

ЕКСПЕРИМЕНТАЛЕН АНАЛИЗ НА ВЛИЯНИЕТО НА ИНТЕРВАЛА МЕЖДУ ПОСЛЕДОВАТЕЛНИТЕ ИЗЛИВАНИЯ ВЪРХУ ОБРАЗУВАНЕТО НА СТУДЕНИ ФУГИ И ВОДОПРОПУСКЛИВОСТТА НА БЕТОНА

**Юстас Бержинис, Арунас Сташаускас, Свайюнас Юочюнас, Миндаугас
Даукшис**

EXPERIMENTAL ANALYSIS OF THE EFFECT OF POURING INTERVAL ON COLD JOINT FORMATION AND WATER PERMEABILITY IN CONCRETE

Justas Beržinis¹, Arūnas Stašauskas², Svajūnas Juočiušas³, Mindaugas Daukšys⁴

Abstract:

This study examines the water permeability and depth of water penetration in concrete specimens with cold joints formed at different time intervals under pressure. Laboratory tests were performed to evaluate two criteria: the water permeability limit based on the orientation of the cold joint relative to the water-pressure jet, and the water penetration depth under pressure. Results of water permeability tests revealed a strong dependence on cold joint orientation. When cold joints were aligned parallel to the water-pressure jet, specimens with cold joints became permeable at only 0.4 MPa, failing to meet the required permissible limit of 0.8 MPa for water-depth penetration. Conversely, test specimens with and without a cold joint, tested perpendicular to the water-pressure jet, withstood pressures up to 1.0 MPa without water leakage. Water penetration tests indicate that all specimens with cold joints showed average penetration depths exceeding the permissible 20 mm limit and maximum depths exceeding the 50 mm limit set by LST 1974:2012 (Annex O). No significant correlation was observed between the delay time of second-layer placement and the penetration depth values. Only the test specimen of the B-2-0 mixture satisfied the water penetration criteria. The findings confirm that cold joints increase the water permeability of concrete and exceed the permissible average and maximum limits for water-depth penetration, particularly when aligned with the direction of a water-pressure jet. This behaviour aligns with trends reported in the scientific literature, which emphasise reduced structural performance and increased permeability through cold joints.

Keywords:

Concrete, Pouring interval, Cold joint, Water permeability, Depth of water penetration under pressure

¹ Master student, Faculty of Civil Engineering and Architecture, Kaunas University of Technology, Studentų str. 48, Kaunas, Lithuania, berzinis.juscus@gmail.com;

² Engineer, UAB Doka Lietuva, Vilniaus str. 9 Vilnius, Lithuania, stasauskas@gmail.com;

³ Lecturer, Faculty of Civil Engineering and Architecture, Kaunas University of Technology, Studentų str. 48, Kaunas, Lithuania, svajunas.juociunas@ktu.lt;

⁴ Professor, Faculty of Civil Engineering and Architecture, Kaunas University of Technology, Studentų str. 48, Kaunas, Lithuania, mindaugas.dauksys@ktu.lt;

1. INTRODUCTION

Challenges in consolidating concrete for reinforced and mass structures were common until the early 1930s, when internal concrete vibrators were introduced. The use of internal vibration during consolidation increased the daily placement rate and minimised internal defects, such as cold joints [1]. Cold joints appear as colour variations between adjacent placements and layer lines. This attribute is not measurable and lacks a method for measurement [2-3]. Delays during concrete pouring can lead to the formation of cold joints. To prevent this, work should be resumed before the surface begins to harden. If there are significant delays, it's crucial to keep the concrete workable by periodically re-vibrating it. This should be done approximately every 15 minutes or less, depending on the conditions at the job site. However, care should be taken not to over-vibrate, as this can cause segregation. If the concrete is nearing its initial setting time, vibration should be stopped and the concrete allowed to set. If a cold joint forms, appropriate surface preparation must be carried out [4]. When placing multiple layers, concrete delivery should be arranged so that each layer is applied while the layer beneath is still plastic, to prevent cold joints. If the lower layer has hardened just enough that the vibrator cannot penetrate it, a bond can still be created by carefully and thoroughly vibrating the new concrete into contact with the previously placed layer; however, this will result in an unavoidable joint line on the surface when the form is removed. Increasing the vertical casting rate, especially in hot weather, can help prevent or manage cold joint issues [5].

