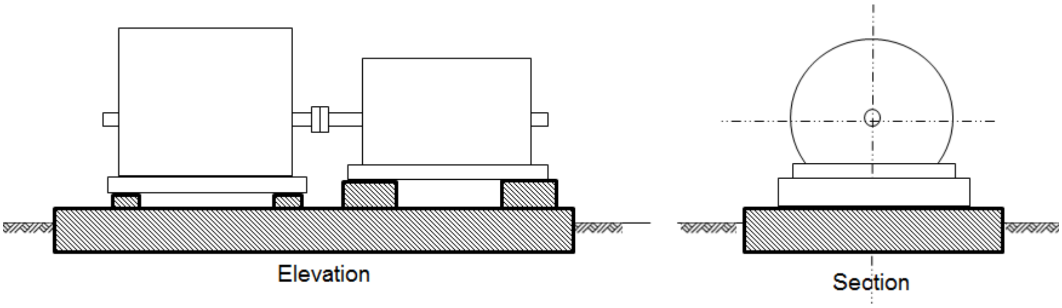
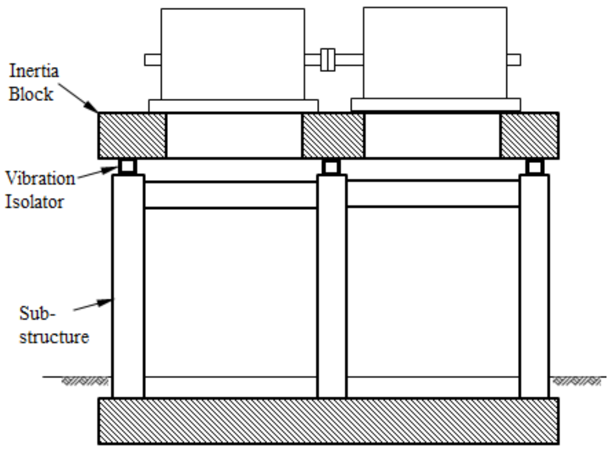


Fig.6 Slab Type Foundation

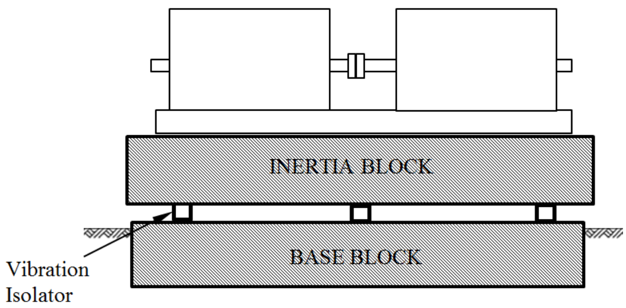
d) *Foundations with vibration isolation system (vis)* — For these foundations, machine is directly supported over the inertia block supported over isolators which in turn are supported by Block/ Frame/ Slab type foundations. In certain cases, machines can also be mounted directly over the isolators (without inertia block). These, however are not recommended for industrial applications but can be used where situations do not permit provision of inertia block but in stand-alone mode. Different foundation types with VIS are shown in Fig.7.

Vibration isolation system comprises of,

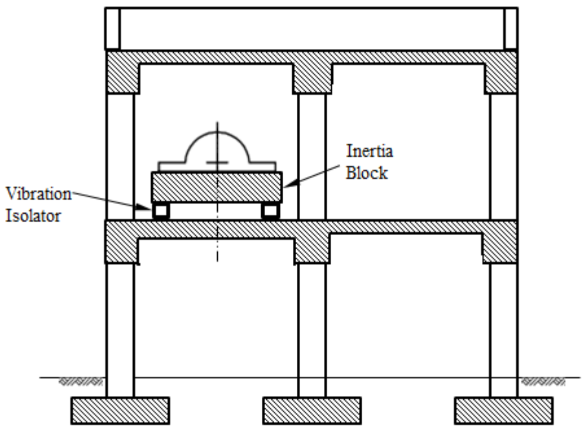
1) Spring and damper units; and
2) Elastomeric pads.



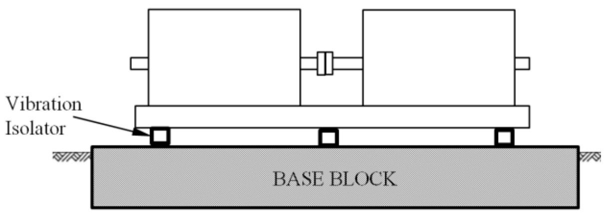
7A Machine with VIS on Frame Foundation



7B Machine with VIS (with inertia block) at Ground Level



7C Machine with VIS on Building Floors



7D Machine with VIS (without inertia block) at Ground Level

Fig.7 Foundation with Vibration Isolators

e) *Machines directly supported on the building super structure/sub-structure without VIS* — In certain case, from operational considerations, some machines are located and mounted directly on the building floor. In certain cases, some suppliers/manufacturers support the machines directly on the floor with isolation pads between machine and its base frame. These include air conditioning plants at roof top/basement, motor-pump units at basement for STP, motor blower units at any floor level, etc. Such support systems, though generally not recommended, can be used only after proper design using influence of structural vibration characteristics including that of the floor supporting the machine. A typical system is shown in Fig.8.

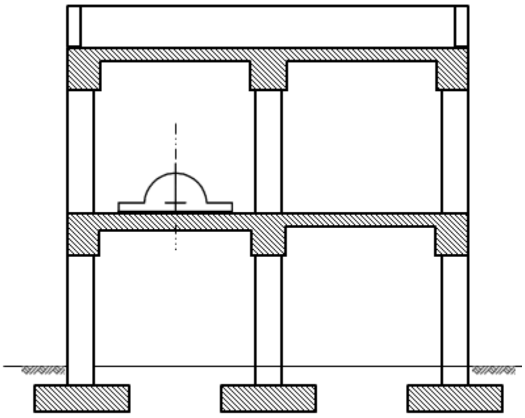


Fig. 8 Machines Supported on Super Structure

7 DESIGN MACHINE PARAMETERS

A typical machine system comprises of (a) a drive machine, and (b) a driven machine connected through a coupling device or through a gear box. For every machine, the following data shall be provided by machine manufacturer:

a) *Machine data and operating loads for rotary machines*:

1) Weight of static parts (stator) and their respective centre of gravity (CG);
2) Weight of rotating parts (rotor) and their respective CG;
3) Number of impeller blades/vanes for pumps and fans;
4) Operating speed range;
5) Coupling details – rigid coupling/flexible coupling/gear box;
6) Bearing support system – end shield bearings or pedestal bearings;
7) Balance quality grade;
8) Unbalanced dynamic forces;
9) Machine power torque;
10) Abnormal/emergency loads like blade failure loads/load due to broken hammer for mechanical machines and short circuit loads/ electro dynamic forces for motor and generator, etc, as applicable;
11) Thermal frictional loads where applicable;
12) Load due to thermal gradients in vertical as well as lateral direction as applicable;
13) Temperatures in various machine locations under operating conditions; and
14) Permissible amplitude of vibration.

b) *Machine data and operating loads for reciprocating machines*:

1) Weight of static parts (stator) and their respective CG;
2) Weight of moving parts and their respective CG;
3) Operating speed/s;
4) Dynamic forces (forces and couples) at operating speed and twice the operating speed (second harmonic);
5) Abnormal/emergency loads, if any;
6) Temperatures in various machine locations under operating conditions; and
7) Permissible amplitude of vibration.

c) *Machine data and operating loads for impact machines*:

1) Capacity of hammer;
2) Weight of tup and its CG;
3) Weight of upper and lower die and their respective CG;
4) Weight of anvil and its CG;
5) Type of frame (mounted on the foundation or part of anvil itself);
6) Dynamic parameters of drive machine;
7) Number of blows per minute; and
8) Permissible amplitude of vibration.

d) *Machine data and operating loads for impulsive machines*:

1) Weight of the cross head and its CG;
2) Gross weight and its CG;
3) Weight of material to be forged;
4) Pressure to be exerted by the press;
5) Stroke of the press;
6) Load-time relationship of the pulse realized during the action of the press;
7) Dynamic force and moment in the case of eccentric presses;
8) Height and cross-section of steel columns; and
9) Permissible amplitude of vibration.

