भारतीय मानक ब्यूरो
(उपभोक्ता मामले, खाद्य एवं सार्वजनिक वितरण मंत्रालय, भारत सरकार)
BUREAU OF INDIAN STANDARDS
(Ministry of Consumer Affairs, Food & Public Distribution, Govt. of India)

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

व्यापक परिचालन मसौदा

हमारा संदर्भ : सीईडी 43/टी-63 **27 अगस्त 2024**

तकनीकी समिति : मृदा एवं नींव इंजीनियरिंग अनुभागीय समिति 43

प्राप्तकर्ता :

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

महोदय/महोदया,

निम्नलिखित मानक का मसौदा संलग्न हैं:

प्रलेख संख्या	शीर्षक
सीईडी 43(26426)	भारतीय मानक मसौदा मशीन फाउंडेशन का डिजाइन और निर्माण — रीति संहिता: भाग 3 फ्रेम नींव [*आई एस 2974 (आई एस 2974 भाग 1 से 5 का पुनरीक्षण)*] (*आईसीएस 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 कठिनाइयां आ सकती हैं।

सम्मतियाँ भेजने की अंतिम तिथि: 27 सितंबर 2024

सम्मति यदि कोई हो तो कृपया अधोहस्ताक्षरी को ई-मेल द्वारा **ced43@bis.gov.in** पर या उपरलिखित पते पर, संलग्न फोर्मेट में भेजें। सम्मतियाँ बीआईएस ई-गवर्नेंस पोर्टल, **www.manakonline.in** के माध्यम से ऑनलाइन भी भेजी जा सकती हैं।

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

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

धन्यवाद।

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

संलग्न: उपरलिखित

भारतीय मानक ब्यूरो
(उपभोक्ता मामले, खाद्य एवं सार्वजनिक वितरण मंत्रालय, भारत सरकार)
BUREAU OF INDIAN STANDARDS
(Ministry of Consumer Affairs, Food & Public Distribution, Govt. of India)

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

WIDE CIRCULATION DRAFT

Our Reference: CED 43/T-63 **27 August 2024**

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

ADDRESSED TO:

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

Dear Sir/Madam,

Please find enclosed the following draft:

Doc No.	1 Title
CED 43(26426)	Design and Construction of Machine Foundations — Code of Practice : Part 3 Frame Foundations [*Revision of IS 2974 (Parts 1 to 5)] [ICS: 93.020]*

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

Last Date for comments: 27 September 2024

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

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

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

Thanking you,

Yours faithfully,

Sd/-

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

Encl: As above

FORMAT FOR SENDING COMMENTS ON THE DOCUMENT

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

Doc. No.: CED 43(26426)

BIS Letter Ref: CED 43/T-63

Title: Design and Construction of Machine Foundations — Code of Practice : Part 3 Frame Foundations [*Revision of IS 2974 (Parts 1 to 5)*]
[ICS: 93.020]

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

Name of the Commentator/ Organization: ____

Sl No.	Clause/ Para/ Table/ Figure No. commented	Type of Comment (General/ Technical/ Editorial)	Comments/ Modified Wordings	Justification of Proposed Change
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				
10.				
11.				
12.				
13.				

NOTE- Kindly insert more rows as necessary for each clause/table, etc.

BUREAU OF INDIAN STANDARDS

DRAFT FOR COMMENTS ONLY

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 93.020

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

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 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 (Medium and high frequency)	1967	1975 and then in 1992
Part 4	Foundations for rotary type machines of low frequency	1968	1979

Part 5	Foundations for impact machines other than hammer (Forging and stamping press, pig-breaker, drop crusher and jolter)	1970	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, performance feedback and failure data, collected over the years from field tests on wide variety of machines and their foundations provide clear indication that the existing design practices needs to be re-looked for improvement 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 codes 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 Foundation 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 3) deals with specific provisions relating to design and construction of **Frame Foundations,** (both Reinforced Cement Concrete (RCC) Foundations and Structural Steel Foundations), for the installation of rotary and reciprocating machines, such as turbo-generators, turbo-compressor, boiler feed pumps, crushers, and reciprocating compressors. Structural Steel Frame Foundation has been added for the first time with no feedback experience from operation of such foundations for land-based units. The design procedures are developed in the present code based on the feedback experience of operations of such machine in marine environment. Structural steel foundations are likely to result in enormous time saving in construction resulting in overall time saving for projects. It is anticipated that introduction of structural steel foundations shall be useful to the engineering industry.

For the general provisions, Part 1 of the standard shall be referred. Further, in the design and construction of foundations for all the machines, a proper coordination between the different branches of engineering, including those dealing with erection and commissioning is essential. Coordinated efforts by the different branches would result in satisfactory performance, convenience of operation, economy and a good general appearance of the complete unit.

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

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.

<u>BUREAU OF INDIAN STANDARDS</u>

DRAFT FOR COMMENTS ONLY

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 93.020

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

SECTION 1 GENERAL

1 SCOPE

1.1 This standard (Part 3) deals with the design and construction of framed type foundations of reinforced cement concrete (RCC) and/or structural steel supporting various kinds of rotary and reciprocating machines. Some typical machines of this type are turbo-generators, turbo-compressor, boiler feed pumps, crushers and reciprocating compressors associated with various industries listed in IS 2974 (Part 1). Frame foundations supporting turbo-generator and double roll crusher are shown in Fig. 1.

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

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 875	Code of practice for design loads (other than earthquake) for buildings and structures:
Part1: 1987	Dead loads – Unit weights of building materials and stored materials (*second revision*)

Part 2: 1987	Imposed loads (*second revision*)
Part 3: 2015	Wind loads (*third revision*)
Part 4: 2021	Snow loads (*third revision*)
Part 5: 1987	Special loads and combinations (*second revision*)
IS 1893 (Part 4):2015	Criteria for earthquake resistant design of structures: Part 4 Industrial structures including stack-like structures (*first revision*)
IS 2974 (Part 1): 2022	Design and construction of machine foundations – Code of practice: Part 1 General Provisions
IS 13920:2016	Ductile design and detailing of reinforced concrete structures subjected to seismic forces– Code of practice (*first revision*)

3 TERMINOLOGY

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

3.1 Beam-Plate Model – Mathematical model of machine foundation consisting of 3-D beam and shell elements.

3.2 Critical Speeds – The speeds at which the frequency of rotation of the shaft (rotor) equals one of the natural frequencies of the shaft, are termed as critical speed/ speeds of the shaft (more than one critical speed i.e., 1st Critical, 2nd Critical etc.).

3.3 Frame Foundation – The entire structure, including the top deck, columns, and base raft. The various components of frame foundations are defined under **3.3.1** to **3.3.4**.

3.3.1 *Top Deck* – The uppermost portion of the machine foundation comprising of longitudinal beams, transverse beams and slabs with required openings, depressions, raised pedestals, cut-outs, bolt pockets and extended cantilevers projections.

3.3.1.1 *Longitudinal beams* – The members that support the machine and are parallel to the machine axis (along X axis)

3.3.1.2 *Transverse beams* – The members that support the machine/bearing pedestals and are transverse to the axis of the machine (along Z-Direction)

3.3.2 *Intermediate Platforms* – Platforms at intermediate level below top deck made either of concrete beams with a concrete slab or steel beam with grating for supporting auxiliary equipment. These platforms i) may be supported on independent columns taken from base raft and are not connected to the main columns or ii) may be connected to the columns of frame foundation itself.

