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TECHNICAL CONDITION ASSESSMENT OF AGING HYDROTECHNICAL STRUCTURES IN SOUTHERN POLAND USING PERIODIC INSPECTION DATA

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Abstract: The aim of this study is to evaluate the technical condition of selected hydrotechnical structures in Southern Poland, based on data collected from periodic inspections and diagnostic testing conducted between 2018 and 2023. The analyzed structures, primarily built in the 1960s–1980s, include culverts, weirs, locks, spillways, and embankments. Most have been in operation for over 60 years and are classified as importance class I or II. The methodology involved a review of inspection protocols and test results, including non-destructive and destructive tests such as Schmidt hammer testing, core specimens with compressive strength analysis, ultrasonic testing, water permeability, frost resistance, and water chemical aggressiveness. Each structure was assessed using a pointwise and verbal rating system. Key findings indicate widespread surface erosion, carbonation, and cracking of concrete elements. Although all structures operate in similar aquatic conditions, testing procedures varied significantly, revealing a lack of a standardized diagnostic approach. Inconsistent data makes comparison difficult and limits the effectiveness of material condition assessment. The study concludes that a unified diagnostic framework is urgently needed to ensure consistent evaluation of aging hydrotechnical infrastructure. It should include standardized test sets, interpretation criteria, and frequency guidelines. Regular, uniform diagnostics are essential for developing effective maintenance and repair strategies, ensuring structural safety and service continuity.

Keywords: hydrotechnical concrete, concrete diagnostics, hydrotechnical structures, diagnostic guidelines

1. INTRODUCTION

Hydrotechnical structures are essential components of water management systems, providing flood protection, water supply, navigation, and renewable energy production. Designed for long-term operation in aggressive aquatic environments, these structures are primarily made of reinforced concrete and often operate under fluctuating mechanical, hydraulic, and chemical loads. Over time, the combined effects of environmental exposure and aging lead to progressive degradation of structural materials, threatening safety and functionality.

In Poland, a large number of hydrotechnical structures were constructed in the mid-to-late 20th century. Many of them, including weirs, locks, and culverts, are now over 50–60 years old. Despite regular inspections, there is growing concern that current diagnostic practices may not be sufficient to ensure long-term safety (Kledyński, 2011). The significance of this issue increases with climate change, which intensifies extreme weather events and accelerates material degradation (Kledyński, 2011; Nowak, et al., 2022).

According to Polish legal regulations (Republic of Poland, 1994; Republic of Poland, 2017), periodic technical assessments are mandatory. Inspections are guided by national standards (PN-EN 12504, PN-EN 13791) and the internal procedures of the Institute of Meteorology and Water Management (IMGW). However, these inspections often rely on visual evaluation and basic non-destructive testing, with little consistency across sites. As highlighted in recent audits (Supreme Audit Office (Poland), 2015; Gruszecka, 2015), there is no unified diagnostic scheme adapted to hydrotechnical concrete structures.

Internationally, significant advances have been made in the use of combined diagnostic approaches for aging hydraulic infrastructure. Studies emphasize the importance of integrating destructive and non-destructive testing with durability modeling, risk assessment, and data-driven maintenance planning (Melchers & Beck, 2018; Chai, 2019). Efforts by institutions such as the U.S. Army Corps of Engineers and CIRIA (UK) have produced comprehensive guidelines for the assessment and life-cycle management of hydraulic structures.

Despite these developments, Poland still lacks a standardized, comprehensive methodology tailored to local hydrotechnical infrastructure. The gap lies not in the absence of tools, but in the absence of their coordinated application and harmonized interpretation across different facilities and regions. Moreover, existing protocols seldom incorporate modern diagnostic technologies or advanced durability assessments.

This study addresses this gap by analyzing data from inspections and material tests conducted on selected aging hydrotechnical structures in Southern Poland. The goal is to evaluate the condition of structural concrete, assess the diagnostic consistency, and identify weaknesses in current inspection practices. The findings are intended to support the development of a unified diagnostic scheme for aging hydrotechnical structures.

2. DIAGNOSTIC GUIDELINES

Every inhabited building or structure, according to the current Building Law (The Construction Law Act, 1994), must undergo periodic inspections. The technical condition of the structure is checked at least once a year, and every five years, an extended technical inspection is conducted along with an assessment of its usability. One of the components of the periodic technical assessment is testing of the structural material.