NOTE — Required machine data for different machines is also given in Annex C.

8 DESIGN FOUNDATION DATA

8.1 Reinforced Concrete Foundations

8.1.1 *Concrete*

The concrete shall be as per IS 456. Minimum concrete grade shall be M25.

8.1.2 *Reinforcing Steel*

High yield strength deformed steel bars conforming to IS 1786 shall be used. However, mild steel bars conforming to IS 432 (Part 1) may also be used for stirrups or for surface reinforcement.

8.1.3 *Material Properties to be Considered for Analysis*

a) *Modulus of elasticity of concrete:*

1) Static Elastic Modulus of concrete shall be taken as,

$$E_c = \left\{5000\sqrt{f_{ck}}\right\} \times 10^3 \text{, in kN/m}^2$$

Where, f_{ck} is the characteristic strength of concrete in N/mm^{2}and shall be as per IS 456.

Actual measured values may differ by ± 20 percent from the values obtained from the above expression. It is recommended to include this variation in the analysis.

2) Dynamic elastic modulus shall be considered as same as static elastic modulus.

b) Poisson ratio (ν_c) = 0.2;

c) Unit weight = 25kN/m^3;

d) Damping = 5 percent; and

e) *Permissible stresses* — Permissible stresses in concrete and reinforcement for working stress method of design shall be in accordance with provisions of IS 456. Where stresses due to either wind or earthquake or short-circuit or loss of blade/hammer/fins or bowed rotor are combined with those due to dead load, operating loads and temperature loads, the permissible stresses as specified in IS 456 may be increased by 33.33 percent. However, the same shall be increased by 50 percent when bearing failure loads are combined with those due to dead load, operating loads and temperature loads.

Alternatively, for limit state method of design, partial safety factor for materials shall be in accordance with provisions of IS 456. Partial safety factors for loads shall be as per respective parts of IS 2974.

8.2 Structural Steel Foundations

Structural steel shall be used only for frame foundation comprising of beams and columns, whereas base raft shall be in reinforced cement concrete only.

8.2.1 Material grade shall be as per IS 2062.

8.2.2 *Material Properties to be Considered for Analysis*

a) Modulus of elasticity (as per IS 800) : 2.0×10^8 kN/m^2;

b) Poisson ratio : 0.3;

c) Unit weight : 78.5 kN/m^3;

d) Damping : 2 percent; and

e) Permissible stresses — Permissible stresses for working stress method of design shall be in accordance with provisions of IS 800. Where stresses due to either wind or earthquake or short-circuit or loss of blade /hammer/fins or bowed rotor are combined with those due to dead load, operating loads and temperature loads, the permissible stresses as specified in IS 800 may be increased by 33 percent. However, the same shall be increased by 50 percent when bearing failure loads are combined with those due to dead load, operating loads and temperature loads.

Alternatively, for limit state method of design, partial safety factor for materials shall be in accordance with IS 800. Partial safety factors for loads shall be as per respective parts of IS 2974.

9 DESIGN REQUIREMENTS OF MACHINE FOUNDATION

9.1 The foundation shall be isolated from adjoining structures at all levels with a minimum gap of 50 mm or the separation gap as calculated based on storey displacement as per IS 1893, whichever is higher. At the base mat level, the isolation gap shall be filled with soft compressible material.

9.2 No building column shall be supported on machine foundation/base raft.

9.3 Staircases/ladders for accessing the machine foundation should necessarily be isolated from machine foundation by providing suitable air gap.

9.4 Base level of the machine foundation shall preferably be below the building foundation level. In special cases, the machine foundation base level can be same as that of building foundation. In no case the machine foundation base level for large machines shall be above the building/structure foundation level. However, for very small machines up to 5 kW (small pumps/motors/fans, etc) the machine foundation base level can be higher that building/structure foundation base level provided it is designed for dynamic response using dynamic soil properties computed at the machine foundation base level.

9.5 For foundation directly supported over soil, the soil pressure below the foundations shall not exceed 80 percent of the net allowable bearing pressure under operating load combinations. For foundation supported on piles, the load on piles under operating load combinations shall not exceed 80 percent of the safe load capacity of piles.

For emergency/accidental load combinations, the soil pressure/pile load capacity shall be permitted up to the full capacity. Further, for earthquake loading, provisions of IS 1893 (Part 4) shall be followed.

9.6 Foundation shall be dimensioned and designed in such a way that dynamic performance requirements as specified by codal provisions are met. However, machine manufacturer's acceptance criteria may also be looked into.

Frequency separation criteria should be applied to vertical natural frequency of the foundation only. However, if it is not possible to fulfil this, it shall be ensured that computed amplitudes are well within permissible limits. This shall supersede the frequency separation criteria and shall become the governing criteria.

9.7 Structural Integrity

The foundation should be designed such that integrity of foundation is maintained under all operational and emergency loading condition.

9.8 All pockets shall be designed for distribution of pull-up forces given by machine manufacturer as well as those generated under emergency load conditions.

9.9 Vibration Transmission from External Sources

If there are other vibrating machines operating in the close vicinity of the machine foundation under consideration, their influence can be ignored (a) if the depth of both the machine foundations are at the same level; (b) if there is a clear air gap more than 300 mm between two foundations at their base level; and (c) if the operating parameters of both the machines are similar.

In case the above conditions are not met, it may be desirable to consider the influence of other machines while designing the said foundation.

> NOTE — There are no said guidelines or specified procedures to handle issue as stated above, except by recording vibration measurements on the said machine (under no-operation condition) when other machine is in operation.

10 DYNAMIC ANALYSIS

10.1 Based on design machine data, design foundation data and design geotechnical data, every machine foundation shall be analysed for its dynamic response to ensure satisfactory operation of the machine. Dynamic analysis consists of,

a) *Free vibration analysis*– It is performed to evaluate natural frequencies and associated mode shapes of machine foundation system.
b) *Forced vibration response analysis* – It is performed to evaluate steady state response (amplitude/velocity) subjected to unbalanced dynamic forces under normal operating conditions.

NOTE — For all under tuned foundations, for every start-up and shut-down operation, the machine will necessarily cross foundation natural frequencies. In such cases, it is desirable to evaluate transient response also.

10.1.1 Steady state response shall be evaluated for dynamic forces generated by both drive machine and driven machine. These loads shall be considered in vertical 'Y' and transverse 'Z' direction, one at a time:

a) Dynamic forces in phase; and
b) Dynamic forces out of phase (with 180° phase difference).

