RELEVANCE OF QUARRY SAND AND NATURAL SAND RATIO IN ACHIEVING DIFFERENT STRENGTHS

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Abstract

In recent time quarry sand is being extensively used in concrete due to environmental concerns leading to restrictions on use of natural sand. The extensive research publications broadly indicate suitability as well as limitations of quarry sand use in concrete. Most of the literature relates the performance of quarry sand concrete in various combinations adopted by researchers. The need is felt by authors to identify some factors directly related to strength parameters. The authors tried ninety different combinations covering M25, M30 & M40 grade of concrete containing various amounts of cement, quarry sand, natural sand and fly ash. Authors observed that quarry sand to natural sand ratio is an important factor governing development of compressive strength, split tensile strength and flexural strength of concrete mixes consisting of quarry sand and natural sand. It has been observed that strength parameters go on increasing with quarry sand to natural sand ratio up to 0.9, there after strength goes on decreasing. The critical analysis of data compiled was used to develop mathematical models for estimating compressive strength split tensile strength and flexural strength at various ages. The models were tested for own result and result from references. It is observed that the mathematical models are realistic and justify the relevance of quarry sand to natural sand ratio in development of strength.

Key Words : Quarry Sand, Quarry Sand to Natural Sand Ratio, Mathematical Models

1. Introduction

Natural river sand is expensive due to excessive cost of transportation from natural sources. Also large scale depletion of these resources creates environmental concerns. The river sand possesses the problem of acute shortage in many areas; in such situations quarry sand can be an economic alternative to river sand. The concern about the depletion of natural sources and the effect on environment has particularly focused attention on possibility of use of synthetically produced (from waste materials) aggregates as an alternative to naturally occurring materials. It has become difficult to get river sand of consistent quality in terms of grading requirement and limited silt and clay content. It is because we do not have control over the natural process. Quarry sand (manufactured sand), is the by product that get during process of stone crushing by using vertical shaft impactor (VSI) and makes the crushed stone sand particles good enough to be compared shape and surface texture of natural sand and with well-designed screening system.

The authors have critically studied concrete strengths by using quarry sand as one of the ingredients. The studies include:

- Performance of Quarry sand in concrete by partial replacement of Natural sand.
- Performance of Fly Ash in concrete in combination with Quarry sand.

To find the optimum percentage of quarry sand in concrete by partial replacement of natural sand. As per G. Balamurugan et al. [1] the variation in the strength of concrete when replacing sand by quarry dust from 0% to 100% in steps of 10%. From test results it was found that the maximum compressive strength is obtained only at 50%. The result shows that quarry dust can be utilized in concrete mixtures as a good substitute for natural river sand giving higher strength at 50% replacement. Priyanka A. Jadhav, et al. [2] in their studies investigated the effect of water cement ratio on fresh and hardened concrete with partial replacement of natural sand by manufactured sand was investigated concrete mix design of M20 grade was investigated as per Indian Standard code. Workability was measured in terms of slump and compaction factor. The concrete exhibits excellent strength with 60% replacement of natural sand.

Dr. A. D. Pofale et al. [3] studied about the use of crusher dust at 30%, 40%, 50% and 60% replacement levels, workability of concrete was reduced from 1-6% and compressive strength increased by 5-22%. Among all mixes highest compressive strength was obtained for 40% replacement of sand by crusher dust and hence it can be concluded that sand upto 30-60% can be replaced by crusher dust for economical work. Sreekantan P et al. [4] studied about the influence of presence of higher percentage of fine particles in quarry sand on the mechanical properties of high strength concrete

containing fly ash and it is studied that, the higher percentage of fine particles in quarry sand does not affect significantly the engineering properties of high strength concrete when river sand is replaced with 50% quarry sand along with a 25% replacement of cement with fly ash. Abhikhekh Kulkarni, Ajay shorkar [5] studied high grade concrete M50 containing quarry sand and natural sand. The replacement natural sand has been made at various percentage. And concluded that artificial sand hold good potential as a replacement to natural sand. Nimitha, Vijayaraghavan et.al [6] in their study replaced river sand by manufactured sand. They have observed that with increasing proportion of manufactured sand up to 50% compressive strength of concrete increase by 5.7% and the results show that concrete become harsh with increase in proportion of manufactured sand. . . Lakshmidhevi, A.V. Narasimha Rao [7] studied the effect of concrete when cement is replacement by fly ash 10%, 20%, 30% by weight of cement and sand by quarry dust at 20%, 30%, and 40% by weight of sand for M20 Mix and studied fresh and hardened properties of concrete with partial replacement of natural sand by manufactured sand. Concrete cube, beam and cylindrical specimens were tested for evaluation of compressive, flexural and split tensile strength respectively.

