Quality Assessment and Quality Control of Cement Concrete by Using Ultrasonic Pulse Velocity (USPV) Test

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ABSTRACT: *In this study total 135 ultrasonic pulse velocity and direct compression test was performed on 135 site laboratory made cubes of age 28 days for development of regression models by using Microsoft Excel software package. USPV model that consists of 6 models i.e. linear, quadratic parabola, cubic parabola, exponential, logarithmic and power model. In this model also linear model is referred due to being simple and no chance of modification of error in measurement of USPV value due to the various factors including age, curing conditions, moisture condition, mix proportions, type of aggregate and type of cement etc. Maximum variation in model predicted strength of structural concrete member and strength of the cube made same concrete is determined. This maximum variation for USPV linear model is 29.838%.*

Key Words: *Non Destructive Testing (NDT), Destructive Testing (DT), Ultrasonic Pulse Velocity (USPV), Compressive Strength, Regression Models, Correlation*

Introduction: It is often necessary to test the quality of concrete in fresh and harden state to determine its suitability for which it is being used. Quality control of concrete lead to safe and cost-effective structures that requires minimal maintenance and cause minimal inconvenience. Ideally such testing should be done in fresh state by testing the properties of fresh concrete such as slump, air content, air-void system, setting time, unit weight, and temperature and in hardened state test available for testing the concrete without damaging the concrete called completely non-destructive test (NDT) such as Schmidt's Rebound Hammer Test, Ultrasonic Pulse Velocity Test, Rebar locator test etc., test available for testing the concrete by slightly damaging the concrete surface and surface has to be repaired after the test called partially destructive test, such as core test, pull out pull off, break off test etc. and test available for testing concrete by damaging the concrete surface called destructive test such as compressive strength test, tensile strength test etc. The range of properties that can be assessed using non-destructive tests and partially destructive tests is quite large and includes such fundamental parameters as density, elastic modulus and strength as well as surface hardness and surface absorption, and reinforcement location, size and distance from the surface. It is been found that the use of NDT techniques are much reliable and can well be fit to assess the quality of concrete structures.

Purpose and Scope of Work: One of the purposes of testing hardened concrete is to confirm that the concrete used at site has developed the required strength. As the hardening of the concrete takes time, one will not come to know, the actual strength of concrete for some time. In present work destructive testing (DT) i.e. compressive strength was used to assess the compressive strength of concrete and non-destructive testing (NDT) i.e. ultrasonic velocity test (USPV) were used to predict the in-place compressive strength and quality of the concrete. USPV test reflects the inner properties of concrete.

Literature Review: Work done by the various researchers on USPV and Cube compressive strength for stabilizing correlation between them to predict the strength of structural concrete has been broadly studied before this work.

Selection of Study Location: Data collection of present research work is done at site of under construction Super Specialty Cancer Institute (**Fig. 1)** near Gajaria Form Sultanpur road, Lucknow and in the laboratory of Mukesh & Associate Consultant and Engineers company working as a third party for quality control of construction work at that site.

Fig. 1 Under Construction Super Specialty Cancer Institute near Gajaria Form Sultanpur road Lucknow

Preparation of Cube Sample: Various cube specimen of size 15 × 15 × 15 cm were prepared for USPV test and cube compressive strength test. The cube specimen are made as soon as practicable after mixing and in such a way as to produce full compaction of concrete with neither segregation nor excessive laitance. The concrete is filled into mould in layers approximately 5 cm deep. In placing each scoopful of concrete, the scoop is required to be moved around the top edge of the mould as the concrete slide from it, in order to ensure the symmetrical distribution of level with the top of the mould, using trowel the concrete within the mould. Each layer is compacted by 35 stokes. Stokes penetrates into the underlying layer and the bottom layer is rodded throughout the depth. After the top layer has been compacted the surface of the concrete is brought to be finished level with the top of the mould, using a trowel. The top is covered with the metal sheet to prevent the evaporation. The test specimen are stored on site at a place free from vibration for 24 hours ±1/2 hour from the time of addition of water to the other ingredients. Temperature of the place of the storage should be within the range of 22º to 32ºC. After the period of 24 hours, they should be marked for later identification removed from the moulds. Now, specimens are stored water for 28 days at temperature of 27º±2ºC. Six cubes are prepared for heavily loaded beam, column and slab while for lightly loaded beam, column and slab three cubes were prepared.

