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Libeň Bridge (V009) Society

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Řásnovka 770/8, 110 15 Prague 1

TSK a.s.

Expert report:

Determination of Loadability of Libeň Bridge V009 and Assessment of Individual Construction Elements in Terms of Feasibility, Applicability, Service Life and Potential Repair Works

SUMMARY REPORT

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ABSTRACT

This summary report presents the results of static analyses testing the loadability of the bridge structures with regard to their current state identified by diagnostics inspections. It also provides an overview of necessary measures, possibilities of reconstruction, repairs and other remediation measures aiming to improve the loadability and service life of the bridge structures to meet the applicable standards.

The results are discussed in detail in the following reports and their appendixes:

1. Report No. 1700 J 019-02 Bridge static reliability and loadability
2. Report No. 1700 J 019-03 Diagnostics
3. Report No. 1700 J 019-04 Reconstruction and assessment of concrete remediation methods

The report was produced by the Libeň Bridge (V009) Society composed of three organisations. The Klokner Institute, ČVUT in Prague serves as its administrator, and Pontex s.r.o. and INSET s.r.o. are its associate members.

Fig. 1: View of the Libeň bridge

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1. INTRODUCTION

The present summary of reports was carried out under contract on work No. 3/17/6300/0001 in effect from 30 January 2017, as amended, signed between Technická správa komunikací hl. m. Prahy, a.s., registered office Řásnovka 770/8, Prague 1, the Libeň Bridge Society (V009), administered by the Klokner Institute at the Czech Technical University ("ČVUT") in Prague, registered office Šolínova 7, Prague 6, and the member companies Pontex, spol. s r.o., registered office Bezová 1658, Prague 4, and INSET, s.r.o., registered office Lucemburská 1170, Prague 3.

The commissioner requested a complete and comprehensive overview of key facts about the bridge condition and the possibilities of its renovation with the aim of improving its loadability and service life to meet the applicable standards. The commissioner requested to investigate both the option of constructing a completely new bridge, and its reconstruction and repair as if regarded as a cultural monument. This gave rise to a very vast set of requirements that could be met only by performing a wide array of works and activities. A representative of the National Heritage Institute (NPÚ) was present during the works and was informed about the project's progression and results.

This report summarizes the results of diagnostic inspections, static analyses and the determination of the loadability of the bridge structures with regard to their current condition. It also provides an overview of necessary measures, possibilities of reconstruction, repairs and other remediation measures aiming to improve the loadability and service life of the bridge structures to meet the applicable standards. The results are discussed in further detail in the individual reports and their appendixes.

2. SUBJECT MATTER AND PROJECT'S MAIN OBJECTIVE

The **principal subject of the works** was the Libeň bridge V009, a vault bridge consisting of five vault parts and several reinforced concrete frame structures, stretching over the river from Holešovice and Libeň city districts. The bridge was erected between 1924 and 1928 according to Pavel Janák's project. The vault parts were designed by František Mencl and the frame structures by Václav Dašek.

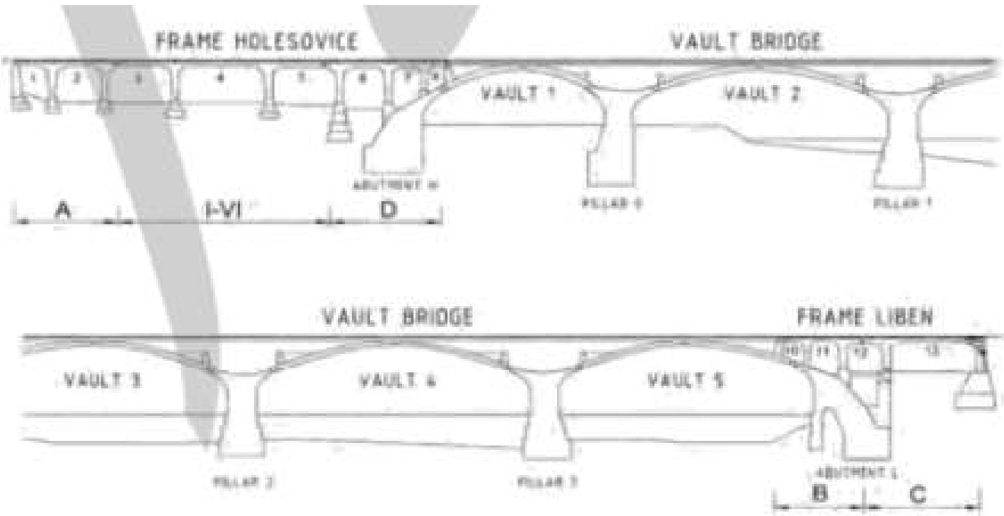

Fig. 2: Cross section of the bridge and its parts, i.e. frames, vaults, abutments and columns.

Fig. 3: Vault part of the bridge

Figs. 4 and 5: Frame structures on both sides of the river (Holešovice and Libeň)

The main objective was to assess the condition of individual construction parts of the bridge with respect to their applicability, service life and repairability based on the following:

1. Static load tests of the vault part focused on deflection of the top part of the vaults and joint deformation;
2. Dynamic load tests of the vault part aimed at obtaining data to develop calculation models;
3. Verification of the real shapes of the bridge structure, including 3D scanning;
4. Periodic temperature measurements to analyse the bridge's static behaviour;
5. Linear and non-linear static tests of the vault part and the frame structures aimed at determining the load-bearing capacities of the individual parts with respect to their current condition;
6. Diagnostic inspections of the bridge structures aimed at determining the properties of the concrete and other materials used, including the causes of degradation and corrosion and the structure's current condition.

As part of the project, a wide array of diagnostic works was conducted, focused primarily on the following activities:

a) Dynamic and static load tests to verify the real behaviour of the bridge;

b) Installation of sensors and periodic measurements of the structures' temperature and their deformation under the influence of heat;

c) Verification of the real shapes of the bridge structure, including 3D scanning;

d) In situ diagnostic works, laboratory tests and analyses, including in particular:
   - visual inspections of the structures and endoscopic inspections of the joints;
   - acoustic emission testing to monitor surface flaws;
   - collection of core drillings and concrete specimens for laboratory tests and analyses;
   - borehole probes and surface drilling to examine the backfills and their impact on concrete degradation to determine the condition of insulation, the upper side concrete and the composition of the topmost part of the bridge;
   - deep drilling from the roadway and the surrounding ground into the bridge foundations and the subsoil to determine the character and load-bearing capacity of the subsoil;
   - testing of mechanical and physical properties of the concrete used (structure, density, compressive strength, modulus of elasticity, water absorption, frost resistance, resistance against de-icing agents, tensile strength of the surface layers, surface water absorption),
   - tests and microscopic, chemical and XRD analyses to determine the causes of corrosion and degradation (depth of concrete carbonation, Alkali-silica reaction, chloride and sulphate attacks, thickness of the protective layer and corrosion of reinforcement).

e) Detailed linear and non-linear static analysis to determine the loadability of the bridge based on the determined material properties, current condition of the structures, the results of loading tests and temperature measurements primarily focused on:
   - analysis of the vault part;
   - analysis of the frame structures;
   - analysis of the foundations and columns of the vault part;
   - analysis of other components (consoles, railing, breast walls and walls above columns).

f) Based on the diagnostic inspections and static analyses, the suggested repair works include:
   - strengthening or replacing parts of the vault bridge;
   - strengthening or replacing the frame structures;
   - stabilise the foundations of the columns and abutments of the vault part.

g) The following concrete remediation methods were evaluated:
   - applying remediation materials to selected parts of the bridge and collected concrete samples, in situ testing of the remediation materials and laboratory testing of the samples collected from the treated surfaces;
   - cleaning the bridge surface using three different procedures;
   - verifying the possibility to remove the railing elements and substitute them with their replicas.

Bridge inspection machines, forklift work platforms, scaffolding, pontoons and an inspection boat were used to access the structures and investigate their condition, install the measuring equipment and perform load tests.

Fig. 6: Diagnostic inspections of the bridge structures

Bridge structure samples that were not used were stored in a designated space in the premises of the Y529 Mitas bridge with the aim of using them to analyse the concrete material for long-term assessment and evaluation of the progress of sulphate induced degradation of concrete.

Fig. 7: Storage of samples on the premises of the Y529 Mitas bridge

The obtained results are discussed in detail in the following reports and their appendixes:

1. Report No. 1700 J 019-02 Bridge static reliability and loadability
2. Report No. 1700 J 019-03 Diagnostics
3. Report No. 1700 J 019-04 Reconstruction and assessment of concrete remediation methods