Challenges associated with hot weather in plastic concrete include higher water requirements, faster slump loss, elevated concrete temperatures, reduced setting time, greater plastic shrinkage, thermal cracking, and a shorter placement interval between successive layers, which can lead to cold joints [6]. For hardened concrete, the issues include reduced long-term strength, an increased risk of uncontrolled cracking, and diminished durability. The primary factor influencing the formation of cold joints is the curing of the concrete layer below [7]. The presence of a cold joint in a concrete structure can lead to issues such as water leakage, chloride diffusion, reduced strength, and a negative impact on the visual appeal of the concrete surface [8]. The authors [9] tested the water permeability of concrete joints using 92-day-old samples. The second concrete block was positioned 24 hours after the first. Their findings revealed that, for various types of concrete, the overall water permeability of the samples increased by 48% and 27% when a cold joint was present. Authors [10] tested the air and water permeability of concrete joints using a packer system inserted into a hole drilled into a section of concrete blocks, constructed in 24 h increments. The flow rate in the joint area is compared with that in the homogeneous area. The conductivity of the joints is found to be $10-10^4$ times larger than the conductivity of the matrix for both fluids. Researchers [11] assessed the depth of water penetration into RCC concrete joints at various placement intervals. Their findings indicated that even with short placement intervals of just 3 hours, there was a notable increase in the depth of water penetration.

Literature analysis showed that water permeability in concrete through the joint depends not only on joint configuration but also on the test method employed. This study examines the water permeability and depth of penetration under pressure in concrete specimens with cold joints formed at different time intervals, considering the cold joint's orientation relative to the water-pressure jet.

2. MATERIALS AND METHODOLOGY

An experimental study was conducted in KTU's controlled laboratory. This empirical research involved physical testing and quantitative measurements.

An ordinary concrete (OC) of C 25/30 strength class, W8 water permeability class and S2 slump class, typically used for on-site monolithic concreting, was selected for this research. Its composition was similar to that of a concrete mixing plant in Lithuania. Local materials were

used to prepare the concrete mix. Portland cements from AB “Akmenės cementas” CEM I 42.5 R and CEM I 52.5 R, which comply with EN 197-1:2011, were used as the binder for OC. The physical and mechanical properties of the cements were as follows: specific surface area (Blaine method) 410 and 515 m²/kg; water demand for standard consistency (Vicat method) 26.5 and 30.0%; initial setting times 195 and 125 minutes; and compressive strengths after 2 and 28 days 36.9/62.5 MPa and 27.1/54.0 MPa, respectively. Sand with fractions of 0/4 and 0/2 from the Zatyšių quarry was used as a fine aggregate. It had the following characteristics: dry bulk densities of 1724 and 1635 kg/m³; specific gravity of approximately 2.66; fineness modulus (CF) of 3.3 and 2.4; and water absorption of 0.50% and 0.56%, respectively. Gravel and crushed gravel, both of fraction 4/16 from the Zatyšių quarry, were used as coarse aggregates. The physical properties of the gravel and crushed gravel were as follows: dry bulk densities of 1582 and 1460 kg/m³, respectively; specific gravities of approximately 2.67 and 2.68, respectively; water absorption of 1.39% and 1.45%, respectively; and particle shape indexes (SI) of 3 and 6, respectively. The particle size distributions of both fine and coarse aggregates met the requirements of standard EN 12620: 2002+A1:2008. A high-range water-reducing superplasticiser, Sika ViscoCrete D-187 (Switzerland), and MasterGlenium ACE 430 were used as plasticising admixtures, with the following specifications: brownish liquid; density of about 1.06±0.02 kg/l; and pH of 4.4±1.0 and 6.0±1.0.

