



# भारतीय मानक ब्यूरो BUREAU OF INDIAN STANDARDS

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व्यापक परिचालन मसौदा

हमारा संदर्भ : सीईडी 43/टी-130

14 दिसम्बर 2022

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

प्राप्तकर्ता :

- 1 सिविल इंजीनियरी विभाग परिषद, सीईडीसी के सभी सदस्य
- 2 मृदा एवं नींव इंजीनियरी विषय समिति, सीईडी 43 के सभी सदस्य
- 3 संयुक्त पाइल राफ्ट नींव के लिए मानक तैयार करने के लिए पैनल, सीईडी 43 : पी17
- 4 रुचि रखने वाले अन्य निकाय

महोदया/महोदय,

निम्नलिखित मसौदा संलग्न है:

प्रलेख संख्या	शीर्षक
सीईडी 43 (21409)WC	संयुक्त पाइल-राफ्ट नींवों का डिज़ाइन और निर्माण - रीति संहिता का भारतीय मानक मसौदा (ICS No. 93.020)

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

**सम्मतियाँ भेजने की अंतिम तिथि: 15 जनवरी 2023**

सम्मति यदि कोई हो तो कृपया अधोहस्ताक्षरी को ई मेल द्वारा [madhurima@bis.gov.in](mailto:madhurima@bis.gov.in) पर या उपरलिखित पते पर, संलग्न फॉर्मेट में भेजें।

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

यह प्रलेख भारतीय मानक ब्यूरो की वैबसाइट [www.bis.gov.in](http://www.bis.gov.in) पर भी उपलब्ध हैं।

धन्यवाद।

भवदीय

ह/-

(अरुण कुमार एस.)

वै. 'ई'/निर्देशक और प्रमुख (सिविल इंजीनियरी)

संलग्न: उपरलिखित



# भारतीय मानक ब्यूरो BUREAU OF INDIAN STANDARDS

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**DRAFT IN  
WIDE CIRCULATION**

Reference	Date
CED 43/T-130	14 December 2022

**TECHNICAL COMMITTEE:**

**SOIL AND FOUNDATION ENGINEERING SECTIONAL COMMITTEE, CED 43**

**ADDRESSED TO:**

1. All Members of Civil Engineering Division Council, CEDC
2. All Members of Soil and Foundation Engineering Sectional Committee, CED 43
3. All Members of Panel for Formulation of Standard for Combined Pile Raft Foundation, CED 43 : P17
4. All other interests

Dear Madam/Sir,

Please find enclosed the following draft:

Doc. No.	Title
CED 43 (21409)WC	<b>Draft Indian Standard Design and construction of combined piled raft foundations — Code of practice (ICS No. 93.020)</b>

Kindly examine the 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: 15 January 2023**

Comments if any, may please be made in the enclosed format and emailed at [madhurima@bis.gov.in](mailto:madhurima@bis.gov.in) or sent at the above address.

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

The document is also hosted on BIS website [www.bis.gov.in](http://www.bis.gov.in).

Thanking you,

Yours faithfully,  
Sd/-

**(Arun Kumar S.)**

**Sc. 'E'/Director and Head (Civil Engg.)**

Encl: As above



**BUREAU OF INDIAN STANDARDS**

**DRAFT FOR COMMENTS ONLY**

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***Draft Indian Standard***

**DESIGN AND CONSTRUCTION OF COMBINED PILED RAFT FOUNDATIONS —  
CODE OF PRACTICE**

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Soil and Foundation Engineering  
Sectional Committee, CED 43

Last date for Comments:  
**15 January 2023**

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Soil and Foundation Engineering Sectional Committee, CED 43

**FOREWORD**

*(Formal clauses to be added later)*

This standard has been formulated to cover provisions for design and construction of combined piled raft foundations (CPRF). This composite foundation which combines load carrying capabilities of raft and pile foundations together may be implemented in any of the following situations:

- a) Where a raft cannot provide an adequate bearing capacity due to excessive settlement beyond permissible limit; and
- b) Where the raft is unable to perform under the serviceability requirement (for example, if settlement exceeds permissible limit for raft) of the structure.

In both cases, piles can be introduced below the raft to improve the safety against failure or to reduce the settlement to an acceptable level.

In the formulation of this standard, considerable assistance has been derived from the following international standards:

- a) DIN 1054:2021-04 Subsoil – Verification of the safety of earthworks and foundations – Supplementary rules to DIN EN 1997-1
- b) DIN EN 1997-1:2014-03 Eurocode 7: Geotechnical design – Part 1: General rules

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 2022 'Rules for rounding of numerical values (*second 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.

**BUREAU OF INDIAN STANDARDS**

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***Draft Indian Standard***

**DESIGN AND CONSTRUCTION OF COMBINED PILED RAFT FOUNDATIONS —  
CODE OF PRACTICE**

---

Soil and Foundation Engineering  
Sectional Committee, CED 43

Last date for Comments:  
**15 January 2023**

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**1 SCOPE**

**1.1** This standard covers the design and construction of combined piled raft foundation (CPRF) for residential and industrial structures, store houses, storage tanks, etc.

**1.1.1** CPRF transmits the load to soil by resistance developed by the components of the foundation, that is, piles and raft, the raft being placed on a competent ground. The piles develop resistance along the pile shaft by skin friction and at the pile tip by end bearing, which is expected to be much smaller than the load taken by the friction. The raft develops the resistance by generating the contact pressure below the raft.

**1.2** CPRF shall not be used in cases where soil layers of relatively low stiffness (for example, very soft cohesive soil, organic soil, collapsible soil, liquefiable soil) are situated closely beneath the raft. It shall also not be applied to layered soil with significantly high stiffness (modulus) contrast between the top and bottom layers.

**2 REFERENCES**

The standards listed in Annex A contains provisions, which through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subjected to revision and parties to agreement based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards listed in Annex A.

**3 TERMINOLOGY**

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

**3.1 Angular Distortion ( $\theta$ )** — Vertical distance after deformation due to applied load between the points of maximum and minimum settlement divided by the horizontal distance between the two points (see Fig. 1).

**3.2 Allowable Load** — The load which can be applied on the combined pile-raft foundation system by taking into account the individual ultimate load capacities of pile and raft, soil-pile-raft interaction effects and allowable displacement from serviceability criteria, negative skin friction on pile and other relevant loading types including reversal of loads, if any. In other words, it is the load at which the allowable settlement reduction ratio considering serviceability is achieved.

**3.3 Combined Piled Raft Foundation** — A pile group in which the raft connecting all the pile heads positively contributes to the overall foundation behaviour. The presence of raft is recognized and its contribution in sharing the load with the pile group is taken into account. This composite foundation which combines load carrying capabilities of raft and pile foundations together, considers four interactions, namely, pile-pile interaction, pile-soil interaction, pile-raft interaction and raft-soil interaction (see Fig. 2A).

**3.3.1 Large CPRF** — CPRF in which the ratio of raft width ( $B_r$ ) to pile length ( $L_p$ ) is greater than 1, that is,  $B_r/L_p > 1$ . In large CPRFs, the raft bearing capacity is insufficient from settlement criteria so that piles are used as settlement reducers.

