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# MASONRY ARCH BRIDGES IN POLAND

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**Abstract.** *The following paper provides general information on railway and road masonry arch bridges in Poland. It involves statistical data with age profiles of railway structures and classification manners commonly applied to masonry arches. Typical damages are shown in exemplary photos and their division into 7 main categories is proposed. A structure of the management system is schematically presented with methods of inspections and testing associated with it. Such an ordered data organization is believed to be helpful in maintenance of these important and often monumental structures.*

## 1 INTRODUCTION

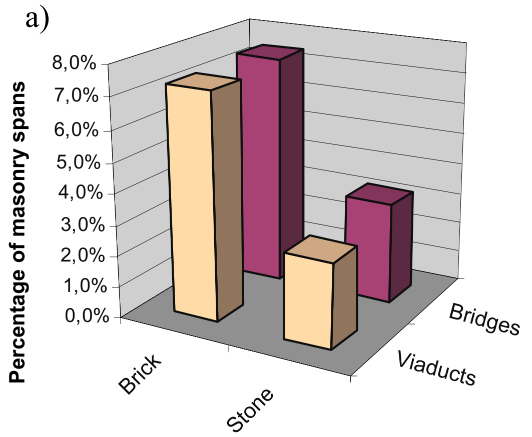
Masonry arch bridges in Poland are still a notable group of structures in spite of their advanced age. They fulfil a very important role on Polish railway and road networks. In connection with their relatively large number masonry bridges are indispensable and can not be easy replaced with new structures. It is even impossible and undesirable in respect of monumental character and exceptionally attractive appearance of most of them. However the technical condition of the majority of masonry arches is very poor and requires systematic maintenance and rehabilitation works. Some of them, which were beautiful and intensively exploited in the past, now look miserably and sometimes are simply near total collapse. Any interventions and assessments are here fairly difficult because of complexity of masonry structures, which are composites of two or more types of materials. The situation is additionally complicated because in many cases source data revealing methods of their designing and erecting are missing and the technical documentation of the structure is not available.

From the other side there are many examples of still used very old structures, which condition is completely satisfying thanks to systematic preservation based on specialists' knowledge.

## 2 STATISTICAL DATA

In Poland there are still in service nearly 1000 masonry arch bridges on the railway network and over 2000 along the roads. These numbers concern structures with spans longer than 3 m. Taking into account also masonry culverts the total masonry bridge stock exceeds as many as 20000 structures. More detailed statistical information presented below describe railway masonry arches, which are significant part of the railway bridge infrastructure. Considering together masonry structures made of bricks and stones, they comprise over 10 % in each of groups of all railway bridges or viaducts what is illustrated in figure 1a. In the group of railway arch structures (figure 1b) brick and stone, both bridges and viaducts, dominate definitely reaching almost 80 %.

a)




b)

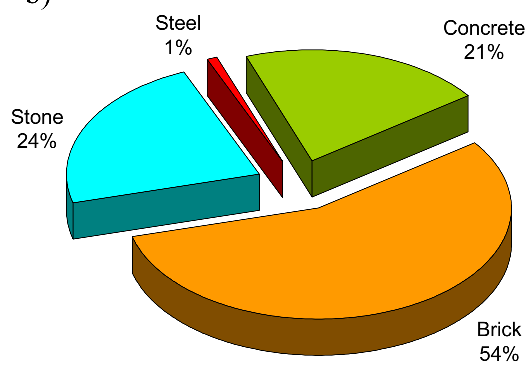



Figure 1: Percentage of masonry railway spans (a) and material of railway arch bridges (b)

Existing detailed data about Polish railway infrastructure enable to create an age profile of masonry arch spans. Figure 2 presents quantitative information about construction of spans in 5-year periods of time since the first half of XIX century, which is the beginning of Polish railway history, till 2000 year. Most of the masonry structures were built about 100 years ago or earlier and also several tens of spans were erected in fifties of XX century just after the World War II. In top right corner of figure 2 age profile of masonry spans is presented. It is divided into 40-year periods of time with their percentage participation in total stock.