The material contents (in kilograms) per cubic metre of mixes B-1 and B-2 were as follows: 320 kg of CEM I 42.5 R and 350 kg of CEM I 52.5 R; 310 kg and 0 kg of sand in the 0/2 mm fraction; 649 kg and 890 kg of sand in the 0/4 mm fraction; 420 kg and 0 kg of gravel in the 4/16 mm fraction; 470 kg and 980 kg of crushed gravel in the 4/16 mm fraction; 2.56 kg of Sika ViscoCrete D-187 and 2.80 kg of MasterGlenium ACE 430, respectively. The water-to-cement ratios were 0.55 and 0.44, respectively. The fresh concrete was prepared in the laboratory in accordance with standard EN 206:2013+A2:2021. The concrete mixtures were prepared using dry materials and a Zyklos rotating pan mixer from Pemat.

After the concrete was prepared, the following fresh concrete properties were assessed: the temperature of the fresh concrete was measured in accordance with EN 12350-1:2019; the slump test was conducted in accordance with EN 12350-2:2019; the density was determined in accordance with EN 12350-6:2019; and the air content of the compacted fresh concrete was measured in accordance with EN 12350-7:2019. After measuring the properties of fresh concrete, test specimens, cubes measuring 150×150×150 mm, were cast in metal moulds in accordance with EN 12390-2:2019. The fresh concrete in the moulds was compacted using a vibrating table, with an optimal vibration time of approximately 15-20 seconds.

Prepared test specimens were then used to determine water permeability in accordance with LST 1974:2012 Annex O and the depth of water penetration under pressure in accordance with EN 12390-8:2019. To determine water permeability, the specimens were securely clamped in the special test equipment. The water pressure in the sockets at the lower ends of the specimens increased by 0.2 MPa over 1-5 minutes. At each water pressure level, a constant pressure was maintained for 16 hours at a specimen height of 150 mm. Water pressure could be increased from 0.2 to 1.4 MPa. The test was continued until signs of water penetration through the concrete appeared on the surface of the specimen - water spots or droplets. During the test, the onset of water penetration through the test specimens and the maximum pressure withstood were determined. To determine the depth of water penetration under pressure, the specimen is placed in the device and subjected to water pressure of (500±50) kPa for (72±2) h. During the test, the appearance of the specimen surfaces not under water pressure is periodically monitored for water. If water leakage is observed, the result is recorded. After the specified pressure exposure time, the specimen is removed from the device. The surface affected by the water pressure is wiped to remove excess water. The specimen is split in half perpendicular to the surface affected by the water pressure. During splitting and inspection, the specimen is held with

the surface under water pressure facing down. As soon as the split surface is sufficiently dry to clearly see the area of water penetration, the boundary of the area is marked on the specimen surface. The maximum depth of water penetration in the test area is measured and recorded to the nearest millimetre.

3. RESULTS

Throughout the research, two distinct scenarios were analysed. To form cold joints in test specimens, multiple layers were placed at different time intervals (0, 30, 60, 90, 120 minutes) within two scenarios: a) during specimen preparation, the same mix B-1 was used to place multiple layers; b) during specimen preparation, mix B-1 was used to place the 1st layer, while mix B-2 was used to place the 2nd layer. Table 1 presents fresh concrete properties determined for each batch.

Table 1. Determined properties of fresh concrete.

Series	Temperature, °C	Air content, %	Density, kg/m ³	Slump, mm
B-1-0	20.3	7.5	2250	50
B-1-30	20.3	5.8	2300	30
B-1-60	20.1	5.5	2300	40
B-1-90	19.6	5.5	2310	40
B-1-120	19.7	5.5	2310	30
B-2-0*	21.2	11.5	2120	120
B-2-30	20.1	3.3	2410	50
B-2-60	20.4	3.4	2390	50
B-2-90	20.1	3.5	2400	60
B-2-120	22.4	3.2	2420	90

Note: *- It is likely that the sand moisture content was higher during the preparation of the mixture.

