NATIONAL TRANSPORT RESEARCH CENTRE

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REPORT ON CONCRETE CORES EXTRACTED FROM BOX CULVERT OF PROVINCIAL HIGHWAY PROJECT (CONTRACT PACKAGE # 5)

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Cement concrete is a mixture of cement, aggregate and water. A well proportioned concrete guarantees high strength and durability. But also of vital importance are the mixing procedures, compaction and placing methods. Standards and specifications are laid down to protect against the unintentional production of substandard concrete. Normally four main factors are regarded as a key for assuring a standard quality concrete.

(a) Appropriate proportioning of aggregates (batching)

(b) Proper mixing procedures

(c) Proper methods of placing and degree of compaction

(d) Adequate curing

The National Transport Research Centre (NTRC) was requested by M/S ITALCONSULT, the consultants for Mardan-Swabi Provincial highway Project, Contract Package #5, for obtaining and analysing the concrete cores in accordance with the standard specifications set forth in AASHTO Manual in order to evaluate the quality of box culvert concrete through density and compressive strength measurements

Table 1 provides the summary of test results.

The field and laboratory observations and analysis showed that:

- The unit weight of normal weight concrete having a strength of 4000 psi (28 N/mm^2) is usually around 145 lb/ft^3 (2320 Kg/m^3). However, density test results showed that with the exception of only one locations, the unit weight (density) at all other locations was found to be far below the standard.
- The compressive strength of 6 cores were below 3000 psi (21 N/mm^2) whereas rest showed higher results.
- Core number 1 and 2 showed signs of extensive honeycombing.
- Four cores showed significant signs of voids.

CONCLUSIONS

From the above observations and results following conclusions can be easily drawn.

- Placing and compaction, both critical in their effect on the quality of the concrete were probably not keenly observed, resulting in voids and honeycombing.
- At two locations (core-1 and core-2) cement slurry was washed away due to in-flowing water course, causing severe honeycombing.
- The various constituting components (cement-aggregates and water) of concrete mix were not proportioned according to specifications resulting in low strength concrete.
- Structural strength depends on care with which an structure is built, which in turn reflects the quality of supervision and inspection, therefore it seems that a low quality supervision was exercised at the site.
- To serve its purpose, a structure must be safe against collapse and serviceable in use.

It is obvious that any concrete structure with the above mentioned deficiencies is not likely to withstand the designed load.

1. INTRODUCTION

As commonly known, concrete is a mixture of cement, aggregate and water. Concrete in a wide range of strength properties can be obtained by appropriate adjustment of the proportions of the constituents materials. An increase in the cement content in the mix and the use of well-graded aggregate, both increase the strength of concrete. The use of mechanical concrete mixers and the proper time of mixing both have favourable effect on strength of concrete. Use of vibrators produce dense concrete with minimum percentage of voids. To protect against the unintentional production of substandard production of substandard concrete, a high degree of skillful control and supervision is necessary throughout the process from proportioning by weight of the individual components, through mixing and placing, until the completion of curing. Curing conditions exercise an important influence on the strength of concrete. The strength of concrete increases appreciably with age and hydration of cement continues for months.

The unit weight of concrete with natural aggregates varies from about 140 to 152 pcf (2240 kg/m-2432kg/m). For concrete of strength less than 4000 psi (280 kg/cm) a value of 145 lb/ft (23200 kg/m) can be used while for higher strength concrete unit weight can be assumed equal to 150 lb/ft (2400 g/m). A void ratio of only 5% may reduce the concrete strength by about 30 percent.

National Transport Research Centre (NTRC) carried out physical tests on concrete cores obtained from the base slab of box culvert being constructed on the Mardan-Swabi provincial highway, contract package #5. These tests were conducted in accordance with the standard specifications set forth in AASHTO Manual. Table 1 provides the summary of test results.

2. Objective

M/s ITALCONSULT requested to NTRC for the "Determination of Compressive Strength of Concrete Cores", in accordance with AASHTO T 24-86. The cores were drilled from the base slab of the box culvert, being constructed on Mardan-Swabi section of the provincial highway project, contract package # 5.

SUMMARY OF TEST RESULTS

TABLE-1

MARDAN-SWABI, PROVINCIAL HIGHWAY PROJECT, CONTRACT PACKAGE # 5
COMPRESSIVE STRENGTH AND DENSITY OF CORES

CORE NUMBER	COMPRESSIVE STRENGTH		DENSITY		LENGTH OF CORE	DIAMETER OF CORE	TYPE OF FAILURE	HONEYCOMBING	AIR VOIDS
	N/mm²	psi	Kg/m³	pcf	mm	mm			%
1.	NIL	NIL	2160!	135	100	100	NIL	EXTENSIVE	8.2
2(a)	29.0	4200	2400	150	109	99.4	Flex-Shear	NO	NIL
2(b)	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
3.	17.1	2480*	2274!	142	200	98.2	Flex-Shear	NO	3.4
4.	11.0	1600*	2240!	140	208	97.2	Flex-Shear	NO	2.0
5(a)	12.3	1780*	2240!	140	176	98.8	Flex-Shear	FEW SIGNS	2.0
5(b)	12.7	1840*	2288!	143	99	98.6	Flex-Shear	NO	2.7
6.	16.5	2390*	2338!	146	179	98.5	Flex-Shear	NO	0.7
7(a)	10.0	1450*	2224!	139	190	98.5	Flex-Shear	NO	5.4
7(b)	21.5	3120*	2320!	145	110	98.6	Flex-Shear	NO	1.4
8.	12.0	1740*	2192!	137	180	98.5	Shear	NO	6.8
9.	23.2	3360	2340!	146	190	98.5	Flex-Shear	NO	0.7

Note :

NIL - Test not carried out

- Compressive Strength values are rounded to the nearest 10 psi

* Less than 3000 psi

! Less than the given 2350 Kg/m3.

3. Scope of Work

The scope of the work consisted of two parts

(a) Obtaining of concrete cores

(b) Laboratory analysis of concrete cores

(a) Obtaining of concrete cores

(I) Obtain concrete cores from the base slab of the reinforced concrete box culvert having dimensions of 254 m^2 and 0.5 m in depth.

(b) Laboratory analysis of concrete cores consisted of :

(i) Observing and recording dimensions of the obtained cores and taking photographs.

(ii) Recording features like voids, cracks, honeycombing etc.

(iii) Determining the unit weight of concrete cores, and voids ratio.

(iv) Determining the compressive strength of drilled concrete cores.

4. Methodology for Obtaining and Determining the Compressive Strength of Drilled Concrete Cores

The methodology adopted for obtaining and determining the compressive strength of the drilled cores was based on AASHTO T 4-86, i.e. "Obtaining and Testing Drilled Cores and Sawed Beams of Concrete" Laboratory analysis of concrete cores was carried out in accordance with other AASHTO methods, i.e. AASHTO T 148, T 22 & T 1198. The cores obtained were duly marked and secured for laboratory testing.