However, for vertical axis machines, these forces should be considered in two transverse directions (one at a time) considering forces acting in-phase (IP) and out-of-phase (OP).

NOTES

1 Computed dynamic forces shall be for one grade higher than the balance grade prescribed for the machine. Wherever, there is a large mismatch between dynamic forces supplied by the machine manufacturer compared to computed dynamic forces and the difference happens to be more than 25 percent, it is recommended to use computed dynamic loads only.

2 Where machines are running at different speeds, dynamic forces computed at corresponding speeds shall be applied simultaneously at respective bearing locations both in phase and out of phase (one at a time).

3 In case of computational restrictions, the dynamic forces can be considered applied for one machine at a time and response evaluated at all bearing locations. The resultant response shall be obtained by square root of sum of square (SRSS) method.

4 Dynamic forces generated in rotary and reciprocating machines are explained in Annex D.

10.1.2 The detailed dynamic analysis of each type of foundation, that is, block, frame, slab, hammers, presses and foundations with VIS shall be carried out as per the procedure given in respective parts of IS 2974.

10.2 Permissible Amplitudes of Vibration

10.2.1 Vibration amplitudes for machines are a function of (a) machine type, (b) foundation type, (c) coupling type, (d) bearing type, (e) its operational parameters, etc. Speed variation for various machines ranges from 100 rpm to 15 000 rpm or so.

Further, the machine vibration can be influenced by its mounting system as well besides coupling arrangement between rotors. Higher bearing vibration may therefore be permitted for flexible bearing supports compared to that for a rigid bearing support.

Thus, it is difficult to define a simple formulation/relationship for permissible amplitudes that fits well for a wide variety of machines supported on different types of foundations.

Though vibration velocity is sufficient to characterize the acceptance criteria of a wide range of machines, the acceptance criteria should ideally be in terms of displacement, velocity and acceleration, depending on the speed range and type of machine.

Permissible amplitudes are at machine bearing locations.

10.2.2 Two conditions are used to classify the foundation flexibility in specified directions:

a) rigid foundations; and
b) flexible foundations.

These foundation conditions are determined by the relationship between the machine and foundation flexibilities.

For horizontal machines, if the vertical natural frequency of the machine foundation system is higher than its operating speed, (this is in most cases the rotational frequency) by at least 25 percent, then the support system may be considered rigid, otherwise flexible.

10.2.3 Wherever, two different machines are coupled together (for example, rotary machine and a reciprocating machine), the permissible amplitudes shall be governed by the machine for which permissible amplitude limits are lower and amplitude limits as given by the manufacturer are to be considered, and in case not provided by manufacturer, the limits shall be in accordance with Table 2.

10.2.3.1 The permissible amplitudes given in Table 2 are only for the dynamic forces produced by machine itself and it does not include vibration transmitted by adjoining machines/ foundations.

10.2.3.2 *Conversion of RMS velocity to amplitude of displacement*

For machine operating at frequency *N* rpm and having RMS vibration velocity of *V*' mm/s (*see* Fig. 9),

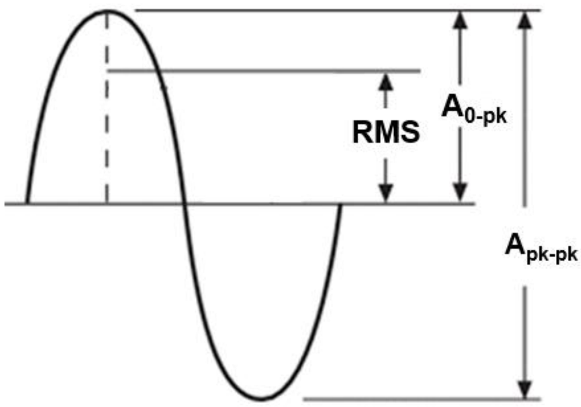


Fig. 9 Relation between RMS velocity and Amplitude of Displacement

Half amplitude, $A_{0\text{-}pk}$, in microns shall be computed as under:

Half velocity, $V_{0\text{-}pk}$, in mm/s = V'/0.707 mm/s;
Machine speed, N, in rpm = N x 2 π/ 60 rad/s; and
Half amplitude, $A_{0\text{-}pk}$, in microns = (V'/N) x 13 507 microns.

11 STRENGTH DESIGN

11.1 Strength design of the foundation shall be carried out for all machine related loads including emergency loads, thermal loads and applicable environmental loads like earthquake, wind, blast, etc.

11.1.1 For earthquake loading, IS 1893 (Part 4) shall be followed for permissible increase in stresses as well as permissible increase in bearing pressure. Since earthquake loads are expected once in life time of the foundation, loss of contact of the foundation with the soil may be permitted to be considered in design. Similar considerations should be followed for permissible load on the heaviest loaded pile. Response reduction factor, R for elevated framed foundation shall be considered as 3. For foundation systems wherein, inelastic action is not relevant such as block foundations and VIS, R value shall be considered as 1. However, the ratio (I/R) shall in no case be more than 1.0.

11.1.2 In addition to the above loads, structural integrity of the foundation shall also be checked for bearing failure loads asper **11.1.2.1**.

NOTE — Bearing failures have been observed for some of the machines globe over. Though the occurrence of this phenomenon is remote, it is desirable to include bearing failure loads as criteria for strength design of the foundation to ensure the integrity of machine foundation system.

11.1.2.1 The bearing failure loads to be considered in design shall preferably be obtained from the machine manufacturer. In the absence of any data given by the machine manufacturer, it is recommended to use the criteria given in **11.1.2.2** for the design of foundation.

11.1.2.2 The bearing failure load may be taken as five times the rotor weight to be applied at respective bearing locations in vertical and transverse direction one at a time. Since, bearing failure may occur at best once in life time of the machine, an increase of permissible stresses to the order of 50 percent shall be permitted. In addition, loss of contact of the foundation with the soil may be permitted to be considered in design.

11.2 Strength design of each type of foundation shall be carried out as per the procedure given in respective parts of IS 2974 and provisions given in **11.1**.

TABLE 2 PERMISSIBLE AMPLITUDES (ZERO TO PEAK), IN MICRONS

(*Clauses* 10.2.3 *and* 10.2.3.1)

Sl No.	**Machine Speed,** *N* rpm	**Rotary Machines: Horizontal mounted on the foundation – Industrial Machines including large Prime-movers with rotating Masses mounted on foundations (including Compressors, Blowers, Fans, Steam Turbines, etc)**		**Gas Turbines with Operating Speed of 1 500 rpm and more**		**Pumps: Vertical and Horizontal**		**Reciprocating Machines with Speeds ranging from 100 rpm to 1 800 rpm (Comprises Reciprocating Piston Machines mounted either rigidly or resiliently with power rating of above 100 kW)[1)]**	
		Rigid Foundation	Flexible Foundation	Rigid Foundation	Flexible Foundation	Rigid Foundation	Flexible Foundation	Rigid Foundation	Flexible Foundation
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
i)	100	190	235			70	85	35	45
ii)	200	95	120			35	45	20	30
iii)	300	65	80			25	30	15	20
iv)	500	40	50			20	25	8	10
v)	750	30	35			15	16	5	7
vi)	1 000	25	30			19	12	4	5
vii)	1 500	23	28	25	35	6	8	4	5
viii)	2 000	17	22	22	28	5	6	3	3
ix)	3 000	15	20	29	25			2	3
x)	3 600	13	16	17	21			2	2
xi)	4 000	11	14	15	19			2	2
xii)	5 000	9	11	12	15			2	2
xiii)	8 000	6	7	8	9			1	1
xiv)	10 000 and above	5	6	6	8			1	1

[1)] Typical examples of application are marine propulsion engines, marine auxiliary engines, engines operating in diesel generator sets gas compressors and engines for diesel locomotives.

