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# INNOVATIVE BRIDGE FOUNDATION FOR HILLY REGIONS

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## Summary

The CIDF system is a combination of a group of Auger Bored Compaction Under-reamed Piles (ABCUP) of small length with grid beams and top slab supported on soil may be used as an innovative foundation system for bridges in eastern provinces of India. However this paper deals with analysis of the foundation and provides some useful data required for design in the field.


## Introduction

The innovative design of combined intermediate depth foundation (CIDF) system is derived from the stilt root system of plants. In present era of development demand of energy is increasing day by day resulting in effort requirement for the digging of more and more oil wells. presently we are looking for north-east provinces of the country for the natural source of energy. These provinces are mostly surrounded by the hills. For the transportation of oil and gases piplines are used and for crossing the deep gorges cable bridges are frequently used. However this paper is devoted to the analysis of suitable bridge foundation especially for these regions.

## The Bridge Foundation

A modified structural form comprising of conventional under-reamed piles (ABCUP) combined with grillage cap for transferring the load of bridge particularly at the banks of stream. As we know the deep gorges and valleys are the common feature of hills. The CIDF system seem to be very suitable where load transferring is not possible at the shallow depth level and anchoring is required. The essential requirements in the design of a foundation are

i. The total settlement of the structure
ii. Differential settlement along with other design capabilities.

To limit settlements it is necessary to transfer the load of the structure to the soil stratum of sufficient strength and to spread the load over a sufficiently large area of the stratum to minimise bearing pressure. However, if the soil of adequate strength is not available immeiately below the bridge support CIDF system (Fig. 1 and Fig.4) may be used to transmit the load.

## The ABCUP

The range of the allowable skin friction for auger Bored Compaction Under-reamed Pile (ABCUP) varies between 180 to 300 kN/m2 (Brandl 1988) where in ordinary under-reamed pile maximum value of skin friction is only 110 kN/m2. still more allowable values of the skin friction are expected but for the design purposes these values are suggested for evaluating the effectiveness of CIDF system.


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## Foundation and Natural Root System

To extend the correlation and draw useful inference between natural plant root system and the man made foundation system, overall study of various rott system, particularly the modified form are logical. Similar to foundation the major function of root is to anchor the plant and resist load due to weight, wind and so on. Functional comparison of foundation and root further reflect similarity in mechanism of load transfer in both the cases friction and by bearing resistance.

## Skin Friction

Apart from vertical load transmitted to soil mass by skin friction at side faces of capping beam it also transmit the load in bearing for design purpose of well foundation, the values of skin friction as recommended by Terzaghi and Peek (2) given in Table-1 may be used for load transfer contribution.

Table - 1
Recommended Skin Friction

| Type of soil | Density kN/m³ | Skin Friction kN/m² |
|---|---|---|
| Silt & soft clay | 130 | 7.25-30 |
| Very stiff clay | 143 | 50-200 |
| Loose Sand | 151 | 10 |
| Medium Dense sand | 181 | 15 |
| Dense Sand | 212 | 50-100 |
| Dense gravel | 212 | 50-100 |

## Assumption

Following assumptions are made for composite block analysis.

1. The depth of the block is considered equal to the sum of depth of beam and the length of pile.
2. The total axial lond carrying capacity of the block is equal to the sum of resistance offered by the all four sides of the foundation block due to allowable skin friction and allowable bearing offered at the face of the block. (Fig.1)
3. Due to confinement and densification of soil the block, coefficient $k_s$ improves so that it is more realistic to assume improved of the skin friction for calculation of sides resistance of the block.
4. The combined structure of slab and beam will jointly behave like a rigid cap.
5. The soil contained within the peripherally circumscribing all the piles behave like a solid composite confined mass.

3.4.2 Assumption for CIDF system as small group of piles.

Following Assumption are made for CEDF system as small group of piles.

1. It is assumed that all piles settle equally and bear same load. for ABCUP the allowable skin friction is given in Table 1.
2. Slab and beam are softer than the piles so only a fraction of the allowable bearing pressure at the level of slab and beam will be mobilised. For this analysis this fraction has been assumed as one half the value given in Table -1.

Analysis

The analysis of foundation may be made on the basis of considering as a rigid disk (Fig. 2a and Fig.2b) at distance 'b' deflection is zero.

