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व्यापक परिचालन मसौदा

हमारा संदर्भ : सीईडी 43/टी-65 **18 जून 2021**

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

प्राप्तकर्ता :
1 सिविल इंजीनियरी विभाग परिषद के सभी सदस्य
2 मृदा एवं नींव इंजीनियरिंग विषय समिति, सीईडी 43 के सभी सदस्य
3 आईएस 2974 के पुनरीक्षण के लिए मसौदा तैयार करने के लिए तदर्थ पैनल, सीईडी 43:पी8 के सभी सदस्य
4 रूचि रखने वाले अन्य निकाय।

महोदय/महोदया,

निम्नलिखित मसौदा संलग्न है:

प्रलेख संख्या	शीर्षक
सीईडी 43 (14226)WC	**मशीनों की नींव का डिज़ाइन एवं निर्माण - रीति संहिता: भाग 5 कंपन पृथक्ककरण पर समर्थित मशीनों (हैमर एवं प्रेसेस के सिवा) की नींव का भारतीय मानक मसौदा [IS 2974 (भाग 1 से 5) का पुनरीक्षण]** **(आई सी एस संख्या : 93.020)**

कृपया इस मसौदे का अवलोकन करें और अपनी सम्मतियाँ यह बताते हुए भेजे कि यह मसौदा प्रकाशित हो तो इन पर अमल करने में, आपको व्यवसाय अथवा कारोबार में क्या कठिनाइयाँ आ सकती हैं।

सम्मतियाँ भेजने की अंतिम तिथि: 18 जुलाई 2021

सम्मति यदि कोई हो तो कृपया अधोहस्ताक्षरी को ई मेल द्वारा madhurima@bis.gov.in पर या उपरलिखित पते पर, संलग्न फोर्मेट में भेजें।

यदि कोई सम्मति प्राप्त नहीं होती है अथवा सम्मति में केवल भाषा संबंधी त्रुटि हुई तो उपरोक्त प्रलेख को यथावत अंतिम रूप दे 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 प्रलेख को अंतिम रूप दे दिया जाएगा।

यह प्रलेख भारतीय मानक ब्यूरो की वैबसाइट www.bis.gov.in पर भी उपलब्ध हैं।

धन्यवाद।

भवदीय

ह/-

(संजय पंत)
प्रमुख (सिविल इंजीनियरिंग)

सलंग्न: उपरिलिखित

भारतीय मानक ब्यूरो
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DOCUMENT DESPATCH ADVICE

Reference	Date
CED 43/T-65	18 June 2021

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
3. All Members of the Adhoc Panel for Preparation of Drafts for the Revision of IS 2974, CED 43:P8
4. All others interested

Dear Sir/Madam,

Please find enclosed the following draft:

Doc. No.	Title
CED 43 (14226)WC	**Draft Indian Standard Design and Construction of Machine Foundations— Code of Practice: Part 5 Machine Foundations (Excluding Foundations for Hammers and Presses) Supported on Vibration Isolation System [Revision of IS 2974 (Parts 1 to 5)] (ICS No. 93.020)**

Kindly examine the draft revision 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 Standards.

Last Date for comments: **18 July 2021**

Comments if any, may please be made in the enclosed format and emailed at **madhurima@bis.gov.in** or sent at the above address.

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, 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/-

(Sanjay Pant)
Head (Civil Engg.)

Encl: As above

BUREAU OF INDIAN STANDARDS

DRAFT FOR COMMENT ONLY

Draft Indian Standard

DESIGN AND CONSTRUCTION OF MACHINE FOUNDATIONS – CODE OF PRACTICE

PART 5 MACHINE FOUNDATIONS (EXCLUDING FOUNDATIONS FOR HAMMERS AND PRESSES) SUPPORTED ON VIBRATION ISOLATION SYSTEM

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

Soil and Foundation Engineering Sectional Committee, CED 43	Last date for Comment: **18 July 2021**

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, 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 such purposes that, the Indian Standard IS 2974 'Code of practice for design and construction of machine foundations' was published in five parts covering foundations for host of machines. The various parts of the standard were published and revised as per the details given below:

	Title of Various Parts	*First published in*	*Subsequently revised in*
Part 1	Foundations for reciprocating type machines	1964	1969 and 1982
Part 2	Foundations for impact type machines	1966	1980
Part 3	Foundations for rotary type machines (medium and high frequency)	1967	1975 and 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 1987

Over the years, improvement in manufacturing technology has provided machines of higher ratings with better tolerances and controlled behaviour. The increased dependence on such machines 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 or 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 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 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 all the existing parts of the standard to meet the current demand of satisfactory performance of machines with no room for failure. While restructuring these standards, it was decided to restructure the standard 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 better clarity in design and construction of the foundations. 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 Machine foundations (excluding foundations for hammers and presses) supported on vibration isolation system,
Part 6 Machines supported on superstructures,
Part 7 Machines supported on strip footings, and
Part 8 Machines supported on common mat/raft.

This Part 5 deals with specific provisions relating to design and construction of machine foundations supported on vibration isolation system. Such foundations for hammers and presses have not been covered in this part of the standard, they being covered in Part 4. The Part 1 of the standard is a necessary adjunct to this part and shall be referred for general provisions.

In the design and construction of foundations for all the machines, a proper coordination between 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.

When making the foundation plans, the main unit should be provided with all its auxiliaries and adjacent piping, 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 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 (14226)WC
June 2021

BUREAU OF INDIAN STANDARDS

DRAFT FOR COMMENT ONLY

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Draft Indian Standard

DESIGN AND CONSTRUCTION OF MACHINE FOUNDATIONS – CODE OF PRACTICE

PART 5 MACHINE FOUNDATIONS (EXCLUDING FOUNDATIONS FOR HAMMERS AND PRESSES) SUPPORTED ON VIBRATION ISOLATION SYSTEM

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

Soil and Foundation Engineering Sectional Committee, CED 43	Last date for Comment: **18 July 2021**

1 SCOPE

1.1 This standard (Part 5) deals with the design and construction of foundations and structures supporting variety of rotary and reciprocating machines supported on vibration isolation system (VIS) associated with the industries listed in IS 2974 (Part 1).

1.2 The foundations of hammers and presses on VIS are not covered in this part and are covered in IS 2974 (Part 4).

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 456:2000	Plain and reinforced concrete – Code of practice (*fourth revision*)
IS 800:2007	General construction in steel – Code of practice (*third revision*)
IS 2974	Design and construction of machine foundations — Code of practice
(Part 1):XXXX	Part 1 General provisions (*under preparation*)
(Part 2): XXXX	Part 2 Block foundations (*under preparation*)
(Part 3): XXXX	Part 3 Frame foundations (*under preparation*)
(Part 4): XXXX	Part 4 Foundations for hammers and presses (*under preparation*)
IS 13301:1992	Vibration isolation for machine foundations — Guidelines

3 TERMINOLOGY

For the purpose of this standard, the terminology given in IS 2974 (Part 1) shall apply in addition to those given below.

3.1 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.

3.2 Damper – A device that dissipates energy.

3.3 Excitation Force (F_{E}) – Force generated by the machine at operating speed/frequency.

3.4 Inertia Block – The concrete block supporting the machine which in turn is supported over the vibration isolators.

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

3.6 Spring – A device that stores energy when deflected and returns the same amount of energy when released (for example, steel springs, elastic pads, etc).

3.7 Substructure Frame – The structural frame [steel or reinforced cement concrete (RCC)] that supports machine and inertia block through vibration isolators. This structural frame is in turn supported on the soil or pile groups.

3.8 Transmissibility Ratio (TR) – Ratio of transmitted force to the excitation force.

3.9 Transmitted Force (F_{T}) – Force transmitted to the foundation through the isolator.

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

3.10.1 *Active Isolation* – Reduction of vibration generated by machine itself and transmitted to the surrounding.

3.10.2 *Passive Isolation* — Reduction of vibration transmitted from external sources to the equipment/machine through the foundation.