12 CONSTRUCTION ASPECTS FOR REINFORCED CEMENT CONCRETE (RCC) FOUNDATION

12.1 Construction of all foundations shall be done in accordance with the provisions of IS 456.

12.2 Reinforcement

12.2.1 Since minimum reinforcement in the foundation is dependent on foundation type, the same shall be provided as given in the respective parts of IS 2974.

12.2.2 *Reinforcement Detailing*

The following points shall be considered while arranging the reinforcements:

a) Reinforcement shall be used at all faces, both ways.
b) If the thickness of foundation block [see IS 2974 Part 2)] exceeds one metre, the requisite shrinkage reinforcement shall be placed at suitable spacing in all the three directions with 12 mm diameter bars at 300 mm c/c placed in layers at every 1 000 mm or less thickness.
c) The secondary shrinkage reinforcement as per **12.2.3 (b)** may be replaced by providing steel fibres of short lengths up to 60 mm and of aspect ratio of 80, inside the mass randomly in accordance with IS 456. Minimum recommended dosages of steel fibres should be either as given below or as recommended by the supplier:

Aspect Ratio	*Length* *mm*	*Diameter* *mm*	*Dosage* *kg/m³*	*Fibre Type /Remarks*
80	60	0.75	10	Glued hooked end
65	60	0.90	15	Glued hooked end

12.2.3 *Reinforcement around Pits and Openings*

Reinforcement equivalent to 1 percent of the cross-sectional area of the pit/opening shall be provided all around the pits and openings having size 300 mm x 300 mm and more. Typical reinforcement arrangement is given in Fig. 10.

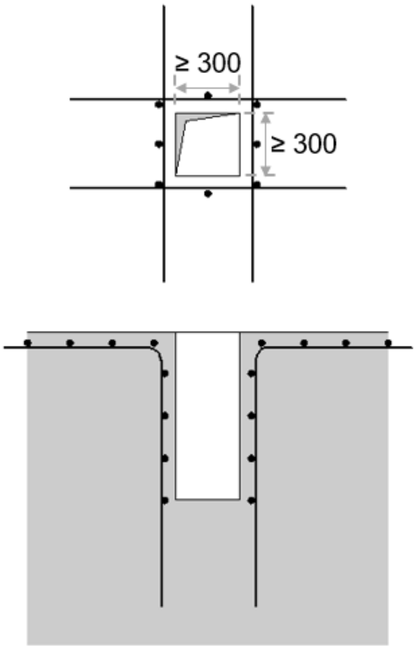


Fig. 10 Reinforcement around Pits and Openings

12.3 For machine foundations, it is desirable to cast the foundation in a single pour. In certain cases, construction joints shall have to be permitted from geometric considerations. In addition, due care needs to be taken for mass concreting as well as concreting the foundation in hot/cold weather. Such specific requirements are given shall be as per **12.3.1** to **12.3**.

12.3.1 *Construction Joints/Continuity of Work*

In general, construction joints are to be avoided for machine foundations. Where, it is inevitable, construction joints shall be appropriately designed and then provided. Necessary shear dowels shall be provided for every construction joint. For details, respective parts of IS 2974 shall be followed.

In case of thick blocks (exceeding 5 m), if needed, construction joints can be provided. In such an event the construction joint shall be suitably designed and shown in working drawing. These joints shall be horizontal. Reinforcement shall be continuous and before placing the new layer of concrete the previously laid surface should be roughened thoroughly cleaned and washed by a jet of water and then covered by cement slurry. Concreting shall be placed not later than 2 h after the cement slurry is laid.

In the event of an unforeseen interruption while concreting that may result in unavoidable joints, such joints shall be treated in the same way as construction joints.

12.3.2 *Mass Concreting*

Large foundations involve mass concreting which is massive enough to prevent dissipation of heat of hydration from the concrete. Unless due precautions are taken for dissipating heat of hydration, cracks are seen on the surface of the concrete. The heat of hydration generates a large thermal differential between the inside and the outside surface, which generates thermal stresses in concrete leading to surface cracks. To overcome this, it is recommended to use skin reinforcement to minimize the occurrence of surface cracking.

In addition, following recommendations shall be followed:

a) Limiting heat of hydration of cement by use of low-heat cement, addition of supplementary cementitious materials such as fly ash, blast furnace slag or pozzolana, use of low cement content and low water content;
b) Precooling the concrete mix by use of chilled water and replacing part of water with ice. Placing temperature to be kept between 10 ºC to 30 ºC;
c) Post-cooling of concrete with embedded pipes cast into concrete;
d) Reducing temperature gradient by insulating concrete surfaces or formworks; and
e) Use of low-thermal-expansion aggregates such as granite, limestone or basalt.

12.3.3 *Concreting in Hot and Cold Weather*

It is desirable to use recommended practices for concreting in extreme hot and extreme cold weather. It is recommended to follow the provisions of IS 7861 (Part 1) and IS 7861 (Part 2). Ready mixed concrete as per IS 4926 may also be used.

12.3.4 *Self Compacting Concrete*

At times, due to congestion of reinforcement or on account of complex geometry, it is not practicable to use vibrators effectively. This results in honey combing which is not good for the dynamic behaviour of the foundation.

Such honey combing may be prevented by following stringent quality norms during construction. Honey combing may also be prevented or minimized by using self compacting concrete (SCC). SCC is a specially design mix concrete which flows under its own weight and does not require any external vibration for compaction. This type of concrete has high flow ability with moderate viscosity to resist segregation and bleeding and can maintain homogeneity during transportation, placing and curing. This concrete shall be of minimum grade M30. SCC for use in machine foundations shall be produced and used as per the provisions of IS 456.

12.3.5 *Grouting*

12.3.5.1 In machine foundation application grouting is used for,

a) Pockets for bolts;
b) For levelling of the soleplates under the machine ensuring complete contact with the foundation for proper load transfer from machine to the foundation; and
c) Under bearing pedestals to ensure proper load transfer from bearings to the foundation.

12.3.5.2 Cement based grouts or epoxy grouts, both of non-shrink type shall be used for grouting. Only pre-packed grout from approved grout manufacturer should be used. Grout strength shall be minimum two grade higher than the concrete used for the machine foundation. Procedure for mixing the grout and using the same should be in accordance with the guidelines provided by the grout manufacturer. Welding to a base plate after grout installation, is not permitted.

In addition, cement based grouts should be capable of being pumped flow-able without segregation. They shall be free from materials known to increase drying shrinkage and/or compromise long-term durability.

Epoxy grouts shall not be used under high temperature (above 60 °C) machine plates.

