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A Study on Enhancement of Properties of Concrete by Vacuum Dewatering Method for Construction of Rigid Pavements and its Cost Evaluation

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Abstract- The road building agencies in India are promoting construction of concrete pavements in a big way due to its ability in handling complex stresses from vehicle loads and temperature. As per the Indian Road Congress guidelines for design of concrete pavements, M40 grade concrete is to be used for the concrete slab and accordingly, the approximate slab thickness shall be varying between 250mm to 320mm. Higher the concrete grade results in further reduction of pavement thickness, temperature stresses and depth of joints. Therefore, in this study, to increase the grade of the concrete, VacuumDewatered Concrete (VDC) technology is adopted in place of conventional method of pavement construction. The properties of concrete such as compressive strength, flexural strength and split tensile strength were found in both the methods and compared. The test results depicted that all the properties discussed above are higher in case of VDC method as compared to the conventional method of construction.

Key words: Design mix concrete, Conventional concrete, Vacuum Dewatered concrete, Rigid pavements, cost comparison.

1.0 Introduction:

To maintain the workability of concrete, it is necessary to add water content above the optimum which is required to attain the strength. The excess water evaporates and left the pores in the concrete which leads to reduction in strength of the concrete. Water above the optimum could be removed after placing the concrete that is the role of workability completes and this will help in attaining the higher strength. To remove the excess water, generally vacuum pressure is applied and therefore, this method is named as Vacuum Dewatered Concrete (VDC). It is an alternative method of pavement construction in which water is removed from the concrete through vacuum pressure after the laying**(Academy, 2011)**. With the help of VDC technique, it is possible to achieve the concrete with higher strength with less cementitious materials and hence, it is cost effectiveness. A pavement constructed with VDC technique is found be more abrasive resistance, less shrinkage, less permeability, high durability and can resist higher traffic loads**(Bolat and Çullu, 2016; Jacobs *et al.*, 2012; Ebensperger and Torrent, 2010)**.Using VDC technique, it is possible to reduce the water content approximately by 15-25% in the concrete **(Feng, Sun and Feng, 2018)**.

The present study is aimed to achieve the high-strength concrete pavement with less cementitious materials. Accordingly, two test sections were constructed with conventional and VDC technique methods. For the test sections, same proportions of materials and water-cement ratio were maintained. While constructing the conventional pavement, testing specimens were casted at the site to check the compressive strength, flexural strength and split tensile strength. In case of VDC technique, cores were extracted after construction to check its properties. These specimens were tested in the laboratory to find the 7 days and 28days strengths and compared the results with both the methods. The results show that the VDC technique has given the better strength and performance as compared to the conventional method of concrete. In addition, cost estimates were carried out to check which method is economical and presented here.

2.0 Materials and methods:

Conventional Portland cement of 53 grades is used. River sand locally available in the market is used. Crushed granite aggregate of 20 mm nominal size produced from local crushing plants are used. Water is the cheapest but the most important constituent of concrete. Generally water fit for drinking called "wholesome water" or potable water is used**(Saeed and Ezzulddin, 2014)**.

To study the parameters, one pavement was constructed by conventional method, and another one using vacuum dewatering method. From the conventional concrete cubes of 150x150x150mm were casted and tested for 7 and 28 days compressive strength. And another pavement casted by vacuum dewatering method is tested for 7 and 28 days compressive strength by taking core samples. The results are compared for both the pavements. And also the cost involvement in the construction for both types of pavements is worked out and comparative studies carried out with these results and conclusions have been made.

TABLE – 2.1			
PHYSICAL PROPERTIES OF CEMENT REFERENCE IS:12269-2013 (First Revision)			
Sl. No.	**Test Conducted**	**Results**	**Requirements as per IS: 12269-2013 (First Revision)**
1.	Brand of cement	ACC	-
2.	Type of Cement	53 Grade, OPC	-
3.	Consistency	28.0%	Not specified
4.	Initial setting time	145 Minutes	Min 30 minutes
5.	Final setting time	290 minutes	Max 600 minutes
6.	**Compressive strength:** (Average of three results)		
	3 days	29.5 MPa	Min 27.0 MPa
	7 days	39.0 MPa	Min 37.0 MPa
	28 days	58.5 MPa	Min 53.0 MPa
7.	Fineness (by Blaine's air permeability method)	301 m^2/kg	Min 225 m^2/kg
8.	Soundness (by Le-Chatelier's method)	0.5 mm	Max 10mm
9.	Density	3.10 g/cc	Not specified

REMARKS: Sample supplied was tested as per guidelines in IS 4031 (Part 3 to 6) 1988 (Reaffirmed 2009), IS 4031 (Part 2) -1999 (Reaffirmed 2008) and it conforms to the Indian Standard specification IS: 12269-2013 (First Revision) for 28-days strength.