3.11 Vibration Isolator — A device comprising spring(s) with or without damper(s).

4 SYMBOLS

Symbol	Description	Unit
ζ	Damping ratio	-
f	Circular frequency	Hz (Cycles/s)
f_{e}	Operating frequency	Hz (Cycles/s)
f_{n}	Natural frequency	Hz (Cycles/s)
f_{nx}	Natural frequency in x-direction	Hz (Cycles/s)

f_{ny}	Natural frequency in y-direction	Hz (Cycles/s)
f_{nz}	Natural frequency in z-direction	Hz (Cycles/s)
f_{nxx}	Rotational natural frequency about x-direction	Hz (Cycles/s)
f_{nyy}	Rotational natural frequency about y-direction	Hz (Cycles/s)
f_{nzz}	Rotational natural frequency about z-direction	Hz (Cycles/s)
N	Operating speed	rpm
ω_e	Operating frequency	rad/s
ω_n	Natural frequency	rad/s
β	Frequency ratio ($\frac{\omega_e}{\omega_n}$) or ($\frac{f_e}{f_n}$)	-
TR	Transmissibility ratio	-
k_{ix}	Translational stiffness of i^{th} isolator in x-direction	N/m
k_{iy}	Translational stiffness of i^{th} isolator in y-direction	N/m
k_{iz}	Translational stiffness of i^{th} isolator in z-direction	N/m
$k_{i\theta}$	Rotational stiffness of i^{th} isolator about x axis	N-m/rad
$k_{i\psi}$	Rotational stiffness of i^{th} isolator about y axis	N-m/rad
$k_{i\phi}$	Rotational stiffness of i^{th} isolator about z axis	N-m/rad
k_x	Translational stiffness of isolator(s) (summation of translational stiffnesses of all the isolators) in x-direction	N/m
k_y	Translational stiffness of isolator(s) (summation of translational stiffnesses of all the isolators) in y-direction	N/m
k_z	Translational stiffness of isolator(s) (summation of translational stiffnesses of all the isolators) in z-direction	N/m
k_θ	Rotational stiffness of isolator(s) (summation of rotational stiffnesses of all the isolators) about x-direction	N-m/rad
k_ψ	Rotational stiffness of isolator(s) (summation of rotational stiffnesses of all the isolators) about y-direction	N-m/rad
k_ϕ	Rotational stiffness of isolator(s) (summation of rotational stiffnesses of all the isolators) about z-direction	N-m/rad
M	Total mass on the top of the isolator	kg
M_x	Mass moment of inertia on the top of the isolator in x-direction	kg-m^2
M_y	Mass moment of inertia on the top of the isolator in y-direction	kg-m^2
M_z	Mass moment of inertia on the top of the isolator in z-direction	kg-m^2
e_x	Eccentricity in x-direction	m
e_y	Eccentricity in y-direction	m
e_z	Eccentricity in z-direction	m

5 GENERAL PRINCIPLES FOR DESIGN OF FOUNDATIONS FOR MACHINES SUPPORTED ON VIBRATION ISOLATION SYSTEM (VIS)

5.1 Need for Isolation

Vibrations are generated during operation of machines due to various reasons depending on type of machines. The vibration generated during machine operation gets transmitted to its foundation. Whenever transmitted force from the machine to the foundation or from foundation to equipment becomes excessive, VIS is provided to reduce such transmission to bring it to acceptable limits.

Transmission of high continuous vibration to the foundation and thereby to the adjoining structures/equipment is not desirable on account of the following:

a) High structural vibrations when machine is supported on superstructure,
b) Presence of sensitive equipment/machine in the vicinity, and
c) Prevention of consequential failures.

5.2 Types of Vibration Isolators

Different types of vibration isolators are as given below:

a) Isolators made of steel springs with or without dampers,
b) Isolators made of rubber or elastomeric pads, and
c) Cork sheets or pads as isolators.

The different types of vibration isolators are explained in **5.2.1** to **5.2.4**.

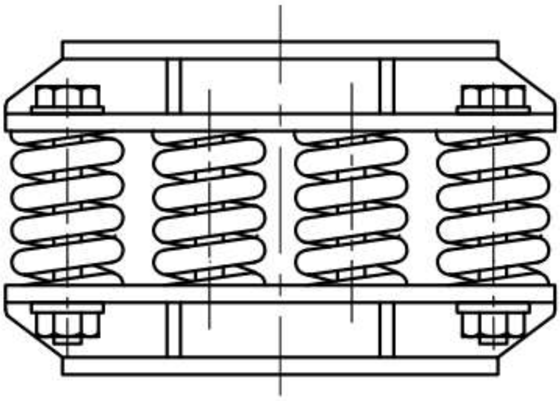
5.2.1 *Isolators Made of Steel Springs with/without Dampers*

Steel spring isolators (VIS module) generally consist of a set of individual springs of same height enclosed by top and bottom plates. Each VIS module has definite vertical and lateral stiffness.

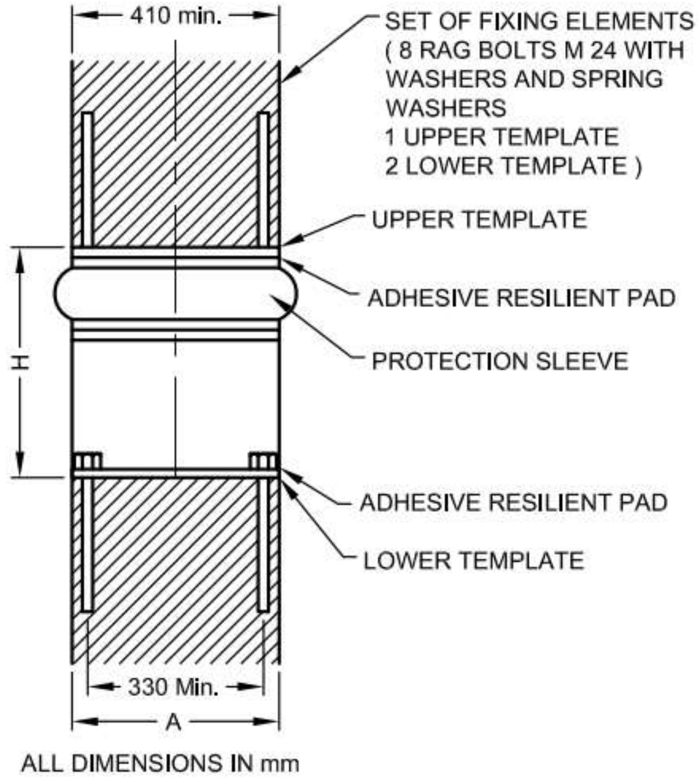
Dampers may be used along with these spring units to minimize the amplitude during transient resonance.

The centre of stiffness of spring assembly shall match the centre of base area of the VIS module.

A typical spring unit made of helical compression springs is shown in Fig.1A and a typical damper unit used in conjunction with the spring unit is shown in Fig.1B.



1A VIS Module with Springs Only



1B VIS Damper in Module

Fig.1 Typical VIS Module Made of Steel Springs

5.2.2 *Isolators Made of Rubber or Elastomer Pads*

Rubber or elastomer pads may be used as single element and/or as distributed pads/plates or mats. Typical rubber or elastomeric pads/plates or mats are shown in Fig. 2.

