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Soil Sampling with Particular Reference to Indian Practices

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The paper presents the historical background on soil sampling and deals the basic issues with a focus on the current state of sampling in India. The approach in standardization of boring, sampling and handling varies widely from country to country. The deficiencies of the Indian samplers with respect to those from outside are discussed and norms for area ratio, inside clearance, length to diameter ratio, recovery ratio and the materials of the sampling tubes of samplers are suggested. The factors affecting sample disturbance, viz, visual inspection, stereoscopic X-radiographic examination, recovery ratio and sample density are discussed. Strength deformation characteristics for ascertaining sample quality is also presented.

HISTORICAL BACKGROUND

The treatise on sub-soil exploration and sampling of soils for civil engineering purposes by Hvorslev[1] was the first important work to give scientific fervour to the art of soil sampling. Eight years later, at the Fourth International Conference on Soil Mechanics and Foundation Engineering (ICSMFE) held in London, a subcommittee on soil sampling was constituted. The committee acquired the status of an International Group on Soil Sampling (IGOSS), the first major act of which was to sponsor a speciality session during the Seventh ICSMFE (Mexico, 1969). India reported considerable interest in soil sampling while answering a questionnaire presented in the proceedins of the speciality session. Research and development work on sampling plus standardization of site investigation and soil sampling practices were reported to be the principal areas of interest in India. It was admitted that piston samplers were rarely in use and for all routine investigations, samplers were not specified to suit soil types and engineering design requirements.

IGOSS sponsored the second speciality session on soil sampling during the Fourth Asian Regional Conference (ARC) on Soil Mechanics and Foundation Engineering held in Bangkok in 1971. The periodicity of two years was, however, broken when no speciality session could be held during the Eighth ICSMFE (Moscow, 1973) although IGOSS had planned it. Also, the sub-committee meeting at Hawaii in 1975 could not be held. Looking at the non-performance, the executive committee of the ISSMFE decided to disband the sub-committee in 1975. Two years later (Tokyo, 1977) the interest once again got revived with the speciality session on the subject held during the Ninth ICSMFE. A sub-committee was formed once again. The subcommittee convened an International Symposium on Soil Sampling with the Sixth Asian Regional Conference (Singapore, 1979). During the Symposium, 18 state-of-the art reports were presented and discussed. Bhandari and Datye[2] contributed a report on 'Soil Sampling Practices in India' based on a country-wide survey.

The committee met in Delft a year later to finalize the draft of an International Manual for 'Sampling of Soft Cohesive Soils' and finally released the publication at the Tenth ICSMFE (Stockholm, 1981). The committee's life has now been extended to 1985.

INTRODUCTION

During the last two decades (1960-80) Indian geotechnical engineers have paid little attention to the quality of boring and sampling and there exists an unlimited scope for improvement. One of the principal reasons for the deficient technology is the fact that contracts are largely awarded to the lowest bidder regardless of the type of boring and sampling equipment the geotechnical contractor has and the merit of the drilling crew. The client, therefore, pays for the number of boreholes made rather than for the geotechnical information fundamental to sub-soil exploration.

Whereas the tools, equipment and technology of boring and sampling are steadily being standardized and research on soil sampling is attracting particular attention, the existing wide gap and meagre inputs are both matters of concern. This paper deals with some

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of the basic issues with a focus on the current state of sampling in India.

BASIC ISSUES

The basic issues are:

1. Are we exploiting the geological information fully before thinking of boring and sampling?

2. Can we classify geotechnical problems which demand undisturbed sampling and those which do not?

3. Are we clear about the purpose for which we often insist on undisturbed sampling?

4. How do we ensure a minimum of disturbance through upgrading of equipment, tools and procedures to suit different situations?

5. With what level of confidence are we able to evaluate the degree and implications of sample disturbance?

6. What are viable alternatives if undisturbed sampling is not possible or not necessary?

Bhandari and Jain[3] attempted to answer some of the questions on the basis of a country-wide survey. The state of information is, however, poor calling for a vigorous effort.

SUGGESTED APPROACH

Standardization of boring, sampling and handling of samples is an essential pre-requisite to introduce healthy sub-soil exploration practices in India. Both equipment and procedures must be standardized (Table 1).