Periodic inspections of hydrotechnical structures are carried out in accordance with guidelines (Sielinski & Śliwiński, 2020) from the Institute of Meteorology and Water Management (polish: IMGW) and performed by the Centre for Technical Control of Dams (polish: CTKZ). The tests are conducted following procedures described in applicable industry standards.

3. APPLICABLE STANDARDS

For tests commissioned for the purpose of assessing the technical condition of water structures, these typically include: sclerometric tests (Schmidt hammer), ultrasonic tests, determination of compressive strength of core drillings taken from the structures.

The basis for conducting material tests on concrete are the standards presented below, encompassing both destructive and non-destructive testing:

• PN-EN 13791 Assessment of concrete compressive strength in structures and precast concrete products.

• PN-EN 12504-1 Testing of concrete in structures. Part 1: Core specimens. Sampling, evaluation and testing of compressive strength.

• PN-EN 12504-2 Testing of concrete in structures. Part 2: Non-destructive testing. Determination of rebound number.

• PN-EN 12504-4 Testing of concrete in structures. Part 4: Non-destructive testing. Determination of ultrasonic pulse velocity.

• PN-EN 206 Concrete - Requirements, properties, production and conformity

4. IMGW GUIDELINES

Under the Water Law (Republic of Poland, 2017), IMGW has been entrusted with the duties of the State Service for the Safety of Dam Structures. The unit implementing the aforementioned service is CTKZ. One of their tasks is to verify guidelines for conducting assessments of technical condition and safety along with necessary measurements and tests. Taking into account the provisions of the Building Law (Republic of Poland, 1994) and current technical knowledge, these guidelines have been developed along with updates.

According to the IMGW guideline (Sielinski & Śliwiński, 2020) , concrete structures should undergo:

- observations - regarding changes in surface condition, leaks, deformations, cracks, and fissures;
- measurements - of displacements, filtration, bathymetric, and "other."

As part of "other" measurements and tests, aging tests of structural concretes are mentioned (non-destructive tests such as ultrasonic, sclerometric, radiographic) and chemical tests (carbonation degree of concrete, corrosion). In the section regarding interpretation of results, it is mentioned that every few years the quality (including strength) of concrete should be analysed with permission for invasive testing (comprehensive tests). However, such tests are recommended at multi-year intervals and in cases of probable significant changes in concrete quality (determined based on observations conducted). Quality concrete tests are described as "Special Measurements and Observations" in Table 3 of the guidelines (Sielinski & Śliwiński, 2020).

5. SELECTED OBJECTS (DESCRIPTION)

The ordering party and the unit possessing Technical Assessments (along with measurement results) for class I and II importance structures is the State Water Holding Polish Waters (polish: PGW WP) - the manager of the objects. According to the request for data disclosure, the names of the objects have been classified due to security and strategic importance. All objects selected for testing are located within the Regional Water Management Board (polish: RZGW) in Cracow.

- Object A

The object is located in the Świętokrzyskie Voivodeship and is part of a complex of hydrotechnical structures (ZBH). For testing, a spillway-discharge structure of the head dam (II class importance) was selected. Permission for the use of the objects was obtained in 1987. The task of the structure is flood protection, energy production using a Small Hydroelectric Power Plant (SHEP - power < 5 MW), and tourism and recreation. The reservoir has a capacity of 24.5 million m3 and an area of 290 ha. The maximum height of the dam is 10 m and its length is 412 m. The spillway-discharge structure consists of four spans with a clearance of 7 m and eight bottom outlets with diameters ranging from φ600 to φ1400. The tailrace has a length of almost 20 m and is equipped with energy dissipation chutes. The SHEP produces approximately 1.1 GWh of energy.

- Object B

The object is located in the Małopolskie Voivodeship and belongs to a complex of hydrotechnical structures (ZOH). One of the culverts (II class importance) was selected for testing. The structures were built around 1960, however, there are no documents for building permits or permits for use. The task of ZOH is to ensure navigability of the river, water supply, and energy production using SHEP. The navigable section is 15.5 km long and ends with a lock chamber of 85 m in length. The tested culvert has dimensions of 3 x 3 m and a length of approximately 119 m. It carries waters from a catchment area of 10 ha and its capacity reaches up to 4.5 m3/s.