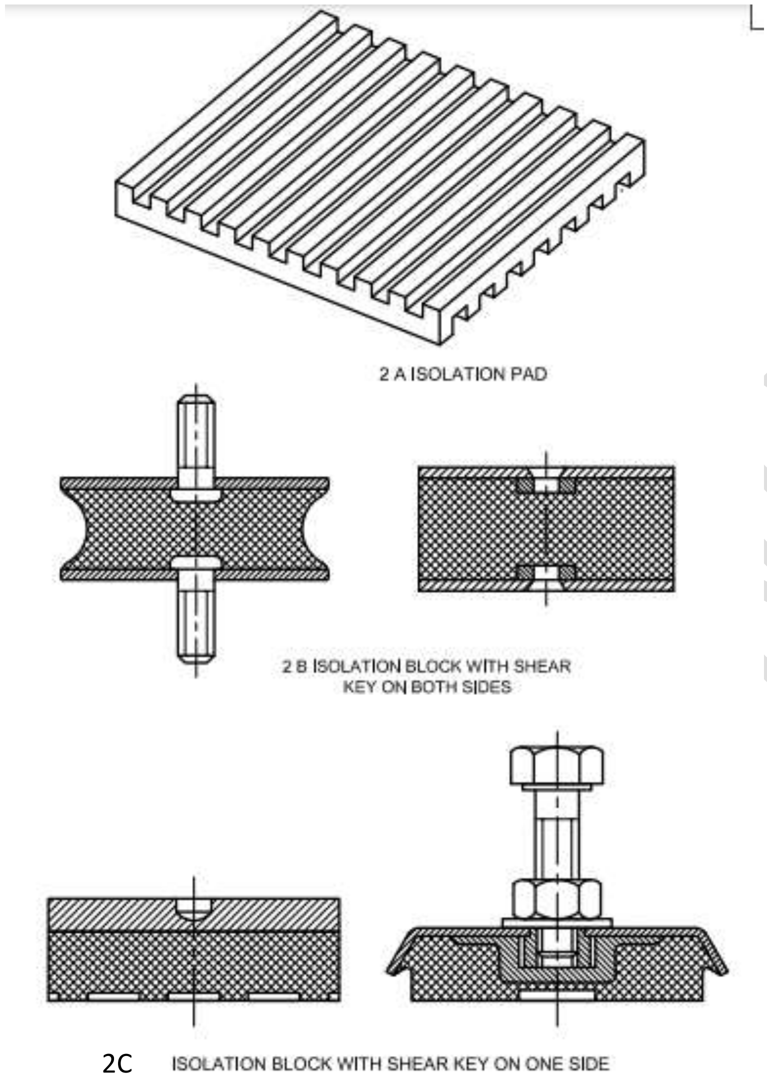


Fig. 2 Typical Isolators made of Rubber or Elastomer Pads/Plates or Mats

5.2.3 *Cork Sheets or Pads as Isolators*

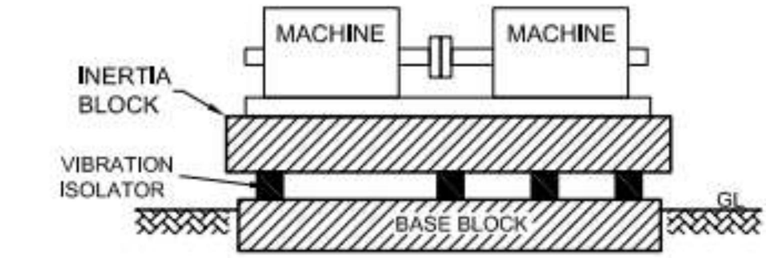
Cork may be used as vibration isolator by laying cork sheets or pads of required thickness below concrete inertia block. Cork sheets or pads are available in various sizes and thicknesses.

5.3 Types of Foundations with Vibration Isolators

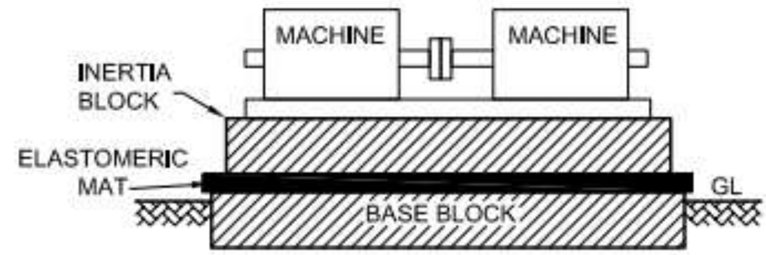
5.3.1 *Block Foundation with VIS*

In this system, machine is directly supported over the inertia block that rests over VIS, which in turn are supported over base block (*see* Fig. 3A, Fig. 3B and Fig. 3C).

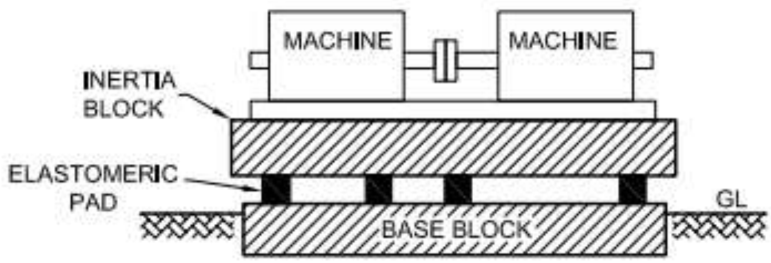
NOTE − Machines directly mounted over the isolators are not covered in this standard.



3A MACHINE SUPPORTED ON ISOLATOR THROUGH INERTIA BLOCK



3B MACHINE SUPPORTED ON ELASTOMERIC MAT THROUGH INERTIA BLOCK



3C MACHINE SUPPORTED ON DISCRETE ELASTOMERIC PADS THROUGH INERTIA BLOCK

Fig. 3 Block Foundation with Vibration Isolators

5.3.2 *Frame Foundation with VIS*

In this system, machine is directly supported over the inertia block that rests over VIS, which in turn is supported over frame type foundations (*see* Fig. 4).

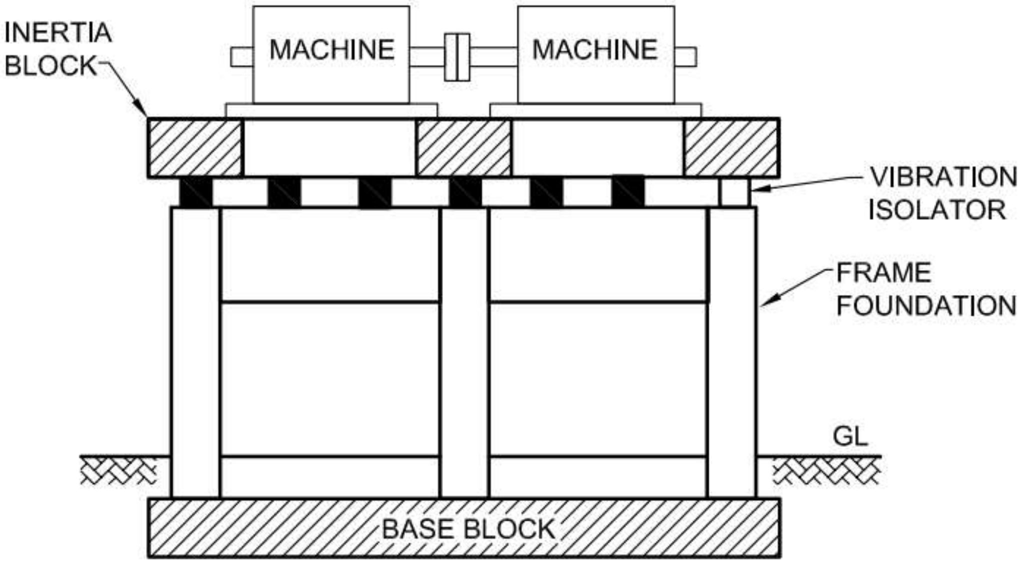


Fig. 4 Frame Foundation with Vibration Isolators

5.3.3 *Machines Supported over Superstructure with VIS*

In this system, machine is directly supported over the inertia block that rests over VIS, which in turn are supported over superstructure as shown in Fig. 5.

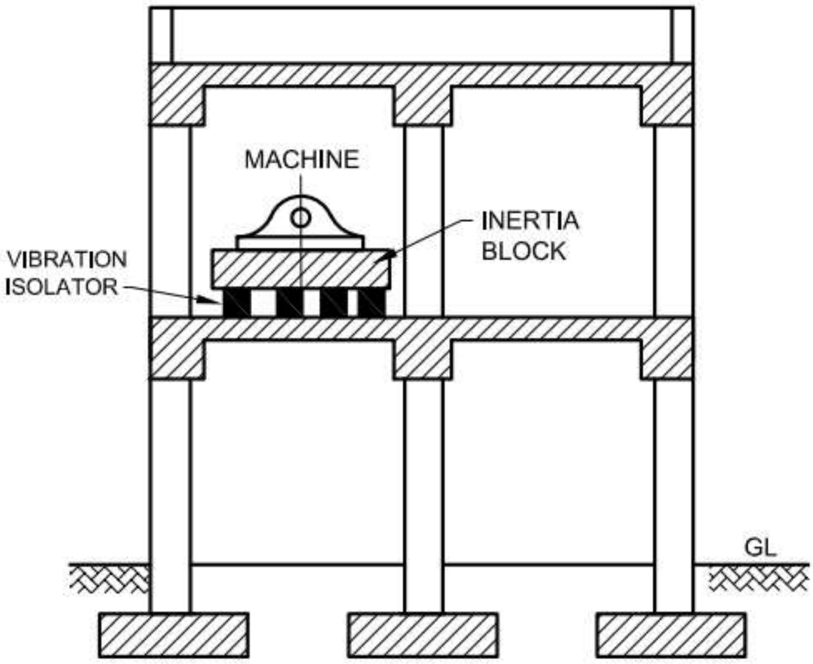


Fig. 5 Machine at Higher Elevation on Building/Structure
with Vibration Isolators

6 DESIGN PARAMETERS

6.1 Material and Geotechnical Data

The material and geotechnical data shall be in accordance with IS 2974 (Part 1).