USPV Test Methodology:

1. To ensure the accuracy of measurement and performance calibrate the USPVT by measuring the transit time on a standard calibration rod supplied along with equipment by manufacturer.**(Fig. 2)**
2. Remove the specimen of curing age 28 days from water and Wiped off the surface water and grit and remove any projection on the surface and makethe specimen completely dry.
3. Note the dimension of specimen nearest 0.2 mm and their weight before testing.
4. Clean the bearing surface of the testing machine and remove loose sand and any other material from the surface of the specimen
5. Take least three reading on each 28 days cube (one reading on two opposite faces) by USPV tester.**(Fig. 3)**
6. Take 8 USPV reading on each 28 days structure such as beams, columns, slabs and footing **(Fig. 4, 5,6)**

Compressive Strength Test Methodology:

1. Place the cube in CTM in such a manner that the load shall be applied to opposite sides of the cubes as cast that is not to the top and bottom.
2. Carefully align the axis of the specimen with the centre of thrust of the spherically seated platen.
3. Apply load without shock and Increase continuously at a rate of approximately 140 kg/sq cm/min until the resistance of the specimen to the Increasing load breaks down.**(Fig.7)**
4. Record the maximum load applied and note appearance of the concrete and any unusual feature in type of failure.
5. Strength of the specimen can be found by dividing max. load to the cross sectional area of the specimen.
6. Take the average of the three value of the strength, make sure that individual variation should not be more than ±15%.

Detail of Experimental Work:

Fig.2: Calibration of USPV Tester

Fig.3 USPVT on Cube

Fig. 4: USPV on Column

Fig.5.: USPV on Slab

Fig. 6: USPV on Plinth Beam

Fig.7: Cube Compressive Strength Test

Data Collection of Cube Compressive Strength Test and USPV Test:

Data obtained by performing USPV test on 28 days hardened cube and structural concrete such as column, beam, slab and wall are represented in tabular form.**(Table.1)**

Table.1: Cube Compressive Strength Test and USPV Test Data

S. No.	Name of Element	Mix	28' Day Cube Compressive Strength (N/mm²)	Age of Test (Days)	U.S.P.V. Test on Structure (Km/sec)								Avg. Value	U.S.P.V. Test on Cube (Km/sec)			Avg. Value
					1	2	3	4	5	6	7	8		1	2	3	
1	Column 1 (600)	M30	33.78	28	4.561	4.407	4.681	4.518	4.489	4.334	4.713	4.435	4.517	4.581	4.491	4.596	4.556
			33.33											4.466	4.630	4.588	4.561
			35.56											4.732	4.763	4.660	4.718
2	Column 2 (600)	M30	39.56	28	4.412	4.677	4.535	4.715	4.172	4.623	4.365	4.488	4.498	4.794	4.763	4.770	4.776
			40.00											4.821	4.666	4.789	4.759
			38.22											4.735	4.832	4.632	4.733
3	Column 3 (600)	M30	32.00	28	4.544	4.287	4.172	4.838	4.461	4.795	4.494	4.171	4.470	4.532	4.602	4.321	4.485
			34.67											4.661	4.423	4.498	4.527
			32.89											4.462	4.440	4.566	4.489
4	Column 4 (600)	M30	30.67	28	4.178	4.853	4.763	4.296	3.935	4.354	4.637	4.262	4.410	4.398	4.446	4.467	4.437
			32.00											4.461	4.521	4.379	4.454
			30.67											4.436	4.449	4.434	4.440
5	Poarch Slab 1 (500)	M25	33.33	28	4.128	4.296	3.838	4.087	4.273	3.869	4.370	4.212	4.134	4.599	4.392	4.462	4.484
			34.67											4.673	4.468	4.484	4.542
			32.89											4.412	4.497	4.532	4.480
			34.67											4.543	4.572	4.572	4.562
			31.11											4.483	4.436	4.419	4.446
			30.22											4.360	4.360	4.541	4.420
6	Column 5 (600)	M30	41.78	28	4.513	4.396	4.455	4.586	4.273	4.386	4.677	4.416	4.463	4.822	4.743	4.772	4.779
			38.67											4.696	4.710	4.660	4.689
			40.00											4.740	4.648	4.810	4.733
7	Column 6 (600)	M30	36.00	28	4.361	4.196	4.582	4.489	4.273	4.317	4.549	4.352	4.390	4.561	4.496	4.568	4.542
			35.11											4.574	4.581	4.550	4.568
			35.56											4.690	4.568	4.533	4.597
8	Column 7 (750)	M30	36.44	28	4.043	4.294	4.281	4.022	3.868	4.324	4.489	4.269	4.199	4.672	4.680	4.501	4.618
			35.56											4.388	4.521	4.634	4.514
			38.67											4.632	4.712	4.710	4.685
9	Column 8 (600)	M30	35.56	28	4.384	4.588	4.449	3.959	4.573	4.465	4.638	4.495	4.444	4.569	4.555	4.343	4.489
			34.67											4.562	4.542	4.337	4.480
			36.44											4.443	4.692	4.672	4.602
10	Column 9 (1200)	M40	43.11	28	4.925	4.711	4.745	4.768	4.854	4.687	4.799	4.843	4.792	4.702	4.669	4.802	4.724
			37.78											4.674	4.690	4.671	4.678
			37.78											4.684	4.732	4.596	4.671
11	Plinth Beam 1 (230)	M25	35.56	28	3.971	4.384	4.256	3.939	4.376	4.281	4.323	3.961	4.186	4.567	4.632	4.732	4.644
			36.44											4.769	4.602	4.583	4.651
			37.78											4.678	4.657	4.753	4.696
12	Lift Wall 1 (230)	M30	36.00	28	4.344	4.287	4.274	4.539	4.322	4.508	4.334	4.452	4.383	4.378	4.573	4.497	4.483
			35.11											4.460	4.655	4.375	4.497
			37.78											4.780	4.554	4.654	4.663
13	Column 10 (1200)	M40	46.22	28	4.952	4.811	4.644	5.079	4.655	4.567	4.862	4.663	4.779	4.881	5.063	4.823	4.922
			44.00											4.943	4.803	4.865	4.870
			40.44											4.745	4.625	4.693	4.688
14	Plinth Beam	M25	35.56	28	3.994	4.346	4.125	4.192	4.336	4.256	4.259	4.383	4.236	4.396	4.658	4.447	4.500