R. S. Deotale et.al. [8] studied the behavior of concrete containing fly ash and quarry sand. The research is carried out in three phases, the first phase sand is replaced by quarry sand with incremental of 25% upto 100% for M25, M30, M35 concrete and determined optimum percentage of replacement at which compressive strength is achieved. They have observed that when natural sand replaced with 50% quarry sand maximum strength is achieved. In the second phase cement is partially replaced with fly ash by 30% and 50%, natural sand is replaced by quarry sand, it has been observed that compressive strength is not much affected as compared to controlled concrete. In third phase fly ash is added at 10%, 20%, 30% it has been observed that compressive strength slightly increase due extra addition of fly ash.

Gradation of aggregates, physical and chemical properties of fly ash play a major role in achieving desired compressive strength, this have also great relevance in water requirements and achieving workability. Thus it is imperative to understand the performance of concrete containing various percentages of these ingredients. This paper summarises the results obtained and relevance of combinations of various concrete ingredients in achieving concrete performance.

R. S. Deotale et.al. [9] studied the Durability of concrete containing fly ash and quarry sand. It is observed

that 100% replacement of natural sand with quarry sand is not justifiable from durability point of view especially in relevance to permeable voids formation, rapid chloride permeability and acid attack. The use of fly ash significantly enhances durability property of concrete. R.

S. Deotale et.al. [10] Studied the effect of replacement of sand by Quarry sand and cement by fly ash with using admixture in concrete, especially in reference to permeable voids development, compressive strength, leaching of $\text{Ca}(\text{OH})_2$ in curing water and Rapid chloride permeability test. It is observed that if quarry sand is used in concrete then suitable percentage natural sand and fly ash must be added to achieve desired compressive strength and performance of concrete. R. S. Deotale et.al. [11] studied the effect of replacement of sand by Quarry sand and cement by fly ash. It is observed that 55% natural sand and 45% quarry sand gives perfect and proper gradation and higher compressive strength and this may be due to higher quantity of CaO present in quarry sand. The fly ash also has significant contribution in increasing compressive strength and workability of concrete. The results of research study open a new dimension in increasing quarry sand use in concrete construction.

The authors developed mathematical models based upon the results obtained and tested them on the data available from references. It is observed that the Quarry Sand/Natural Sand ratio plays a significant role in achieving compressive strengths at various ages, split tensile strengths and flexural strengths of concrete. The mathematical models are indicative of the relevance of Quarry Sand/Natural sand ratio, testing of the models on own results and results from references signifies this. Rajendra P. Mogre and Dhananjay [12] K Parbat, studied about optimum replacement of natural sand with artificial sand in concrete. For the purpose of experimentation concrete mixes are design for M20, M25, M30, M35 and M40 grades by 0 to 100% replacement with increment of 20% and in critical zone the increment is of 5% for Compressive, tensile and flexural strength.

2. Materials Used

Cement: In this study ordinary Portland cement of 43 grade is used conforming to IS 8112-1989 which have specific gravity 3.15 and Normal consistency 32% initial setting time-55 min and final setting 305min

Natural Aggregate: Locally available crushed stone conforming to graded aggregate of nominal size 20 mm and 10 mm was used in this experimental work. Its specific gravity was 2.85

Sand: Locally available river sand of grading zone II conforming IS 383 and having fineness modulus 2.73, specific gravity 2.54 and Water absorption 1%.

Quarry Sand: Quarry sand was obtained from Siddheshwar quarry, Pachgaon Plant, Nagpur, having specific gravity 3.0, Water absorption 2.5% and fineness modulus 2.57. It has rough surface area. In this study, Quarry sand conforming to grading zone-II conforming IS 383 is used as fine aggregate

Fly Ash: Fly ash used was obtained from Koradi Power Plant Nagpur. The specific gravity of fly ash was 2.2.

Water: Potable water was used for making concrete as well as for curing the specimen.

Chemical Admixture: A commercial AC-BV-430 super plasticizer was used to maintain the workability of fresh concrete. The dosage of plasticizer was kept constant in mass basis. It was 1%-2% of cement weight.