6.2 Machine Data

The machine data shall be supplied by the machine manufacturer in accordance with IS 2974 (Part 1).

6.3 Vibration Isolators

The following parameters shall be obtained from the supplier of vibration isolator:

a) Steel springs with or without dampers;

1) Vertical stiffness;
2) Lateral stiffness;
3) Load carrying capacity (load-deflection diagram);
4) Damping characteristics (damping *vs* frequency);
5) Height and plan dimensions; and
6) Other factors of influence (such as creep, temperature, ageing, resistance to acids, moisture, fire resistance, maintenance requirements, etc).

b) Rubber or elastomeric pads

1) Elastic/shear modulus (load-deflection curve);
2) Poisson's ratio;
3) Density;
4) Plan sizes and thickness;
5) Damping characteristics (damping *versus* frequency); and
6) Other factors of influence (such as time, temperature, ageing, resistance to oils, moisture, fire resistance, maintenance requirements, etc).

NOTE — Since the stiffness and damping parameters of rubber or elastomer pads are dependent upon the type of loading (compression forces, shear forces, torsion moments, bending moments, or combinations thereof), care should be taken that the values given by manufacturer are in conformity to the same.

c) Cork sheets or pads

1) Elastic or shear modulus (load-deflection curve);
2) Poisson's ratio;
3) Density;
4) Plan sizes and thickness;
5) Damping characteristics (damping *versus* frequency); and
6) Other factors of influence (such as time, temperature, ageing, resistance to oils, water, moisture, fire resistance, maintenance requirements, etc).

7 DESIGN CRITERIA

7.1 Basic Design Requirements

The basic design requirements for foundations on VIS are as follows

a) *Block Foundation*

1) Block foundation shall consist of a RC base block supported over soil or pile and a RC inertia block supporting the machine; and isolators shall be placed in between base block and inertia block.

2) The inertia block shall be separated from adjoining foundations and structures.

3) Base block below VIS should be rigid enough to minimise differential deflection in base block between VIS.

Stiffness of base block (excluding effect of soil) should be at least ten times the total stiffness of all the VIS considered together over base block. Flexure stiffness, (EI/L) of base block may be calculated with span, L as distance between line of isolators, and I as least moment of inertia across span. The thickness of base block in line of Isolators should not be less than thickness of base block in between line of isolators. Alternatively, for assessing base block stiffness, an equivalent UDL under operating condition may be considered over line of isolators and maximum deflection be measured at any point on base block. The maximum deflection should not be more than $1/10^{th}$ of average deflection of isolators over base block.

Similarly, stiffness of inertia block should be at least ten times the total stiffness of all the VIS considered together below inertia block. Flexure stiffness, (EI/L) of inertia block may be calculated with span, L as distance between line of isolators, and I as least moment of Inertia across span. The thickness of Inertia block in line of Isolators should not be less than thickness of base block in between line of isolators. Alternatively, for assessing Inertia block stiffness, an equivalent UDL under operating condition may be considered over line of isolators and maximum deflection be measured at any point on inertia block. The maximum deflection should not be more than $1/10^{th}$ of average deflection of Isolators over inertia block.

As an approximate assessment, a solid block foundation shall be considered as rigid, provided the thickness *T* of the foundation block is greater than $0.4L$, where L is the greater plan dimension of the foundation.

4) A hollow base block foundation shall be considered as rigid, if the first natural frequency of each panel of the hollow block is more than 1.3 times the highest operating speed of the machine. The minimum thickness of each panel shall be 300 mm. These hollow blocks shall not be filled with any material. Further, air vents shall be provided in the portion above ground level to relieve the entrapped

air. Due care shall be taken to avoid water entry in to the hollow part through these air vents.

5) If the conditions as given in (3) and (4) above are not met, then the type of foundation under consideration (solid or hollow) becomes flexible foundation. Dynamic analysis shall be carried out with FE model duly accounting the actual block stiffness and not manual method where foundation block is considered rigid.

6) Base block can either be isolated block or common base raft with other static foundations.

7) Isolators which require maintenance shall be so placed that they are accessible for maintenance.

b) *Frame Foundation*

1) In frame foundations, there are two elements, namely, base frame and inertia block. Isolators are placed between base frame and inertia block.

2) Base frame is a framed structure made up of a set of columns and beams that support isolators. Vertical stiffness of isolator supporting members (flexure stiffness for beams and axial stiffness for columns) shall be more than ten times the stiffness of isolators placed over that member. Elastic shortening of all the columns should nearly be same.

3) The inertia block shall be separated from adjoining foundations and structures.

4) All columns of frame foundation shall be tied up at top of the column in both the directions. Wherever it is not feasible to connect columns laterally at the top, it shall be connected at a lower elevation such that the lateral stiffness of the unsupported length of the column top is not less than twice that of the isolator stiffness (vertical) supported over that column.

5) Vertical stiffness of the isolator supporting members should be more than ten times that of the respective isolator.

6) Frame foundation can either be in standalone mode or can be common with other static foundations.

7) Isolators which require maintenance shall be so placed that they are accessible for maintenance.

c) *Machines Supported over Superstructure with VIS*,

1) The inertia block on VIS is supported over structural beams.

2) The inertia block shall be separated from adjoining structure.

3) The flexure stiffness of each beam shall be more than ten times that of the isolators supported on that beam.

4) The lateral stiffness of entire structural system supporting the isolators shall be more than ten times that of the lateral stiffness of the isolators supported on that system. If not, the supporting structure shall also be modelled along with the isolators for isolation design. Lateral bracing arrangement between beams may be provided to meet the above criteria.

5) Isolators which require maintenance shall be so placed that they are accessible for maintenance.

7.1.1 The following steps shall be followed for design of foundation with VIS:

a) Selection of VIS as per **7.2** and Annex A and Annex B,
b) Calculation of isolation efficiency of the system, and
c) Calculation of vibration amplitude and compliance with IS 2974 (Part 1).

7.2 Design of VIS

7.2.1 *Selection of VIS and Design Criteria of Inertia Block*

The following shall be the criteria for selection of VIS and design of inertia block

a) Sizing of inertia block

   1) *Block foundation* – The mass of inertia block shall be minimum two times that of the machine to ensure that the flexural natural frequency of the inertia block are more than twice that of the sixth rigid body mode.

   2) *Frame foundation* – The mass of inertia block shall generally be 1.5 to 2 times that of the machine to ensure that the flexural natural frequency of the inertia block are more than twice that of the sixth rigid body mode.

b) The flexural natural frequency of inertia block (7^{th} mode onwards) shall be 20 percent away from operating speed and its harmonics as first 6 modes of vibration of the inertia block are rigid body modes (3 translational modes and 3 rotational modes).

c) The plan dimensions of the inertia block shall be sufficient to support the desired number of isolators required as per design.

d) Placement of isolators shall be such that the eccentricity between centre of vertical stiffness of the isolators and centre of mass of machine and inertia block should not be more than 1 percent (*see* Note). In other words, foundations as well as the layout of the vibration isolators shall be finalized such that the resultant force due to self-weight of machine and deck supported on isolators pass through the centroid of the vertical stiffness of the isolators. In case, where small eccentricities are unavoidable, an eccentricity of up to 1.5 percent may be allowed for both block foundation and frame foundation.