12.3.5.3 *Grouting procedure*

Grouting shall be done in accordance with the procedure given below:

a) All metallic and concrete surfaces shall be thoroughly cleaned and washed to clean all dirt, oil, grease, loose particles and cement laitance.
b) The concrete surfaces shall be roughened and saturated with clean water and kept wet for at least 24 h and all surplus water removed and dried.
c) Forms shall be high enough to provide a head of the grout on all sides which shall be about 150 mm high on side from which cement grout is to be poured. Forms shall be placed with sufficient clearance from the edges to enable smooth flow of grout. Forms shall be strong and secure and well covered to prevent leakage. Wherever necessary, pressure grouting may also be resorted to.
d) Necessary provision shall be made to avoid trapping of air. Air relief holes, wherever necessary shall be provided.
e) The grout shall be poured from one side to avoid forming air pockets and be carried out continuously without interruption so that filling is continuous and dense.
f) On completion of the grouting operation, exposed areas should be thoroughly cured and grout shall be protected from extreme drying conditions.
g) Machine manufacturer’s recommendations, if any, should be followed while placing the grout.
h) Reaction of the grout to oil or other chemicals shall be prevented so as to permit the grout to discharge its function of transfer of machine loads to the foundation effectively. All exposed surfaces of the grout shall be given two coats of oil and alkali resistant coating.

12.3.6 *Embedded Parts (Embedments)*

Embedded parts are necessary elements of any machine foundation. These are required to be placed at specified position/location on the foundation to support piping, valves, bellows, ducts, etc, which are not necessary part of the machine but are essential for machine operation. These embedments are generally anchor bolts/foundation bolts, sleeves for bolts insert plates with welded support lugs etc. All embedded parts shall be properly designed. Anchor/Foundation bolts shall be positioned with appropriate templates. All embedded parts shall be thoroughly cleaned of oils/greases or any other foreign materials before putting in position.

While placing these embedded parts on the foundation, it shall be ensured that lugs of the embedments are not welded to concrete main reinforcement.

Use of edge protection angles are not recommended as these are being misused to support mechanical items arbitrarily.

12.3.6.1 Tolerances for embedded parts shall be as given below:

a) Anchor/Bolts without sleeve:
   1) ±1.5 mm in plan; and
   2) ±1.5 mm in elevation.

b) Anchor/Bolts with sleeve:
   1) ±5 mm in elevation;
   2) Bolts up to 28 mm dia ± 5 mm in all directions; and
   3) Bolts 32 mm dia 7 above ± 3 mm in all directions.

c) Embedded parts ±5 mm in all directions

13 INFLUENCE OF VIBRATION ON INPLANT FOUNDATIONS, STRUCTURESAND ADJOINING BUILDINGS

Transmission of vibration from dynamic machines (machines producing vibrations) is a common phenomenon. These vibrations affect performance of sensitive equipment used for calibration. In addition, these may also induce vibrations in adjoining structures within the plant complex.

In view of wide variations in machine parameters like ratings, speeds, functionalities etc, there is no single solution to cover all such vibration issues. To minimise the influence, it is, however, recommended that depth of machine foundation be provided more than depth of foundations for adjoining equipment and structures. In case of excessive vibrations, the calibrating equipment should be supported using vibration isolation system.

In case there are residential buildings adjoining industrial complex, the vibration transmission from the machines can be disturbing to the residents. Vibration velocities up to 2.5 mm/s, measured on adjoining building floors, should be considered as acceptable.

ANNEX B
(*Clauses* 4.4.1 *and* 4.4.1.1)

ESTIMATION/DETERMINATION OF DYNAMIC PILE STIFFNESS

B-1 ESTIMATION OF THEORETICAL PILE STIFFNESS

In general, the dynamic stiffness of piles can be estimated theoretically as per the procedure given in **A-1.1**.

B-1.1 Stiffness and Damping Constants of Single Pile-Soil System

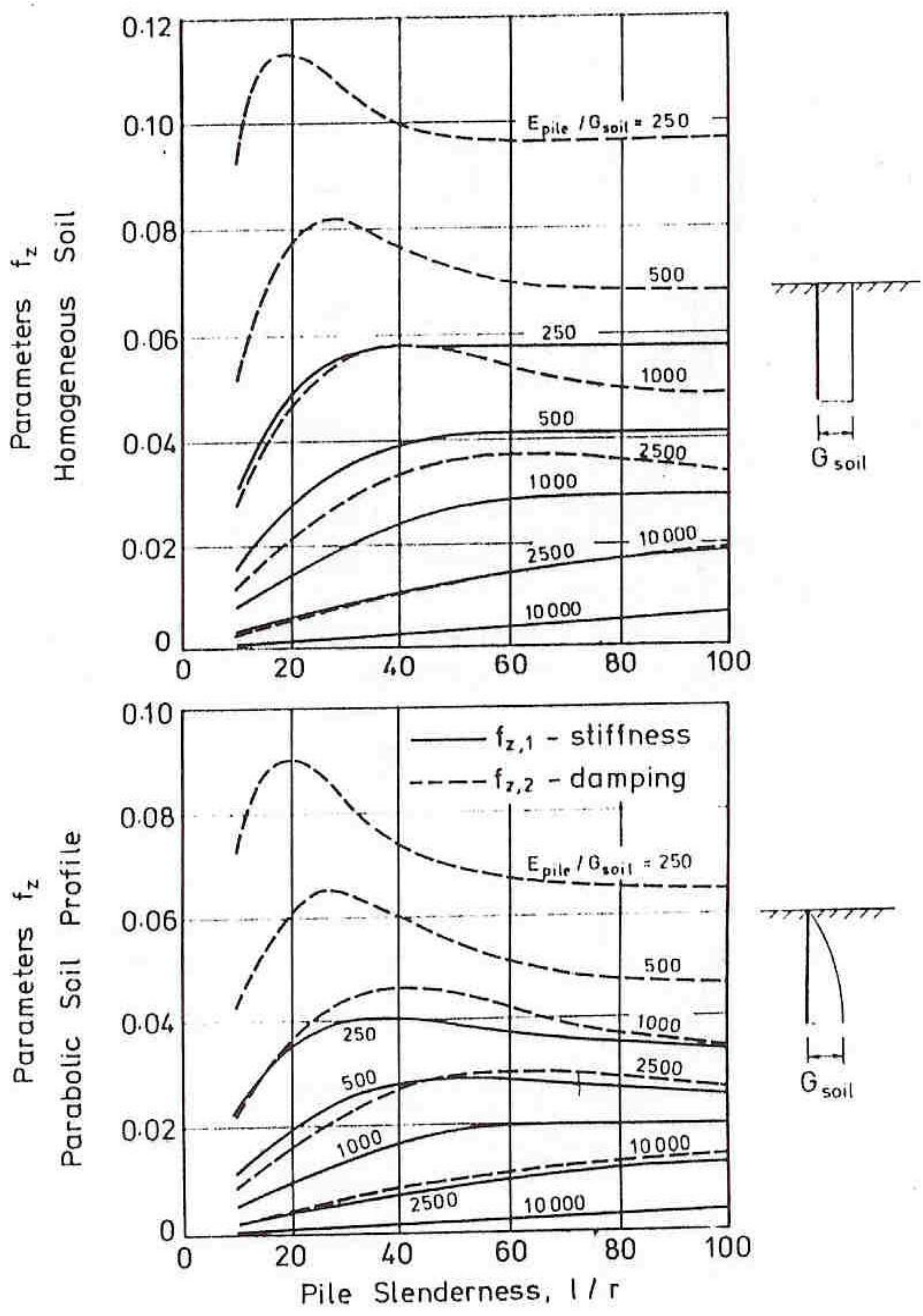
The formulae for estimating the stiffness and damping constants of single pile-soil system for various modes of vibration are given in Table 3.