- Object C

The object is located in the Małopolskie Voivodeship and is part of ZBH. Cable-concrete beams, elements of a rolling bridge with II class importance (closing of the structure's repair units is inserted into recesses using a crane), were selected for testing. The structures were put into operation in 1961. The task of ZBH is water impoundment for navigation, water supply, and energy production using SHEP. The weir has a drop of about 6m, a length of about 117 m, and consists of five spans of 20 m each. The tailrace has a length of about 18.5 m.

- Object D

The object is located in the Małopolskie Voivodeship and is part of ZBH. Concrete elements of the lock structure (II class importance) were selected for testing. The structures were put into operation in 1954. The task of ZBH is water impoundment for navigation, water supply, and energy production using a hydroelectric power plant (HEP). The designed weir slope is 6 m, length is approximately 104 m, and the clearance consists of four spans with a span of 20 m each. The maximum discharge capacity of the weir is 1750 m3/s. The lock has a useful length of 85 m and a chamber width of 12 m, with a slope of about 4 m. The hydroelectric power plant has a nominal slope of 6 m and an installed power of approximately 2x 1.5 MWh

- Object E

The object is located in the Małopolskie Voivodeship and is part of ZBH. Concrete elements of the weir and lock structure (II class importance) were selected for testing. Building permit was issued in 1977, and it was put into operation in 1990. The task of ZBH includes water impoundment for navigation, energy production using HEP, erosion control of the riverbed, and recreational purposes. The sector gate has a clearance of 3x32 m with steel closures maintaining the water level automatically. The chamber lock has a useful length of 195 m and a chamber width of 12 m, with a slope of approximately 4 m. The frontal dam has a length of 31 m and a maximum height of 8 m.

- Object F

The object is located in the Małopolskie Voivodeship and is part of ZBH. Concrete elements of the right bank canal (I and II class importance) were selected for testing. The construction of the weir was completed in 1984, and the lock and canal were put into operation in 2001. The task of ZBH includes water impoundment for navigation, water management, and energy production using HEP (private). The weir clearance is 2x27.5 m, and its maximum slope reaches 3.3 m. The chamber lock has a useful length of 194 m and a chamber width of 12 m, with a slope of 6.5 m. The navigational canal has a bottom width of 50 m and a length of almost 8 km. HEP is a run-of-river power plant equipped with three Kaplan turbines, each with a power of 275 kW.

6. OBTAINED DATA

Information on the technical condition of the structures and the results of conducted tests are compiled in Technical Condition Assessments and Protocols from annual periodic inspections. Documents from the current diagnostic cycle - years 2018 - 2023 - were obtained from PGW WP. Periodic inspections are carried out at least once a year or at least once every five years (may be combined with annual inspections). Guidelines from IMGW provide a dedicated form for each type of inspection, differing in scope and covering all necessary fields for its execution. Regardless of the scope of the inspection, it is based on a local vision and inspections of the structure's elements (without conducting tests). The inspection concludes with a point and verbal assessment of the structure's technical condition. Technical condition assessments should be conducted no less than once every five years, with the frequency determined by the facility's operational instructions or previous assessments. The report should include the results of local vision and inspections of the structure's elements, displacement tests, filtration, and possibly other tests commissioned by the documentation contractor (e.g., structural concrete tests - tests classified as "other" are not mandatory). The technical condition assessment concludes with a point and verbal assessment of the structure's technical condition.

7. SUMMARY OF TESTS FROM THE LAST DIAGNOSTIC PERIOD

After analysing the obtained documentation, Tables 1 and 2 was compiled listing the tests and measurements conducted on embedded concrete elements in the structures. The column "test" includes all types of tests conducted for the analysed structures. In case any of the tests were not performed for a given structure, a "-" sign appears.

The column "technical condition score" contains a score on a scale of 1-7, according to Appendix No. 7 of the IMGW Guidelines, where: 1 - inappropriate condition, 3 - satisfactory condition, 7 - good condition.