	2 (230)		**40.00**											4.690	4.690	4.734	4.705
			37.33											4.688	4.497	4.637	4.607
15	Column 11 (600)	M30	**36.44**	28	4.404	4.616	3.964	4.335	4.664	4.594	4.794	4.315	4.461	4.486	4.660	4.568	4.571
			35.56											4.334	4.454	4.585	4.458
			38.67											4.457	4.886	4.576	4.640
16	Column 12 (750)	M30	**37.78**	28	4.393	4.579	4.266	4.473	4.375	4.435	4.459	4.458	4.430	4.703	4.422	4.736	4.620
			36.44											4.672	4.535	4.566	4.591
			38.67											4.465	4.686	4.855	4.669
17	Column 13 (600)	M30	**36.00**	28	4.400	4.391	4.549	4.306	4.395	4.674	4.325	4.494	4.442	4.418	4.569	4.630	4.539
			35.11											4.364	4.697	4.561	4.541
			35.56											4.654	4.547	4.570	4.590
18	Column 14 (600)	M30	**33.78**	28	4.358	4.496	4.376	4.418	4.462	4.236	4.659	4.587	4.449	4.387	4.654	4.475	4.505
			33.33											4.460	4.453	4.561	4.491
			34.67											4.679	4.490	4.444	4.538
19	Column 15 (1200)	M40	**42.67**	28	4.238	4.456	4.344	4.634	4.135	4.439	4.896	4.643	4.473	4.664	4.894	4.568	4.709
			43.56											4.886	4.754	4.791	4.810
			44.00											4.886	4.754	5.211	4.950
20	Column 16 (600)	M30	**32.44**	28	4.454	4.283	4.548	4.459	4.515	4.301	4.642	4.327	4.441	4.346	4.467	4.622	4.478
			30.67											4.316	4.563	4.234	4.371
			31.11											4.435	4.656	4.256	4.449
21	Column 17 (600)	M30	**44.44**	28	4.531	4.449	4.446	4.138	4.517	4.543	4.402	4.654	4.460	4.765	5.020	4.899	4.895
			44.00											4.955	4.744	4.845	4.848
			38.67											4.656	4.700	4.564	4.640
			39.11											4.561	4.595	4.788	4.648
			39.56											4.733	4.747	4.696	4.725
			41.33											4.807	4.718	4.683	4.736
22	Column 18 (450)	M25	**36.00**	28	4.510	4.398	4.602	4.518	4.363	4.221	4.466	3.890	4.371	4.361	4.692	4.433	4.495
			37.78											4.764	4.365	4.634	4.588
			38.67											4.386	4.802	4.765	4.651
			36.89											4.627	4.633	4.631	4.630
			35.11											4.408	4.667	4.443	4.506
			36.44											4.538	4.641	4.438	4.539
23	Plinth Beam 3 (230)	M25	**33.78**	28	4.272	4.238	4.314	4.290	4.197	4.333	4.115	4.277	4.255	4.270	4.512	4.433	4.405
			34.67											4.586	4.465	4.411	4.487
			36.00											4.644	4.673	4.449	4.589
24	Column 19 (600)	M30	**37.78**	28	4.484	4.344	4.366	4.544	4.383	4.468	4.533	4.416	4.442	4.711	4.583	4.670	4.655
			36.89											4.523	4.465	4.543	4.510
			36.00											4.510	4.493	4.510	4.504
25	Plinth Beam 4 (230)	M25	**28.89**	28	3.984	4.267	4.010	4.185	4.164	4.144	4.073	4.115	4.118	4.386	4.300	4.355	4.347
			31.11											4.488	4.464	4.502	4.485
			32.44											4.543	4.467	4.496	4.502
26	Column 20 (600)	M30	**32.44**	28	4.128	4.435	4.382	4.306	4.011	4.297	4.151	4.480	4.274	4.300	4.433	4.465	4.399