TABLE – 2.2		
CHARACTERISTICS OF FINE AGGREGATE (NATURAL RIVER SAND – NRS)		
1.	a) Dry rodded bulk density	1676 Kg/cu.m
	b) Loose bulk density	1564 Kg/cu.m
2.	Specific gravity	2.58
3.	Water Absorption	1.0%
4.	**Sieve Analysis:**	

IS Sieve **Designation**	Cumulative Percentage		Specification as per IS: 383-1970 (Reaffirmed 2011) (Percentage Passing)		
	Retained	Passing	Zone I	Zone II	Zone III
4.75 mm	2.1	97.9	90-100	90-100	90-100
2.36 mm	10.9	89.1	60-95	75-100	85-100
1.18 mm	30.5	69.5	30-70	55-90	75-100
600 microns	62.0	38.0	15-34	35-59	60-79
300 microns	91.0	9.0	5-20	8-30	12-40
150 microns	98.9	1.1	0-10	0-10	0-10

REMARKS: The sample supplied satisfies the requirement of grading Zone II as per IS: 383-1970 (Reaffirmed 2011).

TABLE – 2.3

CHARACTERISTICS OF COARSE AGGREGATE OF 20 mm DOWN SIZE

1.	Shape	Angular
2.	a) Dry rodded bulk density	1566 Kg/cu.m
	b) Loose bulk density	1407 Kg/cu.m
3.	Specific gravity	2.63
4.	Water Absorption	0.2%
5.	**Sieve Analysis:**	

IS Sieve **Designation**	Cumulative Percentage		Specification as per IS: 383-1970 in respect of 20mm nominal size aggregate (% passing)	
	Retained	Passing	Graded	Single sized
40.00 mm	0	100	100	100
20.00 mm	8.0	92.0	95-100	85-100
12.5 mm	95.3	4.7	-	-
10.00 mm	98.9	1.1	25-55	0-20
04.75 mm	99.9	1.1	0-10	0-5

REMARKS: Sample conforms to the requirement of single size aggregate as per IS: 383-1970 (Reaffirmed 2011).

TABLE – 2.4

CHARACTERISTICS OF COARSE AGGREGATE OF 10 mm DOWN SIZE

1.	Shape	Angular
2.	a) Dry rodded bulk density	1539 Kg/cu.m
	b) Loose bulk density	1406 Kg/cu.m
3.	Specific gravity	2.62
4.	Water Absorption	0.4%
5.	**Sieve Analysis:**	

IS Sieve **Designation**	Cumulative Percentage		Specification as per IS: 383-1970 in respect of 10mm nominal size aggregate (% passing)
	Retained	Passing	
12.50 mm	0	100	100
10.00 mm	2.7	97.3	85-100
4.75 mm	94.2	5.8	0-20
2.36 mm	98.9	1.1	0-5

REMARKS: Sample conforms to the requirement of 10 mm aggregate as per IS: 383-1970 (Reaffirmed 2011).

TABLE – 2.5

COMBINED SIEVE ANALYSIS OF 20 mm AND 10 mm COARSE AGGREGATE

Cumulative sieve size (mm)	**Cumulative % passing 20 mm**	**Cumulative % passing 10 mm**	**Cumulative % passing when 20 mm and 10 mm are mixed in 60:40 ratio**	**Requirement of Cumulative % passing for 20 mm graded aggregate as per IS: 383-1970 (RA 2011)**
40.0	100	100	100	100
20.0	92.0	100	95.2	95 - 100
12.5	4.7	100	42.8	-
10.0	1.1	97.3	39.6	25 - 55
4.75	0.1	5.8	2.4	0 - 10

3.0 Results and Discussion

3.1 Compressive strength

From Fig 3.1 it can be observed that as design mix concrete, conventional concrete and vacuum de-watered concrete are cured and hardened, vacuum de-watered concrete has attained a considerably high amount of compressive strength with progress of time. Also it can be seen that vacuum de-watered concrete attained stability quicker. The mix proportions of design mix concrete, conventional concrete and Vacuum dewatered concrete for investigating compressive strength are presented in Table 3.1., Table 3.2 and Table.3.3 respectively.