5. Field Sampling

After receipt of request M/S ITALCONSULT, a field visit was made on 01.10.98. But due to unsuitable working conditions and non clearance of site, only two cores were drilled. Second visit was made on 7.10.98 and all cores were obtained. It was also planned to do rebound hammer test to determine the strength of the slab but because of muddy/boggy conditions, this test was not done. The test specimens were drilled from the base slab of the box culvert of the Mardan-Swabi provincial highway project, contract package no. 5. The site was located 43 kilometers from Mardan, near Swabi. The size of the box culvert was 254 m^2 and was 0.5 m in depth. The photographs 5.1 to 5.8 show different pictures of the site.

Initially six (6) cores were to be drilled as per request, but to increase and rationalise the sample size nine (9) cores were drilled. Cylindrical core specimens were removed by drilling downward perpendicular to the horizontal surface. Each core was of 100 mm in diameter and approximately 250-300 mm deep as per AASHTO T 24-86.

All cores were drilled after removing the clear cover so as to locate the reinforcement. This was done to prevent any damage to coring equipment. Figure 1 shows the location of extracted cores. Cores obtained were duly marked* and secured for laboratory analysis.

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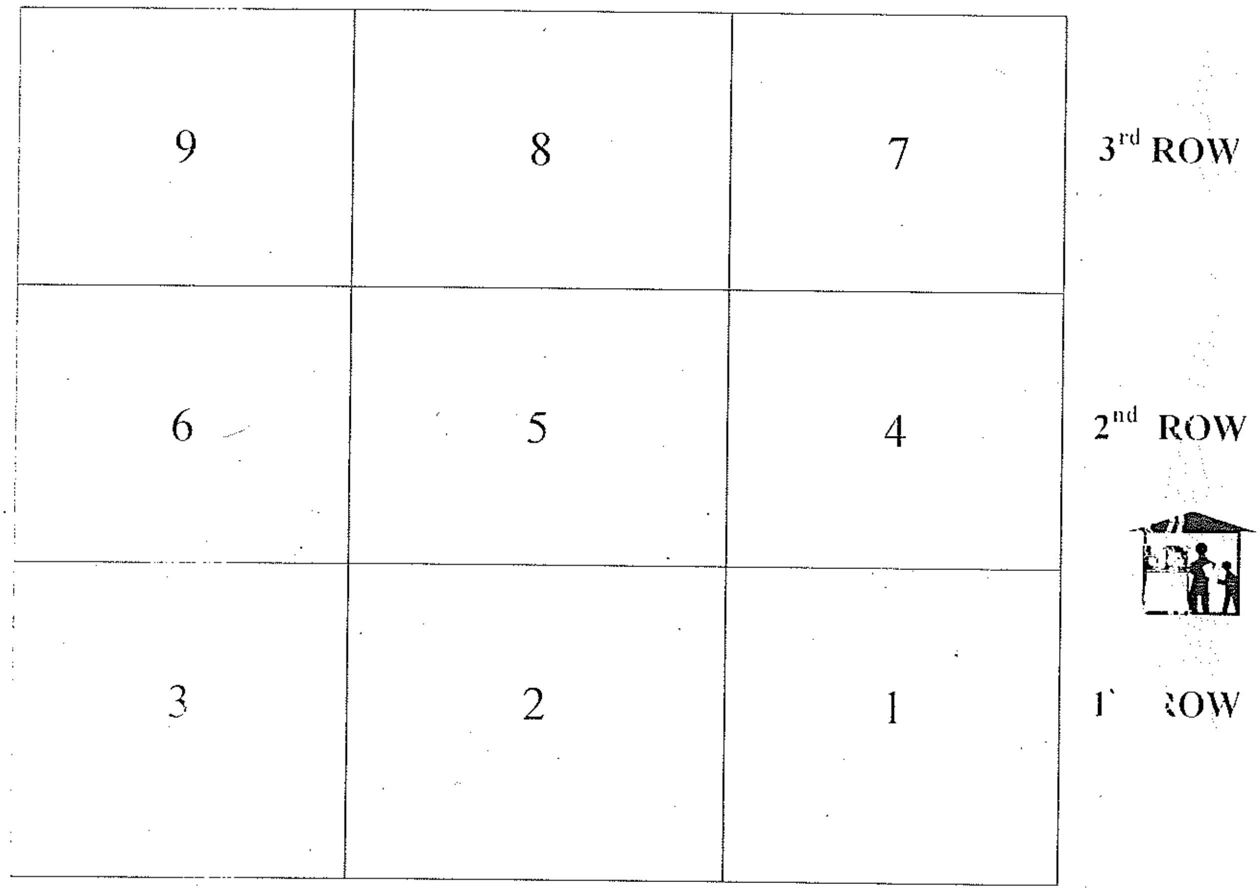
* The markings on cores were made on site, in accordance with the area prepared for coring. Therefore these markings have been re-designated in laboratory and are shown on the attached map (fig-1).

Figure 1: MAP SHOWING LOCATION OF DRILLED CORES

(As Designated in Laboratory)

Direction of Water Flow ↓



Visual observations were made at each core location at the site and all cores were thoroughly observed during laboratory analysis. The record so made for each core locations and core is presented below.

Core No. 1

The dimensions of this core could not be recorded as a complete core could not be extracted. Only an irregular shaped specimen was extracted having a diameter of around 100 mm and a depth of around 100 mm. Further coring exercise just made a shlush of concrete due to continuous disintegration of aggregates. The photographs 6(a) & (b) show the picture.

Photographs No.6(a),(b) and 8(a),(b) show a very poor concrete, where mortar has been washed away and only coarse aggregates were locked into each other. The water was seeping into the hole at a fast rate. The location is shown on the attached map. The specimen showed significant signs of honeycombing due to washing away of cement mortar.

Core No. 2

A core of 100 mm diameter and 150 mm depth was extracted below the clear cover level. The core was solid, having no signs of honeycombing and voids. But the later portion showed extensive honeycombing as no core can be extracted due to disintegration/collapsing of the core. It was observed that water was seeping into the hole at a fast rate. The photographs 7(a), 7(b) and 7(c) show the picture.

Core No. 3

A full core of 100 mm diameter and 250 mm depth was extracted. Some voids were visible but no honeycombing area was visible and the core looked solid as shown in the laboratory pictures. No signs of water seeping into the hole were observed as against the case of cores No.1 and No.2.

Core No. 4

A core of 100 mm dia and 280 mm depth was extracted below the clear cover level. The core have no signs of honeycombing but significant signs of voids were clearly visible, as shown in the photograph taken in laboratory.

