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व्यापक परिचालन मसौदे

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

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

प्राप्तकर्ता :

1 सिविल इंजीनियरी विभाग परिषद् के रूचि रखने वाले सदस्य

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

3 रूचि रखने वाले अन्य निकाय

महोदय/महोदया,

निम्नलिखित मसौदे संलग्न है :

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

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

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

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

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

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

धन्यवाद ।

भवदीय,

(संजय पंत)
प्रमुख (सिविल इंजीनियरी)

संलग्न : उपरिलखित

भारतीय मानक ब्यूरो
BUREAU OF INDIAN STANDARDS

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DRAFTS IN WIDE CIRCULATION

DOCUMENT DESPATCH ADVICE

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

TECHNICAL COMMITTEE:

Soil and Foundation Engineering Sectional Committee, CED 43

ADDRESSED TO:

1. All Members of Civil Engineering Division Council, CEDC
2. All Members of Soil and Foundation Engineering Sectional Committee, CED 43 and the Adhoc Panel for Preparation of Drafts for Revision of IS 2974 (Parts 1 to 5), CED 43:P8
3. All other interests

Dear Sir/Madam,

Please find enclosed the following drafts:

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

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

Last Date for comments: 15 October 2020.

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

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

The documents are also hosted on BIS website, **www.bis.gov.in**.

Thanking you,

Yours faithfully,

(Sanjay Pant)
Head (Civil Engg.)

Encl: as above

FORMAT FOR SENDING COMMENTS ON BIS DOCUMENTS

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

DOC. NO.	**Doc: CED 43 (13264)**
TITLE	**Draft Indian Standard Design and Construction of Machine Foundatio — Code of Practice: Part 3 Frame Foundations [Revision of IS 2974 (Parts 1 to 5)] (ICS No. 93.020)**
LAST DATE OF COMMENTS	**15 October 2020**
NAME OF THE COMMENTATOR/ ORGANIZATION	______________________________

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

Doc: CED 43 (13264)
August 2020

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: **15 October 2020**

FOREWORD

(*Formal clauses to be added later*)

Installation of heavy machinery has assumed increased importance in the wake of the vast programme of industrial development in the country. The overall foundation design of such machines shall have to be in accordance with the dynamic requirements of machine, and foundation and soil, besides special requirements of the machine as laid down by machine manufacturer. It was well realized that the dynamic soil parameters underneath the foundations play a significant role in achieving the said objective. It is to serve this purpose that, IS 2974 'Code of practice for design and construction of machine foundations' was published in five parts covering foundations for host of machines, thereby meeting development needs of the country. The various parts of the Code were published and revised as per the details given below:

	Various Parts	*First published in*	*Subsequently revised in*
Part 1	Foundations for reciprocating type machines	1964	1969 and then in 1982
Part 2	Foundations for impact type machines	1966	1980
Part 3	Foundations for rotary type machines (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, failure data collected over the years from field tests on wide variety of machines and their foundations provides clear indicator that the existing design philosophy needs a re-look and suggests host of changes to be incorporated in the codes covering various design and construction aspects of the foundations. In view of the above as well as the recent developments reported globally on this subject, it has been felt that the provisions regarding the design and construction of machine foundations should be further revised.

To cater to these objectives, it was decided to revise and restructure various Parts of IS 2974 to meet the current demand of satisfactory performance of machines with no room for failure. While restructuring these, it was decided to address the code foundation-wise rather than machine-wise except foundations for impact and impulsive load machines, that is, hammers and presses, where it necessarily has to be machine-wise. This would also avoid any overlapping of the provisions between different Parts of the 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 reinforced cement concrete (RCC) and steel frame foundations for the installation of rotary and reciprocating machines, such as turbo-generators, turbo-compressor, boiler feed pumps, crushers and reciprocating compressors. 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.

Doc: CED 43 (13264)
August 2020

BUREAU OF INDIAN STANDARDS

DRAFT FOR COMMENTS ONLY

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Draft Indian Standard

DESIGN AND CONSTRUCTION OF MACHINE FOUNDATIONS — CODE OF PRACTICE

PART 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: **15 October 2020**

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).

