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EVALUATION OF EFFECTING FACTORS OF TRADITIONAL AND SUPER PLASTICIZER CONCRETE CORE STRENGTH

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ABSTRACT

This paper deals with the investigation factors effecting core strength estimation by conducting an experimental study which included casting of six plain concrete beams. For each beam, 12 cubes were cast in addition to twenty-four core samples were extracted. The investigated factors involved the concrete compressive strength, concrete type, core extracting direction, core location, core depth in the beam, and the damage factor.

It obtained results showed that the ratio of compressive strength in the vertical to horizontal cast direction is (1.075) and (1.080) for the traditional and superplasticizer concrete, respectively. Also, the depth factor of bottom to top zone strength in vertical cast direction is (1.110) and (1.066) for traditional concrete and the super plasticizer concrete respectively, while the location factor of center zone in vertical cast direction corresponding to (1.088) and (1.103). Finally, the damage factor is directly proportional with the concrete strength for both concrete types.

KEYWORDS: Concrete, Superplasticizer, Compressive Strength, Drilled Core, Damage Factor.

1. INTRODUCTION

The core test is represented as partially destructive a test which is used as quality control test for concrete in the hardened state (IAEA, 2002). Core tests provide the most reliable in-situ strength assessment than other methods (ultrasonic pulse velocity, surface hardening, and Penetration resistance), but the principal limitations of core testing are those of cost, inconvenience and damage, the localized nature of the results, and expensive analysis (Bungey, 2006). The presence of the reinforcements and other buried ferromagnetic objects e.g. water pipes, steel joists, and lighting conduits represent another problem of the test.

Also, the core samples may be used in the laboratory for strength (compression and indirect tensile strength) test and for other physical tests (density, water absorption, thickness, resistivity, and permeability) and chemical tests (chloride content, sulphate content, and pH value) (Malhotra, 2004; Mahure, 2011).

Since all codes of practice include different strength factors for the assessment and evaluation of core test results, therefore a conflict may be happened in the interpretation of core results for assessment of real equivalent concrete strength as declared by (Neville, 2001). Unfortunately, not all these factors are well estimated and expected for one code, and not their variations are good predicated or approved. Some of these factors are the length to diameter ratio, the core diameter, the moisture condition of core, and the concrete strength. Some codes of practice specify the influence one or more factors but refer to others only. As example, ASTM C 42 (2013) considers the length to diameter ratio of core specimen, but does not involve a factor to the core direction effect. Table 1 summarizes the factors considered by different codes of practice to interpret the core strength.

Table 1. Factors involved in interpretation of core results by different codes.

List	Code	Aspect Ratio	Diameter	Rebar	Moisture	Damage	Direction	Voids	Age
1	BS 1881-120:1981	√		√			√	√	
2	BS EN 12504-1 (2009)	√	√	√		√			
3	Concrete Society TR 11 (1987)	√		√		√	√		
4	ACI 214.4 (2013)	√	√		√	√			
5	ASTM C 42 (2013)	√							
6	Iraq Building Code (1987)	√							

In addition to the strength factors of Table 1, there are additional factors which are mentioned in some codes and researches but without specifying their effect clearly and/or indicating their nature (ASTM C 42, 2013; Neville, 2001; and ACI 214.4, 2003, and Bruce, 1995). These additional factors are the concrete casting and curing condition, concrete strength, the maximum aggregate size, the type of concrete members (slab, beam, column, wall), the location of core sample along member length (at ends or middle), and finally the core depth through concrete section (top, middle, bottom) in which concrete in the uppermost part of any member is nearly always weak.

The significance of the strength factors on the core results encouraged many researches to investigate the variations of these factors and analysis the different reasons that control them. Some of these studies are given below:

Sanga (1976) investigated the direct reliable procedure for estimation the standard (28) days cube strength from core strength. He introduced a correction factor for converting the nonstandard cores to the standard core strength, and he found that the strength reduction between cured cylinder and core obtained under simulated site condition tested in standard manner equals to 34%. He gave a relationship between core and cube strength.

Yip (1988) estimated in situ strength of hardened concrete by testing cores of small diameters rather than using 100 or 150 mm diameter cores. He listed various reasons for using these sizes, such as the a small size of structural member, small distance between reinforcement rebar, and drilling through these size was not yet fully recognized in standards and guidance documents..

Bollin (1993) conducted a study to develop precision and bias statements for ASTM C 42. Seventeen laboratories participated in testing core specimens that were removed from concrete slabs. The given results were the basis for this statement. Additional information was developed pertaining to the relative strength between 56-days laboratory-cured cylinders and 56-days drilled cores.