Core No. 5

A full depth core was obtained from this location having a diameter of 100 mm and a depth of 400 mm. The core was broken during extraction. The larger piece had a length of about 260 mm while the smaller one had a length of approximately 140 mm. The larger piece had no signs of voids or signs of honeycombing, but at the broken point and the bottom (140 mm piece) showed clear signs of voids and honeycombing.

Core No. 6

A full depth core was extracted having a diameter of 100 mm and length of 320 mm. After a depth of 230 mm some voids were visible.

Core No. 7

A core of 100 mm diameter and 380 mm length was obtained. The top 150 mm showed no signs of honeycombing or voids while the lower portion showed clear signs of voids, but no signs of honeycombing were visible.

Core No. 8

A full depth core of 340 mm length and 100 mm diameter was extracted in two parts. The core was broken due to excessive honeycombing in the top 120 mm portion. The bottom portion of the core had only fewer voids and no signs of honeycombing.

Core No. 9

A core of 100 mm diameter and 230 mm was extracted showing no signs of honeycombing or voids, the laboratory photograph shows the picture. The core drill stuck between reinforced steel at this depth. Therefore further coring work could not be carried out.

7. Laboratory Testing

Standard tests on the concrete cores were carried out in the following manner;

7.1 Specimen Preparation

The specimens were sawed to required size to keep a length/diameter ratio (of capped specimen) between the prescribed limit of 1.94 to 2.1, as specimen within these ratio required no correction. It is also mentioned that four diagonal measurements of each test specimen were taken. But large samples were cut into two pieces, the larger piece was kept within a ratio of 1.94 to 2.1 while the smaller one between 1.94 to 1. The lengths and diameter of each core are provided in table 7.6. The ends of core specimens were made smooth, perpendicular to longitudinal axis and of the same diameter as the body of the specimen.

7.2 Curing of Specimen

The specimen were moisture cured for 48 hrs in the laboratory at 25 C prior to making compression test. The specimens were tested in moist condition soon after removal from the curing tank.

7.3 Capping of Specimen

The specimen were duly capped in conformance with AASHTO T 231, specification, i.e. capping cylindrical concrete specimens.

7.4 Measurement of Specimen

The diameter and length of each specimen were measured in accordance with the provisions of AASHTO T-148. Table 7.6 provides the diameter and length of each test specimen.

7.5 Density of Cores, Voids percentage & Honeycombing

Bulk specific gravity of each specimen was determined in accordance with the AASHTO T 85-88 method. Table 7.5 provides the density, voids percentage and honeycombing observed during laboratory analysis. As already mentioned that voids have a very detrimental effect on the strength of concrete. A void ratio of only five percent may reduce the concrete strength about 30 percent. Voids and honeycombing are produced in concrete because of :

(a) large amount of free-water in the mix

(b) poor standard of aggregate gradation

(c) poor compaction and segregation during placing

7.6 Compressive Strength Test

The main measure of the structural quality of concrete is its compressive strength. Tests for this property were made on cylindrical specimen of height equal to twice the diameter or atleast equal to diameter as prescribed by AASHTO T 24-86. Extreme care was taken to determine the compressive strength of specimen as a number of factors like size, shape, mixing etc. effect the final quality of concrete. Core specimen were sawed into two from locations which showed variation in concrete quality, and compressive strength of each specimen was determined alongwith voids ratio and honeycombing. Table 7.6 provides the compressive strength or cylinder strength f' of each core number. The cores were re-marked in laboratory. The results are rounded to the nearest 10 psi (689 kpa).

8. Laboratory Test Results, Analysis & Conclusions

The laboratory test results of concrete cores show a poor quality concrete. The unit weight (density) of concrete was far below specifications, except at one locations. Except at three locations out of nine, the compressive strength was below 3000 psi (21 N/mm^2). Signs of voids and honeycombing were visible on certain cores, particularly, at two core locations extensive honeycombing was observed.

It is concluded that various components of mix were not proportioned according to required specifications and therefore the resultant concrete did not had adequate strength. At later part, placing and compaction standards, both critical in their effect on the quality of the concrete were most probably not adequately observed, resulting in voids and honeycombing. It was also observed, that the course of water flow was not appropriately changed, which resulted in washing away of cement slurry at two core locations.

Density, Air Voids and honeycombing of concrete cores

Core Number	Density of Core		Air voids	Honeycombing
	Kg/m³	Pcf	Percent	
1.	2160*	135	8.2	EXTENSIVE
2(a)	2400	150	NIL	NO
2(b)	NIL	NIL	NIL	YES
3.	2274*	142	3.4	NO
4.	2240*	140	2.0	NO
5(a)	2240*	140	2.0	FEW SIGNS
5(b)	2288*	143	2.7	NO
6.	2338*	146	0.7	NO
7(a)	2224*	139	5.4	NO
7(b)	2320*	145	1.4	NO
8.	2192*	137	6.8	NO
9.	2340*	146	0.7	NO

Note :

- NIL : Test not carried out.
- Values are rounded to the nearest whole number.

* Less than given 2350 Kg/m³

Strength of Concrete Cores

Core Number	COMPRESSIVE STRENGTH		Length of Core	Diameter of Core	Type of Failure
-	N/mm^2	psi	Mm	mm	-
1.	NIL	NIL	100!	100!	NIL
2(a)	29.0	4200	109	99.4	FLEXURE-SHEAR
2(b)	NIL	NIL	NIL	NIL	NIL
3.	17.1	2480*	200	98.2	FLEXURE-SHEAR
4.	11.0	1600*	208	97.6	-DO-
5(a)	12.3	1780*	176	98.8	-DO-
5(b)	12.7	1840*	99	98.6	-DO-
6.	16.5	2390*	179	98.5	-DO-
7(a)	10.0	1450*	190	98.5	-DO-
7(b)	21.5	3120	110	98.6	-DO-
8.	12.0	1740*	180	98.5	SHEAR
9.	23.2	3360	190	98.5	FLEXURE-SHEAR

Note :

- NIL - Test not carried out.
- Compressive Strength values are rounded to the nearest 10 psi.

* Less than 3000 psi (21 N/mm^2)

! Approximate Values

Photo.5.1: A General view of the site on 01-10-1998 at 11:00 am. The site was unsuitable for Coring works as can be seen. Upto two feet mud covered the base slab of the box culvert.

Photo. 5.2: Another view of the site on 01-10-1998 showing clearing works in progress.