NOTE — Eccentricity in percent is the eccentricity in a direction is equal to eccentricity between centre of mass and centre of stiffness in that direction divided by plan dimension in that direction multiplied by 100.

e) Isolators shall be placed (1) directly over the base block for block foundation, and (2) directly over beams/columns for frame foundations. While selecting isolators, effort should be made such that all isolators are of same characteristic. This shall ensure avoiding chances of wrongly placing isolators as well as minimize inventory stock. Suggestive method for selection of isolators is given in Annex B.

f) The maximum vertical reaction due to self-weight of machine and inertia block shall be limited to 80 percent of the load carrying capacity of the isolator.

g) The maximum vertical reaction due to normal operating load conditions of machine as well as due to emergency load conditions such as blade failure, short circuit, seismic/wind etc, shall be less than the full load carrying capacity of the isolator.

h) Foundation shall be dimensioned and designed in such a way that dynamic performance requirements (amplitude) as specified in IS 2974 (Part 1) are met.

j) Strength design – The inertia block should be designed such that integrity of foundation shall be maintained under all operational and emergency loading condition.

k) Design life of the isolators should match with plant life. The isolators shall be suitable for temperature ranging from 0°C to 60°C. Stiffness of Isolators shall be determined from individual spring capacity in an Isolator for its designed fatigue life.

m) The VIS shall be designed in such a way that foundation system achieves isolation efficiency of 90 percent or above.

Isolation efficiency = $(1 - TR) \times 100$ percent

where,

$$TR = \frac{F_{\mathrm{T}}}{F_{\mathrm{E}}} = \frac{\sqrt{1+(2\beta\zeta)^2}}{\sqrt{(1-\beta^2)^2+(2\beta\zeta)^2}}$$

and F_{E} is excitation force and F_{T} is the transmitted force.

NOTES

1 Annex A shall be referred for principle of vibration isolation.

2 Annex B shall be referred for steps for selection of vibration isolation system for machine foundation resting over base block.

n) The viscous fluid should be time tested to prove that material property does not get changed with time. Accelerated performance test for visco-liquid should confirm non-changeability of its property in lifetime of plant. The viscous fluid shall have practically same material properties in the commonly exposed weather condition including temperature condition during whole plant life.

o) The damper units or spring cum damper units should be of viscous type offering velocity proportional damping. The damping resistance of the individual damper units shall be such that the designed damping can be provided using reasonable number of units.

p) All the VIS modules in same category should have same deflection under its rated load carrying capacity.

q) The VIS module shall consist of a number of springs with same or different stiffness properties. The total number of springs in a VIS module should be even and structurally stable under its maximum load capacity.

r) The springs shall conform to the requirements specified in IS 13301 (*revision under preparation*).

s) The spring units shall have definite stiffness in both vertical and horizontal directions with the horizontal stiffness not less than 50 percent of vertical stiffness. The stiffness of Isolator should be such that the vertical natural frequency of any spring unit at its rated load carrying capacity is between 2.2 Hz to 3.8 Hz.

t) The VIS module in the same foundation should have same deflection under its rated load carrying capacity. The VIS modules having same deflection under its respective maximum rated load are categorised in same category. Plan dimension of the modules of same category may vary as per the required load carrying capacity. However, the height of all the modules of same category must be same.

u) The bolts in the VIS module shall be designed with minimum factor of safety of 2. Double nut with washer plates shall be used in top and bottom plate.

8 DYNAMIC ANALYSIS

8.1 Dynamic analysis shall be carried out to assess vibration behaviour of the machine foundation system under applied/generated operational loads. Dynamic analysis shall consist of,

a) free vibration analysis, and
b) forced vibration response analysis.

The dynamic response shall be computed either in terms of velocity, in mm/s or in terms of displacement, in microns or both, as the case may be.

For more details, refer **10.1** of IS 2974 (Part 1).

The response amplitude shall be evaluated at,

a) machine bearing locations,
b) base of bearing pedestals, and
c) on the inertia block in longitudinal and transverse directions.

The dynamic analysis shall be carried out either by manual method or finite element method as given in **8.3** and **8.4** respectively.

8.2 Modeling for Dynamic Analysis

8.2.1 All those elements/components in Inertia block or in machine above it that have mass/stiffness shall be included in the model. All the connected piping up to first support point/first bellow point shall also be included in the model for their mass effect only.

8.2.2 *Spring Stiffness for Isolators*

8.2.2.1 The Isolator spring stiffness shall be idealized as six elastic springs, three translational and three rotational. These spring stiffnesses, that is, vertical stiffness (ky), horizontal/sliding (kx, kz), rocking ($k\theta$, $k\emptyset$), and torsional ($k\psi$) shall be computed as per IS 2974 (Part 1).

8.3 Dynamic Analysis by Manual Method

Dynamic analysis by manual method is applicable only for rigid inertia block in block foundation as per **7.1(a)**. Manual method shall not be used for flexible inertia block in block foundations or in frame foundations.

8.3.1 If the concrete inertia block is sufficiently rigid as per **7.1**(a) and **7.1**(b), elastic deformations within the concrete inertia block become negligible as compared to the overall rigid body deflections. For such a system, the machine foundation system is considered as a rigid block supported on elastic springs and shall be idealized as a single mass spring system with 6 degrees of freedom. The natural frequencies for the 6 uncoupled modes shall be calculated as follows:

$$f_{\mathrm{nx}} = \sqrt{\frac{k_{\mathrm{x}}}{M}}; \quad f_{\mathrm{ny}} = \sqrt{\frac{k_{\mathrm{y}}}{M}}\ ; \quad f_{\mathrm{nz}} = \sqrt{\frac{k_{\mathrm{z}}}{M}}$$

$$f_{\mathrm{nxx}} = \sqrt{\frac{k_{\theta}}{M_{\mathrm{mx}}}}; \quad f_{\mathrm{nyy}} = \sqrt{\frac{k_{\varphi}}{M_{\mathrm{my}}}}; \quad f_{\mathrm{nzz}} = \sqrt{\frac{k_{\emptyset}}{M_{\mathrm{mz}}}}$$

NOTE – An example is given in Annex B.

The natural frequencies for coupled modes of Inertia block shall be calculated as per Annex A of IS 2974 (Part 2) wherein the springs are idealised for Isolators below inertia block.

8.3.2 Forced vibration analysis of such rigid Inertia block shall be carried out as per Annex A of IS 2974 (Part 2). The response can be computed for damped/ undamped condition depending upon isolator type. The springs are represented for Isolators in this case.

8.4 Dynamic Analysis by Finite Element Method (FEM)

Dynamic analysis by finite element method (FEM) is applicable both for rigid as well as flexible Inertia block in Block foundation as well as frame foundations. Rigid inertia block can be analyzed using equations however, for analysing flexible inertia block, advanced computational techniques like FE analysis is required.

8.4.1 *Modelling for Dynamic Analysis of Inertia block by FEM*

a) *Inertia Block* — The Inertia block shall preferably be modelled using first/higher order 3D solid elements. The model shall include all openings/cutouts, cantilever projections, raised pedestals, etc., unless considered insignificant. At least three elements shall be modelled in any direction of the block. A typical FE model using 3D solid element is shown in Fig.6

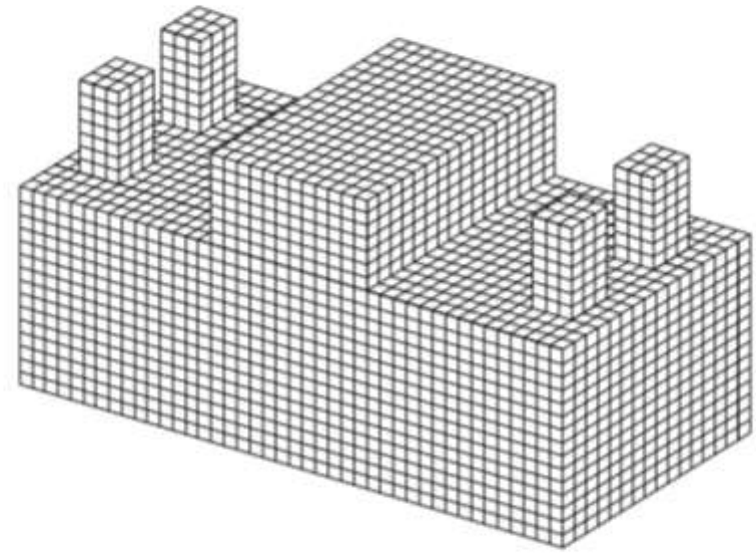


Fig 6. Typical Finite Element Model of a Solid Inertia Block

b) *Supporting Isolators* — The Stiffness of VIS shall be modelled using linear 3D spring elements applied at the bottom of the Inertia Block.

