# Design Approach and Field Control for Stone Columns

## Colonne en Pierre — Capacité Prévue et Construction

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SYNOPSIS : The paper describes stone column installation techniques developed in India over the last few years, which admit of using commonly available piling equipment. For the cases reviewed bores were advanced both by displacement and non-displacement techniques. The granular aggregates were compacted by heavy rammer operated in the hole, field control was achieved by stipulating the consumption of the stone which indirectly indicated the insitu cross section of the column and the set achieved which was measured in terms of penetration of the rammer for a given energy input. A theory is postulated for predicting the performance of stone columns on the basis of single column load test. Test results are furnished. Irrespective of the method of installation as long as the field control criteria are satisfied the behaviour of stone column is consistent and results from single column load test can be used for predicting the behaviour of stone column-ground system.

INTRODUCTION

Several applications of compated granular columns for ground improvement have been reported (Green Wood 1970, Geotechnique Symposium 1975, Datye & Nagaraju, 1977). Where as vibratory equipment has been extensively used in the cases reported by Green Wood and those reported in the Geotechnique Symposium, under Indian conditions this method works out to be relatively expensive. The authors therefore introduced installation methods involving ramming of stone and sand in prebored holes. A merit of this method is that ordinary bored piling equipment available at most construction sites can be used. The initial development of the technique viz : ramming with in a cased bore hole has been described in an earlier paper (Datye & Nagaraju, 1975) which also presented field data from large scale load tests. Initially the ramming technique was conceived to be a low cost substitute for vibratory compaction. Field trials however, revealed that better compaction and a greater degree of ground improvement can be achieved by use of rammed stone columns. Attempts have been made to improve and simplify installation procedures. The paper briefly presents installation techniques developed in India over the last few years. In the light of experience a design approach is postulated which is based on load test performance of single column installed with control on set and stone consumption. Test results are furnished along with corresponding control criteria.

INSTALLATION TECHNIQUES

Methods of advancing bore hole, placing of stone and sand and ramming techniques along with their merits and limitations are presented in Table I, Fig. 1 shows the installation techniques.

TABLE I

Stone Column Installation Techniques

BORING METHODS

| | Non-displacement | Displacement |
|---|---|---|
| Methods | • Bailor boring<br>• Air and water jet<br>• Direct mud circulation | • Driving tube with dispensable shoes. |
| Limitations and merits | • No remoulding<br>• Water is required in large quantities | • Causes remoulding of soil but easy to control.<br>• Longer lengths require heavier plants. |

TABLE I (Continued)

| Non displacement | Displacement |
|---|---|
| • Suitable method of preventing contamination of stone by soil is necessary. | • Very convenient upto 6 to 8 M. |

FILLING STONE AND SAND

- Gradual filling and controlled withdrawal of casing
- Pre-assembled around dispensable sheath such as bamboo vertical strips with horizontal ties of organic fibre.
- Filling in limited number of stages and controlled withdrawal of casing.

RAMMING

- Use of drop hammer or heavy diesel hammer with a mandrel
- Ramming in short lifts
- Ramming only in limited number of stages.

## FIELD CONTROL

An important parameter governing the performance of stone column is the consumption of material in the stone column. A mixture of crushed stone and sand is used. Stone and sand in the proportion of 1:0.2 to 0.5 by volume can be expected to give a well compacted mass with the sand filling the voids in the crushed stone. Volumes of stone and sand are measured in boxes of standard sizes and the loose or bulk volume is determined on the basis of the size and number of boxes filled into the stone column. The insitu compacted volume is taken as 0.8 of the volume of stone measured in boxes. Since sand is presumed to fill the voids in the stone, the volume of the sand is neglected. The consumption of stone as it varies progressively with depth is plotted. The cross sectional area of the stone column for the purpose of analysis and interpretation is derived from this compacted volume.

The degree of compaction that can be achieved depends on several factors (Datye & Nagaraju, 1975). In general the degree of compaction can be measured by a 'set' criterion, i.e. penetration of rammer into the filled material for a given number of blows. Control on consumption of stone with a specific energy input for ramming as measured by 'set' will ensure a uniform quality of construction.