It is worth adding that between road masonry bridges there are also numerous examples of structures from XVII and some even from XIV century!

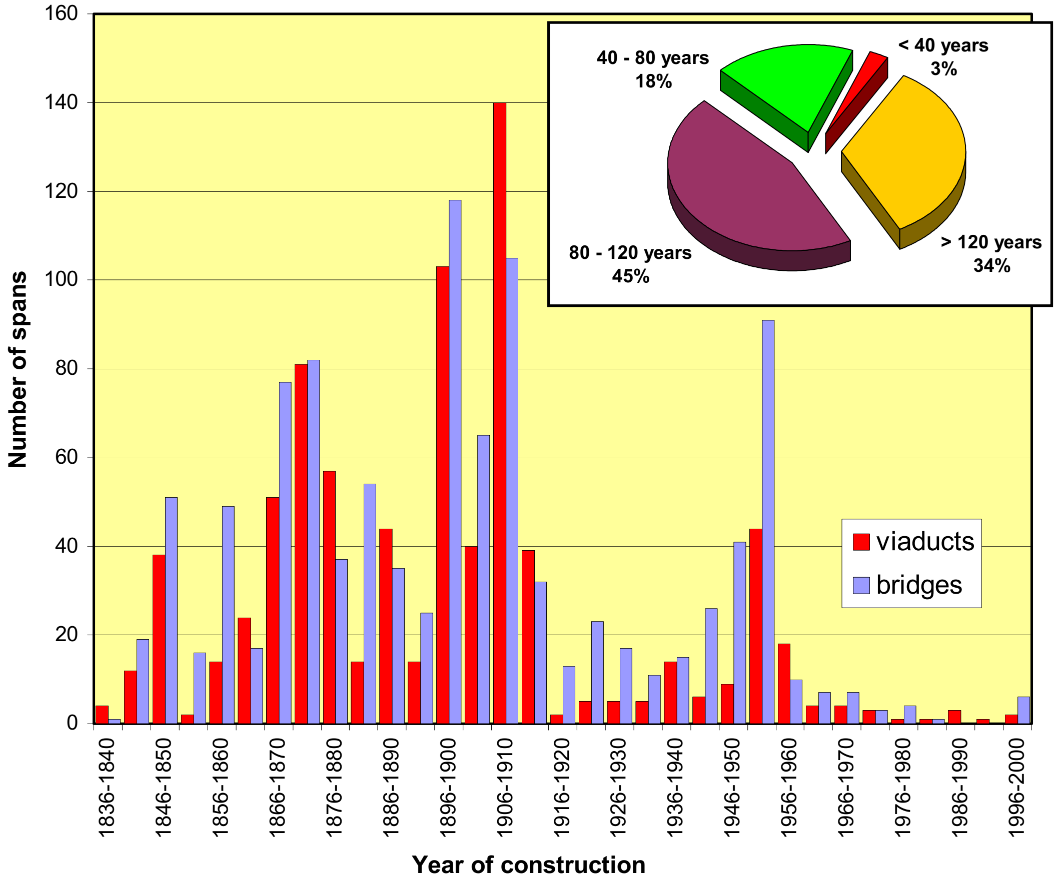



Figure 2: Year of construction and age profile of masonry arch spans of railway bridges and viaducts in Poland

Very helpful in collecting and sorting inventory data of masonry arch bridges is a simple and unequivocal classification. The most often applied criterion of such classification are demonstrated in figure 3. All types of structures listed on the diagram are present in Poland, however majority of masonry bridges are brick ones, with circular and constant thickness arch barrel, singled-span and closed spandrel. Quite rarely appear arches with variable barrel thickness and opened spandrel. The mean length of a masonry bridge is equal 7,5 m and an average span is about 5 m long.