To determine water permeability, concrete samples with cold joints were placed in the testing equipment, with the cold joint oriented both parallel and perpendicular to the water-pressure jet. The concrete composition was selected so that the water permeability of the concrete exceeds the maximum pressure it withstands by at least 0.8 MPa. After performing the tests, it was observed that all concrete specimens with cold joints, oriented parallel to the water-pressure jet, began leaking as soon as the pressure reached 0.4 MPa. However, the test specimens without a cold joint (B-1-0 and B-2-0) exceed the set limit (0.8 MPa) and reach a water pressure of 1.0 MPa (Figure 1).

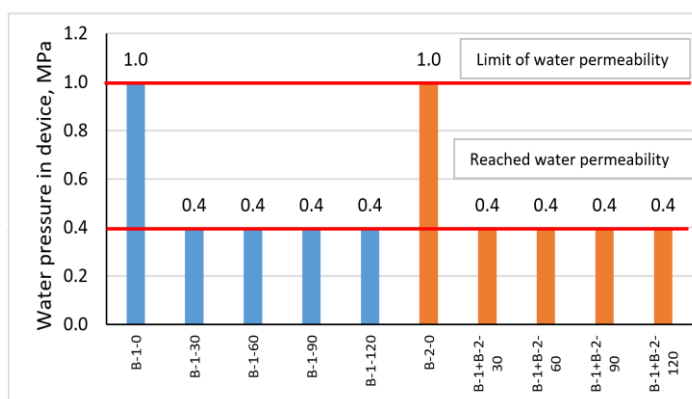


Figure 1. Results of the water permeability test for concrete specimens in the B-1 series and B-1+B-2 series, when the cold joint is oriented parallel to the water-pressure jet

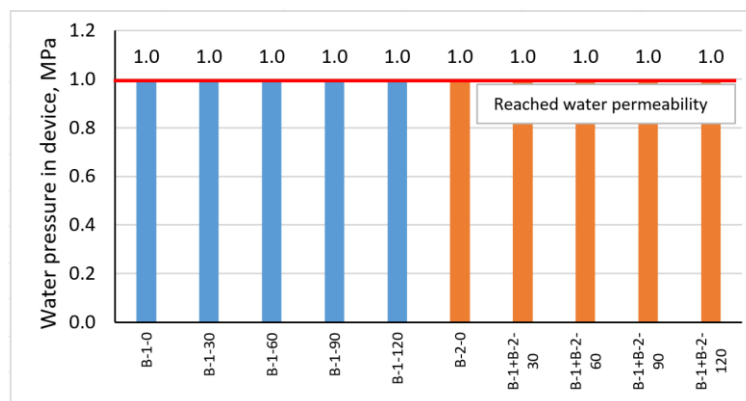


Figure 2. Results of the water permeability test for concrete specimens in the B-1 series and B-1+B-2 series, when the cold joint is oriented perpendicular to the water pressure jet

From Figure 2, it is seen that test specimens with a cold joint exceed the set limit (0.8 MPa) and reach a water pressure of 1.0 MPa when the cold joint is oriented perpendicular to the water-pressure jet. The orientation of the cold joint in test specimens significantly affected the water permeability of concrete as water pressure increased from 0.2 to 1.0 MPa.