Table 3 Stiffness and Damping Constants of Single Pile
(*Clause* B-1.1)

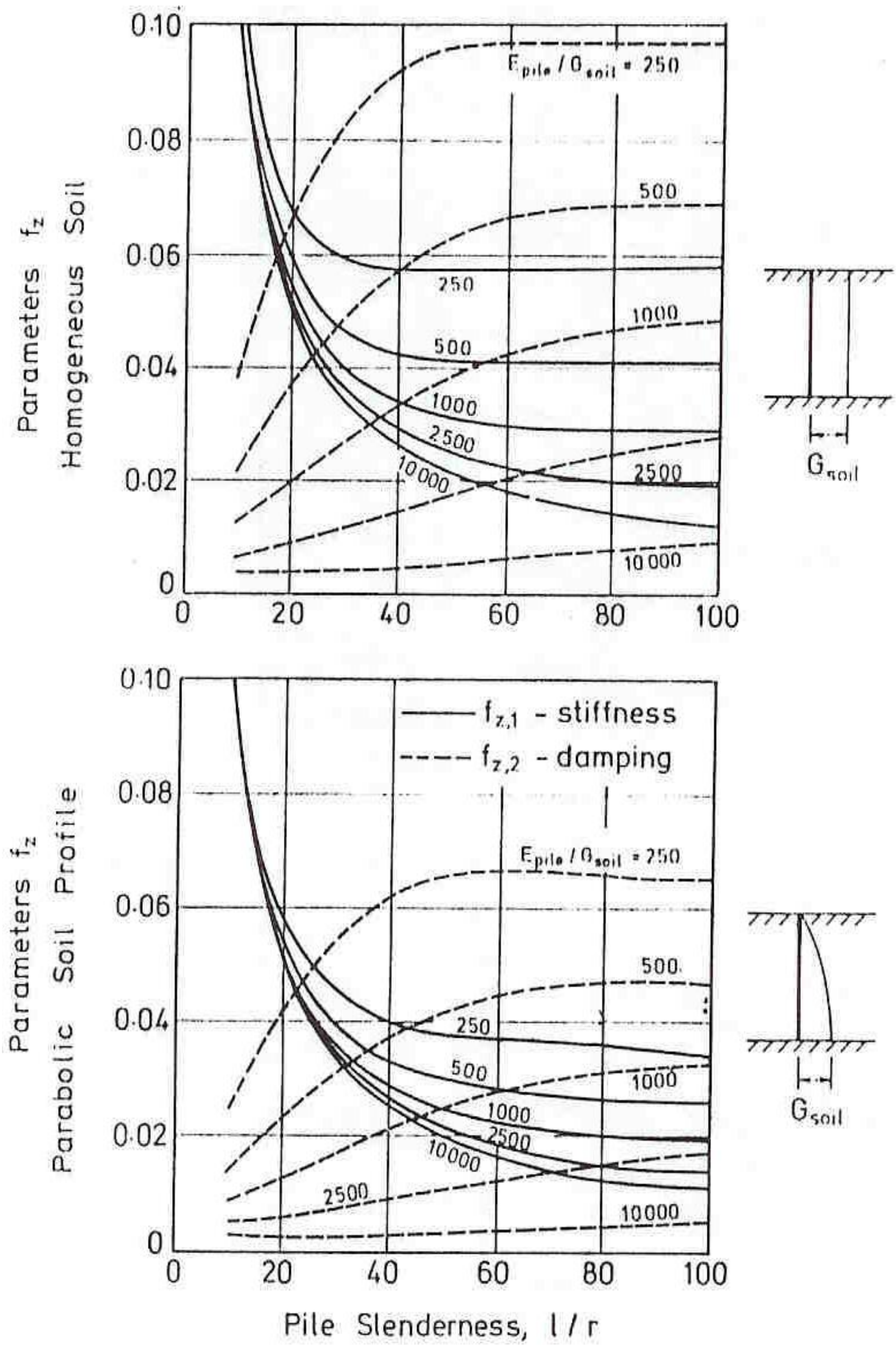
Sl No.	Mode of Vibration	Stiffness Constant	Damping Constant
(1)	(2)	(3)	(4)
i)	Vertical	$k_z^1 = \frac{E_p A_p}{r_o} f_{w1}$	$c_z^1 = \frac{E_p A_p}{V_s} f_{w2}$
ii)	Lateral	$k_x^1 = \frac{E_p I_p}{r_o^3} f_{x1}$	$c_z^1 = \frac{E_p I_p}{r_o^2 V_s} f_{x2}$
iii)	Rocking	$k_\phi^1 = \frac{E_p I_p}{r_o} f_{\phi1}$	$c_\phi^1 = \frac{E_p I_p}{V_s} f_{\phi2}$
iv)	Torsional	$k_\psi^1 = \frac{G_p J}{r_o} f_{T1}$	$c_\psi^1 = \frac{G_p J}{V_s} f_{T2}$
v)	Coupled horizontal, lateral and rotation	$k_c^{'} = \frac{E_p I_p}{r_o^2} f_{c1}$	$c_c^{'} = \frac{E_p I_p}{r_o V_s} f_{c2}$

Where,

E_P	Elastic modulus of pile material, in N/m^2
A_p	Area of the pile cross-section, in m^2
I_p	Moment of inertia of pile material, in m^4
r_o	Radius of pile, in m
f_{w1} and f_{w2}	Stiffness and damping constants for vertical vibration respectively
f_{x1} and f_{x2}	Stiffness and damping constants for lateral vibration respectively
$f_{\phi1}$ and $f_{\phi2}$	Stiffness and damping constants for rocking vibration respectively
f_{T1} and f_{T2}	Stiffness and damping constants for torsional vibration respectively
f_{c1} and f_{c2}	Stiffness and damping constants for coupled vibration respectively
V_s	Shear wave velocity, in m/sec
G_p	Shear modulus of pile material
J	Polar moment of inertia, in m^4

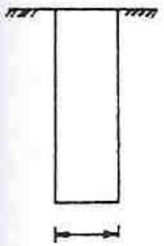
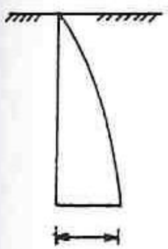