3. Experimental Program

The mix proportioning is designed as per the Indian standard recommended method IS 10262-2009. This research is carried out in seven cases, in each different case mix M25, M30, M45 grade concrete with replacement of 15%, 30%, 45%, 60% and 100% of natural sand with quarry sand is carried out to determine the optimum percentage of replacement. And cement is partially replaced by 30% fly ash and also the effect of extra fly ash is studied by adding it at 10%, 20%, of cement. The effect of water reducer, plasticizer is considered. Water absorption of quarry sand is of much concern, more amount of quarry sand is expected to require more water for workability, and this may also affect compressive strength development.

Testing was carried out as per provisions of relevant IS code. The compressive strength of cubes were measured after 7, 28, 56, 90 days curing as per IS: 516 – 1959, the flexural strength of beam were measured at 28 days as per IS: 516-1959 and the split tensile strength of cylinder were measured at 28 days as per IS: 5816 – 1999.

4. Development of mathematical models

Mathematical Models Developed in predicting various strengths of combinations containing quarry sand with respect to mix containing only natural sand. Mathematical models are developed for predicting compressive strengths at 7, 28, 56 and 90 days of age, Split Tensile Strength at 28 days of age and Flexural Strength at 28 days of age. Following procedure is adopted while developing the mathematical models:

- Strength of controlled mix was considered as the base.
- Ratio of strengths of mixes containing quarry sand and strength of controlled concrete was found out
- Average of the Quarry sand / Natural sand Ratio and Average of the strengths ratio (strength index) were considered for development of mathematical models. The data is presented in table 1. Graphs are plotted based on the data in table 1 and presented in figure 1.
- Based upon the trends, the graphs were separated into two graphs, trendline equations for each graph was noted. Details are presented in figures 2 & 3.
- The trend line equations were used in development of mathematical models.

Mathematical Models Developed in predicting various strengths of combinations containing quarry sand with respect to mix containing only natural sand are presented here. Mathematical models for Quarry Sand/Natural sand ratio up to 1 and above are different.

Model 1 Prediction compressive strength at 7 days of age

- i) Up to quarry sand to natural sand ratio 1

Predicted compressive strength = $7 D \text{ CS (Controlled Mix)} \times (0.049 \times \text{Loge(Quarry Sand / Natural Sand)} + 1.121)$

- ii) For quarry sand to natural sand ratio above 1

Predicted compressive strength = $7 D \text{ CS} \times (0.047 \times (\text{Quarry Sand / Natural Sand}) + 1.163)$

Model 2 Prediction compressive strength at 28 days of age

- i) Up to quarry sand to natural sand ratio 1

Predicted compressive strength = $28 D \text{ CS (Controlled Mix)} \times (0.043 \times \text{Loge(Quarry Sand / Natural Sand)} + 1.103)$

- ii) For quarry sand to natural sand ratio above 1

Predicted compressive strength = $28 D \text{ CS} \times (0.033 \times (\text{Quarry Sand / Natural Sand}) + 1.130)$

Model 3 Prediction compressive strength at 56 days of age

- i) Up to quarry sand to natural sand ratio 1 ($R^2=0.998$)

Predicted compressive strength = $56 D \text{ CS (Controlled Mix)} \times (0.045 \times \text{Loge(Quarry Sand / Natural Sand)} + 1.112)$

- ii) For quarry sand to natural sand ratio above 1 ($R^2=1$)

Predicted compressive strength = $56 D \text{ CS} \times (0.049 \times (\text{Quarry Sand / Natural Sand}) + 1.156)$

Model 4 Prediction of compressive strength at 90 days of age

- i) Up to quarry sand to natural sand ratio 1 ($R^2=0.998$)

Predicted compressive strength = $90 D \text{ CS (Controlled Mix)} \times (0.035 \times \text{Loge(Quarry Sand / Natural Sand)} + 1.096)$

- ii) For quarry sand to natural sand ratio above 1 ($R^2=1$)

Predicted compressive strength = $90 D \text{ CS} \times (0.042 \times (\text{Quarry Sand / Natural Sand}) + 1.134)$

Model 5 Prediction of split tensile strength at 28 days of age

- i) Up to quarry sand to natural sand ratio 1

Predicted split tensile strength = $28 D \text{ STS (Controlled Mix)} \times (0.060 \times \text{Loge(Quarry Sand / Natural Sand)} + 1.686)$