Table 1

Results of tests on concrete elements of selected structures A-C (own elaboration)

Study/ Object	A	B	C
Year of Construction	1985	1961	1961
Year of Examination	2022	2023	2023
Tested Element	Overflow	Culvert No. 20	Cable-concrete bridge (girder)
Concrete class	C30/37	C16/20	C45/55

Study/ Object	A	B	C
Year of Construction	1985	1961	1961
Year of Examination	2022	2023	2023
Schmidt Hammer Test [MPa]	13.1 - 19.4	10.8 - 11.8	35.9
Core Specimens Test [MPa]	32.0 - 58.0	-	-
Ultrasonic Method [m/s]	-	2898 - 3462 (weak/ doubtful concrete)	-
Surface Erosion	yes	yes	yes
Carbonation	-	-	yes
Characteristic Compressive Strength [MPa]	20.7	-	35.9
Absorption [%]	6.4 - 8.3	-	-
Tensile Strength [MPa]	0.72	-	-
Evaluation of Reinforcement Cover Thickness [mm]	> 80	-	-
Frost Resistance	-	-	-
Water Aggressiveness Test	-	no aggressiveness	no aggressiveness
Pointwise assessment of technical condition (concrete elements)	7	7/3	3
Verbal assessment of technical condition (concrete elements)	good	good/ satisfactory	satisfactory

Table 1
Results of tests on concrete elements of selected structures D – E (own elaboration)

Study/Object	D	E	F
Year of Construction	1954	1978	1977/2001
Year of Examination	2018	2020	2021
Tested Element	Lock	Weir and lock	Right embankment
Concrete class	C40/50	C50/60	C20/25
Schmidt Hammer Test [MPa]	41.6 - >50	-	12.2 - 30.4
Core Specimens Test [MPa]	41.7 - 58.4	58.7	-
Ultrasonic Method [m/s]	-	-	-
Surface Erosion	yes	yes	yes
Carbonation	yes	yes	yes
Characteristic Compressive Strength [MPa]	-	-	-
Absorption [%]	6.2 - 7.7	-	-
Tensile Strength [MPa]	sufficient	-	-
Evaluation of Reinforcement Cover Thickness [mm]	-	-	-
Frost Resistance	> 75	-	-

Study/Object	D	E	F
Year of Construction	1954	1978	1977/2001
Year of Examination	2018	2020	2021
Water Aggressiveness Test	no aggressiveness	chemical aggressiveness	-
Pointwise assessment of technical condition (concrete elements)	3	3	3
Verbal assessment of technical condition (concrete elements)	satisfactory	satisfactory	satisfactory

The majority of the examined structures have been in operation for over 60 years in unfavorable water environments, exposed to multiple freeze-thaw cycles. Such operating conditions, coupled with a lack of proper maintenance, primarily contribute to the degradation of the concrete in these structures. In all cases, surface erosion of concrete elements was observed, and a significant majority also showed signs of carbonation.

Structures built between the 1960s and 1980s differed significantly from modern facilities in terms of construction technology and design standards. Some structures do not meet the currently required exposure class or are characterized by poor workmanship – insufficient concrete compaction or insufficient concrete cover for the reinforcement bars. Access to some of the original design documentation is unavailable – it has been lost or destroyed, which makes it difficult to determine the "initial state." Additionally, during the construction of these facilities, discrepancies between the design and the actual execution of the structure were common.

The properties of the concrete they are built from vary significantly – this is best illustrated by the results of compressive strength tests, which were the only tests conducted for each of the structures: either core specimen testing or Schmidt hammer testing. There is a lack of consistency in the diagnostic model – different tests are commissioned for similar degradation symptoms of the embedded material (concrete).

Progressive concrete degradation can lead to a decrease in the concrete's structural strength parameters (reduction in compressive strength), deterioration of reinforcement adhesion (loss of cover in the carbonation process), and an increase in concrete absorbency and permeability. The consequence of these processes will be the necessity to limit the function of the structure or cease its operation due to the risk of failure.

The photos below (Fig. 1 - Fig. 5) present the current condition of the structure and the ongoing degradation processes.

