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Determination of concrete strength class from different types of non-destructive tests on B60 concrete structures in reactor building of Rooppur nuclear power plant by using experimentally established calibration dependences

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Abstract

Non-destructive test (NDT) has been used in this research to find out the strength class of concrete structures which is necessary for ensuring the serviceability of the structure. Two NDT methods, shock impulse and ultrasonic method have been conducted on different locations of B60 concrete structures of reactor building facility of Rooppur Nuclear Power Plant (NPP). These two NDT methods are indirect non-destructive methods. To determine the actual concrete grade, it is important to develop calibration dependence between strength results indirect and direct non-destructive methods. In this paper, two experimentally established calibration dependence equations from previous research have been applied where pull-out test is used as direct non-destructive method. Non-destructive tests have been conducted in inner and outer annular corridor walls, reactor cavity wall and two columns of reactor facility of Rooppur NPP in order to monitor the construction work and to ensure the quality of concrete work. The concrete strength classes found from shock impulse test at the depth of 40 mm from surface of structures are B63 for inner and outer annular corridor wall, B69 for reactor cavity wall and B70 and B69 for two columns respectively. Further, strength classes at the depth of 40 mm from ultrasonic tests are B63 for inner and outer corridor wall, B63 for reactor cavity wall and B63 and B62 for two columns respectively. All the strength classes found at the depth of 40 mm of the structures have a satisfactory indication to the construction work.

Keywords: Non-destructive test, shock impulse method, ultrasonic method, pull-out test, calibration dependence, concrete strength class.

1. Introduction

Rooppur Nuclear Power Plant is the biggest investment project of power sector after the independent of the Bangladesh. It is also the largest project among all of the development projects under Bangladesh Government. The construction work of this plant has been conducted with the help of Russian Federation. This plant is located in Pabna district. The concrete strength class of B60 structures of reactor building has been checked by using the non-destructive test methods for ensuring the quality of construction works. The most widely spreading technology to check concrete strength during construction is to collect cube or cylindrical test specimen. However, different types of Non-Destructive tests (NDT) have been used worldwide to investigate the concrete strength of existing structure. According to Workman and O. Moore (2012), Non-destructive testing (NDT) can be explained as the process of examining, testing, or assessing materials, components or assemblies without destroying the serviceability of the part or structure. Moreover, Lim and Cao (2013) stated that NDT techniques rely on the certain physical and chemical properties of concrete which have connection to strength and durability of the structures. These techniques have been performed for more than three decades for determining the properties of a structures.

Shaw and Xu (1998) considered NDT methods as powerful tools for determining strength and durability of existing concrete structures. Moreover, NDT methods have been attracting more and more consideration due to the reliability and effectiveness. Recognizing the ability of testing in situ concrete, this trend is increasing as compared to traditional random sampling of concrete for material analysis. Further, main factors that affect the success of a non-destructive testing are depth of penetration, vertical and lateral resolution, contrast in physical properties, signal-to-noise ratio and existing information about the structure (McCann & Forde, 2001).

Many researchers conducted several non-destructing tests to find out the different types of properties of concrete structure. Rens and Kim (2007) investigated a steel bridge by using several NDT methods which are visual inspection, hammer sounding, Schmidt hammer, and UPV testing including tomographic imaging. The outcomes of these NDT methods had been used to estimate areas, to be tested with local destructive tests such as compressive strength, chloride testing, and petrographic testing. Bhadauria and Gupta (2007) described the case study of deteriorated water tanks located in the semitropical area of India where different NDT methods like cover meter, Phenolphthalein indicator test, Quantab test, Potentiometric Titration, Schist’s hammer test, and UPV test were applied to identify the characteristics of concrete cover, carbonate depth, chloride concentration, compressive strength, and so forth. In this research, NDT methods were applied in accordance with GOST code to find out the actual strength class of concrete structures in reactor building of Rooppur Nuclear Power Plant by using experimentally established calibration dependences.

2. NDT procedures for evaluating concrete strength

There are different types of NDT methods for evaluating different kinds of characteristics of concrete structures. McCann and Forde (2001) observed the performance of five types of NDT techniques on concrete structures such as, ultrasonic, electromagnetic techniques, electrical methods, infra-red thermography and radiography. Maierhofer et al. (2010) described the effect of deterioration mechanisms of reinforced concrete structures by applying standard testing techniques of microscopic inspection of concrete and evaluation of chloride content. Maierhofer et al. (2010) explained the process, planning and execution of NDT methods for examining structural health and discussed several methods such as, wireless monitoring, electromagnetic and acoustic waves, magnetic flux leakage, electrical resistivity and determining corrosion rate. Proper knowledge of principles, advantages and limitations of

NDT methods are necessary for the successful implementation of NDT techniques (Verma et al. 2013).

Here, three NDT methods were used for the evaluation of strength class of concrete structures. These methods are Shock Impulse, Ultrasonic and Pull-out test. According to GOST 22690-2015, shock impulse and ultrasonic are indirect non-destructive test methods where the concrete strength can be determined by using predetermined calibration dependences. Besides, pull-out test is a direct non-destructive test method where concrete strength can be determined directly with a local mechanical impact on the concrete structure. In this research, shock impulse and ultrasonic methods have been applied on different types of concrete structures and the value of actual concrete strength is determined by using two predetermined calibration dependences between shock impulse and pull-out test results and between ultrasonic and pull-out test results.