Small group of 9 piles displacement as rigid disk in soil annulus.
So that vertical deflection is given by

$$\frac{d^2w}{dl^2} + \frac{1}{r}\,\frac{dw}{dr} = 0 \qquad (1)$$

when the displacement of the disk is $w_0$ the solution of the above equation may be given by

$$w = w0\left[1 - \frac{\ln r/d}{\ln b/d}\right] \qquad (2)$$

The vertical load from the bridge applied through the grillage slab cause all piles to deflect through the same vertical distance. The deflection at a point at radius r/d, w (r/d) due to a load F applied to a rigid centrally located disk radius d is

$$w(r/d) = f/2\pi G \ln\{(b/d)/(r/d)\} \qquad (3)$$

if r/d = b/d then w (r/d) will be zero.
Depending upon the load 9p or 5p system can be used.

$$F0 + 4F1 + 4F5 = F \qquad (4)$$

After normalization by F the above equation can be rewritten as

$$f0 + 4f1 + 4f5 = 1 \text{ where } f0 = F0/F \qquad (5)$$

from Eq. (3) we see that the deflection of the three typical pile sections are

$$w0 = \frac{1}{2\pi G}\left[f_0 \ln\left[\frac{b/d}{1}\right] + 4 f_1 \ln\left[\frac{b/d}{2s}\right] + 4 f5 \ln\left[\frac{b/d}{2\sqrt{2s}}\right]\right] \qquad (6)$$

$$w1 = \frac{1}{2\pi G}\left[f_1 \ln\left[\frac{b/d}{1}\right] + f_0 \ln\left[\frac{b/d}{2s}\right] + 2 f_1 \ln\left[\frac{b/d}{2s}\right]\right.$$

$$\left. + 2 f1\left[\frac{b/d}{2\sqrt{2s}}\right] + 2 f_5 \ln\left[\frac{b/d}{2\sqrt{5s}}\right] + f1 \ln\left[\frac{b/d}{4s}\right]\right] \qquad (7)$$

$$w5 = \frac{1}{2\pi G}\left[f5 \ln\left[\frac{b/d}{1}\right] + 2f1 \ln\left[\frac{b/d}{2s}\right] + f0 \ln\left[\frac{b/d}{2\sqrt{2s}}\right] + 2f5 \ln\left[\frac{b/d}{4s}\right] + 2f1 \ln\left[\frac{b/d}{2\sqrt{5s}}\right] + f5 \ln\left[\frac{b/d}{4\sqrt{5s}}\right]\right]$$

But since these deflection must all be the same we can write

$w0 - w1 = 0$ (9)

and $w0 - w5 = 0$ (10)

The eq. (9) and Eq. (10) can be writen as

$f0 \ln 2s + f1 \ln (2/s) + f5 \ln (5/4) = 0$ (11)

and $f0 \ln 2\,2s + f1 \ln 5 + f5 \ln [(2)/5] = 0$ (12)

from Eqs. (5). (11) and (12) one can get f0. f1 and f5 for the value of s selected. When a solution is obtained. the dimensionless displacement $w' = 2 \Pi GW/F$ of the pile disk group can be find out by the use of equation (5) and (6) or (7).

The subgrade reaction coefficient for each pile is computed by dividing the dimensionless force in the pile by displacement w' thus

$Ki = 2\Pi G\, fi / w'$ (13)

However the coefficent K for a solitary pile can be written

$K = 2\Pi G / \ln (b/d)$ (14)

The ratio of the individual reaction coefficient can be obtained

$Ki / K = fi / w' \ln (b/d)$ (15)

The relevant values are given in Table 2.

**Table - 2**

Displacement. Forces and Relative Stiffness in a 9p system

| Spacing Diameters, S | F0 | F1 | F5 | w' | Group Displacement Efficiency $k_n/k$ or | $k_0/k$ | $k_1/k$ | $k_5/k$ |
|---|---|---|---|---|---|---|---|---|
| 2 | -0.0298 | 0.0721 | 0.1854 | 2.2274 | 0.195 | -0.0524 | 0.1266 | 0.3256 |
| 3 | -0.0024 | 0.0820 | 0.1686 | 1.8822 | 0.231 | -0.0051 | 0.1705 | 0.3504 |
| 4 | 0.0116 | 0.0864 | 0.1607 | 1.6338 | 0.266 | 0.277 | 0.2069 | 0.3848 |
| 5 | 0.0203 | 0.0890 | 0.1560 | 1.4399 | 0.302 | 0.0551 | 0.2417 | 0.4237 |
| 6 | 0.0264 | 0.0907 | 0.1527 | 1.2810 | 0.339 | 0.0806 | 0.2770 | 0.4663 |
| 8 | 0.0345 | 0.0929 | 0.1484 | 1.0294 | 0.422 | 0.1312 | 0.3697 | 0.5641 |
| 10 | 0.0417 | 0.0973 | 0.1423 | 0.8439 | 0.515 | 0.1932 | 0.4510 | 0.6596 |