## DESIGN APPROACH

In the design approach for estimating stone column capacity, it is considered that column derives its support from the resistance provided by the clay layer to cavity expansion caused by the bulging of the uncemented granular column. After gaining experience in the installation of stone columns, it is postulated that given a set criterion the cavity expands during installation and the consumption of the granular material adjusts to attain a cross sectional area such that lateral resistance to further expansion is developed. The load carrying behaviour under undrained condition can be predicted (Datye & Nagaruju 1975, 1977) by the use of cavity expansion theory (Vesic, 1972).

The soil surrounding the column is subjected to dynamic consolidation during driving of the columns. By analogy of the experience of dynamic consolidation by falling weights it can be postulated that vertical fissures would be formed and drainage paths would be created by the fissures. This would accelerate the dissipation of excess pore water pressures, thus consolidating the clay in the immediate vicinity of the stone column. The increase in the capacity of the stone column due to dynamic compaction can be estimated on the basis of strength gain due to dissipation of excess pore pressure using the well known $Cu/\bar{p}$ relationship.

For analysis of behaviour under drained conditions the soil is considered as normally loaded cohesive soil whose shear strength can be expressed with satisfactory accuracy by Coulomb's equation in which C = 0, thus $S = \bar{p} \tan \phi$. Analysis is carried out for a range of values of rigidity index covering loose to dense frictional materials. Such analysis would reveal the adequacy of the stone column capacity even if $\sigma_1/\sigma_3$ ratio is reduced by dilation of granular stone column material under shear associated with gradual lateral enlargement of the cavity under drained conditions.

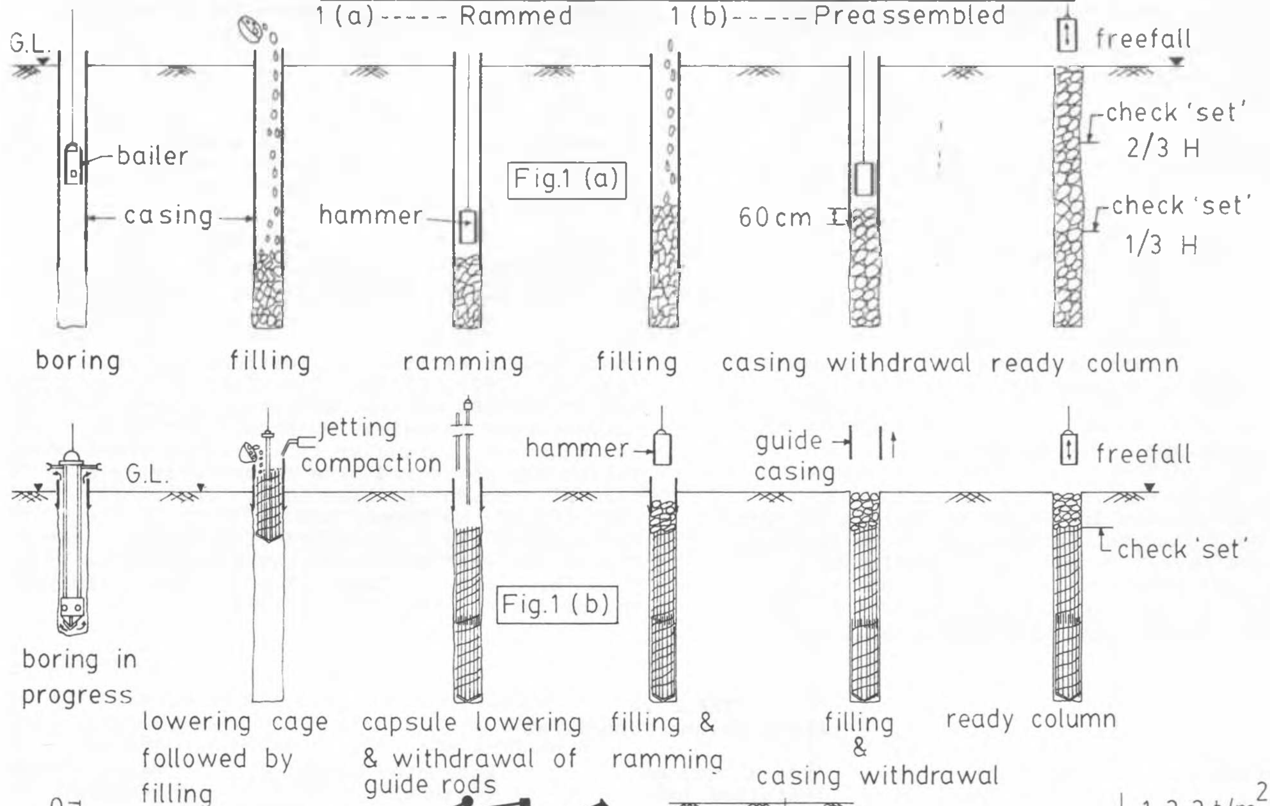
While the stone consumption indicates the development of a cross sectional area and resistance of cavity expansion, in order that the column develops a dilatant behaviour under drained conditions to reduce compressibility, it is necessary that a certain degree of compaction be achieved. The degree of compaction to produce such a behaviour can be achieved by control on set.