TABLE 1 BORING, SAMPLING AND HANDLING

Boring	Equipment	Selection of borehole diameter and equipment
	Procedure	Selection of method of boring for minimization of disturbance during boring and stabilization of borehole sides
Sampling	Equipment	Selection of sampler type and diameter. Design aspects: Materials, area ratio, inside and outside clearances, cutting edge angle, length to diameter ratio, permissible ovality, coatings for reduction of friction
	Procedure	Method and rate of penetration; Method of detaching the sample bottom; Manner of withdrawal; Minimization of out-of-balance water pressure in borehole
Handling	Material	Sealing and packing materials
	Procedure	Sealing, packing, labelling, transportation, storage and extrusion

BORING

The method of boring should be such that (a) soil disturbance at the bottom of the borehole is minimum, and (b) water level difference inside and outside the borehole is not created. Usual methods of boring involve rotary drilling, percussion drilling, auger boring or wash boring. Rotary drilling is the most common and best suited to undisturbed sampling. Percussion drilling may follow rotary drilling in popularity but cannot be recommended for undisturbed sampling. If percussion drilling must be employed, the percussive advance must be halted about 25 cm above the intended sampling depth. Auger boring is simple, economical and reasonably good for undisturbed sampling provided auger withdrawal does not lead to suction at the borehole bottom. Wash boring also disturbs the soil, though the degree of disturbance may be less than that due to percussion.

Guidelines must be formulated on the selection of boring methods, stabilization of boreholes and their cleaning ISI have recently finalized its recommendations on bentonite mud for use in bored piling and diaphragm walling[4]. A similar exercise is needed for driling fluid in a bore hole. Specific gravity of the drilling mud may be recommended in the range 1.05 to 1.15 in keeping with international practices.

SAMPLING

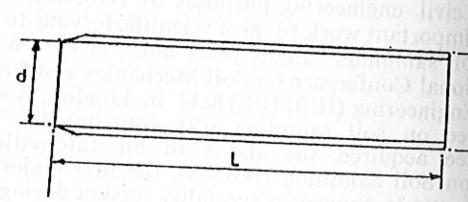
Standardization of sampling tubes includes decisions on material of which sampling tubes should be made, their area ratio, inside clearance, length to diameter ratio, cutting edge angle and mounting details.

The dimensions of sampling tubes commonly used in India are given in Table 2.

TABLE 2 SOME SOIL SAMPLERS IN INDIAN PRACTICE

Thin Wall Samplers:

$$\text{Area Ratio} = \frac{D^2 - d^2}{d^2} \times 100$$

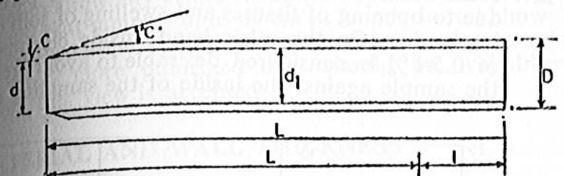


ORGANIZATION	L, mm	D, mm	d, mm	AREA RATIO, %
ISI	L′ = 300	40	38	10.8
	L′ = 450	74	70	11.8
	L′ = 450	106	100	12.4
CBRI	455	85.6	82.3	8.8
CEMENTATION		53.6	50.0	14.9
UOR	600	88.9	85.7	7.6
AFCONS		110	102	16.3
MERI	Varying	104.0	100.2	7.7
NI (D-D)		41.3	38.0	18.0
AIMIL	105, 200, 225, 300, 450	41.2	38.0	17.5
			50, 100 150	
HEICO	150, 200 300, 450		38	
	450		50, 100 150	15 to 20
CSMRS	400	103	99	9.0
	400	104	100	8.3
CRRI	600	114.5	108.0	12.4
	600	105.0	100.0	10.3
	600	89.0	86.0	7.1
	600	74.0	71.0	8.6
UPIRI	460	112.2	105.3	13.6

Piston Samplers:

$$C_i = \frac{d_i - d}{d} \times 100$$

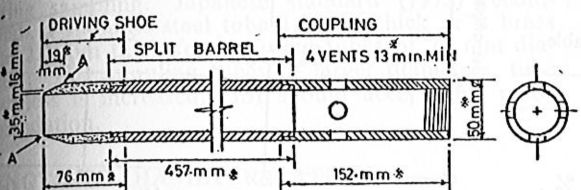
where i is the area occupied by piston and adoptor, and L' the length of soil sample.