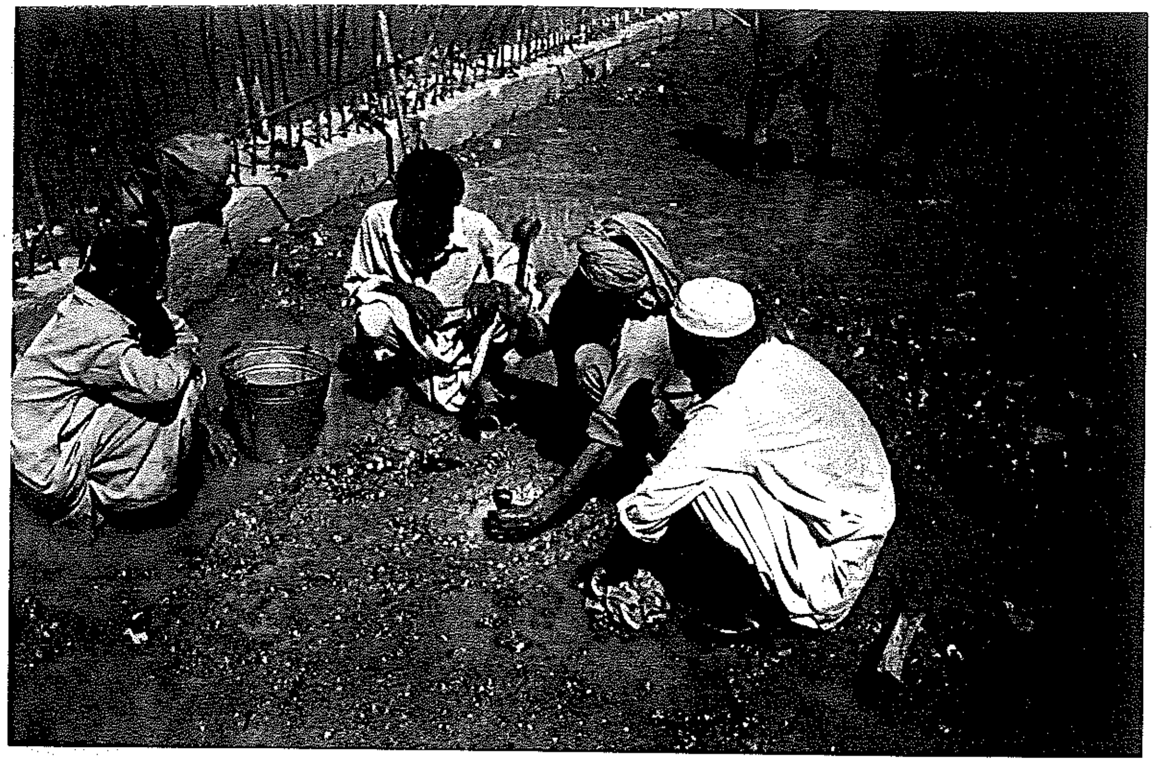


Photo. 5.3 Work in progress for exposing the reinforcement, and in the background debris being removed from the base slab.

Photo. 5.4: The photograph shows positioning of coring equipment.

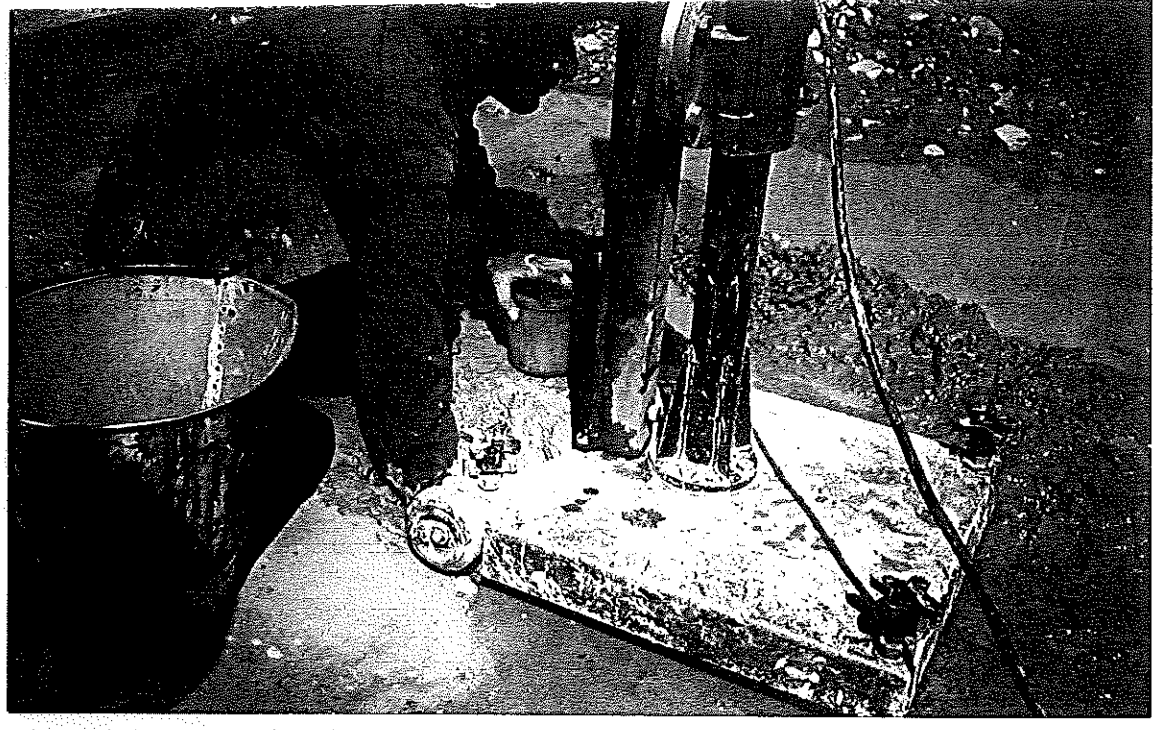


Photo.5.5: Clearing the hole from chiseled concrete.

Photo. 5.6: Coring works in progress. In the background inhospitable environment is quite visible.

Photo.5.7: Coring works in progress.

Photo.5.8: Coring works in progress. In the background in hospitable environment is quite visible.

Photo.6(a): First drilled core. Only a core of around 100 mm diameter and 100 mm in depth could be extracted. The water was continuously seeping-in through the core hole; easily distinguishable because of muddy water outside the hole while clear water inside the hole.