			31.56											4.517	4.437	4.481	4.478
			30.67											4.278	4.342	4.278	4.299
27	Plinth Beam 5 (230)	M25	**34.22**	28	3.932	3.872	4.863	4.820	4.841	4.968	4.071	4.064	4.429	4.591	4.487	4.528	4.535
			33.33											4.436	4.503	4.454	4.464
			35.11											4.700	4.432	4.455	4.529
28	Plinth Beam 6 (230)	M25	**28.89**	28	4.244	3.793	3.890	4.078	4.289	4.125	4.275	4.099	4.099	3.856	4.367	4.430	4.218
			31.11											4.500	4.375	4.439	4.438
			30.22											4.638	4.35	4.349	4.445
29	Column 21 (600)	M30	**34.22**	28	4.415	4.366	4.408	4.374	4.435	4.451	4.360	4.444	4.407	4.622	4.480	4.503	4.535
			35.11											4.571	4.526	4.585	4.561
			36.44											4.494	4.629	4.600	4.574
30	Column 22 (450)	M25	**28.00**	28	4.309	4.476	3.955	4.383	4.523	4.424	4.294	4.291	4.332	4.365	4.385	4.430	4.393
			27.11											4.321	4.355	4.368	4.348
			25.78											4.411	3.969	4.332	4.237
31	Column 23 (600)	M30	**38.67**	28	4.611	4.584	4.661	4.606	4.413	4.146	4.638	4.445	4.513	4.736	4.684	4.720	4.713
			35.56											4.599	4.376	4.543	4.506
			39.11											4.845	4.645	4.697	4.729
32	Tunnel Wall 1 (500)	M30	**34.67**	28	4.431	4.368	4.331	4.116	4.430	4.406	4.338	4.375	4.349	4.471	4.445	4.480	4.465
			31.56											4.423	4.354	4.482	4.420
			30.22											4.330	4.466	4.428	4.408
33	Column 24 (600)	M30	**32.00**	28	4.625	4.585	4.322	4.732	4.451	4.774	3.873	3.991	4.419	4.459	4.424	4.484	4.456
			36.00											4.577	4.646	4.603	4.609
			33.33											4.600	4.537	4.610	4.582
34	Column 25 (600)	M30	**37.78**	28	4.351	4.401	4.452	4.457	4.565	4.379	4.423	4.541	4.446	4.613	4.570	4.655	4.613
			36.00											4.551	4.599	4.583	4.578
			38.22											4.720	4.623	4.643	4.662
35	Column 26 (600)	M30	**37.33**	28	4.512	4.605	4.407	4.365	4.520	4.452	4.565	4.465	4.486	4.572	4.609	4.584	4.588
			36.44											4.558	4.498	4.526	4.527
			37.78											4.620	4.57	4.500	4.564
36	Plinth Beam 7 (230)	M25	**34.22**	28	4.583	4.662	4.465	4.252	4.361	4.524	4.454	4.540	4.480	4.447	4.397	4.353	4.399
			30.22											4.304	4.352	4.461	4.372
			33.78											4.432	4.401	4.445	4.426
37	Column 27 (450)	M25	**28.44**	28	4.003	4.078	4.285	4.253	4.443	4.473	4.465	4.110	4.264	4.432	4.343	4.345	4.373
			30.67											4.451	4.347	4.376	4.391
			29.78											4.343	4.452	4.334	4.376
38	Lift Wall 2 (230)	M30	**30.22**	28	3.892	4.215	4.382	4.442	4.558	4.123	4.421	4.312	4.293	4.412	4.406	4.380	4.399
			34.67											4.457	4.511	4.465	4.478
			32.44											4.403	4.443	4.388	4.411
39	Plinth Beam	M25	**34.67**	28	4.346	4.435	4.354	4.179	4.875	4.423	4.367	4.246	4.403	4.607	4.101	4.712	4.473