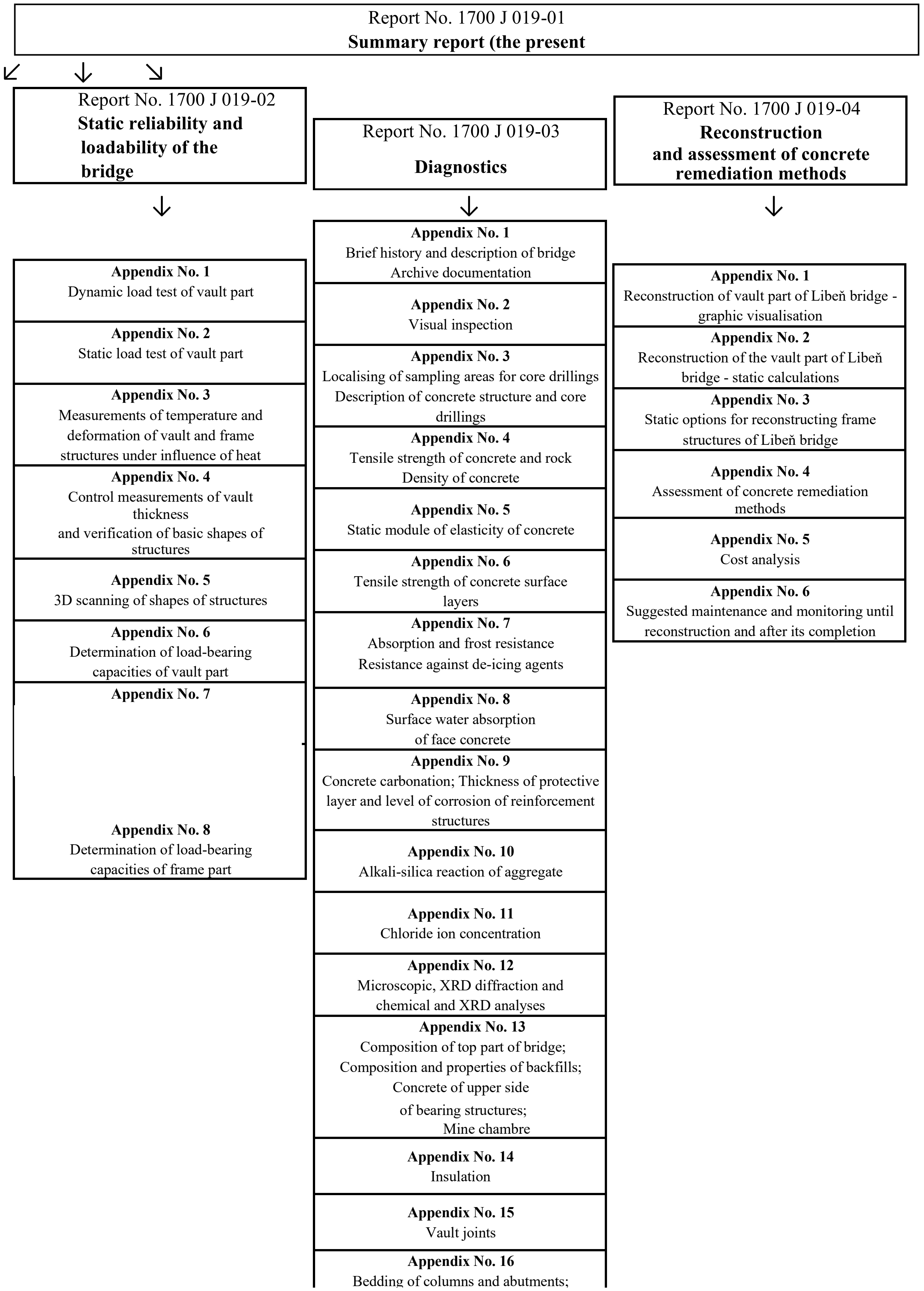

Fig. 8: Report and appendix structure

3. SUPPORTING DOCUMENTS

Documents forming part of this report (constitutive reports)

[02] Report No. 1700 J 019-02 Static reliability and loadability of the bridge

[03] Report No. 1700 J 019-03 Diagnostics

[04] Report No. 1700 J 019-04 Reconstruction and assessment of concrete remediation methods

Norms, technical requirements (TP) and technical quality requirements (TKP)

[1] ČSN 73 6201 Design of bridge structures.

[2] ČSN 73 6221 Inspections of road bridges.

[3] ČSN 73 6222 Loadability of road bridges.

[4] ČSN 73 6203 Bridge loads (in effect until 2010).

[5] ČSN 73 6209 Bridge load testing.

[6] ČSN 73 2030 Building structure load testing.

[7] ČSN 73 6200 Bridges. Terminology and classification.

[8] ČSN EN 1990 Construction design principles.

[9] ČSN EN 1991-1-1 Construction loads. Part 1-1: General loads. Density, self-weight and live load of buildings.

[10] ČSN EN 1991-1-4 Construction loads. Part 1-4: General loads. Wind load.

[11] ČSN EN 1991-1-5 Construction loads. Part 1-5: General loads. Temperature load.

[12] ČSN EN 1991-1-6 Construction loads. Part 1-6: General loads. Loads during implementation.

[13] ČSN EN 1991-1-7 Construction loads. Part 1-7: General loads. Extraordinary loads.

[14] ČSN EN 1991-2 Construction loads. Part 2: Traffic load.

[15] ČSN EN 1992-1-1 Design of concrete structures. Part 1-1: General guidelines and rules for buildings.

[16] ČSN EN 1992-2 Design of concrete structures. Part 2: Concrete bridges. Design and construction principles.

[17] ČSN 736206 (as amended) Design of concrete and reinforced bridge structures.

[18] ČSN ISO 13822 Construction design principles. Assessment of existing structures.

[19] ČSN 73 0038 Assessment and verification of existing structures - additional provisions.

[20] ČSN EN 12504-1 Concrete tests used in existing structures. Part 1: Drillings. Sampling, investigation and compressive testing.

[21] ČSN EN 12390-3 Testing of hardened concrete. Part 3: Compressive strength of test specimens.

[22] ČSN 73 1317 Determination of concrete’s compressive strength (validity expired).

[23] ČSN 73 1373 Schmidt hammer testing of concrete.

[24] ČSN EN 12504-2 Testing of concrete used in existing structures. Part 2: Non-destructive testing. Determination of hardness using a rebound hammer.

[25] ČSN 73 2011 Non-destructive testing of concrete structures.

[26] ČSN EN 13791 Evaluation of concrete's tensile strength in concrete structures and precast concrete components.

[27] ČSN EN 206 Concrete. Part 1: Specifications, properties, production and compliance. ČSN P 73 2404 Concrete. Specifications, properties, production and compliance - additional information.

[28] ČSN ISO 1920-10 Concrete tests Part 10: Determination of static module of compressive strength.

[29] ČSN 73 1371 Non-destructive testing of concrete. Ultrasonic pulse concrete tests.

[30] ČSN 73 1322 (+Z1) Determination of concrete's frost resistance.

[31] ČSN 73 1325 Determination of concrete's frost resistance through shortened tests. (validity expired in December 2003).

[32] ČSN 73 1326 (+Z1) Determination of surface resistance of cement concrete to water and de-icing agents.

[33] ČSN 73 2578 Test of water tightness of surface protective coating in buildings.

[34] ČSN EN 1015-12 Testing methods of mortar used in building walls - Part 12: Determination of bond strength between hardened mortars used for internal and external plastering and building blocks.

[35] ČSN 73 2577 Testing of bond strength between protective coating and building blocks.

[36] ČSN EN 1926 Testing methods of natural stone. Determination of concrete common compressive strength.

[37] ČSN 72 0103 Basic method for analysis of silicates. Determination of loss on ignition.

[38] ČSN 72 0117 Basic method for analysis of silicates. Gravimetric sulphate determination.

[39] ČSN 72 1215 Concrete structures. Classification of aggressive environments. (validity expired in January 2004).

[40] ČSN ISO 10523 Water quality. Determination of pH.

[41] ČSN EN ISO 10304-1 Water quality. Determination of dissolved anions by liquid-sold chromatographic method. Part 1: Determination of bromides, chlorides, fluorides, nitrates, nitrites, phosphates and sulphates.

[42] ČSN ISO 9964-1 Water quality. Determination of sodium and potassium. Part 1: Determination of sodium by atomic absorption spectroscopy.

[43] ČSN ISO 9964-2 Water quality. Determination of sodium and potassium. Part 2: Determination of potassium by atomic absorption spectroscopy.

[44] ČSN ISO 7980 Water quality. Determination of calcium and magnesium. Atomic absorption spectroscopy.

[45] ČSN 73 1001 Soil type under shallow foundations (validity expired in April 2010).

[46] ČSN EN 1997 Eurocode 7: Design of geotechnical structures.

[47] ČSN CEN ISO/TS 17892-4 Determination of soil gradation.

[48] ČSN CEN ISO/TS 17892-1 Determination of soil humidity.

[49] ČSN EN ISO 14688-1 Geotechnical inspection and testing - Denomination and description.

[50] ČSN EN ISO 14688-2 Geotechnical inspection and testing - Classification principles.

[51] ČSN EN ISO 12570 Temperature and humidity behaviours of construction materials and products. Determination of humidity by drying at high temperatures.

[52] ČSN P 73 0610 Waterproofing of buildings. Treatment of damp walls. Basic provisions.

[53] ČSN EN 1504-10 Products and systems of protection and repairs of concrete structures. Definition, requirements, quality assessment and compliance evaluation. Part 10: Use of products and systems and assessment of quality of works.

[54] Concrete structures. Testing of corrosion resistance of concrete. General requirements (not valid)

[55] TP SSBK III - Technical requirements for remediation of concrete structures.

[56] TP 72 Bridge diagnostic inspections.

[57] TKP18 Concrete structures and bridges.

[58] TKP31 Repairs of concrete structures.

[59] TP 200 Determination of the loadability of road bridges designed in compliance with the applicable norms and legislation before the entry into force of EN.

Overview of existing literature and other supporting documents:

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[63] Libeňský most přes Vltavu v Praze - Statický výpočet zatížitelnosti. Pontex, 2003.

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[94] IDEA StatiCa verze 8.0.15.43212; IDEA

[95] MIDAS Civil 2017, verze 2.1; MIDAS IT, Co.

[96] Scia Engineer verze 15.3; Nemetschek Group

[97] ATENA verze 5.4.1; Cervenka Consulting

4. DIAGNOSTIC INSPECTION

The results of the diagnostic inspection are presented in more detail in Report No. 1700 J 019-03 Diagnostics [03] which is an integral part of this comprehensive evaluation of the bridge condition. It includes an in-depth discussion of results, findings and applied methods. A complete overview is provided below.