Shock impulse method was applied in accordance with GOST 22690-2015 and ultrasonic method was applied in accordance with GOST 17624-2012. A device named IPS-MG4.03, serial number 6006 was used to perform shock impulse test. A reference block has been used to check the accuracy of the shock impulse machine where the standard strength value of this block is 30 ± 1.5 MPa. The procedure applied on reference block is shown in Figure 1(a). The force by the machine was applied perpendicularly to a test surface of 100-900 cm^2 in accordance with GOST 22690-2015. In Figure 1(b), a shock impulse test has been shown. A measurement cycle on one section contains 15 measurements based on the Operator's decision in this experiment. Device reading shall not differ more than 5% between values of separate measurements of same section.

Fig. 1(a). Checking the shock impulse machine using reference block.

Fig. 1(b). Shock impulse test on annular floor wall.

In case of conducting ultrasonic test, a device named UK 1401 with 150 millimeters (mm) has been used according to GOST 17624-2012. Ultrasonic measurements have been executed through the device by determining the time and speed of propagation of ultrasonic in concrete, in the prescribed way. There must be a reliable acoustic connection between the concrete surface and the working surfaces of the ultrasonic transducers to get the accurate results. The contact surface of concrete should be free of dust and porous. There must be minimum of two measurements with surface sounding and one measurement with continuous sounding on each section of the surface in accordance with clause 7.8 of GOST 17624-2012. Further, the difference between two individual measurements should not exceed 2% according to GOST 17624-2012. However, the direct determination of concrete strength is not possible to measure by applying both shock impulse and ultrasonic test. An indirect indicator has been evaluated to estimate the concrete strength after the development of calibration dependence between instrument reading and concrete strength. The process of ultrasonic test measurement has been shown in Figure 2.

Fig. 2. Ultrasonic test on concrete annular wall.

Two calibration dependences have been used in this research to find out the actual strength of concrete class. One is developed between the test results of pull-out test and shock impulse test in same concrete section. Another is constructed between the test results of pull-out test and ultrasonic tests in same concrete section. These calibration dependences are previously experimentally determined. Pull-out test has been conducted in this experiment also to estimate the adjustment coefficient at 40 mm depth of concrete layer from the surface. A device, POS 50MG4 with anchor device type II and anchor depth 48 mm has been used to perform pull-out test.

An area of 100-900 cm^2 in between the rebar was selected with the help of rebar locator for pull-out testing as per GOST 22690-2015. In Figure 3(a), pull-out test has been conducted on the surface. On the other hand, in Figure 3(b), pull-out test has been performed at the depth of 40 mm. A hole is drilled in the middle of sections for locating the anchor. The diameter of anchor device is 24 mm and the length is 48 mm, which is in the category of type II in accordance with GOST 22690-2015. There must be no dust in the hole and there must be no visible cracks or defects within a radius of 90 mm from the hole center. The anchoring device is set with a plow into the hole. After that, pull-out test is performed by uniformly rotating of the loading knob clockwise and by maintaining the loading speed in between 1.5 and 3 kN/s. When the maximum load is exceeded, the display shows indication by an intermittent beep. Then the test is stopped and loading handle is rotated counterclockwise to return exciter to its primary position. Thus, the slip of the anchor is measured by observing the value of displacement of micrometer nut. The actual values of Force (P) and Strength (R) are shown in the display after entering the value of slip difference in the displacement sensor. From the difference of strength of concrete from depth to surface, the adjustment coefficient is calculated. The adjustment coefficient is necessary to calculate the original strength of concrete layer from the concrete strength at concrete surface or, concrete cover.

Fig. 3(a). Pull-out test on the surface.

Fig. 3(b). Pull-out test at the depth of 40 mm.

3. Methodology to determine concrete strength class

Non-destructive tests have been performed in both inner and outer corridor wall, two columns and reactor cavity wall of the reactor building, unit-1 of Rooppur Nuclear Power Plant. The sections where the NDT has done are shown by zig-zag lines in Figure 4. The age of these sections' concrete is more than nine months. Axes 2-3/B-C, 2-3/C-D, 3-4/B-C and 3-4/C-D at elevation -5.450m to -1.850m for both inner and outer corridor wall are selected for testing. The reactor cavity wall is located at axes 2-3-4/B-C-D at elevation -4.900m to +1.950m.

Total forty-two (42) sections of outer corridor wall and thirty-nine (39) sections of inner corridor wall are selected for non-destructive testing. A scheme of showing test sections of inner and outer corridor walls is presented in Figure 5. The numbering of test sections is started from outer corridor wall and is ended in inner corridor wall. Another scheme of showing the numbering of test sections of reactor cavity wall is represented in Figure 6. Six sections for testing are chosen in each column. All these sections of reactor building are used for shock impulse and ultrasonic testing. The outcomes of these tests are applied in the equations of previously established calibration dependences to find out the actual concrete strength of these sections. The procedures of finding out of concrete strength are described below:

3.1 Experimentally established calibration dependences

Two calibration dependences are developed by following the methodology of GOST 22690-2015. One is in between impact impulse and pull-out test (Figure 7) and another one is in between ultrasonic and pull-out test (Figure 8). According to Figure 7, the relationship equation between impact impulse and pull-out test is,

$$R = 0.799H + 17.4 \quad (1)$$

Where, R represents the value of pull-out test and H represents the value of impact impulse test and correlation co-efficient of this equation is, R=0.72 which is greater than 0.7 according to GOST 22690-2015. The standard deviation is, S=4.5.