	8 (230)		**35.56**											4.627	4.556	4.584	4.589
			36.00											4.703	4.571	4.588	4.621
			40.00											4.762	4.647	4.695	4.701
40	Column 28 (1200)	M40	**40.89**	28	4.517	4.864	4.641	4.819	5.314	4.723	4.524	4.834	4.780	4.746	4.812	4.656	4.738
			40.44											4.703	4.770	4.747	4.740
			35.56											4.566	4.488	4.503	4.519
41	Column 29 (600)	M30	**36.00**	28	4.328	4.472	4.561	4.586	4.449	4.474	4.458	4.425	4.469	4.669	4.476	4.457	4.534
			33.33											4.468	4.455	4.354	4.426
			36.00											4.593	4.578	4.554	4.575
42	Column 30 (600)	M30	**33.78**	28	4.486	4.492	4.453	4.534	4.335	4.359	4.272	4.572	4.438	4.428	4.637	4.545	4.537
			34.22											4.397	4.560	4.553	4.503

Development of Ultrasonic Pulse Velocity Models:

Development of ultrasonic pulse velocity models (i.e. linear, quadratic and cubic parabola, exponential, power and logarithmic) are done using Microsoft Excel Software Package and models are shown in **fig.8, 9,10,11,12 and 13.**

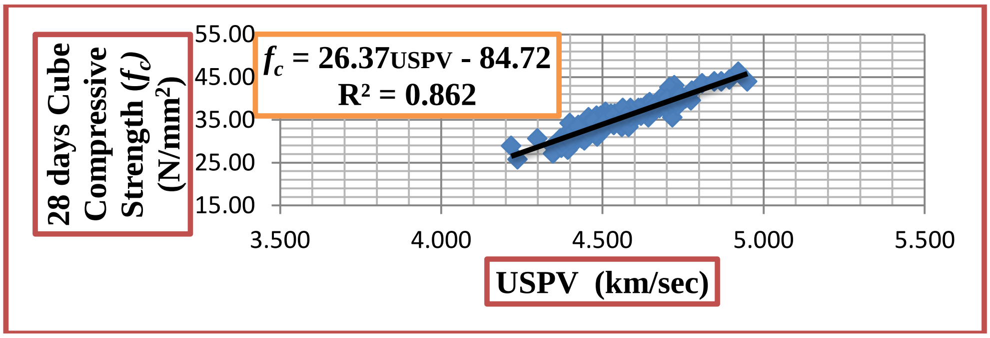

Fig.8: USPV Linear Regression Model