TABLE – 3.1

DESIGN MIX (BY WEIGHT) FOR CONCRETE

Cement used	Mix Designation	Aggregate Max. Size (mm)	Cement content (Kg/cu.m)	Free water cement ratio (max)	Mix Proportions C:FA:CA*	Dosage of admixture per bag of cement (g)#	Slump obtained (mm)	Compressive strength (N/sq.mm)	
								7 days	28 days
ACC, 53 grade, OPC	M 40	20	380	0.42	1: 1.85 : 3.08	250	35	38.5	53.1

* Cement: Fine Aggregate : Coarse Aggregate

\# Admixture used is SAVEMIX SP 111 R of M/s. MYK Schomburg India Pvt. Ltd.

REMARKS:- (1) Coarse aggregate shall satisfy the grading requirements as per IS: 383-1970 (Reaffirmed 2011).

(2) Correction for water absorption of sand and coarse aggregate to be applied.

(3) Coarse aggregate of 20 mm & 10 mm shall be used in the ratio of **60:40** respectively

(4) Performance of admixture shall be checked and verified periodically.

TABLE – 3.2									
FOR CONVENTIONAL CONCRETE									
Cement used	Mix Designation	Aggregate Max. Size (mm)	Cement content (Kg/cu.m)	Free water cement ratio (max)	Mix Proportions C:FA:CA*	Dosage of admixture per bag of cement (g)#	Slump obtained (mm)	Compressive strength (N/sq.mm)	
								7 days	28 days
ACC, 53 grade, OPC	M 40	20	380	0.42	1: 1.85 : 3.08	250	35	28.20	43.80

TABLE – 3.3									
FOR VACUUM DE-WATERING FLOORING CONCRETE									
Cement used	Mix Designation	Aggregate Max. Size (mm)	Cement content (Kg/cu.m)	Free water cement ratio (max)	Mix Proportions C:FA:CA*	Dosage of admixture per bag of cement (g)#	Slump obtained (mm)	Compressive strength (N/sq.mm)	
								7 days	28 days
ACC, 53 grade, OPC	M 40	20	380	0.42	1: 1.85 : 3.08	250	35	41.47	54.00