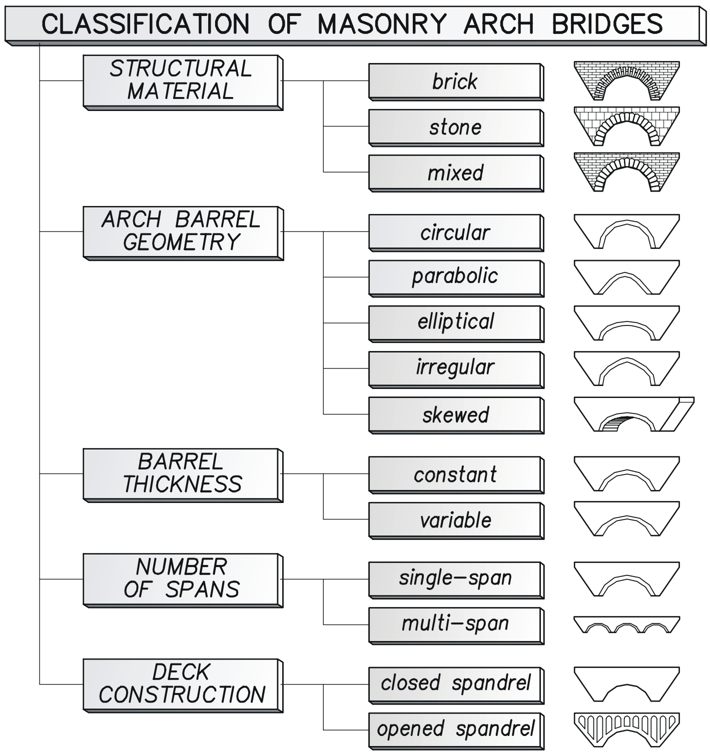



Figure 3: Classification of masonry arch bridges

## 3 TYPICAL DAMAGES

Mainly in connection with advanced age most of masonry structures suffer damages often seriously decreasing their technical condition. Majority of defects result from material degradation due to ageing and an inefficient or inappropriate waterproofing. More often they are caused by natural environmental influences than by human activity.

Main types of damages occurring on masonry arch bridges are listed in table 1. They are divided into 7 groups described with short definitions and illustrated with photos. For each main type of damages a 4-level hierarchic classification is elaborated and is applied for detailed identification of damages.

Presence of water or moisture in the fill of a structure comprises the dominant reason of almost all damages and is very difficult to eliminate. The only solution is a continuous preservation of a water protection, which unfortunately was neglected in Poland for many years. Deformations or displacements are frequent defects appearing on masonry arch bridges that concern first of all spandrel walls. The walls are than separating from the arch barrel what produces longitudinal cracks. All these effects are visible at photos presenting fragments of Polish stone and brick structures.

Some masonry bridges are covered with a plaster, which protects the material of bricks or stones from environment. Loss of its part is thus regarded as a damage of protection. Also defect of a waterproof covering or a drainage system could be included into this group.

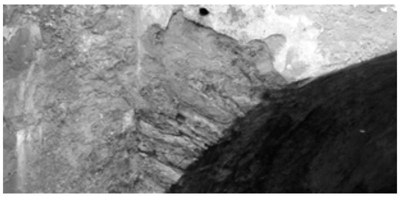
| Type of damage | Examples | |
|---|---|---|
| | Stone bridge | Brick bridge |
| DEFORMATIONS<br>Geometry changes incompatible with the project, with changes of mutual distances of structure points |  |  |
| MATERIAL DESTRUCTION<br>Deterioration of physical and chemical structural features |  |  |
| MATERIAL DISCONTINUITY<br>Break in a structure material continuity |  |  |
| LOSSES OF MATERIAL<br>Decrease of a structure material amount |  |  |
| DAMAGES OF PROTECTION<br>Partial or complete dysfunction of a protection coat |  |  |
| DISPLACEMENT DEFECTS<br>Displacements of a structure or its part incompatible with project but without changes of distances of structure points |  |  |
| CONTAMINATIONS<br>Appearance of any type of a dirtiness or a plant vegetation |   |  |

Table 1: Classification of main types of damages observed on masonry arch bridges

With the aim of uniform identification of structure damages and establishing their not always obvious and conclusive causes the “Album of Railway Bridge Damages” is developed. It contains collection of over 1500 high quality photos of damage examples for all types of bridge structures, including masonry arch bridges. Figure 4 represents screen dumps of the program with explanation of its main functions. The album is developed in an electronical as well as in a paper form but now only in Polish language version.