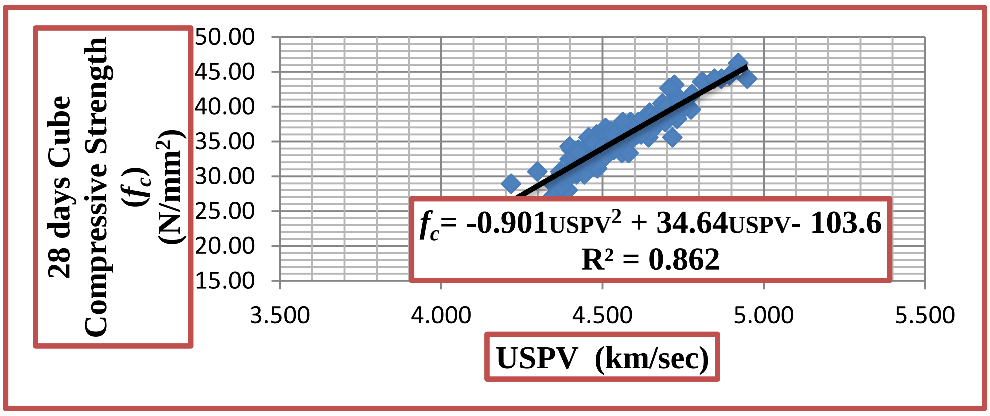

Fig.9: USPV Quadratic Parabolic Regression Model

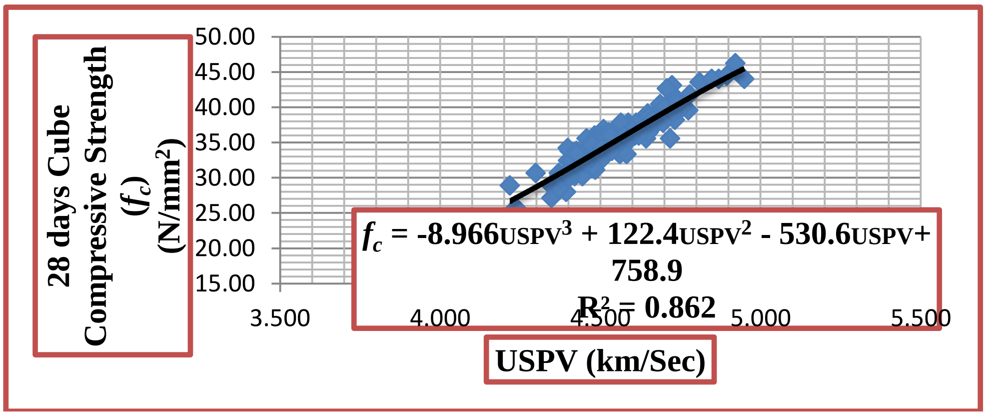

Fig. 10: USPV Cubic Parabolic Regression Model

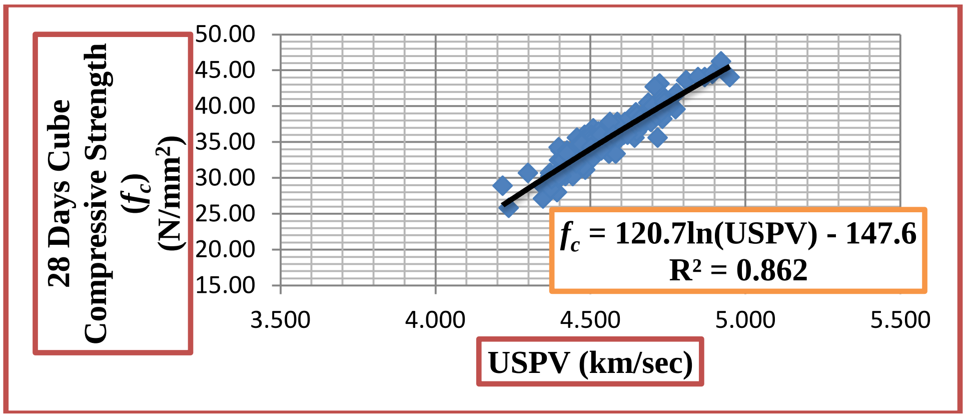

Fig.11: Logarithmic Regression Model

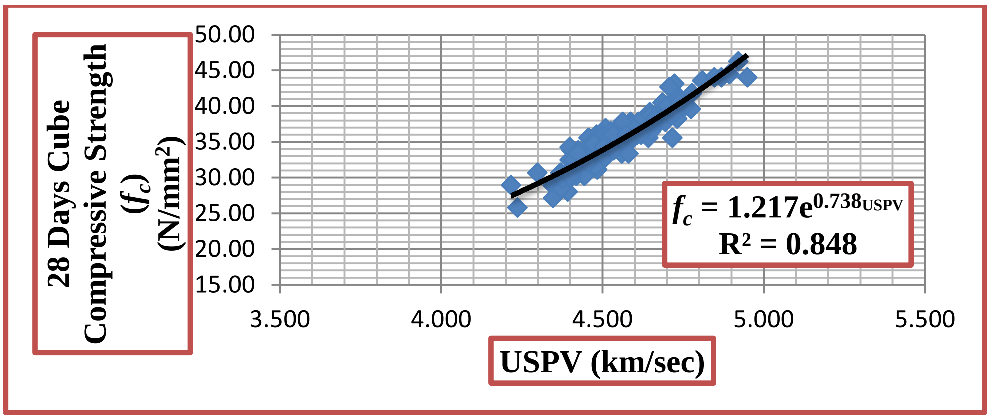

Fig. 12: Exponential Regression Model

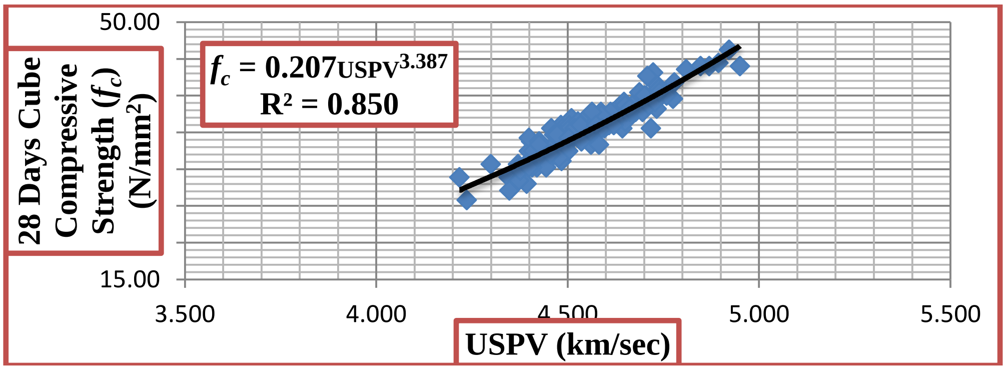

Fig. 13: Power Function Regression Model

Result of data analysis of USPV and cube compressive strength:

Following regression models are obtained on the basis of above developed correlation. **(Fig.8, 9, 10, 11, 12, 13)**

Table.2: USPV Models

S. No.	Model	Model Equation	Model R^2 Value
1	Linear Regression Model	$f_c = 26.37USPV - 84.72$	0.862
2	Quadratic Parabolic Regression Model	$f_c = -0.901USPV^2 + 34.64USPV - 103.6$	0.862
3	Cubic Parabolic Regression Model	$f_c = -8.966USPV^3 + 122.4USPV^2 - 530.6USPV + 758.9$	0.862
4	Power Regression Model	$f_c = 0.207USPV^{3.387}$	0.850
5	Exponential Regression	$f_c = 1.217e^{0.738USPV}$	0.848