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 (Part 3): 2015	Code of practice for design loads (other than earthquake) for buildings and structures: Part 3 Wind loads (third 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): 20**	Design and construction of machine foundations — Code of

	practice: Part 1 General Provisions (*under preparation*)
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 Speed — The rotational speed at which the rotor or rotating elements vibrate at its natural frequency resulting resonance.

3.3 Framed Foundation — The entire structure, including the top deck, columns and base raft. Typical framed foundations supporting turbo-generator, double roll crusher and compressor are shown in Fig. 1. The various framed foundations components are defined under **3.5.1** to **3.5.4**.

3.3.1 *Top Deck* — The uppermost portion of the machine foundation comprising of longitudinal beams, transverse beams and/or 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 of beams and slabs for supporting auxiliary equipment.

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

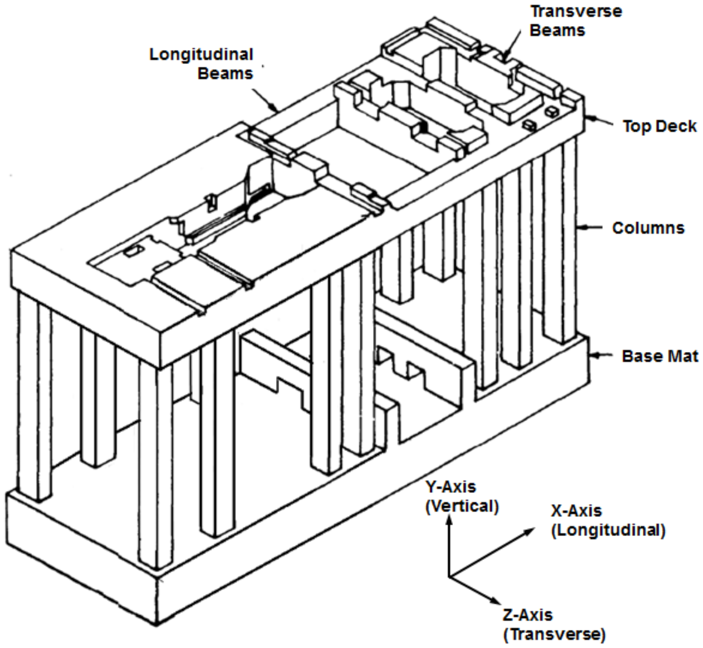
3.3.4 *Base Raft (Base Mat)* — The part of the foundation that supports columns and rests on soil, rock, or piles.

3.4 Overall Eccentricity — The distance between the centre of mass of 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.

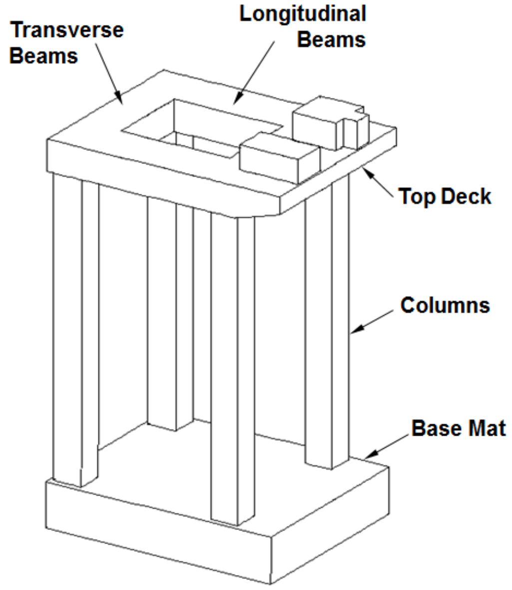
3.5 Solid Model — Mathematical model of machine foundation consisting of 3-D solid elements.

3.6 Thrust Bearing — Aparticular type of rotary bearing designed to support predominately axial load.

3.7 Top Deck Eccentricity — The distance between the centre of mass of machine and top deck and the centre of stiffness of columns considering columns fixed at base raft level.