Pawan et al., (2013) examined the effect of H/D ratio on the strength characteristics of the core. Cubes of 150mm x 150mm x 150mm were casted and cured for (28) days in which the required core samples having diameter of 50mm and 75 mm have been prepared from these cubes which gives different H/D ratios of (1, 1.25, 1.5, 1.75 and 2), respectively. It has been observed that the strength of core samples was less than those of the standard cubes.

Shafik et al., (2014) projected a comprehensive experimental study to examine the factors affecting the interpretation of core test results. Results indicated that the core strength reduces with the increase the aspect ratio, the reduction in core diameter, the presence of reinforcing steel, the incorporation of gravel in concrete, the increase in core moisture content, the drilling perpendicular to casting direction, and the reduction in concrete strength.

2. DEFINITION OF STRENGTH DIFFICULTIES

According to many codes and specifications, to determine the equivalent in-situ concrete strength (cube /cylinder) from the extracted core specimen, the core strength shall be multiplied by the strength correction factors which are adopted by a specific code of practice. For example, the equivalent cylinder strength according to ACI 214.4 (2003) can be computed using the equation:

$$f_c = F_{l/d} \times F_{dia} \times F_{mc} \times F_D \times f_{core} \quad (1)$$

Where:

f_c = The equivalent in-place concrete cylinder strength

f_{core} = The concrete core strength

$F_{l/d}$ = The strength correction factor for aspect ratio

F_{dia} = The strength correction factors for diameter,

F_{mc} = The strength correction factor for moisture condition of core sample,

F_D = The strength correction factor for effect of damage sustained during core drilling.

And from ASTM C 42 (2003):

$$f_c = F_{l/d} \times f_{core} \quad (2)$$

On the other hand, BS EN 12504-1 (2009) proposed the following relationship to convert the strength of a core specimen into the equivalent in-situ concrete strength as follows:

$$f_c = F_{l/d} \times F_{dia} \times F_{Rin} \times F_D \times f_{core} \quad (3)$$

where F_{Rin} = The strength correction factor for the presence of reinforcing steel and the other items has the same definitions as given above but not the same magnitude.

Finally, for Iraq Building Code (1987), the equivalent cube strength is estimated from the following equation:

$$f_{cuE} = F_{l/d} \times F_d \times f_{core} \quad (4)$$

where f_{cuE} =The equivalent cube strength

F_d =The factor converting core strength to cube strength.

There are three important demand answers for two questions related to the above discussion; the first: If there is available capability to categorize the strength factors behavior into local and global nature of concrete quality or not? The second question: What is the limit of the acceptance criteria about value of combined of strength factors (allowable maximum percent) which can be applied to the core strength in order to obtain accurate and acceptable the concrete strength? For question one, any code of practice adopts a philosophy related to it, but there are differences between the assumptions of each code and the real behavior of the concrete.

For question two, no answer was found or established, but (Neville, 2001) only warned about using the above solution without giving any advice about the limit acceptable to solve the problem for this value, and finally he gave a recommendation as the need for tests on cores is rare. Consequently, the strength factors must be covered or filled all the variations surrounding by the core test to reach the concrete strength. Some codes such as ACI 301 (2005) gave the choice to engineers (as a responsibility to the client or owner) who have a professional responsibility to ensure the structural adequacy of the concrete that conducted in accordance with specified procedures (clause 1.6.6.3).

3. PAPER PLAN

From Table 1, it can be concluded that there are many factors which are not considered in the Iraqi Codes of Reinforced Concrete, and these factors play an important role in justifying the core test. In addition, the weather of south and middle regions suffered from high temperature for a long period during the year which causes many concrete problems during casting, curing, and using. Consequently, for above reason the need for understanding and investigating different strength core tests must be checked to reach a correct view for concrete quality in Iraq.

4. METHODOLOGY

4.1. Constituent Materials

The mix components materials were used in this work involved fine and coarse aggregate, Portland ordinary cement, water, and superplasticizer (type Gelinume 51). All these mixing materials satisfied ASTM standards such as ASTM C 33 (2013) for fine and coarse aggregate, and ASTM C 150 (2004) for cement. Also, the maximum size aggregate was 20 mm and slump of fresh concrete of 150 mm.