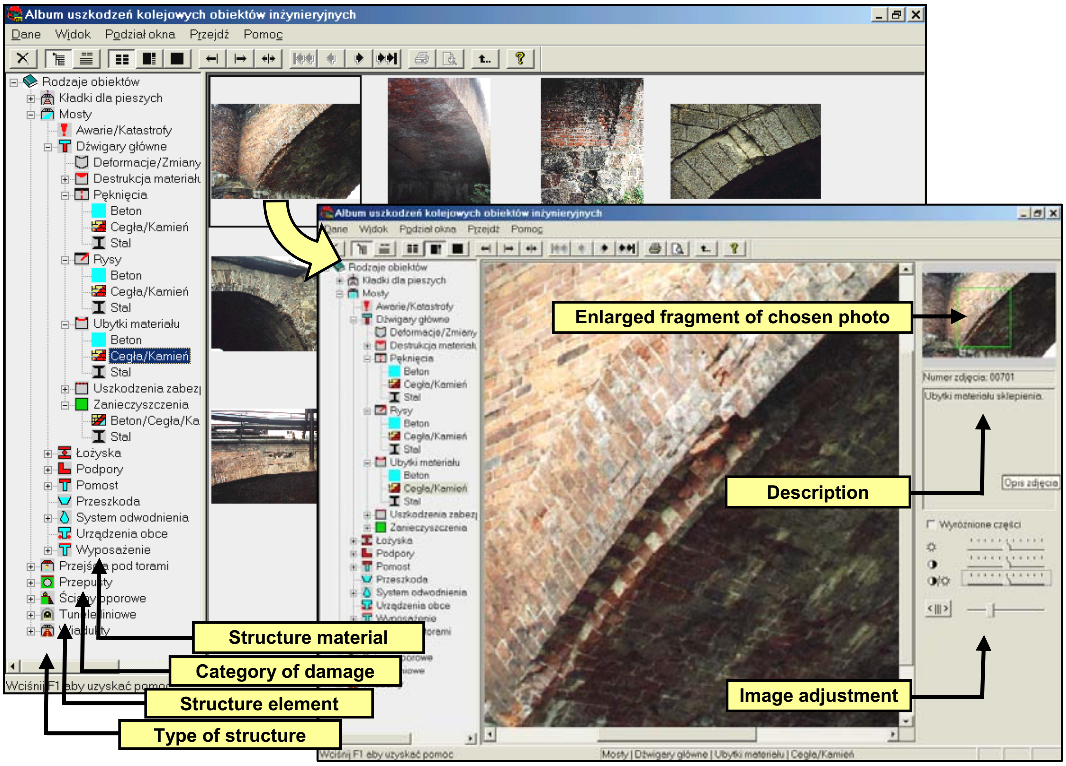



Figure 4: Album of Railway Bridge Damages

## 4 INSPECTIONS AND TESTING

All exploited bridge structures belonging to Polish both railway and road infrastructure come under strictly defined inspection system. There are 4 types of surveys which are indicated in table 2. The inspections varies in respect of their performance frequency, executor’s qualifications, testing methods and generally in respect of scope and accuracy level. These rules are in accordance with requirements of state regulations for road[1] and railway[2,3] bridges.