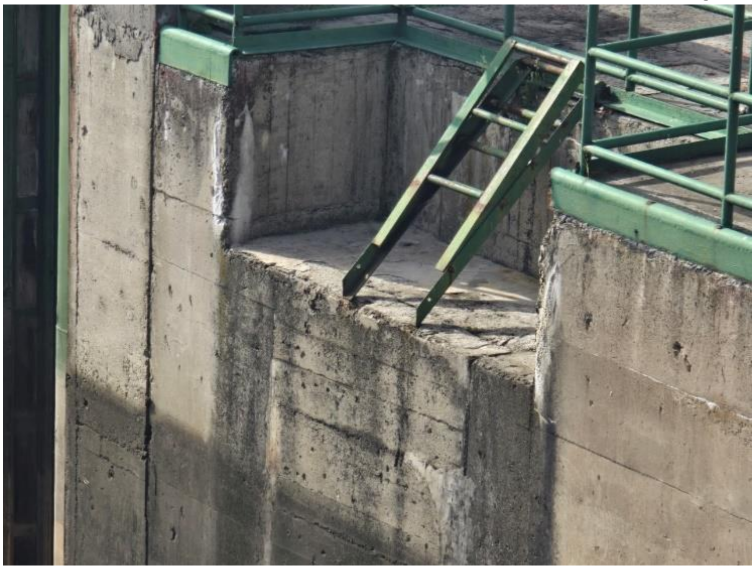

Fig. 1. Structure D, lock wall, carbonation (source: own photo)

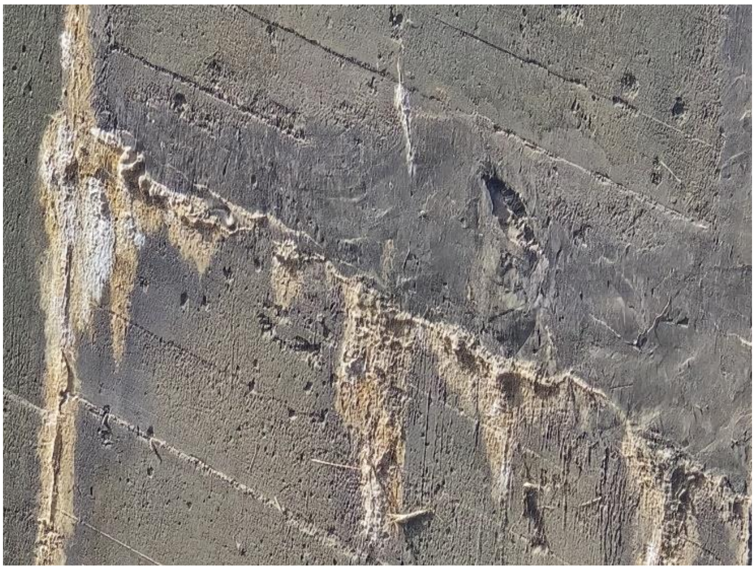

Fig. 2. Structure E, weir, carbonation and leaks (source: own photo)

Fig. 3. Structure A, overflow, carbonation and erosion (source: own photo)

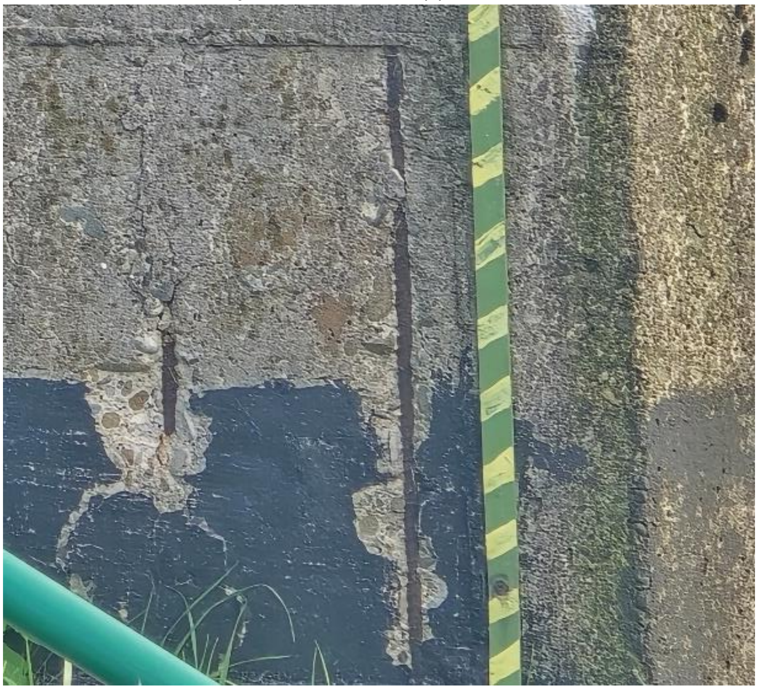

Fig. 4. Structure B, culvert, corrosion and visible reinforcement (source: own photo)

