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Pervious Concrete for Road Intersection Drainage

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Abstract**—**Road performance and traffic safety are highly influenced by improper water drainage system performance, particularly within intersection areas. So, the aim of the presented paper is the evaluation of pervious concrete made with two types and two aggregate fractions for potential utilization in intersection drainage areas. Although the studied pervious concrete mixtures achieved proper drainage but lower strength characteristics, this pervious concrete has a good potential for enhancing pavement drainage systems if it is embedded on limited intersection areas.

Keywords**—**Pervious concrete, drainage, road, intersection.

I. Introduction

ONE of the main problems faced by today's road builders is how to effectively solve the problem of quality drainage. For many years, to the issue of drainage no or very little attention has been given, which resulted in a rapid road deterioration and aggravated driving conditions. Today, to the issue of drainage is devoted more attention, which is supported by the fact that the price for a drainage and all measures for preventing harmful effect of water are 5-20% of the total road construction works.

Drainage usually consists of surface and underground elements. Surface drainage is important in terms of traffic safety, while underground drainage is essential for roadway stability and durability.

Subsidence of road surfaces can result from improper performance of the water drainage system. Research has shown [1] that there exists a direct correlation between the condition of underground pipeline infrastructure and road traffic safety. Improper installation, maintenance, repair, rehabilitation, or replacement of underground utility pipelines as well as their aging and deterioration may be responsible for hazards of road surface failures, such as road surface subsidence, bulging or collapse, and, in consequence, a hazard to road traffic safety.

As for the underground drainage, surface drainage is also one of the most important factors affecting traffic safety. Increased number of crashes can occur on approaches and intersections particularly in urban areas where drainage is usually more challenging and costly. For the effective drainage at the intersection, some new materials and technologies are investigated during the past years and one of them is usage of pervious pavements. By the pervious pavement, usually is considered surface course of comprised of permeable block pavers, porous asphalt, concrete or resin, generally with the underlying bedding layer divided from the coarse aggregates beneath by means of a geotextile. Construction of pervious pavements can reduce water quantity and slow water flow, but also improve water quality [2]. Another characteristic of pervious pavement is reduction of drive-by noise annoyance due to the fact that a dense road surface mainly reflects the sound energy, while a porous road surface mainly absorbs it [3]. This noise reduction of a drainage asphalt road surface can be 1-7 dB for passenger cars, 3-4 dB for light trucks, and 4-7 dB for heavy trucks [4].

Pervious concrete, also referred to as porous or permeable concrete is material with the same basic components as standard concrete but designed to have high porosity (void content is between 11% and 35% [5], [6]) and permeability (typically about 2-6 mm/s). It is a mixture of Portland cement, uniform coarse aggregate and with either a small amount of or without fine aggregate and water [7]. Due to its high porosity, pervious concrete has good drainage properties and high noise absorption characteristics which are important elements for quality pavement. High porosity of pervious concrete is also its main disadvantage since it is associated with strength decrease. Pervious concrete mixtures can develop compressive strengths in the range of 3.5 MPa to 28 MPa (typical values are about 17 MPa) and flexural strengths generally ranging between 1 MP to 3.8 MPa [8], [9]. Low strength of pervious concrete influence the stability and durability of structure because of susceptibility to frost damage and low resistance to chemicals. That is the reason of its limited application in construction of high traffic highways and its potential use on limited areas within intersections.

The main objective of this paper is the investigation of pervious concrete properties for its potential use on limited areas within the intersection in urban areas due to its drainage characteristics and low strength. For that purpose, strength and drainage characteristics on four mixtures of pervious concrete were tested.

II. Experimental Program

A. Materials

For pervious concrete mixture preparation, two types of aggregate were used: diabase (fractions 4-8 mm and 8-11 mm) and steel slag (fractions 4-8 mm and 8-16 mm). Steel slag has been confirmed to be good quality concrete aggregate in some previous studies [10]-[12]. As fine fraction (fraction 0-2 mm), natural sand originating from the Drava River was used. Particle size distribution of aggregates are shown in Fig. 1. The density of diabase was 2.91 kg/dm^3, steel slag 3.21 kg/dm^3, a sand 2.65 kg/dm^3.