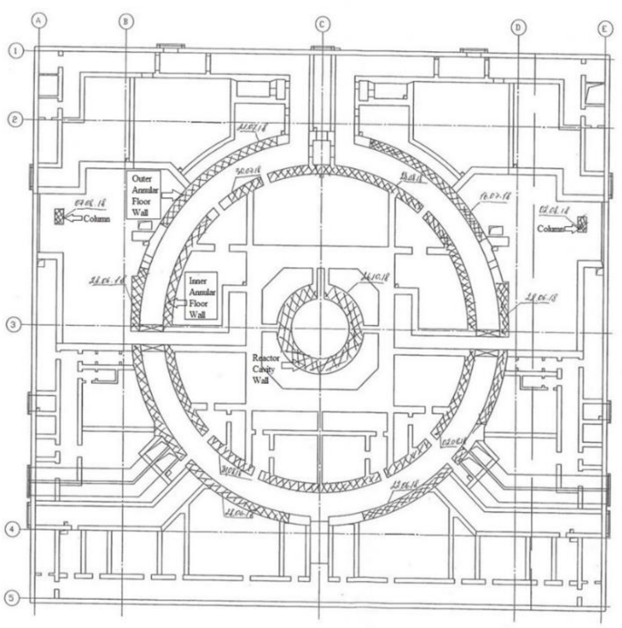

Fig. 4. NDT test Sections are presented by Zig-zag line in the Reactor Building Cross-Section.

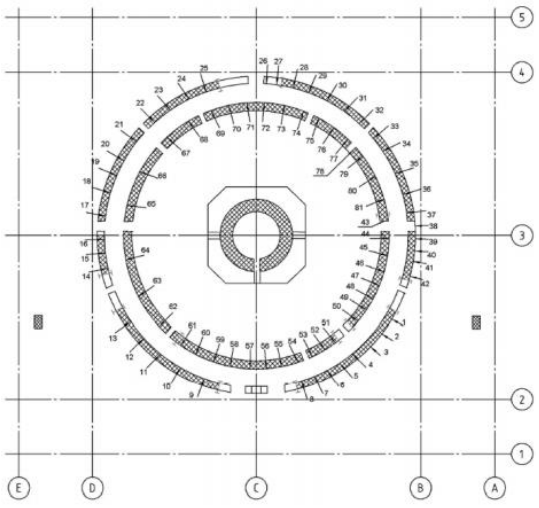

Fig. 5. Scheme for inspection the concrete strength in outer and inner annular wall at elevation -5.450m to -1.850m.

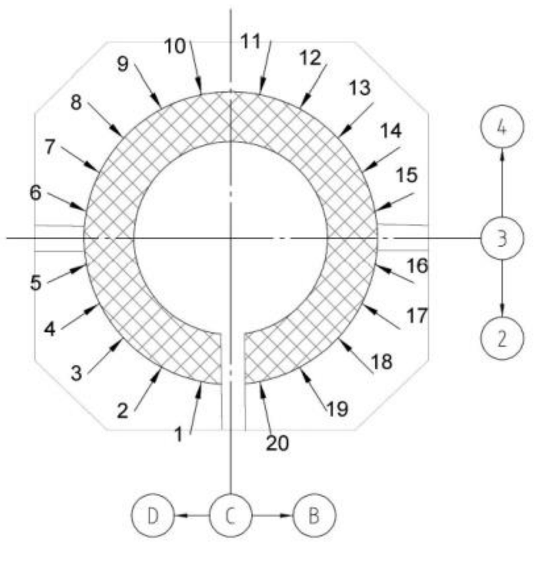

Fig. 6. Test Scheme for inspecting concrete strength in reactor cavity wall at elevation -4.90m to +1.950m.

On the other hand, the calibration equation between ultrasonic and pull-out test is,

$$y = 0.0448x - 112.77 \quad (2)$$

Where, y represents the value of pull-out test and x represents the value of ultrasonic test and correlation co-efficient of this equation is, R=0.78 which is greater than 0.7 according to GOST 22690-2015. In this case, the standard deviation is, S=5.3.

The test results of impact impulse and ultrasonic tests in different sections of this research are applied in the Equation no (1) and (2) respectively to find out the actual concrete strength.