Organizations	L, mm	D, mm	d, mm	Ci %	Ar, %	°	tc, mm
CBRI	725	89	86	0	7.1	6	0.5
AIMIL	L' = 580	55	50	4	21	33	0.75
HEICO	600	—	51	—	—	—	—

Exploratory Samplers :

A. Standard Penetration Test Samplers :



Corners of A may be slightly rounded
Essentil Dimensions are indicated by an asterisk

Split-barrel sampler assembly

Organization	D, mm	d, mm	d_1, mm	d_2, mm	Area ratio, %
ISI	50.8	35.0	—		111
CSMRS	50.8	35.0	37.3	39.6	111
	69.6	50.2	50.5	52.5	92
	94.5	76.3	76.3	80.7	53
UPIRI	47.3	35.0			83
CBRI	50.8	35.0			111
UOR	50.8	33.0	33.0	37.0	137
AIMIL	50.8	35.0	35.0	38.0	111
HEICO	50.8	35.0	—	—	111

B. Static Penetration Sampler :

Organization	L, mm	D, mm	d, mm	Area ratio, %
CBRI	200	42	32.7	64.9

C. Thick Wall Samplers :

Organization	L, mm	D, mm	d, mm	Area ratio, %
CSMRS	400 to 500	103.8	88.8	36.5
CEMENTATION	450	114.4	103.0	23.4
	420	116	100	34.6

ISI Indian Standards Institution; CBRI Central Building Research Institute; CEMENTATION Cementation Co Ltd; UOR University of Roorkee; AFCONS Asia Foundations & Construction Pvt Ltd; MERI Maharashtra Engineering Research Institute, Nasik; NI (D,D) North India Practice ; AIMIL Associated Instrument Manufacturers (India) Pvt Ltd; HEICO Hydraulic & Engineering Instruments Co, New Delhi; CSCMRS Central Soil & Material Research Station, New Delhi; CRRI Central Road Research Institute, New Delhi; UPIRI UP Irrigation Research Institute, Roorkee.

These can be compared with those used abroad (Table 3).

TABLE 3 SOME SOIL SAMPLERS IN PRACTICE ABROAD THIN WALLED AND PISTON SAMPLERS

Organization/ Code	Length, mm	D, mm	d, mm	Area Ratio, %
Thin Walled Samplers:				
Thin walled AIT (Shelby, 1979)	600 740	75.4	71.6	11
Thick walled AIT (1979)	450	77.0	71.0	18
Large Size AIT (1979)	600	273.0	260.0	10
ASTMD 1587 - 74[7]	91	50.8	48.3	10.5
	91	76.2	72.9	9.25
	145	127.0	120.9	10.34
KSF : 2317 - 1966 (Korean Standard)[8]	914	50.0 or 54.0	47.6 or 51.6	10.34 or 9.51
	914	76.0	72.8	8.98
	1372	127.0	120.6	10.89
BS:1377-1975[9]	685	50.0	35.0	
Split Barrel Sampler				
Piston Samplers				
NGI[8] (Original),	400-600 800-1 000	54	51.4	12
NGI[10] (Modified),	762	54	42.5	60
NGI (Composite),	768	54	45·4	42
AIT, Bangkok	600	273	260	10
Norwegian Geonor and other proprietary samplers, UK	600-1 000	50-100	48.94.5	8-12
Large diameter sampler, UK	upto 1 000	150-260	147-251	4-7
Delft Continuous sampler, UK	upto 18 000			29
Rotary Cored samplers, UK	15 000 generally	75-150		Not applicable
T Berre, K Schjetre and S Sollie[11]	1 000	101.6	95	14

The comparison shows a wide variability. It is specified that sampling tubes could be made of brass, stainless steel or aluminium. Whereas use of aluminium is hardly reported in international literature, IS: 2132-1972[5] recommends a thin wall tube of the specifications outlined in Fig 1. One would notice the absence

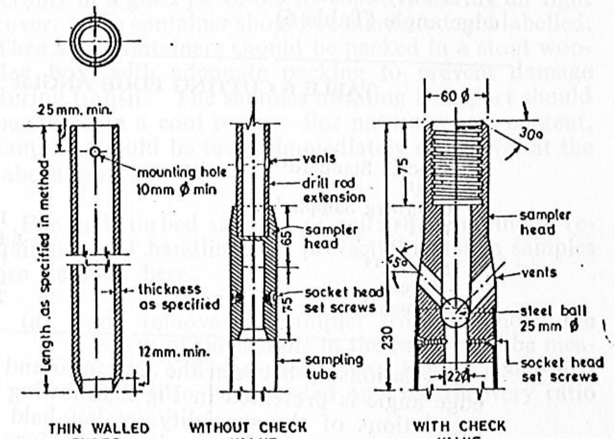


Fig 1 Sampler head details as recommended by ISI

of definite recommendations on cutting edge angle, inside clearance, recovery ratio, etc.

Area Ratio and Cutting Edge Angle:

The differing recommendations are summarised in Table 4 and Table 5.