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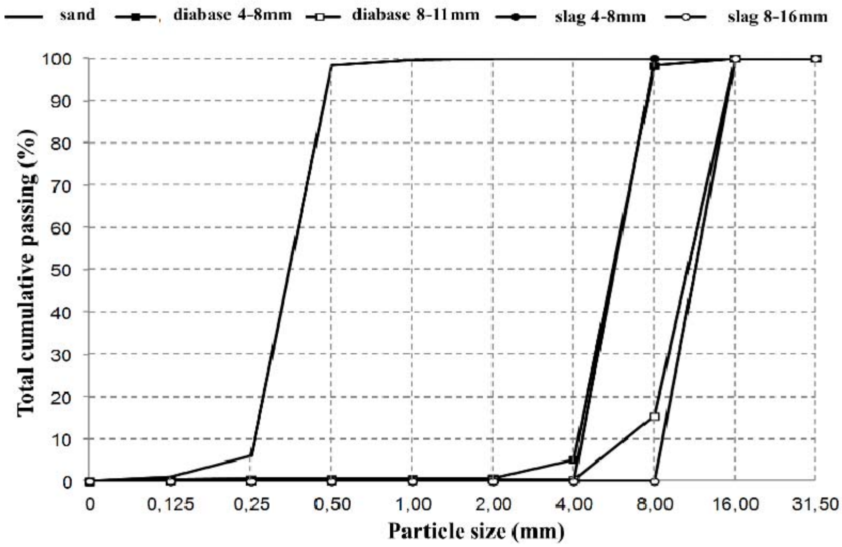

Fig. 1 Particle-size distribution curves for used aggregate [13]

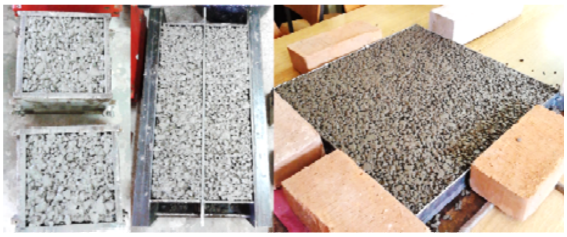

Fig. 2 Pervious concrete samples: cubes, prisms and slab

Fig. 3 Pervious concrete permeability test setup [13]

In all mixtures, cement CEM II / A-M (S-V) 42.5N, density of 3.0 kg/dm^3 and in a quantity of 300 kg/m^3 was used. All blends have been designed with the same water-cement ratio, w/c = 0.33 and a content of sand in the same amount of 10% relative to the total weight of the aggregate.

B. Experimental Program

Mechanical properties of hardened concrete were tested on 3 of the kind specimens (10/10/40 cm prisms and 15/15/15 cm cubes). All specimens were demolded 24h after the casting and placed in a water tank for 27 days. For permeability test, slabs were cast dimensions of 50/50/5 cm in order to simulate pervious concrete element embedded in the field. Testing samples are presented in Fig. 2.

All testing on fresh and hardened concrete were performed according to relevant European Standards. Compressive strength was determined according to standard HRN EN 12390-3:2009, flexural strength according to HRN EN 12390-5:2002 and permeability according to standard test method for testing infiltration rate of in place pervious concrete ASTM C 1701/C. Permeability test setup is presented in Fig. 3. Porosity (void content) and density were according to ASTM C1754/C1754M-12:2012 standard.

III. Laboratory Test Results

Results of conducted laboratory tests on pervious concrete characterization are presented in Table I.