3.3.3 *Columns* – The vertical members that support the top deck and are in turn supported on the base raft.

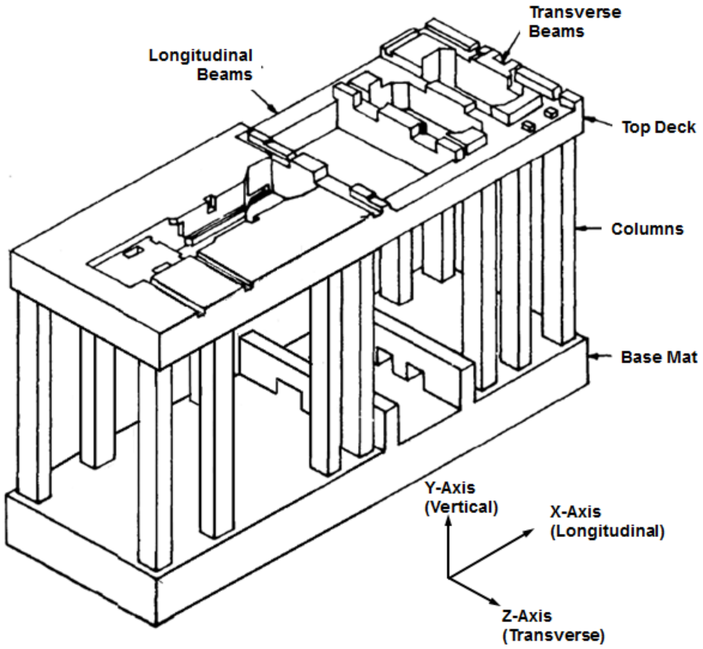
3.3.4 *Base Raft (Base Mat)* – The part of the foundation supported on soil, rock, or piles, consisting of continuous concrete slab extending in both directions and supporting columns, pedestals, and/or walls.

3.4 Overall Eccentricity – The distance between the **Centre of Mass** of the frame foundation system (machine + top deck + columns + intermediate slab + base raft + all equipment with their support system on the base raft and earth fill over base raft) and the **Centre of Stiffness** of soil/pile system.

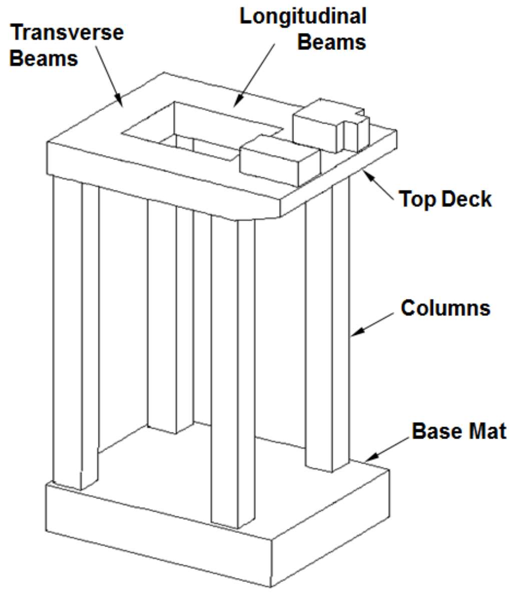
3.5 Solid Model – Mathematical model of machine foundation consisting of 3-D solid elements.

3.6 Thrust Bearing – A type of bearing, that resists axial thrust in addition to vertical (gravity loads).

3.7 Top Deck Eccentricity – The distance between combined **Centre of Mass** (comprising of machine mass, top deck mass & 25 percent of mass of all the columns) and **Centre of lateral Stiffness** of all the frames (considering frame columns fixed at top of base Raft).



1A Typical Frame Foundation for a Turbo Generator



1B Typical Frame Foundation for a Double Roll Crusher

FIG. 1 TYPICAL FRAME FOUNDATION

4 NOTATIONS

For the purpose of this standard, the notations given in IS 2974 (Part 1) shall apply in addition to those used and explained under various clauses of this Part.

5 SYSTEM DATA

5.1 Machine Data

5.1.1 The necessary machine data required for the design of *frame* foundation for supporting different types of machines as given in **7** of IS 2974 (Part 1) shall be obtained from the machine manufacturer. In addition, the data as specified in **5.1.2** to **5.1.3** shall also be obtained from the machine supplier/customer/machine manufacturer.

5.1.2 *Machine Data for Rotary Machines*

a) Critical speed of individual and coupled rotors;
b) Thrust bearing, if any (location, weight, etc);
c) Condenser (if any);
   1) Rigidly supported on base raft (Bellow connected): Bellow stiffness parameters (axial, transverse and torsional);
   2) Rigidly connected to turbine (supported on springs at base raft): Supporting spring stiffness parameters (vertical, transverses and torsional); and
d) Air cooler duct details; if any.

5.1.3 Static deflection criteria to be satisfied, if any.

5.2 Foundation Data

5.2.1 *Data from Layout Considerations*

The following foundation data shall also be obtained from the machine supplier/customer/machine manufacturer/layout engineer:

a) Foundation layout showing foundation dimensions, levels, machine center lines, details of openings, trenches, notches, pedestals, inserts/embedment's, extent of machine sole plate/grout area, etc;
b) Layout of piping, ducting, cabling, etc, within foundation area as well as their supporting details; and
c) Level and size of intermediate platforms requirement (if any) from machine layout consideration.

5.2.2 *Foundation Material*

5.2.2.1 *Reinforced cement concrete (RCC)*

The design of top deck, columns, intermediate platforms, and base raft shall be as given in **Section 2** of this Part. The material specifications and the material properties to be considered for design shall be in accordance with **8** of IS 2974 (Part 1).

5.2.2.2 *Structural steel*

Structural steel shall be used only for columns and intermediate platforms. Top deck shall be made of structural steel for those machines where machine external body temperature is below 60°C, else top deck shall be either made of RCC or with Structural steel members encased in concrete.

NOTE — Design of structural steel members encased in concrete is not covered by this standard.

The design of structural steel frame foundation is covered in **Section 3** of this Part. The material specifications and the material properties to be considered for design shall be in accordance with **8** of IS 2974 (Part 1).

5.3 Geotechnical Data

The soil or pile parameters required for the analysis of foundation shall be considered as per **4** of IS 2974 (Part 1).

6 GENERAL DESIGN REQUIREMENTS

6.1 The general design requirements as given in **9** of IS 2974 (Part 1) shall be complied.

SECTION 2 RCC FOUNDATION

7 SIZING OF THE FOUNDATION

7.1 Sizing of the Top Deck

The proportioning of the deck is basically governed by the machine manufacturer's drawing giving the soleplate locations and opening details for the various parts of the machine.

The following shall be used while fixing the sizes of the top deck:

a) Weight of the top deck shall not be less than the weight of the machine resting on it.
b) Cantilever projection should preferably be avoided unless necessitated by machine layout criteria. In case cantilevers are unavoidable, their depths shall be at least equal to 0.6 times the projection.
c) All the bearing pedestals (including thrust bearing) shall preferably be supported on the main frame beams. Wherever it is unavoidable due to machine layout constraint and the bearing gets supported on i) deck slab; ii) extended cantilever slabs, it shall be ensured that natural frequency of such slabs under all applied machine loads including the bearing load, shall be more than 50% away from machine operating frequency/ frequencies.
d) The perimeter of the top deck may have a minimum 100 mm overhang from the faces of the column to avoid reinforcement interferences.

7.2 Sizing of Columns

Column sizes shown in the layout drawing by the machine manufacturer are only given as a guideline.