TABLE 4 AREA RATIO

	%
ASTMD 3550-1977[12] and ASTM D 1587-1974[7]	9-15
KSF 2317-1964[8]	9-11
WES-1979	10 acceptable 13 preferred
NGI-1969[10]	14
DIN 4021, B1-1971[13]	15
Shackel[14]	18
Osterberg sampler[5]	18
PN/B-04451-1962[16]	18
Swedish Standard[17]	21
SGI[18]	27
IS: 1892 - 1962[4]	20 10 desirable

TABLE 5 LARGEST PERMISSIBLE AREA

Country	Largest Area Ratio, %
Denmark	15
Finland	15
France	15
India	20
Israel	4-5
Italy	12
Japan	11
Mexico	10
Norway	12
UK	10
USA	13
Yogoslavia	12

According to the International Manual on Sampling[6] (1981) the largest permissible area ratio reported from various countries differ considerably (Table 5). Variability is also observed in the values of cutting-edge angle (Table 6).

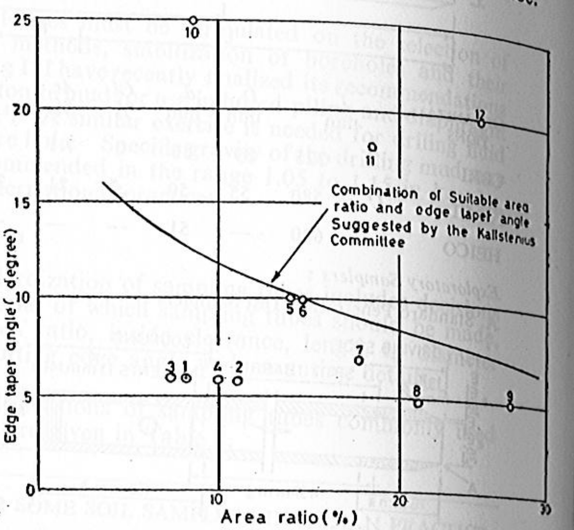
TABLE 6 CUTTING EDGE ANGLE

	°
Swedish Standard[17]	5
SGI[17]	5
Osterberg Sampler[15]	7
NGI[10]	10
Mori[31]	6±10
Shackel[14]	18
Berre[20]	10
Brenner[31]	20

A relationship between the area ratio and the cutting edge angle is presented in Fig 2 following the recommendations of the speciality session held during the Sixth ICSMFE. The overall picture favours cutting edge angle between 5° to 10°, closer to the former. Besides, the 10% area ratio seems to be in order.

Inside Clearance

The need or otherwise of inside clearance in sampling tubes is a matter of debate. One school of thought strongly believes that provision of inside clearance could lead to disturbance of the sample particularly due to opening of fissures and swelling of soils containing gases. On the other hand, inside clearance ratio of 0.5-1% is considered desirable to avoid pressing of the sample against the inside of the sampling tube.



1 Japanese Standard Draft Manual : Stainless Steel
2 Japanese Standard Draft Manual : Brass
3 Bhandari and Datye[2]
4 Brenner[20]
5 NGI 45 mm Sampler Norwegian Geotechnical Institute[10]
6 Berre, *et al*[19]
7 Osterberg[15]
8 Swedish Committee on Piston Sampling[18]
9 Swedish Committee on Piston Sampling
10 DIN 239 st 35 reported in DIN (4021-1971)[13]
11 Shackel[14]
12 Brenner and Phillipson

Fig 2 Relationship between edge taper angle and area ratio

The differing recommendations on inside clearance are presented in Table 7.

TABLE 7 INSIDE CLEARANCE

	%
Swedish Standard[17]	0.4
Osterberg Sampler[16]	0.4
WES (1979)	0.5 to 1
DIN 4021, BI-1971[13]	0.5 to 1
SGI[17]	1.2
NGI[10]	1.4
NGI (1981)	1.4
ASTM D 3350 - 1977[12]	0.5 to 3
ASTM D 1587 - 1974[7]	0.5 to 3
KSF 2317 - 1964[8]	0.5 to 3
IS : 1892 - 1962[4]	1 to 3

Although in most samplers, one finds $0 < C_i < 1.4$, some codes continue to permit C_i upto 3%.

