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HIDRAVLIČNA USTREZNOST MERILNIH MEST ZA MERJENJE PRETOKOV
HYDRAULIC VERIFICATION OF FLOW MEASURING SITES

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V članku je predstavljen pomen meritev pretokov in opis metodologije za presojo ustreznosti merilnih mest za merjenje pretokov. Izvajanje meritev pretokov lahko zahteva sam tehnološki proces, kjer je pretok, izmerjen z določeno natančnostjo, pogoj za uspešno izvajanje nadzorovanega procesa, lahko pa ga zahteva tudi upravni akt, kot na primer sklop predpisov, ki obravnavajo meritve emisijskega monitoringa. Usposobljenost za meritve pretokov zahteva specifična znanja, orodja in izkušnje, posebnosti pa so tudi v samih postopkih. Razvit je bil postopek za preverjanje merilnih mest za meritve pretokov, s katerim lahko z uporabo različnih orodij verificiramo primernost in ustreznost merilnega objekta. Ta postopek je v osnovi mogoče razčleniti na naslednje tri elemente: meritve hitrostnega polja in izračun pretokov, verifikacija po mednarodnih standardih in preverjanje ustreznosti hidravličnih robnih pogojev z matematičnim modeliranjem. Predstavljena je uporaba metodologije na dveh primerih.
Ključne besede: *kanalizacija, odpadne vode, modeliranje, meritve, pretok, hidrologija*

This paper presents the significance of flow measuring and a description of the methodology for the hydraulic verification of flow measuring sites. Flow measurements may be necessary within the technological process where the flow data, measured with defined accuracy, are vital for the control of the process l. It can be also requested by an administrative act, for example, emission monitoring regulation. Specific knowledge, devices, experience and, at times, special procedures, are needed for the measurements. With years of experience, a procedure for hydraulic verification of flow measuring sites has been developed. Basically, it consists of three elements: velocity field measurements with flow calculation, verification of the measurement device regarding the international standards applied and verification of hydraulic boundary conditions with mathematical modeling. The application of this methodology on two case studies is presented.
Keywords: *sewer, wastewater, modelling, measurements, discharge, hydrology*

1. UVOD

Ena od temeljnih fizikalnih veličin v hidrotehniki je vsekakor pretok. Podatke o pretokih potrebujemo pri načrtovanju novih in sanaciji starih objektov, pri spremljanju in modeliranju pojavov v naravi in laboratorijih, pri nadzorovanju procesov v industrijski proizvodnji, pri spremljanju emisij iz virov onesnaževanja in še v mnogih drugih primerih. Meritve se lahko izvajajo občasno ali kontinuirano, odvisno od cilja in potreb meritev. Izvajanje meritev pretokov lahko zahteva sam tehnološki proces, kadar je

1. INTRODUCTION

One of the fundamental physical quantities in hydraulics is a flow. Accurate flow data are necessary in many fields of engineering. For example, the construction of new and the reconstruction of old hydraulic structures, the observation and modelling of processes in nature and laboratories, industry process control, for the monitoring of emissions pollution sources and in many other cases. Measurements can be made periodically or continuously, depending on goals and needs. Flow measurements can be required by the pretok, izmerjen z določeno natančnostjo, pogoj za uspešno izvajanje nadzorovanega procesa, lahko pa ga zahteva tudi upravni akt, kot na primer sklop predpisov, ki obravnavajo meritve emisijskega monitoringa.

Usposobljenost za meritve pretokov zahteva specifična znanja, orodja in izkušnje, posebnosti pa so tudi v samih postopkih. Merilne metode za merjenje pretokov lahko delimo na :

– neposredne in
– posredne.

Neposredno merjenje izvajamo z volumsko metodo, kjer neposredno merimo pretok s pomočjo umerjene merilne posode in z merjenjem časa polnitve in z metodami mešanja substanc v vodno maso. Pri posrednih metodah pretok običajno izračunamo na podlagi meritev veličin, ki so funkcija pretoka.