While finalizing column sizes, it shall be ensured that:

a) Total weight of all the columns should not be less than 0.5 times the combined weight of top deck and machine weight on the deck.
b) Pair of columns of each transverse frame, shall preferably be of the same size and the size shall be same through its full height. It is implied that top of the columns of each transverse frame are connected with a transverse beam, unless dictated otherwise by machine layout.
c) Top deck eccentricity criteria given in **7.4** are met with.
d) The first two natural frequencies of each column, with its top and bottom ends fixed, shall be away from the operating speed of the machine by at least 20 percent.
e) The clear distance between columns and any equipment (located at intermediate slabs or at base raft) should not be less than 100 mm.

7.3 Sizing of Base Raft

The weight of the base raft should not be less than the combined weight of machine and top deck. Edges of base raft should extend at least 200 mm from the faces of the columns.

While finalizing base raft thickness, it shall be ensured that:

a) The overall foundation eccentricities given in **7.5** are met with.
b) Thickness of base raft shall be provided such that the elastic settlement/ deflection of base raft under all applied loads (machine + foundation) at all the frame column locations shall be uniform, be it supported on soil or on piles. If this condition is not met, base raft thickness shall be enhanced suitably.
c) Base raft shall be rectangular in plan and cut-outs or reduction in the plan of base raft is not recommended. Wherever, deviations are required from layout considerations, it shall be ensured that the overall foundation eccentricities given in **7.5** are met with as well as elastic settlement criteria as in (ii) above is satisfied.

7.4 Top Deck Eccentricity

7.4.1 *Deflections along Lateral and Longitudinal Directions*

7.4.1.1 The columns shall be so sized that deflection at the top deck level in lateral and longitudinal directions, under 1 g loading along transverse / longitudinal directions (one at a time), is uniform. Variation in deflection from the average value shall be within 3 percent. This will ensure that top deck eccentricity in lateral and longitudinal direction is well within 3 percent.

7.4.1.2 Top deck should preferably be rectangular in plan with due consideration of top deck eccentricity as per **7.4.1.1**. Wherever, deviations are required from layout considerations, it shall be ensured that top deck eccentricity criteria given in **7.4.1.1** are met with.

7.4.2 *Vertical Directions*

The columns should be so sized that elastic shortening of all the columns under 1 g gravity load is uniform.

7.5 Overall Foundation Eccentricity

7.5.1 *Lateral and Longitudinal Directions*

7.5.1.1 The base raft shall be so dimensioned such that the deflection of overall foundation, comprising of complete foundation mass including mass of top deck, columns and base raft; all machine masses on the top deck, on the base raft, on the intermediate platform (if any), and mass of soil on the base raft, both along lateral and longitudinal directions, under respective 1 '*g*' loading is uniform. Variation in deflection from the average value shall not exceed 5 percent.

7.5.1.2 As far as possible, the base raft shall be rectangular in plan meeting the requirements as per **7.5.1.1**. Wherever, deviations are required from layout considerations, it shall be ensured that the overall foundation eccentricity criteria given in **7.5.1.1** are met with. The horizontal eccentricity, in either direction, between the centre of gravity of the combined machine-foundation system and the centre of stiffness, should not exceed 5 percent of the corresponding base raft dimension. For pile foundations, refer **8.1.3.1.3**.

7.5.2 *Vertical Direction*

Base raft should be made thick enough not to permit differential vertical deflection at each frame location under 1 '*g*' vertical loading. Variation in vertical deflection at each frame location, if any from the average value, shall be within 3 percent.

8 DYNAMIC ANALYSIS

Dynamic analysis of the machine-foundation-soil/ Pile system shall be carried out to assess dynamic response and ensure suitability of the foundation under normal operating conditions. Dynamic analysis consists of,

a) Free vibration analysis, and
b) Forced vibration analysis.

NOTE — Dynamic requirements specified by machine manufacturer (if any), may be considered only as contractual requirement. Such compliances are outside the purview of this standard.

8.1 Modelling for Dynamic analysis

A Machine Foundation System comprises of i) Machine; ii) Frame Foundation; and iii) Soil/ Pile system and a typical frame foundation comprises of Top Deck, Columns, Intermediate Slabs (if any) and Base Raft. All those foundation/machine elements that contribute to inertia or stiffness shall be included in the model.

It is desirable to use 3-D modelling such that the behaviour of the foundation is compatible with actual machine foundation system. 2-D modelling of the frame foundation is not recommended.

8.1.1 *Machine*

The following shall apply for modelling of machine:

a) Machine shall be modelled as rigid body.
b) Machine masses shall be lumped at centroid location of the respective machines.
c) Bearing pedestals, wherever present, shall be modelled as rigid body. Machine rotor weight shall be lumped appropriately at bearing locations.
d) Often, large machines such as turbo generators are having one thrust bearing and remaining are journal bearings. In such cases, rotor shall be modelled in such a way that entire rotor mass in axial direction shall be distributed to thrust bearing location and mass in vertical and transverse direction shall be distributed to all other bearings.
e) Gear boxes, wherever present, shall also be modelled as rigid body.

f) Condenser, if present, shall be modelled as rigid body and connected to the foundation/machine using appropriate support stiffness (springs or bellows). All connected piping up to the bellow location should be included along with condenser.
g) All machine components supported on intermediate slab shall be modelled as rigid body.

h) All machine components supported directly on the base raft shall be modelled as rigid body with their weight located at their respective centroid.

j) All machine components (piping, ducting, etc), which are supported through insert plates, need not be modelled unless their weight component is more than 5 percent of the respective machine weight.

8.1.2 *Foundation*

A typical frame foundation comprises of Top Deck, Columns, Intermediate Slabs (if any) and Base Raft. Various structural elements of the foundation include beams, columns, slabs, pedestals, cantilever projections, intermediate platforms, raft etc. Foundation shall be modelled either as beam-plate model in accordance with **8.1.2.1** or solid model in accordance with **8.1.2.2**.

8.1.2.1 *Beam-plate model*

Typical Beam Plate Model (with raft) is shown in Fig 3.

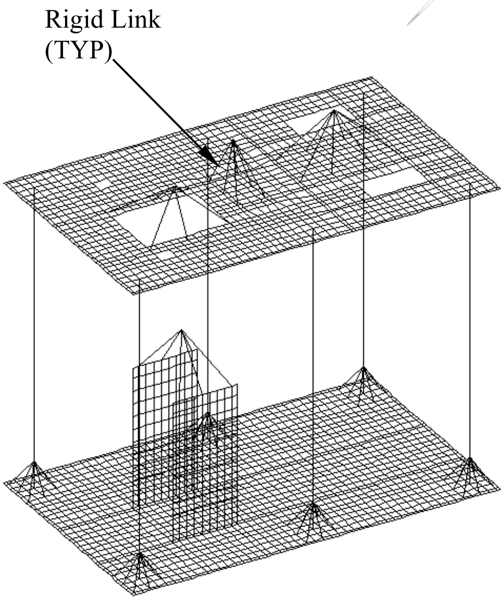


FIG. 3 BEAM- PLATE ELEMENT MODEL OF FRAME FOUNDATION WITH BASE RAFT

Beam - Plate model shall be developed using any standard finite element software package with dynamic analysis capabilities. The following shall apply for beam-plate model of foundation:

a) Foundation elements like beams and columns shall be modelled as beam elements. All beam elements shall be modelled at centre of the member location.

   i) Every beam/column shall be divided into minimum 8 elements except very short span beams where minimum number of elements could be 4 or so.
   ii) Where span/depth ratio of the beam/plate is less than 5, shear deformation shall be included in the model for analysis.

iii) Portion of beams and columns within beam-column junctions shall be modelled using rigid links. Similarly portion of column within plate thickness shall also be modelled with rigid elements

iv) Since cantilever projections (projected elements) cannot be modelled using beam or plate elements, their mass effect shall be computed manually and lumped/distributed on the appropriate beam elements.