1A Typical Framed Foundation for a Turbo Generator



1B Typical Framed Foundation for a Double Roll Crusher

Fig. 1 Typical Framed 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 *framed* 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 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 RCC 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 can be made of structural steel for those machines where higher temperatures are not involved. The design of structural steel framed 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 GENERALDESIGN 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 be at least equal to 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) Location of thrust bearing (wherever applicable) should not be on extended cantilever potion.
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.

The following shall be ensured for column sizing:

a) Total weight of all the columns should not be less than 0.4 to 0.5 times the weight of top deck plus machine on deck.
b) Each pair of columns (transverse) should preferably be of the same size and should be connected with a transverse beam unless dictated otherwise by machine layout.
c) While finalizing column sizes, it shall be ensured that the top deck eccentricity criteria given in **7.4** are met with.
d) The first two natural frequencies of 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 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 weight of machine plus top deck. Edges of base raft should extend at least 150 mm from the faces of the columns.

While finalizing base raft thickness, it shall be ensured that the overall foundation eccentricities given in **7.5** are met with. Base raft should be rectangular in plan. Any cut-out or reduction in the plan of base raft is not recommended.

7.4 Top Deck Eccentricity

7.4.1 *Lateral and Longitudinal Directions*

7.4.1.1 The columns shall be so sized that deflection in lateral and longitudinal directions one at a time under 1 g loading is uniform. Variation in deflection from the average value shall be within 2 percent. This will ensure that top deck eccentricity in lateral and longitudinal direction is well within 2 percent.

7.4.1.2 Top deck should preferably be rectangular in plan. 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 with all machine masses, both along lateral and longitudinal directions, under respective 1 g loading is uniform. Variation in deflection from the average value shall not exceed5 percent.

7.5.1.2 As far as possible, the base raft shall be rectangular in plan. 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.

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 2 percent.

8 DYNAMIC ANALYSIS

Dynamic analysis of the machine-foundation-soil 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.

8.1 Modelling for Dynamic analysis

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

NOTE — In case, the recommendations of 7.4 are met, base raft can be ignored for modelling of dynamic analysis for frame foundations not exceeding 3 frames. Columns shall be considered fixed at top of base raft level.

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 should be modelled as rigid body.

b) Machine masses shall be lumped at centroid level of the respective machines.

c) Bearing pedestals, wherever present, to be modelled as rigid body. Machine rotor weight shall be lumped appropriately at these locations.

d) Often, large machines such as turbo-generators are having one thrust bearing and remaining are sliding 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 (spring or bellow). 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*

Foundation should 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.

The following shall apply for beam-plate modelling 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.

b) Slabs (top deck) and intermediate slab shall be modelled as plate elements. All plate elements shall be modelled at mid plane of the respective slab. Any offset between the adjacent plate thicknesses shall be modelled by rigid links or by offset command wherever permitted by software.

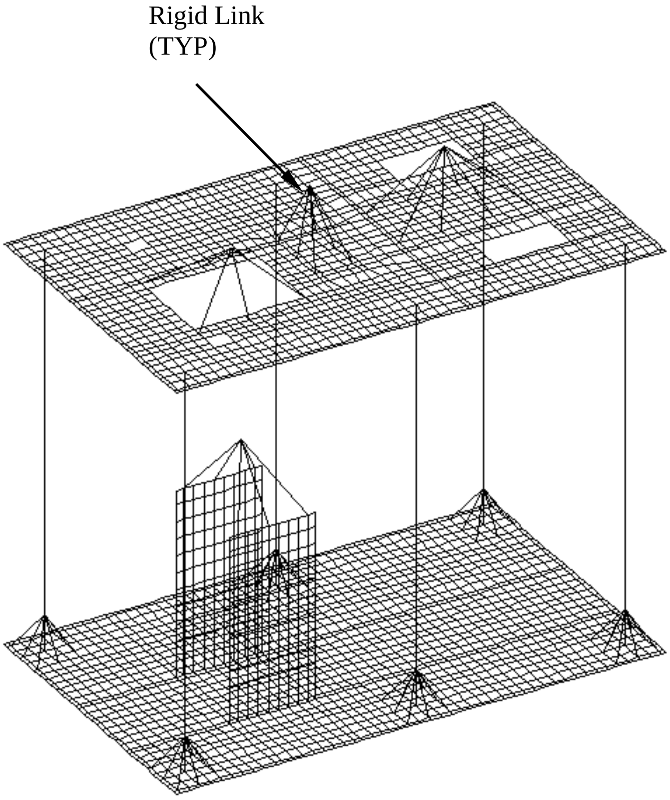


Fig. 3 Beam and Shell Element Model of Frame Foundation with Base Raft

c) 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.