Posredne metode lahko v osnovi delimo na:

– metode površina-hitrost
– metoda naklon - površina
– metode z uporabo merilnih korit in jezov.

2. VRSTE MERILNIH OBJEKTOV

Merilne objekte lahko razdelimo v tri glavne skupine, ki imajo tudi vsaka svoje posebnosti pri umerjanju in verifikaciji:

a) *Merilni objekti za merjenje pretoka, opisani v standardih (SIST, CEN, ISO, DIN standardi):* Glavna skupna lastnost merilnih naprav za meritve pretokov, ki so zabeleženi v skladu z določili standardov je, da se izvaja pretvorba iz ene merilne veličine (npr. globine) preko fizikalno – analitičnih transformacij neposredno v merjeno veličino (pretok). Ta preprost način pretvorbe merjene enote v veličino močno olajša kalibracijo in verifikacijo tovrstnih merilnih objektov. Primeri tovrstnih naprav so Venturijevo korito, Khafagi Venturijevo korito, ostrorobi prelivi in zareze, jezovi s široko krono, ipd.
b) *Merilni objekti, opisani v strokovni literaturi:* Ti objekti spadajo nekako vmes, med objekte, opisane v standardih in tiste,

technological process where the flow data are measured with the defined accuracy necessary for successfully controlling the process; but, on the other hand, flow measurements can also be required by regulation, for example, a regulation regarding emissions monitoring.

Qualification for performing flow measurements requires specific knowledge, experience, instruments and the use of certain procedures. We can divide flow measurements methods into two groups:

– direct methods
– indirect methods

A direct measurement is possible with the volumetric method, where we measure discharge with a calibrated measuring tank and the time of filling the tank, and with dilution methods, where we mix conservative substances with the body of water. By indirect methods we usually calculate the discharge from the measurements of values that are related to the discharge.

Indirect methods are:

– Velocity - area methods;
– Slope - area method;
– Critical depth methods.

2. TYPES OF MEASUREMENT STRUCTURES

We can divide measurement structures into three main groups, each having their own specifics for calibration and verification:

a) *Flow measurement structures defined with standards (SIST, CEN, ISO, DIN standards):* The basic common characteristic of this type of measurement structures, described in the standards, is that we execute the transformation from one measuring value (for example, depth) through the physical and analytical relations, directly into the measured value (discharge). This simple way of transformation enables easier calibration and the verification of these measuring structures. Venturi flumes, Khafagi Venturi flumes, sharp and broad crested weirs, etc. are typical representatives.
b) *Flow measurement structures described in technical literature:* These structures are somehow between the structures defined in

ki so specifični za vsakega proizvajalca. Nekateri, bolj specifični merilni objekti za meritve pretokov, so namreč zabeleženi in relativno dobro opisani v strokovni literaturi, vendar (še) niso bili uvrščeni med standardne. Še vedno spadajo v skupino objektov, ki jih je mogoče verificirati preko preprostih pretvorb. Ta skupina merilnih objektov je večja od skupine, opisane pod točko a), primeri pa so Terzaghijev jez, Cipolletijev jez, H-korito ipd.

c) *Merilni objekti zunaj standardov (verifikacija po navodilih proizvajalca):* Ta skupina merilnih objektov zajema objekte za merjenje pretokov, ki so specifični izdelek določenega proizvajalca. V mnogih primerih neposredni odnos med merjeno veličino (ali več merjenimi veličinami) in pretokom ne obstaja, temveč je način izvrednotenja določen s proizvajalčevo specifikacijo. Zato je kalibracija in verifikacija tovrstnih merilnih mest načeloma bolj zahtevna v primerjavi z objekti pod točko a) in b).