**3.3.2 Small CPRF** — CPRF in which the ratio of raft width ( $B_r$ ) to pile length ( $L_p$ ) is less than 1, that is,  $B_r/L_p \leq 1$ . Small CPRFs are those in which the bearing capacity of the unpiled raft is insufficient from settlement criteria so that piles are added to achieve a suitable factor of safety against bearing capacity. In such a case, the flexural stiffness of the raft is made rather high so that differential settlement is not a major problem.

**3.4 Cut-off Level** — The level where a pile is cut-off in order to make structural connection to the pile caps or beams or raft or any other structural component at that level.

**3.5 Design Load** — The loads (compression, tension, lateral, moment or any combination thereof) considered to act on the CPRF during the life of the structure satisfying provisions mentioned in other relevant Indian Standards.

**3.6 Design Stress** — The stress (compressive, tensile or combination) imposed on the CPRF by the design load and calculated in accordance with engineering practice.

**3.7 Differential Settlement of CPRF ( $S_{pr,diff}$ )** — The difference between the maximum and the minimum settlement, across any section of the CPRF (see Fig. 1).

**3.8 Limiting Capacity** — The vertical load at which for a CPRF, bearing capacity failure occurs due to exceedance of the combined capacity of raft resistance and that of piles in terms of shaft resistance and end bearing resistance. The assessed value of the total resistance  $R_{tot,k}(s)$  of the CPRF depends on the settlements of the foundation and consists of the sum of the assessed pile resistances  $\sum R_{pile,k,j}(s)$  and the assessed raft resistance,  $R_{raft,k}(s)$  (see Fig. 2A). The assessed raft resistance results from the integration of the settlement dependent contact pressure,  $\sigma(s, x, y)$  in the ground plan area of the raft and can be expressed as,  $R_{raft,k}(s) = \iint \sigma(s, x, y) dx dy$ . Similarly, due considerations for horizontal load capacity and moment capacity should be considered for the CPRF system.

**3.9 Load Eccentricity ( $e_L$  or  $e_B$ )** — Distance between the point of application of applied resultant load and the centre of gravity of the pile-raft system along length and width, respectively (see Fig. 1).

**3.10 Maximum CPRF Settlement ( $S_{pr,max}$ )** — The maximum value of settlement occurred at a particular point of the CPRF system (see Fig. 1).

**3.11 Pile-Pile Interaction** — The result of pile group effect, defined as the changes in the load-displacement response of a pile group and single piles due to superimposition of stress and displacement field of a single pile in a group (see Fig. 2A).

**3.12 Pile-Raft Interaction** — The changes in the load-displacement response of pile group when the raft is being rested to the soil surface (see Fig. 2A).

**3.13 Pile-Raft Coefficient or Load Sharing Ratio ( $\alpha_{pr}$ )** — The ratio between the sum of the characteristic pile resistances and the characteristic value of the total resistance.

NOTE —  $\alpha_{pr} = \frac{R_{piles}}{R_{total}}$ , in which  $R_{piles}$  is the resistance provided by piles and  $R_{total}$  is the total resistance provided by the CPRF system under vertical load. Whenever,  $\alpha_{pr}$  is equal to 1, all the vertical loads are taken up by the pile component which essentially makes the system to behave as a pile group foundation. Whereas,  $\alpha_{pr}$  equal to 0 indicates that the vertical loads are borne by raft component, hence, the foundation behaviour will be like spread raft foundation. To utilize both the foundation components effectively, the value of  $\alpha_{pr}$  should be chosen carefully and the standard is not valid for  $\alpha_{pr} \geq 0.9$ , as shown in Fig. 2B.

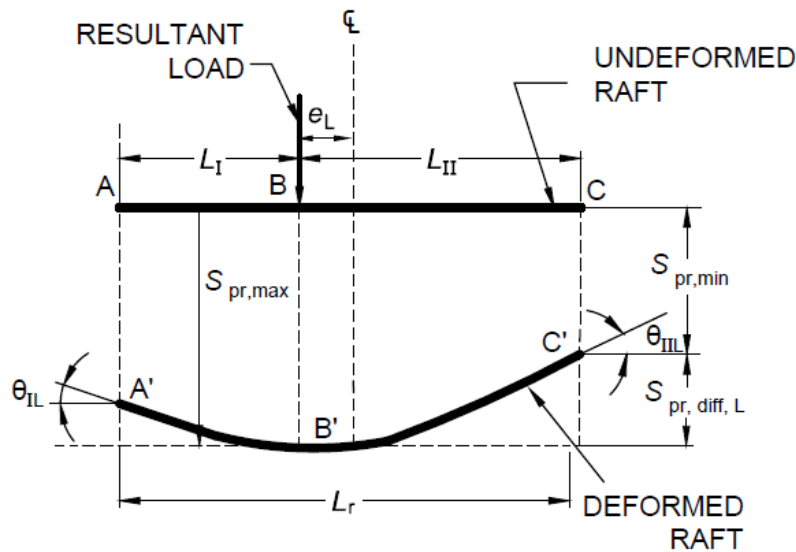
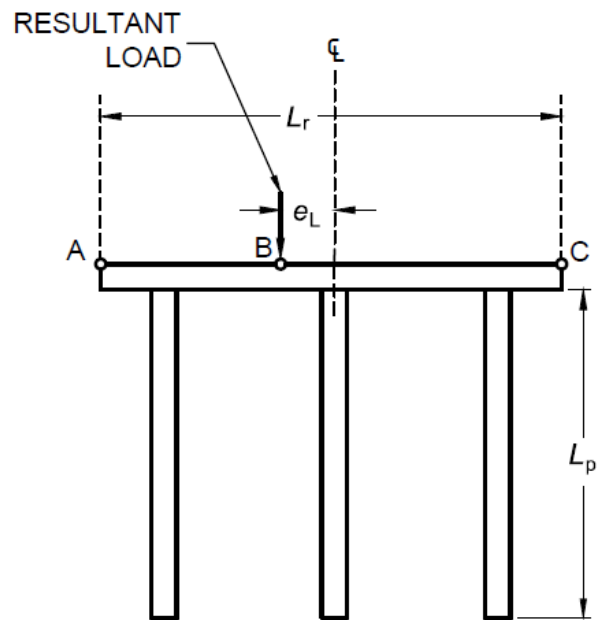
**3.14 Pile-enhanced Raft** — CPRF in which the piles are designed to mobilize their total ultimate capacity and the raft carries majority of the design load (see Fig. 3A).

**3.15 Raft-Pile Interaction** — The modification in the load carrying mechanism of the raft when piles are introduced beneath (see Fig. 2A).



**3.16 Raft-Enhanced Pile** — CPRFs in which both the piles and raft work within a pseudo-elastic range of behaviour. The pile group capacity is not fully mobilized at working load and the pile group carries majority of the design load (see Fig. 3B).