d) Every beam/column shall be divided in to minimum 8 elements.

e) Where span/depth ratio of the beam/plate is less than 5, shear deformation shall be included in the model for analysis.

f) Since cantilever projections cannot be modelled using beam elements, their mass shall be computed and lumped/distributed on the appropriate beam elements.

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

g) Base raft shall be modelled as plate elements. All machine components supported directly on base raft shall appropriately modelled as rigid body with their masses lumped at respective centroids (*see* **7.1.1**).

8.1.2.2 *Solid model*

Typical Solid Model (with raft) is shown in Fig 4. Solid model is preferable over beam-plate model as all aspects of foundation, for example, haunches, cantilever projections, etc, can conveniently be modelled. The following shall apply for solid modelling of foundation:

a) Foundation elements like beams, columns, slabs pedestals, cantilever projections, etc., shall be modelled as solid elements (with minimum 8 noded brick element).

b) Machine shall be modelled using rigid elements (rigid links) as given in **8.1.1.**

c) *Degree of freedom incompatibility*— Solid elements have 3 degrees of freedom (DOF) whereas rigid links (beam elements) representing machine have 6 DOF. Connecting rigid links with solid elements will cause DOF incompatibility and will lead to wrong results. Necessary corrective steps shall be taken at the modelling stage itself. Since, corrective steps are software dependent, these should be introduced accordingly.

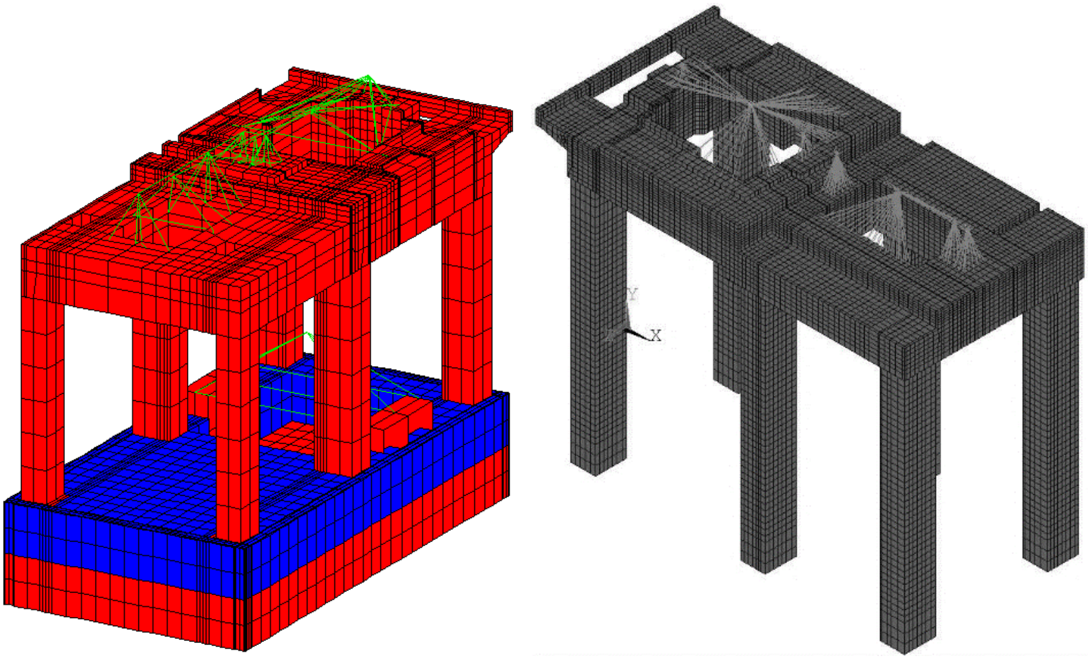


Fig.4 Solid Model of Frame Foundation with Base Raft

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 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.