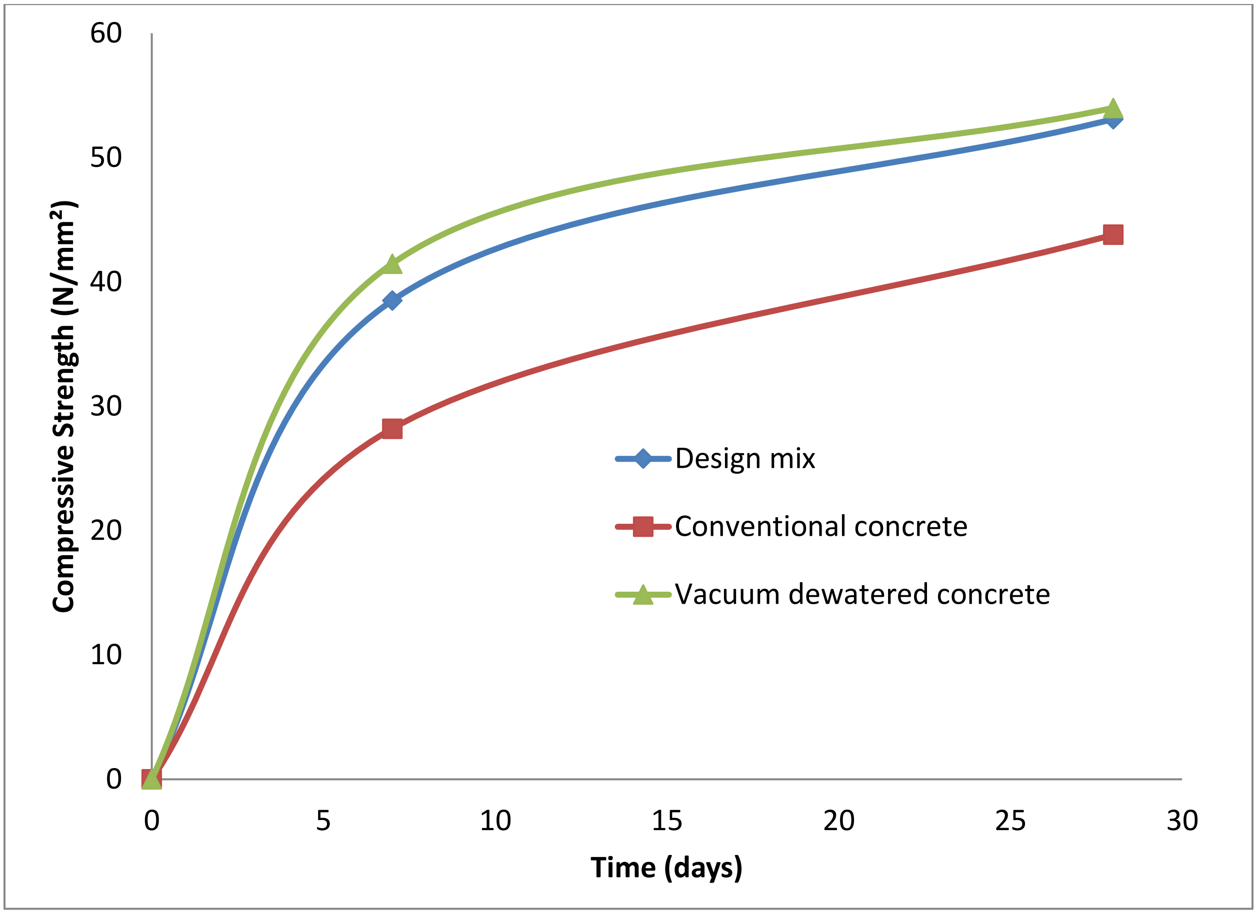


Fig 3.1: Comparison of compressive strengths of Design mix, conventional concrete and vacuum de-watered concrete with progress of time

3.2 Flexural strength

From Fig 3.2 it can be observed that as design mix concrete,conventional concrete and vacuum de-watered concrete are cured and hardened, vacuum de-watered concrete has attained a considerably high amount of compressive strength with progress of time. Also it can be seen that vacuum de-watered concrete attained stability quicker. The mix proportions of design mix concrete, conventional concrete and Vacuum dewatered concrete for investigating flexural strength are presented in Table 3.4., Table 3.5 and Table.3.6 respectively.

TABLE – 3.4									
DESIGN MIX (BY WEIGHT) FOR CONCRETE									
Cement used	Mix Designation	Aggregate Max. Size (mm)	Cement content (Kg/cu.m)	Free water cement ratio (max)	Mix Proportions C:FA:CA*	Dosage of admixture per bag of cement (g)#	Slump obtained (mm)	Flexural strength (N/sq.mm)	
								7 days	28 days
ACC, 53 grade, OPC	M 40	20	380	0.42	1: 1.85 : 3.08	250	35	3.9	5.1

TABLE – 3.5									
FOR CONVENTIONAL CONCRETE									
Cement used	Mix Designation	Aggregate Max. Size (mm)	Cement content (Kg/cu.m)	Free water cement ratio (max)	Mix Proportions C:FA:CA*	Dosage of admixture per bag of cement (g)#	Slump obtained (mm)	Flexural strength (N/sq.mm)	
								7 days	28 days
ACC, 53 grade, OPC	M 40	20	380	0.42	1: 1.85 : 3.08	250	35	3.9	4.80

TABLE – 3.6									
FOR VACUUM DE-WATERING FLOORING CONCRETE									
Cement used	Mix Designation	Aggregate Max. Size (mm)	Cement content (Kg/cu.m)	Free water cement ratio (max)	Mix Proportions C:FA:CA*	Dosage of admixture per bag of cement (g)#	Slump obtained (mm)	Flexural strength (N/sq.mm)	
								7 days	28 days
ACC, 53 grade, OPC	M 40	20	380	0.42	1: 1.85 : 3.08	250	35	4.1	5.30