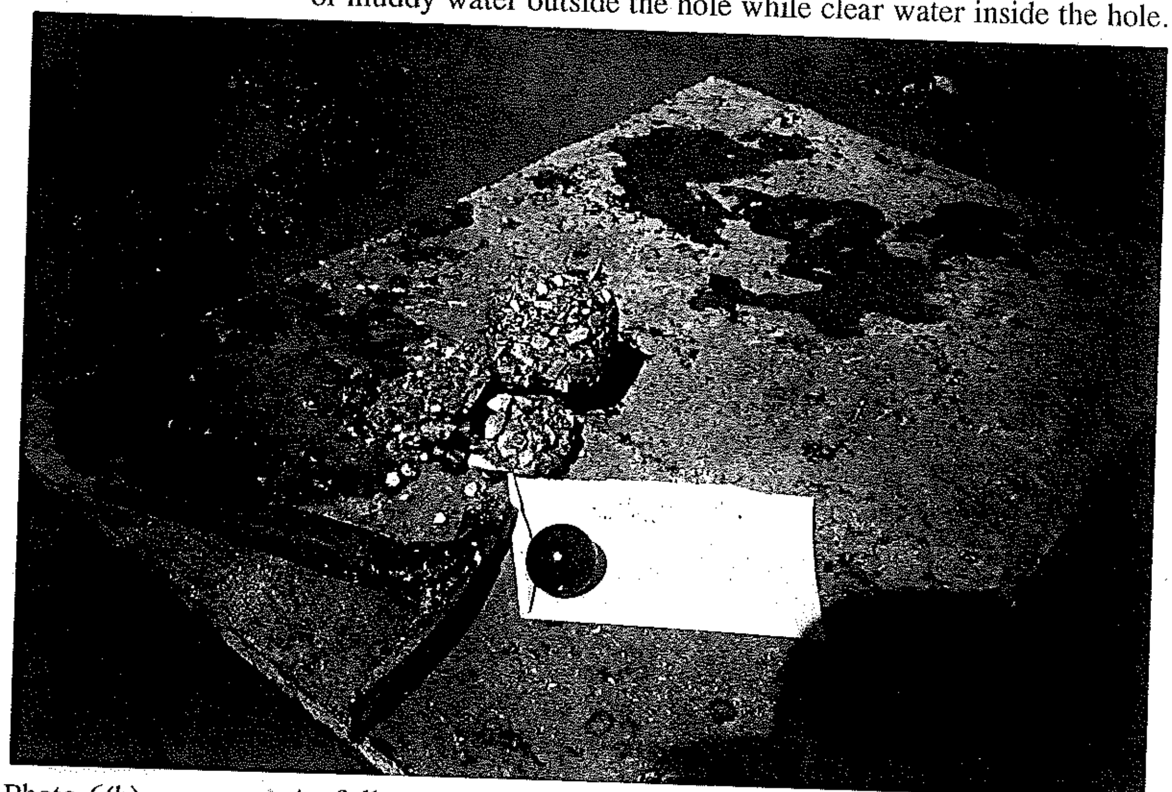


Photo.6(b): As full core could not be extracted and further coring resulted in disintegration of concrete, hence only slush material was removed.

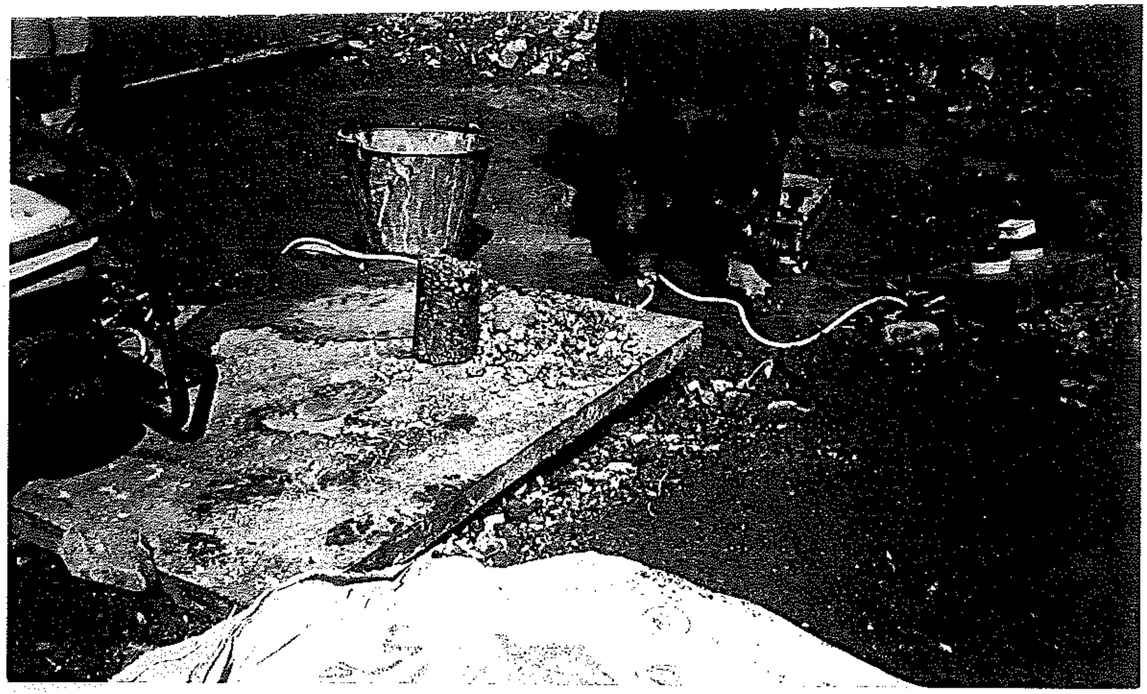


Photo.7 (a): Core 2 could only be drilled upto 150 mm below the clear cover level. Further coring works were abonded after disintegration of concrete core.