**3.17 Settlement Reduction Ratio (*SRR*)** – The ratio of the difference of settlement of the unpiled raft under the given loading,  $S_r$  and the settlement of the piled raft under the same loading considered in the case of the unpiled raft,  $S_{pr}$  to the settlement of the unpiled raft, that is, under any given loading conditions,  $SRR = (S_r - S_{pr})/S_r$



1A ALONG RAFT LENGTH

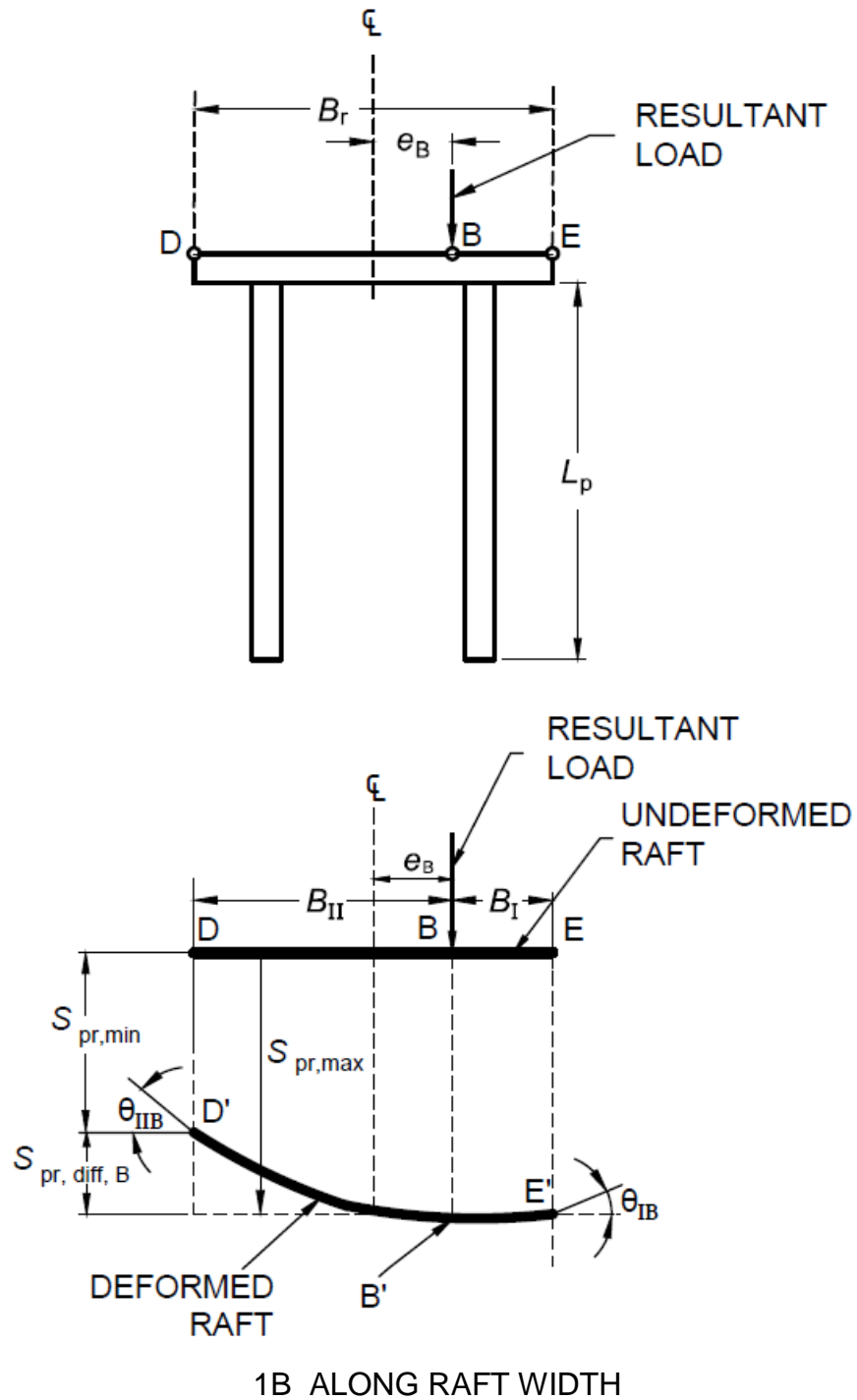
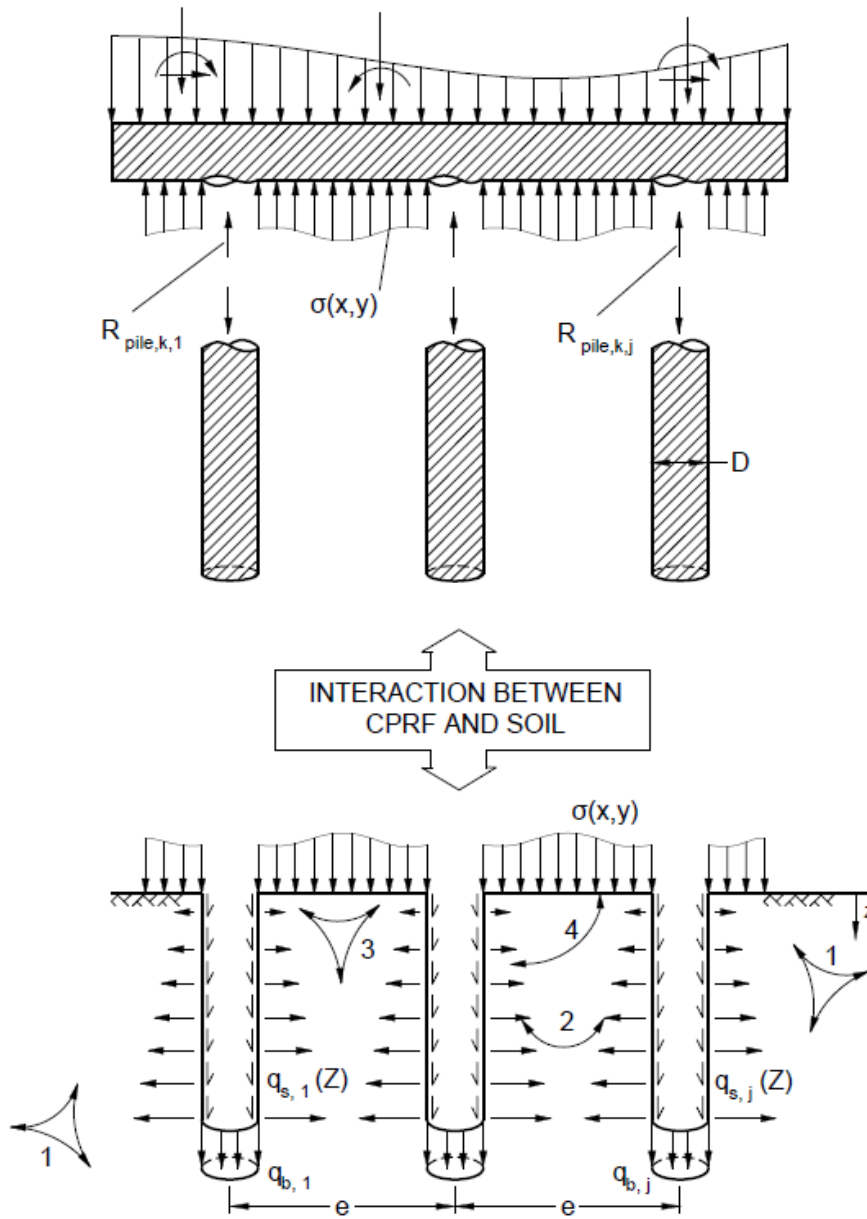


