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Development of calibration dependences between different types of non-destructive testing applied on B60 concrete structures in reactor building of Rooppur nuclear power plant

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Abstract

The objective of this research is to establish relationship through developing calibration dependences between various types of non-destructive testing on B60 concrete structures in reactor building of Rooppur nuclear power plant. Calibration dependence between two types of non-destructive testing is necessary to find out the original strength class of concrete structure. Three Non-destructive testing (NDT) have been used in this research which are shock impulse method, ultrasonic method and pull-out method. Among these methods, shock impulse method and ultrasonic method are indirect non-destructive methods whereas pull-out is a direct non-destructive test. Two types of calibration dependences have been developed from the test results of three types of NDT methods. One calibration dependence has been developed between the test results of shock pulse method and pull-out test method where correlation co-efficient is 0.72 and standard deviation is 4.51. Another one calibration dependence has been constructed between the test values of ultrasonic method and pull-out method where correlation co-efficient is 0.78 and standard deviation is 5.34. In both cases, correlation co-efficient and standard deviation meet the requirements of GOST 22690-2015. Moreover, each individual concrete strength value of pull-out test for both cases is within the limit of 0.7 to 1.3 times of the average concrete strengths in accordance with GOST 22690-2015.

Keywords: Non-destructive test, Shock impulse method, Ultrasonic method, Pull-out test, Calibration dependence.

1. Introduction

Rooppur Nuclear Power Plant is the largest project of Bangladesh which is situated in Pabna district and its co-ordinate is 24º4/0// North and 89º2/50// East. Russian Federation plays an important role for the implementation of this plant. As this power plant is the first nuclear power plant of Bangladesh, the quality of the construction work is necessary to supervise properly for the safe operation of this plant. The quality of the concrete is required to be tested for ensuring the serviceability of the structure. There are different types of testing methods for the inspection of concrete properties. The common method of determining the quality of concrete is to collect the cube or cylindrical test specimens of different size and shape during the time of construction for compressive strength test of concrete. However, the quality checkup of concrete of an existing structure is not possible in such a way. For the purpose of proper maintenance of an existing civil infrastructure, new methods of concrete quality checkup are required. Rens et al. 1997 showed their opinion on better investigation methods for deteriorating infrastructure.

To investigate the characteristics of concrete of an existing structure, non-destructing testing (NDT) is a suitable process. Non-destructive testing (NDT) can be described as the sequence of examining, testing, or assessing materials, components or assemblies without destroying the serviceability of the part or structure (Workman and O. Moore, 2012). According to Helal et al. 2015, the objective of NDT is to notice the characteristics and nature of the materials, components or assemblies without harming the capacity to accomplish their projected roles. When a test procedure does not influence the future usefulness of a component or structure, it is considered to be non-destructive even if it consists of aggressive activities. For example, coring, a well-known NDT method and used to determine concrete properties, slightly affects structural integrity.

Breysse et al. (2008) indicated different kinds of objectives of NDT methods such as to identify the condition of reinforced concrete (RC) structures, classify the structures according to current condition, and compare the various properties based on threshold values. In this paper, three popular NDT methods, Shock impulse, Ultrasonic and Pull-out have been used to evaluate the properties of B60 concrete in the reactor building of Rooppur Nuclear Power Plant. Calibration dependence between NDT methods is important to determine the actual strength class of concrete structures. Here, two calibration dependences have been developed from the test results of three types of NDT methods whereas, one is between shock impulse and pull-out test and another one is between ultrasonic and pull-out test. Moreover, the correlation co-efficient has been determined from these relationships. The justification of these relationships has been done by following the methodology of GOST 22690-2015.

2. Non-destructing testing (NDT)

In case of destructive testing, the mechanical properties of material such as yield strength, compressive strength, tensile strength, ductility and fracture toughness are evaluated through failure mechanisms. On the other case, NDT methods evaluate indications of features without reaching component or assembly failures (Helal et al. 2015). There are several types of Non-Destructing Testing (NDT) of concrete structure to identify the concrete strength for the purpose of building safe and sustainable civil infrastructure. Rens and Kim (2007) performed different types NDT methods of visual inspection, hammer sounding, Schmidt hammer, and UPV testing including tomographic imaging on a steel bridge to determine areas, compressive strength, chloride testing, and petrographic testing.

Zhu and Popovics (2007) performed air coupled impact echo (IE) for NDT of concrete structures, where air couple sensor is a small (6.3 mm diameter) dimension microphone positioned several cms above the top surface of the concrete. They showed that the outcomes of the air-coupled sensors are effective for IE experiments. McCann and Forde (2001) discussed five different types of NDT methods. These are sonic/ultrasonic, electromagnetic methods, electrical methods, infra-red thermography and radiography.