4.2. Mix Proportions of Concrete Mixes

Since the traditional concrete (sometimes called ordinary concrete) was extensively used for low to moderate concrete compressive strength requisite while the superplasticizer concrete type is widely used for moderate to high concrete compressive strength requirements. In this study, six concrete mixtures were prepared with different w/c ratios which were chosen to produce the desired compressive strength grades for both traditional and superplasticizer concrete. Here for traditional concrete, the concrete compressive value is chosen as 20, 25, and 30 MPa while C35, C40, and C45 were selected for superplasticizer concrete. The constituent materials used in this paper are given in Table 2 to give the required concrete compressive strength at age (28) days.

4.3. Preparation and Testing of Concretes

Six concrete plain identical beams with dimensions of (0.40×0.40×1.20 m) were cast, and for each beam (12) cubs of dimensions 150x150 x150 mm are cast in steel molds and kept in their molds for one day. Later, the both concrete specimens had been cured in weather like the actual weather in situ. ACI 318 (2014) specifies that to assessment any case of concrete strength there are at least three successful extracting cores shall be tested to estimate the average core strength. Also, all selected tested cores have an aspect ratio (core height / diameter) equals to 2, so that the height correction is taken value equals to 1.2 according to Iraq Building Code (1987), and this result means herein the elimination of the correction factor for height/diameter ration between 1.0 and 2.0 because this factor is investigated, verified, and covered by all the standard of practice and many researchers as in Table 1.

This paper deals with those factors that have not been given sufficient importance to determine obviously their effect on the core results. So that, these parameters, for each concrete mix either traditional or super plasticizer concrete, are the concrete compressive strength, the core direction, the location of cores along the beam length, and finally the depth of core on beam section. Consequently, eight cases had been established for each concrete mix which is given as vertical direction extracting (parallel in cast direction) in beam edge located at beam top and bottom. The same sequence is repeated for middle beam location, and the entire process is recurrent for horizontal direction extracting.

Thus, for each beam, (24) drilling cores (core diameter is taken as 100 mm i.e. 4 inch) were selected and distributed as follows. For the vertical cast orientation, three cores were selected in the beam top location and three cores in the beam bottom location and in two places i.e. the beam edge and beam center. This procedure was repeated to the horizontal cast orientation. Therefore, for the present study, the entire present work involves casting (6) plain concrete beams, casting (72) cubes, and extracting (144) cores, and all these samples were tested at (28) days noting that the core state at test is similar to its state at extracting situation. Fig. 1 shows casting of a beam with corresponding cubes while Fig. 2 illustrates the core sample in crushing machine before testing.

Table 2. Physical properties of concrete constituent materials.

Type of Concrete	Design Cube Strength	w/c	Water (kg)	Cement (kg)	Sand (kg)	Gravel (kg)	Super Plasticizer (Cement %)
Tradition	C20	0.58	220	380	670	1130	None used
	C25	0.54	220	405	685	1090	
	C30	0.51	218	427	695	1060	
Super Plasticizer	C35	0.43	192	447	700	1061	0.88
	C40	0.40	185	464	705	1056	1.00
	C45	0.38	180	476	710	1034	1.10

4.4. Statistical Analysis Parameters

The tests data were subjected to statistics program in order to reach the accurate relationships and required factors. The standard deviation, the modulus of correlation between selected parameters, and arithmetic mean or average values were calculated for the purpose of analysis. The analysis of the obtained results was made by using Microsoft Excel 2010 and SAS software which gives the required outputs results parameters, equations, and figures.

In this study, the (6) beams and (72) cubes were cast using six different concrete mixes, and (24) cores were extracted from each beam. The (144) cores and (72) cubes are tested at 28 days and their results are summarized in Table 3. The cores strength values of Table 3 are multiplied by the height correction value which equal to (1.20) as specified by Iraq Building Code (1987) to convert them to equivalent cube strength then these values were compared with cube strength for each different state which are given in Table 4. Also, Table 5 displays the average compared values of Table 3 to distinguish the effect of the above variables between the traditional and superplasticizer concrete types. The relation between cube strength and equivalent cube strength was plotted for eight cases as shown in Figs. 3 to 6. Hence, the discussion of the variables affecting the core strength estimation had been divided into the next sections.