Based on the results of the diagnostic investigation, the following conclusions were drawn:

1) **The bearing components of the bridge**, i.e. the vaults, columns and abutments of the vault part and their foundations as well as both frame structures **do not comply with the material requirements laid down by the applicable rules for road structures** (especially in terms of their durability and properties' variability).
2) **The durability and service life of the bearing components of the bridge** as required by the applicable legislation **cannot be ensured by any remediation or repair method.**
3) **Parts of the frame structures' decks around the expansion and deck joints are in an emergency condition.** In the frame of the Holešovice side, this includes areas around the longitudinal expansion joints of frame fields RP1 and RPF2 (frame part A) and areas around the joints of frame fields RP3 and RP5 (frame part I-VI). In the frame of the Libeň side, this includes the longitudinal expansion joints of frame field RP13 (frame part C). The detected damage has a critical impact on the load-bearing capacity and static reliability (weakened reinforcement and deeply penetrated degradation).
4) **The foundations of the vault part, columns and abutments** (up to the bottom joints of the vaults) **suffer from internal sulphate corrosion.** The inspections have shown that the concrete's micro-structure has not yet been severely affected. If it was the case, it would have acutely decreased its strength. As a result, the progression of sulphate corrosion is very slow and **does not constitute an imminent danger** (no significant decrease in the load-bearing capacity due to degradation of the concrete's mechanical properties was observed). **Gradual degradation cannot however be excluded** and if the structures are to remain in place, they must be periodically inspected and monitored in the long term. Sulphate corrosion has attacked the foundations of the frame structures. The severity of the attack is however significantly lower than in the vault part of the bridge.
5) **The staircase structures are in an emergency condition** (weakened reinforcement, profound and locally complete degradation and disintegration). They must be replaced.
6) **Construction elements of the ornamental surface concrete layer** (used in the architectural elements) have much better properties in terms of durability. In contrast to the concrete used for construction, the ornamental concrete layer has fewer divisions (with the exception of the staircases and the upper side of the cantilevered columns and abutments). There are numerous cracks, especially in the area of the cantilevers and cantilevered parts of the columns and abutments. Parts of railings and historical decorative street lamp posts show signs of considerable damage (broken edges, cracks).
7) Tab. 1 presents a summary of the mechanical and physical properties of the concrete used in the individual construction elements, including its degradation influences.

Tab. 1: Summary of mechanical and physical properties of concrete and its degradation influences

	Mechanical and physical properties of concrete and its degradation influences	Vaults	columns and abutments – above water surface or ground	columns and abutments – under water surface or ground	columns and abutments – foundations	Breast walls, walls above columns, cantilevers	Railings	Street lamp posts	Staircases	Frame structures – Holešovice frame part	Frame structures – Libeň frame part
CONCRETE (USED FOR CONSTRUCTION)	Density [kg/m^3]	2270	2190	2220	2210	2310; 2290	2270	-	2320	2340	2320
	Compressive strength (destructive test) [MPa]	31.3	25.8	24,4 1)	17,0 1)	42,7; 37,0	32.1	-	36.9	47.1	26.9
	Variation strength coeff. (destructive test) [%]	22	26	30	41	24; 25	30	-	50	21	25
	Strength class under ČSN EN 13791 (destructive tests)	C 20/25	C 12/15	C 12/15	C 6/7.5	C 20/25	C 20/25	-	C 25/30	C 30/37	C 25/30
	Recommended strength class for static analysis	C 16/20	C 12/15	C 8/10	C 4/5	C 16/20	C 16/20	-	C 20/25	C 20/25	C 20/25
	Strength class from documentation archive	C 10/13.5	-	between C 4/5 and C 6/7,5	C 3/3.5	-	-	-	-	C 16/20	C 16/20
	Static module of elasticity [GPa]	21.0	16.9	17.9	16.8	-	-	-	-	24.8	18.8
	Variation coeff. of the elastic modulus [%]	16	14	21	27	-	-	-	-	11	19
	Recommended value of the static modulus of elasticity for the static analysis [GPa]	21	17	17	16	-	-	-	-	21	21
	Water absorption [%]	3.4	5.2	5.8	-	4.4	4.0	-	3.4	4.0	4.4
	Frost resistance degree of environmental influence XF1, XF3	< T25 non-complying	< T25 non-complying	-	-	< T25 non-complying	T25 non-complying	-	< T25 non-complying	T25 non-complying	< T25 non-complying
	Resistance against de-icing agents degree of environmental influence XF1-XF4	non-complying	non-complying	-	-	-	-	-	-	non-complying	non-complying
	Alkali-silica reaction (ASR)	NO	-	-	-	NO	NO	-	NO 2)	NO; only trace amount	NO; only trace amount
	Sulphate corrosion	NO	YES	YES	YES	-	-	-	-	YES - foundations	YES - foundations
	Chloride ion concentration (Cl^-)	0.56	-	-	-	-	-	-	-	bridge deck 1,28 columns 0,50 3)	bridge deck 0,56 columns 1,60
	Limit chloride ion concentration (ČSN EN 206)	1.0	-	-	-	-	-	-	-	0.4	0.4
	Risk of reinforcement corrosion induced by Cl^-	plain concrete	-	-	-	-	-	-	-	YES	YES
	Carbonation [mm]; average (range)	65 (10 - 150)	90 (20 - 150)	-	-	-	-	-	(45 - 90) 4)	40 (2 - 90)	65 (15 - 130)
	Thickness of the protective layer [mm] and minimal required thickness under ČSN EN 1992-1-1 degree of environmental impact XF2 or XF4 6)	plain concrete				complying for walls 5) consoles 35 < 45 non-complying 7)	slabs 70 - 90 8) hand rails 65 > 55 complying posts 25 - 45 < 55 non-complying	35 - 45 < 55 non-complying	precast staircase parts 30 - 35 < 45 others 45 - 70 > 45 complying	posts 40 - 45 bridge deck 25 - 60 < 45 non-complying	columns 40 - 45 bridge deck 25 - 45 < 45 non-complying
	Corrosion of the reinforcement structure and corrosion-induced loss of the cross-section [%], influence on the load-bearing capacity	plain concrete				consoles locally dilatations up to 50 % without influence on the load-bearing capacity	only locally in the damaged area 10 - 20 %	only locally in the damaged area up to 15 %	precast staircase walls and landings 50 % central columns 20 % of the area influence on the load-bearing capacity	beams of the deck around the expansion and deck joints 10 - 20 % locally up to 25 % influence on the load-bearing capacity	beams of the deck around the expansion joints 15 - 20 % locally 25 - 40 % influence on the load-bearing capacity

	Description	Property	Breast walls, walls above columns, cantilevers	Railings	Street lamp posts	Staircases	Frame structures
ORNAMENTAL CONCRETE	Ornamental concrete is a special surface layer applied over the construction concrete covering the breast walls, walls above columns, cantilevers, railings, street lamp posts and staircases. In the vaults, columns and abutments, this layer covers only a very small area on the side parts of the outer vaults and the side parts of cantilevered parts of the columns and abutments. The specimens of ornamental concrete were placed in storage boxes at the same time as the construction concrete specimens.	Density [kg/m^3]	2380	-	-	-	This ornamental concrete layer does not cover the surface of the frame structures of the bridge.
		Compressive strength [MPa]	52 - 56	35	45	44	
		Surface water absorption V_{30} [l/m^2]	0,08; 0,31	0.08	0.42	0.13	
		Resistance against de-icing agents degree of environmental influence XF1-XF4	complying with XF4	complying with XF4	complying XF4 9)	complying with XF4	
		Carbonation [mm]	2 - 15	0 - 10	0 - 10	10 - 25	
		Chloride ion concentration (Cl^-)	walls 0.35 consoles 0.53	0.08	0.07	0.71	
		Limit chloride ion concentration under ČSN EN 206	0.4	0.4	0.4	0.4	
		Risk of reinforcement corrosion induced by chloride ions	consoles yes	NO	NO	YES	

1) The tests were carried out using samples of cohesive parts of core drillings which were suitable for the preparation of testing samples.
2) Manifestations of ASR were detected only in one sample. As a result, it will be treated as an isolated incident and will not be considered as relevant.
3) Average value in the depth of 15 mm at maximum.
4) In areas where the ornamental surface layer fell off.
5) Reinforcement in breast walls is placed in the inner part and in walls above the columns it is placed deeper than in other parts.
6) For the degree of environmental influence XF2 = 56 mm, for XF4 = 55 mm (construction class 6).
7) The vertical part of the cantilever beneath the railing directed towards the pavement should meet the XF4 requirement (55 mm).
8) Reinforcement in the slab, the circumferential reinforcement element along the vertical groove is protected by a layer thinner than 55 mm.
9) Assessed based on the results of testing of the ornamental concrete layers collected from other parts of the bridge.

Based on the obtained results, further significant conclusions were reached:

a) Both the mechanical and physical properties of the concrete are highly variable (Tab. 1).

b) Due to insufficient compaction, the micro-structure of the concrete is porous, sometimes cavernous, and it contains large aggregate grains (50-90 mm on average). The foundations of the vault part are also porous, little cohesive and locally non-cohesive at all. Both river water and groundwater can penetrate and move through them easily.

c) 20-25 % of the surface of the concrete used in the vaults, columns and abutments suffer from corrosive degradation as deep as 10 to 30 mm caused by exposure to water leakages and frost. In some areas around gravel pockets severely affected by intense water leakages, i.e. around drainage holes, corrosive degradation has penetrated as deep as 100 mm.

d) Endoscopic inspection of selected plumb slabs in the vault joints did not reveal any discernible form of deformation.

e) Insulation of the vault part is damaged (completely consumed by corrosion) in areas where the insulation material stretches across the joints connecting several vault slabs (approximately 50 % of their length). Insulation of the frame structures is damaged especially in areas around the expansion and deck joints.

f) The backfills of the vault part of the bridge are composed of river sands, gravel sands, gravels and building debris consisting predominantly of bricks. The backfills contain only low levels of water-soluble salts, so their influence on degradation can be considered as negligible. The density of backfills recommended for static analysis is 1900 kg/m^3.

g) A plain concrete slab is placed above the vaults and covered with bitumen coating. This slab customarily consists of two concrete layers of different thickness each connected by a large joint. Apart from areas around the upper vault parts, the total thickness of the slab typically ranges between 500 - 650 mm.

h) The columns and abutments of the vault bridge are built on shale bedrock (rock type R4, and R4/R5). Calculation value of the bedrock load-bearing capacity recommended for the static analysis is $\mathbf{R_d}$ = 800 kPa.