NOTE — The above assumption will lead to lower bound of beam frequencies.

b) **Top Deck —** It shall be modelled using plate elements. All machine components supported directly on the top deck shall appropriately be modelled as rigid body with their masses lumped at respective centroids (*see* **8.1.1**). Lumped masses shall be connected to the top deck through appropriate rigid links. Any offset between the adjacent plate thicknesses shall be modelled by rigid links or by offset command wherever permitted by software

c) **Intermediate Slabs** – If any shall be modelled, as plate elements at mid plane of the respective slab.

d) **Base Raft –** Base raft shall be modelled as plate elements. All machine components supported directly on base raft shall appropriately be modelled as rigid body with their masses lumped at respective centroids (*see* **8.1.1**). Lumped masses shall be connected to the base raft through appropriate Rigid Links.

e) Soil/ Pile support shall be represented by suitable spring elements connected to the Base Raft through rigid links. (as per 8.1.3)

8.1.2.2 *Solid model*

Typical Solid Model is shown in Fig 4.

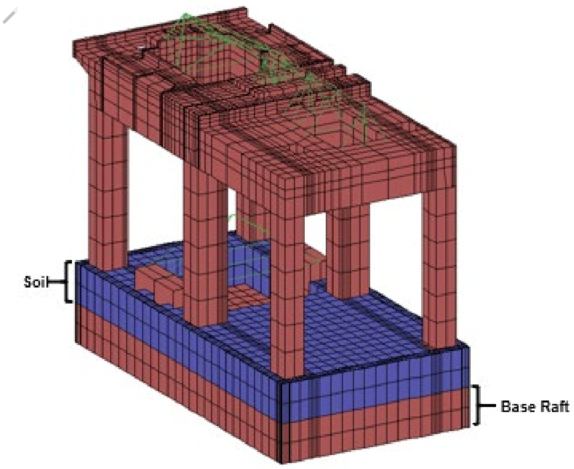


FIG. 4 SOLID MODEL OF FRAME FOUNDATION WITH BASE RAFT AND EARTH FILL AND

Solid model is preferable over beam-plate model as all structural aspects of foundation, for example, haunches, cantilever projections, etc, can conveniently be modelled. Solid Model shall be developed using standard FE software. The following shall apply for solid model of foundation:

a) Various elements of the foundation like beams, columns, slabs, pedestals, cantilever projections, intermediate platforms, base raft etc., shall be modelled as solid elements (with minimum 8 noded brick element).
b) All machine components supported directly on the top deck, intermediate slabs, and base raft, shall appropriately be modelled as rigid body with their masses lumped at respective centroids (see 8.1.1). Lumped masses shall be connected to the respective foundation elements (viz. top deck, intermediate slabs, base raft) through appropriate Rigid Links.
c) Soil/ Pile support shall be represented by suitable spring elements connected to the Base Raft through rigid links. (As per 8.1.3)

8.1.2.3 *Degree of freedom incompatibility* – Solid elements have 3 Degrees of Freedom (DOF) per node, whereas rigid links (beam elements representing machines) as well as spring elements (representing soil stiffness as per **8.1.3**) have 6 DOF per node. Thus, connecting rigid links and springs with solid elements shall lead to DOF incompatibility. Necessary corrective steps (in accordance with the software requirements) shall be taken at the modelling stage itself to overcome this DOF incompatibility.

8.1.3 *Modelling of Soil/Pile*

8.1.3.1 *Soil*

Soil shall be represented by equivalent springs. Based on the dynamic soil properties and base area in contact with soil, dynamic stiffnesses and damping of the supporting media shall be evaluated as per IS 2974 (Part 1). Stiffness thus calculated shall be applied to analysis model using either of two commonly used methods.

a) Soil stiffness (overall stiffness applicable to complete base raft) is represented by six springs (3 translational springs and 3 rotational springs). These springs are attached at centre of gravity (CG) of the base area of base raft in contact with the soil and other end of the spring is restrained. Such a modelling is good enough only for manual computation and not good for 3-D FE Model of the foundation. It is given here only to get a feel of overall behaviour of the foundation subjected to soil stiffness applied to the foundation.

b) Soil is represented by a set of only three translational springs attached to each node of the base raft, in contact with the soil, and other end of the spring is restrained. Rotational soil springs at these nodes shall not be considered (see note below). Translational stiffness of individual springs shall be based on the influence area of the corresponding node to which the spring is connected. It shall be ensured that overall translational spring stiffnesses, as in (a) above, are the same as the sum of stiffness of individual springs in vertical as well as lateral directions.

NOTE – Rotational soil springs at these nodes shall not be considered for evaluating rotational soil stiffness of the foundation. The three rotational stiffness at the foundation base, in all the three directions, shall get computed automatically using three translational soil springs at each node. This type of model results in marginally upper bound of rotational frequencies.

c) Soil springs connection to base raft:

i) **Solid Model –** Three linear soil springs (one vertical spring and two lateral springs) are applied per node. For solid model, one end of these three linear springs shall be connected to corresponding node of base raft and other end shall be restrained.

DOF Incompatibility – Since spring elements have 6 DOF per node and solid elements have 3 DOF per node, the DOF incompatibility need to be corrected at design stage itself. Necessary corrective steps (in accordance with the software requirements) shall be taken at the modelling stage itself.

ii) **Beam Plate Model –** Here also, three linear soil springs (one vertical spring and two lateral springs) are applied per node.

For beam-plate model, there are no DOF incompatibilities as both the elements (Plate element as well as spring elements) have 6 DOF per node.

Since Plate model is at mid plane level of the base raft, the distance (height difference between base area in contact with the soil and mid plane level of base raft) shall be modelled using rigid link. Soil springs, at each node of the beam plate model of the raft, are connected to the ground (fixed end of the springs) through these rigid links.

8.1.3.2 *Piles*

Suitable pile size and pile type shall be selected based on the Geo-technical parameters of the site and foundation design loads.

8.1.3.2.1 *Pile design*

Piles shall be provided as per **4.4** of IS 2974 part 1. Depending upon the type of piles selected for the foundation, the design of the piles shall be carried out as per relevant parts of 2911. Only dynamic stiffness shall be evaluated as per IS 2974 Part 1. Total Number of piles provided shall have overall pile capacity 20 percent more than that required for withstanding design loads.

8.1.3.1.2 *Effective pile stiffness*

Vertical and lateral pile stiffnesses shall be evaluated as per provisions of IS 2974 (Part 1) and influence of pile group shall be computed as per **4.4.1.1** of IS 2974 (Part 1).