The effect of compaction extends over a distance of 3 to 4 M and hence it is not necessary to compact at close intervals as was done in earlier installations. For a satisfactory behaviour the set need not be checked at close intervals. However, the set criteria should be related to the overburden pressure.

### Settlement of Stone Columns

Deformation of stone columns under applied loads is a complex phenomenon as pointed out

Fig. 1 STONE COLUMN INSTALLATION TECHNIQUES
1 (a) ----- Rammed 1 (b) ----- Preassembled



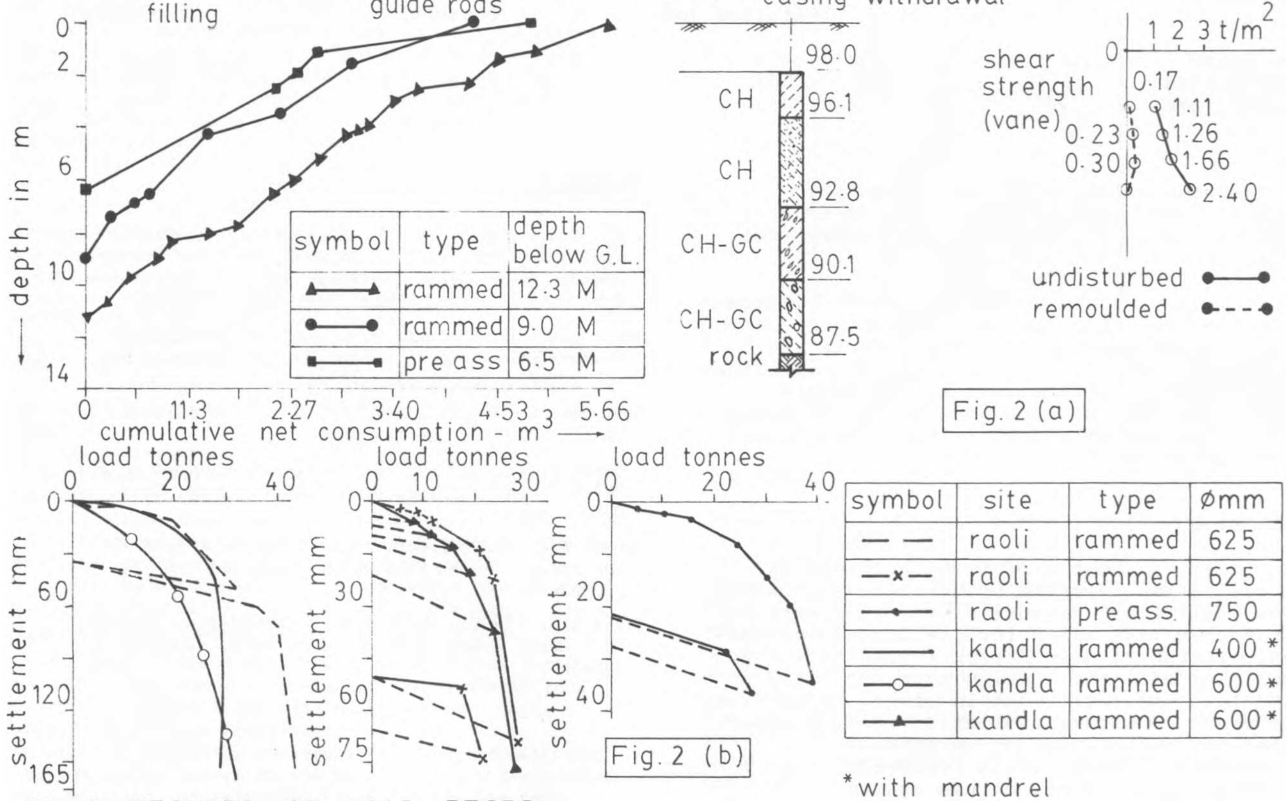




Fig. 2 RESULTS OF LOAD TESTS
2 (a)----Consumption data & Subsurface condition. 2(b)---Load settlement diagrams

in an earlier publication (Datye & Nagaraju, 1975) and a precise mathematical analysis accounting for all the variables would be far too involved for practical value. Initial settlement could be estimated on the basis of compressibility of crushed stone measured in laboratory tests (Marsal, 1967). Stone column compressibility under undrained and drained conditions and its collapse load are verified by single column load test. This data can be utilised to predict group behaviour provided the installation in the field can be controlled to get consistent behaviour in the single column load test.

Design approach postulated herein is thus based on performance in a single column load test - consistent behaviour being ensured by close control on consumption and set.

## LOAD TESTS AND INTERPRETATION

Fig 2. shows result of single column load tests on columns installed by ramming in cased bore hole and preassembled and installed in prebored hole. Details of installation techniques are shown in Fig. 1. At the site located at Raoli in Greater Bombay the sub-surface consists of very soft to soft clay (CH) extending to a depth of 6 to 12 M below ground level. Fig 2(a) shows the subsurface conditions at this site and also the stone consumption data. The stone column capacities were estimated on the basis of theoretical postulations presented in the previous section. It is found that the behaviour of the pre-assembled stone column is comparable to the rammed stone column and similar methods of analysis can be used for rammed as well as preassembled columns.