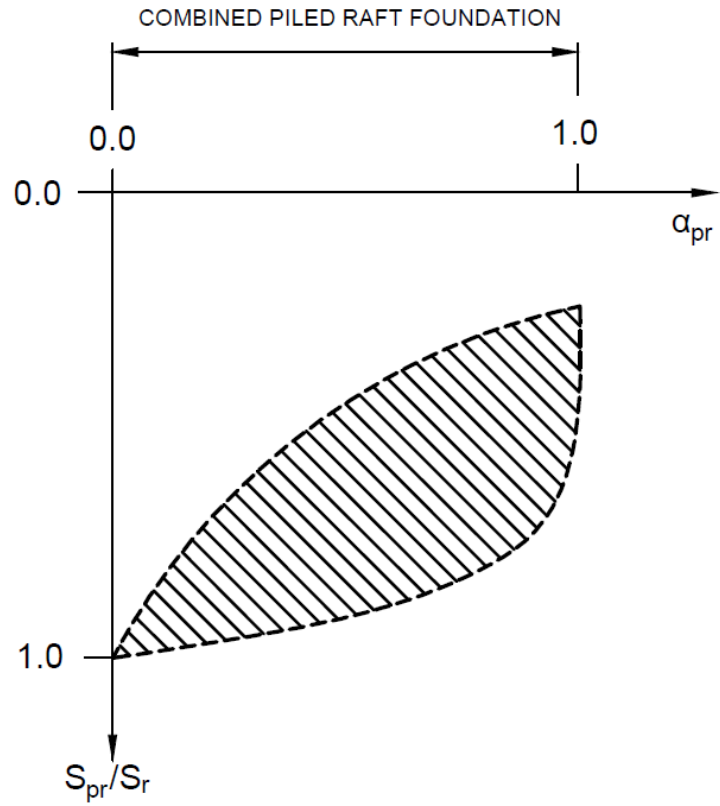
FIG.1 SCHEMATIC REPRESENTATION OF CFRP SYSTEM AND VARIOUS PARAMETERS FOR DESIGN CONSIDERATION BASED ON SERVICEABILITY LIMIT STATE



Key

- 1 PILE-SOIL INTERACTION
- 2 PILE-PILE INTERACTION
- 3 RAFT-SOIL INTERACTION
- 4 PILE-RAFT INTERACTION

Fig. 2A SOIL-STRUCTURE INTERACTION

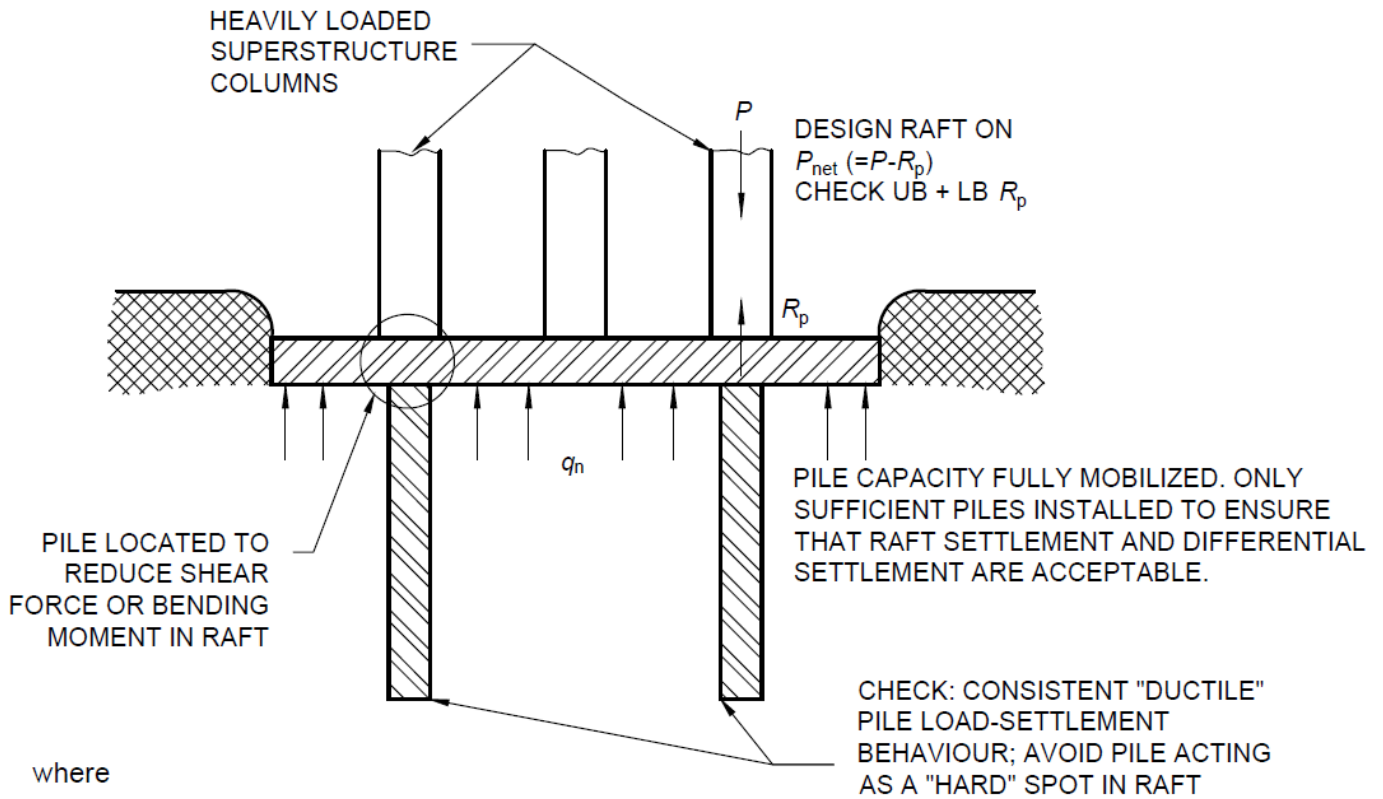


where

$S_{pr}$  = Settlement of combined piled raft foundation; and  
 $S_r$  = Settlement of raft foundation