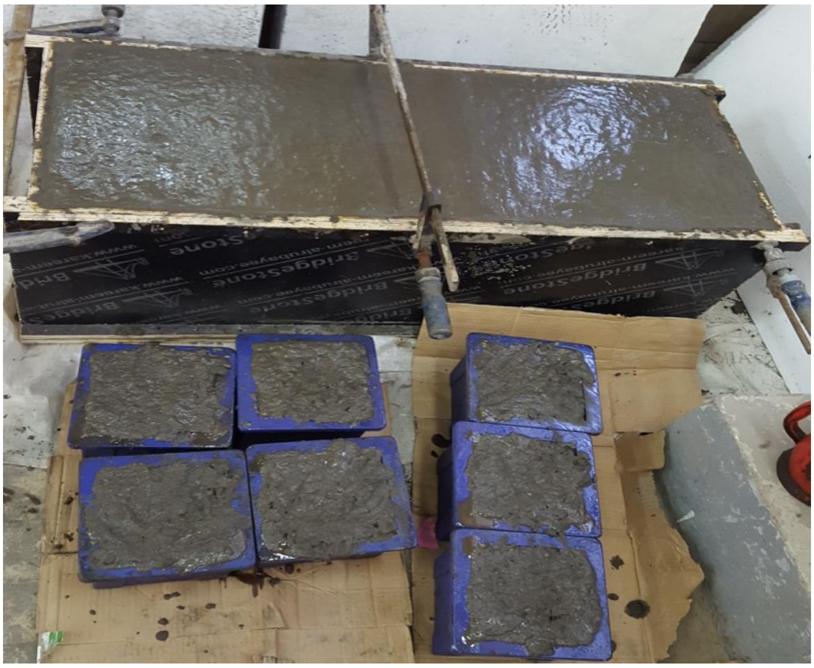

Fig. 1. Cast of beam with its cubes.

Fig. 2. Core sample in crushing machine.

5. RESULTS AND DISCUSSION

5.1. Concrete Compressive Strength

It is obviously from Figs. 3 to 6 that for eight cases the relationship between the concrete cubes strength and equivalent cube strength from the relevant cores has a linear tendency regardless of the concrete type or the concrete zone used for extracting the cores. This means that the factors of core direction, place, and location not have any influence the quality or nature of the strength relationship, but these factors have only a quantity effect (as discussed later). The reason of the above results is that the concrete behavior for any zone or region, here corresponding to any one of eight cases, is not changed according to the method applied for the sampling whether the samples used simulation is a cube or a core for this purpose.

5.2. Core Direction

From Table 4 and 5 , it is found that the direction relative to the casting in extracting cores has a sensible effect varying from (0.098) to (0.061) for the traditional concrete type and (0.091) to (0.074) for the super plasticizer concrete type. Also, the average value of all zones is (0.075) for the traditional concrete type and (0.080) for the super plasticizer concrete type. This results indicate that the direction factor is not dependent on the concrete type leading to a good agreement with BS 6089 (1981) which specified (0.087) values for this correction factor and BS EN 12504-1 (2009) specified percent ratio for this effect ranging from (0) to (8). The obtained results may be attributed to the stability of the fresh concrete which is greater in vertical direction (parallel to cast direction) than the core drilled horizontally from the same concrete. The above result can be explained in other way, when the concrete member casted by many layers, then the final mixing loses some homogenous between the adjacent casted layers which causes a potential flaw or probable defects so that these potential surfaces is more stronger to resist normal forces than the tangential forces nevertheless the direction of applied forced.

Table 3. Results of cores and cubes for six beam mixes.

Mix Design	Vertical Direction					Horizontal Direction				
	Cube Strength (Mpa)	Core Strength (MPa)				Cube Strength (Mpa)	Core Strength (MPa)			
		Edge		Middle			Edge		Middle	
		Top	Bottom	Top	Bottom		Top	Bottom	Top	Bottom
C 20	25.12	15.85	17.15	18.12	19.17	23.65	14.25	15.02	15.36	16.36
	24.87	15.78	16.58	17.66	18.95	22.75	15.52	15.95	18.25	18.64
	26.30	16.32	19.36	16.57	20.30	21.45	16.30	17.25	16.22	17.89
Average	**25.43**	**15.98**	**17.70**	**17.45**	**19.47**	**22.62**	**15.36**	**16.07**	**16.61**	**17.63**
C 25	32.60	21.65	19.35	20.64	22.36	28.69	17.32	19.00	19.78	21.02
	30.28	18.36	20.89	19.36	24.17	28.47	18.74	20.54	18.75	20.39
	31.74	19.25	22.16	22.34	24.09	30.25	19.92	21.48	20.44	23.54
Average	**31.54**	**19.75**	**20.80**	**20.78**	**23.54**	**29.14**	**18.66**	**20.34**	**19.66**	**21.65**
C 30	34.95	22.65	25.58	24.69	26.33	31.69	19.23	21.36	22.65	23.66
	36.55	22.36	25.63	24.44	25.66	33.67	22.36	22.32	25.32	24.02
	35.59	23.68	24.33	26.72	27.19	32.50	21.47	24.10	22.65	24.25
Average	**35.70**	**22.90**	**25.18**	**25.28**	**26.39**	**32.62**	**21.02**	**22.59**	**23.54**	**23.98**
C 35	40.12	25.98	29.76	28.55	32.35	39.62	23.56	24.99	25.87	27.38
	42.71	24.06	26.08	31.22	30.93	38.74	24.66	27.65	26.54	29.66
	42.83	27.46	28.41	27.84	29.33	39.65	24.65	25.14	27.72	29.20
Average	**41.89**	**25.83**	**28.08**	**29.20**	**30.87**	**39.34**	**24.29**	**25.93**	**26.71**	**28.75**
C 40	45.36	26.35	29.38	30.25	34.22	43.12	25.47	28.90	28.55	32.36
	47.36	28.66	28.34	29.66	34.56	42.29	24.14	27.66	27.30	30.36
	45.20	29.38	31.59	30.25	31.25	40.58	26.33	26.47	30.66	29.78
Average	**45.97**	**28.13**	**29.77**	**30.05**	**33.34**	**42.00**	**25.31**	**27.68**	**28.84**	**30.83**
C 40	51.26	30.25	33.02	37.05	35.34	48.77	29.36	30.58	31.36	36.55
	52.75	33.14	35.08	35.73	38.41	46.95	28.02	32.36	34.25	33.02
	53.08	34.21	33.69	34.85	38.20	49.32	31.43	32.69	33.13	34.48
Average	**52.36**	**32.53**	**33.93**	**35.88**	**37.32**	**48.35**	**29.60**	**31.88**	**32.91**	**34.68**