TABLE I
Results of Pervious Concrete Laboratory Tests

Tested property	Mixture			
	M1	M2	M3	M4
Compressive strength (MPa)	10.87	15.57	10.31	15.80
Flexural strength (MPa)	2.33	2.01	1.72	1.59
Density (kg/m^3)	1847	1927	2037	2124
Porosity (%)	30	27	23	19
Permeability (mm/s)	5.66	11.07	2.60	8.49

M1 – diabase 4-8 mm; M2 – diabase 8-11 mm; M3 – steel slag 4-8 mm; M4 – steel slag 8-16 mm

As presented in Table I, mixtures of pervious concrete made with coarse fractions of both types of aggregates (M2, M4) achieved better compressive but lower flexural strength compared with mixtures made with the finer fraction of the same aggregates (M1, M3). Density of pervious concrete with steel slag aggregate (M3, M4) is higher comparing to the density of pervious concrete made with diabase aggregate. This was partially expected due to the higher density of steel slag compared to the diabase. The share of pores with a mixture of the finer fraction of both types of aggregates (M1, M3) is higher than the share of pores with a mixture of coarse fraction of these aggregates (M2, M4). The permeability is more pronounced in mixtures with coarse fractions of both types of aggregates (M2, M4) in relation to the mixture with finer fractions (M1, M3). This is partially unexpected given the higher porosity of a mixture with finer fraction of both types of aggregates. However, within this research, porosity is determined in the manner of total porosity of the concrete, i.e. the sum of open and closed pores on the basis of which it can be concluded that the mixture of the finer fraction of both types of aggregates have a greater proportion of closed pores, while in a mixture with large fractions of both types of aggregates dominated by open (linked) pores which are critical for pervious concrete permeability. In addition, by examining the results of permeability, it is evident that mixtures with diabase aggregate (M1, M2) increased permeability compared to a mixture of steel slag aggregate (M3, M4) and the explanation for this result could be sought in the form of grains aggregates. Although steel slag aggregate has the high-density, aggregate grains are highly porous and during its passing through the element, water is entering the grain pores trickling through longer path which affects the lower permeability speed. In contrast, diabase aggregate grains have sharp edges, which increase the water passage speed. However, the presented assumptions should be confirmed by more detailed study including some microscopic level research.