It seems highly desirable to link the recommendations on inside clearance with the recovery ratio. Since the recovery ratio, R, of less than 95% indicates substantial sample disturbance, one could limit the inside clearance to $\frac{1}{2}(1-R)$, *ie* 2.5%. But when viewed in the backdrop of practices elsewhere[21-29], the Indian standards should limit the inside clearance to 1.4%[5,19]

The present trend in America[30] and Japan[31,32] is not to allow any inside clearance because it has been noticed that samples upto 80 cm in length do not show disturbance even without provision of inside clearance. However, more published data should be available before this view is accepted

MATERIAL AND WALL THICKNESS

Sampling must be rigid, resistant to corrosion and machinable to a smooth surface. IS : 2132-1972[6] recommends use of steel, brass or aluminium. Similar recommendation is furnished by KSF : 2317[7]. In the USA, use of a welded-and-drawn-over-the-mandrel (DOM) steel tube coated with lacquer or epoxy resin is recommended.

A sampling tube 2 to 3 mm thick is commonly used in various countries so as to be able to resist distortion during sampling. Japanese standard (1972) recommends a stainless steel tube 1.5 mm thick or a brass tube 2.0 mm thick for sampling tubes of 75 mm diameter. For sampling tubes of larger diameters, tube thickness is increased. ISI should accept this recommendation.

LENGTH-TO-DIAMETER RATIO

The Indian standards are silent on the recommendation relating to length to diameter ratio $\left(\frac{L}{D}\right)$ of sampling tubes. Recommendations made by others are summarized in Table 8.

TABLE 8 LENGTH-TO-DIAMETER RATIO

PN/B-04451-1962[18]	2.5 to 4
Mori[31]	4 to 10
DIN 4021, B1-1971[13]	4.77
KSF 2317-1964[8]	5 to 10 for sands 10 to 15 for clays
ASTM D 1587 - 1974[7]	5 to 10 for sands 10 to 15 for clays
Hvorslev[1]	10 to 20

Of these, the recommendations made by ASTMD 1587 seem to represent a common view.

DEGREE OF OVALITY IN THE SAMPLING TUBES

Most of the standards do not stipulate permissible degree of ovality in a sampling tube but do recognize that the degree of sample distrubance increases with the degree of distortion in tube cross-section. The Japanese standard specifies that the difference between the maximum and the minimum outside diameters at any cross-section of a sampling tube should be less than 1.5 mm. This appears to be a reasonable recommendation for ISI to follow.

RECOVERY RATIO

Hvorslev[1] defines total recovery ratio, *R*, as the ratio of the length of the sample, *L*, to the length of penetration of the sampler, *H*. Various recommendations are summarized in Table 9.

TABLE 9 RECOVERY RATIO, *R*

Mori[31]	0.90—0.95
Shackel, Australia[14]	0.94—0.99
WES	0.5 to 1
Hvorslev[1]	$1.0 \leq R \leq 12\, C_i$
IS: 1892-1962[4]	$1.0 \leq R \leq 12\, C_i$

where C_i is the inside clearance $= D_i - D_e$, D_i the inside diameter of the sampler and D_e diameter at cutting edge.

IS: 1892-1962 endorses the recommendation made by Hvorslev[1]. In view of the recent thinking on nominal to no inside clearance as against a maximum of 3% allowed by the Indian standard, it is desirable to be specific and stipulate not less than 95% recovery ratio to avoid sample disturbance.

Mounting Holes on Sampling Tubes

Available recommendations are summarized in Table 10.

TABLE 10 NUMBER OF MOUNTING HOLES FOR DIFFERENT DIAMETER OF TUBES

IS : 2132-1972[5]	Minimum two mounting holes on opposite side for 38 mm and 70 mm samples. Minimum four mounting holes spaced at 90° for samplers 100 mm.
	Minimum diameter of mounting hole is 10 mm. Minimum distance of centre from end is 25 mm.
ASTMD 1587-1974[7]	Minimum two mounting holes on opposite sides for 50 mm and 88 mm sampler; minimum four mounting holes spaced at 90° for samplers of 100 mm diameter

The experiences with the recommendation of IS: 2132-1972 appears to be satisfactory so far.

Handling and Labelling of Samplers

The following procedure is recommended by IS: 1892-1962.

For disturbed representative samples of soil: Immediately after obtaining from the borehole or trial pit the sample should be placed in a cloth bag or tin, preferably in a glass jar of 0.5 kg capacity having air tight cover. The container should be numbered and labelled. Then such containers should be packed in a stout wooden box, with adequate packing to prevent damage during transit. The samples awaiting transport should be stored in a cool room. For natural water content, samples should be tested immediately on arrival at the laboratory.

For undisturbed samples of soil: The minimum requirement of handling and protection of such samples are detailed here.

(a) Upon removal of sampler from borehole, the length of the sample in the tube, shall be measured and recorded. The length penetrated shall also be recorded and the recovery ratio determined.