b) Soil is represented by a set of three translational springs attached to each node of the base raft in contact with the soil and other end is restrained. Total stiffness of the whole base raft shall be distributed to individual springs based on the influence area of nodes. Rotational springs shall not be used as rotational stiffnesses. Rotational stiffnesses in all three directions shall get computed automatically using linear springs, at each node. This type of model results in upper bound of rotational frequencies.

c) Soil springs connection to base raft:

   1) For solid model, one end of these six springs shall be connected to corresponding node of base raft and other end shall be restrained.
   2) For beam-plate model, the distance between CG of base area of actual base raft and CG of plate (representing base raft) shall be modelled using rigid link. Soil springs are connected to this rigid link.

8.1.3.1 *Piles*

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

8.1.3.1.1 *Pile design*

Design of piles shall be carried out as per provisions of 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 effective pile stiffness 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 centre of mass of machine + foundation (including machines on the base raft). Maximum eccentricity shall be limited to 2 percent. Clear clearance of pile from edge of base raft shall be minimum 500 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.

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*

Approximate value of vertical natural frequency can be evaluated as under:

Vertical deflection under 1 g vertical load, in mm = δ_v

Vertical natural frequency = $f_{nv} = \frac{1}{2\pi}\sqrt{\frac{9810}{\delta_v}}$

It is recommended that the vertical natural frequency shall be at least 20 percent away from the machine excitation speed, that is,

$f_{nv} < 0.8\ f_e$ (this a condition representing under tuned foundation)

or,

$f_{nv} > 1.2\ f_e$ (this a condition representing over tuned foundation)

Where,

f_{nv} = vertical natural frequency of the foundation, and
f_e = excitation frequencies of the machine.

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

8.3 Forced Vibration Analysis

Forced vibration analysis shall be harmonic analysis. 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 To cater to uncertainties and eventualities, it is recommended to evaluate dynamic forces for balance quality grade 1 (one) grade higher than the balance quality grade mentioned for the machine.

2 In certain cases, there is large mismatch between dynamic forces supplied by the machine manufacturer verses 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 based on balance quality grade of the rotor. 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 should be evaluated in time domain. The entire forcing function shall be discretised at time interval of $\frac{1}{16} \times \left(1/f_{\mathrm{i}}\right)$ 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. Steady state response of the machine/foundation shall be evaluated at 0.9 to 1.1 times the operating speed.

2 From the sweep run as above, transient response shall also be obtained corresponding to foundation natural frequency (below operating speed) as well as at rotor critical speeds.

3 Dynamic unbalance force given below shall be considered while calculating dynamic response at excitation frequencies other than operating frequency:

Dynamic unbalance force at other excitation frequency	=	Dynamic unbalance force at operating frequency	×	$(f_{\mathrm{i}}/f_{\mathrm{m}})^2$

Where,

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

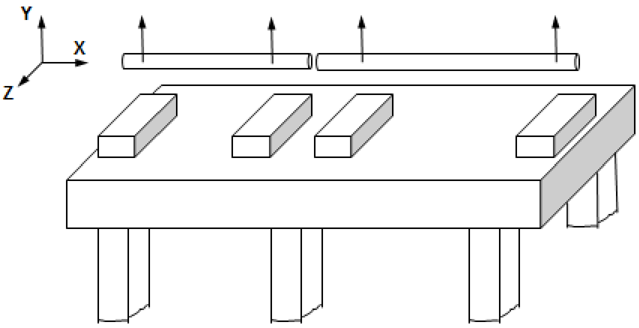
8.3.2.1 As far as possible, dynamic forces shall be applied simultaneously at all bearing locations. In case software has limitations in considering all forces at the same time, these forces shall be applied one at a time and overall response shall be computed using SRSS (square root of sum of squares)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