8.1.3.1.3 *Pile layout*

Piles shall be provided below the base raft. Pile layout shall be done such that centre of vertical stiffness of piles coincides with overall centre of mass of the machine and the foundation (including machines on the base raft). Maximum eccentricity shall be as per

7.5.1.2. Clear overhang of the outermost pile from the edge of base raft shall be minimum 200 mm.

8.1.3.1.4 *Modelling of piles for dynamic analysis*

Piles are modelled as equivalent springs at each pile location. Each pile shall be represented by three equivalent springs (one along Vertical direction and one each along two lateral directions) with their respective effective pile stiffness. DOF incompatibility, in case of solid model, shall be considered as in 8.1.3.1 (c).

a) Based on three linear pile stiffness values (equivalent stiffness) of each pile at its respective location, overall pile stiffness is evaluated at CG of Base Raft Area and represented by six pile springs (3 translational springs and 3 rotational springs). These springs are attached at centre of gravity (CG) of the base area of base raft in contact with the pile and other end of the spring is restrained. Such a modelling of piles is good enough only for manual computation and not good for 3-D FE Model of the foundation. It is given here only to get a feel of overall behaviour of the foundation supported on piles.

b) Piles are modelled as equivalent springs at each pile location. Each pile shall be represented by three equivalent springs (one along Vertical direction and one each along two lateral directions) with their respective effective pile stiffness. DOF incompatibility, in case of solid model, shall be considered as in 8.1.3.1 (c).

8.2 Free Vibration Analysis

Free vibration analysis shall be carried out to calculate natural frequencies and mode shapes of the machine foundation system. The highest natural frequency calculated should be at least 20 percent higher than the operating frequency of the machine. Damping shall be neglected for the purpose of free vibration analysis.

8.2.1 *Frequency Criteria*

It shall be ensured that the vertical natural frequency (that happens to be uncoupled mode) shall be more than 20% away from machine operating speed/ speeds. Frequency separation criterion to be achieved, shall be as under:

It is recommended that:

1) **For Fixed Speed Machine** (having one operating frequency f_e) - the vertical natural frequency shall be at least 20 percent away from the machine excitation speed.

   If the above requirements are not satisfied, the foundation shall be resized.

2) **For Variable Frequency Drive (VFD) Machines or Machines coupled through Gear Box having multiple Machine speeds**

In such cases frequency separation shall not be applicable but final amplitude shall be governing criteria. If dynamic amplitudes (as per 8.3) are not satisfied, the foundation shall be resized.

8.3 Forced Vibration Analysis

Forced vibration analysis shall be harmonic for both steady state and transient response. Dynamic forces generated by machine are applied at respective bearing locations at corresponding excitation frequencies.

8.3.1 *Dynamic Force*

8.3.1.1 *Rotary machines*

a) *Directly Coupled Machines*

1) System where drive machine and driven machine speeds are same, dynamic forces shall be considered at machine operating frequencies.
2) Dynamic forces shall be evaluated for each machine based on rotor weight, balance quality grade and operating frequency of the machine.

b) *Machines Coupled through Gear Box*

Since drive machine and driven machine speeds are different, dynamic forces shall be computed for each machine at its operating speed using respective balanced quality grade.

NOTES

1 As per industry practice, dynamic forces shall be computed for balance quality grade one level higher than the design balance quality grade of the machine.

2 In certain cases, there is large mismatch between dynamic forces supplied by the machine manufacturer versus dynamic forces obtained by balance quality grade computations. If the difference happens to be more than 25 percent, it is recommended to use dynamic forces evaluated on balance quality grade mentioned in note 1 above. In parallel, this difference should be communicated to the machine supplier/manufacturer.

8.3.1.2 *Reciprocating machines*

Dynamic forces are obtained from the manufacturer/supplier at machine operating speed as well as its second harmonic.

8.3.2 *Dynamic Response*

Dynamic response shall be obtained using harmonic response analysis method (frequency domain). Wherever, the software does not permit use of harmonic response, dynamic response shall be evaluated in time domain at discrete time steps. The entire forcing function shall be discretised at time interval of $\frac{1}{16} \times \left(1/_{frequency\ of\ excitation} \right)$ seconds. Total duration of forcing function shall be considered such that the response is obtained in steady state domain.

NOTES

1 It is advisable to use dynamic force considered at frequencies varying from 0 Hz to 1.2 times the operating speed. To account for grid frequency variation, steady state response of the machine/foundation shall be evaluated at 0.95 to 1.05 times the operating speed.

2 If the dynamic unbalance force is computed at operating frequency and the same force is applied for the sweep analysis, all transient amplitudes are to be scaled down by square of the ratio of resonant frequency to operating frequency.

Transient Amplitude = Amplitude at resonant frequency due to dynamic unbalance force computed at operating frequency × $(f_i/f_m)^2$

where,

f_i = resonant frequency, and
f_m = operating frequencies of the machine.

3 Damping and vibration limits shall be as per IS 2974 (Part 1).

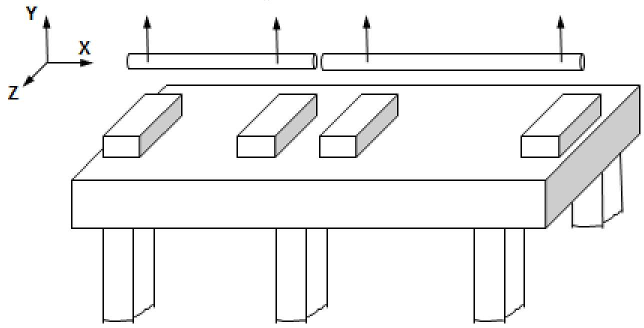
8.3.2.1 It is desirable and recommended that dynamic forces shall be applied simultaneously at all bearing locations. In case software has limitations in considering all forces at the same time, these forces shall be applied one at a time and overall response shall be computed using SRSS (square root of sum of squares) value.

8.3.2.2 *Dynamic forces (in-phase or out-of-phase)*

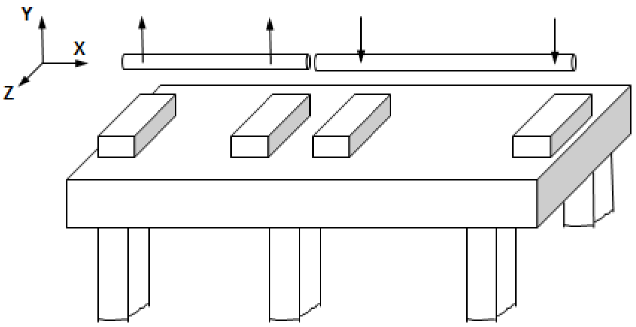
Dynamic forces from drive machine and driven machine should be considered as below:

a) In-Phase (IP)
b) 180° Out-of-Phase (OP)

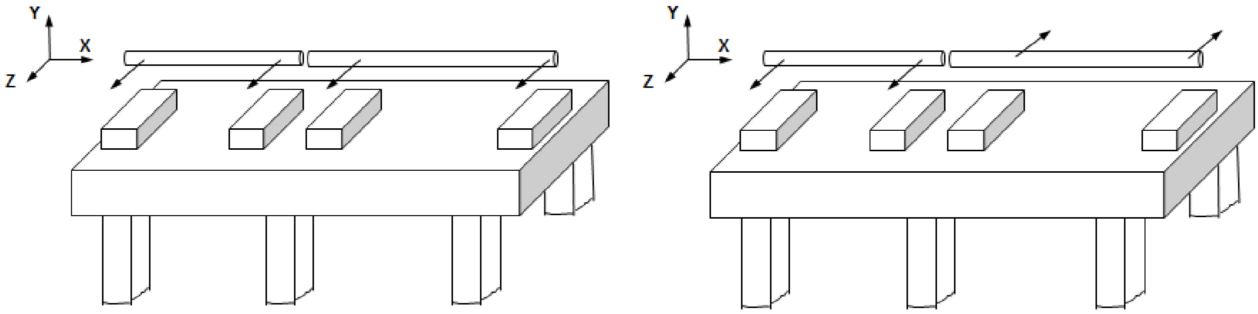
Fig. 5 shows the application of dynamic force in IP and OP.