- ii) For quarry sand to natural sand ratio above 1

Predicted split tensile strength = $28 \text{ D STS} \times (0 - 0.104) \times (\text{Quarry Sand} / \text{Natural Sand}) + 1.263$

Model 6 Prediction Flexural strength for 28 days

i) Up to quarry sand to natural sand ratio 1

Predicted flexural strength = $28 \text{ D FS (Controlled Mix)} \times (0.025 \times \text{Loge}(\text{Quarry Sand} / \text{Natural Sand}) + 1.081)$

ii) For quarry sand to natural sand ratio above 1

Predicted flexural strength = $28 \text{ D FS} \times (0 - 0.055) \times (\text{Quarry Sand} / \text{Natural Sand}) + 1.1035$

Sample table for testing of mathematical model for predicting compressive strength at 7 days of age on own research data is presented in table 2, similar tables are developed for other strengths. Sample table for testing of mathematical model for predicting compressive strength at 7 days of age on research data from references is presented in table 3, similar tables are developed for other strengths.

Table 1
(Quarry sand / Natural sand Ratio and Average of the strengths ratio)

QS/NS Ratio	Compressive Strengths				Split Tensile Strength	Flexural Strength
	7 Day	28 Day	56 Day	90 Day		
0.201	1.04	1.03	1.04	1.04	1.07	1.04
0.487	1.08	1.07	1.08	1.07	1.12	1.06
0.931	1.12	1.10	1.11	1.09	1.17	1.08
1.710	1.08	1.07	1.07	1.06	1.08	1.04

Table
Testing of mathematical model for predicting compressive strength at 7 days on own research data

Identification Symbol	Quantities(kg/m ³)					QS/NS	Compressive Strength		
	Cement	Quarry Sand	Natural Sand	Coarse Aggregate	Water		7 Day	Predicted	% Error
M25-A	458.15	0	641	1171.50	213.40	0.00	25.47		
M25 A1	458.14	106	458	1171.51	214.25	0.23	26.44	26.73	-1.08
M25-A2	458.14	211.7	430.15	1171.51	216.70	0.49	28.90	27.67	4.27
M25-A3	458.14	320.5	336.7	1171.51	218.52	0.95	29.00	28.49	1.76
M25-A4	458.14	427.27	245	1171.51	220.27	1.74	28.30	27.53	2.71
M30-A	492.5	0	601.97	1151.93	212.83	0.00	28.00		
M 30-A1	492.5	104	511.68	1151.93	214.57	0.20	30.19	29.20	3.27
M30-A2	492.5	210	421.38	1151.93	216.38	0.50	30.22	30.43	-0.70
M30-A3	492.5	314	331	1151.93	218.14	0.95	31.24	31.32	-0.24
M30-A4	492.5	419.25	240.8	1151.93	219.93	1.74	30.40	30.27	0.42
M25-B	311.11	0	734.7	1342.50	158.70	0.00	23.60		
M25-B1	311.11	121.3	595.3	1342.40	160.50	0.20	24.29	24.62	-1.34
M25-B2	311.11	202.1	491.12	1342.40	202.10	0.41	25.30	25.43	-0.51
M25-B3	311.11	367.2	385.8	1342.40	164.50	0.95	25.70	26.40	-2.72
M25-B4	311.11	398.9	293.9	1342.40	164.82	1.36	24.90	25.94	-4.18
M30-B	350	0	690	1321.00	158.10	0.00	27.25		
M30-B1	350	119.37	586.8	1321.00	160.10	0.20	29.77	28.42	4.53
M30-B2	350	241	483	1321.00	162.10	0.50	31.40	29.62	5.67
M30-B3	350	360	379	1321.00	164.20	0.95	31.50	30.48	3.24
M30-B4	350	481	276.1	1321.00	166.33	1.74	30.20	29.46	2.45
M25-C	335	0	690	1017.72	214.18	0.00	24.00		
M25-C1	335	120.26	585.5	1017.72	214.18	0.21	24.10	25.04	-3.91
M25-C2	335	238	482.5	1017.70	220.74	0.49	25.70	26.07	-1.45
M25-C3	335	361	379	1017.70	220.00	0.95	26.20	26.85	-2.47
M25-C4	335	481	275.7	1017.70	222.40	1.74	25.50	25.94	-1.74
M30-C	379.2	0	664.1	977.40	212.00	0.00	24.22		
M35- C1	379.2	115.8	564.1	977.40	214.00	0.21	25.88	25.27	2.35
M30- C2	379.2	230.8	465	977.40	215.80	0.50	26.30	26.32	-0.07
M30-C3	379.2	346.15	365	977.40	217.90	0.95	27.39	27.09	1.10