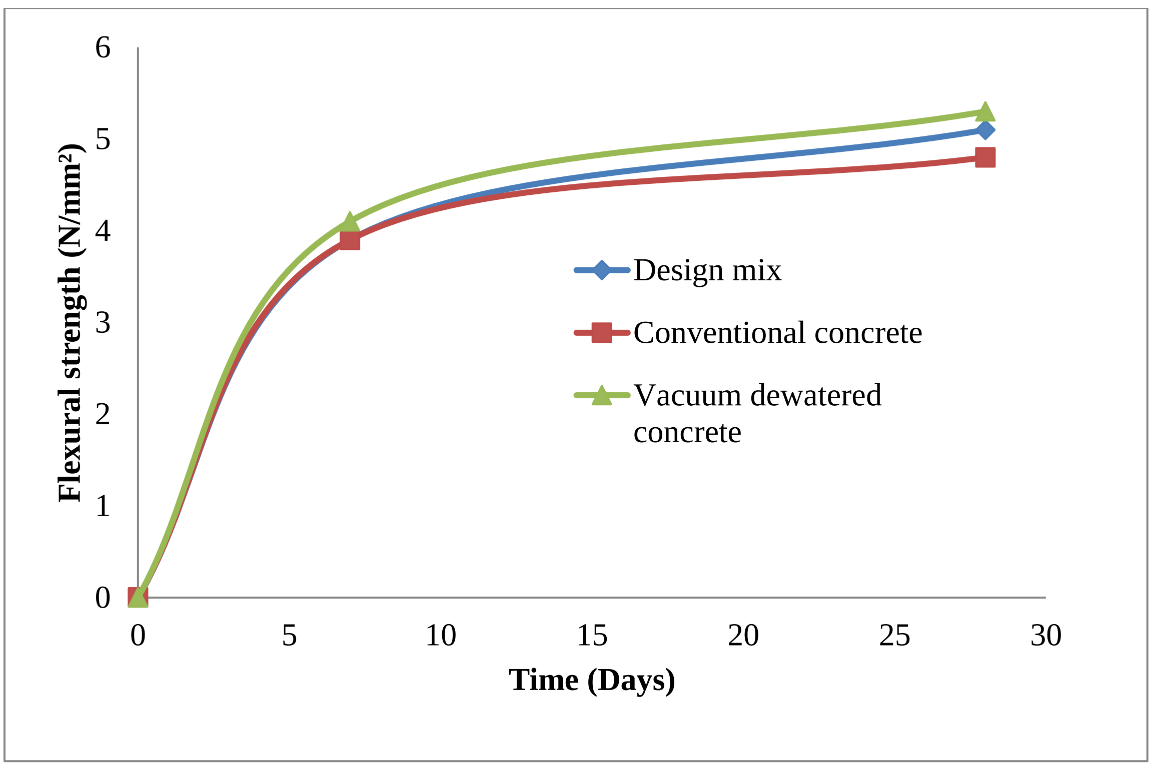


Fig 3.2: Comparison of Flexural strengths of Design mix, conventional concrete and vacuum de-watered concrete with progress of time