11 A Floating piles



11 B End bearing piles

Fig. 12 Stiffness and damping parameters for vertical response of piles

	ν	$\frac{E_{pile}}{G_{soil}}$	Stiffness parameters				Damping parameters			
			$f_{\psi,1}$	$f_{c,1}$	$f_{x,1}$	$f^{p*}_{x,1}$	$f_{\psi,2}$	$f_{c,2}$	$f_{x,2}$	$f^{p}_{x,2}$
Homogeneous soil profile										
		10000	0.2135	−0.0217	0.0042	0.0021	0.1577	−0.0333	0.0107	0.0054
		2500	0.2998	−0.0429	0.0119	0.0061	0.2152	−0.0646	0.0297	0.0154
	0.25	1000	0.3741	−0.0668	0.0236	0.0123	0.2598	−0.0985	0.0579	0.0306
		500	0.4411	−0.0929	0.0395	0.0210	0.2953	−0.1337	0.0953	0.0514
		250	0.5186	−0.1281	0.0659	0.0358	0.3299	−0.1786	0.1556	0.0864
		10000	0.2207	−0.0232	0.0047	0.0024	0.1634	−0.0358	0.0119	0.0060
		2500	0.3097	−0.0459	0.0132	0.0068	0.2224	−0.0692	0.0329	0.0171
G_{soil}	0.40	1000	0.3860	−0.0714	0.0261	0.0136	0.2677	−0.1052	0.0641	0.0339
		500	0.4547	−0.0991	0.0436	0.0231	0.3034	−0.1425	0.1054	0.0570
		250	0.5336	−0.1365	0.0726	0.0394	0.3377	−0.1896	0.1717	0.0957
Parabolic soil profile										
		10000	0.1800	−0.0144	0.0019	0.0008	0.1450	−0.0252	0.0060	0.0028
		2500	0.2452	−0.0267	0.0047	0.0020	0.2025	−0.0484	0.0159	0.0076
	0.25	1000	0.3000	−0.0400	0.0086	0.0037	0.2499	−0.0757	0.0303	0.0147
		500	0.3489	−0.0543	0.0136	0.0059	0.2910	−0.1008	0.0491	0.0241
		250	0.4049	−0.0734	0.0215	0.0094	0.3361	−0.1370	0.0793	0.0398
		10000	0.1857	−0.0153	0.0020	0.0009	0.1508	−0.0271	0.0067	0.0031
		2500	0.2529	−0.0284	0.0051	0.0022	0.2101	−0.0519	0.0177	0.0084
G_{soil}	0.40	1000	0.3094	−0.0426	0.0094	0.0041	0.2589	−0.0790	0.0336	0.0163
		500	0.3596	−0.0577	0.0149	0.0065	0.3009	−0.1079	0.0544	0.0269
		250	0.4170	−0.0780	0.0236	0.0103	0.3468	−0.1461	0.0880	0.0443

*Superscript p refers to pinned head piles.

Fig. 12 Stiffness and damping parameters for lateral response of piles

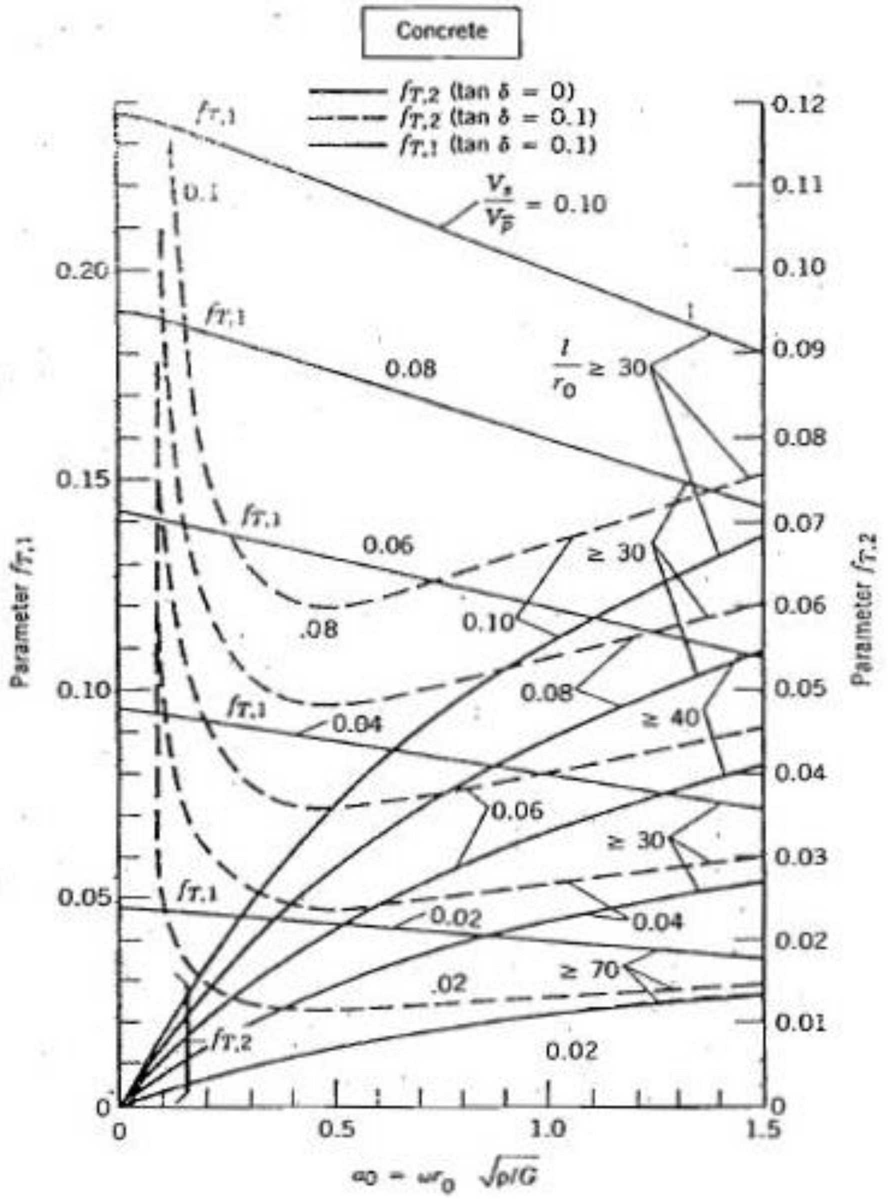


Fig. 13 Torsional stiffness and damping parameters of single piles

NOTES

1 It may be noted that the formulae given in B-1.1 are based on the assumption of linear behaviour of soils.

2 If shear wave velocity profiles are measured directly at the site, then it can be decided to use either 'constant soil modulus' or 'parabolic soil modulus' conditions based on the variation of shear wave velocity or shear modulus. Otherwise, depending on the predominant nature of soil type of different layers along the pile length, either constant soil modulus or parabolic soil modulus conditions can be used. For layers having predominantly silty and/sand, 'parabolic soil modulus' condition can be assumed. For layers having predominantly clay/clayey silt, 'constant soil modulus' condition can be assumed.

3 Depending on the pile tip conditions Fig. 11 A or Fig. 11 B may be chosen.

4 For lateral stiffness and damping constants of piles, the pile head conditions: free head or fixed head may be chosen in Fig. 12, based on the site conditions. For torsional stiffness and damping parameters of single piles, Fig. 13 is to be used.

5 Shear modulus obtained from wave velocity is typically maximum, which is likely to reduce at relatively higher strain levels produced during machine vibration. For sites having soft/loose to medium deposits ($V_s \approx$ 150 – 200 m/s), shear modulus obtained based on wave velocity or SPT N-value may be reduced by 20-30 percent, before using it in the above formulae.

B-2 STIFFNESS FROM DYNAMIC PILE LOAD TEST

The stiffness and damping of piles may also be obtained by conducting in-situ dynamic pile load tests as per IS 9716.

The stiffness and damping of piles estimated theoretically using the procedure given in **B-1** shall be verified through field dynamic pile load tests conducted as per IS 9716, for the following cases:

a) For very important machines to be supported on pile foundation; and
b) For sites having very soft clay/loose sand deposits ($V_s <$ 150 m/s), as such sites are likely to exhibit strong non-linear behaviour of soils.

For other cases, the design engineer shall decide on the requirement of conducting pile load tests depending upon the importance and criticality of the machine, sub-strata characterisation, etc.