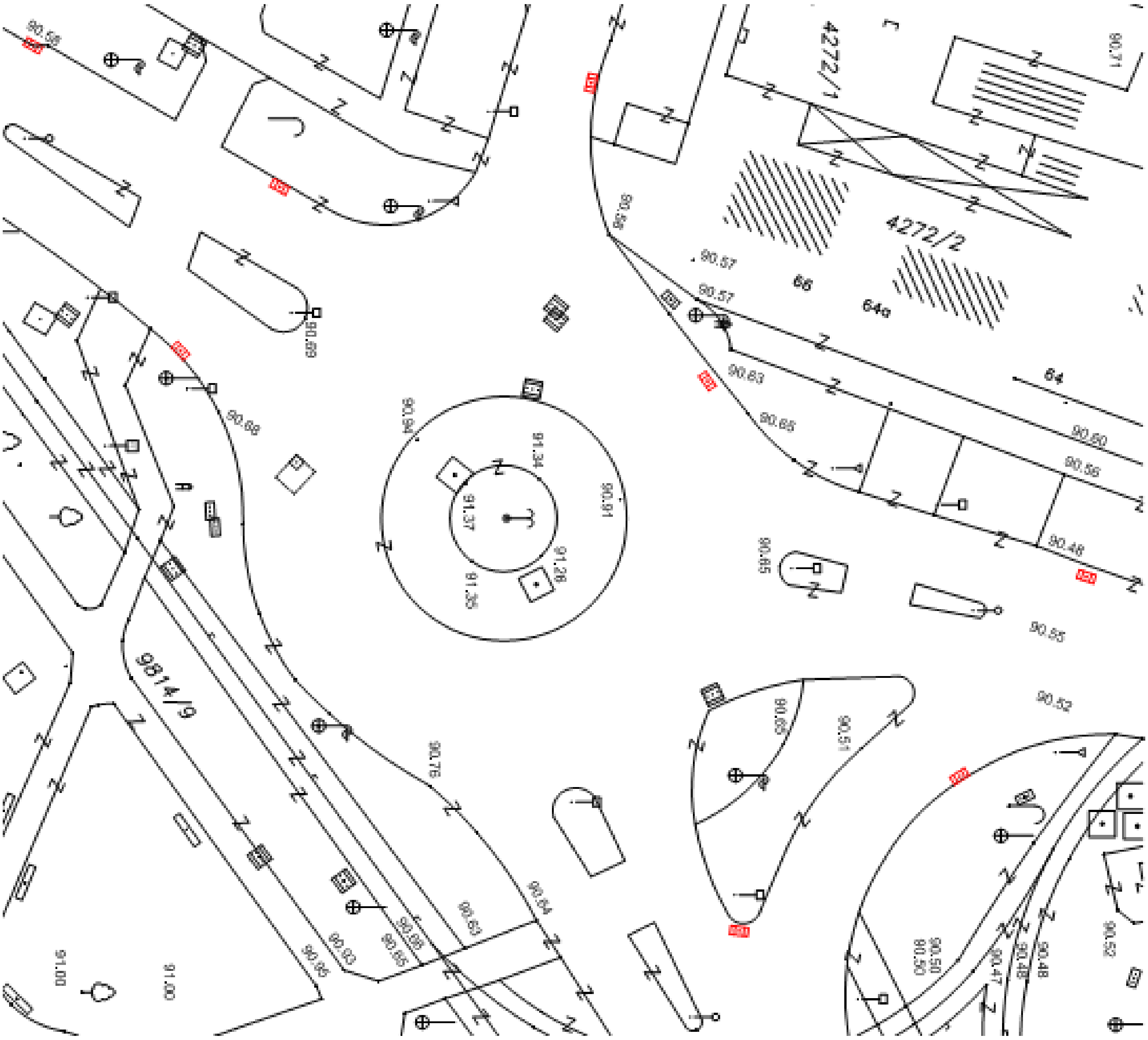

Fig. 4 Example of a small urban roundabout water inlet position

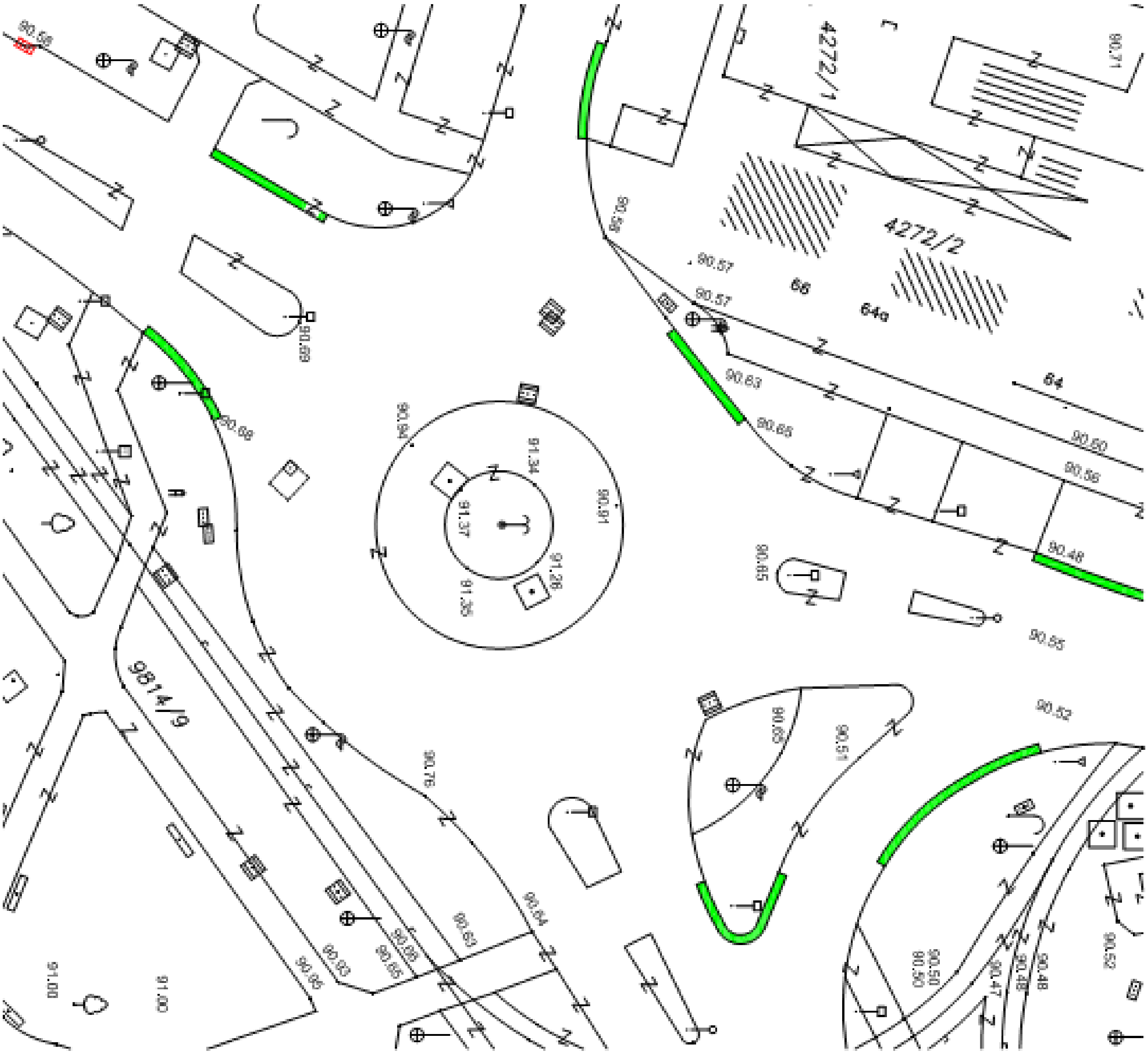

Fig. 5 Potential application of pervious concrete on a small urban roundabout

IV. Pervious Concrete Potential for Intersection Drainage

Concrete pavements are usually constructed by concrete class of C 35/40 and flexural strength of 5 MPa for very heavy duty roads, C 30/37 and flexural strength of 4.5 MPa for heavy duty roads and C 25/30 and flexural strength of 4 MPa for other roads. As presented in Table I, none of the studied mixture did meet the requirements for pavement construction according to these requirements. However, all mixtures achieved significant porosity and permeability giving the potential for its application on a limited area. As presented in the Introduction section, drainage problems on intersections area, particularly in urban environment highly affect traffic safety and can contribute to crashes. In Fig. 4, typical surface drainage scheme for small urban roundabout is presented by using water inlets (marked red), while in Fig. 5 green areas present potential areas for pervious concrete application. Similarly, Figs. 6 and 7 present urban at-grade intersection with water inlet (red) and linear drainage system (blue) scheme and potential pervious concrete application (green).