Maierhofer et al. (2010) elaborated deterioration mechanisms of reinforced concrete structures with standard NDT testing procedures, which was microscopic examination of concrete for the estimation of chloride content.

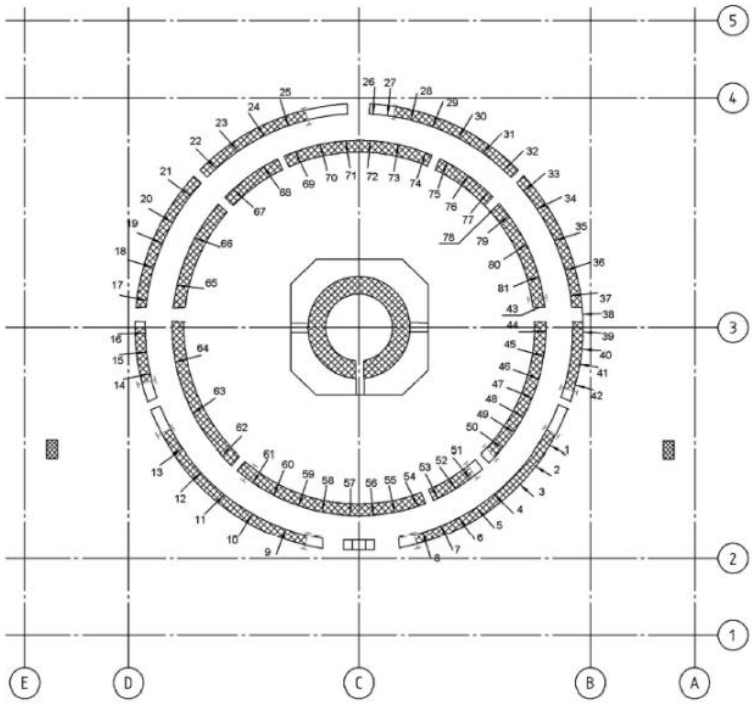


Fig. 1. Different sections of inner and outer corridor wall have been numbered for NDT.

In GOST 22690-2015, titled “Concretes. Determination of strength by mechanical methods of non-destructive testing”, described several non-destructive mechanical methods for determining the strength of concrete such as impact, tear, cleavage, indentation, separation with chipping, elastic rebound. In these methods, the strength of concrete is determined directly in the structure with a local mechanical impact on the concrete. On the other hand, there are indirect non-destructive methods for determining the strength of concrete where, the strength of concrete is determined according to predetermined calibration dependencies. According to GOST 22690-2015, calibration dependence is a graphical or analytical relationship between an indirect characteristic of the strength and compressive strength of concrete, evaluated by one of the destructive or direct non-destructive procedures. Pull-out is direct non-destructive test methods whereas, shock impulse and ultrasonic are indirect non-destructive test methods.

Verma et al. (2013) indicated that the combination of several NDT methods for evaluating the structures is required for better assessment. As NDT results are complex and it has been tough to realize the results of NDT, combination of several methods has been important to strengthen the results of each other. In this paper, two relationships have been established between indirect non-destructive testing (Shock impulse and Ultrasonic) and direct non-destructive testing (Pull-out test).

3. Test procedure

Non-destructive tests have been done in both inner and outer corridor wall in 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. The age of the concrete is more than nine months. The shock impulse method and pull-out test have been performed in accordance with GOST 22690-2015. On the other hand, ultrasonic method has been done following GOST 17624-2012. The number of different sections in inner and outer annular wall has been shown by zig-zag line in Figure 1. Number and location of these sections for testing are selected as per the requirements of GOST 18105-2010 depending on the structure type, tasks of testing.