5.3. Core Location

From Table 3, it is seen that the center section has greater values than the edge for all concrete strengths and for both concrete types. Also, the bottom location is larger than the top for at edge and center sections. This result was signifying by many causes for the weakness of top concrete surface than bottom, such as the concrete bleeding so that the strength decreases at the top attributed to higher water-cement ratios. In additions, Table 5 shows that that the traditional concrete is more sensitive than the super plasticizer concrete for the compared of the core strength ratio between bottom to top locations as an example for vertical extracting cores (1.101) than (1.069) at center section and (1.119) than (1.063) at edge section. This effect is easy explained from the reduction of the water in superplasticizer concrete, so that the related water problems are usually reduced as water quantity reduced. The final point here, it is found that the compressive strength of core sample extracted from middle of beam is larger than that from the edge of beam by 9% and 10% for traditional and superplasticizer concrete, respectively.

Table 4. Comparison of cubes and equivalent cube strength.

Item	Vertical Direction					Horizontal Direction				
	Cube Strength (Mpa)	Equivalent Cube Strength				Cube Strength (Mpa)	Equivalent Cube Strength			
		Edge		Middle			Edge		Middle	
		Top	Botto	Top	Botto		Top	Botto	Top	Botto
C 20	25.43	19.18	21.24	20.94	23.37	22.62	18.43	19.29	19.93	21.16
fcu/fcu		1.326	1.197	1.215	1.088		1.227	1.173	1.135	1.069
V/H	1.124	1.041	1.101	1.050	1.104					
Bo/To			1.107		1.116			1.047		1.061
Ce /Ed				1.092	1.100				1.082	1.097
C 25	31.54	23.71	24.96	24.94	28.25	29.14	22.39	24.41	23.59	25.98
fcu/fcu		1.331	1.264	1.265	1.117		1.301	1.194	1.235	1.122
V/H	1.082	1.059	1.022	0.993	1.087					
Bo/To			1.053		1.133			1.090		1.035
Ce /Ed				1.052	1.132				1.121	1.064
C 30	35.70	27.47	30.21	30.34	31.67	32.62	25.22	27.11	28.25	28.77
fcu/fcu		1.299	1.181	1.177	1.127		1.293	1.203	1.155	1.134
V/H	1.094	1.089	1.114	1.074	1.101					
Bo/To			1.100		1.044			1.075		1.019
Ce /Ed				1.104	1.048				1.120	1.061
C 35	41.89	31.00	33.70	35.04	37.05	39.34	29.15	31.11	32.05	34.50
fcu/fcu		1.351	1.243	1.195	1.131		1.350	1.264	1.227	1.140
V/H	1.065	1.064	1.083	1.093	1.074					
Bo/To			1.087		1.057			1.067		1.076
Ce /Ed				1.130	1.099				1.100	1.109
C 40	45.97	33.76	35.73	36.06	40.01	42.00	30.37	33.21	34.60	37.00
fcu/fcu		1.362	1.287	1.275	1.149		1.383	1.265	1.214	1.135
V/H	1.095	1.111	1.076	1.042	1.081					
Bo/To			1.058		1.109			1.093		1.069
Ce /Ed				1.068	1.120				1.139	1.114
C 40	52.36	39.04	40.71	43.05	44.78	48.35	35.52	38.25	39.49	41.62
fcu/fcu		1.341	1.286	1.216	1.169		1.361	1.264	1.224	1.162
V/H	1.083	1.099	1.064	1.090	1.076					
Bo/To			1.043		1.040			1.077		1.054
Ce /Ed				1.103	1.100				1.112	1.088

Table 5. Comparison of the average values between cubes and cores for eight cases.