3. STANDARDIZACIJA MERITEV PRETOKOV

Standarde lahko definiramo kot dokumentirane dogovore, ki vsebujejo tehnične specifikacije in kriterije v obliki pravil, navodil ali definicij karakteristik. Z njimi naj se zagotovi kakovost pri uporabi materialov in izdelkov in izvajanju procesov ter delovanju služb. Uporaba standardov je namenjena poenotenju izrazov in postopkov pri delu, v našem primeru meritev pretokov, hkrati pa omogoča tudi lažjo strokovno komunikacijo.

V našem prostoru uporabljamo na področju meritev pretokov v glavnem poleg slovenskih SIST standardov še mednarodne ISO in nemške DIN standarde. Uporaba standardov je sicer neobvezna, vendar pomeni standardiziranje postopkov in obdelav meritev običajno predpogoj za kakovostno izvedbo postopkov. Potreba po standardizaciji pa se pojavi vsekakor, če želimo uspešno nastopati na mednarodnem tržišču.

Na področju meritev pretokov je največje

the standards and the structures specific for any certain manufacturer. Some of them, more specific structures, are described relatively well in the literature, but they have still not been included in the standards. They are also in the group of structures that can be verified through simple transformations. This group of structures is larger than group a); for example, the Terzaghi weir, the Cipolleti weir, the H-flume, etc.

c) *Flow measurement structures not defined in the standards or in technical literature (verification by manufacturer instructions):* This group of measuring structures includes structures and devices that are not standardised in any manner, and which are usually produced by a certain manufacturer. In many cases, the relationship between the measuring value (or more measuring values) and the discharge does not exist, but it is defined by manufacturers' specifications. Calibration and verification are, in general, more difficult than for the structures of type a) and b).

3. STANDARDISATION OF DISCHARGE MEASUREMENTS

Standards are documented agreements containing technical specifications or other criteria as rules, guidelines, or definitions of characteristics. With standardisation, we ensure the quality use of material and products, the execution of processes and the operation of services. Standardisation creates uniform terminology and makes technical communication easier.

In Slovenia, the Slovenian SIST standards, as well as international ISO and German DIN standards, are generally applied in the field of liquid flow measurements. The use of standards is not obligatory, but standardisation of the procedures and the processing of measurement data is usually the first step in obtaining reliable measurement results. The need for standardisation appears, in any case, if we would like to compare any results obtained.

In the field of the measurement of fluid flow, the largest set of standards was adopted število standardov sprejela mednarodna organizacija za standardizacijo (ISO). Področje meritev pretokov je zajeto v standardni klasifikaciji pod šifro 17.120. Do konca leta 1999 je bilo sprejetih skupno 33 standardov s področja meritev v zaprtih vodih (17.120.10) in 61 standardov s področja meritev v odprtih vodih (17.120.20) ter 1 standard skupen za obe področji(17.120.01).

DIN norme obsegajo na področju meritev pretokov (17.120) 29 standardov za meritve pretokov v zaprtih vodih, 1 standard za meritve v odprtih vodih (DIN 19559) in 1 standard za obe področji.

V Sloveniji deluje na področju standardizacije Urad za standardizacijo in meroslovje (USM). Sprejemanje standardov poteka preko tehničnih komisij, ki so po področjih podobno organizirane kot pri mednarodni ISO organizaciji. Skupno je bilo do leta 1999 sprejetih 17 SIST standardov s področja pretokov v zaprtih vodih, medtem ko področje pretokov v odprtih vodih SIST standardi še ne pokrivajo.

Opis metod merjenja pretokov v odprtih kanalih najdemo v standardih ISO 8363 in ISO 9824 in DIN 19559. Standard DIN 19559 je kot metoda dela predpisan za izvajanje monitoringa odpadnih vod po Pravilniku o prvih meritvah in obratovalnem monitoringu odpadnih vod (UL RS 35/96).

4. VERIFIKACIJA MERILNIH MEST

V Sloveniji so bili s sprejetjem Pravilnika o prvih meritvah in obratovalnem monitoringu odpadnih vod (UL RS 35/96) določeni zavezanci za monitoring. Z uvedbo takse na količine in vrste polutantov, ki obremenjujejo okolje, stalno narašča potreba po kakovostnih meritvah pretokov odpadnih vod in koncentracij snovi v njej.