Fig. 9: Porous and little cohesive concrete in foundations of the column of the vault part and bedrock

Fig. 10: Concrete degradation in the vaults and abutments caused by water leakages in conjunction with frost

Fig. 11: Plumb slabs in the vault joints without any apparent damage

Fig. 12 and 13: Damage in the railings and cantilevers in the upper part of the vault caused primarily by dilation. Damage of the street lamp post caused by reinforcement corrosion and weather conditions

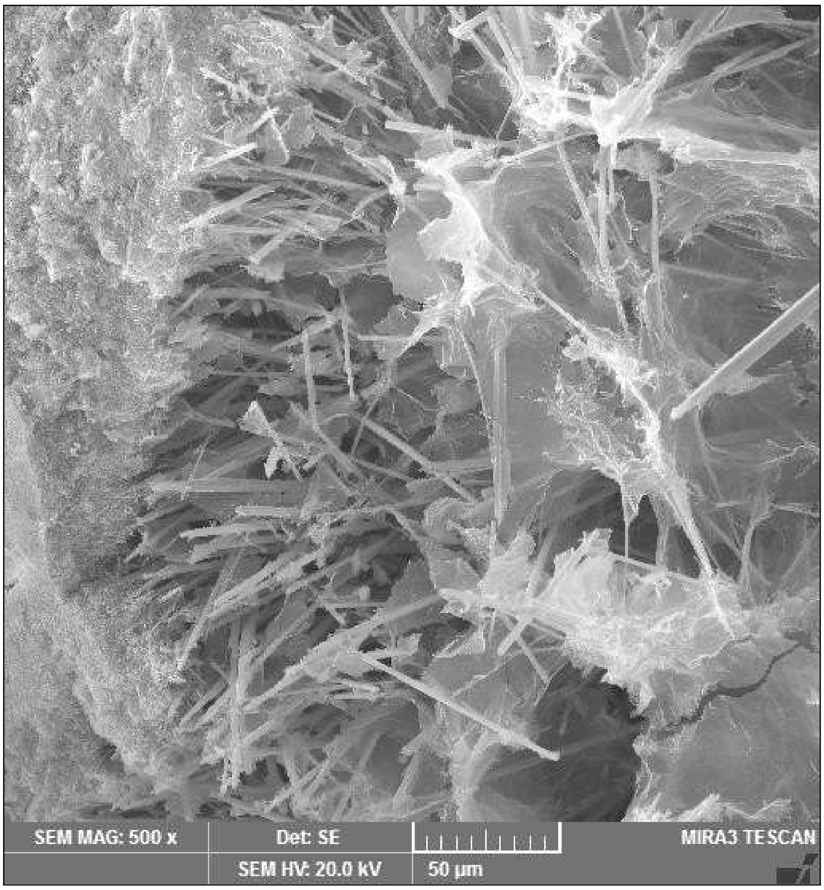

Fig. 14: Ettringite in the foundations of the column of the vault part (formed as a result of sulphate corrosion in concrete)

Fig 15: Concrete layers underneath the roadway of the vault part
and backfill consisting of gravel sands and building debris

Fig. 16: Staircases; weakened reinforcement and deep degradation of concrete -
emergency condition

Fig. 17: Frame structure; Holešovice frame part, part I-VI in the joint area; weakened reinforcement and deep degradation of concrete - emergency condition

Fig. 18: Frame structure; Libeň frame part, part C in the area along the expansion joint; weakened reinforcement and deep degradation of concrete - emergency condition

5. LOADABILITY AND STATIC RELIABILITY OF THE BRIDGE

Loadability was calculated according to the procedure set forth in ČSN 73 6222 [3]. Three different values were identified: normal, exclusive and exception loadability. Loadability of a bridge is defined as the maximum permissible weight of one vehicle in the following three traffic scenarios:

a) **Normal loadability**: normal traffic on the bridge (both passenger and freight traffic). The full loadability value according to applicable norms is Vn = 32 t.

b) **Exclusive loadability:** Only one vehicle is permitted to go over the bridge. Other vehicles are banned from the bridge. The full value of loadability according to applicable norms is Vr = 80 t.

c) **Exceptional loadability**: a special scenario during which the bridge is loaded by a special set of vehicles and both pedestrian and vehicles are banned from the bridge. The full value of loadability according to applicable norms is Ve = 196 t.

Normal loadability Vn and exclusive loadability Vr were calculated based on the assumption that a normalised tramway crosses the bridge in both directions. Real tramways (T14 and T15) were used for calculation of the frame structures.

5.1. Loadability of the vault part

To determine the loadability and static reliability of the vault bridge, calculation models were designed and linear and non-linear analyses of the construction performed. MIDAS, SCIA and ATENA computing programmes were used.

The calculations are presented in detail in report No. 1700 J 019-02 Static reliability and loadability of the bridge [02] and the appendices.

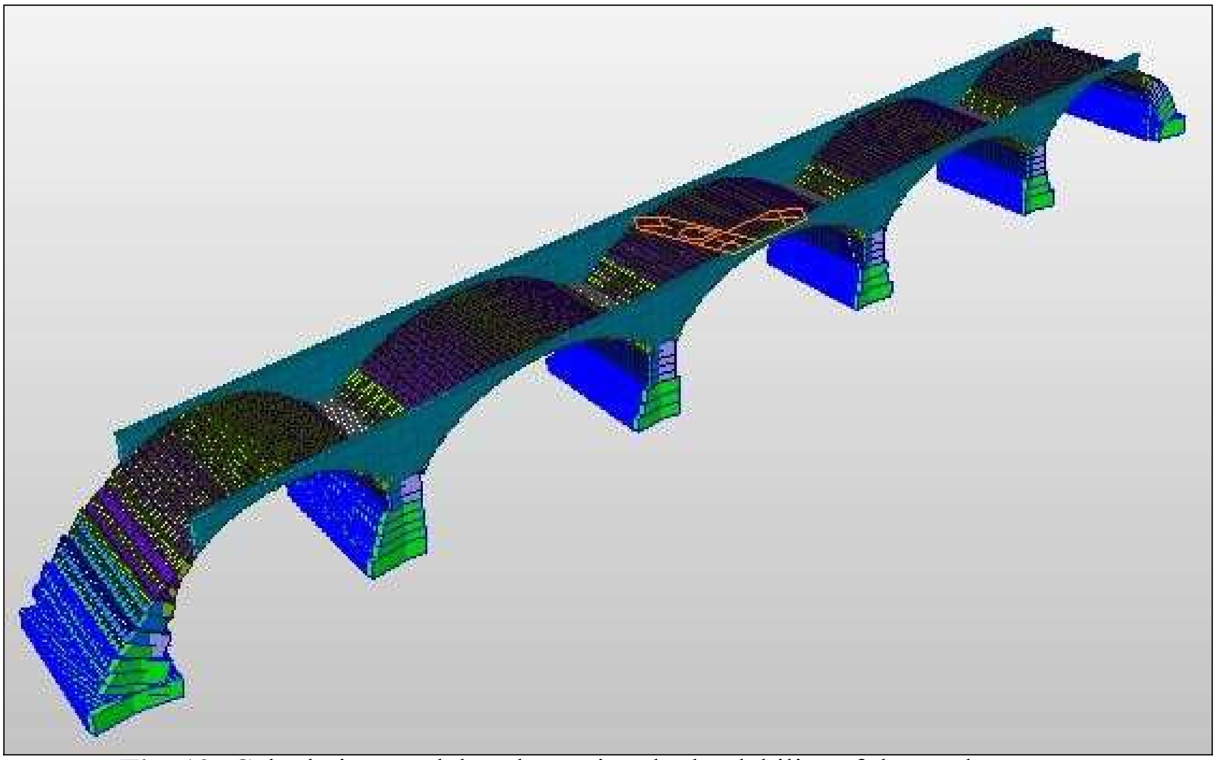

Fig. 19: Calculation model to determine the loadability of the vault part

The following negative impacts were taken into consideration in all calculations:

- Impact of self-weight on increasing the natural reinforcement of vault parts.
- Impact of the changes in the vaults' central line geometry in contrast to the values used in the calculations (based on the archive documentation)
- Impact of the cross-section reduction in the vaults due to concrete degradation or insufficient compaction.

Loadability of the vault part with respect to all the possible negative impacts is presented in Table 2.

Tab. 2: Loadability of the vault structure (see conditions in the description below)

Normal	Exclusive	Exceptional
6 t < 32 t non-complying	**15 t < 80 t non-complying**	**196 t = 196 t complying**

Table 2 indicates:

1) Normal loadability must be capped at 6 tons at maximum (1 x 6-ton vehicle and regular traffic of passenger vehicles) for each direction of the road traffic together with the operation of a two-way normalised tramway.
2) Exclusive loadability must be capped at 15 tons at maximum and only one road vehicle in each direction can be permitted (with no other vehicles) together with the operation of a two-way standardised tramway.
3) Exceptional loadability corresponds to the value set forth in applicable norms, i.e. 196 tons. Only one vehicle is permitted in this scenario and the passage of all other vehicles must be banned. Furthermore, the vehicle must move on the bridge axis at the prescribed speed not exceeding 5,0 km/h.

5.2. Loadability of the frame structures

To determine the loadability and static reliability of the vault bridge, calculation models were designed and linear and non-linear analyses of the construction were performed.

The calculations are presented in detail in report No. 1700 J 019-02 Static reliability and loadability of the bridge [02] and the appendices.

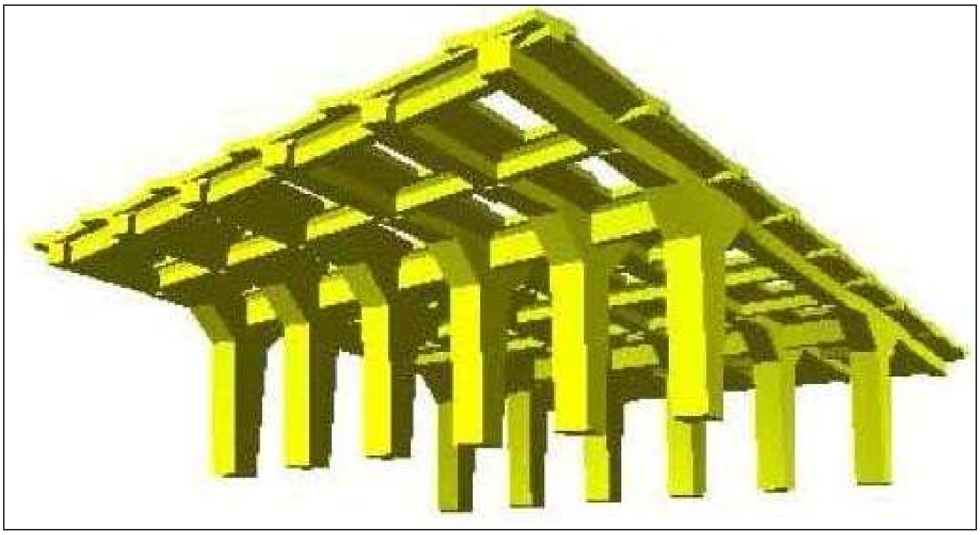

Fig 20: Calculation model to determine the loadability of the frame part (part I-VI)

Based on the results obtained by the static analysis, it can be assumed that frame part C in its current state has the lowest loadability values. Without any tramway traffic operations, its normal loadability is Vn = 5 t.