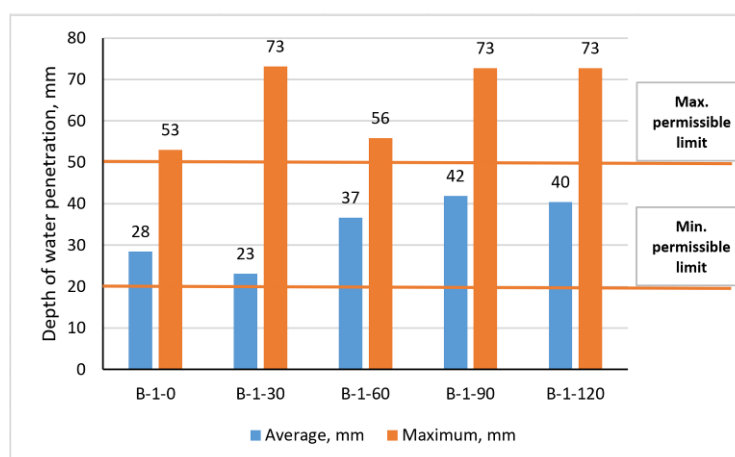


Figure 3. Results of the depth of water penetration under pressure in concrete with a cold joint (B-1 series)

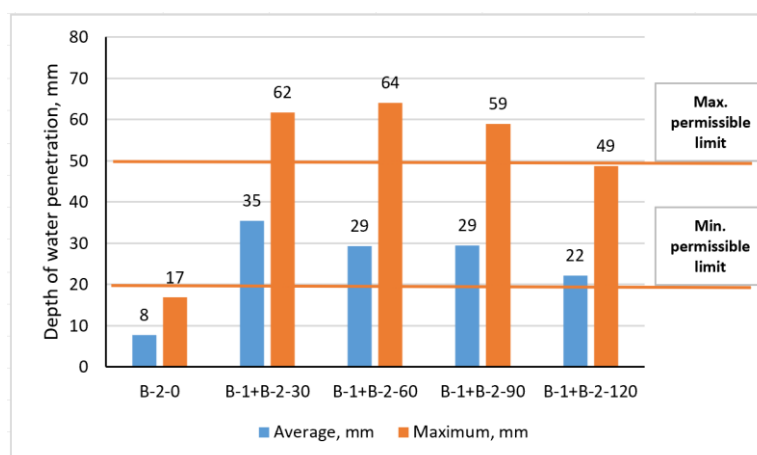


Figure 4. Results of the depth of water penetration under pressure in concrete with a cold joint (B-1+B-2 series)