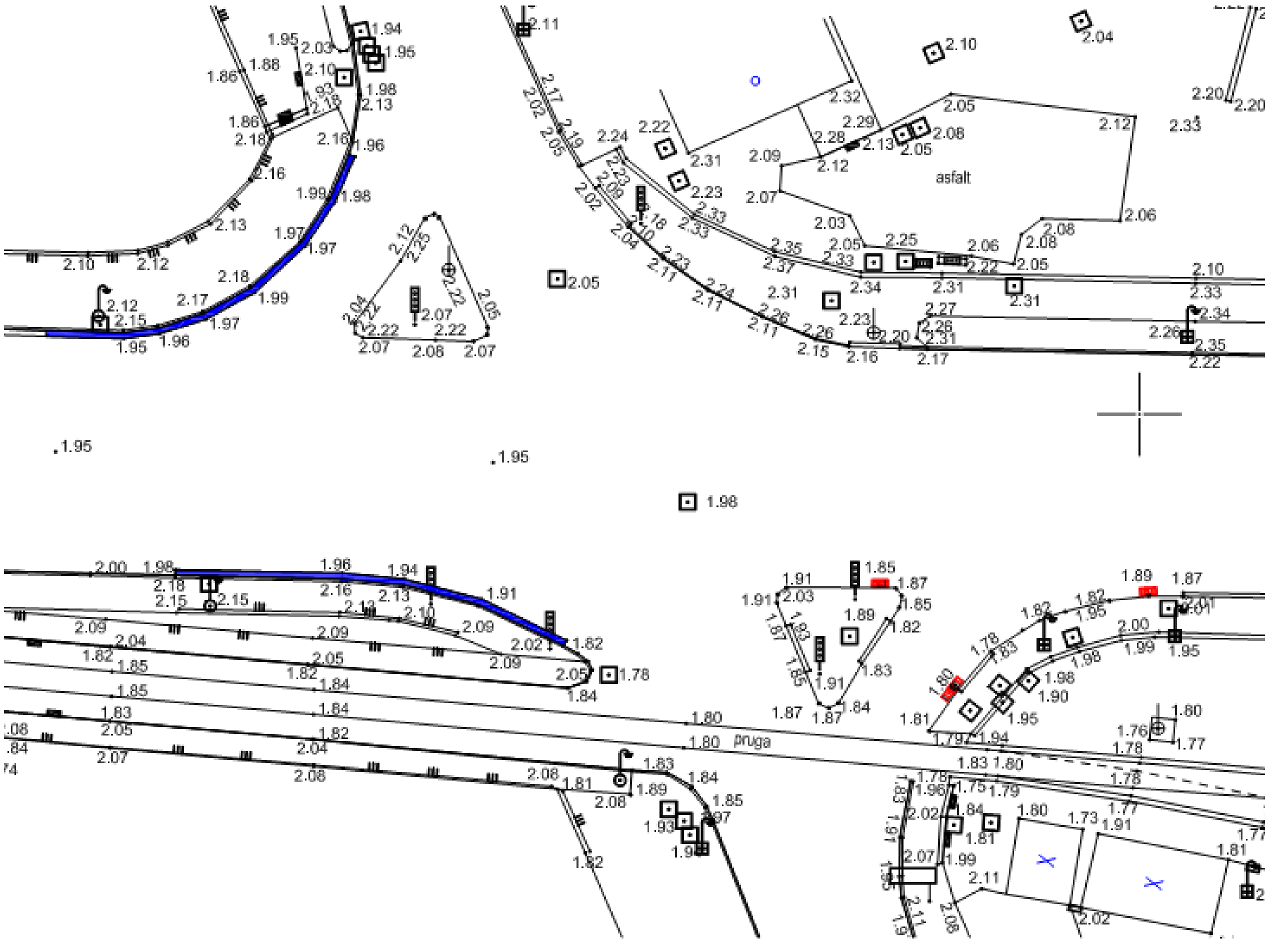

Fig. 6 Example of at-grade intersection drainage scheme

V. Conclusion

Today, to the issue of drainage is devoted more attention, which is supported by the fact that the price for a drainage, and all measures for preventing harmful effect of water are presenting significant amount in total road construction works costs. Improper performance of the water drainage system can have harmful consequences on road performance and traffic safety. In that sense, the aim of this paper was to investigate potential application of new material for intersection drainage purposes. Based on the conducted research, following conclusions can be drawn:

- High quality drainage is essential for safe and comfortable traffic at intersections;
- Pervious concrete with coarse fractions aggregates achieved better compressive but lower flexural strength;
- Density of pervious concrete with steel slag aggregate are higher compared to the density of pervious concrete made with diabase aggregate
- Porosity is higher in mixtures with finer fraction of both types of aggregates;
- Permeability is more pronounced in mixtures with coarse fractions of both types of aggregates;
- There is potential for pervious concrete utilization on limited intersection areas in order to enhance pavement drainage.