5A Dynamic Forces along Y Axis – In-Phase



5B Dynamic Forces along Y Axis – Out-of-Phase



5C DYNAMIC FORCES ALONG Z AXIS – IN-PHASE

5D DYNAMIC FORCES ALONG Z AXIS – OUT-OF-PHASE

FIG. 5 APPLICATION OF DYNAMIC FORCES

8.3.2.4 *Point of interest for response computation*

Response shall be evaluated at,

a) Machine bearing locations
b) Base of bearing pedestals
c) Foundation top points – column top and mid span of deck beams; and
d) Column mid height points.

8.3.2.5 Response shall be computed in terms of displacement (microns).

8.3.5 *Permissible Response Amplitude*

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

9 CHECKS FOR DEFLECTION CRITERIA

i) Overall vertical deflection of the foundation under 1 '*g*' loads shall be uniform under all the frames computed at the base raft bottom level. Vertical Natural Frequency corresponding to this overall deflection shall be more than 25% away from machine operating speed. This becomes more relevant for low to medium speed machines. Wherever, this separation criterion is not met, the foundation resizing is a must even though the computed amplitudes are within prescribed limits.

ii) Vertical deflection under 1 'g' loads in the frame beams, at the support points of all the bearing pedestals, shall be nearly uniform such that the rotor catenary is not disturbed and is maintained all through the entire rotor length. Any abrupt change in deflection pattern indicates re-sizing of foundation elements responsible for such behaviour.

NOTE — Static deflections criteria for catenary alignment, wherever given by machine manufacturer, shall be complied with provided all other design criteria as per this code are met.

10 STRENGTH ANALYSIS

10.1 Modelling for Strength Analysis

10.1.1 Beam-Plate model is recommended to be used for strength analysis as solid model will not yield forces and moments required for structural design. Beam-Plate model of the foundation developed for dynamic analysis along with base raft shall be used for strength analysis as well. Equivalent springs representing soil/pile shall be used for the analysis.

10.1.2 *Foundation Supported on SOI* **–** To compute shears, moments and deformations in the base raft, soil shall be modelled as under:

a) Same model as used for dynamic analysis using beam plate element
b) Soil shall be modelled as a set of isolated springs (Winkler foundation).

10.1.3 *Foundation Supported on Piles* – For combined pile raft foundations, piles shall be modelled as equivalent pile springs and shall be applied at respective nodal point at the intersection of pile.

Here again, same model as used for dynamic analysis using beam plate element shall be used for computing shears, moments and deformations in the base raft.

10.2 Loads

The loads considered for strength design shall be as per 11.1 of Part 1 and are considered as under:

a) Dead loads (*DL*):

  i) Foundation self-weight,
  ii) Machine dead loads, and
  iii) All equipment dead loads + all structural loads (air duct, etc) at base raft level
  iv) Weight of soil above raft/pile cap.

  NOTE — Dead loads mentioned in ii) and iii) above shall be applied at their respective centroid location.

b) Imposed load (*IL*) on Top Deck: 10 kN/m^2 around the machine shall be considered. Wherever erection and maintenance loads (*EML*) are specified by manufacturer, the imposed load (*IL*) shall be replaced by (*EML*) on the designated foundation area.

c) Equivalent static dynamic loads (*ESDL*): Equivalent static loads considered for strength design shall be 5 times the Dynamic loads, both in lateral and vertical direction one at a time. Dynamic Loads considered shall be same as used for dynamic response analysis.

In addition, a fatigue factor of 2.0 shall be used for conducting strength design.

a) Other Operating loads (*OL*)

  i) Machine operating torque,

ii) Friction forces due to expansion/contraction of machine (if any),
iii) Piping loads,
iv) Condenser operating load (if any), and
v) Any other operating loads, as applicable.

b) Thermal loads (*TL*) due to temperature change and temperature gradient change shall be considered in the following situations:

i) Outdoor units wherein equipment is protected by an enclosure and foundation is in contact with high and uneven temperatures,
ii) Indoor units in which there are temperature gradients across the top deck members of the frame foundation, and
iii) If machine manufacturer specifies high temperature (more than 80°C) for operating conditions around and within the top deck of the frame foundation.

NOTE — When a high temperature is specified by the manufacturer under operating conditions, cracked section properties need to be used to reflect the expected cracking under high temperature. In such cases, moment of inertia of the cross section shall be reduced to half to one third of the full section. In other cases, uncracked section properties shall be used.

c) Emergency loads, wherever applicable, shall be as per IS 2974 Part 1. These are:

i) Load due to broken blade (*LBB*)
ii) Load due to broken hammer (*LBH*)
iii) Loads due to Bowed Rotor (*LBR*)
iv) Short-circuit loads (*SCL*)
v) Electro-dynamic load-If any (*LED*)

d) Bearing Failure Loads (*BFL*): 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, the bearing failure loads (*BFL*), to be considered in design, shall be five times the rotor weight applied at respective bearing locations in vertical and transverse direction one at a time.

e) Wind loads (*WL*) for out station plants shall be calculated as per IS 875 (Part 3)
f) Earthquake Loads (*EL*): Response spectrum analysis shall be carried out as per IS 1893 (Part 4) by lumping all masses including machine masses at respective centroid locations. Also, refer to 11.1.9 of IS 2974 (Part 1).

NOTE — Seismic forces given by vendor, if any, shall not be considered.

10.3 Load Combinations

10.3.1 *Load Combinations for Working Stress Method of Design and for Serviceability Limit State*

a) Operating condition
$DL + IL + OL \pm ESDL + TL$

b) Emergency loading condition

1) Short circuit condition
   DL+ IL+ OL ± *ESDL* + *TL* ± *SCL*
2) Loss of blade unbalance/bowed rotor
   DL+ IL+ OL+ TL ± *LBB*/LBH/LBR
3) Bearing failure condition
   DL ± *BFL*

c) Environmental condition
   DL+ IL+ OL ± *ESDL +TL+EL*/*WL*

d) Erection condition (*Wherever erection & maintenance loads (EML) are specified by manufacturer, the imposed load (IL) shall be replaced by (EML) on the designated foundation area.*)

   DL+IL

10.3.2 *Load Combinations for Limit State Method*

a) Operating condition
   1.5 [*DL+IL+OL* ± *ESDL* + *TL*]

b) Emergency loading condition

   1) Short circuit condition
      1.2[*DL+IL+ OL* ± *ESDL +TL* ± *SCL*]

   2) Loss of blade unbalance/bowed rotor
      1.2 [*DL+IL+OL+TL*] ± *LBB*/LBH/LBR

   3) Bearing failure condition
      1.0 [*DL* ± *BFL*]

c) Environmental condition

   1.2[*DL+IL+OL* ± *ESDL +TL+EL*/*WL*]
   1.5[*DL* + *EL*/*WL*]
   1.5[0.6 *DL* + *EL*/*WL*]

d) Erection condition (*Wherever erection & maintenance loads (EML) are specified by manufacturer, the imposed load (IL) shall be replaced by (EML) on the designated foundation area.*)
   1.5 [*DL+IL*]

NOTE — Reversible nature of dynamic load, frictional loads and seismic loads shall be considered.