M30- C4	279.25	462.13	265.36	977.40	219.80	1.74	25.50	26.19	-2.69
M25-D	240	0	790.5	1177.50	157.80	0.00	22.00		
M25-D1	240	134.5	671.82	1177.50	160.12	0.20	23.60	22.93	2.85
M25-D2	240	269	553.3	1177.55	162.88	0.49	24.30	23.88	1.71
M25-D3	240	403.5	434.5	1177.50	164.60	0.93	25.30	24.58	2.84
M25-D4	240	538.1	316.1	1177.50	167.00	1.70	24.40	23.83	2.35
M30-D	270	0	778.14	1145.30	157.56	0.00	23.77		
M30-D1	270	138.85	661.6	1145.30	159.80	0.21	24.50	24.83	-1.34
M30-D2	270	269.8	544.77	1145.30	162.11	0.50	24.60	25.83	-4.99
M30-D3	270	405.7	427.68	1145.30	164.42	0.95	25.70	26.58	-3.44
M30-D4	270	541	311	1145.30	166.72	1.74	24.70	25.70	-4.05
M25-E	311.11	0	733.2	1343.20	158.67	0.00	25.10		
M25-E1	311.11	119.8	588.28	1343.20	160.34	0.20	26.60	26.18	1.58
M25-E2	311.11	239.4	485.2	1343.20	162.40	0.49	28.00	27.27	2.61
M25-E3	311.11	361.74	374.8	1343.20	164.34	0.97	28.40	28.09	1.08
M25-E4	311.11	560.63	322.2	1343.20	168.98	1.74	27.80	27.14	2.38
M30-E	350	0	664.51	1316.20	157.85	0.00	26.20		
M30-E1	350	116	565	1316.00	159.80	0.21	27.20	27.34	-0.51
M30-E2	350	232	465.1	1316.00	161.77	0.50	28.70	28.48	0.78
M30-E3	350	346	365.5	1316.00	163.70	0.95	31.10	29.30	5.79
M30-E4	350	463.35	264.33	1316.00	165.70	1.75	30.40	28.31	6.87
M25-F	311.11	0	711.28	1299.70	158.15	0.00	25.55		
M25-F1	311.11	119.83	588.28	1299.70	161.25	0.20	26.70	26.65	0.19
M25-F2	311.11	275.44	552.7	1299.70	163.56	0.50	27.50	27.77	-0.98
M25-F3	311.11	413.17	434.2	1299.70	165.89	0.95	28.00	28.58	-2.07
M25-F4	311.11	550.9	315.74	1299.70	168.30	1.74	27.40	27.62	-0.80
M30-F	350	0	642.8	1295.50	157.46	0.00	26.33		
M30- F1	350	112.15	546.3	1295.50	159.35	0.21	27.56	27.47	0.32
M30-F2	350	224.3	450	1295.50	161.25	0.50	29.20	28.62	1.99
M30-F3	350	336.5	353.5	1295.50	163.10	0.95	31.60	29.45	6.80
M30-F4	350	447	256	1295.50	165.00	1.75	30.50	28.46	6.69