Določitev masnega pretoka (pa tudi celotne mase, npr. v 1 letu) nekega polutanta predstavlja t.i. sestavljeno meritev in je odvisna od časovnega spreminjanja koncentracije in pretoka odpadne vode, zato je treba oba parametra izmeriti enako kakovostno oz. z enako natančnostjo.

by the ISO organisation. The measurement of fluid flow has the standard classification number 17.120. By the end of 1999, 33 standards regarding flow in closed conduits (17.120.10), 61 standards regarding flow in open channels (17.120.20) and one general standard for the measurement of fluid flow had been adopted by the ISO.

The DIN standards have 29 standards regarding flow in closed conduits, one standard regarding flow in open channels (DIN 19559) and one general standard.

In Slovenia, the state institution responsible for the field of standardisation is the Office for Standardisation and Metrics (USM). Standards are adopted by technical committees inside the USM, which is organised similarly to an ISO organisation. By 1999, 17 Slovenian (SIST) standards addressing the flow in closed conduits had been adopted, but the SIST standards still don't cover flow in open channels.

Standards ISO 8363, ISO 9824 and DIN 19559 describe methods of measurement flow in open channels. Standard DIN 19559 was adopted as a working method for the monitoring of wastewater discharges according to the Regulation of first measurements and the operational emission monitoring of wastewater (Official Gazette of Republic Slovenia No. 35/96).

4. VERIFICATION OF MEASUREMENT SITES

The regulation of first measurements and the operational emission monitoring of wastewater (Official Gazette of the Republic of Slovenia No. 35/96) determines who must carry out the monitoring of wastewater discharges. With the taxation of the large polluters according to their pollution discharges, the need for the quality measurement of discharges and concentrations is growing.

With the need to determine the mass flow of the pollutant (or mass within, for example, one year), the combined measurement of discharge and concentrations is performed. It is, of course, necessary to measure both parameters with a similar accuracy in order to obtain useful results.

Pri samem načrtovanju meritev pretokov je predvsem pomembno, da imamo jasno definiran cilj (namen) meritve in določilo, kakšna je zahtevana natančnost meritev. Pri izbiri merilnega mesta moramo pogosto upoštevati omejitve glede razpoložljive energije, saj so merilna mesta pogosto določena na izbranih strateških lokacijah na obstoječih kanalizacijskih sistemih, t.j. npr. na iztokih iz čistilnih naprav, na priključkih večjih onesnaževalcev na javno kanalizacijo ipd, kjer ni na voljo energije za meritev pretokov. Načrtovanje merilnega mesta je zato kompleksen proces, pri katerem je treba upoštevati veliko dejavnikov. Največjo vlogo pri tem igrajo hidravlične razmere na širšem odseku merilnega mesta in robni pogoji, npr. vpliv visokih vod odvodnika na delovanje merilnega objekta.

V praksi se lahko pojavljajo številne napake na merilnih objektih :

– napaka pri projektiranju geometrije in umestitve merilnega objekta,
– napaka zaradi neustrezne nastavitve merilne opreme,
– napaka neustrezne izvedbe merilnega mesta,
– vpliv dolvodne zajezitve na merilno mesto,
– vpliv neustreznih dotočnih razmer (deroči tok, neenakomeren tok v profilu, povratni tokovi),
– prevelika nihanja pretokov za vzpostavljeno merilno mesto (zunaj merilnega območja),
– motnje zaradi spreminjajoče se vsebine odpadnih snovi v vodi (umazanija, odlaganje, zamašitve),
– agresivnost okolja (temperatura, kemizem),
– motnje v merilnem profilu (vzorčevalniki, odvzemi itd.).

Pogoj za normalno obratovanje merilnega objekta je tudi, da nimamo prisotnosti plavja in sedimentov. Obseg velikosti pretokov, v katerem objekt omogoča zadovoljivo merjenje oz. merilni obseg naprave je definiran z najmanjšim in največjim pretokom in je pogojen z vrsto in velikostjo merilnega objekta.