Mix Design	Item	Vertical Direction				Horizontal Direction			
		Edge		Middle		Edge		Middle	
		Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
Normal	fcu/fcuE	1.319	1.214	1.219	1.111	1.274	1.190	1.175	1.108
	V/H	1.063	1.079	1.061	1.098				
	Average		1.075						
	Bo/To		1.119		1.101		1.100		1.056
	Average		1.110				1.078		
	Ce /Ed			1.083	1.093			1.108	1.074
	Average		1.088				1.091		
Super Plasticizer	fcu/fcuE	1.351	1.272	1.229	1.150	1.364	1.264	1.222	1.146
	V/H	1.091	1.074	1.075	1.077				
	Average		1.080						
	Bo/To		1.063		1.069		1.079		1.066
	Average		1.066				1.073		
	Ce /Ed			1.101	1.106			1.117	1.104
	Average		1.103				1.110		

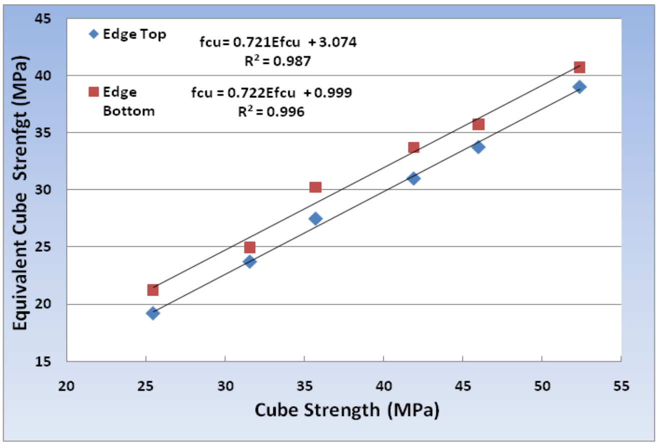

Fig. 3. Relationship between cube strength and equivalent cube strength from cores located at the beam edge zone for vertically extracted cores

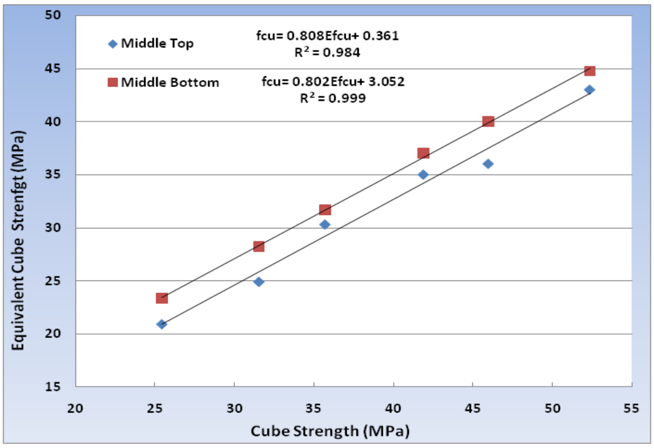

Fig. 4. Relationship between cube strength and equivalent cube strength from cores located at the beam middle for vertically extracted cores.

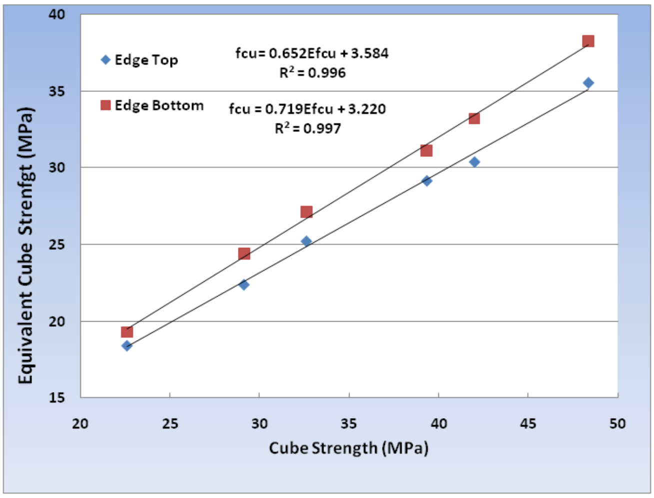

Fig. 5. Relationship between cube strength and equivalent cube strength from cores located at the beam edge zone for horizontally extracted cores