2B VARIATION OF  $\alpha_{pr}$

Fig. 2 SOIL-STRUCTURE INTERACTION AND VARIATION OF  $\alpha_{pr}$  FOR A CPRF

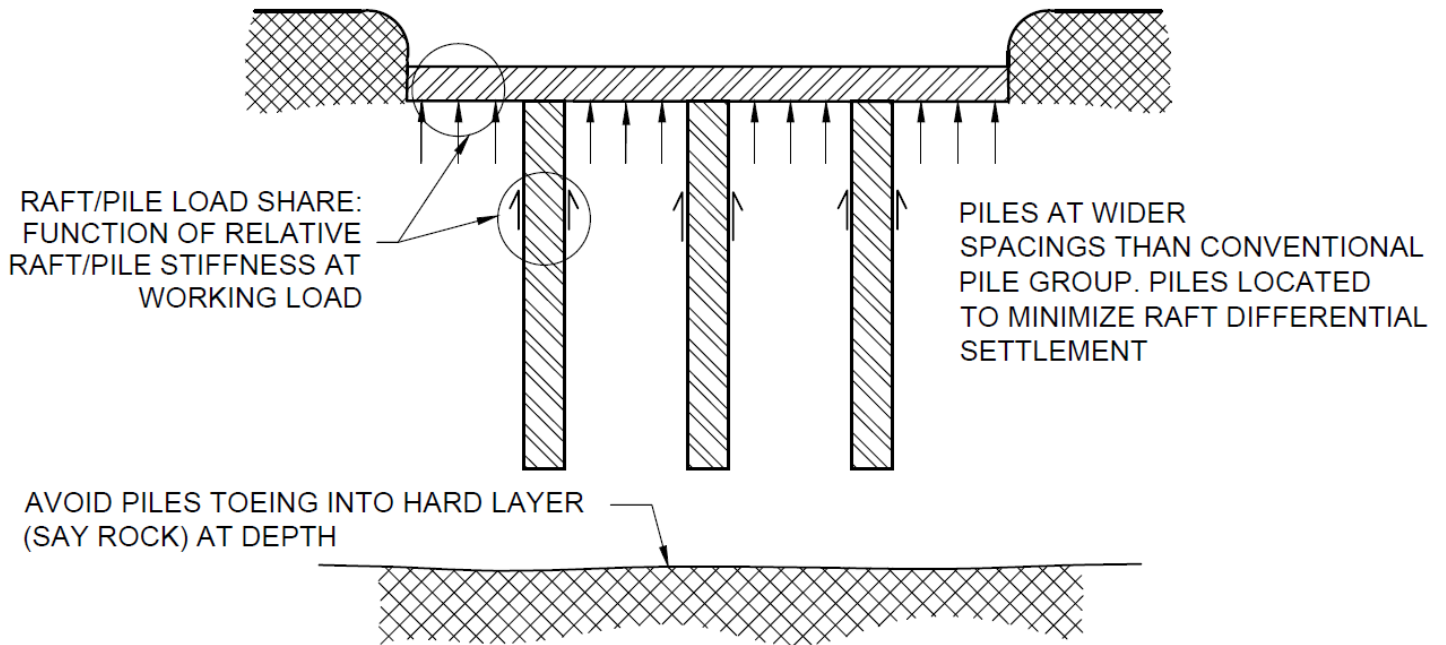


$q_n$  = Net contact stress on underside of raft;  
 $P$  = Column load;  
 $R_p$  = Pile capacity;  
 UB = Upperbound; and  
 LB = Lower bound.

**Favourable ground conditions:** Deep deposits of homogenous clays; typically stiff clays at raft level.

**Typical design scenario:** A raft which doesn't quite work, a small number of piles are added to resolve local non-compliances (for example, differential settlement, shear or bending moment).

### 3A PILE-ENHANCED RAFT



**Favourable Ground Conditions:** Competent soils at raft level (stiff clays, dense sands) and depth; interbedded sands/clays.

**Typical Design Scenario:** A value-engineered pile group, often the raft was provided as a pile cap, but is then used to provide significant capacity.

### 3B RAFT-ENHANCED PILE

FIG. 3 PILE-ENHANCED RAFT AND RAFT-ENHANCED PILE

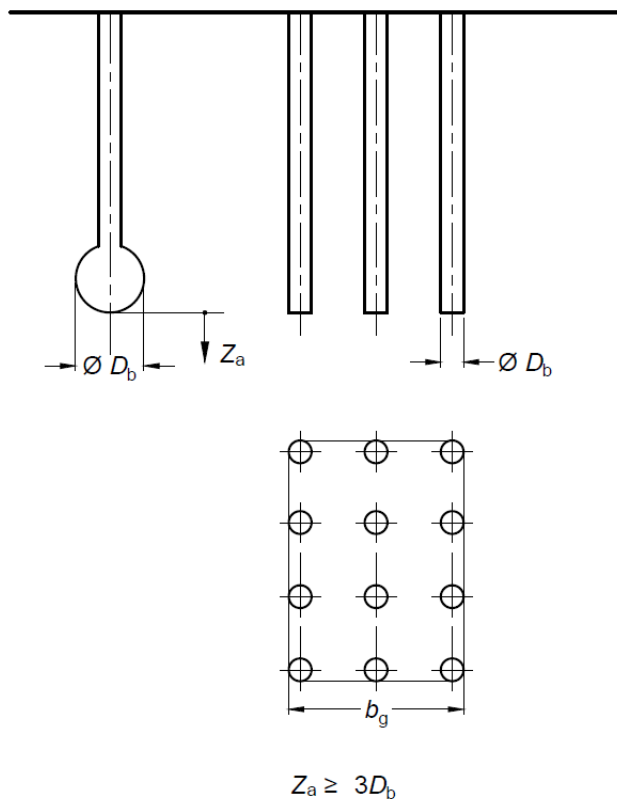
## 4 NECESSARY INFORMATION

4.1 For satisfactory design and construction of a combined pile-raft foundation, the following information is necessary:

- a) Details of site plan showing location of proposed and adjacent structures.
- b) Details of plan and vertical cross-section of the proposed building with position of beam and columns.
- c) Different load combinations and their intensity indicating design loads, preferably shown in schematic plan.
- d) All the loads due to seismic, wind, and water current, etc indicated separately.
- e) Limiting values of performance parameters, such as allowable bearing pressure, allowable total settlement, allowable differential settlement, allowable angular distortion, that the foundation and superstructure can withstand.
- f) Information on geological history, seismicity, seasonal variation of ground water, climatic factors, for example, sudden flooding, erosion, etc.
- g) The design and construction of CPRF requires rigorous geotechnical investigations by using both field and laboratory techniques. The proper dimensioning of CPRF will purely depend up on the outcome of geotechnical investigations. The data obtained from the both the investigations, that is, preliminary investigation for feasibility study and detailed investigation for analyses and design shall be analyzed by geotechnical experts.
- h) *Geotechnical Information* —Sub-surface profile with stratification details, engineering and index properties of founding media as per IS 1892, IS 2720 (relevant parts) and other relevant standards which are essential for the design of CPRF system. Any supplementary investigations should be carried out to obtain additional geotechnical information for design of CPRF.
- j) *Extent of Geotechnical Investigations* — The structure and properties of the substrata and the groundwater conditions shall be known in sufficient detail for any piled-raft construction project. This is necessary to reliably assess the stability and serviceability of the pile and piled-raft foundations and of the overall structure as required by relevant Indian Standards and to assess the effects of foundations on their surroundings. The geotechnical investigations shall extend to sufficient depth to record all ground formations and strata influencing the structure and its execution, and to identify the load-bearing and deformation properties of the ground. In addition to the stipulations in Fig. 4, the geotechnical investigations should extend to a depth of at least  $Z_a \geq 3D_b$  below the pile base [see IS 2911 (relevant parts)].
- k) The geotechnical investigation report and the geotechnical design report, respectively, shall contain all relevant data that can affect CPRF capacity, choice of the execution method and the pile installation. Design soil parameters shall be derived for the CPRF system. The ground information

and the parameters related not only to pile capacity, but also to drillability, drivability, etc shall be provided.