   Isolator damping — Though damping is undesirable for VIS, it is recommended to provide damping to control transient response.

c) The mass of the rotating or any other equipment on the foundation shall be modelled at their respective centers of gravity and shall be connected to the foundation top at appropriate locations by massless rigid links.

d) The FE model results shall be validated using simple manual calculation to avoid gross error in modelling.

8.4.2 *Free Vibration Analysis*

Free vibration analysis based on Eigen solution shall be carried out to extract the natural frequencies of machine-Inertia block system. Free vibration analysis shall be carried out to calculate natural frequencies and mode shapes of the Inertia block system over Isolators. The natural frequency shall be extracted at least 20 percent higher than the highest operating frequency of the machines. Damping shall be neglected for the purpose of free vibration analysis.

The results shall be used to check whether the vertical natural frequency of the foundation system is sufficiently away from the operating frequency of the machine. In case the criteria as above is not satisfied, this is an indication that foundation needs re-sizing.

8.4.3 *Forced Vibration Analysis*

a) A steady state harmonic response analysis shall be performed to obtain the steady state amplitude of vibration due to various design unbalanced loads caused by the vibrating machine.

b) The analysis shall be carried out over a forcing frequency range within ±20 percent of the machine operating frequency.

c) Either direct integration technique or a mode superposition technique may be used.
d) When modal superposition procedure is used, at least all modes within 1.2 times the highest operating frequency shall be included while performing the dynamic analysis.

8.4.4 *Modelling Damping*

Damping can be specified as constant for all modes or selectively changed for each mode in case of mode based dynamic analysis. For direct integration technique, Rayleigh damping can be considered. In case of Rayleigh damping, the constants shall be chosen appropriately so that the damping applied within the range of frequency of interest is less than the applicable damping of the Inertia block system.

8.5 Permissible Amplitude of Vibrations

Permissible response amplitudes shall be as given in IS 2974 (Part 1).

9 STRENGTH ANALYSIS

Modelling for strength analysis shall be done in accordance with **9.1** of IS 2974 (Part 2) for block foundations or **9.1** of IS 2974 (Part 3) for frame foundations.

Strength analysis shall be done for the load cases and combinations mentioned in **9.2** of IS 2974 (Part 2) for block foundations or **9.2** and **9.3** of IS 2974 (Part 3) for frame foundations as well as machine manufacturer's recommendations, if any. Static deflection criteria mentioned in **10** of IS 2974 (Part 3) or as per recommendation of machine supplier shall be complied.

10 ANALYSIS OF BASE FRAME AND BASE BLOCK

10.1 The stiffness of the base frame/base block shall be at least ten times of the stiffness of the isolators and in that case the structure below isolators shall be analysed for static load only.

10.2 The base frame/base block shall be analysed for the reactions from isolators placed above.

10.3 The bearing pressure due to the reaction for normal operating load shall not exceed 80 percent of the bearing capacity. However, in case of emergency load combination, the bearing pressure shall be limited within full capacity.

11 DESIGN

Design of concrete inertia block, base frame/base block shall be done as per limit state method or working stress method of IS 456. Minimum grade of concrete shall be used M 25. Design of steel base frame shall be done as per IS 800.

12 CONSTRUCTION ASPECTS

12.1 In addition to the construction aspects specified in **12** of IS 2974 (Part 1), the specific requirements given in **12.2** shall also be followed.

12.2 The suppliers shall be asked to furnish guidelines for placing as well as for removing (for replacement of springs) vibration isolators. The following general guidelines should be followed in addition to manufacturer's specific guidelines:

a) The surface on which the spring elements are to be placed shall be levelled with care to have smooth finished surface. The surface shall be made clean and dry before placing of spring units.

b) The spring elements are placed over the substructure after completion of bottom shuttering of top deck.

c) Proper openings shall be kept in the bottom shuttering at the location of the spring units. These openings shall be closed by placing embedded steel cover plates. The anchors in the steel cover plate shall be properly designed.

d) Proper bracing system shall be provided in the bottom shuttering to prevent any sagging.

13 TESTING OF ISLOATORS

All isolators shall be tested for their stiffness and damping characteristics. Testing shall be in accordance with IS 13301.

14 SNUBBERS

High lateral displacements are anticipated on account of emergency/faulted load conditions such as blade loss, earthquake, etc. For VIS supported machines, snubbers/stoppers shall be provided to restrain the excessive lateral displacements.

ANNEX A

[*Clauses* 7.1.1(a), 7.2.1(m) *and* 8.3.1]

PRINCIPLE OF VIBRATION ISOLATION

The working of vibration isolation is best understood by idealising machine, structure/foundation and isolation as simple mass-spring-damper system, as shown in Fig. 7.

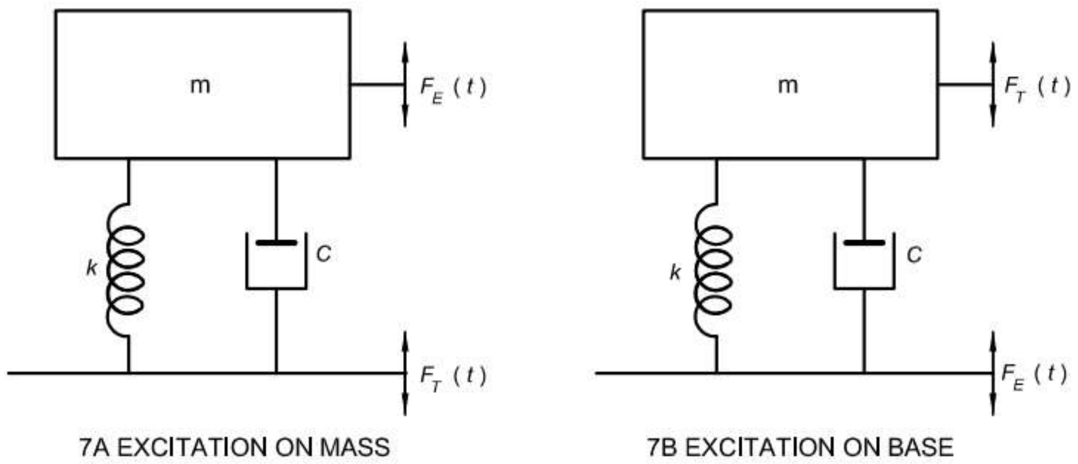


Fig. 7 System

Where, $F_{\mathrm{E}}(t)$ is excitation force with the frequency of the source of vibration or disturbing frequency/ excitation frequency/ operating speed/ operating frequency (f_{o}) and $F_{\mathrm{T}}(t)$ is transmitted force, system mass is m, isolator stiffness is k, isolator damping constant is C, then,

Natural frequency, $f_1 = \sqrt{\frac{k}{m}}$

Frequency ratio, $\beta = \frac{f_{\mathrm{o}}}{f_1}$

Damping ratio, $\zeta = \frac{C}{C_{\mathrm{c}}}$, where C_{c} is critical damping

Magnification factor = $\frac{1}{\sqrt{(1-\beta^2)^2+(2\beta\zeta)^2}}$, graphically shown in Fig. 8.

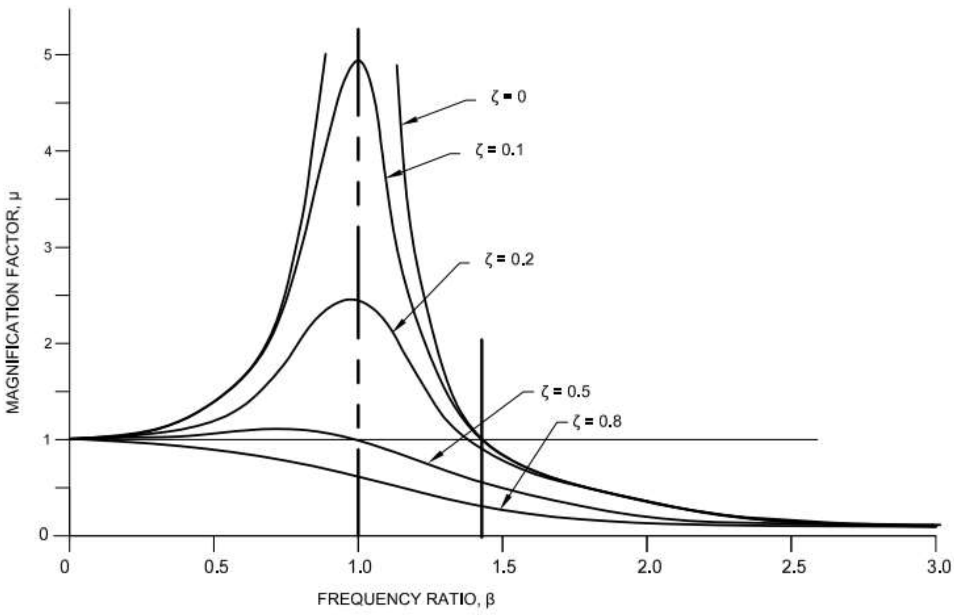


Fig. 8 Magnification Factor, μ for Simple Mass-Spring-Damper System

For frequency ratio, $\beta = \sqrt{2}$, the magnification factor, $\mu = 1$. The isolation is achieved when of $\beta > \sqrt{2}$. Isolation becomes effective when β is more than 4.