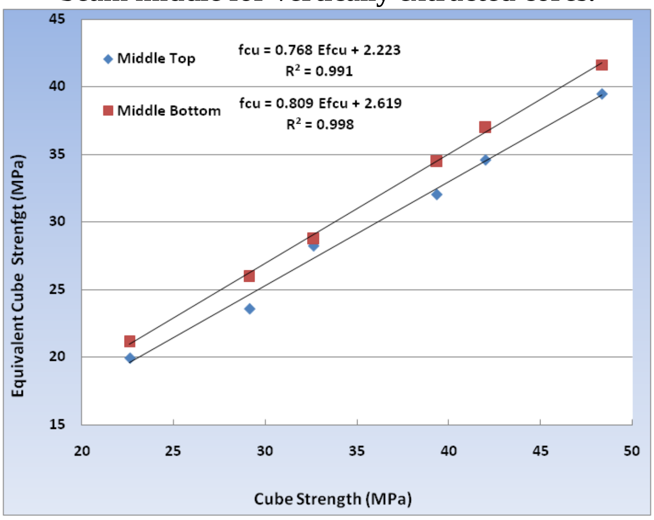

Fig. 6. Relationship between cube strength and equivalent cube strength from cores located at the beam middle for horizontally extracted cores

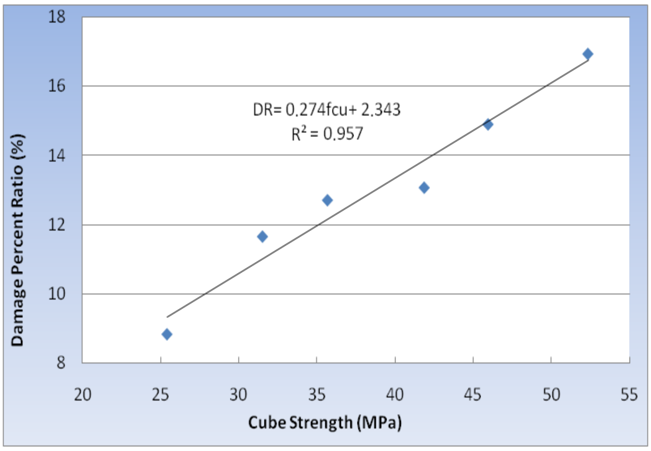

Fig.7. Relationship between cube strength and the damage percent ratio from cores located at the centre bottom vertically extracted.

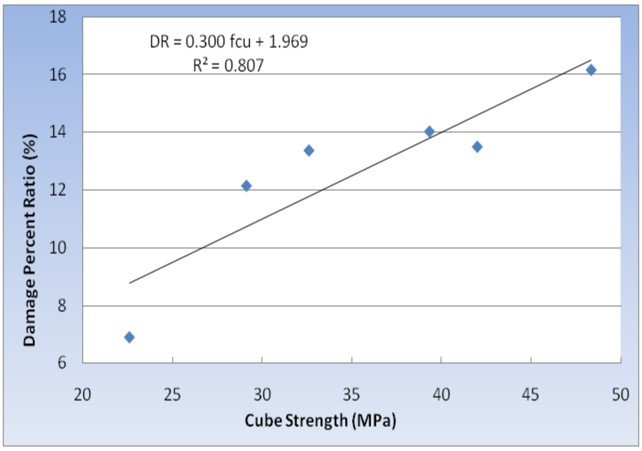

Fig. 8. Relationship between cube strength and the damage percent ratio from cores located at the centre bottom horizontally extracted.

6. CONCLUSIONS

The results of present study deals with the factors influence the concrete core strength estimation. From this study, the following conclusion may be summarized as follows:

1- The experimental program has been conducted together with the statistics analysis that achieved to find the value of many factors (the concrete compressive strength, type of concrete, direction of core extracting relative to the casting, location of core, core depth in the beam, and the damage factor) which effecting the estimation of concrete strength from the core test.

2-The vertical direction of core extracting has the overall average percent value greater than the horizontal direction by 7.5% for the traditional concrete type and 8.0 % for the superplasticizer concrete type. These ratios are compatible with European standard BS EN 12504-1.