M40-A	562.85	0	586.7	1121.00	211.80	0.00	30.66		
M40-A1	562.85	96	498.7	1121.00	213.31	0.19	31.52	31.89	-1.19
M40-A2	562.85	193.755	410.7	1121.00	214.80	0.47	32.40	33.24	-2.60
M40-A3	562.85	290.64	322.694	1121.00	216.31	0.90	33.38	34.21	-2.49
M40-A4	562.85	387.5	234.687	1121.00	217.20	1.65	32.19	33.28	-3.38
M40-B	400		685.8	1310.00	157.33	0.00	29.40		
M40-B1	400	113.21	582.82	1310.00	159.00	0.19	31.22	30.60	2.00
M40-B2	400	226.43	479.97	1310.00	160.83	0.47	31.89	31.88	0.05
M40-B3	400	339.65	377.12	1310.00	162.59	0.90	32.50	32.81	-0.94
M40-B4	400	457.8	274	1310.00	210.81	1.67	31.10	31.88	-2.52
M40-C	433.39		546	1044.00	212.20	0.00	25.81		
M40-C1	433.39	90.23	464.51	1044.00	213.60	0.19	26.76	26.86	-0.38
M40-C2	433.39	180.47	382.5	1044.00	215.00	0.47	28.00	27.98	0.06
M40-C3	433.39	270.7	300.57	1044.00	215.60	0.90	28.87	28.80	0.24
M40-C4	433.39	361	219	1044.00	216.00	1.65	27.91	28.02	-0.38
M40-D	308	0	656.35	1254.00	156.59	0.00	25.48		
M40-D1	308	108	557.9	1254.00	158.80	0.19	25.13	26.51	-5.50
M40-D2	308	216.75	459.5	1254.00	159.94	0.47	26.44	27.62	-4.48
M40-D3	308	325.12	361	1254.00	161.61	0.90	28.00	28.43	-1.54
M40-D4	308	433.5	262.5	1254.00	162.76	1.65	27.50	27.66	-0.57
M40-E	562.85	0	544.42	1040.00	210.76	0.00	30.21		
M40-E1	562.82	89.89	462.76	1040.00	212.14	0.19	31.38	31.44	-0.19
M40-E2	562.82	179.78	381	1040.00	213.54	0.47	32.10	32.75	-2.04
M40-E3	562.85	269.7	299	1040.00	215.00	0.90	32.98	33.71	-2.22
M40 -E4	562.85	359.6	217	1040.00	215.60	1.66	30.01	32.78	-9.23
M40-F	562.85	0	501.75	958.00	209.70	0.00	31.35		
M40-F1	562.85	82	426.5	958.00	211.00	0.19	32.15	32.61	-1.43
M40-F2	562.85	165.7	351	958.00	212.24	0.47	32.85	33.99	-3.47
M40-F3	562.85	248.5	276	958.00	213.25	0.90	34.18	34.98	-2.35
M40-F4	562.85	331	201	958.00	231.53	1.65	33.80	34.03	-0.69