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

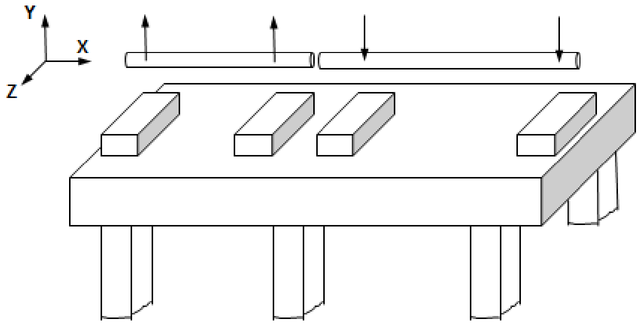
Dynamic forces from drive machine and driven machine should be considered as below:

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

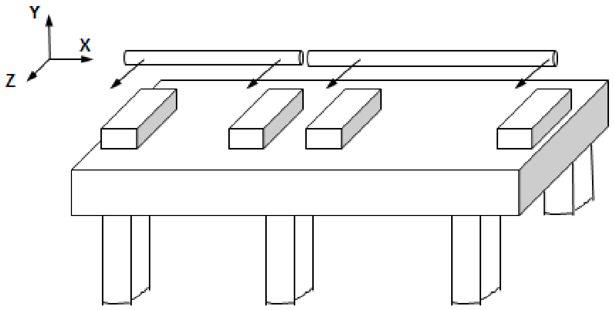
Fig. 5shows the application of dynamic force in IP and OP.



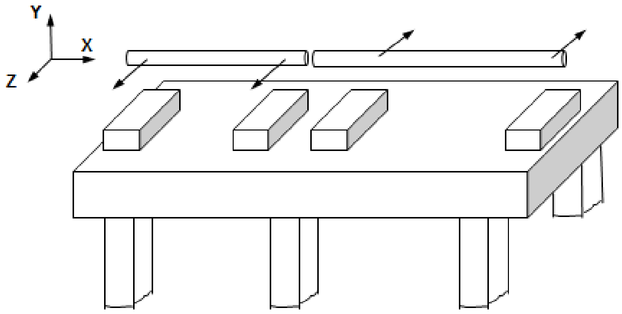
5A Dynamic Forces along X Axis – In-Plase



5B Dynamic Forces along X Axis – Out-of-Plase



5C Dynamic Forces along Z Axis – In-Plase



5D Dynamic Forces along Z Axis – Out-of-Plase

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 points.

8.3.2.5 Response shall be computed in terms of velocity (mm/s) as well as displacement response in microns.

8.3.5 *Permissible Response Amplitude*

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

9 STRENGTH ANALYSIS

9.1 Modelling for Strength Analysis

9.1.1 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.

9.1.2 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.

9.2 Loads

The following loads shall be considered for the foundation design:

a) Dead loads (*DL*);

1) Foundation self-weight,
2) Machine dead loads, and
3) All equipment dead loads + all structural loads (air duct, etc) at base raft level.

NOTE — Dead loads mentioned in 2) and 3) above shall be applied at their respective centroid location. Alternatively, these loads can be applied along with moments due to eccentric loading.

b) Floor imposed load (*IL*) of 10 kN/m^2 around the machine shall be considered;

c) Operating loads;

1) Dynamic force due to rotating/moving parts (*NUL*) – Dynamic force due to rotating/ moving parts, which is an operating load can be evaluated by detailed dynamic analysis or by a pseudo dynamic analysis (static equivalent method). Fatigue factor of 2.0 shall be used while calculating the dynamic force. Dynamic force shall be considered separately in vertical and transverse direction.

2) 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.

d) Thermal loads (*TL*) (if any);

1) Uniform temperature change, and
2) Temperature gradient across members.

NOTE — When considering the temperature gradient across structural members, moment of inertia of the cross section can be reduced to half to one third of the full section.

e) Emergency loads (if applicable);

1) Short circuit loads for motor/generator (*SCF*),
2) Forces due to loss of moving parts like blade, hammer, fins, etc (*LBL*),
3) Bearing failure load (*BFL*), and
4) Bowed rotor forces (*BRF*).

f) Environmental loads;

1) Seismic force (*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. Seismic forces specified by the manufacturer at the deck level will generally be higher as these are generated with the use of floor response spectrum and hence, can be neglected.