- m) The results of field test on single piles (both ultimate capacity and load-displacement curve). Static test as initial test can be used for design of CPRF, whereas dynamic test is not essential for CPRF design. Dynamic test may be used for additional check, if necessary, on later stage, but not directly related to CPRF design.
- n) Dynamic properties of founding media to be taken from geotechnical investigation report.
- p) A review of performance of CPRF in similar locality or ground conditions, if available.



where

$Z_a$  = Depth of investigation below pile base;

$D_b$  = Pile base diameter; and

$b_g$  = The smaller dimension of a rectangle surrounding the pile group at base level

NOTE — If the pile resistances of compression pile foundations are determined based on data from proven experience, the subsurface investigation should extend to a depth below the pile base of at least  $Z_a \geq 3D_b$ .

FIG. 4 MINIMUM GROUND INVESTIGATION DEPTHS FOR PILE FOUNDATIONS



**4.2** The work as per this standard should be carried out by a professional practicing geotechnical engineer having current experience and qualification in the pile and raft foundation design, construction and understanding of verification methods as per the project's requirement.

## **5 DESIGN CONSIDERATIONS FOR STATIC LOAD**

### **5.1 General Design Considerations**

**5.1.1** The design of CPRF should consider the following criteria:

- a) Fluctuation in the water table condition and long-term stability of the bearing strata;
- b) Consideration for handling sensitive clays and loose bearing soils;
- c) Effect of soil excavations;
- d) Differential movement of the foundations between the old and new structures;
- e) Wherever possible, the centre area of the foundation should be located directly beneath the centre of gravity of the imposed load or else effect of eccentricity should be considered;
- f) The load carrying capacity of the combined system subjected to vertical, lateral and moment loadings, total and differential settlement;
- g) Some of the key design considerations are,
  - 1) Load carrying capacity of the combined system at the desired settlement level for vertical, lateral and moment loadings;
  - 2) Maximum settlement;
  - 3) Differential settlement;
  - 4) Raft moments and shears for the structural design of the raft; and
  - 5) Pile loads and moments, for the structural design of the piles.

### **5.2 Stages of CPRF Design**

**5.2.1** The three main stages of CPRF design are,

- a) *Preliminary Stage (Feasibility Study)* — Assessment of the performance of raft without piles that includes estimation of vertical and lateral bearing capacity and the settlements. Assessment of the feasibility of using a pile raft and the required number of piles to satisfy the design requirement.
- b) *General Pile Characteristics (Preliminary Design Stage)* — Pile should be designed for the combined resistances.
- c) *Final Detailed Design* — Final detailed design to obtain the number of piles, location and configuration, settlement, bending moment and shear forces in raft and the pile loads and moments.

### 5.3 Design Steps

Design philosophy is illustrated in Fig. 5 and the subsequent design steps to be followed are given in **5.3.1** to **5.3.7**, **5.4** and **5.5**.

**5.3.1** The static pile formula based on the ground parameters as per IS 2911 can be used for estimation of ultimate load capacity. The provision made in IS 2911 (Parts 1/Sec 1 to 4) as applicable should be followed for the design and construction of piles unless otherwise stated. The procedure for pile load testing should be as per IS 2911 (Part 4). Information obtained (load-settlement response) from pile load test shall be interpreted by geotechnical engineer to arrive at the allowable load with reference to a particular settlement. Pile loads and moment for the structural design of the piles should be considered.

**5.3.2** The stability and capacity of raft based on the ground parameters as per IS 6403 and IS 2950 (Part 1) can be estimated. The provision made in IS 2950 (Part 1) should be followed for the design and construction of raft foundation unless otherwise stated. For estimation of raft settlement, the guidance given in IS 8009 (Part 1) may be used. However, the calculation of settlement for entire CPRF system will be different as described in subsequent section of this standard. Raft moment and shear forces for structural design of raft should be considered.

**5.3.3** The following are the design philosophies:

- a) *Conventional Approach* — Piles are designed as a group while making some allowances for contribution of the raft, primarily to load carrying capacity.
- b) *Settlement Control Approach* — Piles are placed strategically below the raft in order to reduce the total and differential settlement. However differential settlement reduction is more important than to reduce the overall average settlement.
- c) *Creep Piling Approach* — Piles are designed to operate at a working load at which significant creep starts to occur at some fraction, typically 70-80 percent of the ultimate load capacity, sufficient piles are introduced to reduce the net contact pressure between the raft and the soil below the preconsolidation pressure.

**5.3.3.1** For CPRF, the design philosophy is generally governed by settlement control approach to meet the serviceability criteria.

**5.3.4** The vertical load carrying capacity ( $Q_{pr,ult}$ ) of CPRF should be calculated as per Annex B.

**5.3.5** Dimensionless factors for CPRF design with practical range of parameters are given in Table 1. This guideline should ensure the complete behavioural mechanism of CPRF system.

**Table 1 Dimensionless Factors for Combined Piled Raft Foundations**  
(Clause 5.3.5)

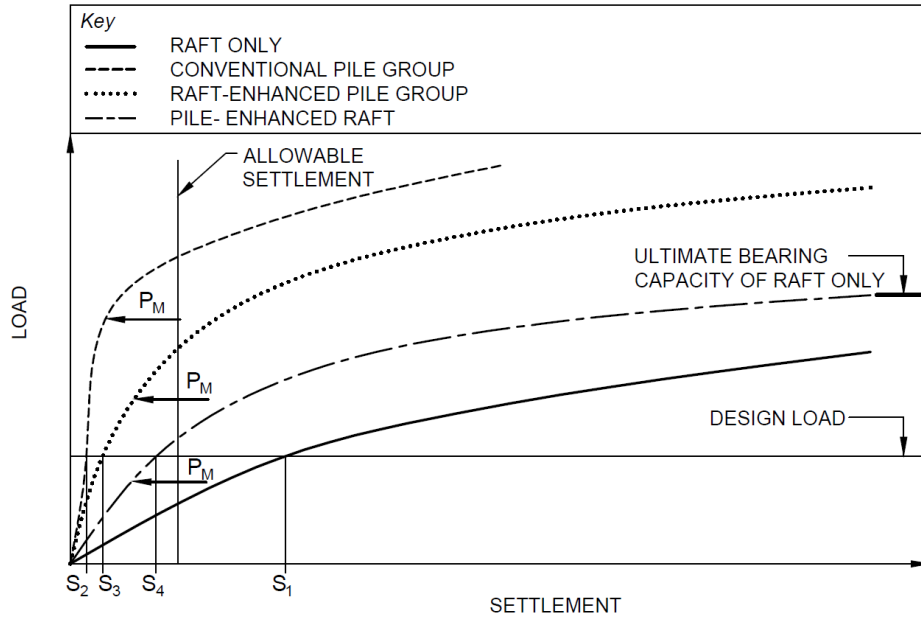
SI No.	Dimensionless Factors	Definition	Practical Range
(1)	(2)	(3)	(4)
i)	Pile slenderness ratio	$L_p/D_p$	10 – 100
ii)	Pile spacing ratio	$S_p/D_p$	2.5 – 8
iii)	Pile-soil stiffness ratio	$K_{ps} = E_p/E_s$	100 – 10 000
iv)	Raft plan aspect ratio	$L_r/B_r$	1 – 10
v)	Raft-soil stiffness ratio	$K_{rs} = \frac{4E_r B_r t_r^3 (1 - \nu_s^2)}{3\pi E_s L_r^4 (1 - \nu_r^2)}$	0.001 – 10

where

- $L_p$  = length of the pile;
- $D_p$  = diameter of the pile;
- $S_p$  = spacing between the piles;
- $E_p$  = elastic modulus of pile material;
- $E_s$  = elastic modulus of soil;
- $L_r$  = length of the raft;
- $B_r$  = width of the raft;
- $t_r$  = thickness of raft;
- $\nu_s$  = Poisson's ratio of soil; and
- $\nu_r$  = Poisson's ratio of raft material.