Table 3
Testing of mathematical model for predicting compressive strength at 7 days on data from references

S.N.	Concrete Ingredients			QC/NS	7 Days Comp. Strength in Mpa			28 Days Comp. Strength in Mpa			Reference Paper No.
	Cement %	Q.sand%	N.sand%		Actual	Predicted	% Error	Actual	Predicted	%Error	
1	100	0	100		21.13			31.84			3
2	100	30	70	0.43	21.65	22.81	-5.36	34.47	33.96	1.48	3
3	100	40	60	0.67	22.47	23.27	-3.55	38.96	34.56	11.28	3
4	100	50	50	1.00	21.32	23.69	11.10	37.74	35.12	6.94	3
5	100	60	40	1.50	21.64	24.11	-11.40	33.40	35.67	-6.81	3
6	100	0	100	0.00	27.86			39.84			3
7	100	30	70	0.43	27.92	30.07	-7.72	41.93	42.49	-1.34	3
8	100	40	60	0.67	28.19	30.68	-8.82	46.19	43.25	6.37	3
9	100	50	50	1.00	27.60	31.23	-13.16	44.81	43.94	1.93	3
10	100	60	40	1.50	27.89	30.44	-9.13	43.26	44.64	-3.19	3
11	100	0	100	0.00	19.25			22.22			1
12	90	10	90	0.11	19.67	19.51	0.83	22.67	23.5	-3.65	1
13	80	20	80	0.25	20.35	20.27	0.39	24.00	24.1	-0.38	1
14	70	30	70	0.43	20.89	20.78	0.53	25.33	24.5	3.33	1
15	60	40	60	0.67	21.33	21.20	0.62	25.77	24.8	3.72	1
16	50	50	50	1.00	22.67	21.58	4.81	27.56	25.1	8.89	1
17	100	0	100	0.00	23.21			31.03			1
18	90	10	90	0.11	23.54	23.52	0.09	31.19	31.98	-2.52	1
19	80	20	80	0.25	23.97	24.44	-1.97	31.52	32.81	-4.08	1
20	70	30	70	0.43	24.12	25.05	-3.88	31.75	33.36	-5.07	1
21	60	40	60	0.67	24.29	25.56	-5.22	32.54	33.81	-3.91	1
22	50	50	50	1.00	23.59	26.02	-10.29	32.92	34.23	-3.97	1
23	100	0	100	0.00	19.80			27.50			11
24	100	20	80	0.25	20.30	20.85	-2.71	28.09	29.44	-4.79	12
25	100	40	60	0.67	20.59	21.80	-5.89	28.82	30.60	-6.16	12
26	100	60	40	1.50	21.28	21.63	-1.65	30.03	29.71	1.05	12
27	100	65	35	1.86	21.74	21.30	2.03	30.38	29.39	3.26	12
28	100	70	30	2.33	21.56	20.86	3.27	30.25	28.96	4.27	12
29	100	75	25	3.00	20.81	20.24	2.76	29.90	28.35	5.18	12
30	100	80	20	4.00	20.21	19.31	4.48	28.70	27.45	4.37	12
31	100	100	0	1.00	19.70	22.20	-12.67	27.41	30.17	-10.06	12
32	100	0	100	0.00	23.30			33.30			12
33	100	20	80	0.25	24.44	24.54	-0.40	35.13	34.74	1.10	12
34	100	40	60	0.67	24.97	25.66	-2.75	35.93	37.05	-3.11	12
35	100	60	40	1.50	25.11	25.46	-1.37	36.36	35.98	1.04	12
36	100	65	35	1.86	25.44	25.06	1.48	36.49	35.59	2.47	12
37	100	70	30	2.33	25.25	24.54	2.80	36.29	35.06	3.38	12
38	100	80	20	4.00	23.91	22.72	4.99	34.30	33.23	3.11	12
39	100	75	25	3.00	24.71	23.81	3.63	35.80	34.33	4.10	12
40	100	0	100	0.00	27.37			39.10			12
41	100	20	80	0.25	28.60	28.82	-0.78	41.05	41.85	-1.95	12
42	100	40	60	0.67	29.28	30.14	-2.93	41.84	43.50	-3.97	12
43	100	60	40	1.50	29.55	29.90	-1.19	42.37	42.25	0.29	12
44	100	65	35	1.86	26.69	29.44	-10.31	42.58	41.79	1.86	12
45	100	70	30	2.33	29.58	28.83	2.54	42.51	41.17	3.15	12
46	100	75	25	3.00	29.11	27.97	3.91	42.01	40.31	4.04	12
47	100	80	20	4.00	28.51	26.69	6.40	41.30	39.02	5.52	12
48	100	100	0	1.00	23.30	21.58	7.39	39.01	42.89	-9.95	12
49	100	0	100	0.00	29.12			42.21			12
50	100	20	80	0.25	30.37	30.67	-0.97	44.27	45.18	-2.06	12
51	100	40	60	0.67	31.13	32.06	-3.00	45.03	46.96	-4.29	12
52	100	60	40	1.50	31.45	31.81	-1.16	45.79	45.61	0.40	12
53	100	65	35	1.86	31.19	31.32	-0.43	45.78	45.11	1.46	12
54	100	70	30	2.33	31.54	30.67	2.75	45.51	44.45	2.34	12
55	100	75	25	3.00	31.01	29.76	4.03	44.21	43.52	1.56	12
56	100	0	100	0.00	32.80			49.10			12