2) Wind loads (*WL*)for out station plants shall be calculated as per IS 875 (Part 3).

g) Erection loads(*ERL*)

9.3 Load Combinations

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

a) Operating condition
DL + IL + OL±NUL + TL

b) Emergency loading condition

1) Short circuit condition
DL+ IL+ OL ± NUL+ TL±SCF
2) Loss of blade unbalance/bowed rotor
DL+ IL+ OL+ TL ± LBL/BRF
3) Bearing failure condition
DL+ IL+ OL+ TL ± BFL

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

d) Erection condition
DL + IL + ERL

9.3.2 *Load Combinations for Limit State Method*

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

b) Emergency loading condition

1) Short circuit condition
1.2[*DL*+*IL*+ *OL* ±*NUL*+*TL*±*SCF*]

2) Loss of blade unbalance/bowed rotor
1.2[*DL*+*IL*+*OL*+*TL* ± *LBL*/*BRF*]

3) Bearing failure condition
1.0[*DL*+*IL*+*OL*+*TL* ±*BFL*]

c) Environmental condition

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

d) Erection condition
1.5[*DL*+*IL*+*ERL*]

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

10 STATIC DEFLECTION CRITERIA

The machine foundation shall have sufficient stiffness to ensure adequate bearing alignment under all operational loads. Deflection and rotation of deck beams supporting bearings can affect the mechanical operation of machine, reduce clearances and cause unpredicted stress in shaft. For these reasons, structural deflections should be limited to magnitudes that are detrimental to the mechanical operation of the machine. These deflection and rotations shall be limited to allowable values as specified by the machine manufacture.

11 DESIGN

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 Flexural members may be subjected to substantial torsion and the same has to be accounted in the design.

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 given in 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	0.25 percent of gross sectional area on each face
	b) Sides	0.1 percent gross sectional area on each side
ii)	Slabs of top deck	
	a) Top and bottom	0.12 percent of gross sectional area in each direction on each face
	b) Sides	12 mm diameter bar at 200mm c/c
iii)	Columns	
	a) Longitudinal reinforcement	0.8 percent of gross sectional area
iv)	Base raft	
	a) Top and bottom	0.12 percent of gross sectional area in each direction on each face
	b) Sides	16 mm diameter bar at 200mm c/c
	c) Intermediate Layer	Though not necessary, for base raft of thickness greater than 1.5 m, 16 mm diameter bars at 600 mm to 1 000 mm spacing may be provided at every 1m depth to provide lateral support to vertical chair bars and thus forming a stable reinforcement cage.

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. Construction joints may also be provided approximately at every 8m, if the height of the column exceeds 8 m.

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 Embedments

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.

Top deck shall be in the form of box girder/cellular construction provided with necessary cut-outs. The deck is built to suit the elevations of individual components including bearing pedestals. Columns are slender elements.

Structural steel foundation shall not be used where the foundation outer surface is subjected to temperature greater than 60 °C.

13.1 Sizing of the Top Deck

13.1.1 Top deck beams shall be sized in such a way that all beams shall give the sufficient bending (vertical and lateral) and torsional stiffness. Generally, machines are supported at the edge of beams leaving sufficient working space around the machine and this creates torsional moments. Hence, beams shall have sufficient torsional strength to transfer torsional moments. Therefore, to obtain the sufficient bending and torsional rigidity, it is preferable to have box girder construction.

The arrangement of stiffeners separating into cells (*see* Fig. 6) should ensure that no individual plate or wall is in resonance with the frequency of the operating speed and fundamental natural frequency shall be separated by ±20 percent from operating frequency.