(b) For sample obtained in a liner or in a seamless tube sampler, about 2.5 cm of its length at both ends as well as any disturbed soil in top of sampler should be removed. If sample is very porous, a layer of waxed paper should be placed on both ends and then several layers of molten wax should be applied to form a plug 2.5 cm thick on each end. Any space left between the top of wax and the end of the liner should be tigthly packed with saw dust and a close-fitting lid.

(c) Samples which are not retained in tube should, if necessary, be protected by waxed paper cover and then wholly covered with several layers of molten paraffin wax. Then they should be placed in a packed metallic container.

The steps of sealing of samples with paraffin wax or a mixture of paraffin wax and microcrystalline was suggested for sampling of soft cohesive soils[25] are:

1. A cap should be placed on the end of the sampling tube immediately after sampler disassembly to prevent damage of the cuttingedge.

2. Cuttings and any obviously disturbed soil deposited at the end of the sampler should be removed, and the inside of the tube should be cleaned by an instrument as shown in Fig 3.

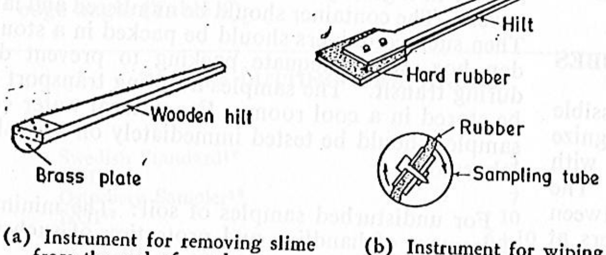
3. The sample should be supported firmly in a place shaded from direct rays of sun.

4. A circular piece of paper should be placed at the top of a sample.

5. Melted paraffin should be poured into the top of the tube. Paraffin wax of 30-50mm thick should be applied, preferably in two layers to make sure of sealing.

6. After the paraffin hardens, the tube should be inverted and steps (2)-(5) should be repeated.

7. A close fitting lid or screw cap should be placed on each end of the tube and the lids should be held in position by adhesive tape. Samples which are not retained in a tube should be wholly covered with several layers of melted-paraffin or soil and moist sawdust.



(a) Instrument for removing slime from the end of a tube

(b) Instrument for wiping the inside of a tube

Fig 3 Instruments for cleaning the inside of sampling tube

ISI should adopt these recommendations. In recent years, use of mechanical seals (Fig 4) has come up as an alternative to sealing by wax. Experience tells us that wax does not adhere well particularly if inside of sampling tube is unclean. On the other hand, mechanical seals are simple to use and more reliable. The only limitation is use of such seals is that the sampling tubes should be perfectly round. Andersen and Kolstad have suggested a mechanical seal which was used in Norway. An improved mechanical seal (Fig 5) has two rubber rings to avoid rotation due to distorstion of the tube.

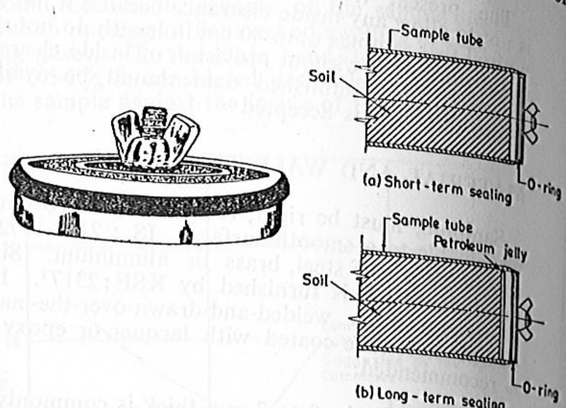


Fig 4 Mechanical seal and its application

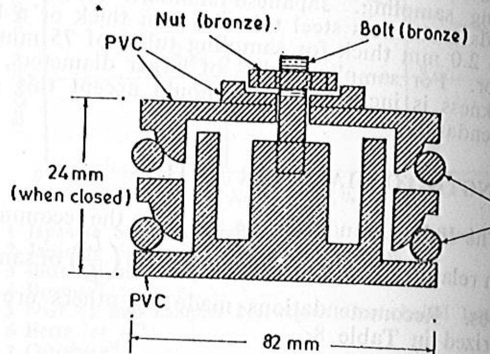


Fig 5 Mechanical seal for ID 89-mm thin-walled tubes

TRANSPORT AND STORAGE OF SAMPLES

During transportation and storage, samples must be fully protected from heat, frost, vibration, shock or any other mode of disturbance. This could be achieved by proper sealing and packing before transportation. Sampling tubes should be placed in boxes with adequate padding (Fig 6) of foam rubber, sponge or moist saw