3.1 Shock impulse method

The device of IPS-MG4.03, serial number 6006 has been used, when shock impulse method has been performed. Before shock impulse tests, it is important to check the concrete strength estimation device IPS-MG4.03 using a reference block that is supplied together with the device. In Figure 2(a), a reference prism was used to check the shock impulse machine and the result of strength was shown in Figure 2(b). The standard value of strength of the reference prism is 30 ± 1.5 MPa. Device reading shall not vary from values shown on the test specimen for more than 5%. Tests are executed as per GOST 22690-2015 on the structure section of 100-900 cm^2. According to GOST 22690-2015, the device is placed in such way that the force is applied perpendicular to the test surface in accordance with the instrument manual of the device. In Figure 3, shock impulse tests have been occurred in annular floor wall. One should pull the striker lever until it is fixed with the latch to make measurements. Thus, the converter is located on three supporting points perpendicularly to the surface of the tested item and the converter is held in the hand. Then, the converter is pressed tightly against the surface of the item. Here, the force of pressing should be so hard so that when the striker strikes the concrete surface. The converter's supporting points would become on the surface of the tested item. After that the trigger is pressed. Due to the impact, the electronic unit display will show measurement results. Simultaneously with the measurement result the display shows its index number (R01…R15). Moreover, the lower line of the display shows the number of archive cell (e.g., N.018) where the result will be recorded.

Fig. 2(a). Checking the shock impulse machine using reference prism.

Fig. 2(b). Result of calibration test.

A measurement cycle on one section consists of 10-15 measurements depending on the Operator's discretion. In this research, 15 measurements are used to complete a cycle. After the completion of a cycle of fifteen measurements, automatic processing of results is taken place and the display shows arithmetic mean strength out of fifteen single outcomes. If the number of single measurements is lower, the 'ENTER' button will be pressed for processing of results. If any attained strength value is beyond the measurement range during the assessments (below 3 MPa or over 100 MPa), the display shows "Out of range!".

Fig. 3. Shock pulse test on annular floor walls.

Fig. 4. Ultrasonic measurement of concrete of annular wall.

Concrete strength on the tested section shall be determined based on the average value of an indirect indicator recorded by the IPS-MG4.03 device based on the calibration curve developed from the shock impulse test's strength and pull-out test's strength of the same section.

3.2 Ultrasonic test

A device, UK 1401 with 150 millimeters (mm) base and serial number 6006 has been used for the measurement of ultrasonic. According to GOST 17624-2012, ultrasonic measurement is conducted by instruments designed to determine the time and speed of propagation of ultrasonic in concrete, certified and attorneys in the prescribed way. There should be a reliable acoustic contact between the concrete surface and the working surfaces of the ultrasonic transducers. This procedure if confirming contact must be the same when monitoring concrete in a structure and developing a calibration dependence. The direct determination of concrete strength is not possible by using of ultrasonic devices. An indirect indicator is used to determine the concrete strength after the establishment of calibration dependence between instrument reading and concrete strength. The measurement of ultrasonic has been shown in Figure 4.

Minimum two measurements should be taken with surface sounding and one measurement with continuous sounding on each section of the structure according to clause 7.8 of GOST 17624-2012. Moreover, the deviation of an individual measurement result of an indirect indicator in each sample from the arithmetic mean of the measurement results for a given sample should not exceed 2% in accordance with GOST 17624-2012. Further, there must not be presence of any shells and air pores with a depth of more than 3 mm and a diameter of more than 6 mm, as well as protrusions with a height of more than 0.5 mm in the contact zone of ultrasonic transducers with the concrete surface. Also, the surface of concrete should be free of dust.

3.3 Pull-out test

The testing area should be inspected before starting the test of pull-out techniques. A device POS 50MG4 No.927 with anchor device type II at the depth of the anchor device 48mm has been used in this test. A visual inspection is carried out for identifying the presence of visible cracks, the boundaries of the concreting tiers, chips and concrete flows and determining the location and depth of the reinforcement. The location of the rebar is selected by Rebar Locator (Shown in Figure 5a). An area of 100-900 cm^2 is chosen for pull-out testing in between the rebar as per GOST 22690-2015. The hole for placing the anchor is drilled in the center of the reinforcement cells (Shown in Figure 5b) after identifying the reinforcement mesh at a distance of at least 150 mm from the borders of the concrete layers.

Fig. 5(a). Usage of Rebar Locator.

Fig. 5(b). Drilling of 48 mm hole for placing Anchor.

There should be no visible defects (cracks, chips and concrete inflows) within a radius of 90 mm from the hole center. The hole must not be closer than 70 mm from the nearest rebar or embedded part. Tests are conducted using the anchor device with 24 mm diameter and embedding depth of 48 mm, which is type II according to GOST 22690-2015. As the working depth of the anchor is more than 40 mm, one measurement on test place should be taken according to GOST 22690-2015. After the completion of drilling work, the hole must be clean to remove the dust which is shown in Figure 6(a). For the preparation of the anchor device, the rod is screwed with a micrometer nut onto the threaded shank of the anchor device according to Figure 6(b).