During each inspection specific testing methods are applied to determine the main kinds of damages given in table 1. These relationships are demonstrated in table 3. It is worth seeing that current inspection is limited to visual assessment and taking into account its frequency of execution it is the most economical and usually sufficient procedure. Besides all the types of inspection are based on visual survey which is always the first stage of any testing and gives

| Name | Frequency | Executor | Testing methods |
|---|---|---|---|
| CURRENT INSPECTION | 3 months | bridge inspector* | visual inspection |
| BASIC INSPECTION | 1 year | bridge inspector* | visual inspection & simple tests |
| DETAILED INSPECTION | 5 years | division inspector** & bridge inspector* | visual inspection & advanced tests |
| SPECIAL INSPECTION | if any needs | consultants & division/bridge inspector* | high-tech tests, proof loads, etc. |
| * special basic-level certificate is required, ** special advanced-level certificate is required | | | |

Table 2: Inspections of railway bridge structures in Poland

lots of fundamental qualitative information about structure material condition. Most of the listed testing methods are the standard techniques, however there are also mentioned the procedures quite rarely used in Poland. What is more, there are many missing modern tests based on advanced technologies, requiring sophisticated and expensive apparatus, which have been not used in Poland so far. Many of them are described in some other sources[4,5].

| Damage type | Testing method | Current Inspection | Basic Inspection | Detailed Inspection | Special Inspection | Comment |
|---|---|---|---|---|---|---|
| DEFORMATIONS | Visual assessment | ✓ | ✓ | ✓ | ✓ | standard procedure |
| | Geodetic methods | | | ✓ | ✓ | standard procedure |
| | Displacement/strain gauges | | | | ✓ | rarely used |
| MATERIAL DESTRUCTION | Visual assessment | ✓ | ✓ | ✓ | ✓ | standard procedure |
| | Uncover + measurement | | ✓ | ✓ | ✓ | standard procedure |
| | Boroscopy test | | | | ✓ | rarely used |
| | Cut-out specimen test | | | ✓ | ✓ | standard procedure |
| | Sclerometric tests | | | ✓ | ✓ | standard procedure |
| | Chemical tests | | | ✓ | ✓ | standard procedure |
| | Flat jacks | | | | ✓ | pilot implementations |
| MATERIAL DISCONTINUITY | Visual assessment | ✓ | ✓ | ✓ | ✓ | standard procedure |
| | Direct measurement | | ✓ | ✓ | ✓ | standard procedure |
| | Radar test | | | | ✓ | pilot implementations |
| LOSSES OF MATERIAL | Visual assessment | ✓ | ✓ | ✓ | ✓ | standard procedure |
| | Direct measurement | | ✓ | ✓ | ✓ | standard procedure |
| | Boroscopy test | | | ✓ | ✓ | rarely used |
| DAMAGES OF PROTECTION | Visual assessment | ✓ | ✓ | ✓ | ✓ | standard procedure |
| | Mechanical properties | | | ✓ | ✓ | standard procedure |
| | Direct measurement | | ✓ | ✓ | ✓ | standard procedure |
| | Uncover + measurement | | ✓ | ✓ | ✓ | standard procedure |
| | Chemical test | | | ✓ | ✓ | standard procedure |
| DISPLACEMENT DEFECTS | Visual assessment | ✓ | ✓ | ✓ | ✓ | standard procedure |
| | Geodetic methods | | | ✓ | ✓ | standard procedure |
| | Displacement gauges | | | | ✓ | rarely used |
| CONTAMINATIONS | Visual assessment | ✓ | ✓ | ✓ | ✓ | standard procedure |
| | Direct measurement | | ✓ | ✓ | ✓ | standard procedure |

Table 3: Testing methods used during inspections of masonry arch bridges

## 5 MANAGEMENT

Management systems of masonry railway and road arch bridges in Poland are components of global systems developed for all types of bridge structures on the respective communication networks. On the railway network commonly used is a computerised Railway Bridge Management System called "SMOK"[6]. For the road administration there are available two systems: "SZOK" and "SGM". All the programs generally have a similar structure, which enables to assemble inventory data as well as to plan inspections and maintenance, rehabilitation or repair works on the basis of bridge condition and serviceability. "SMOK" is the most widely developed system and its structure of fundamental inventory data is shown in figure 5. The example concerns masonry arch bridge but for other types of bridge structures the main groups of information are analogical.