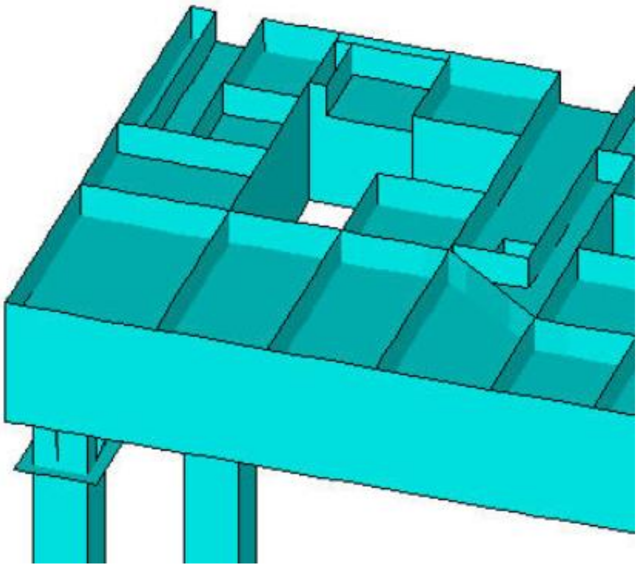


Fig. 6 Typical Arrangement of Stiffeners in Steel Foundation Deck

13.1.2 Box girder shall have sufficient number of stiffeners so that fundamental natural frequencies of top/bottom plates and walls shall be separated from operating frequency by more than 20 percent.

13.1.3 Location of thrust bearing, wherever applicable, should not be on extended cantilever portion.

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 (transverse) should preferably be of the same size and should be connected with a transverse beam unless specified otherwise by machine layout.

b) While finalizing column sizes, it shall be ensured that the top deck eccentricity criteria given below are met with.

c) Fundamental natural frequencies of columns shall be separated by 20 percent from machine operating speed.

d) Columns shall also be in the form of box and fundamental natural frequency of column plates shall be away from machine operating frequency by more than 20 percent.

13.3 Sizing of Base Raft

The weight of the base raft should not be less than the weight of machine plus top deck.

While finalizing base raft thickness, it shall be ensured that the overall foundation eccentricities given in **13.5** are met with.

13.4 Top Deck Eccentricity

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

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.

NOTE — In case, the recommendations of **13.4** are met, base raft can be ignored for modelling of dynamic analysis. Columns shall be considered fixed at top of base raft level.

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 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.

d) Where span/depth ratio of the beam/plate is less 5, shear deformation shall be included in the model for analysis.

e) Since cantilever projections cannot be modelled using beam elements, their mass shall be computed and lumped/distributed on the appropriate beam elements.

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

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

14.1.2.2 *Plate element model*

Plate element model is preferable over beam element model as all aspects of foundation, for example, haunches, pedestals, cantilever projections, etc, can conveniently be modelled. The following shall apply for plate element model:

a) Foundation elements like beams, columns, slabs 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 as plate elements. All machine components supported directly on base raft shall appropriately modelled as rigid body with their masses lumped at respective centroids.

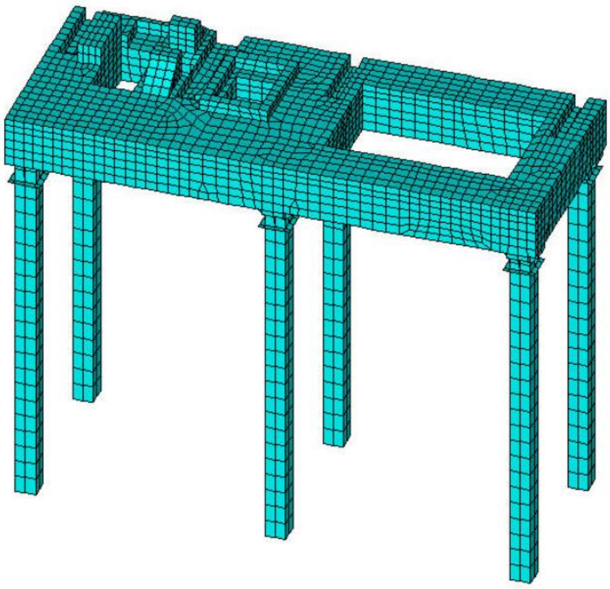


Fig.7 Finite Element Model of Turbo-Generator Structural Steel Foundation

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 **10** shall apply.

17 DESIGN

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.

Prefabricated parts of the steel foundation should be shipped to the site and then assembled. The size of the individual prefabricated components depends on the mode of transportation.

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.