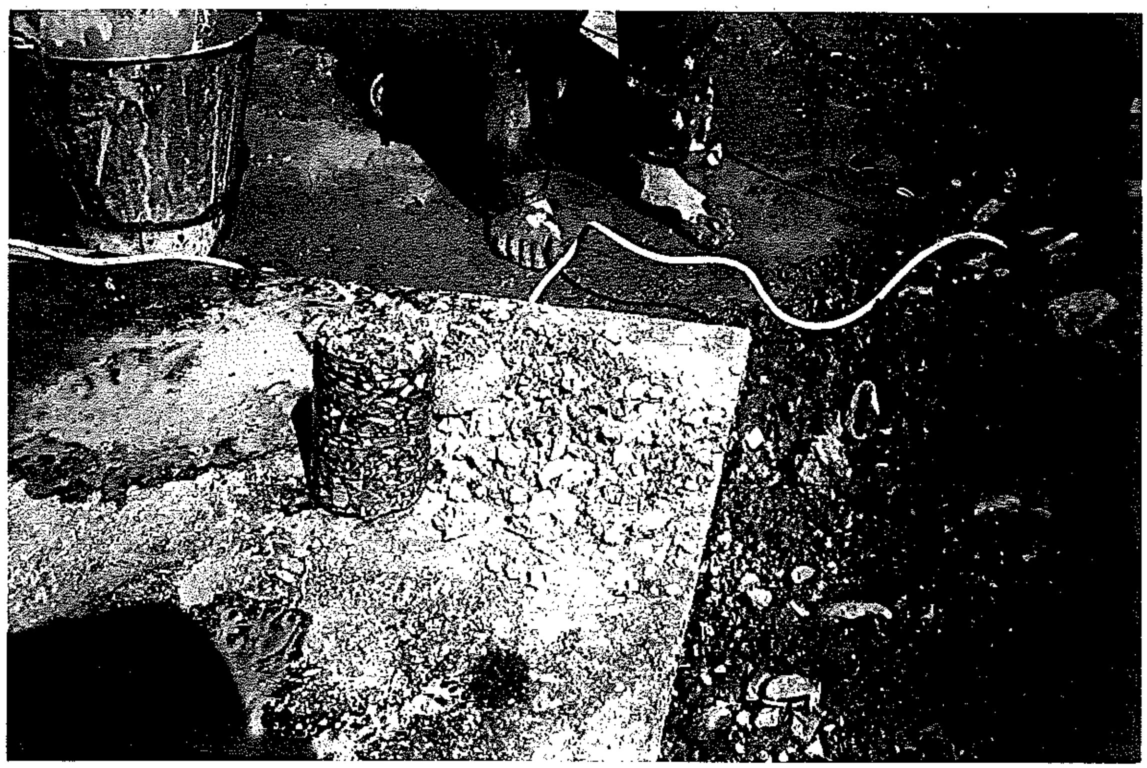


Photo.7 (b): Photograph showing a core of 100 mm diameter and 150 mm length alongwith the disintegrated concrete.

Photo.7 (c): Photograph showing a solid core-hole upto 150 mm length, while the bottom portion (below 150 mm) shows no `regular' hole. Water was seeping into the hole at an stable rate.

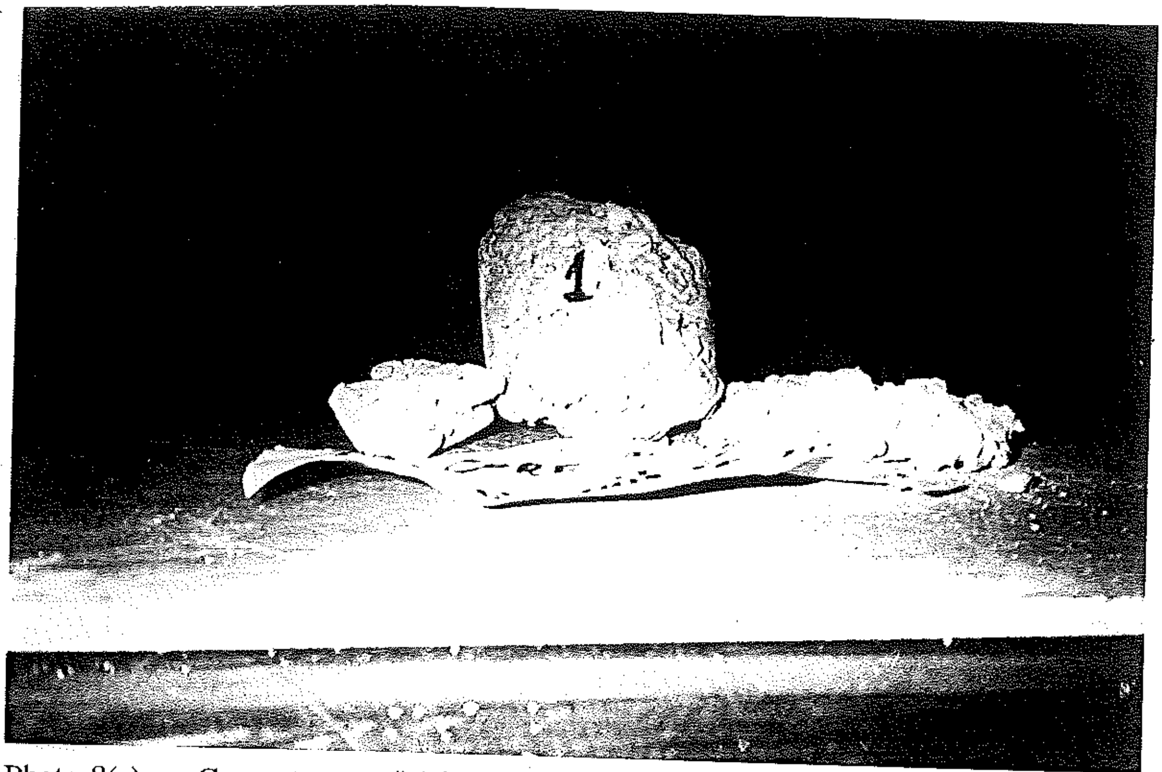


Photo.8(a): Concrete core # 1 in laboratory.