## Allowable Load Carrying Capacity of CIDF System

(a) Block Foundation (Fig. 1)

P = [Fs + Fb] - - weight of the block

Where Fs and Fb are average allowable frictional resistance and allowable bearing resistance at Depth 'D' and P is the load carrying capacity

### (b)CIDF system as a small group of piles.

$$P = Pp + Pb + Ps \tag{17}$$

Where Pp, Pb and Ps are the load carried by the ABCUP, beam and the slab individually. (Fig.4)

However the load carrying capacity of the foundation may be computed by the use of Eq. (16) and Eq. (17) and the lower one will be treated as the load carrying capacity of the foundation. the load settlement and other values regarding load, spacing and diameter of ABCUP are shown in fig. 3, Fig.6 and Fig.7

## Conclusion

Following are the main conclusions

1. If pile spacing is up to three times of the diameter, thecentral pile will not be effective so that the minimum spacing of ABCUP should be 4d.

2. When the spacing of ABCUP is more the load carrying capacity of individual pile group will be more so that the whole system, will carry more load. Although, due to interaction effect of pile to pile average load carrying capacity of individual pile in system will be lesser than single pile. But in the CIDF system contribution of grid cap, effect of densification, confinement will also come into the picture resulting in more load carrying capacity of the system.

3. The confining effect in loose soil is more than that of the denser soil.

4. Load carrying capacity must be verified with field tests of minimum 2% of total number of ABCUP used.

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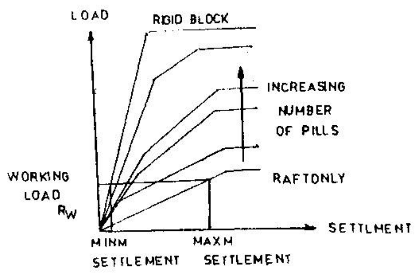


FIG-5 LOAD SETTLEMENT CHARACTERISTICS OF PILE COMBINED WITH CAP AFTER POLOUS AND DEVIS atal. (1972)