57	100	20	80	0.25	34.11	34.54	-1.26	51.46	52.56	-2.13	12
58	100	40	60	0.67	35.03	36.12	-3.10	52.29	54.63	-4.47	12
59	100	60	40	1.50	35.39	35.83	-1.25	53.01	53.05	-0.08	12
60	100	65	35	1.86	35.43	35.28	0.41	53.11	52.47	1.20	12
61	100	70	30	2.33	35.03	34.55	1.37	52.78	51.70	2.04	12
62	100	75	25	3.00	34.81	33.52	3.70	51.21	50.62	1.15	12
63	100	80	20	4.00	33.51	31.98	4.57	50.01	49.00	2.02	12
64	100	100	0	1.00	29.10	21.58	25.84	41.80	53.86	-28.86	12
65	100	0	100	0.00	18.97			26.67			7
66	100	20	80	0.25	17.93	19.98	-11.42	24.30	27.83	-14.52	7
67	90	20	80	0.25	22.67	19.98	11.88	27.71	27.83	-0.42	7
68	80	20	80	0.25	25.48	19.98	21.60	34.22	27.83	18.68	7
69	70	20	80	0.25	21.48	19.98	7.00	32.74	27.83	15.01	7
70	100	30	70	0.43	19.85	20.48	-3.16	27.71	28.45	-2.65	7
71	90	30	70	0.43	24.59	20.48	16.72	33.93	28.45	16.16	7
72	80	30	70	0.43	26.07	20.48	21.45	36.30	28.45	21.64	7
73	70	30	70	0.43	21.04	20.48	2.67	30.37	28.45	6.34	7
74	100	40	60	0.67	16.59	20.89	-25.91	25.93	28.95	-11.65	7
75	90	40	60	0.67	23.85	20.89	12.42	32.15	28.95	9.95	7
76	80	40	60	0.67	22.81	20.89	8.42	30.52	28.95	5.14	7
77	70	40	60	0.67	20.74	20.89	-0.72	29.53	28.95	1.96	7
78	100	0	100	0.00	18.37			22.00			1
79	100	10	90	0.11	18.45	18.61	-0.89	22.22	22.19	0.15	1
80	100	20	80	0.25	19.25	19.34	-0.49	22.52	22.95	-1.93	1
81	100	30	70	0.43	19.67	19.83	-0.81	24.30	23.46	3.44	1
82	100	40	60	0.67	20.44	20.23	1.04	24.89	23.88	4.05	1
83	100	50	50	1.00	21.18	20.59	2.77	26.22	24.27	7.45	1
84	100	60	40	1.50	19.67	20.07	-2.03	24.43	23.77	2.70	1
85	100	70	30	2.33	18.15	19.35	-6.61	22.22	23.17	-4.26	1
86	100	80	20	4.00	17.55	17.91	-2.06	20.89	21.96	-5.10	1
87	100	90	10	9.00	15.85	13.59	14.23	19.67	18.33	6.83	1
88	100	0	100	0.00	21.33			28.58			1
89	100	10	90	0.11	22.22	21.61	2.73	29.18	28.82	1.22	1
90	100	20	80	0.25	22.76	22.46	1.31	29.33	29.82	-1.67	1
91	100	30	70	0.43	23.25	23.03	0.97	29.48	30.48	-3.40	1
92	100	40	60	0.67	23.56	23.49	0.31	29.62	31.03	-4.74	1
93	100	50	50	1.00	24.43	23.91	2.12	30.07	31.52	-4.83	1
94	100	60	40	1.50	22.76	20.07	11.82	28.66	23.31	18.67	1
95	100	70	30	2.33	20.44	19.35	5.33	26.22	22.45	14.39	1
96	100	80	20	4.00	19.25	17.91	6.96	24.29	20.72	14.68	1

Fig. : 1

Fig. : 2

Fig. : 5

Fig. : 3

Fig. : 6

5. Validation of Mathematical Models

Validation of all mathematical models developed was tested by drawing graphs indicating ranges of percentage errors in predicting various strengths of concrete containing quarry sand in different proportions. The mathematical models are not significant if the proportion of quarry sand : natural sand in more than 70:30. Validation graphs are presented in figures 4 to 9.

Fig. : 4

Fig. : 7

Fig. : 8

Fig. : 9

6. Discussion

The literature indicate enhancement of strength parameters due to addition of quarry sand in concrete. However the exact trends have not been quantified in the literature. The test results of author and development mathematical models based on their own research and validation of model indicate the significance quarry sand to natural sand ratio in strength enhancement as well as strength reduction. The graphical trend indicates that the replacement of natural sand to quarry sand up to equal proportions may enhance the compressive strength at

7,28,56 and 90 days of ages and split tensile strength at 28days and flexural strength at 28days age.

Many parameters such as type of cement, type of aggregate, casting and curing conditions and testing environment influence the strength development in mixes. For testing the mathematical models on reference data may result into futile attempt, in view of above mentioned conditions. The data available for testing mathematical models was also limited, 7 and 28 days strength (96 combinations), 56 days (20 combinations), 90 days (13 combinations), flexural strength (64 combinations), split tensile strength (51 combinations)

Irrespective of this the majority of mathematical models are found significant as percentage error in predicting strengths was within +15% and -15%.

Though the normal trends suggest enhancement of strength is linked to quarry sand and natural sand ratio 1, some of the observations in the references have indicated negative response, still they are considered in validation of mathematical models, these were very peculiar in predicting flexural strength.

7. Concluding Remarks

Development of mathematical models based upon experimental findings, development of mathematical models and validation of mathematical models clearly indicate the importance quarry sand to natural sand ratio in gain of compressive strength, split tensile strength, flexural strengths. The rate of development of strength in split tensile strength is much higher for quarry sand to natural sand ratio 1. The mathematical models can very well be used in predicting various strengths, with limitation of quarry sand to natural sand ratio 2.33

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