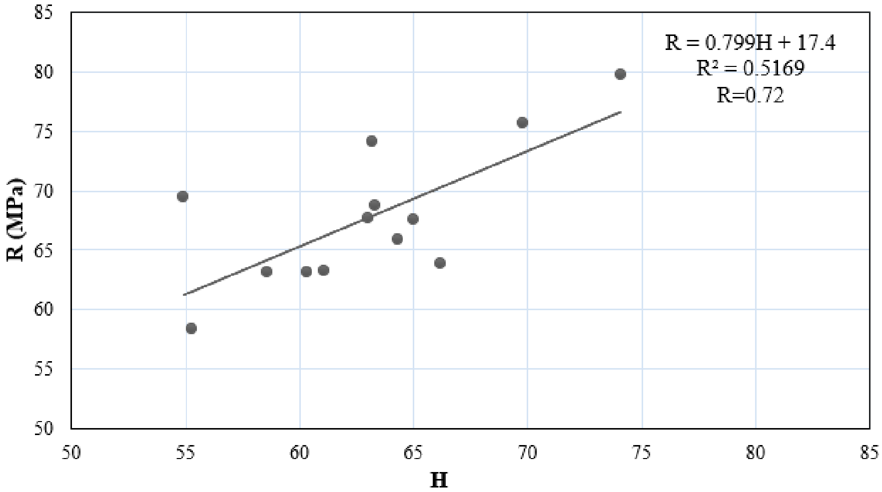

Fig. 7. Calibration dependence graph between shock impulse and pull-out test results.

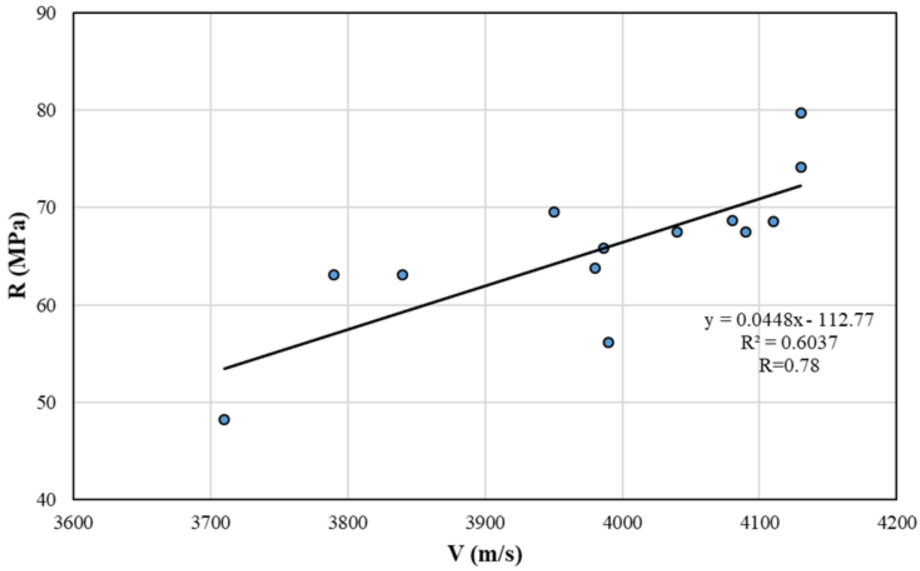

Fig. 8. Calibration dependence graph between ultrasonic and pull-out test results.

3.2 *Method of identification of properties of concrete strength homogeneity*

The properties of concrete strength homogeneity are identified in accordance with GOST 18105-2010. The standard deviation S_m and the current variation coefficient of concrete strength V_m shall be determined for each batch of the structure. At the time of calculating impact pulse test, if the strength of the location, zone or individual structure is considered as the separate value, the standard deviation S_m of the concrete strength on the batch shall be determined by the following equation:

$$S_m = \left(S_{H.M.} + \frac{S_T}{\sqrt{n-1}}\right)\frac{1}{0.7r + 0.3} \qquad (3)$$

Where S_T is the estimated standard deviation of the used calibration curve, MPa is calculated from the following formula:

$$S_T = \sqrt{S^2_{T.H.M} + S^2_{T.P.M}} \tag{4}$$

Where, $S_{T.P.M}$ is the standard deviation of the direct non-destructive test, which is considered equal to: in case of pull-out test, 0.04 of average concrete strength in positions used for the calibration curve creation with 48 mm anchor setting depth according to GOST 18105-2010.

Here, r is the correlation coefficient, which can be calculated at the time of creation of the calibration curve. If the number of individual values of the concrete strength in the batch is 2 to 6, the standard deviation S_m can be determined by using the following equation,

$$S_m = \frac{W_m}{\propto} \tag{5}$$

Where, α is the coefficient that shall be applied as per Table 1.

Table 1
Value of coefficient α in accordance with the number of individual values, n

Number of individual values, n	2	3	4	5	6
Coefficient, α	1.13	1.69	2.06	2.33	2.5

Table 2
Calculation of adjustment coefficient

No.	Axes	Anchor Slip (mm)	Separation Size (mm)	Concrete Strength (MPa)		Adjustment Coefficient, K	
				Depth	Surface	Section	Average
1.	B-C/2-3	2.3	90x180	71.1	65.9	1.09	
2.	B-C/3-4	2.2	100x170	72.9	68.7	1.06	1.08
3.	B-C/3-4	1.1	100x145	65.8	59.6	1.10	

The current variation coefficient of concrete strength V_m in the batch of structure can be calculated as per the following formula:

$$V_m = \frac{S_m}{R_m} 100 \tag{6}$$

Where, R_m is the original average concrete strength in the structure, MPa, which can be calculated by applying the following formula:

$$R_m = \frac{\sum_{i=1}^{n} R_i}{n} \tag{7}$$

Where, R_i is the individual value of the strength of the concrete, MPa;
n is the total number of individual values of the strength of concrete in the batch.