Tab. 3: Loadability without **any tramway traffic operations** with temporary additional support system

Normal
5 t < 32 t   **non-complying**

Given the emergency condition of several frame structures, the operation of tramways must be interrupted until a temporary support system is installed (Fig. 21). It is necessary to make sure that the loadability does not exceed 5 t in case of a sudden change.

To operate the tramways at least in a limited regime (i.e. one-direction tramway), it is necessary to install a temporary support system of selected parts (Fig. 21).

Tab. 4: Loadability for **alternating tramway traffic** with installed temporary support structures

Normal
11 t < 32 t   **non-complying**

Tables 3 and 4 indicate:

1) Before the temporary support structures are installed, the loadability must be limited to 5 tuns at maximum for each direction of road traffic and **tramway traffic must be entirely interrupted**

2) When the temporary support structures are installed, the loadability must be limited to 11 tons at maximum for each direction of road traffic and tramway traffic must be kept in an alternating mode.

3) The temporary support structures must be duly designed based on values verified by static calculations.

5.3. Assessment of the remaining construction parts:

During the assessment of the bridge, special attention was paid to all elements and details. The assessment focused on the following:

a) behaviour of expansion interlocking joints;
b) columns including their cantilevered parts;
c) foundations;
d) cantilevers of pavements;
e) railings;
f) breast walls and walls above columns.

The non-linear analysis shows:

a) The expansion interlocking joints work well, they expand according to expectations. The vault structure does not shift in the transversal way.
b) The cantilevered parts of the columns work well. Tension in the columns reaches values that are not dangerous for the functionality of the construction.
c) According to the non-linear analysis, the structure functions well, and its results correspond to the conclusions of the linear analysis.

Cost analysis:

When the foundations were loaded by their natural force and the live load of the structure, no signs of cracking due to side traction were observed. The maximum design tension in the ground joint determined by the diagnostic inspection is 0.8 MPa. The obtained results show that the properties of the foundation structure meet the applicable standards in terms of the maximum permissible tension in the foundation joint, as indicated in Table 5.

Tab. 5: Tension in the foundation joint of the columns and abutments

Indicators - archive documents	Indicators - report	Surface [m^2]	Tension - archive documents [MPa]		Tension - calculations [MPa]
			max.	in the centre	
1	H	175.1	0.70	0.317	0.359
2	0	153	1.11	0.590	0.600
3	1	153	1.04	0.686	0.710
4	2	153	1.15	0.700	0.740
5	3	153	1.04	0.686	0.710
6	L	153	1.15	0.550	0.582

Assessment of the pavement cantilevers and breast walls:

The breast walls, their ribs above the columns and pavement cantilevers were assessed based on the information available in the archive documentation. This allowed for the identification of the properties of the reinforcement structures used in the cantilevers, breast walls and ribs. The distance between the ribs above the column, which allows for the determination of their load width, is unknown. Their assessment will have to be performed after the extraction of the backfill during the reconstruction. The number of reinforcement profiles anchoring the breast walls to the bridge vault remain unknown, too.

a) The assessment of the cantilevers of pavements showed that their permissible load is sufficient. The structure of the cantilevers has met the requirements in all of the analysed sections.
b) The breast walls were assessed only based on one section. Their structure in this analysed section has met the requirements. Other parts are also expected to meet the requirements. In spite of that, we recommend verifying the robustness of the reinforcement system during the reconstruction works after the extraction of the backfill.
c) As the distance between the ribs within the structure is unknown, their structure and the structure of the middle part of the wall could not be assessed. The calculations of the loadability of the ribs above the columns have identified a weak area in one section with less robust reinforcement. In case of reconstruction, the load-bearing capacity of the structure must be additionally inspected and assessed after the extraction of the backfill. It is assumed that this area of the structure will not meet the requirements and it will be necessary to implement additional reinforcement elements.

Assessment of the railings

The calculations of the load-bearing capacity of the railings have shown their resistance is sufficient.

Assessment of the staircases

The conducted diagnostic inspections have concluded that the staircases are in irreparable condition. This part was not subjected to static assessment.

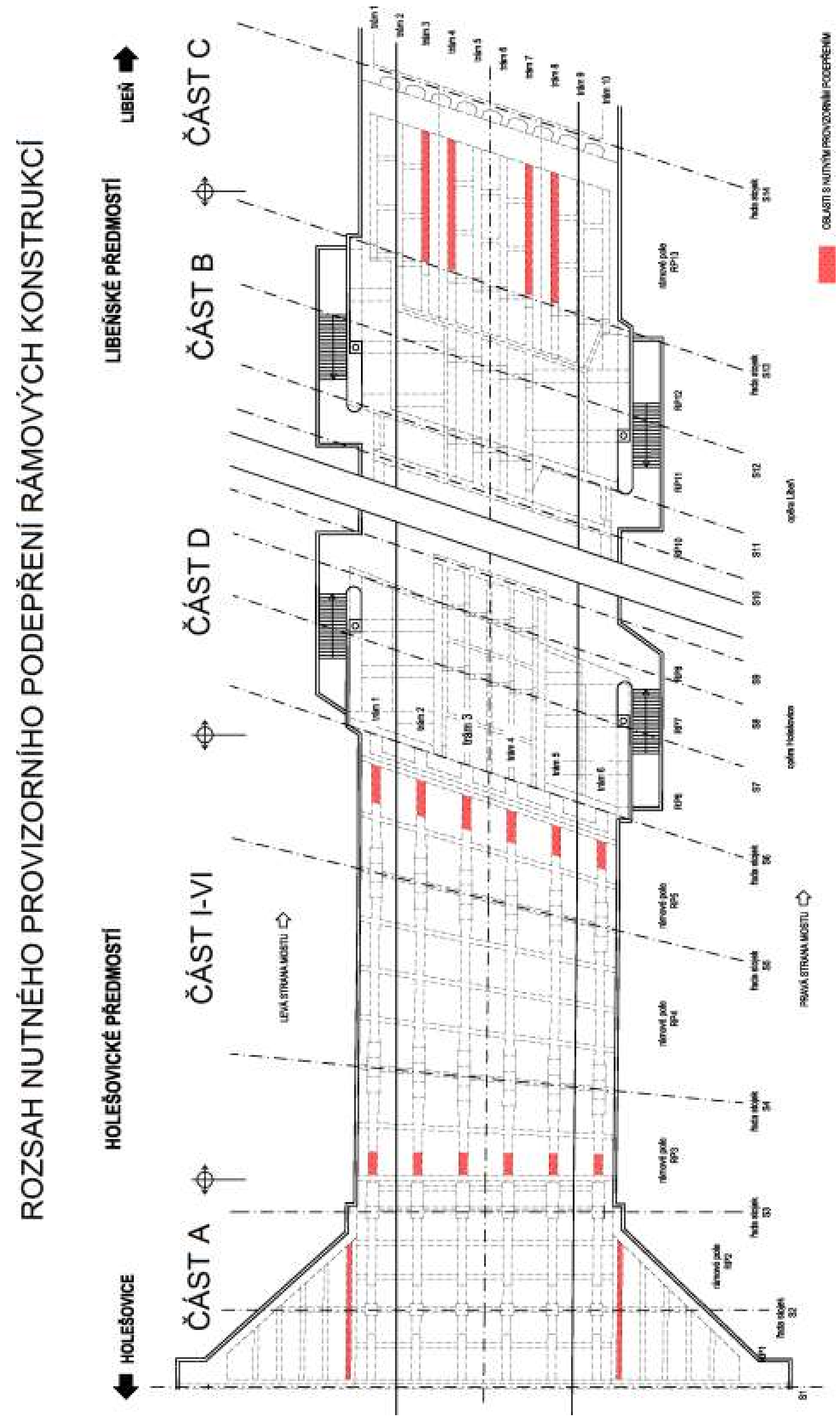

Fig. 21: The extent of the necessary temporary support structures of the frame parts to allow for the normal permissible load of 11 tons at maximum for each direction of road traffic and alternating tramway traffic

5.4. Static analysis results and determination of loadability

The below-mentioned assessment was performed with regard to the current condition of the bridge as determined by the diagnostic inspections.

The results of static linear and non-linear analyses show:

1) No part of the bridge structure meets the loadability requirement under the currently applicable ČSN 73 6222 [3]. The condition of the vault part is better than the frame structures. To meet the loadability requirement laid down by ČSN 73 6222, complete reconstruction is necessary (see below).
2) The frame structures on both sides are the weakest parts of the bridge.
3) Frame part C located on the Libeň side near the railing is in the worst condition. The reinforcement structure lost 40 % of its cross-section area due to corrosion. The normal permissible load of frame part C is **Vn = 5 t when tramway traffic is interrupted.**
4) **The bridge is in an emergency condition.**
5) To enable a safe one-way tramway operation on the bridge until a final solution is found and realised (reconstruction or construction of a new bridge), a temporary support system must be established to support several cross sections of the frames (see Fig. 21).
6) **After the most damaged frame parts are supported with additional structures, alternating traffic** (real tramways T14 and T15 were taken into consideration) **must be implemented for tramways operating above frame part B and the loadability of road vehicles must be limited to Vn = 11 t over the entire bridge V009.**

6. RECONSTRUCTION

For any bridge structure to be used in accordance with the applicable standards of the City of Prague, two basic requirements must be observed:

a) **Static reliability** and design safety with specified loadability (see Chapter 5).

b) **Durability and service life** of the structure (current design value at least 100 years),

As a result, the works were focused on the possibilities and ways to meet these two basic requirements in the case of the main bridge V009 of the Libeň group of bridges. As mentioned previously, the commissioner of the project requested a complete and comprehensive overview of key facts about the bridge condition and the possibilities of its reconstruction and repairs regarding it as a cultural monument. The aim was to preserve as many existing structures as possible.