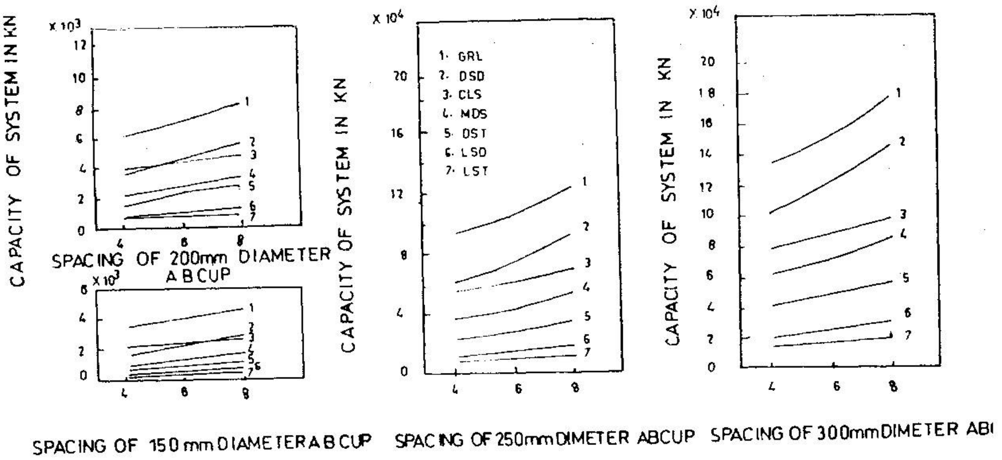


FIG.6 SPACING Vs CAPACITY OF CIDF SYSTEM

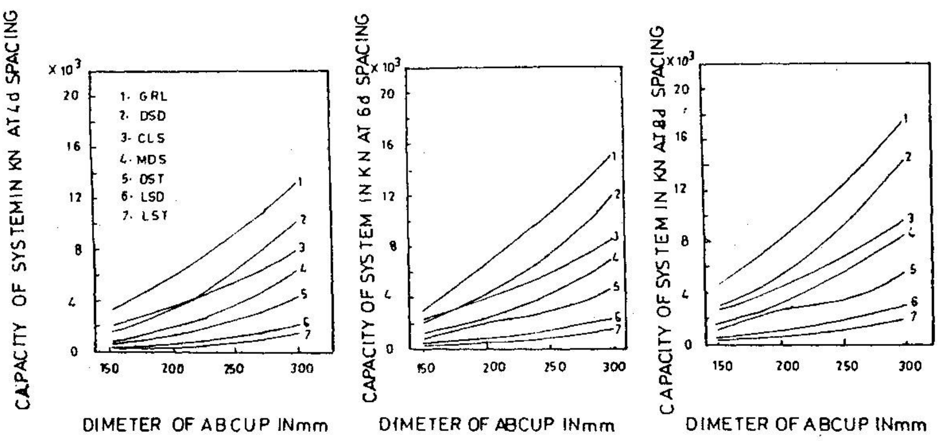


FIG.7 DIAMETER OF ABCUP Vs CAPACITY OF CIDF SYSTEM AT VARIOUS SPACINGS OF ABCUP

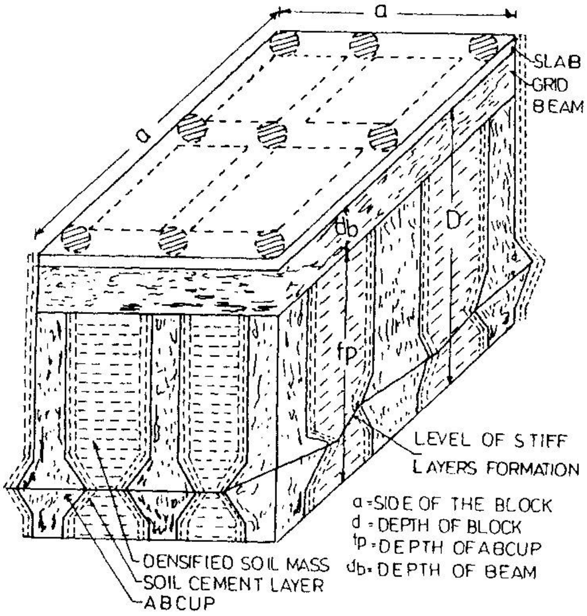


FIG 1 CIDF SYSTEM AS BLOCK FOUNDATION

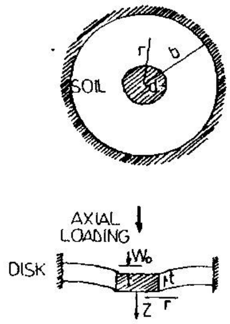


FIG-2a. PILE SECTION DISPLACEMENT AS RIGID DISK IN SOIL ANNULUS

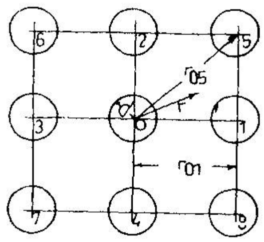


FIG-2b CIDF SYSTEM AS GROUPS OF PILES

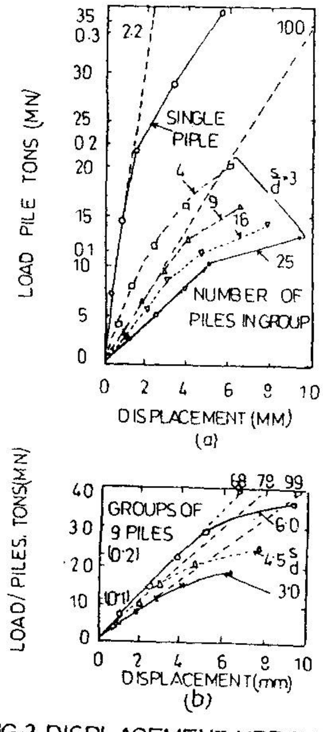


FIG-3. DISPLACEMENT VERSUS PILE LOAD (a) SINGLE PILE & VARIOUS GROUP AT 3d SPACING IN SILTY SAND, (b) NINE PILE GROUP AT VARIOUS SPACING

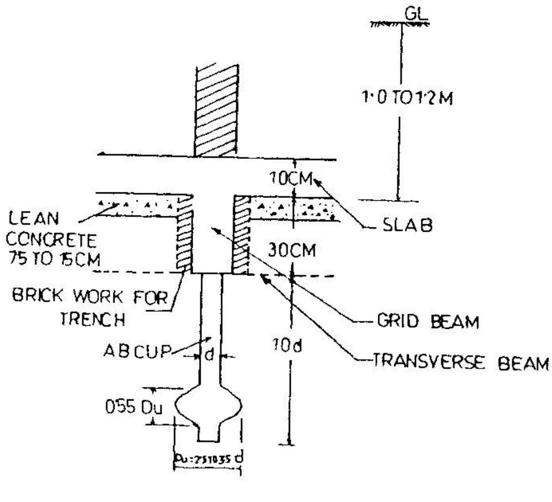


FIG 4-A VIEW OF JUNCTION OF BEAM SLAB & ABCUP

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