The adjustment coefficient, K is taking into account from the difference in concrete strength on the surface and in the depth of the structure, obtained by non-destructive methods and determined as per following formula in accordance with 6.1.2.10 of GOST 31914-2012.

$$K = \frac{1}{n}.\sum_{1}^{n} \frac{R_{гл}}{R_{лОВ}} \tag{8}$$

Where,
$R_{гл}$ is the concrete strength in the position of 35-50 mm depth from the structure surface, determined by direct non-destructive pull-out test, MPa;
$R_{лOB}$ is the concrete strength in the surface layer of the structure, estimated by direct non-destructive pull out test, MPa;
n is the number of test sections.

Table 3
Concrete strength of outer annular corridor wall by shock impulse

Axes of Outer Annular Wall	No. of sections	Strength of Concrete, MPa	Average strength of Concrete, MPa	Average Strength of Concrete, MPa
B-C/2-3 (Date of Concreting: 21.07.2018)	1	71.8	66.35	66.63
	2	68.8		
	3	65.7		
	4	65.6		
	5	69.1		
	6	62		
	7	66.2		
	8	61.6		
C-D/2-3 (Date of Concreting: 16.07.2018)	9	68.1	66.9	
	10	65.5		
	11	67.9		
	12	71.2		
	13	61.6		
C-D/2-4 (Date of Concreting: 22.06.2018)	14	67.1	66.1	
	15	68.5		
	16	66.1		
	17	70.2		
	18	62.7		
	19	69.9		
	20	63.3		
	21	63.8		
	22	61.5		
	23	64.2		
	24	64.9		
	25	71.4		
B-C/3-4 (Date of Concreting: 28.06.2018)	26	68	67.16	
	27	68.6		
	28	68.7		
	29	66.8		
	30	66.9		
	31	66.2		
	32	66.6		
	33	65.6		
	34	63.4		
	35	60.4		
	36	65.4		
	37	66.1		
	38	69.3		
	39	68.1		
	40	70.9		
	41	69.7		
	42	71.1		

At the time of determining the adjustment coefficient, the following conditions must be fulfilled according to GOST 22690-2015: (1) the number of test sites taken into account when determining the coincidence rate must be $n \geq 3$; (2) each particular value of $R_{гл}/R_{лOB}$ must be at least 0.7 and not more than 1.3, which means $0.7 \leq R_{гл}/R_{лOB} \leq 1.3$; (3) each separate value of $R_{гл}/R_{лOB}$ should vary from the mean value by no more than 15%, which means $0.85K_c \leq \frac{R_{гл}}{R_{лOB}} \leq 1.15K_c$. If the values of $R_{гл}/R_{лOB}$ do not satisfy the condition no. (2), then condition no (3) should not be considered when estimating the adjustment coefficient K.

3.3 Evaluation of actual concrete strength grade

Inspection and assessment of concrete grade of batches of cast-in-place structures are conducted by maintaining the following steps as per Scheme C of GOST 18105-2010:

- The actual concrete strength R_m is estimated by using the Equation (7) in the testable batch by non-destructive method.
- The current variation coefficient of concrete strength Vm is determined in the testable batch by using the formula (6), considering the error of the applied non-destructive method during calculation of the strength in Equation (3), (4) and (5).
- The actual strength grade of concrete in cast-in-place structure ($B_{\emptyset}$) at the time of inspection as per Scheme C of GOST 18105-2010 can be determined by using the following formula:

$$B_{\emptyset} = \frac{R_m}{K_T} \tag{9}$$

Where, K_T is the strength coefficient. The required strength coefficient value shall be selected from Table 2 of GOST 18105-2010. For high-strength concretes, K_T shall not be less than 1.14 according to GOST 31914-2012.

3.4 Condition of acceptance of concrete strength

The concrete strength of the batch of cast-in-place structures shall be approved if the actual concrete strength grade $B_{Φ}$ in each individual structure within this batch is not lower than the design concrete strength grade B_{HOPM}:

$$B_{\emptyset} \geq B_{HOPM} \tag{10}$$

Evaluation and approval of heavy-strength concretes on the outcomes of non-destructive tests shall be performed in accordance with 6.1.2.11 of GOST 31914-2012.

4. Calculations

4.1 Determination of adjustment coefficient

Adjustment coefficient, K is determined in three sections by using the Equation no. (8). The value of concrete strength both in surface and 40 mm depth and other related data are shown in Table 2. The average value of adjustment coefficient is found 1.08.

4.2 Calculations of concrete strength of annular corridor walls by shock impulse

Shock impulse method has been done in forty-two sections of Outer annular corridor wall according to Figure 5. The outcomes of the tests’ have been applied in the Equation no (1) to find out the actual concrete strength. The list of concrete strength for different sections of outer corridor wall is shown in Table 3. Here, the average strength of concrete is 66.63 MPa. Standard Deviation of the Statistical Values of the Table 3 is, $S_{H.M.}$=3.02 & n=42.