The diagnostic inspections and static analyses have shown that in order to operate the bridge in accordance with the **required loadability** (see Chapter 5) according to the applicable standards, it is necessary to:

a) either perform a **large-scale and exacting reconstruction** focused on improving the static properties of the currently non-compliant parts of the bridge, including stabilisation works on the bridge foundations,
b) or **build a completely new bridge** (without using the foundations and abutments in place, as originally planned in 2005).

The obtained results clearly indicate that a reconstruction project consisting solely of partial static repairs and "cosmetic" surface repairs without large-scale and comprehensive static works (as presented below) will enable to use the bridge only with permanent traffic restrictions.

To ensure the durability (service life) of the entire bridge in accordance with the applicable standards (design value at least 100 years), the construction of a new bridge is inevitable. In case of choosing the reconstruction scenario, it must be noted that no remediation method can ensure the required durability. In reconstructions of historical buildings, this is however quite expectable and common. This fact must be necessarily taken into account when laying down specifications of the repair works, including the parameters of the final result and maintenance works in the years to come.

The suggested reconstruction possibilities are presented in further detail in Report No. 1700 J 019-04 Reconstruction and assessment of concrete remediation methods [04] which is an integral part of the present comprehensive evaluation of the bridge condition.

This chapter presents the possibilities to perform the necessary large-scale static repairs, including the works that need to be done to ensure the bridge's durability. To perform the works and repairs described below, approximately 50 % of the total volume of the structure would have to be replaced completely. This part also discusses the possibilities of surface treatment to meet the aesthetical requirements and to increase the durability of materials (increasing their service life) of the preserved historical parts. It is noteworthy that the durability (service life) of the preserved parts in accordance with the applicable standards and requirements (design service life of at least 100 years) cannot be met by mere reconstruction.

6.1. Vault part of the bridge

Several options and static operating scenarios were considered when investigating the possibilities of reconstruction of the vault bridge (see Report [04]). The below-mentioned option was discussed based on a study conducted by the Klokner Institute, ČVUT, in cooperation with Novák & Partner s.r.o. as commissioned by TSK a.s. TSK a.s. requested that the suggested works aim at preserving the historical parts to the maximum extent possible and that the detected corrosion attacks in the foundations be taken into consideration. The study was conducted without the participation of Pontex s.r.o. and INSET s.r.o.

Based on the static analyses, the examination of reconstruction possibilities and remediation repairs of the vault part of the bridge, the following can be assumed:

1) In order **to ensure sufficient static reliability and loadability of the bridge** in accordance with the applicable standards, the most appropriate solution involves replacing the middle vault strips of all of the five vaults with new reinforced concrete strips (see Figs. 22-23 below) as well as stabilising the condition of the foundations and abutments.
2) Static calculations have proved that when the middle vault strips will be replaced with new reinforced concrete strips with identical static properties (three-joint vault), the loadability of the vault structure will meet the applicable standards (see Chapter 5), i.e.:
   - normal loadability Vn = 32 t (two-way tramway operation according to EN);
   - exclusive loadability Vr = 80 t (two-way tramway operation according to EN);
   - exceptional loadability Ve = 196 t.
3) This solution maintains the original static scheme of both the outer vault strips and the new inner vault strips (three-joint vaults).
4) By replacing the old inner vault strips with new strips, the overall stress level in the outer vault strips bearing the architectural elements will be reduced. In case of local damage detection following the extraction of the backfill and subsequent diagnostic inspections, the outer strips can be reinforced by adding a composite over-concreting reinforced slab.
5) By adjusting the weight of the newly used backfill, the natural force of the normal load force can be optimised in order to meet the decompression condition necessary for frequent load combination.
6) Given the detected sulphate corrosion in the columns of the foundations, it will be necessary to add an additional shell cover from reinforced concrete.
7) The surface of the preserved parts of the bridge will be treated using conventional surfacing procedures and cleaned in order to restore the required aesthetical appearance and increase the structures' durability (service life). For further details see Report [04], Appendix 4.
8) Elements of the surface ornamental concrete can be resurfaced applying a special cement-based repair coating with adequate content of crushed aggregate. Another option is to replace them with suitable replicas.
9) To ensure that the newly reconstructed bridge will function smoothly, new waterproofing and drainage systems must be conceived, the backfill must be replaced and the bridge topmost part completely remodelled.
10) **The reconstruction of the vault part, including stabilisation works in the foundations, will be highly demanding both in terms of the preparatory design works and the implementation.** The technical design presented in this report is solely theoretical, not accounting for a number of legal aspects (impact on the current construction permit) and technical details (solution of networks, connected buildings and roads).

The following figures illustrate the concept of the inner vault strip replacement.

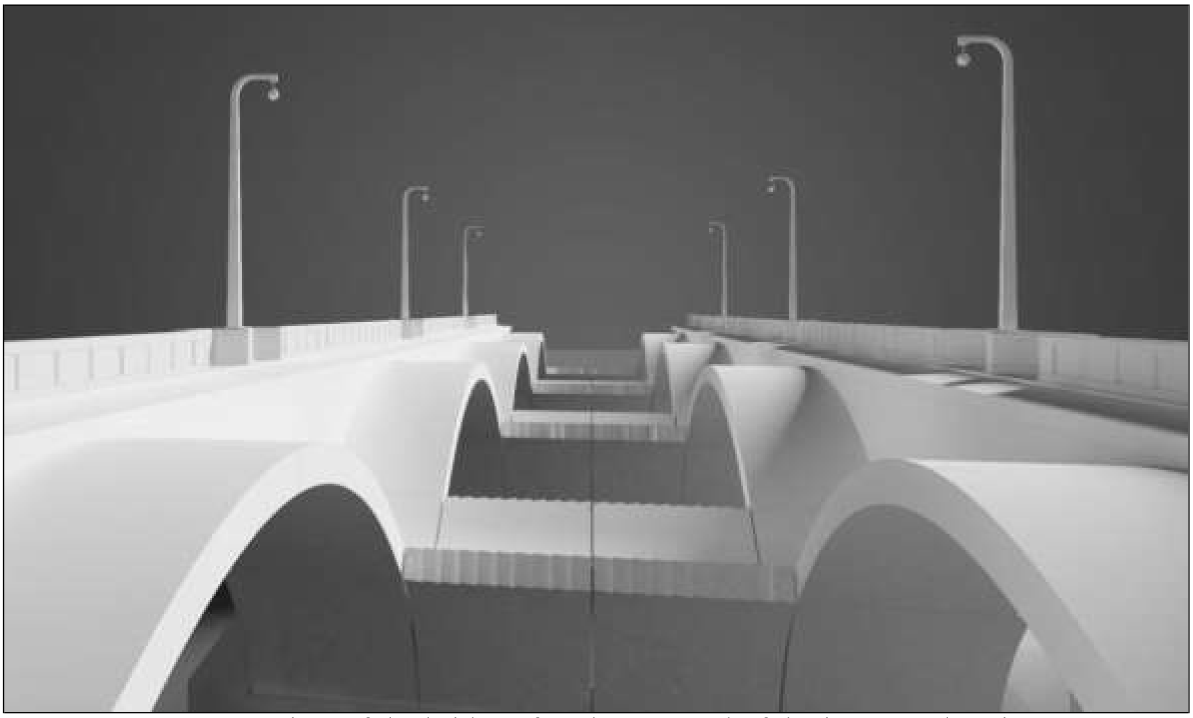

Fig. 22: View of the bridge after the removal of the inner vault strips

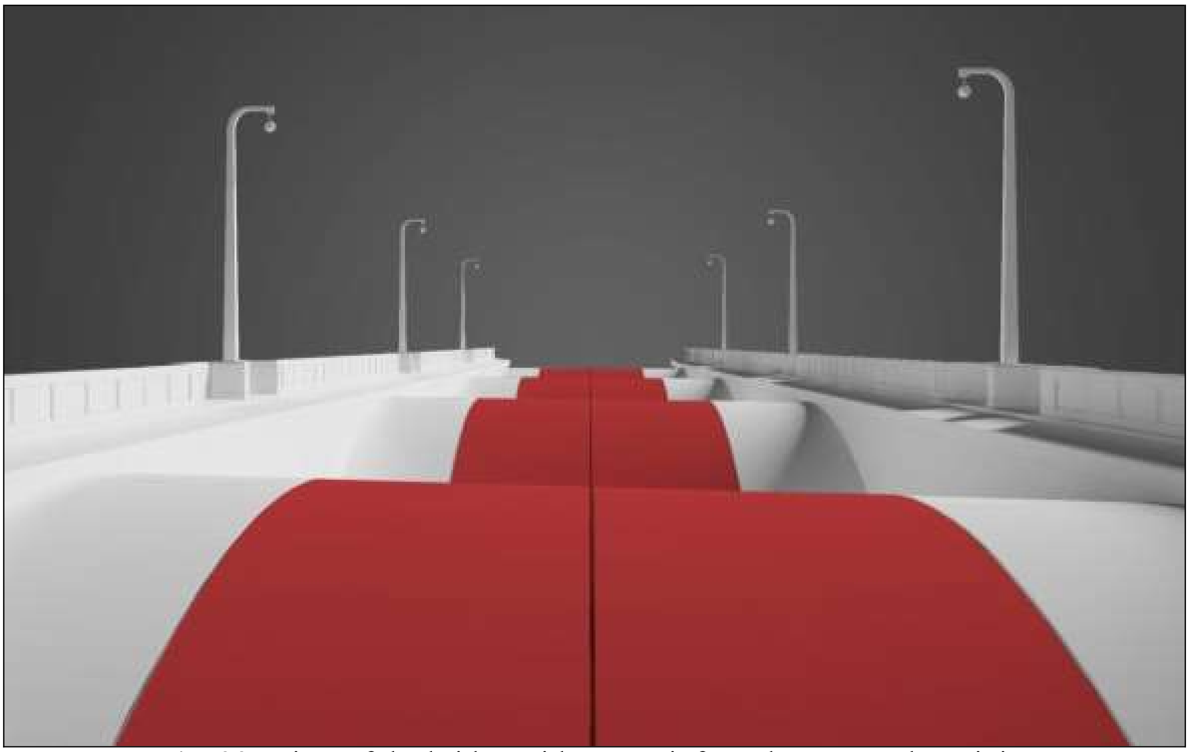

Fig. 23: View of the bridge with new reinforced concrete three-joint vault strips

6.2. Frame structures and staircases

The frame structures of the Libeň bridge consist of five construction parts. This includes frame parts A, I-VI and D in Holešovice, and parts B and C in Libeň (Chapter 2). The static possibilities of the frame structures reconstruction are presented in further detail in report [04] Reconstruction and assessment of concrete remediation methods, Appendix 6.