	Model		
6	Logarithmic Regression Model	$f_c = 120.7ln(USPV) - 147.6$	0.862

All shows good relationship between USPV and cube compressive strength. Among all the developed models Linear, Quadratic Parabola, Cubic Parabola and Logarithmic Regression Model have highest R^2 value(i.e. 0.862) which implies that these models best correlation than other models but linear model is simple and there is less chance of magnification of error in prediction of compressive strength by error involved in measuring USPV due influence of various factors. That's why prediction of compressive strength by linear regression model in best which has same correlation that of Linear, Quadratic Parabola, Cubic Parabola and Logarithmic Regression Model.

Predicted of Compressive Strength of Structural Concrete by developed Linear Regression Model: After developing the correlation between cube compressive strength and USPV on cube the strength of the structural concrete can be predicted by putting the avg. USPV of structural concrete in developed correlation equation '$f_c = 26.37USPV - 84.72$' in place of '*USPV*' and finding corresponding 'f_c'. This value of 'f_c' is the predicted strength of structural concrete and percentage variation or % error in development of relationship can be find out by formula given below **(Table.3)**:

Table .3: %Variation of Linear USPV Model and Prediction of Strength of Structural Concrete by Linear USPV Regression Model

S. No.	Name of Element	Mix	Avg. Cube Compressive Strength	Avg. USPV Value on Structure	Predicted Compressive Strength of Structural Concrete Member by Linear Model N/mm2	%Variation between Cube Compressive Strength and Predicted Strength by Linear USPV Model	Remark Fail (If $f_c < f_{ck}$) O.K. (If $f_c > f_{ck}$)
1	Column 1 (600)	M30	34.223	4.517	34.400	0.516	O.K.
2	Column 2 (600)	M30	39.260	4.498	33.902	-13.647	O.K.
3	Column 3 (600)	M30	33.187	4.470	33.160	-0.079	O.K.
4	Column 4 (600)	M30	31.113	4.410	31.565	1.452	O.K.
5	Poarch Slab 1 (500)	M25	32.815	4.134	24.297	-25.958	Result is not reliable due to Indirect Transmission
6	Column 5 (600)	M30	40.150	4.463	32.963	-17.901	O.K.
7	Column 6 (600)	M30	35.557	4.390	31.041	-12.700	O.K.
8	Column 7 (750)	M30	36.890	4.199	26.001	-29.517	Fail
9	Column 8 (600)	M30	35.557	4.444	32.465	-8.695	O.K.
10	Column 9 (1200)	M40	39.557	4.792	41.632	5.246	O.K.
11	Plinth Beam 1	M25	36.593	4.186	25.675	-29.838	O.K.
12	Lift Wall 1 (230)	M30	36.297	4.383	30.847	-15.016	O.K.
13	Column 10	M40	43.553	4.779	41.306	-5.161	O.K.
14	Plinth Beam 2	M25	37.630	4.236	26.993	-28.267	O.K.
15	Column 11 (600)	M30	36.890	4.461	32.910	-10.789	O.K.

16	Column 12 (750)	M30	37.630	4.430	32.093	-14.716	O.K.
17	Column 13 (600)	M30	35.557	4.442	32.409	-8.853	O.K.
18	Column 14 (600)	M30	33.927	4.449	32.600	-3.910	O.K.
19	Column 15	M40	43.410	4.473	33.236	-23.436	Fail
20	Column 16 (600)	M30	31.407	4.441	32.392	3.139	O.K.
21	Column 17 (600)	M30	41.185	4.460	32.890	-20.140	O.K.
22	Column 18 (450)	M25	36.815	4.371	30.543	-17.036	O.K.
23	Plinth Beam 3	M25	34.817	4.255	27.471	-21.098	O.K.
24	Column 19 (600)	M30	36.890	4.442	32.422	-12.111	O.K.
25	Plinth Beam 4	M25	30.813	4.118	23.865	-22.550	Fail
26	Column 20 (600)	M30	31.557	4.274	27.979	-11.338	Fail
27	Plinth Beam 5	M25	34.220	4.429	32.069	-6.285	O.K.
28	Plinth Beam 6	M25	30.073	4.099	23.374	-22.277	Fail
29	Column 21 (600)	M30	35.257	4.407	31.483	-10.704	O.K.
30	Column 22 (450)	M25	26.963	4.332	29.512	9.451	O.K.
31	Column 23 (600)	M30	37.780	4.513	34.288	-9.243	O.K.
32	Tunnel Wall 1	M30	32.150	4.349	29.973	-6.771	Fail
33	Column 24 (600)	M30	33.777	4.419	31.812	-5.816	O.K.
34	Column 25 (600)	M30	37.333	4.446	32.524	-12.881	O.K.
35	Column 26 (600)	M30	37.183	4.486	33.586	-9.675	O.K.
36	Plinth Beam 7	M25	32.740	4.480	33.421	2.080	O.K.
37	Column 27 (450)	M25	29.630	4.264	27.715	-6.463	O.K.
38	Lift Wall 2 (230)	M30	32.443	4.293	28.490	-12.186	Fail
39	Plinth Beam 8	M25	35.410	4.403	31.390	-11.352	O.K.
40	Column 28	M40	40.443	4.780	41.315	2.156	O.K.
41	Column 29 (600)	M30	34.963	4.469	33.131	-5.241	O.K.
42	Column 30 (600)	M30	34.667	4.438	32.307	-6.807	O.K.