Table 4
Concrete strength of inner annular corridor wall by shock impulse

Axes of Outer Annular Wall	No. of sections	Strength of Concrete, MPa	Average strength of Concrete, MPa	Average Strength of Concrete, MPa
B-C/2-4 (Date of Concreting: 30.07.2018)	43	65.2	67.24	67.83
	44	71.3		
	45	69.7		
	46	67.5		
	47	66.7		
	48	69.5		
	49	60.4		
	50	73.2		
	51	66.7		
	52	59.7		
	53	69.5		
	54	64.1		
	55	74		
	56	63.8		
C-D/2-3 (Date of Concreting: 28.08.2018)	57	76.6	70.3	
	58	64.6		
	59	61.7		
	60	74.3		
	61	76		
	62	76.3		
	63	70		
	64	62.9		
C-D/3-4 (Date of Concreting: 02.08.2018)	65	75.6	66.4	
	66	66.3		
	67	63.3		
	68	60.9		
	69	65.7		
B-C/3-4 (Date of Concreting: 30.08.2018)	70	69.7	67.44	
	71	71.3		
	72	61.5		
	73	67.4		
	74	63.5		
	75	66.3		
	76	63.3		
	77	65.7		
	78	64.9		
	79	69		
	80	72.3		
	81	74.4		

From Equation no (4), $S_T = \sqrt{(4.5)^2 + (0.04 \times 66.63)^2}$ = 5.23

Where, $S_{T.H.M.}$=4.5 and Correlation Co-efficient, r=0.72 are come from the Calibration Dependence of Figure 3.4.
From Equation no (3), S_m=4.94
From Equation no (6), $V_m = \frac{4.94}{66.63} \times 100\%$=7.41%

From Table 2 of GOST 18105-2010, K_T=1.10.
According to the requirements of clause 6.1.1.12 of GOST 31914-2012, minimum value of K_T=1.14. Then, from Equation no (9), $B_{\emptyset} = \frac{66.63}{1.14}$= 58.5 MPa

The correspond class of obtained concrete strength for surface of outer annular corridor wall is B58. The concrete strength after applying Equation (1) of inner annular corridor wall from shock impulse tests is shown in Table 4.

Here, the average strength of concrete is 67.83 MPa.
Standard Deviation of the Statistical Values of the Table 4 is, $S_{H.M.}$=4.97 & n=39.

From Equation no. (4), $S_T = \sqrt{(4.5)^2 + (0.04 \times 67.83)^2}$=5.255
From Equation no. (3), S_m=7.24
From Equation no. (6), $V_m = \frac{7.24}{67.83} \times 100\%$=10.7%

From Table 2 of GOST 18105-2010, K_T=1.17 which is greater than 1.14.
Then, from Equation no (9), $B_{\emptyset} = \frac{67.83}{1.17}$= 57.97 MPa

The correspond class of obtained concrete strength for surface of inner annular corridor wall is B58. Now, taking into account the adjustment coefficient, K=1.08, the strength of concrete in the depth 40mm is 63 MPa which denotes the class B63 for both inner and outer annular corridor wall.

4.3 Calculation of concrete strength of reactor cavity wall by shock impulse

The actual concrete strength after applying Equation (1) of reactor cavity wall from shock impulse tests is explained in Table 5.

Table 5
Concrete strength of reactor cavity wall by shock impulse

Name of Structures	No. of sections	Strength of Concrete, MPa	Average strength of Concrete, MPa
Reactor Cavity Wall co-ordinate B-D/2-4 at elevation -4.900 to -1.950 (Date of Concreting: 26.10.2018)	1	74.3	73.5
	2	73.8	
	3	73.6	
	4	72.1	
	5	77	
	6	76.8	
	7	76.4	
	8	75.9	
	9	75.5	
	10	71.3	
	11	71.6	
	12	69.3	
	13	73.9	
	14	72.1	
	15	70.7	
	16	72	
	17	75.2	
	18	72.6	
	19	76.6	
	20	68.9	

Here, the average strength of concrete is 73.5 MPa.
Standard Deviation of the Statistical Values of the Table 4 is, $S_{H.M.}$=2.47 & n=20.

From Equation no (4), $S_T = \sqrt{(4.5)^2 + (0.04 \times 73.5)^2}$=5.37
From Equation no (3), S_m=4.99
From Equation no (6), $V_m = \frac{4.99}{73.5} \times 100\%$=6.79%

From Table 2 of GOST 18105-2010, K_T=1.10 which is less than 1.14. So, K_T=1.14
Then, from Equation no (9), $B_{\emptyset} = \frac{73.5}{1.14}$= 64.5 MPa

The correspond class of obtained concrete strength for surface of reactor cavity wall is B64. Now, taking into account the adjustment coefficient the concrete class of reactor cavity wall inside 40 mm depth is B69.

4.4 Calculation of concrete strength of columns by shock impulse

Shock impulse test has been conducted in six locations of each column. The actual strength of concrete after applying Equation (1) of columns from shock impulse tests is discussed in Table 6.

