and a free fall cast iron hammer has also been used (Rao, 1982, Ranjan and Rao, 1983). In this method the bore hole is made by spiral auger and the bore hole is cleaned manually by using specially made tools. In the cleaned bore hole granular piles are cast using 20 to 30 mm size stone aggregate and 20 to 25% of sand with uniformity coefficient of 2. The aggregate and sand layers are placed alternatively with layer thicknesses of 300 to 500 mm and 50 to 100 mm respectively. Each two-layer unit with sand layer at top is compacted with the help of a cast iron hammer of weight 1250 kN with a free fall of 750 mm. Due to the impact of hammer the sand fills the voids of the stone aggregate followed by the lateral and downward displacements of the charged material till full compaction is achieved. Various stages of installation by this technique is shown in Fig. 5.17. This technique can be applied to small building foundations. Ranjan and Rao (1988) have indicated that granular piles of 600 mm diameter and 15 m deep have been successfully installed using this technique. A detailed treatment of granular piles is dealt by Ranjan (1989).

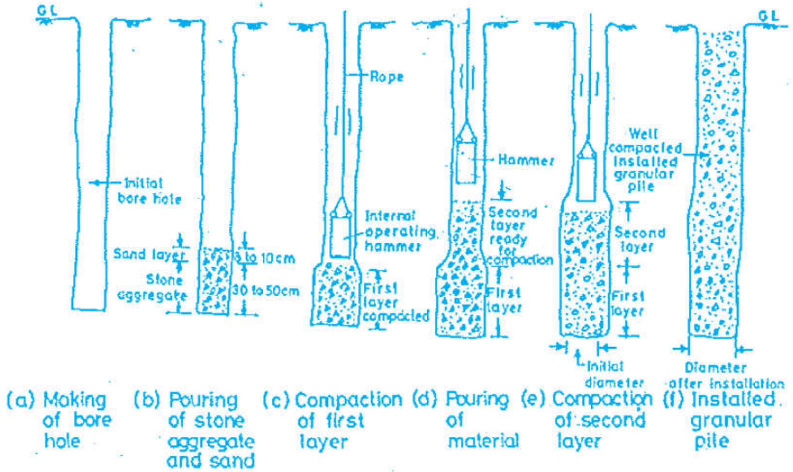

Fig. 5.17. Granular pile installation method using indigenous know how (After Rao, 1982).

The variation in pile diameter installed by vibroflot (diameter 300 to 500 mm) varies between 0.6 m (stiff clays) and 1.1 m (very soft cohesive soils). Datye and Nagaraju (1985) have reported stone columns ranging from 400 to 750 mm using rammed process. Using the simple boring equipment and the light hammer Rao (1982) and Ranjan and Rao (1986) reported granular pile diameters ranging from 250 to 600 mm.

The spacing of stone columns is determined based on the settlement tolerances for the loads to be applied (Greenwood, 1970) and the degree of improvement required (Engelhardt and Kirsch, 1977). Stone columns are spaced from 1.2 to about 3 m on centre over the site (Bowles, 1988). Spacing ranges recommended for sand piles can be adopted for granular piles also.

The length of the stone columns is sufficient either to extend below the depth of significant stress increase caused by the foundation or should extend through the soft clay

to firm strata to control settlements. The resistance is derived by stone columns only by the perimeter shear and not by end-bearing. On this basis the stone column length (L_c) should be greater than (Bowles, 1988)

$$L_c \geq \frac{P - A_c\,(9\,c_{pt})}{\pi\, dc}$$

where P = total load on the stone column

A_c = cross-sectional area of the stone column

d = average diameter of the stone column

c, c_{pt} = side and point cohesion.

There is no theoretical procedure available to accurately predict the combined improvement of the ground. Thus it is usual to assume the foundation loads are carried only by the total number of stone columns with no contribution from the intermediate ground (Bowles, 1988).

Stone columns may be arranged to support isolated footings, strip footings or mat foundations. The entire foundation area should be covered with a blanket of sand or gravel at least 0.3 m thick to help distribute loads and to facilitate drainage of water conducted out of the soft soil through the columns which act as vertical drains as well as reinforcing elements.

The load capacity of a stone column is controlled by the passive resistance of the soft soil that can be mobilised to withstand radial bulging and on the friction angle of the gravel. An approximate formula for the allowable bearing capacity of stone columns is given by

$$q_a = \frac{k_p}{SF}\,(4c + \sigma'_r)$$

where $K = \tan^2 (45 + \phi'/2)$

ϕ' = drained angle of internal friction of stone

c = either drained cohesion (suggested for large areas) or the undrained shear strength, s_u.

σ_r' = effective radial stress as measured by a pressure meter (but may use $2c$ if pressure meter data is not available)

SF = safety factor used about 1.5 to 2.

As bearing capacity of stone columns is generally high, settlement is the important criterion. For want of theoretical equations to predict settlement of stone columns, empirical methods are used. The settlement of stone column foundation depends on column spacing. The settlement of a single column of a group in a load test may be in the range of 5 to 10 m at the design load. The settlement of large group is usually about 5 to 10 times, the single column settlement (Mitchell, 1976). Figure 5.18 shows estimated settlement of the treated ground as a function of soil strength and column spacing (Greenwood, 1970).

Stone columns are very much suitable for soft, inorganic cohesive soils. They also can be used in loose, sand deposits to increase the density. Stone columns are capable of