Results of single column load test on columns compacted by use of mandrel driven by heavy hammer is presented in Fig. 2. The subsurface conditions at this site consists of soft silty clay extending to 18 Meters depth extensively described in earlier publications (Datye & Nagaraju, 1975, 1977). Two sizes of bores 400 mm and 600 mm were advanced by non-displacement technique to a depth of 10 M below ground. Granular fill forming the stone column was compacted by a hammer driving a mandrel through the bore hole. The rated capacity of the hammer was 5.5 TM. Filling and ramming was in 3 stages of 4, 4 and 2 metre depths; at each stage set was specified as 2 cm for 8 blows. Table II shows the estimated capacities and the failure load.

TABLE II
Stone Column Capacities

| Location | Nominal dia. (mm) | Area at top as installed ($m^2$) | Estimated capacity, (tonnes) | Failure load (tonnes) |
|---|---|---|---|---|
| Ware House | 600 | 0.9613 | 21.5 | 24.0 |
| Bagging Plant | 600 | 0.8906 | 19.9 | 25.8 |
| Bagging Plant | 400 | 1.0091 | 22.6 | 27.5 |

The compressibility of stone column back computed from the test results (0.0002 $m^2/t$) compares favourably with the values reported by Marsal for $\sigma_1/\sigma_3$ ratios of 3 to 4.

In one case boring was done by non displacement method in the other case by displacement method using a dispensable shoe, set criteria and consumption were same. There was no significant difference in the behaviour in the single column load test so much so even the diameter of the tube had no effect on the size of the column developed.

## CONCLUSIONS

It is realised that a rigorous analysis for the prediction of stone column behaviour would be very difficult because of the complexities of the phenomena which involve dynamic compaction, dilatancy, pore pressure dissipation and remoulding effects. Design approach based on yield load and settlement in single column load test combined with installation control based on set and consumption holds promise of providing a rational basis for predicting the behaviour of stone column systems.

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