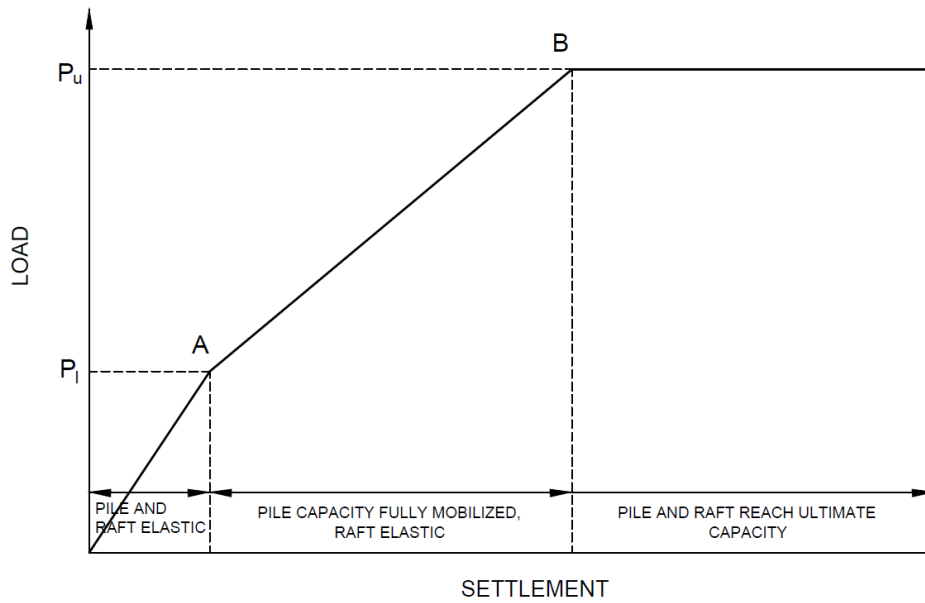
**5.3.6** Under horizontal load, the raft initially shares higher load than piles, however with increase in displacements, piles carry higher load than the raft in CPRF system with rigid pile head connection. Rigid pile head connection in CPRF contributes higher lateral stiffness compared to hinged pile head connection cases. Accordingly, bending moment at pile in hinged connection cases is relatively smaller compared to rigid connection cases.

**5.3.7** The soil stratigraphy shall be considered when calculating pile responses in the CPRF system.



where  
 $P_M$  = Pile capacity fully mobilized; and  
 $S_1, S_2$ , etc = Settlement for raft, pile group, etc

**5A LOAD-SETTLEMENT BEHAVIOUR OF RAFTS, CONVENTIONAL PILE GROUPS AND DIFFERENT TYPES OF CPRF**



**5B SIMPLIFIED LOAD SETTLEMENT CURVE OF A CPRF**

**FIG. 5 LOAD-SETTLEMENT BEHAVIOUR OF A CPRF**

## 5.4 Computational Model

Analysis of CPRF needs to be conducted using computational model which will be able to simulate the appropriate bearing behaviour of single pile. Later from the actual field test results on single pile, the computational model needs to be revised. The computational model should capture all the interactions as mentioned in Fig. 2A. Also, the superstructure effect needs to be considered appropriately as shown in Fig. 6A. The two features of estimating the stiffness of soil-pile-raft system are through estimation of pile spring stiffness and raft-soil spring stiffness. The iterative process of convergence of pile and raft response (if implicit) will only come after that. Figure 6 presents the design model of CPRF system considering soil-pile-raft stiffness. Different values of pile stiffness can occur within a group of piles, depending on their position and on the relative stiffness of the raft.

### 5.4.1 Estimation of Pile Spring Stiffness

Stiffness of spring representing the pile shall be estimated by dividing the load carried by pile top element in respective direction with the corresponding top displacement of the pile.

$$\text{Pile spring stiffness, } K_p = \frac{\text{Normal contact force at nodes}}{\text{Nodal displacement}}$$

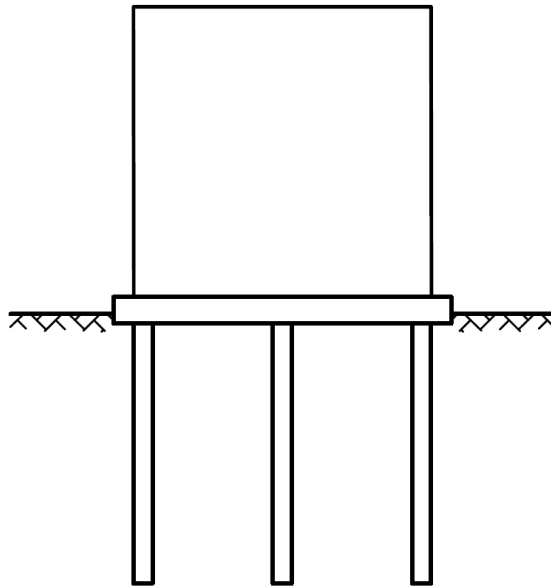
### 5.4.2 Estimation of Raft-Soil Spring Stiffness

The soil spring stiffness shall be estimated from the load deformation behaviour of the founding medium as given below:

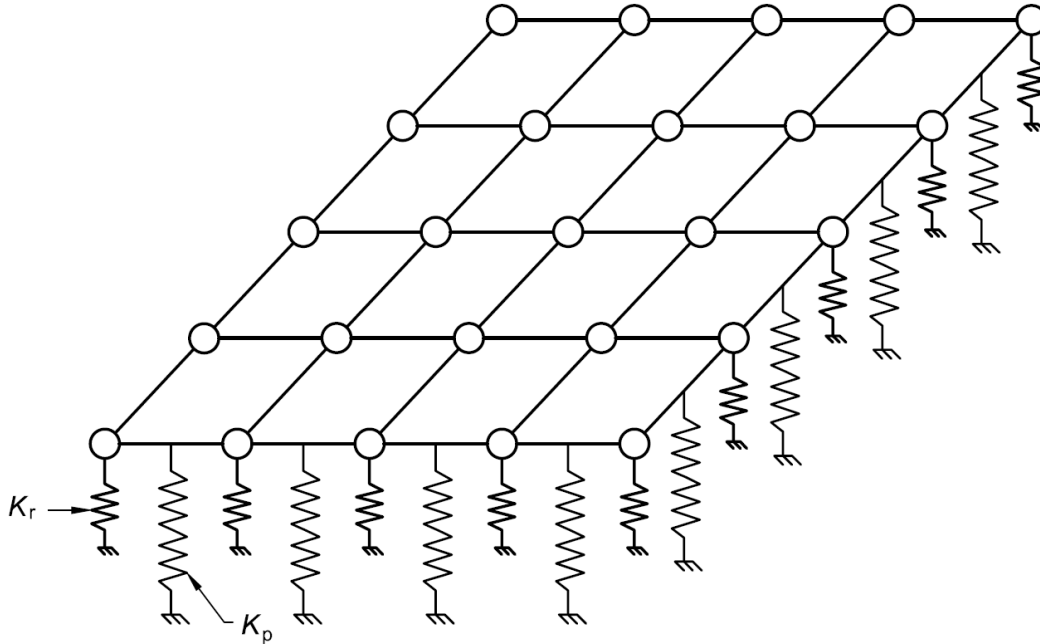
$$\text{Raft-soil spring stiffness, } K_s = \frac{\text{Normal contact force at nodes}}{\text{Nodal displacement}}$$