11 STRENGTH DESIGN OF THE FOUNDATION

11.1 Foundation shall be designed by limit state method or working stress method in accordance with IS 456.

11.1.1 When working stress method of design is adopted, permissible stresses in concrete and steel for emergency and environmental conditions shall be appropriately increased as per IS 2974 (Part 1).

11.2 Members shall be designed for all forces and moments including torsion.

11.3 Grade of Concrete

The grade of concrete shall be as per the requirements specified in IS 2974 (Part 1).

11.4 Reinforcement Steel

The reinforcement steel shall be as per the requirements specified in IS 2974 (Part 1). The minimum reinforcement shall be provided as per **11.4.1**.

11.4.1 *Minimum Reinforcement*

The minimum reinforcement for various framed foundation components shall be as under: Table 1.

Table 1 Minimum Reinforcement for Various Framed Foundation Components
(*Clause* 11.4.1)

Sl No.	*Components*	*Minimum Reinforcement*
(1)	(2)	(3)
i)	Beams of top deck	
	a) Top and bottom	As per IS 456
	b) Sides	As per IS 456
ii)	Slabs of top deck	
	a) Top and bottom	As per IS 456
	b) Sides	16 mm diameter bar at 200mm c/c
iii)	Columns	
	a) Longitudinal reinforcement	As per IS 456
iv)	Base raft	
	a) Top and bottom	As per IS 456
	b) Sides	16 mm diameter bar at 200mm c/c
	c) Intermediate Layer	For base raft > 1.5 m thick, reinforcement mesh of 12mm diameter at 200 c/c both ways shall be provided at every 1.0m of height over 1.5 m. Necessary chairs, as

		required, shall be provided to support these intermediate bar layers.

Notwithstanding the above, the minimum reinforcement in Beams, Columns, Slabs including base raft shall not be less than the following:

Base Raft 60 kg/m^3
Columns 80 kg/ m^3
Top Deck 100 kg/m^3

12 CONSTRUCTION ASPECTS

12.1 Construction Joints

12.1.1 The base raft shall be cast in a single uninterrupted operation.

12.1.2 Properly designed construction joints shall be provided one above the base raft and one below the top deck. Additional construction joints (duly designed) may also be provided approximately at every 8m, if the height of the column exceeds 8 m. Such joints shall be duly designed for shear and moment consideration and shall be provided at locations other than $1/4^{th}$, ½, and $3/4^{th}$ of the clear height of the column between base raft and top deck bottom.

12.1.3 The top deck shall be cast in a single uninterrupted operation.

12.1.4 The other provisions as given in **12.3.1** of IS 2974 (Part 1) shall apply.

12.2 Reinforcement Detailing

12.2.1 *Nominal cover to reinforcement*

Minimum nominal cover to reinforcement shall be higher of those arrived in accordance with IS 456 and the following:

a) Base Raft:

  i) 75 mm at the bottom;
  ii) 50 mm on the sides; and
  iii) 50 mm at the top.

b) Columns and Top Deck: 50 mm

12.2.2 Care should be taken while detailing to facilitate ease of concreting. The clear space between bars should be at least 5 mm more than the sum of aggregate size and the largest bar diameter used.

12.2.3 Lap splices in the reinforcement bars shall be staggered and shall be located away from sections of maximum tensile stress as far as possible.

12.2.4 Mechanical or welded splices can be used in accordance with IS 456, and they shall be staggered.

12.2.5 Minimum diameter of reinforcement bars used as main reinforcement shall be 16 mm.

12.2.6 The maximum spacing of the reinforcement bars shall not exceed 300 mm.

12.3 Mass Concreting

The provisions of **12.3.2** of IS 2974 (Part 1) shall apply.

12.4 Concreting in Hot and Cold Weather

The provisions of **12.3.3** of IS 2974 (Part 1) shall apply.

12.5 Self-Compaction Concreting

The provisions of **12.3.4** of IS 2974 (Part 1) shall apply.

12.6 Grouting

The provisions of **12.3.5** of IS 2974 (Part 1) shall apply.

12.7 Embedment

The provisions of **12.3.6** of IS 2974 (Part 1) shall apply.

SECTION 3 STRUCTURAL STEEL FOUNDATION

13 GENERAL

Structural steel shall be used only for top deck and columns, whereas base raft shall be in RCC only. Structural steel foundation shall not be used where the foundation outer surface is subjected to temperature greater than 60 °C.

Top deck and columns may be constructed using rolled / built-up sections with stiffeners. These can be open or cellular in form comprising of frame beams, longitudinal beams and deck slab leaving required openings as dictated by machine layout.

Frame Columns and transverse frame beams (main frame beams) shall be provided to support the bearing pedestals. Each transverse frame is connected to adjacent transverse frame through longitudinal beams. Steel deck is provided connecting these transverse and longitudinal beams forming top deck leaving necessary openings as dictated by machine layout.

All the bearing pedestals (including thrust bearing) shall preferably be supported on the main frame beams. Wherever it is unavoidable due to machine layout constraint and the bearing gets supported on i) deck slab; ii) extended cantilever slabs, it shall be ensured that natural frequency of such slabs under all applied machine loads including the bearing load, shall be more than 50 percent away from machine operating frequency/ frequencies.

13.1 Sizing of the Top Deck

13.1.1 Top deck frame beams shall be sized such that the vertical deflection under each bearing pedestal is nearly uniform. This is necessary to ensure that the rotor catenary, as dictated by machine, is maintained. While computing deflections of the frame beams under bearing pedestals, it shall be ensured that Influence of vertical stiffness, lateral stiffness as well as torsional stiffness is considered.

Note: Machine stator gets supported over the longitudinal beams and the rotor gets supported on the frame beams through bearing pedestals as dictated by machine layout. Machine placement over the beams may not always be concentric and may have off-centre placement that would induce torsional moments of the beams. Beams shall be designed to cater to such torsional moments as well and thus suggesting use of box girder construction of the deck. Typical arrangement of Box girder deck is shown in Figure 6.

While providing stiffeners, it shall be ensured that that no individual plate or wall is in resonance with the frequency of the operating speed and shall have a separation margin of ±20 percent.

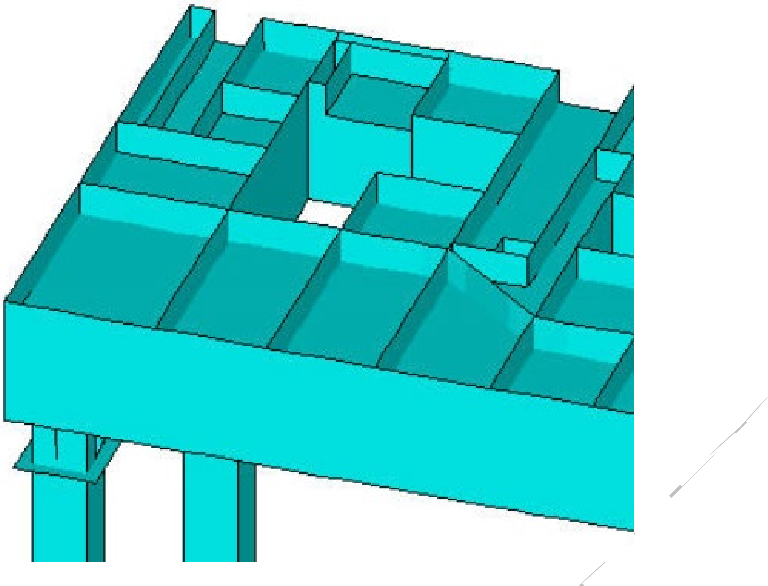


FIG. 6 TYPICAL ARRANGEMENT OF STIFFENERS IN STEEL FOUNDATION DECK

13.2 Sizing of the Columns

Column sizes shown in the layout drawing by the machine manufacturer are only given as a guideline.