Table 6
Concrete strength of columns by shock impulse

Name of Structures	Axes	No. of sections	Strength of Concrete, MPa	Average strength of Concrete, MPa
Columns (fragment 1.6 and 2.6) at elevation -5.450 to -1.250 (Date of Concreting: 07.08.2018)	A-B/2-3	1	70.6	71.2
		2	71.1	
		3	71.8	
		4	70.9	
		5	70.7	
		6	71.9	
Columns (fragment 1.6 and 2.6) at elevation -5.450 to -1.250 (Date of Concreting: 02.08.2018)	D-E/2-3	1	69.1	69.9
		2	69.9	
		3	69.5	
		4	70.3	
		5	70.1	
		6	70.3	

Now, by following the similar methods of corridor walls and reactor cavity wall, the concrete class of these two columns is found B65 and B64 respectively. Applying adjustment coefficient in this case, the strength class of concrete of columns at the depth of 40mm was found B70 and B69 respectively.

4.5 Calculations of concrete strength of annular corridor walls by ultrasonic method

Ultrasonic tests have been conducted in forty-two sections of Outer annular corridor wall according to Figure 5. The results of the tests' have been applied in the Equation no (2) to calculate the actual concrete strength. The actual concrete strength for different sections of outer corridor wall is shown in Table 7.

Now, the average strength of concrete is 67.41 MPa.
Standard Deviation of the Statistical Values of the Table 3 is, $S_{H.M.}$=4.33 & n=42.

From Equation no. (4), $S_T = \sqrt{(5.3)^2 + (0.04 \times 67.41)^2}$=5.95
Where, $S_{T.H.M.}$=5.3 and Correlation Co-efficient, r=0.78 are come from the Calibration Dependence of Figure 3.5.

From Equation no. (3), S_m=6.21
From Equation no. (6), $V_m = \frac{6.21}{67.41} \times 100\%$=9.21%

Table 7
Concrete strength of outer annular corridor wall by ultrasonic test

Axes of Outer Annular Wall	No. of sections	Strength of Concrete, MPa	Average strength of Concrete, MPa	Average Strength of Concrete, MPa
B-C/2-3 (Date of Concreting: 21.07.2018)	1	64.2	65.0	67.41
	2	60.6		
	3	62.4		
	4	59.2		
	5	68.6		
	6	71.8		
	7	64.6		
	8	68.6		
C-D/2-3 (Date of Concreting: 16.07.2018)	9	69.8	69.8	
	10	70.7		
	11	72.2		
	12	70		
	13	66.4		
C-D/2-4 (Date of Concreting: 22.06.2018)	14	62.4	68.1	
	15	70.4		
	16	72.2		
	17	64.2		
	18	68.9		
	19	67.7		
	20	69.3		
	21	72		
	22	64.6		
	23	66		
	24	68.2		
	25	71.8		
B-C/3-4 (Date of Concreting: 28.06.2018)	26	75.6	66.7	
	27	72		
	28	68.7		
	29	73.1		
	30	67.3		
	31	72		
	32	72.7		
	33	68.4		
	34	65.1		
	35	62.8		
	36	63.3		
	37	66		
	38	61		
	39	59.7		
	40	60.1		
	41	61.9		
	42	63.7		

From Table 2 of GOST 18105-2010, K_T=1.13.
According to the requirements of clause 6.1.1.12 of GOST 31914-2012, minimum value of K_T=1.14. Then, from Equation no. (9), $B_{\emptyset} = \frac{67.41}{1.14}$= 59.13 MPa

The correspond class of obtained concrete strength for surface of outer annular corridor wall is B59. The concrete strength after applying Equation (2) for inner annular corridor wall from ultrasonic tests is shown in Table 8.

Table 8
Concrete strength of inner corridor annular wall by ultrasonic tests

Name of Structures	No. of sections	Strength of Concrete, MPa	Average strength of Concrete, MPa	Average Strength of Concrete, MPa
B-C/2-4 (Date of Concreting: 30.07.2018)	43	64.6	64.9	68.32
	44	63.9		
	45	61.2		
	46	67.5		
	47	65.7		
	48	63.3		
	49	61.9		
	50	59.2		
	51	64.2		
	52	63.3		
	53	64.2		
	54	65.1		
	55	71.8		
	56	72.7		
C-D/2-3 (Date of Concreting: 28.08.2018)	57	72.2	70.9	
	58	72.7		
	59	69.3		
	60	71.3		
	61	73.8		
	62	67.5		
	63	70.4		
	64	70.2		
C-D/3-4 (Date of Concreting: 02.08.2018)	65	69.8	67.9	
	66	65.1		
	67	66.8		
	68	68.2		
	69	70.2		
	70	67.7		
	71	67.5		
B-C/3-4 (Date of Concreting: 30.08.2018)	72	66.4	69.6	
	73	65.5		
	74	71.8		
	75	70.2		
	76	70		
	77	72.2		
	78	71.3		
	79	73.1		
	80	72.7		
	81	62.4		

Here, the average strength of concrete is 68.32 MPa.

Standard Deviation of the Statistical Values of the Table 3 is, $S_{H.M.}$=3.86 & n=39.