The anchoring device is placed with a plow into the prepared hole until the leveling washer stops against the concrete surface. Figure 7(a) displays the set-up of pull-out testing machine named POS-50MG4U. In Figure 7(b), pull-out test is performed by uniformly rotating the loading knob clockwise, where the loading speed must be maintained in between 1.5 and 3 kN/s. The loading speed is shown in the upper line of the display.

Fig. 6(a). Clearing dust from the hole.

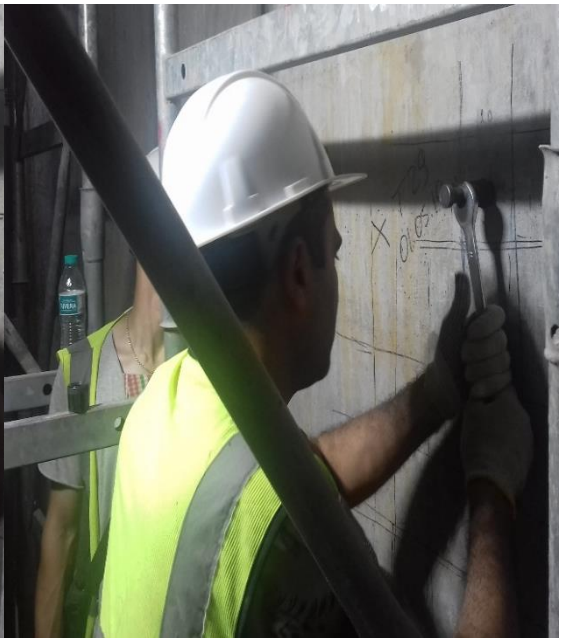


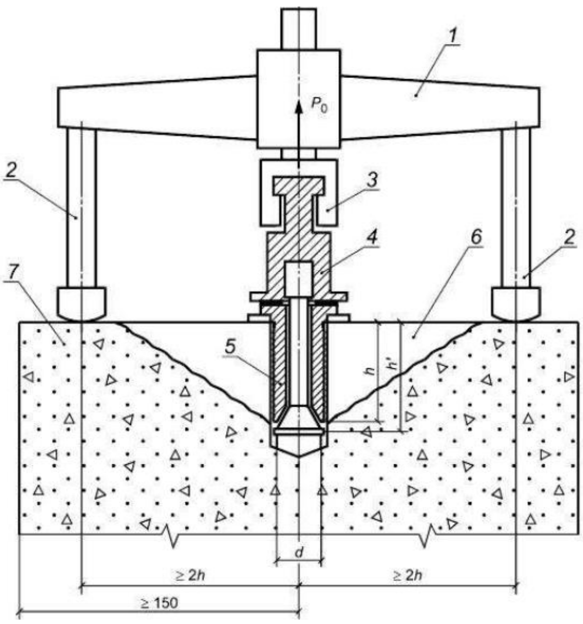
Fig. 6(b). Placing & tighten the anchor.

Fig. 7(a). Set-up of pull-out test instrument.

Fig. 7(b). Pull-out test is conducted.

The anchor is loaded continuously until the fragment of concrete is torn off and the load is fixed. It has been noted that when the maximum load is exceeded, the display shows indication such as accompanied by an intermittent beep. In such case, the test is stopped and the loading handle is rotated counterclockwise to return exciter to its initial state. After that, the micrometer nut is tightened all the way into the concrete surface and the amount of slip of the anchor, h is determined with an accuracy of ± 0.1 mm, as the division value of micrometer nut is 0.1 mm. Thus, the slip difference value Δh, read from micrometer nut is entered to the displacement sensor to find out the correct values of Force (P) and Strength (R).

The mechanism of standard pull-out test set-up is displayed in Figure 8, which is stated in GOST 22690-2015. This standard test set-up can be used in the following conditions: (1) tests of heavy concrete with compressive strength from 5 to 100 MPa, (2) tests of light –weight concrete with compressive strength from 5 to 40 MPa and (3) the maximum fraction of coarse aggregate of concrete is not more than the working depth of embedding anchor devises. The supports of the loading device must be evenly assembling the surface of the concrete at a distance of at least 2h from the axis of the anchor device, where h is the working depth of the anchor device.



1 - device with a loading device and a load cell; *2* - support loading device; *3* - gripping the loading device; *4* - transition elements, thrust; *5* - anchor device; *6* - breakable concrete (separation cone); *7* - tested design

Fig. 8. Scheme of pull-out testing (GOST 22690-2015).