The following shall be ensured for column sizing:

a) Each pair of columns of transverse frame shall preferably be of the same size and the size shall be same through its full height. Invariably, these frame columns are connected to each other with a transverse frame beam unless otherwise as dictated by machine layout.

b) Columns shall preferably be in the form of box. Lateral natural frequencies of columns (1st two lateral modes) with column top and bottom ends fixed, shall be more than 20 percent away from machine operating speed. The natural frequency of column plates with outer periphery assumed as fixed shall also be more that 20 percent away from machine operating speed.

c) The columns should be so sized that elastic shortening of all the columns under 1 'g' gravity load is uniform. Further the lateral (transverse as well as longitudinal deflection) under 1 'g' loads, shall also be nearly uniform and the top deck eccentricity criteria given below is complied.

13.3 Top Deck Eccentricity

The requirements for top deck eccentricity shall be as given in **7.4**.

13.4 Sizing of Base Raft

The weight of the base raft shall not be less than combined weight of machine and top deck. Base raft shall be supported directly by soil or set of piles. Base raft thickness shall be such that the vertical deflection of the base raft, under all structural dead loads including applied machine loads, shall be nearly uniform under each frame column. While finalizing base raft thickness, it shall be ensured that the overall foundation eccentricities given in **13.5** are met with.

13.5 Overall Foundation Eccentricity

The requirements for overall foundation eccentricity shall be as given in **7.5**.

14 DYNAMIC ANALYSIS

Dynamic analysis shall be carried out to assess dynamic response and ensure suitability of the foundation under normal operating conditions. Dynamic analysis consists of:

a) Free vibration analysis, and
b) Forced vibration analysis.

14.1 Modelling for Dynamic Analysis

All those foundation/machine elements that contribute to inertia or stiffness shall be included in the model.

It is desirable to use 3-D modelling such that the behaviour of the foundation is compatible with actual machine foundation system. 2-D modelling of the frame foundation is not recommended.

14.1.1 *Machine*

The machine shall be modelled as per **8.1.1**.

14.1.2 *Foundation*

Foundation should be modelled either as beam element model or plate element model.

14.1.2.1 *Beam-plate element model*

The following shall apply for beam element model:

a) Foundation elements like beams and columns shall be modelled as beam elements. All beam elements shall be modelled at centre of the member location.
b) Portion of beams and columns within beam-column junctions should be modelled using rigid element. Similarly portion of column within plate thickness should be modelled with rigid elements.
c) Every beam/column shall be divided in to minimum 8 elements. For short span beams, minimum number of elements shall be 4. Where span/depth ratio of the beam/plate is less 5, shear deformation shall be included in the model for analysis.
d) Wherever beams are provided with cantilever projections, the mass of these projections shall be considered as lumped/distributed mass on the respective beam elements.

e) Base raft shall be modelled using plate elements. All machine components supported directly on base raft shall appropriately be modelled as rigid body with their masses lumped at their respective centroids.

14.1.2.2 *Plate element model*

Wherever necessary to include haunches, pedestals, cantilever projections, etc, only plate element model shall be used instead of beam ~~plate~~ element model. The following shall apply for plate element model:

a) Foundation elements like beams, columns, pedestals, cantilever projections, etc, shall be modelled as plate/shell elements (with minimum 4 noded plate/shell elements).
b) Machine shall be modelled using rigid elements (rigid links) as given in **14.1.1.**
c) Base raft shall be modelled using plate elements. All machine components supported directly on base raft shall appropriately be modelled as rigid body with their masses lumped at their respective centroids

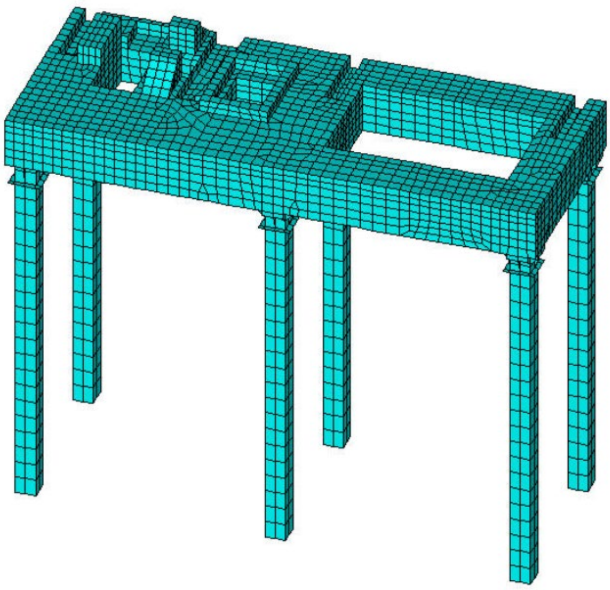


FIG.7 FINITE ELEMENT PLATE MODEL OF TURBO-GENERATOR STRUCTURAL STEEL FOUNDATION

14.1.3 *Modelling of Soil/Pile (Geotechnical Data)*

The requirements shall be as given in **8.1.3.**

14.2 Free Vibration Analysis

The requirements shall be as given in **8.2**.

14.3 Forced Vibration Analysis

The requirements shall be as given in **8.3**.

15 STRENGTH ANALYSIS

15.1 Modelling for Strength Analysis

Model of the foundation developed for dynamic analysis along with base raft shall be used for strength analysis as well.

Equivalent springs representing soil/pile shall be used for the analysis.

Soil shall be modelled as a set of isolated springs (Winkler foundation). The modulus of subgrade reaction shall be used for expressing the pseudo-elastic behaviour of subgrade soil beneath the foundation.

Piles are modelled as equivalent springs and shall be applied at respective nodal point at the intersection of pile.

15.2 Loads

Loads shall be determined in accordance with **8.2**.

15.3 Load Combinations

The load combinations shall be as per **8.3**.

16 STATIC DEFLECTION CRITERIA

The requirements of **9** shall apply.

17 STRENGTH DESIGN OF THE FOUNDATION

17.1 Foundation shall be designed by limit state method or working stress method in accordance with IS 800.

17.2 When working stress method of design is adopted, permissible stresses for emergency and environmental conditions shall be appropriately increased as per IS 2974 (Part 1).

17.3 Material Grade

Grade of material shall be in accordance with IS 2974 (Part 1).

18 FABRICATION AND ERECTION

Fabrication and erection shall be as per IS 800.

The size of the individual prefabricated components depends on the mode of transportation. It is desirable that prefabricated parts of the steel foundation be shipped to the site and then assembled.

In general, the building enclosing the machine should be erected first, making, the building crane available for the erection of the steel foundation. However, if the building crane is not available, erection of the steel foundation may be carried out with the mobile crane. The welding of the different parts should be done in a sequence that ensures a structure within permitted tolerances. After welding, all bearing plates should be checked for levelness, squareness and proper elevation. Distortions of the prepared baseplates can be corrected by grinding to achieve a tolerance as small as 1: 10000.

NOTE — The field erection of steel foundation generally takes only few weeks.

19 DURABILITY ASPECTS

For durability related aspects, provisions of **15** of IS 800 shall apply.