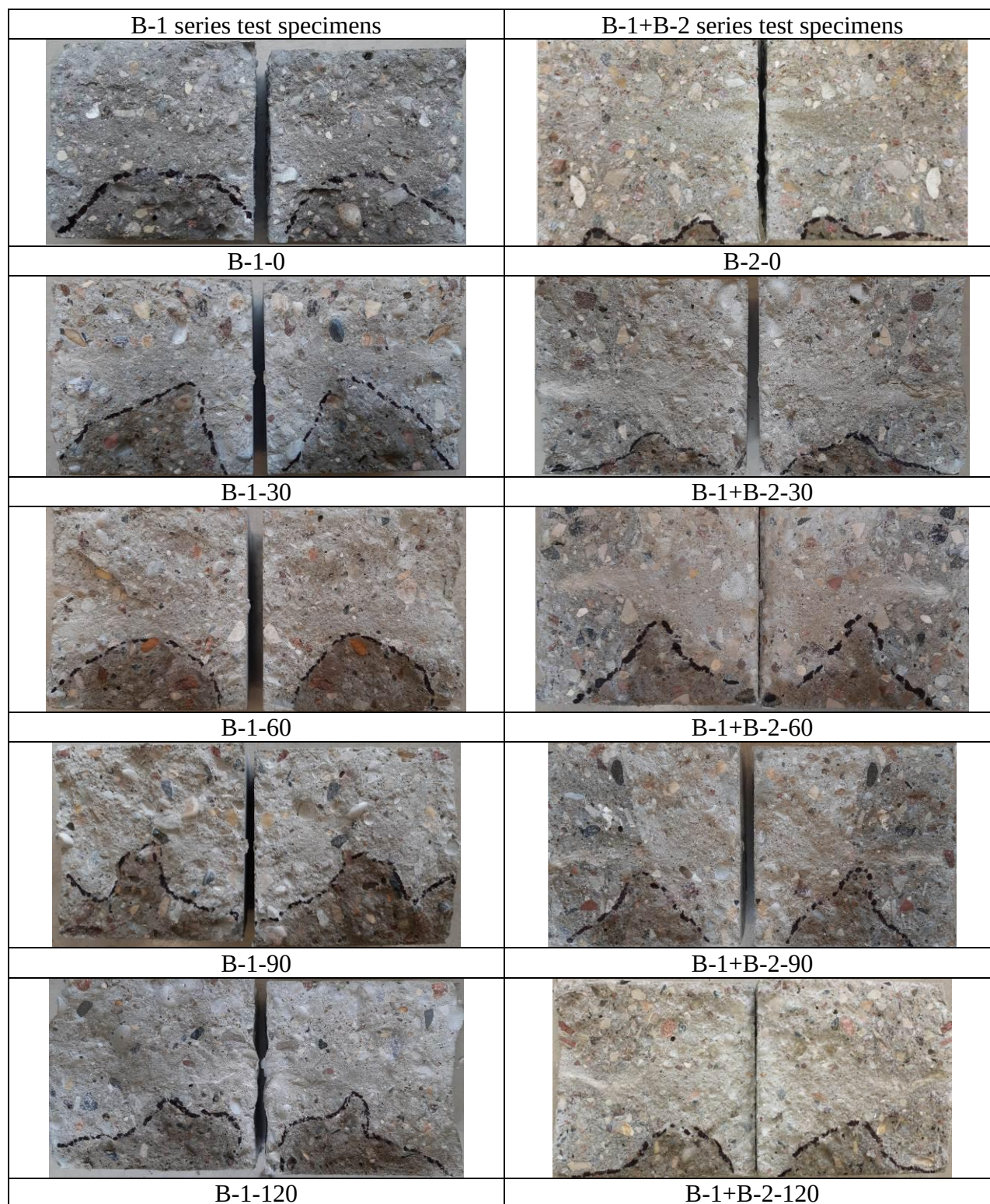


Figure 5. The view of split concrete test specimens after the water-depth penetration test under pressure

Results for water penetration depth under pressure in concrete with a cold joint are presented in Figures 3 and 4, while examples of split concrete test specimens are shown in Figure 5. Figures 3 and 4 show that water penetration in concrete specimens with cold joints exceeded the permissible 20 mm limit, with maximum depths exceeding the 50 mm limit set by LST 1974:2012 (Annex O). The area of water penetration, defined by the boundary marked on

the specimen surface, is shown in Figure 5. In this case, the microscopic pore structure was the dominant factor influencing the water permeability of concrete [12]. To address this, research has focused on incorporating materials that fill the gaps between aggregates and improve the microstructure of cement paste by participating in hydration [13]. In addition, the delay time for second-layer placement did not affect the water penetration depth in concrete. Only the test specimens made of the B-2-0 mixture did not exceed the permissible depth limit of 20 mm and the maximum depth limit of 50 mm set by LST 1974:2012 (Annex O). Those specimens were formed from fresh concrete containing 11.5% entrapped air. It is likely that entrapped air bubbles reduced the open-pore structure of hardened concrete and improved its watertightness.

4. CONCLUSIONS

Concrete specimens with cold joints, oriented parallel to the water-pressure jet, begin to leak as soon as the pressure reaches 0.4 MPa. Only the test specimens without a cold joint (B-1-0 and B-2-0) exceed the set limit (0.8 MPa) and reach a water pressure of 1.0 MPa. In addition, specimens with a cold joint exceed the set limit (0.8 MPa) and reach 1.0 MPa when the cold joint is oriented perpendicular to the water-pressure jet.

Results of water-depth penetration in concrete specimen tests indicate that all specimens with cold joints showed average penetration depths exceeding the permissible 20 mm limit and maximum depths exceeding the 50 mm limit set by LST 1974:2012 (Annex O).

No significant correlation was observed between the delay time of second-layer placement and the penetration depth values. Only the test specimens made of the B-2-0 mixture did not exceed the permissible depth limit of 20 mm and the maximum depth limit of 50 mm.

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