Transmissibility (TR) through the isolation system consisting of stiffness, k and damper, with damping constant, C and damping ratio, ζ is defined as,

$TR = \frac{F_T}{F_E} = \frac{\sqrt{1+(2\beta\zeta)^2}}{\sqrt{(1-\beta^2)^2+(2\beta\zeta)^2}}$, graphically shown in Fig. 9.

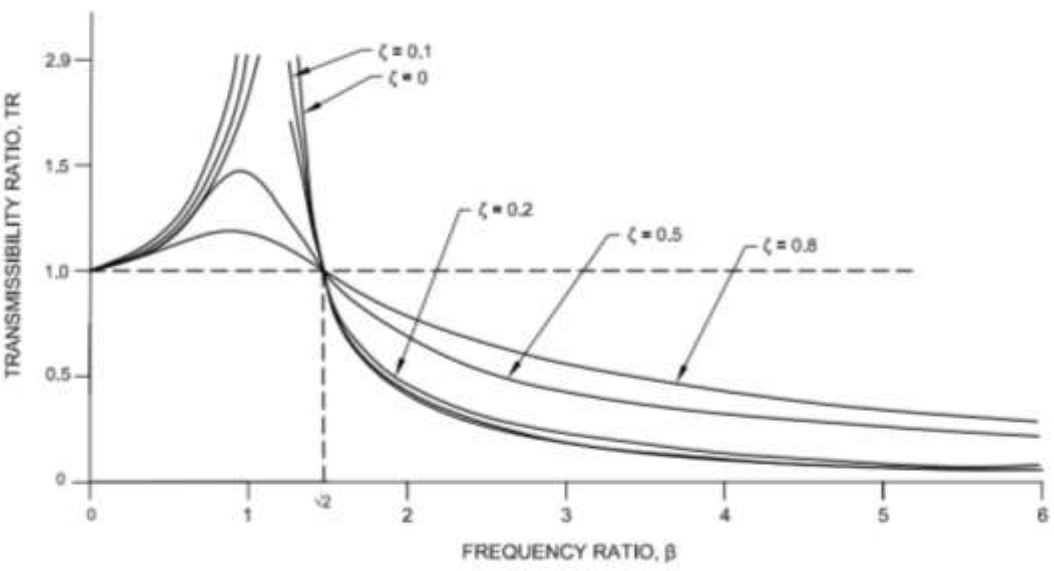


Fig. 9 Transmissibility Ratio, TR for Simple Mass-Spring-Damper System

Vibration isolation (< 1) occurs when the excitation frequency $(f_o) > 1.4\, f_1$, where, f_1 is the natural frequency. For minimum transmissibility (maximum isolation), the frequency ratio (β) should be as high as possible.

It may be noted that high damping reduces amplitude significantly at near resonance condition but it enhances amplitude when $f_o > 1.4\, f_1$. Dampers have detrimental effect when frequency ratio $\beta > 1.4$.

The effectiveness of isolator is known as isolation efficiency, $\eta = (1 - TR)$, and it is defined as the percentage of vibration force or motion that is not transmitted through the vibration mount.

The effectiveness of isolator, expressed in dB is,

$$E = 10\ \log_{10} \frac{1}{TR}$$

The effectiveness of isolator, expressed in percent is,

$Percentage\ isolation\ = (1 - TR) \times 100$, graphically shown in Fig. 10.

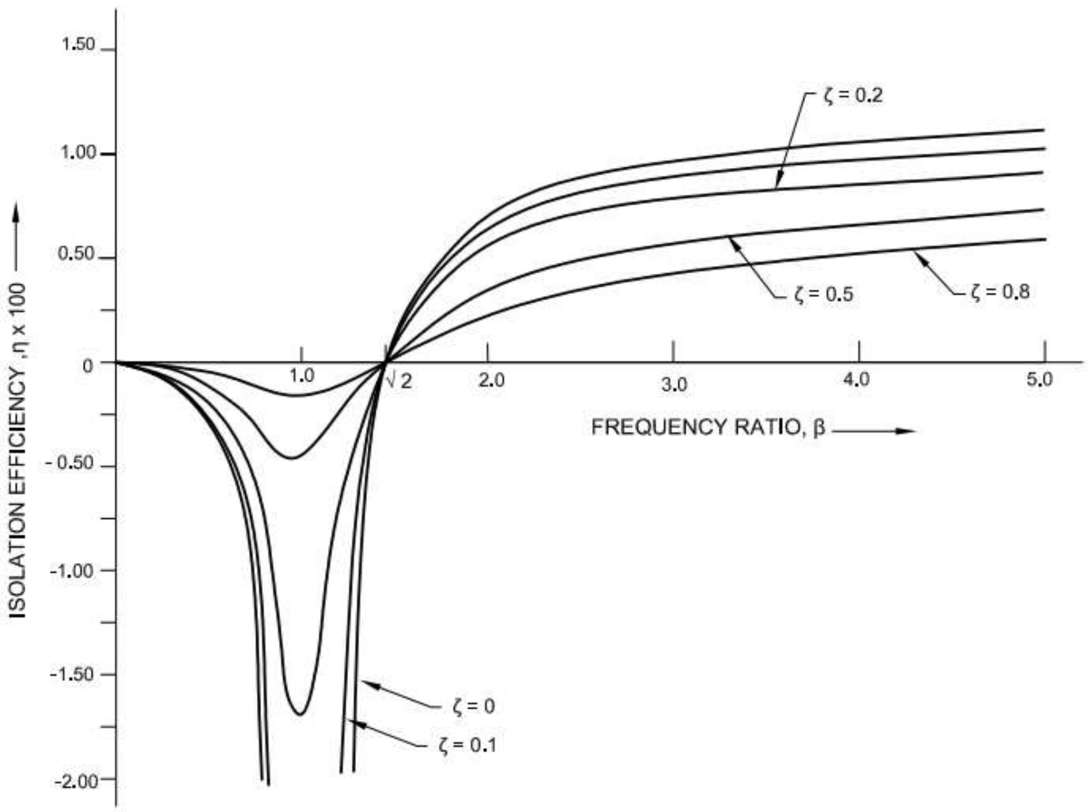


Fig. 10 Isolation Efficiency for Simple Mass-Spring-Damper System

ANNEX B

[*Clauses* 7.1.1(a), 7.2.1 (e), 7.2.1 (m) *and* 8.3.1)]

STEPS FOR SELECTION OF VIBRATION ISOLATION SYSTEM FOR MACHINE FOUNDATION RESTING OVER RIGID BASE BLOCK

Step 1: Machine Data

Foundation outline, machine mass location, and machine mass distribution, dynamic unbalance loads etc, as given in IS 2974 (Part 1) (*see also* Fig. 11).