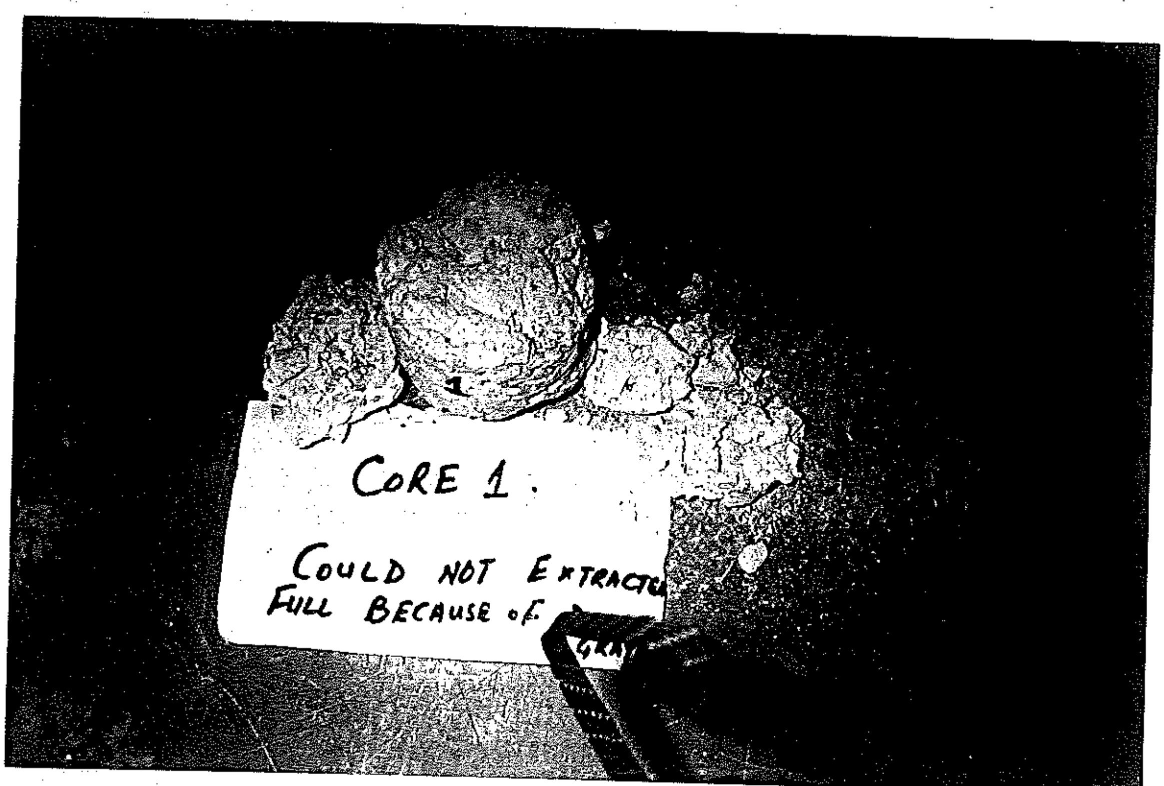


Photo.8(b): Concrete core # 1 kept in the laboratory for analysis.

Photo. 9: Photograph showing 1st row of cores, in order are (from right) core No.1, core No.3, core No.2.

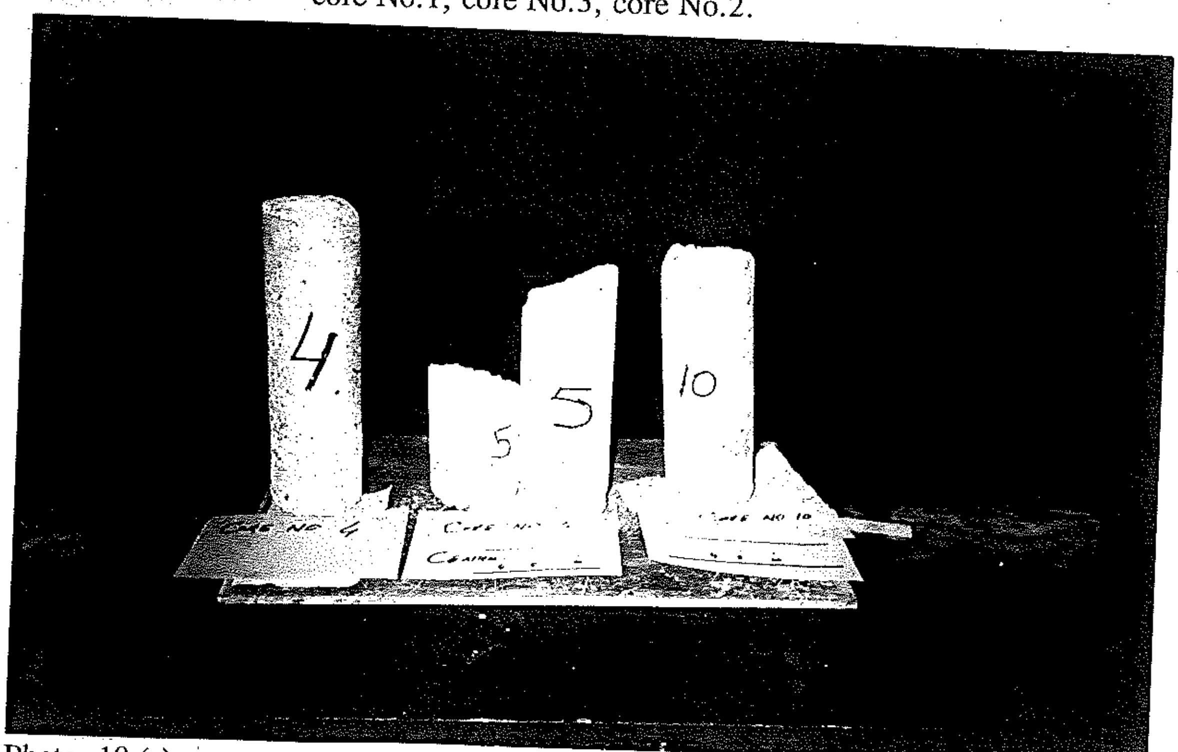
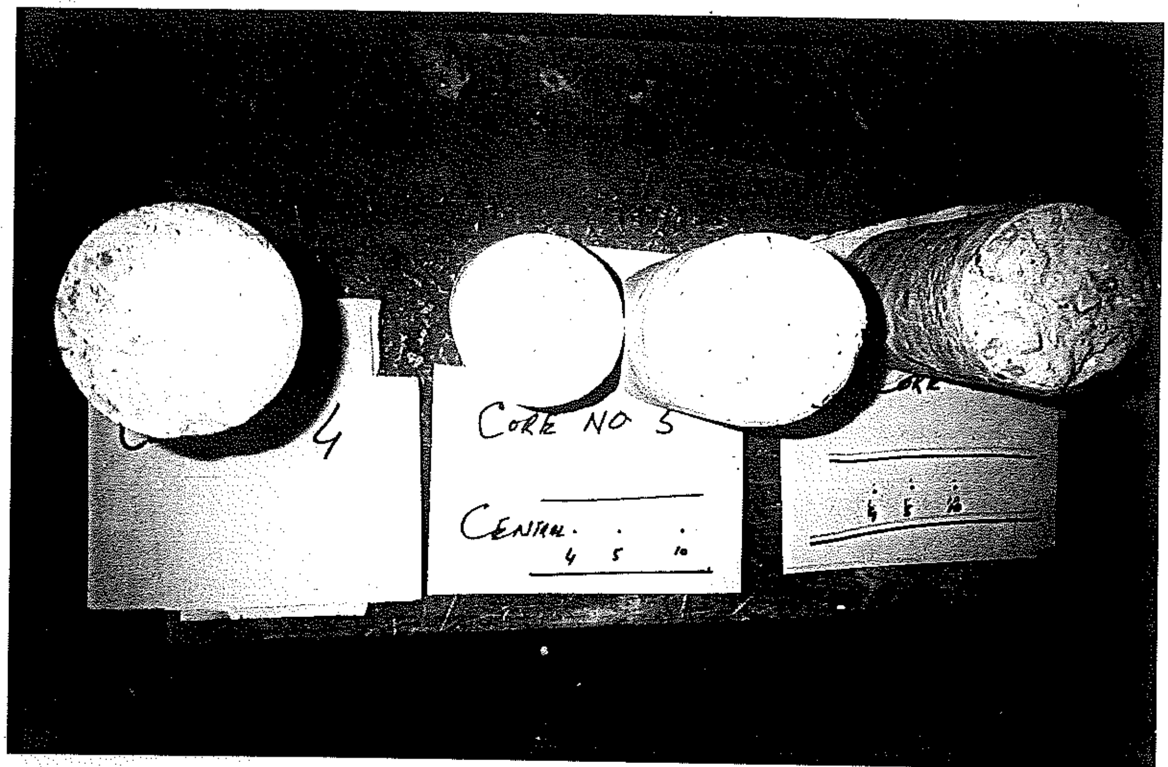
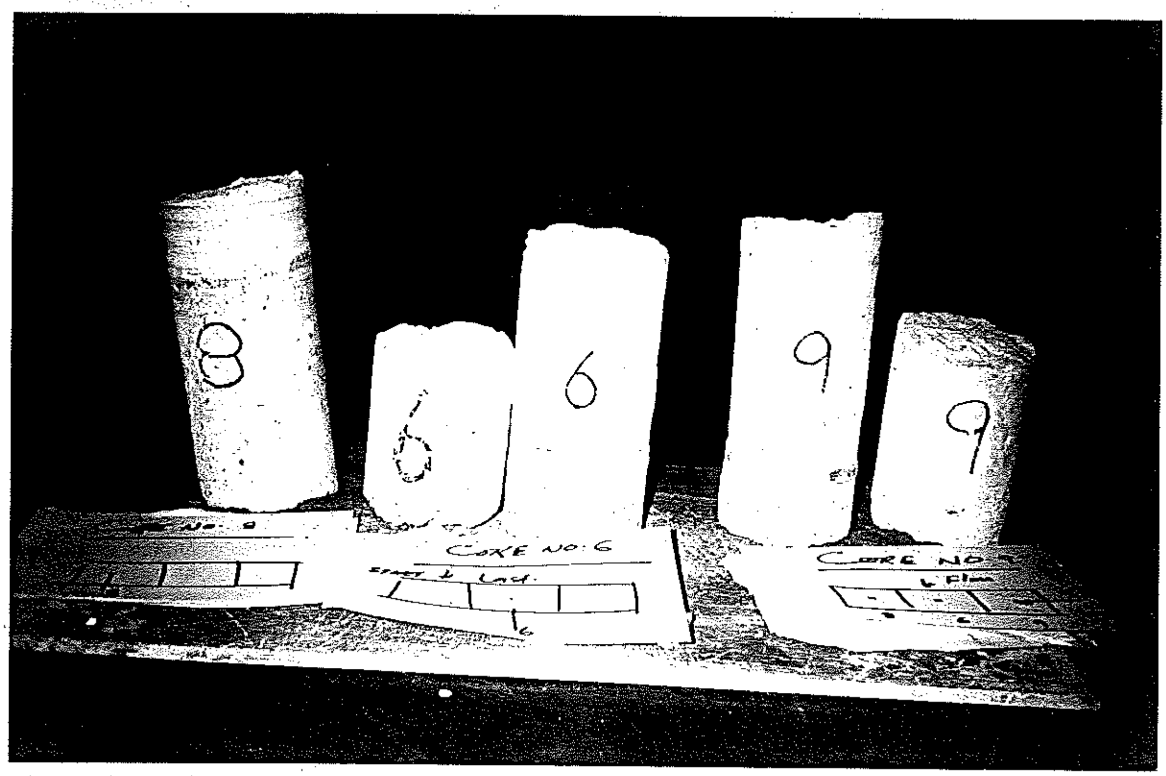