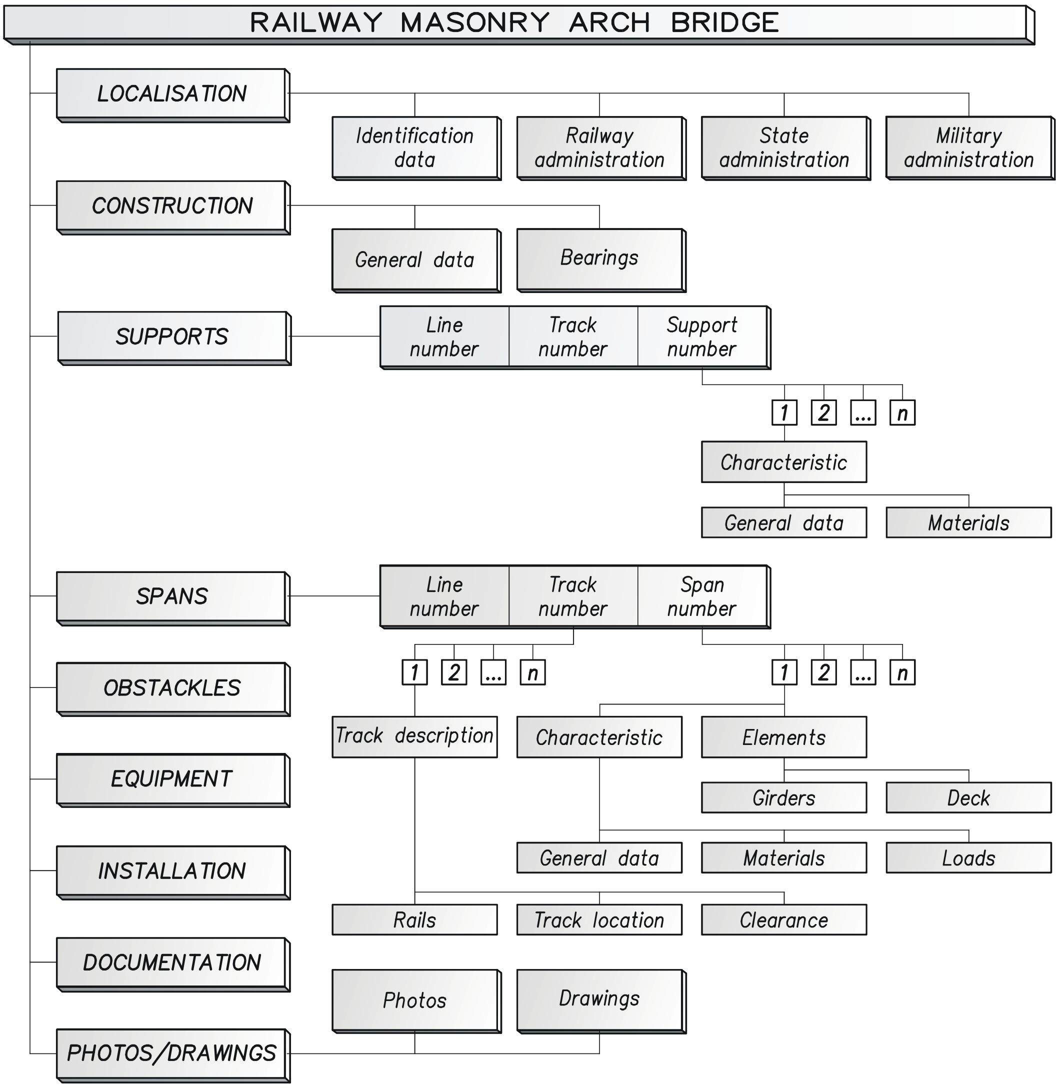



Figure 5: Structure of inventory data in Railway Bridge Management System "SMOK" [6]