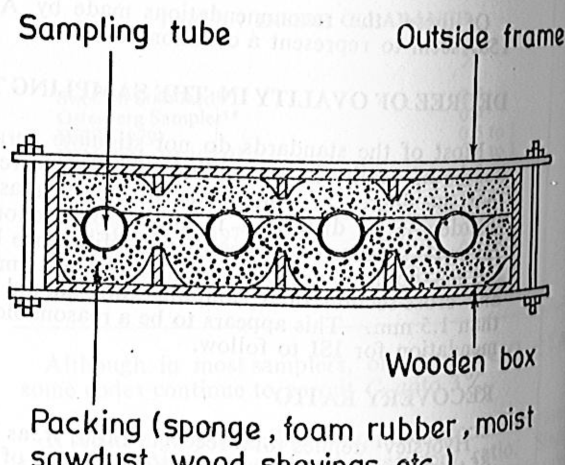


Fig 6 Example of proper packing of samples for shipping

dust. If the number of samples to be transported is samll, transportation by hand is recommended.

SAMPLE DISTURBANCE

A sample gets disturbed due to the boring and sampling operations and thereafter by stress-relief, handling, transportation and extrusion. Even with a perfect understanding of these factors and all possible care in boring and sampling, a certain degree of sample disturbance is inevitable. Some of the common ways of evaluating sample disturbance are summarised in Fig 7 and discussed here.

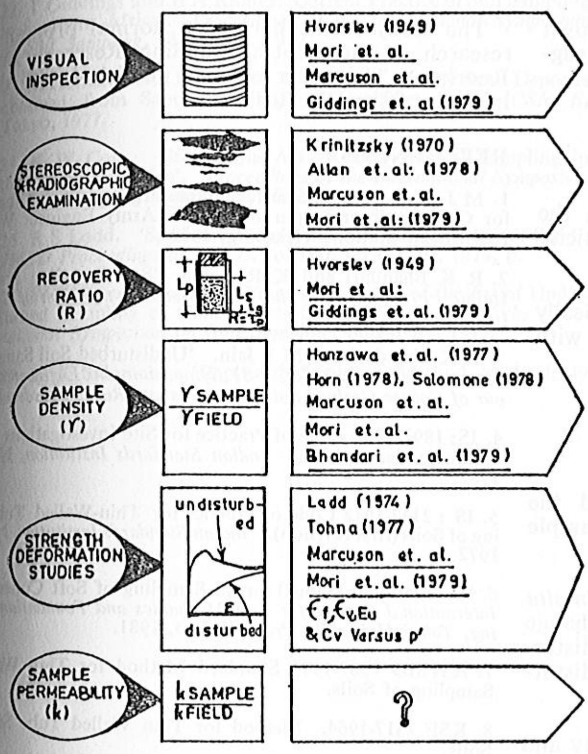


Fig 7 Ways of evaluating sample disturbance

Visual Inspection

Visual inspection at the site is important in evaluating the quality of a sample. If the end of a sample contained in a tube is extraordinarily soft, the whole sample may be disturbed. If the tip of the tube is bent or damaged, the sample may also be disturbed. It is important to identify by visual inspection the disturbed portion or portions not suitable for laboratory testing. But visual inspection cannot always guarantee the quality of a sample.

In addition to visual inspection, tests using a pocket cone are helpful in evaluating the quality of a sample. It must be emphasized that appropriate supervision by a qualified engineer is of fundamental importance in obtaining high quality soil samples.

Stereoscopic X-Radiographic Examination

X-radiography has been shown to be a valuable aid in non-destructive examinations of a sample quality. Arch-shaped fringes, cracks or fissures, and voids in disturbed samples have been detected by X-ray pictures. Gravels, shells or organic compounds may also be distinguished[33, 34].