In Figure 9(a), displacement sensor shows the result of the test after inputting the value of anchor slip. Figure 9(b) represents the destruction area due to the pull-out test. If the maximum and minimum dimensions of pulled out concrete area from the anchoring devices to the boundaries of destruction along the surface of the structure differ between each other more than twice, and also if the depth of pulled out section varies from the depth of anchoring device embedding more than by 5% ($\Delta h > 0.05h$), then test outcomes may only be taken into account approximate assessment of concrete strength.

4. Methodology of developing of calibration dependence

The calibration dependence between different types NDT tests has been established in accordance with GOST 22690-2015. Moreover, the justification of this calibration dependence has been done by following the methodology of GOST 22690-2015.

4.1 Derivation of calibration dependence equation

According to GOST 22690-2015, the relationship between the indirect and direct characteristics of strength can be expressed by the following linear formula,

$$R = aH + b \tag{1}$$

Fig. 9(a). Displacement sensor shows the result of strength and force.

Fig. 9(b). Measuring the length of destruction.

Where, R is the direct strength of concrete found from pull-out testing.
H is the indirect characteristics of strength found from Shock Impulse test or, Ultrasonic test
a and b are the coefficients calculated by the following formulas,

$$b = \bar{R}_{\emptyset} - a\overline{H} \tag{2}$$

$$a = \frac{\sum_{i=1}^{N}(R_{i\emptyset} - \bar{R}_{\emptyset})(H_i - \bar{H})}{\sum_{i=1}^{N}(H_i - \bar{H})^2} \tag{3}$$

Where, $R_{i\phi}$ is the strength of concrete in the i-th section, determined by testing with a direct non-destructive method. H_i is the strength of indirect characteristic in the i-th area, determined indirect non-destructive method. N is the number of individual samples used to construct the calibration dependence.
The average values of concrete strength, $\bar{R}_{\emptyset}$ and indirect characteristics, $\bar{H}$ can be calculated by the following formulas:

$$\bar{R}_{\emptyset} = \frac{\sum_{i=1}^{N} R_{i\emptyset}}{N} \tag{4}$$

$$\bar{H} = \frac{\sum_{i=1}^{N} H_i}{N} \tag{5}$$

4.2 Conditions of rejection of test results

The calibration dependence is corrected by rejection of single test results that do not satisfy the following condition discussed in GOST 22690-2015:

$$\frac{|R_{iH} - R_{i\emptyset}|}{S} \leq 2 \tag{6}$$

Here, R_{iH} is the concrete strength in the i-th section, estimated by the considered calibration dependence. S is the residual standard deviation determined by the following formula:

$$S = \sqrt{\frac{\sum_{i=1}^{N}(R_{i\emptyset} - R_{iH})^2}{N-2}} \tag{7}$$

After rejection of a test result due to not fulfilling the condition (6), the calibration dependence is determined again by using the formulas from Equation (1) to Equation (5) according to the remaining test results. The rejection of the remaining test results is repeated, considering the condition (6) at the time of using new calibration dependence. Each individual value of concrete strength should fulfill the requirements that deviations of individual concrete strength $R_{i\emptyset}$ from the average concrete strength $R_{\emptyset}$ on locations, used for formation of the calibration curve should be within 0.7 to 1.3 of the average concrete strength, where, 50 MPa < $R_{\emptyset} \leq$ 80 MPa.

4.3 Acceptance of parameters of calibration dependence

For the acceptance of calibration dependencies, it is necessary to determine the minimum and maximum value of the indirect characteristic (H_{min} and H_{max}). The standard deviation, $S_{T.H.M.}$ is derived calibration dependence according to the formula in Equation (7). The correlation coefficient of the calibration dependence, r can be calculated according to the following formula:

$$r = \frac{\sum_{i=1}^{N}(R_{iH} - \bar{R}_H)(R_{i\emptyset} - \bar{R}_{\emptyset})}{\sqrt{\sum_{i=1}^{N}(R_{iH} - \bar{R}_H)^2}\sqrt{\sum_{i=1}^{N}(R_{i\emptyset} - \bar{R}_{\emptyset})^2}} \tag{8}$$

Where, $\bar{R}_H$ is the average value of concrete strength according to the calibration dependence, which can be calculated by the following formula:

$$\bar{R}_H = \frac{\sum_{i=1}^{N} R_{iH}}{N} \tag{9}$$

4.4 Conditions of applying calibration dependence

The use of calibration dependence to estimate the concrete strength according to the discussed standard is valid only for the values of indirect characteristics staying within the range from H_{min} to H_{max}. If the correlation coefficient, r <0.7 or, a value of $S_{T.H.M.}/\bar{R}_{\emptyset} > 0.15$, thus the monitoring and calculation of strength based on the obtained dependence are not accepted.