## 5.5 Allowable Settlement for Static Design Consideration

For CPRF system, total settlement under gravity load should be restricted within 125 mm and the maximum angular distortion of raft as 1/500. There are four angular distortions ( $\theta_{IL}$ ,  $\theta_{IIL}$ ,  $\theta_{IB}$  and  $\theta_{IIB}$ ) (see Fig. 1) and maximum of these four angular distortions will govern CPRF design for Serviceability Limit State (SLS). The total settlement under gravity load may be taken only as a guide and the permissible total settlement should be decided as per serviceability criteria to fulfill the load sharing mechanism of CPRF system.



6A RAFT-PILE-SOIL IN A CPRF



6B PILE AND RAFT-SOIL SPRINGS

FIG. 6 COMBINED ACTION OF SOIL-PILE SYSTEM (TYPICAL DESIGN MODEL)

## **6 PROOF OF DESIGN AND CONSTRUCTION OF A CPRF**

The examination of the design and the construction of a CPRF with respect to the geotechnical engineering aspects should be controlled by a geotechnical expert particularly qualified on this subject, assigned by the owner or the supervising authority. This includes the construction for piles and deciding the foundation level. The protocols of the acceptance procedure and the measured values have to be included into the examination. The following aspects shall be considered:

- a) Critical review of the soil investigation report (field and laboratory tests), including the selection of input parameters;
- b) Evaluation of the computational model used for the design of the CPRF and the computation results by using independent comparative calculations. Apart from the independent comparative calculations, additional quality assurance measures in design should be ensured;
- c) Assessment of the effects on the adjacent structures; and
- d) Examination of the field monitoring (measuring) program within the construction process of the CPRF.

## **7 MONITORING OF A CPRF**

The load-settlement behaviour and the load transfer within a CPRF should be monitored for further use by a geotechnical expert. The monitoring comprises of geotechnical and geodetic measurements at the new building and also at the adjacent buildings for settlement. The monitoring of the contact pressure at the level of raft, axial load in selected piles, settlement at the level of raft, ground water table and pore-pressure may be adopted for important projects. The monitoring of a CPRF is an elementary and indispensable component of the safety concept and should be used for the following purposes:

- a) Observational method should be followed for monitoring of the response of CPRF both during and post construction phases for projects of high importance;
- b) The verification of the computational model and the computational approaches;
- c) Detection of possible critical conditions in CPRF system;
- d) An examination of the quality assurance during the construction and post construction process; and
- e) Examination of distribution of loads on piles in centre and edges to capture soil-pile-raft interactions.

The monitoring program should be designed by a geotechnical expert during the design phase depending on importance of the project, complexity of the ground condition and long-term performance. Summary of desired instrumentations and their

locations should be highlighted in plan as well as sectional view of the foundation layout.

## **8 STRUCTURAL DESIGN**

The general provision for load, shrinkage, creep and temperature effects and provision of design, reinforcement and detailing shall conform to IS 456 and other relevant standards.

## **9 SEISMIC DESIGN**

Design of the CPRF system considering the seismicity of the ground and entire structure and sub-structural system should be handled by experts to ensure conformity to various relevant standards. Both inertial and kinematic effects should be considered in the seismic design.



**Annex A**  
(Clause 2)

<i>IS No.</i>	<i>Title</i>
IS 456 : 2000	Plain and reinforced concrete — Code of practice ( <i>fourth revision</i> )
IS 1892 : 2021	Subsurface investigation for foundations — Code of practice ( <i>second revision</i> )
IS 1904 : 2021	General requirements for design and construction of foundations in soils — Code of practice ( <i>third revision</i> )
IS 2911	Design and construction of pile foundations — Code of practice
Part 1/Sec 1 : 2010	Concrete piles, Section 1 Driven cast in-situ concrete piles ( <i>second revision</i> )
Part 1/Sec 2 : 2010	Concrete piles, Section 2 Bored cast in-situ concrete piles ( <i>second revision</i> )
Part 1/Sec 3 : 2010	Concrete piles, Section 3 Driven precast concrete piles ( <i>second revision</i> )
Part 1/Sec 4 : 2010	Concrete piles, Section 4 Precast concrete piles in prebored holes ( <i>second revision</i> )
Part 4 : 2013	Load test on piles ( <i>second revision</i> )
IS 2950 (Part 1) : 1981	Code of practice for design and construction of raft foundations: Part 1 Design ( <i>second revision</i> )
IS 6403 : 1981	Code of practice for determination of bearing capacity of shallow foundations ( <i>first revision</i> )
IS 8009	Code of practice for calculation of settlement of foundation
Part 1 : 1976	Shallow foundation subjected to symmetrical static vertical loads
Part 2 : 1980	Deep foundation subjected to symmetrical static vertical loading

**ANNEX B**  
(Clause 5.3.4)

**LOAD CARRYING CAPACITY OF CPRF SYSTEM**

**B-1 LOAD CARRYING CAPACITY OF CPRF SYSTEM**

**B-1.1** The ultimate vertical capacity shall be taken as the least of:

- a) The capacity of the block containing the piles, plus that of the portion of the raft outside the periphery of the pile group;
- b) The sum of the capacity of the raft,  $Q_{\text{unpiled-raft}}$  and of all the piles  $Q_{\text{pile-group}}$  in the system, expressed as,  $Q_{\text{CPRF}} = 0.8 (Q_{\text{unpiled-raft}} + Q_{\text{pile-group}})$ ; and
- c) The capacity of CPRF system considering pile-soil-raft interactions. The capacity of CPRF should be expressed as,

$$Q_{\text{CPRF}} = \alpha_{\text{pr}} \alpha_{\text{pp}} \sum_{n=1}^n Q_{\text{single pile}} + \alpha_{\text{rp}} Q_{\text{unpiled-raft}}$$

In the above expression,

- 1)  $Q_{\text{unpiled-raft}}$  should be calculated based on IS 6403.
- 2)  $Q_{\text{single pile}}$  should be calculated based on IS 2911.
- 3)  $\alpha_{\text{pp}}, \alpha_{\text{rp}}$  and  $\alpha_{\text{pr}}$  are the pile-pile, raft-pile and pile-raft interaction factors, respectively. These interaction factors may be suitably taken from various relevant literature based on the expertise of the designer for case-to-case basis.