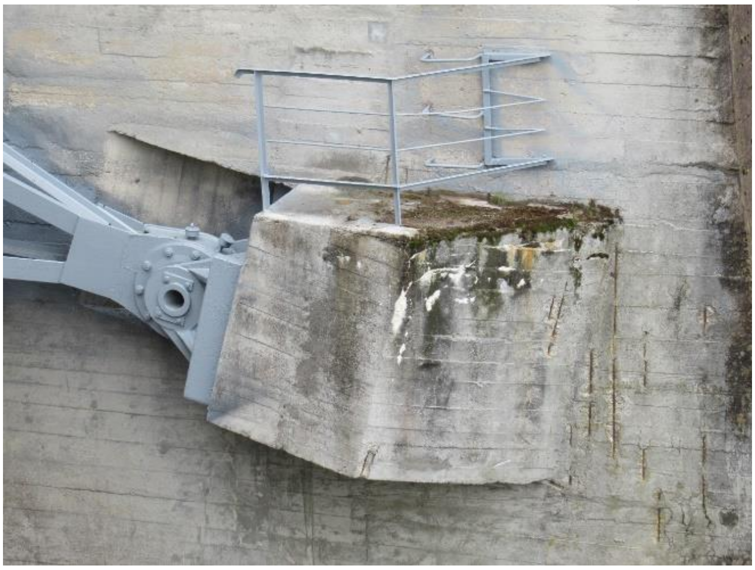

Fig. 5. Structure E, lock wall, corrosion and visible reinforcement (source: own photo)

8. CONCLUSIONS

This study analyzed diagnostic data from six hydrotechnical structures in southern Poland, assessed between 2018 and 2023. The findings reveal a widespread occurrence of material degradation, with surface erosion observed in all cases (100%), carbonation identified in 67% of the structures, and reduced compressive strength confirmed in 50% of the cases. Notably, five out of the six structures received a technical condition rating of “satisfactory” or lower, underscoring the systemic need for corrective interventions.

The degradation of structural concrete is attributed to a combination of historical design limitations, prolonged environmental exposure, and irregular maintenance practices. Many of the analyzed structures, constructed in the 1960s through the 1980s, exhibit insufficient concrete cover and poor compaction quality, which facilitate moisture penetration and carbonation. Environmental factors – particularly sustained exposure to freeze-thaw cycles, variable hydraulic loads, and chemically aggressive water – further exacerbate the deterioration. Operationally, the infrequent use of invasive or advanced non-destructive testing has limited the timely detection of damage. Moreover, incomplete or missing archival documentation has hindered efforts to compare current performance against the original design standards.

The observed degradation processes have clear technical implications. Carbonation lowers the pH of concrete, increasing the risk of reinforcement corrosion and reducing bond strength, ultimately compromising the structure's load-bearing capacity. Elevated porosity and water absorption reduce frost resistance and watertightness, directly affecting durability. Structures rated as "satisfactory" (rating 3, according to IMGW guidelines) may face serious safety risks, especially under extreme hydraulic or climatic conditions. The inconsistent application of diagnostic methods across sites further impairs the comparability and reliability of the assessments.

To address these challenges, a unified national framework for the condition assessment of hydrotechnical concrete structures is critically needed. This framework should mandate a standardized set of tests – including Schmidt hammer, core sampling, ultrasonic testing, carbonation depth analysis, frost resistance evaluation, and water absorption measurement – accompanied by defined testing frequencies and interpretation criteria (Runkiewicz & Hoła, 2018; Runkiewicz, et al., 2021). Additionally, digital recordkeeping and centralized data systems would improve longitudinal monitoring and support evidence-based maintenance planning. The professionalization of diagnostic procedures should be reinforced through standardized training and certification for inspection personnel, with emphasis on advanced non-destructive testing techniques and service-life modeling. Diagnostic findings must be explicitly tied to repair planning, with threshold criteria established to trigger maintenance or reconstruction decisions. In the longer term, the implementation of predictive maintenance strategies, supported by risk assessment and degradation modeling, is strongly recommended to ensure structural safety and continuity of operation.

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