5. Results and discussion

According to the clause 6.2.2 of GOST 22690-2015, the minimum number of unit values for the construction of the calibration dependence on the test results of the strength of concrete in any structures is twelve. For the construction of calibration dependence between strength of shock impulse and pull-out test, results of twelve sections have been selected. In these results, pull-out test results of nine sections have been met all the requirements of both anchor slippage and size of destruction. However, results of three sections did not fulfil the requirement of size of destruction. The test results are described in Table 1. Test result no. 5, 11 and 12 have destruction ratio more than twice; which exceed the requirement of clause 7.6.4 of GOST 22690-2015. Calculation of co-efficient, a and b has been done according to the Equation no. (2) and (3).

Table 1
Determination of calibration dependence between shock pulse and pull-out test results

No	Section No. (Axes)	Anchor slippag-e Δh (mm)	Size of Destruction (mm x mm)	Shock Pulse test reading, H (MPa)	Pull-out Test reading, R (MPa)	a	b	R=a*H+b
1	2(B-C/2-3)	2	90x175	64.3	65.9	0.799	17.4	0.799H+17.4
2	46(B-C/2-4)	2.2	100x140	65	67.5			
3	50(B-C/2-4)	1.9	110x165	69.8	75.7			
4	23(C-D/2-4)	2.2	135x270	60.3	63.1			
5	11(C-D/2-3)	2	95x200	63.2	74.1			
6	8(B-C/2-3)	1.7	140x235	55.3	58.4			
7	4(B-C/2-3)	2.3	120x220	58.6	63.1			
8	53(B-C/2-4)	1.9	95x180	54.9	69.5			
9	56(B-C/2-4)	2.3	100x180	66.2	63.8			
10	57(C-D/2-3)	2	105x185	74.1	79.7			
11	37(B-C/3-4)	2.4	100x210	61.1	63.2			
12	34(B-C/3-4)	2.3	80x185	63.3	68.7			

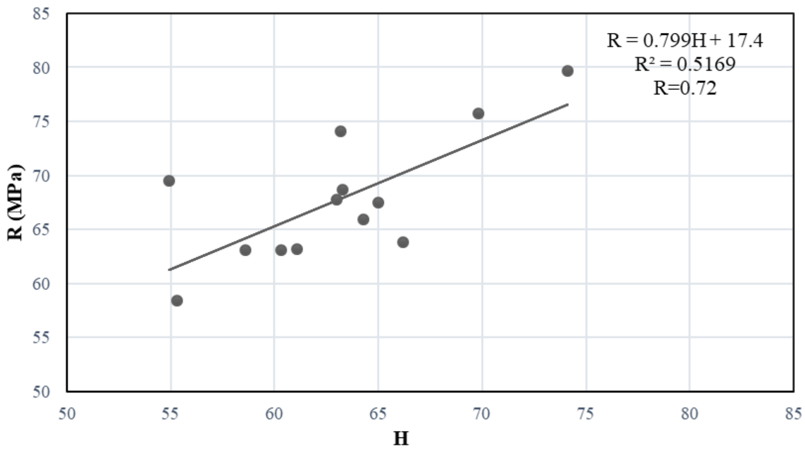


Fig. 10. Calibration dependence graph between shock pulse test & pull-out test results.

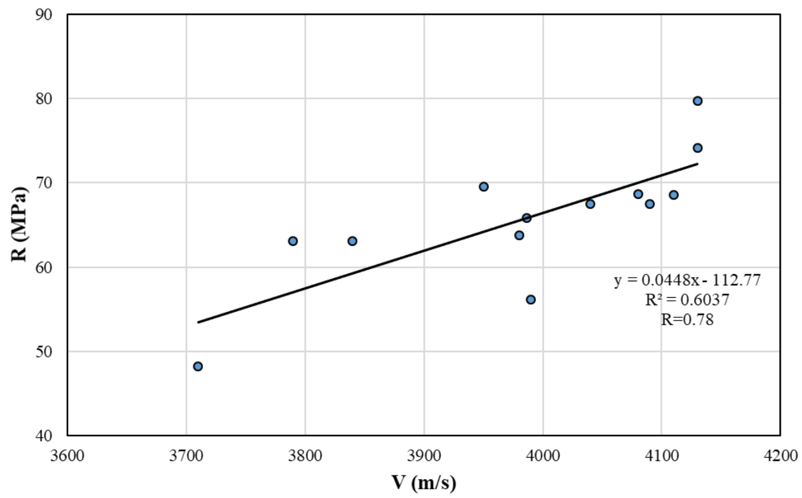


Fig. 11. Calibration dependence graph between ultrasonic test & pull-out test results.