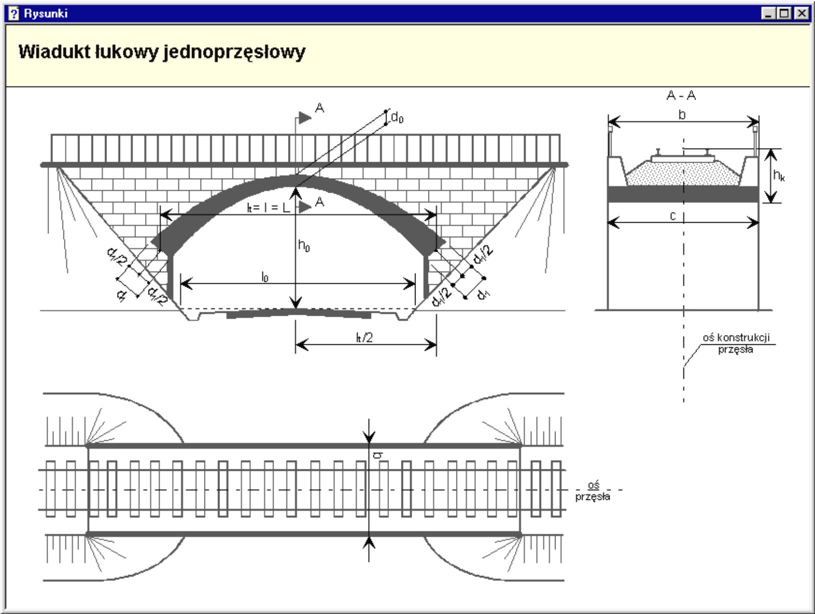



Figure 6: Masonry arch bridges – geometrical data

Figure 6 is aimed to demonstrate geometrical data of masonry arches collected in the system with rules of their measurement. An exemplary appearance of the RBMS “SMOK” is presented in figure 7. In the central window are displayed the detailed localisation data about a chosen masonry structure including line and truck number, kilometre and exact geographical coordinates. In the background is presented a numerical map of the whole Polish railway network with all the bridge structures marked on it.

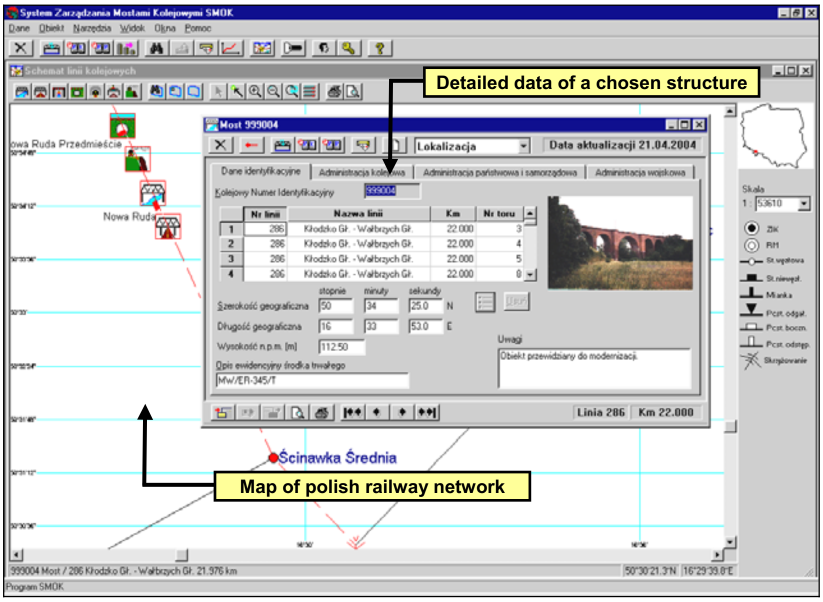



Figure 7: Bridge inventory data in RBMS “SMOK”

## 6 CONCLUDING REMARKS

Masonry bridges are very important and very specific structures. In Poland the masonry bridges are under supervision of computer-based Bridge Management System with systematic inspection and condition evaluation procedures. In the near future the following problems should be solved:

- development and implementation of advanced testing methods,
- creation of a knowledge-based expert tools supporting assessment of the structure condition as well as prediction of condition changes,
- effective methods of masonry bridges rehabilitation and strengthening.

In all these areas an international cooperation in research and in practical implementation is needed.

## ACKNOWLEDGEMENTS

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