Photo. 10 (a): Photograph showing second row of cores. In order (from right) core No.4, ore No.5 and core No. 6.



<u>Photo. 10 (b):</u> Top view of core No.4, 5 & 6.



<u>Photo. 11(a):</u> Photograph showing second row of cores. In order (from right) core No.6, core No.8 and core No. 9.

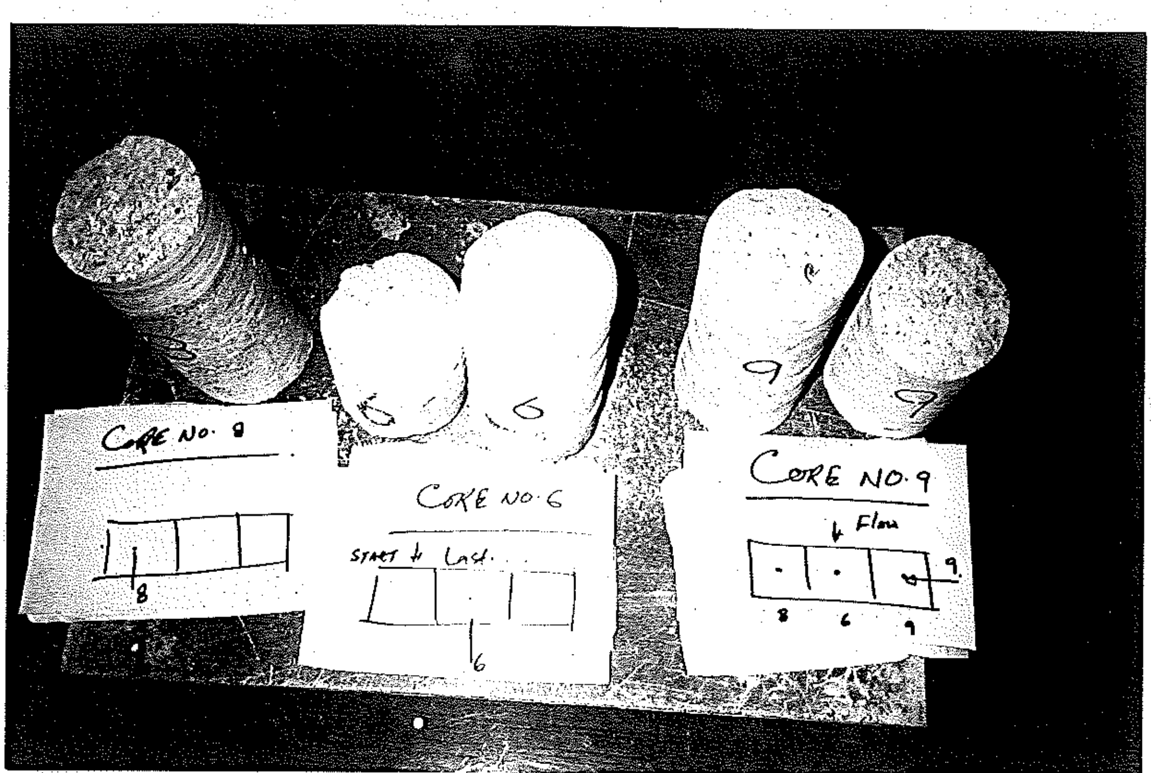


Photo. 11(b): Top view of core No.6, 8 & 9.

1. AASHTO Manual, 1990.
2. Design of Reinforced Concrete Structures by Winter Nilson.
3. Design of Reinforced Concrete Structures by Nadeem Hussain.
4. Specification for Road & Bridge Works, Department of Transport, London.