A graphical representation of relationship between Shock pulse test result and pull-out test result has been shown in Figure 10. From this relationship, the calibration dependence equation has been found $R = 0.799H + 17.4$ and the correlation co-efficient has been found

R=0.72; which is greater than 0.7 and fulfils the requirement of clause 6.1.6 of GOST 22690-2015. The verification of the equation of calibration dependence has been done in Table 2. Each value of shock pulse test has been used to find out the value of R_{iH}. Hence, Standard Deviation (S) has been calculated according to the Equation no. (7); which is found 4.51 that do not exceed 15% of the average strength value (67.73 MPa). Then, relationship described in Equation no. (6) has been checked for this calibration dependence in where all the test results have been passed. Further, the acceptance of concrete strength of pull-out testing has been done in Table 3. Each individual value of concrete strength is within the 0.7 to 1.3 times of the average concrete strengths; which also indicates the fulfillment of requirement.

Table 2
Justification of calibration dependence between shock pulse test & pull-out test

No.	R_{iH}	$(R_{i\varphi}-R_{iH})$	$(R_{i\varphi}-R_{iH})^2$	Standard Deviation, S	$\frac{\lvert R_{iH}-R_{i\varphi}\rvert}{S} \leq 2$	Status Fulfilled on Condition
1	68.78	-2.88	8.27	4.51	0.64	Ok
2	69.34	-1.84	3.37		0.41	Ok
3	73.17	2.53	6.40		0.56	Ok
4	65.58	-2.48	6.15		0.55	Ok
5	67.90	6.20	38.48		1.38	Ok
6	61.58	-3.18	10.14		0.71	Ok
7	64.22	-1.12	1.26		0.25	Ok
8	61.27	8.23	67.81		1.83	Ok
9	70.29	-6.49	42.17		1.44	Ok
10	76.61	3.09	9.57		0.69	Ok
11	66.22	-3.02	9.11		0.67	Ok
12	67.98	0.72	0.52		0.16	Ok

Table 3
Verification of concrete strength on pull-out testing during constructing calibration dependence between shock impulse and pull-out test

No.	Concrete Strength of Pull-out Test, $R_{i\varphi}$ (Mpa)	$0.7*R_{\varphi}$	Status Fulfilled the Condition $0.7*R_{\varphi}<R_{i\varphi}$	$1.3*R_{\varphi}$	Status Fulfilled the Condition $R_{i\varphi}<1.3*R_{\varphi}$
1	65.9	47.41	Ok	88.04	Ok
2	67.5		Ok		Ok
3	75.7		Ok		Ok
4	63.1		Ok		Ok
5	74.1		Ok		Ok
6	58.4		Ok		Ok
7	63.1		Ok		Ok
8	69.5		Ok		Ok
9	63.8		Ok		Ok
10	79.7		Ok		Ok
11	63.2		Ok		Ok
12	68.7		Ok		Ok
	Average, R_{φ}: 67.73				

In case of construction of calibration dependence between ultrasonic test and pull-out test, test results of twelve sections have been selected according to the clause 6.2.2 of GOST 22690-2015. In these results, pull-out test results of eight sections have been met all the requirements of both anchor slippage and size of destruction. However, results of four sections did not fulfil the requirement of size of destruction. Here, test result no. 1, 2, 6 and 12 have destruction ratio more than twice; which exceed the requirement of clause 7.6.4 of GOST 22690-2015.

All the test results and calculation of co-efficient of calibration dependence has been shown in Table 4. From this relationship, the calibration dependence equation has been found $R = 0.0448V - 112.8$. Further, a graphical representation of relationship between ultrasonic test result and pull-out test result has been shown in Figure 11. The correlation co-efficient has been found R=0.78; which is greater than 0.7 and fulfils the requirement of clause 6.1.6 of GOST 22690-2015.