ANNEX C

(*Clause* 7)

Machine Data Required for Various Machine Types

C-1 The machine data required for various machine types shall be as per the table below:

Sl No.	Required Data for Machines	Rotary Machine											Reciprocating Machines		
		Steam Turbine	Gas Turbine	Hydro Turbine	Motor	Compressor	Generator	Fan	Pumps	Blower	Crusher	Bowl Mill	Compressor	Engine	Pump
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
1	Total weight of machine (stator + rotor) including base frame, if any	√	√	√	√	√	√	√	√	√	√	√	√	√	√
2	Weight of rotating parts (rotor only)	√	√	√	√	√	√	√	√	√		√			
3	Number of impeller blades	--	-	-	-	-	-	√	√	√					
4	Operating speed	√	√	√	√	√	√	√	√	√		√	√	√	√
5	Rotor critical speed/speeds	√	√	√	√	√	√	√	√	√		√			
6	Permissible amplitude of vibration at (bearing level)	√	√	√	√	√	√	√	√	√		√			
7	Machine centroid location (in all three directions)	√	√	√	√	√	√	√	√	√		√			
8	Coupling details - Rigid coupling/flexible coupling/gear box	√	√	√	√	√	√	√	√	√		√	√	√	√
9	Bearing support system - Whether end shield bearings or pedestal bearings	√	√	√	√	√	√	√	√	√		√	√	√	√

Sl No.	Required Data for Machines	Rotary Machine											Reciprocating Machines		
		Steam Turbine	**Gas Turbine**	**Hydro Turbine**	**Motor**	**Compressor**	**Generator**	**Fan**	**Pumps**	**Blower**	**Crusher**	**Bowl Mill**	**Compressor**	**Engine**	**Pump**
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
10	Weight of bearing pedestal (where applicable)	√	√	√	√	√	√	√	√	√			√	√	√
11	Balance quality grade	√	√	√	√	√	√	√	√	√		√			
12	Unbalanced dynamic loads at bearing locations														
12 a)	*At 1st harmonic (operating speed)*	√	√	√	√	√	√	√	√	√		√	√	√	√
12 b)	*At 2nd harmonic (twice operating speed)*												√	√	√
13	Abnormal/emergency loads														
13 a)	*Load due to broken blade (blade failure loads)*	√	√	√		√		√	√	√					
13 b)	*Load due to broken hammer*										√				
13 c)	*Short circuit load/torque*				√		√								
13 d)	*Elctro-dynamic load (If any)*				√		√								
13 e)	*Thermal frictional loads*	√	√												
13 f)	*Temperature gradients*	√	√												
13 g)	*Bearing failure loads (optional)*	√	√	√	√	√	√	√	√	√		√			

ANNEX D
(*Clause* 10.1.1)

DYNAMIC FORCES GENERATED BY MACHINES

D-1 ROTARY MACHINES

Unbalanced forces in rotary machines are generated when the mass centroid of the rotating part does not coincide with the centre of rotation (see Fig.14). This unbalance force (F_o) is a function of the mass of the rotor (m), speed of rotation (ω), and eccentricity (e) of mass with reference to centre of rotation.

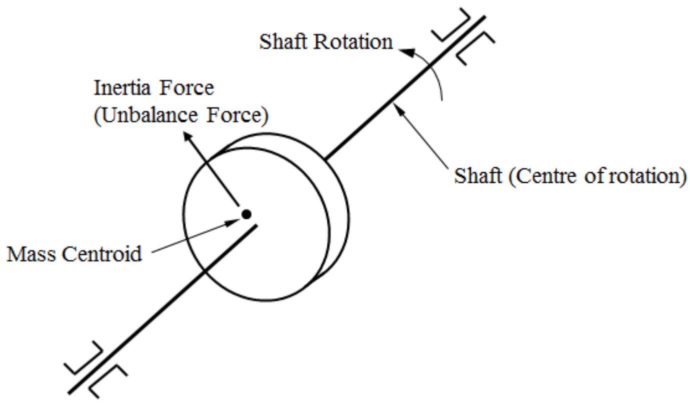


Fig. 14 Rotary Machine Diagram

Therefore, Unbalance force $F_o = me\omega^2 = mG\omega$

Where,

G = Balance quality grade (mm/sec)

Rigid Rotor:

A rigid rotor is defined as the one where the flexure caused by its unbalance distribution can be neglected with respect to the agreed unbalance tolerance at any speed up to the maximum service speed.

The rotor is balanced to a required balance quality grade. Balance quality grade of a rotor depends on operating speed and intended use of machine. IS/ISO 21940-11 can be referred for the recommended balance quality grade for rigid rotors of all type machines.

Flexible Rotor:

A flexible rotor is defined as the one where the flexure caused by its unbalance distribution cannot be neglected with respect to the agreed unbalance tolerance at any speed up to the maximum service speed.

In case of flexible rotors, eccentricity under operating condition is the sum of eccentricity due to imperfection during manufacturing and dynamic amplitude of vibration of rotor. Calculation of unbalance force of flexible rotor is complex and will be done by machine manufacturer.

D-2 RECIPROCATING MACHINES

The simplest type of reciprocating machine uses a single crank mechanism as shown in Fig. 15. The idealization of this mechanism consists of a piston that moves within a guiding cylinder, a crank that rotates about a crank shaft, and a connecting rod. The connecting rod is attached to the piston at point P and to the crank at point C. The wrist pin P oscillates while the crank pin C follows a circular path. This idealized single cylinder illustrates the concept of a machine producing both primary and secondary reciprocating forces.

Most reciprocating machines have more than one cylinder, and manufacturers arrange the machine components in a manner that minimizes the net unbalanced forces. The forces generated by reciprocating mechanisms are functions of the mass, stroke, piston arrangement, connecting rod size, crank throw orientation (phase angle), and the mass and arrangement of counterweights on the crankshaft. For this reason, calculating the reciprocating forces for multi-cylinder machines can be quite complex and are therefore normally provided by the machine manufacturer.

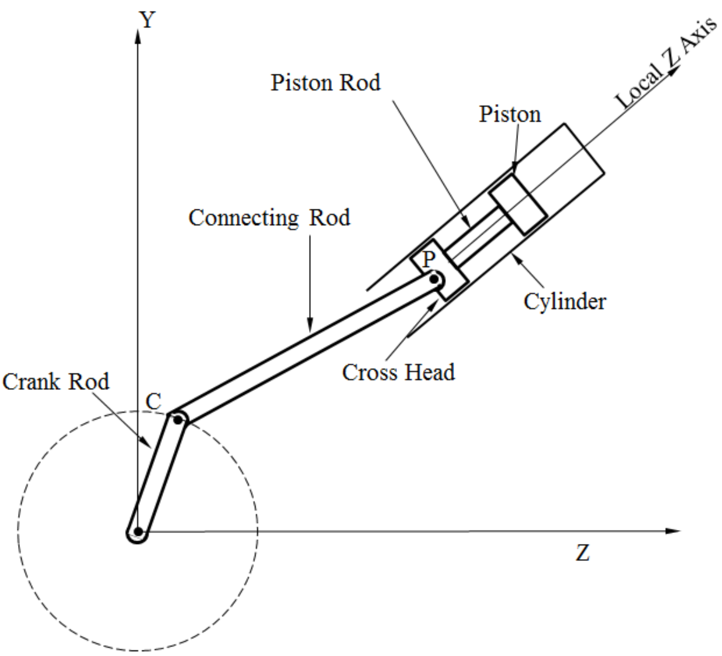


Fig. 15 Reciprocating Machine Diagram