Based on the static analyses and the determined condition of the frame structures, the following can be assumed:

1) Frame parts A, I-VI and C are in an emergency condition. From the static point of view, the extent of damage (due to concrete degradation and reinforcement corrosion) in the areas of all longitudinal and transversal expansion joints, deck joints and recesses constitutes the most serious problem.
2) Frame part B and the outer deck part of frame D have not met the requirements stipulated by the applicable loadability standards since their construction.
3) The staircase structures (in frame parts B and D) are in an emergency condition.
4) The possibilities of adding additional concrete layers to the frame parts, or partially replacing their most damaged sections, are very complicated, technically practically unfeasible and would ensure only limited durability. By adding protective layers, these parts would lose their original shape and appearance.
5) As a result, it is impossible to repair the frame parts in order to ensure sufficient static reliability and loadability (load-bearing capacity) in the long term.
6) **In case of a large-scale reconstruction, the frame structures and staircases cannot be repaired in a satisfactory manner. That is why we deem necessary to replace them with completely new structures (their replicas or new same-shaped structures). This will ensure sufficient loadability and durability (service life) complying with the applicable standards.**

6.3. Measures to increase durability - resurfacing possibilities

As part of evaluating all the reconstruction possibilities of the vault bridge, a vast array of technology procedures and remediation methods aiming at preserving the bridge as a cultural monument were assessed. The conclusions and suggested solutions are discussed in further detail in Report [04], Appendix 4.

The results obtained by the diagnostic investigation, surface remediation measures and follow-up tests can be summed up as follows:

1) Surface remediation of concrete bridge structures can be performed using existing and proved technological methods. Remediation however only slows down the ongoing degradation processes. At the same time, it enhances the aesthetic quality of surfaces.
2) It must be noted that damage in the railings is localised and occurs systematically in areas surrounding the joints and cantilevers above the columns. The damage in these structural

elements is caused by the design of the load-bearing structure with defective expansion joints from the time of the bridge construction. These signs of degradation will reappear repeatedly regardless of the quality of remediation works performed, unless adequate construction repairs are performed.

3) To repair larger damaged areas of precast components of the railings (especially decks and columns) occurring on their circumference (broken tongues and grooves, edged, etc.), from the technical point of view we recommend giving preference to replacing them with replicas (if acceptable) to plain surface remediation.

4) Tests of bond strength and resistance performed on samples of selected reference surfaces showed that the weakest part of all elements is the base material (the original material). It proved to be the weakest part in the vault parts, core concrete elements as well as ornamental surface concrete elements.

5) While it is possible to locally replace parts of the structure attacked by corrosion that penetrated deeper in the concrete of the vaults, columns and abutments (less dense or degraded concrete layer at a depth greater than 50 mm), such a procedure would be technologically very demanding and with very uncertain result given the weak adhesion between this newly applied layer and the base material.

6) As a result, we do not recommend applying new full-scale concrete layers to open surface areas of the vaults. Their adhesion and bonding coherence would be problematic, even if additional mechanical anchoring elements of several centimetres were applied. This procedure would definitely not improve the durability of the structure. On the contrary, it would worsen the risk of increased air condensation, humidity and frost along the boundary space between the new and the old layer. The best remediation method for this type of surfaces would involve only local surface treatments limited to the extent necessary to ensure the efficiency of potential secondary protective measures (e.g. filling surface cavities while maintaining the current level of the structure's upper parts).

7) It was experimentally established that the appearance of the ornamental surface layer can be improved using various cleaning methods (high-pressure washer, sanding, etc.).

8) Given the age and heterogeneity (varying compaction) of the concrete used in the bridge, we recommend applying colourless hydrophobic surface treatment all over the surface of the preserved construction elements (vaults, railings, cantilevers, breast walls, etc.). This method is relatively cost-friendly, it will not alter the aesthetic appearance and it can slow down significantly the progression of the degradation processes, thus increasing the durability (service life) of the inspected materials and structures. Prior to this, all surfaces must be duly cleaned and locally missing material must be filled.

9) With respect to repairs of the concrete surface and its final treatment, we recommend following the guidelines set forth in the rules on concrete repairs, such as SSBK III [55] or TKP 31 [58], bearing in mind that given the current material and construction condition of the bridge, it will very likely not meet many of these strict requirements.

6.4. Cost analysis

No detailed project of the above-mentioned reconstruction has been conceived so far, but a summary report on this topic was prepared (see Report [04]). Financial costs are presented in further detail in Report [04], Appendix 5.

Based on the cost analysis, the following can be assumed:

1) According to our calculations, **the total costs** of a construction of a new bridge and a large-scale reconstruction of the existing bridge are similar and comparable, amounting to **CZK 500 - 600 million (excluding VAT).**

In case of a large-scale reconstruction, it cannot be ruled out that especially during the implementation of the works, **the final costs increase** given the intricacy and complexity of the works aiming at preserving the historically valuable parts. The following must be kept in mind:

a) reconstruction involves working with unique and rarely used materials and technologies,
b) the extent of works and procedures is susceptible to change over the course of the reconstruction as new information about the condition of the structure will come to light after exposing all of its parts (especially the foundations and the upper vault parts).

2) The maintenance and operating costs of the reconstructed bridge will be higher than of a completely new bridge.

Following a large-scale reconstruction, it is to be expected that in addition to the usual maintenance costs comparable to maintenance of a new bridge (road surface cleaning, pavement cleaning and repairs, removing wind-borne plants, etc.), the reconstructed bridge will require detailed monitoring and more frequent inspections.

In this respect, a plan of monitoring, maintenance and repair works will have to be drawn and observed. The most significant supplementary measures can be summed up as follows:

a) monitoring the sulphate corrosion progression in the preserved foundations and columns,
b) monitoring the temperature changes and deformation (sensors, regular levelling),
c) more frequent surface repairs and repairs of cracks caused by load forces and weather conditions (temperature changes, frost, water), including regular application of hydrophobic surface treatment (approximately once in every 10 years).

The above-mentioned measures involve the following:

Ad a) An extremely complex collection of samples through core drilling and subsequent assessment of the obtained information. Monitoring would be carried out continuously in-situ and complemented with a long-term experimental study performed at laboratories. It must be noted that the collection of core samples by drilling can obstruct traffic on the bridge. Core drillings can be prepared during the construction works over the entire height of the columns and abutments, including the foundations. One possible way involves creating the drills and placing samples of the lower parts of the bridge structure. This would allow to expose the concrete samples to an authentic corrosive environment. This would allow for periodic checks at defined intervals (partial checks once a year, detailed assessment once every 5 years) to be performed by taking the specimens out and analysing them (visual inspections, microscopic tests, chemical analyses of nuisance content, mechanical tests, etc.).

Ad b) Various types of sensors (temperature, deformations) have already been installed on the bridge. It is thus possible to exploit them, restore their function, add more and continue to gather information. The extent of the monitoring activities could be adjusted based on the information obtained during the reconstruction works.

Ad c) It can be assumed that, compared to a new bridge, the historically valuable elements that are to be preserved will very likely require significantly more frequent repair works. The frequency of the necessary repair works is likely to increase over time. The necessity to reapply hydrophobic surface treatment at least once in every 10 years must also be taken into account.

It is impossible to determine the total operating costs without knowing in detail the extent of the works. Further and more precise calculations must be performed. Based on our previous experience with the above-mentioned works, the estimated costs of maintenance and monitoring of the reconstructed bridge would exceed the maintenance costs of a new bridge by CZK hundreds of thousands per year.

In conclusion, it is left up to the consideration and decision of the owner of the bridge to determine which economic, technical, social and cultural aspects will they take into account when deciding about the final solution of the main bridge structure V009 of the Libeň region, which is in a really bad condition.

7. SUMMARY AND CONCLUSIONS

The present summary of reports was carried out under contract on work No. 3/17/6300/0001 in effect from 30 January 2017, as amended, signed between Technická správa komunikací hl. M. Prahy, a.s., registered office Řásnovka 770/8, Prague 1, the Libeň Bridge Society (V009), administered by the Klokner Institute at the Czech Technical University ("ČVUT") in Prague, registered office Šolínova 7, Prague 6, and the member companies Pontex, spol. s r.o., registered office Bezová 1658, Prague 4, and INSET, s.r.o., registered office Lucemburská 1170, Prague 3.

The Commissioner requested a comprehensive overview of information on the bridge condition and the possibilities of its renovation with the aim of improving its loadability and service life to meet the applicable standards. The Commissioner requested to discuss both the construction of a completely new bridge, and especially the option of its renovation and repair, as if regarded as a cultural monument. This led a very vast set of requirements, that could be met only by performing a wide array of works and activities. A representative of the National Heritage Institute (NPÚ) was present during the works and was regularly informed about the project's progression and results.