Table 4
Determination of calibration dependence between ultrasonic test and pull-out test results

No.	Section No. (Axes)	Anchor slippage Δh (mm)	Size of Destruction (mm x mm)	Velocity at Ultrasonic testing, V (m/s)	Concrete Strength of Pull-out Test, R (MPa)	a	b	R=a*V+b
1	3(B-C/2-3)	2.4	95x215	3710	48.2	0.0448	-112.8	0.0448V-112.8
2	28(B-C/3-4)	2.3	80x185	4080	68.7			
3	46(B-C/2-4)	2.2	100x140	4040	67.5			
4	4(B-C/2-3)	2.2	135x270	3840	63.1			
5	5(B-C/2-3)	2	135x230	3990	56.1			
6	11(C-D/2-3)	2	95x200	4130	74.1			
7	23(C-D/2-4)	2.3	120x220	3790	63.1			
8	53(B-C/2-4)	1.9	95x180	3950	69.5			
9	56(B-C/2-4)	2.3	100x180	3980	63.8			
10	57(C-D/2-3)	2	105x185	4130	79.7			
11	60(C-D/2-3)	1.7	110x180	4090	67.5			
12	64(C-D/2-3)	2	105x220	4110	68.6			

Table 5
Justification of calibration dependence between ultrasonic test & pull-out test

No.	R_{ih}	$(R_{i\varphi}-R_{iH})$	$(R_{i\varphi}-R_{iH})^2$	Standard Deviation, S	$\frac{\lvert R_{iH} - R_{i\varphi}\rvert}{S} \leq 2$	Status on fulfilling the Condition
1	53.41	-5.21	27.12	5.34	0.97	Ok
2	69.98	-1.28	1.65		0.24	Ok
3	68.19	-0.69	0.48		-0.13	Ok
4	59.23	3.87	14.96		-0.72	Ok
5	65.95	-9.85	97.06		-1.84	Ok
6	72.22	1.88	3.52		-0.35	Ok
7	56.99	6.11	37.31		-1.14	Ok
8	64.16	5.34	28.52		1.00	Ok
9	65.50	-1.70	2.90		0.32	Ok
10	72.22	7.48	55.89		1.40	Ok
11	70.43	-2.93	8.60		0.55	Ok
12	71.33	-2.73	7.44		-0.51	Ok

The justification of the equation of calibration dependence has been done in Table 5. Each value of ultrasonic test has been used to find out the value of R_{iH} Thus, Standard Deviation (S) has been determined according to the Equation no. (7); which is found 5.34 that does not exceed 15% of average strength value (65.825 MPa).

Finally, relationship described in Equation no (6) has been supervised for this calibration dependence in where all the test outcomes have been passed. Moreover, the acceptance of concrete strength of pull-out testing has been done in Table 6; where each individual value of concrete strength is within the 0.7 to 1.3 times of the average concrete strengths; which also indicates the fulfillment of requirement.

Table 6
Verification of concrete strength on pull-out testing during constructing calibration dependence between ultrasonic and pull-out test

No.	Concrete Strength of Pull-out Test, $R_{i\varphi}$ (Mpa)	$0.7*R_{\varphi}$	Status Fulfilled the Condition $0.7*R_{\varphi}<R_{i\varphi}$	$1.3*R_{\varphi}$	Status Fulfilled the Condition $R_{i\varphi}<1.3*R_{\varphi}$
1	48.2	46.08	Ok	85.573	Ok
2	68.7		Ok		Ok
3	67.5		Ok		Ok
4	63.1		Ok		Ok
5	56.1		Ok		Ok
6	74.1		Ok		Ok
7	63.1		Ok		Ok
8	69.5		Ok		Ok
9	63.8		Ok		Ok
10	79.7		Ok		Ok
11	67.5		Ok		Ok
12	68.6		Ok		Ok
	Average, R_{φ}: 65.825				

6. Conclusion

All the procedures and calculations used in this research have been done and supervised according to the GOST regulations. Following observations have been made based on the outcomes of this research:

- Correlation co-efficient values of two calibration dependences have been found 0.72 and 0.78 respectively; that are more than acceptance value 0.7 according to GOST 22690-2015.
- Standard deviation values for two calibration dependence are 4.51 and 5.34, which do not exceed the limit of 15% of corresponded average strength according to the clause 6.1.6 of GOST 22690-2015 (67.73 and 65.825 MPa respectively).
- Each individual concrete strength value of pull-out test for both cases is within the limit of 0.7 to 1.3 times of the average concrete strengths in accordance with the clause 6.1.7 of GOST 22690-2015.
- All the anchor slippage values of pull-out testing for both cases are within the limit of 5% of embedding depth of anchor device following the GOST 22690-2015 (for 48 mm embedding depth, anchor slippage limit is 2.4 mm). However, total seven sections' destruction values differ more than two times. In these cases, test results are considered only for an indicative assessment of the strength of concrete according to clause 7.6.4 of GOST 22690-2015.

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