3- The core strength of vertical direction extracting in bottoms location is greater than top location by (11 %) for traditional concrete and (6.6 %) for the superplasticizer concrete type while in the horizontal direction the percent ratio is (7.8) % versus (7.3 %.).

4- The compressive strength values of the extracted cores from the center zone is larger than that extracted from the edge zone of a beam by a mount (8.8% for vertical cores, 9.1% for horizontal cores) associated to traditional concrete than (10.3% for vertical cores , 11.0% horizontal) related to superplasticizer concrete, respectively.

5- The damage effect is proportional with the concrete strength for both concrete types, but it is more sensitive to superplasticizer concrete type than the ordinary concrete type (average overall damage ratio in vertical direction is 1.111 in traditional concrete than 1.150 for superplasticizer), and these values are higher than the ratio specified by ACI 214.4.

7. REFERENCES

ACI Committee ACI 214.4R-03, 2003, Recommended Practice for Evaluation of Strength Test Results of Concrete (ACI 214-4), American Concrete Institute, Farmington Hills, Mich.

ACI Committee 301, 2005, Specifications for Structural Concrete (ACI 301-99), American Concrete Institute, Farmington Hills, Mich.

ACI 318, 2014, Building Code Requirements for Structural Concrete, Copyright by American Concrete Institute American Concrete Institute, Farmington Hills, Mich.

ASTM Designation: C 33, 2003, Standard Specification for Concrete Aggregates, July, ASTM International, USA, pp.8.

ASTM Designation C 42, 2013 Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete1, April, ASTM International, USA, pp.5.

ASTM Test Designation C 150, 2013," Standard Specification for Portland Cement", May, ASTM International, USA, pp.6.

BS 1881-120, 1983, Method for determination of the compressive strength of concrete cores, published by BSI.

BS 6089:1981, 2000, Guide to Assessment of concrete strength in existing structures, published by BSI.

BS EN 12504-1, 2009, Cored specimens Taking, examining and testing in compression, published by BSI.

BS EN 13791, 2007, Assessment of in-situ compressive strength in structures and precast concrete components, published by BSI.

Bartlett, F. and MacGregor, J. (1994), 'Effect of Core Diameter on Concrete Core Strengths', ACI Materials Journal, 91 (5), 460-470.

Bollin, G. (1993), 'Development of Precision and Bias Statements for Testing Drilled Cores in Accordance with ASTM C 42 Cement, Concrete and Aggregates, CCAGDP', ASTM International, 15 (1), 85-88.

Bruce A. S., 1995, Understanding Concrete Core Testing, published by the National Ready Mixed Concrete Association (NRMCA).

Bungey, J. Millard, S. and Grantham, M. (2006) Testing of Concrete in Structures, 4th ed., London, Taylor & Francis Press.

Concrete Society, 1987, Concrete Core Testing for Strength, Technical Report No. 11 (TR11), The Concrete Society, London.

IAEA INTERNATIONAL ATOMIC ENERGY AGENCY, 2002, Guidebook on non-destructive testing of concrete structures, Austria.

Iraqi Building Code, 1987, Requirements for Reinforcing Concrete Code 1987, Republic of Iraq, Baghdad.

Mahure, N. Vijh, G. Sharma, P. Sivakumar, N. and Murari, R. (2011) 'Correlation between Pulse Velocity and Compressive Strength of Concrete', International Journal of Earth Sciences and Engineering, 4 (6), 871-874.

Malhotra, V and Carino, N. (2004) Handbook on Nondestructive Testing of Concrete, 2nd. ed., New York: CRC Press.

Neville, A. M., Properties of Concrete, 4th ed., London, John Wiley and Addison Wesley Longman.

Neville, A. (2001) 'Core Tests: Easy to Perform, Not Easy to Interpret', Concrete International, 23 (11), 59-68.

Pawan, K. and Sanjay, S. (2013) 'Experimental Study Of Core Diameter Varying H/D Ratio On Concrete Core Strength', International Journal of Engineering Research & Technology , 2 (3), 1-5.

Sanga, C. and Dhir, R. (1976), 'Core-Cube Relationships of Plain Concrete', Advances in Ready Mixed Concrete Technology, R. K. Dhir, ed., Pergamon Press, Oxford, pp. 193-292.

Shafik, K. Ali, A. and Ahmed, G. (2014) 'Reliability of core test – Critical assessment and proposed new approach', Alexandria Engineering Journal, 53, 169-183.

Yip, W and Tam, C. (1988) 'Concrete Strength Evaluation Through the Use of Small Diameter Cores', Magazine of Concrete Research, 40 (143), 99-105.