This report summarizes the results of the diagnostics, static analyses and determination of the loadability of the bridge structures with regard to their current condition. It furthermore provides an overview of necessary measures, the possibilities of reconstruction, repairs and other restorative interventions aiming to improve the loadability and service life of the bridge structures to meet the applicable standards.

The works were performed between 1 February 2017 to 1 February 2018.

The results are discussed in detail in the following reports and their appendixes:

1. Report No. 1700 J 019-02 Static reliability and loadability of the bridge [02].
2. Report No. 1700 J 019-03 Diagnostics [03].
3. Report No. 1700 J 019-04 Reconstruction and assessment of remediation methods [04].

For any bridge structure to be used in accordance with the applicable standards, two basic requirements must be observed:

a) **Static reliability** and design safety with specified loadability (see Chapter 5).

b) **Durability and service life** of the structure (current design value at least 100 years).

As a result, the works were focused on the possibilities and ways to meet these two basic requirements also in the case of the main bridge V009 of the Libeň region.

The most significant findings regarding the durability of the materials and individual construction elements obtained by extensive diagnostic inspections can be summarized as follows:

1) The bearing components of the bridge do not comply with the material requirements laid down by the applicable rules for road structures (especially in terms of their durability and properties' variability).
2) The durability and service life of the bearing components of the bridge as required by the applicable legislation cannot be ensured by any remediation measure or repair.
3) Parts of the frame structures' decks around expansion joints and deck joints are in an emergency condition (extensive corrosion attacks in the reinforcement structures, large-scale concrete degradation).
4) The foundations of the vault part, the columns and abutments (up to the bottom joints) suffer from internal sulphate corrosion (the foundations of the frame structures are also corroded, yet the severity of corrosive attack is significantly lower).
5) **The staircases are in an emergency condition and it is imperative that they be completely replaced** (severe reinforcement corrosion, deep concrete corrosion).
6) Construction elements of the ornamental surface concrete layer (used in the architectonical elements) have considerably better properties in terms of durability. There are however numerous cracks in the ornamental concrete layer, especially in the area around the cantilevers and cantilevered parts of the columns and abutments. Parts of railings and historical street lamp posts show signs of considerable damage (broken edges, cracks).

   The results of the diagnostic investigation served as a basis for static analyses and the determination of loadability of the bridge structures, reflecting the material properties, current condition as well as degradation and corrosion progression.

The results of static linear and non-linear analyses show:

1) **No part of the bridge structure meets the loadability requirement under the currently applicable ČSN 73 6222 [3].** The condition of the vault part is better than the frame structures. To meet the loadability requirement laid down by ČSN 73 6222, a **large-scale reconstruction** focused on statics is **necessary**.
2) The frame structures on the both sides are the weakest parts of the bridge.
3) **Frame part C** located on the Libeň side of the bridge near the railing is in the worst condition. The reinforcement structure lost 40 % of its cross section due to corrosion. The normal permissible load of frame part C is **Vn = 5 t when tramway traffic is interrupted.**
4) **The bridge is in an emergency condition.**
5) To enable a safe one-way tramway operation at the bridge until a final solution is found and realised (reconstruction or a new bridge), a **temporary support system must be established to support several cross sections of the frames** (see Fig. 21).
6) **After the most damaged frame parts of the bridge are supported with additional support structures, alternating traffic** (real tramways T14 and T15 were taken into consideration) **must be put in place for tramways operating above frame part B and the loadability of road vehicles be limited to Vn = 11 t on the entire bridge V009.**

Based on the obtained findings and information regarding the bridge condition and the possibilities of reconstruction and repair, the following conclusions were drawn:

1) To meet the **loadability requirement** currently in place under ČSN 73 6222 [3] (see Chapter 5), two options are suggested:

   A) **A large-scale reconstruction** involving the following:
      a) Stabilising the current condition of the foundations of the vault bridge (remediation measures aimed at sulphate corrosion)
      b) Replacement of two middle vault strips (three-joint vaults) stretching across all of the five vaults with completely new reinforced concrete strips (three-joint vaults).
      c) Repair and remediation works applied in the preserved structures and their surfaces, including the improvement of their aesthetic appearance.
      d) Additional surface treatment aimed at increasing their service life and durability.
      e) Replacement of the frame structures and staircases with completely new structures, including the improvement of the aesthetic appearance of the ornamental surface concrete used in the staircases.
      f) New waterproofing, drainage, backfills and repair of the uppermost part.
      g) Periodic expert and long-term (permanent) inspections of the bridge condition and the degradation processes, especially in the area of the foundations, coupled with the assessment of the obtained results (monitoring its proper functioning).

      The implementation of the above-mentioned procedures and construction works would require the replacement of more than 50 % of the total volume of the construction material currently in place.

   B) **The construction of a new bridge** without its lower part (foundations and abutments).

2) **The durability and service life** stipulated by the applicable standards (the design value of 100 years) can be met only if a completely new bridge is built.

3) According to our analyses, **the total cost** of a new bridge and the large-scale reconstruction is similar and comparable, reaching **CZK 500 - 600 million (excluding TVA).**

4) **The reconstructed bridge would have to be thoroughly monitored and inspected.** It is therefore fair to assume that the total maintenance and operating costs of the reconstructed bridge would overweight the maintenance costs of a new one.

8. SUGGESTED MEASURES

1.1. Immediate measures

1) **Given the emergency condition of some parts of the frames, it is necessary to close tramway traffic and restrict car traffic operating on the bridge while maintaining the normal loadability at Vn = 5 t, until a system of temporary support structures is put in place under the weakest parts of the bridge.**
2) It is necessary to put in place a system of temporary support structures under the damaged beams of **frame part C** in the Libeň side and the weakened beams in frame **part I-VI** in the Holešovice side (see Fig. 21, p. 25).
3) It is necessary to put in place temporary support structures to support the outer beams extending the structures on both sides of **frame part A** (see Fig. 21, p. 25) to ensure safety of workers passing under it (to access workshops, storehouses); traffic does not operate on this part of the bridge.
4) **After the most damaged frame parts are supported with additional support structures, alternating traffic** (real tramways T14 and T15 were taken into consideration) **must be implemented for tramways operating above frame part B and the loadability of road vehicles must be limited to Vn = 11 t over the entire bridge V009.**
5) Given the obtained findings regarding the Libeň bridge V009, we recommend verifying the current condition of connected frame structures connecting the inundation bridge No. X-656, which is part of the Libeň group of bridges. These structures were not subjected to a detailed diagnostic investigation. Their frames can, however, be also in a very bad condition. According to a report by the Klokner Institute published in 2016 [69], only vehicles under 6 tons can operate on this bridge and tramway traffic must be operated in an alternating mode (two tramways cannot meet above the frames).
6) It is necessary to design a plan of monitoring and checks of the temporary support structures after their completion.
7) It is necessary to close down the staircase situated on the right side of the Libeň side, having regard to its very bad condition (other staircases have been closed down).
8) As far as street light posts are concerned, it is necessary to remove broken and loose concrete parts on the edges of the arches and heads with light bulbs, since they can fall and harm the public. The posts in question are L2, L6, P3, P5 and P7 (see Report [03], Chapter 4 and Appendix 2).

2.2. Long-term measures

1) It will be necessary to launch without further delay either reconstruction works focused on the enhancement of the bridge statics and durability, or the construction of a new bridge (including new foundations and abutments). Prior to conducting a large-scale reconstruction, which will be complicated both in terms of planning and realisation, as much detailed reconstruction plan as possible will have to be drawn up in conjunction with an overview of load states during the works and a list of planned procedures (i.e. stabilisation works in the foundations, surface treatments, etc.)

2) **Until the start of the works, it will be necessary to:**

   a) Monitor and check the temporary support structures installed under the bridges V009 and X-656.

   b) Restart measuring tension using strain gauges that were installed during the construction of the temporary support structures under the bridge V009 in the Holešovice side in 2009.

   c) Continue measuring temperature and deformations under the influence of heat as well as the joint movements in vaults 1 and 2 of the bridge V009.

   d) Continue performing control levelling measurements of the bridge V009.

   e) Conduct inspections of the group of bridges according to ČSN 73 6221 [2], or, alternatively, according to a different inspection plan. It is necessary to assess the results obtained through the above-mentioned measurements and monitoring should become a part of general inspections of the bridge.

   f) Design a monitoring plan and launch a long-term monitoring scheme of the progression of sulphate corrosion of the concrete used in the foundations of the abutments and columns.

3) **During reconstruction, it will be necessary to:**

   a) Develop an appropriate method of adjusting the weight of the new backfill applied to the vaults which would allow to create an ideal and natural "prestressing" normal force in the vault strips.

   b) After the extraction of the old backfills, it will be necessary to:

      - define and measure the shape of the preserved structures, especially in the outer vault strips,
      - perform dynamic tests in the outer vault strips in order to detect potential discontinuances and, in case of disrupted homogeneity, design and add a composite over-concreting reinforced slab,
      - perform diagnostic inspections in the reinforcement structure of the breast walls and ribs of the walls above the columns of the outer part of the bridge, assess the cross sections that could not have been assessed previously, and, if their condition is insufficient, design their strengthening.

   c) Once the foundations are exposed, it will be necessary to perform control checks and core drillings to gain more precise information about their condition and determine the right type and extent of grouting. The specimens obtained through core drillings will be used in studies on the progression of sulphate corrosion.

4) After the reconstruction, it will be necessary to:

g) Design and fulfil a detailed plan of long-term checks of the condition of the vault bridge with regard to the information obtained during the reconstruction works.

h) Perform inspections according to ČSN 73 6221 [2].

i) Conduct due operating and construction maintenance and immediately perform repairs of identified deficiencies.

j) Design a monitoring plan and launch a long-term monitoring scheme of the progression of sulphate corrosion of the concrete used in the foundations of the abutments and columns.

9. MAIN SUPPORTING DOCUMENTS

SUPPORTING DOCUMENT NO. 1 Report No. 1700 J 019-02 Static reliability and loadability of the bridge

SUPPORTING DOCUMENT NO. 2 Report No. 1700 J 019-03 Diagnostics

SUPPORTING DOCUMENT NO. 3 Report No. 1700 J 019-04 Reconstruction and assessment of concrete remediation methods.