From Equation no. (4), $S_T = \sqrt{(5.3)^2 + (0.04 \times 68.32)^2}$=5.96
Where, $S_{T.H.M.}$=5.3 and Correlation Co-efficient, r=0.78 are come from the Calibration Dependence of Figure 3.5.

From Equation no. (3), S_m=5.7
From Equation no. (6), $V_m = \frac{5.7}{68.32} \times 100\%$=8.34%

From Table 2 of GOST 18105-2010, K_T=1.11.
According to the requirements of clause 6.1.1.12 of GOST 31914-2012, minimum value of K_T=1.14. Then, from Equation no. (9), $B_\emptyset = \frac{68.32}{1.14}$= 59.93 MPa

The correspond class of obtained concrete strength for surface of inner annular corridor wall is B59. Now, taking into account the adjustment coefficient for both inner and outer corridor wall, the strength class of concrete in the depth of 40 mm is B63.

4.6 Calculation of concrete strength of reactor cavity wall by ultrasonic

The concrete strength after applying Equation no (2) for reactor cavity wall by Ultrasonic method is shown in Table 9.

Table 9
Concrete strength of reactor cavity wall by ultrasonic test

Axes	No. of sections	Strength of Concrete, MPa	Average strength of Concrete, MPa
B-D/2-4 at elevation -4.900 to -1.950 (Date of Concreting: 26.10.2018)	1	67.3	66.0
	2	69.1	
	3	72.7	
	4	72	
	5	68.2	
	6	67.7	
	7	65.5	
	8	67.1	
	9	63.7	
	10	66.4	
	11	66	
	12	62.8	
	13	63	
	14	62.4	
	15	66	
	16	63.3	
	17	64.8	
	18	63.7	
	19	62.4	
	20	65.7	

Now, the average strength of concrete is 66 MPa.
Standard Deviation of the Statistical Values of the Table 9 is, $S_{H.M.}$=2.95 & n=20.

From Equation no (4), $S_T = \sqrt{(5.3)^2 + (0.04 \times 66)^2}$=5.92
From Equation no (3), S_m=5.09

From Equation no. (6), $V_m = \frac{5.09}{66} \times 100\%$=7.71%

From Table 2 of GOST 18105-2010, K_T=1.10.
According to the requirements of clause 6.1.1.12 of GOST 31914-2012, minimum value of K_T=1.14. Then, from Equation no (9), $B_{\emptyset} = \frac{66}{1.14}$= 58 MPa. The correspond class of obtained concrete strength for surface of reactor cavity wall is B58. By applying adjustment coefficient, K, the concrete strength class for reactor cavity wall at a depth 40 mm is B63.

4.7 *Calculation of concrete strength of columns by ultrasonic method*

The concrete strength after applying Equation no. (2) for columns by Ultrasonic method is shown in Table 10.

Table 10
Concrete strength for columns by ultrasonic method

Name of Structures	Axes	No. of sections	Strength of Concrete, MPa	Average strength of Concrete, MPa
Columns (fragment 1.6 and 2.6) at elevation -5.450 to -1.250 (Date of Concreting: 07.08.2018)	A-B/2-3	1	66	65.0
		2	62.1	
		3	62.8	
		4	67.3	
		5	66.8	
		6	65.1	
Columns (fragment 1.6 and 2.6) at elevation -5.450 to -1.250 (Date of Concreting: 02.08.2018)	D-E/2-3	1	63.9	64.7
		2	63.3	
		3	64.4	
		4	64.6	
		5	63.5	
		6	68.6	

By applying the similar kinds of calculations for the concrete strength class of columns, the strength class of concrete is found B58 and B57 respectively. Thus, applying the adjustment coefficient, K the concrete strength class of columns at 40 mm depth is found B63 and B62 respectively.

5. Results

The concrete strength classes of different structures of reactor building, determined by shock impulse method and taking into account the adjustment co-efficient at the depth of 40 mm are given below:

- Concrete strength class for both inner and outer corridor wall is B63
- Concrete strength class for reactor cavity wall is B69
- Concrete strength classes for Columns are B70 and B69 respectively.

Moreover, concrete strength classes of different structures of reactor building, determined by ultrasonic method and taking into account the adjustment co-efficient at the depth of 40 mm are given below:

- Concrete strength class for both inner and outer corridor wall is B63
- Concrete strength class for reactor cavity wall is B63
- Concrete strength classes for Columns are B63 and B62 respectively.

6. Conclusions

All the test procedures and calculations have been done in this research by following the rules and regulations of GOST code. Observations made from this experiment are given below:

- The concrete strength classes found in the depth of 40 mm of different structures of reactor facility, unit-1 of Rooppur NPP is above B60 which ensure the satisfactory performance of the construction work.
- Shock impulse, ultrasonic and pull-out tests are applied on the structures by following the methodology of GOST 22690-2015 and GOST 17624-2012.
- All the calculations of this experiment have been completed according to GOST 18105-2010 and GOST 31914-2012.
- Experimentally established Calibration dependences from previous research have been used here, which play an important role to determine the actual strength classes from the results of shock impulse and ultrasonic testing.
- The strength of the concrete surface is lower by 8% than the concrete strength at the depth of 40 mm.

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