3.3 Split Tensile strength

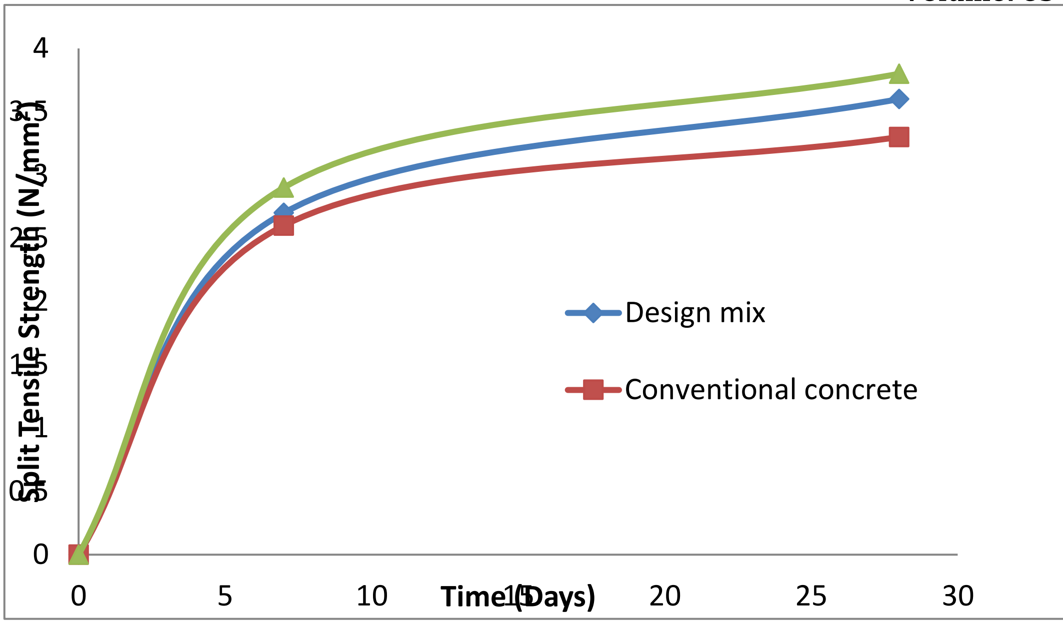
From Fig 3.3, it can be observed that as design mix concrete,conventional concrete and vacuum de-watered concretes, vacuum de-watered concrete has attained a considerably high amount of compressive strength with progress of time. Also it can be seen that vacuum de-watered concrete attained stability quicker. The mix proportions of design mix concrete, conventional concrete and Vacuum dewatered concrete for investigating Split Tensile strength are presented in Table 3.7., Table 3.8 and Table.3.9 respectively.

TABLE – 3.7

DESIGN MIX (BY WEIGHT) FOR CONCRETE

Cement used	Mix Designation	Aggregate Max. Size (mm)	Cement content (Kg/cu.m)	Free water cement ratio (max)	Mix Proportions C:FA:CA*	Dosage of admixture per bag of cement (g)#	Slump obtained (mm)	Split Tensile strength (N/sq.mm)	
								7 days	28 days
ACC, 53 grade, OPC	M 40	20	380	0.42	1: 1.85 : 3.08	250	35	2.7	3.6

TABLE – 3.8									
FOR CONVENTIONAL CONCRETE									
Cement used	Mix Designation	Aggregate Max. Size (mm)	Cement content (Kg/cu.m)	Free water cement ratio (max)	Mix Proportions C:FA:CA*	Dosage of admixture per bag of cement (g)#	Slump obtained (mm)	Split Tensile strength (N/sq.mm)	
								7 days	28 days
ACC, 53 grade, OPC	M 40	20	380	0.42	1: 1.85 : 3.08	250	35	2.6	3.30



3.4 Cost estimation for Conventional Concrete

TABLE – 3.9									
FOR VACUUM DE-WATERING FLOORING CONCRETE									
Cement used	Mix Designation	Aggregate Max. Size (mm)	Cement content (Kg/cu.m)	Free water cement ratio (max)	Mix Proportions C:FA:CA*	Dosage of admixture per bag of cement (g)#	Slump obtained (mm)	Split Tensile strength (N/sq.mm)	
								7 days	28 days
ACC, 53 grade, OPC	M 40	20	380	0.42	1: 1.85 : 3.08	250	35	2.9	3.80

The following aspects were included in estimating the cost of conventional concrete:

Table. 3.10 shows the detailed cost analysis of Normal concrete for 1 m^3 of concrete work. From this table, it can be observed that the cost of vacuum de-watered concrete is a little bit higher compared with conventional concrete by a margin of just Rs. 271 or by a mere 3%. But the benefits accrued far surpass the marginal increase in cost. Therefore it can be said considering the compressive strength and cost analysis that vacuum de-watered concrete is invariable better.