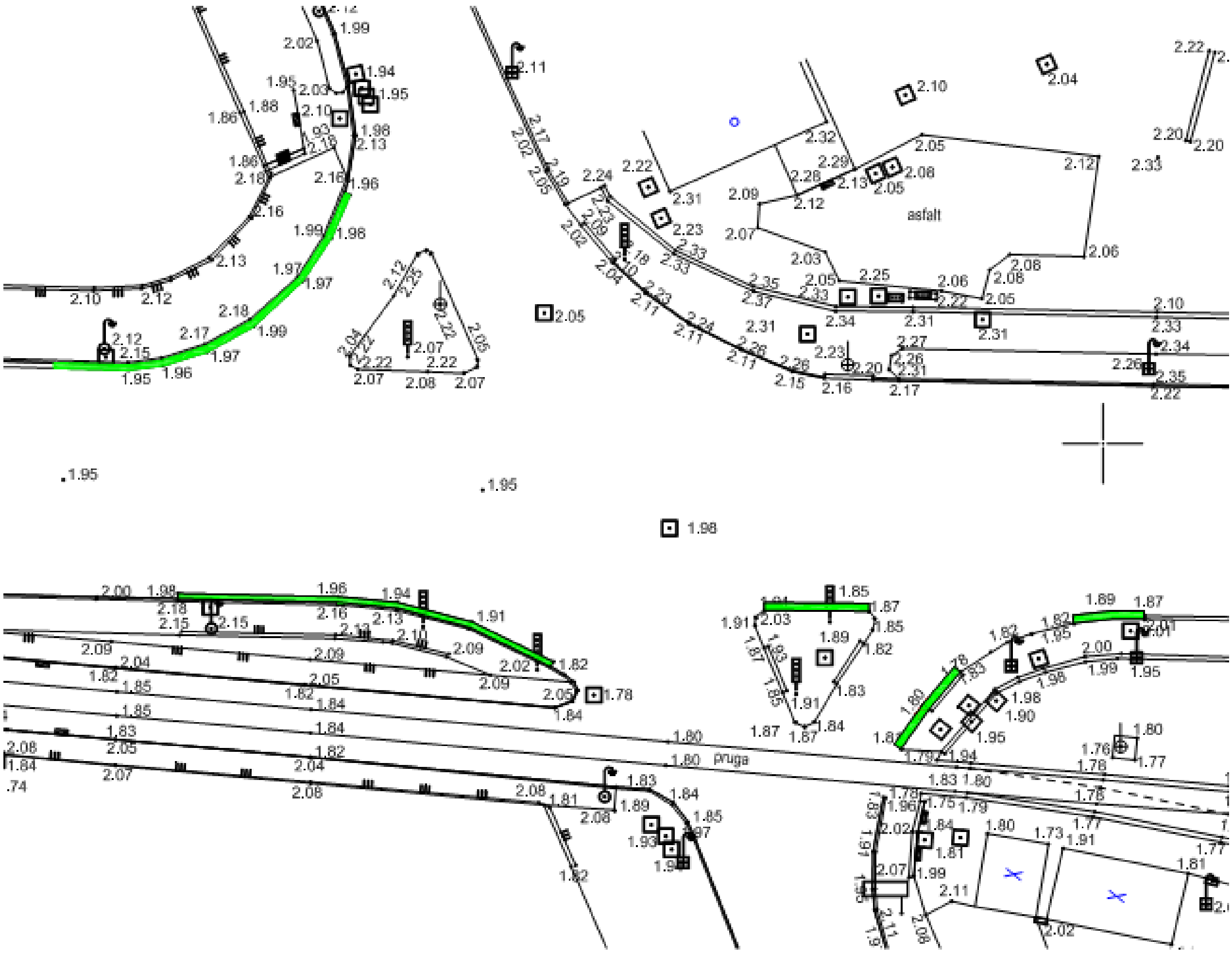

Fig. 7 Potential application of pervious concrete on at-grade intersection

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