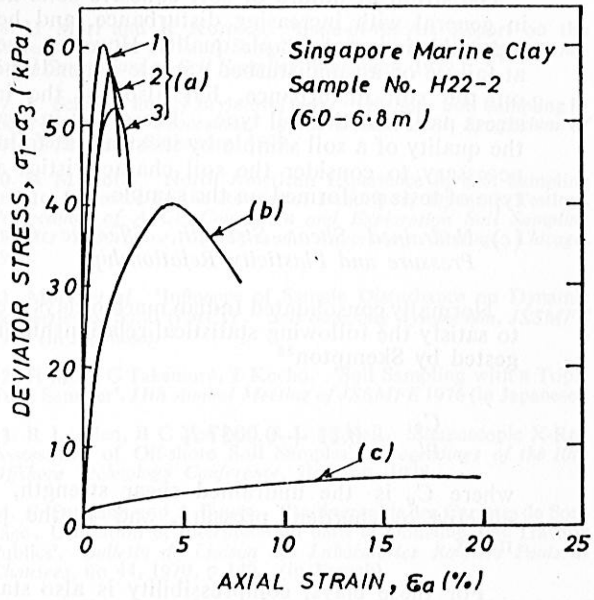


Fig 8 Quality evaluation from stress-strain curve

Recovery Ratio

The recovery ratio gives an indication of the quality of samples. It should be 100% if a sample is not shortened or lost during the penetration and withdrawal of a sampling tube. It is hard to achieve at 100% recovery ratio since the accuracy of measurement is limited. In practice, a recovery ratio of 98% is satisfactory and anything less than 95% indicates inaccurate procedures and measurements during sampling or loss of sample, and may be considered as a sign of possible disturbance. Over-driving, resulting in a recovery ratio actually in excess of 100%, is difficult to identify by sampling tube observation; since it is a cause of major disturbance every possible measure should be taken to avoid over-driving.

Sample Density

Very loose or very dense samples of sand when disturbed undergo a change of density. Samplers with high length-to-diameter ratios are often responsible for such a disturbance. Only a comparison of sample density with that of undisputably undisturbed sample could give an idea of sample disturbance.

Strength Deformation Studies

(a) *Stress-Strain Curve*

The stress-strain curve obtained from undrained triaxial compression tests (Fig 8) is indicative of sample quality. In curve (a), for a high-quality sample, the strain at failure is small and the curve is linear to approximately the peak stress. Curve (b), for a slightly disturbed sample, is roundish and the strain at failure is larger than that of a high quality sample. Curve (c), for a remoulded sample, has no clear stress peak. The curves in Fig 8 are typical of sensitive soils. In soils of low sensitivity, however, the drop in stress after peak may be quite small even in undisturbed samples.

(b) *Strain at Failure*

The strain at failure of soft cohesive soils increases in general with increasing disturbance, and hence, is a possible index of sample quality. However, the strain at failure of an undisturbed sample depends not only on the soil disturbance, but also on the imposed stress path and the soil type. Therefore, in evaluating the quality of a soil sample by its strain at failure, it is necessary to consider the soil characteristics and the type of tests performed on the sample.

(c) *Undrained Shear Strength, Effective Overburden Pressure and Plasticity Relationship*

Normally consolidated Indian marine clays are known to satisfy the following statistical relationship first suggested by Skempton[35]

$$\frac{C_c}{P'_o} = 0.11 + 0.0037\, I_p$$

where C_u is the undrained shear strength, P'_o the effective overburden pressure, and I_p the plasticity index.

For these clays, compressibility is also statistically related with natural water content in accordance with Lambe and Whiteman's (1969) relationship

$$\frac{C_c}{1+e_o} = 0.358 \log w - 0.448$$

If a clay deposit is normally consolidated and the above relationship is violated, one must suspect sample disturbance.

A triaxial specimen is usually restressed to *in situ* stresses before performing a test. Any volume change during this process depends on the degree of disturbance and generally increases with increasing disturbance.

A tentative relationship between sample quality and volumetric strain is suggested for Indian soft clays in Table 11.

TABLE 11 VOLUMETRIC STRAIN AND SAMPLE QUALITY

Volumetric Strain, %	Sample Quality
1.5	Very good
1.5-2.5	Good
2.5-5.0	Ordinary
5	Poor to very poor

CONCLUDING REMARKS

Boring, sampling and handling procedures differ a great deal from country to country, pointing to the need for revision and updating of the existing standards, introduction of new ones and for concurrent effort on conscentious implementation towards a unified approach. The paper contains recommendation on the specifications of sampling tubes, such as area ratio, inside clearance, length-to-diameter ratio, cutting edge angle, recovery ratio, fabrication materials and degree of ovality. The specifications of sealing and transportation of samples are also given.

The area ratio should be of the order of 10%, the cutting edge angle should range between 5°-10°, the inside clearance should be limited to 1.4%, of recovery ratio of the sample and should not be less than 95% and the length to diameter ratio of samplers should be 5-10 for sands and 10-15 for clays. The diameter of the sampling tube may be 75 mm, made of steel (1.5 mm thickness) or brass (2.0 mm thickness). It is hoped that these recommendations would stimulate discussion and eventually pave way for adoption better Indian standards.

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