Table.3.10: Cost estimate of conventional concrete

S.No	Description	Rate (Rs)	Unit	Quantity	Total (Rs)
1	Details of cost for 1.00 cum				
2					
3	Stone Aggregate (Single size) : 20 mm nominal size	1562.75	cum	0.5	781.375
4	Stone Aggregate (Single size) : 10 mm nominal size	1562.75	cum	0.33	515.708
5	Carriage of Stone aggregate below 40 mm nominal size	141.632	cum	0.83	117.554
6	Coarse sand (zone III)	1596	cum	0.45	718.2
7	Carriage of Coarse sand	141.632	cum	0.45	63.7343
8	Portland Cement	8379	tonne	0.38	3184.02
9	Carriage of Cement	125.885	tonne	0.38	47.8361
10	Plasticizer / super plasticizer	50.54	kilogram	1.9	96.026
11	0.50% of cement	0	0	0	0

12	Production cost, pumping to respective floors and laying in position	0	0	0	0
13	Production cost of concrete by batch mix plant.	465.5	cum	1	465.5
14	Pumping charges of concrete including Hire charges of pump, piping work & accessories etc.	199.5	cum	1	199.5
15	LABOUR	0	0	0	0
16	Labour for pouring, consolidating & curing	0	0	0	0
17	Mason (average)	554.61	Day	0.17	94.2837
18	Beldar	437.57	Day	2	875.14
19	Bhisti	482.79	Day	0.9	434.511
20	Vibrator(Needle type 40mm)	465.5	Day	0.07	32.585
21	Sundries	2.3674	L.S.	13	30.7762
Total					7656.75
Add 1 % for water charges					76.5675
Total					7733.32
Add 15 % for contractor's profit and overheads					1160
Cost per 1.00 cum					8893.31
Say					8894

3.5 Cost estimate of vacuum Dewatered Concrete

The following aspects were included in estimating the cost of vacuum dewatered concrete:

Table.3.11: Cost estimate of vacuum de-watered concrete

S.No	Description	Rate (Rs)	Unit	Quantity	Total (Rs)
1	Details of cost for 1.00 cum				
2					
3	Stone Aggregate (Single size) : 20 mm nominal size	1562.75	cum	0.5	781.375
4	Stone Aggregate (Single size) : 10 mm nominal size	1562.75	cum	0.33	515.708
5	Carriage of Stone aggregate below 40 mm nominal size	141.632	cum	0.83	117.554
6	Coarse sand (zone III)	1596	cum	0.45	718.2
7	Carriage of Coarse sand	141.632	cum	0.45	63.7343
8	Portland Cement	8379	tonne	0.38	3184.02
9	Carriage of Cement	125.885	tonne	0.38	47.8361
10	Plasticizer / super plasticizer	50.54	kilogram	1.9	96.026
11	0.50% of cement	0	0	0	0
12	Production cost, pumping to respective floors and laying in position				
	Production cost of concrete by batch mix plant.	465.5	cum	1	465.5

13	Pumping charges of concrete including Hire charges of pump, piping work & accessories etc.	199.5	cum	1	199.5
14	LABOUR				
15	Mason (average)	554.61	Day	0.17	94.2837
16	Beldar	437.57	Day	2	875.14
17	Bhisti	482.79	Day	0.9	434.511
18	Vibrator(Needle type 40mm)	465.5	Day	0.07	32.585
19	Sundries	2.3674	L.S.	13	30.7762
20	Operational charges for vacuum dewatering system including screed vibration, placing of filter mat, top mat, vacuum process, floating, troweling, brooming etc.	2.3674	L.S.	57.2	135.415
21	T & P charges including consumable power charges, loading , unloading and hire charges of equipments	2.3674	L.S.	41.6	98.4838
Total					7890.64
Add 1 % for water charges					78.9065
Total					7969.56
Add 15 % for contractor's profit and overheads					1195.43
Cost per 1.00 cum					9164.99
Say					9165

Table. 3.10 shows the cost estimate of conventional concrete and Table. 3.11show the cost estimate of vacuum dewatered concrete. It can be observed from these tables, that with just an additional cost of Rs.271/- per Cu.m, exorbitant benefits such as increase in compressive strength, lower consumption of cement etc can be achieved.

4.0 Concluding remarks:

It can be arrived that there is a considerable enhancement in compressive strength, flexural and split tensile strength and on usage of vacuum de-watered concrete. With a marginal increase in cost of construction, good benefits such as overall increase in all the three strength parameters, reduction in cement consumption, early utilization of pavement, reduction in maintenance cost etc, are possible by using this technology.

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