Discussion over USPV Models:

USPV tests were performed on 135 cubes by direct transmission for development of correlation between USPV by direct transmission and cube compressive strength. After that USPV tests were performed on 42 structural elements i.e. 30 on columns, 1 on slabs, 3 on walls of lift wells, and 8 on a beam. The characteristic strength of concrete for columns are 25 MPa, 30MPa and 40MPa and for lift wells and tunnel wall are 30MPa whereas for slabs and beam it is 25MPa. Developed model are Linear Regression Model, Quadratic Parabola Regression Model, Cubic Parabola Regression Model, Exponential Regression Model, Power Regression Model and Logarithmic Regression Model. Linear, Quadratic Parabola, Cubic Parabola and Logarithmic Regression Model have R^2 value 0.862, Exponential Regression Model 0.848 and Logarithmic Regression Model 0.850. All shows good relationship between USPV and cube compressive strength. Among all the developed models Linear, Quadratic Parabola, Cubic Parabola and Logarithmic Regression Model have highest R^2 value(i.e. 0.862) which implies that these models best correlation than other models but linear model is simple and there is less chance of magnification of error in prediction of compressive strength by error involved in measuring USPV due influence of various factors. That's why prediction of compressive strength by linear regression model is best which has same correlation that of Linear, Quadratic Parabola, Cubic Parabola and Logarithmic Regression Model. However the USPV increases as the strength increases and is also affected by a lot of parameters i.e. entity of the load, age of the concrete, form and the dimension of the structure, run length, presence of metallic reinforcements, water/cement ratio, state of strength, temperature, humidity of the concrete etc. That's why it not possible to develop a unique correlation between USPV and cube compressive strength. Moreover the USPV is indicative of inner property of concrete.

Conclusion:

The following conclusions can be drawn based on the outcome of the experiment, analysis and discussion of ultrasonic pulse velocity test results:

1. The Presents study puts forward a useful mathematical linear and nonlinear relationships of USPV and cube compressive strength that help the engineer to predict confidently the compressive strength of concrete, by measuring the USPV by ultrasonic pulse velocity tester. The mathematical models presented are simple, quick, reliable, and covers wide ranges of concrete strengths (i.e. 25.78MPa to 44.44MPa). The method can be easily applied to concrete specimens as well as existing concrete structures.

2. The correlation coefficient of the proposed models (i.e. linear, quadratic parabola, exponential, power and logarithmic) of USPV ranges from 0.848-0.862. This shows USPV has good correlation with the compressive strength of concrete. That's why these models can be used in predicting compressive strength of concrete.

3. Among all the developed models linear model is adopted for prediction of strength of structural elements because it is simple and there is less chance of magnification of error in prediction of compressive strength by error involved in measuring USPV value due influence of various factors. Maximum variation between predicted compressive strength by linear USPV model and actual cube compressive strength is 29.838.

4. The deviation between actual results and predicted results may be attributed to the fact that there is not perfect correlation between cube compressive strength and USPV of the model prepared by regression analysis.

5. The quality of concrete is usually specified in terms of strength and it is therefore, sometimes helpful to use ultrasonic pulse velocity measurements to give an estimate of strength. The relationship between ultrasonic pulse velocity and strength is affected by a number of factor including age, curing conditions, moisture condition, mix proportions, type of aggregate and type of cement. That's why the assessment of compressive strength of concrete from ultrasonic pulse velocity values is not accurate because the correlation between ultrasonic pulse velocity and compressive strength of concrete is not very strong because there are large number of parameters involved, which influence the pulse velocity greatly. However, if details of material and mix proportions adopted in the particular structure are available, then estimate of concrete strength can be made by establishing suitable correlation between the pulse velocity and the compressive strength of concrete specimens made with such material and mix proportions, under environmental conditions similar to that in the structure

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