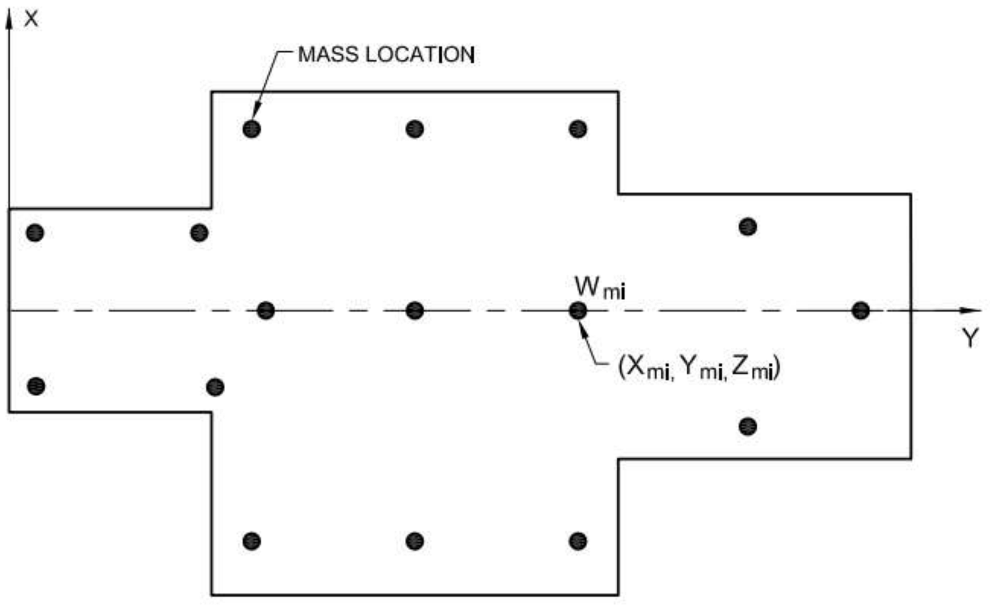


Fig. 11 Outline of Inertia Block and Machine Mass Location Points

Step 2: Calculation of Centre of Mass of Machine-Foundation System in X-Y Plane

C.G of mass of machine = $\overline{x_{\mathrm{m}}},\ \overline{y_{\mathrm{m}}},\ \overline{z_{\mathrm{m}}}$

C.G of foundation block = $\overline{x_{\mathrm{f}}},\ \overline{y_{\mathrm{f}}},\ \overline{z_f}$

C.G of mass of machine–foundation = $(\overline{X}, \overline{Y}, \overline{Z})$

$$\overline{X} = \frac{(W_m * \bar{x}_m) + (W_f * \bar{x}_f)}{(W_m + W_f)}$$

$$\overline{Y} = \frac{(W_m * \bar{y}_m) + (W_f * \bar{y}_f)}{(W_{\mathrm{m}} + W_{\mathrm{f}})}$$

$$\overline{Z} = \frac{(W_{\mathrm{m}} * \bar{z}_{\mathrm{m}}) + (W_{\mathrm{f}} * \bar{z}_{\mathrm{f}})}{(W_{\mathrm{m}} + W_{\mathrm{f}})}$$

Step 3: Selection of Isolators

Depending upon target isolation efficiency and isolator capacity, number and type of isolators are selected and placed at an assumed location as trial (*see* Fig. 12).

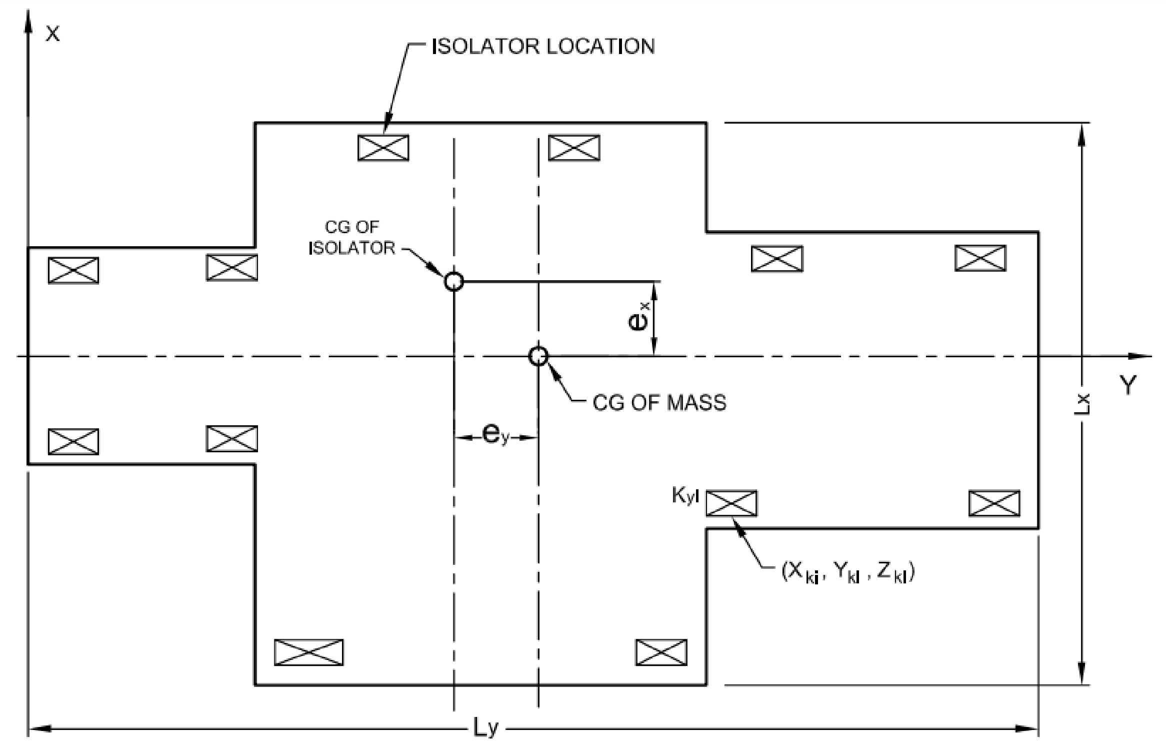


Fig. 12 Isolator Location Points underneath the Inertia Block

Centre of isolator stiffness in X-Y plane,

$$\overline{X_k} = \sum (k_{iz} * X_{ik}) / \sum k_{iz}$$

$$\overline{Y_k} = \sum (k_{iz} * Y_{ik}) / \sum k_{iz}$$

Eccentricity with centre of mass,

$$e_x = \frac{\overline{X} - \overline{X_k}}{L_x} * 100\, percent$$

$$e_y = \frac{\overline{Y} - \overline{Y_k}}{L_y} * 100\, percent$$

Location of isolator shall be chosen such that eccentricity is kept as minimum as possible. For better performance, it is desirable to keep eccentricity less than 5 percent.

Step 4: Calculation of Centre of Stiffness and Natural Frequencies

Translational and rotational stiffness at centre of stiffness,

$$K_{\mathrm{x}} = \sum_{j=1}^{j=n} k_{\mathrm{ix}} \; ; \; K_{\mathrm{y}} = \sum_{j=1}^{j=n} k_{\mathrm{iy}}; \quad K_{\mathrm{z}} = \sum_{j=1}^{j=n} k_{\mathrm{iz}}$$

$$K_{\theta} = \sum k_{\mathrm{iz}} * (\overline{Y}_{\mathrm{k}} - Y_{\mathrm{i}})^2$$

$$K_{\varphi} = \sum k_{\mathrm{iz}} * (\overline{X}_{\mathrm{k}} - X_{\mathrm{i}})^2$$

$$K_{\emptyset} = \sum (k_{\mathrm{ix}} * \left(\overline{Y}_{\mathrm{k}} - Y_{\mathrm{i}}\right)^2 + k_{\mathrm{iy}} * \left(\overline{X}_{\mathrm{k}} - X_{\mathrm{i}}\right)^2)$$

Natural frequency of machine foundation system,

$$f_{\mathrm{nx}} = \sqrt{\frac{k_{\mathrm{x}}}{M}} \; ; \; f_{\mathrm{ny}} = \sqrt{\frac{k_{\mathrm{y}}}{M}} \; ; \; f_{\mathrm{nz}} = \sqrt{\frac{k_{z}}{M}}$$

$$f_{\mathrm{nxx}} = \sqrt{\frac{k_{\theta}}{M_{\mathrm{mx}}}}; \quad f_{\mathrm{nyy}} = \sqrt{\frac{k_{\varphi}}{M_{\mathrm{my}}}}; \quad f_{\mathrm{nzz}} = \sqrt{\frac{k_{\emptyset}}{M_{\mathrm{mz}}}}$$

Step 5: Depending upon assumed isolators, natural frequency of machine-foundation system, amplitudes under dynamic loads and isolation efficiency of isolator are calculated. Frequency separation, amplitudes and isolation efficiency are compared with permissible limits as stipulated by the standard and/or machine manufacturer's recommendations.

In case the above criteria are not achieved, Step 3 is repeated with different isolator arrangement. This process is repeated till desired result is achieved.