Sanacija neustreznih merilnih objektov v mnogih primerih zahteva velika finančna vlaganja, ali pa sploh ni mogoča, zato je najbolje že v fazi načrtovanja merilnega mesta izvesti celovito presojo ustreznosti oz. verifikacijo merilnega mesta.

The first important step in planning the discharge measurements is a clearly defined purpose and the accuracy of measurements. When we choose the location of the measurement site, the available energy on the section is many times limited, because we have measuring sites on the strategic points in the system, for example WWTP outlets, connections of large pollutants, etc.

Designing the discharge measurement site is a very complex process, within which many factors have to be considered, with hydraulic boundary conditions in the section upstream and downstream playing a very important role.

The most frequent irregularities on measuring sites in praxis are:

– unsuitable geometry and location of the measuring structure,
– mistake in the calibration of the measuring instruments,
– construction faults of the measuring structure,
– downstream backwater influencing the measuring site,
– irregular upstream boundary conditions (supercritical flow, irregular flow in profile, backflows, etc.),
– excessive oscillations of discharge (outside of the measurement range),
– quality changes in wastewater composition (dirt, deposition, obturations, temperature, foam),
– aggressive environment (temperature, chemical mechanisms),
– irregularities and disturbances in the flow structure (samplers, etc.),

It is very important to avoid the sedimentation and stagnation of floating objects during the operation of the site. The full scale measurement range of the discharge measurement site is defined by the minimum and maximum discharge, and is dependent on the type and size of the measurement structure.

We have to stress that the reconstruction of irregular measurement sites sometimes requires an excessive investment of effort, making it, in many cases, impossible. Therefore, it is important to perform the necessary tasks at the design stage.

Na Inštitutu za hidravlične raziskave in Fakulteti za gradbeništvo in geodezijo – Katedra za mehaniko tekočin z laboratorijem smo skupaj razvili postopek za presojo merilnih mest za meritve pretokov, s katerim lahko z uporabo različnih orodij verificiramo, v kakšnem stanju je merilni objekt ali verificiramo ustreznost izbrane lokacije za merilno mesto. Postopek je mogoče razčleniti na naslednje tri elemente:

a) *Verifikacija skladnosti z obstoječimi standardi, strokovno literaturo ali navodili proizvajalca.* Cilj je preverjanje skladnosti ureditve merilnega mesta s SIST, ISO, CEN in DIN standardi. Če merilno mesto ni standardizirano, upoštevamo podatke iz strokovne literature ali navodila proizvajalca. Rezultat analize je določitev geometrijskih podatkov za nov merilni objekt ali preverjanje odstopanj geometrijskih podatkov za obstoječe merilno mesto in izračun pretoka po veljavnih enačbah.
b) *Terenske meritve dejanskih hidravličnih razmer.* Namen meritev je analiza dejanskih razmer na merilnem objektu in/ali predvideni lokaciji. Meritve obsegajo izmero dvo ali trodimenzionalnega polja hitrosti v merilnem prerezu (ISO 748 : metode hitrost-površina) in integracijo hitrosti po prerezu za določitev pretoka (ISO 8363). Kadar je s pregledom ugotovljeno, da je merilno mesto urejeno v skladu z določili ustreznih standardov in so zagotovljeni ustrezni robni pogoji na dotoku in iztoku, izvajanje meritev ni nujno potrebno, vendar pa z meritvami hitrostnega polja ugotavljamo tudi neregularnosti na dotoku v merilni objekt.
c) *Matematično modeliranje hidravličnih razmer.* Cilj je preverjanje ustreznosti hidravličnih robnih pogojev za merilno mesto. Pri merilnih objektih, v katerih se pojavi kritični tok, je npr. pomembno, da ne prihaja do zajezitev z dolvodne strani. Z matematičnim modelom lahko tudi analiziramo vplive morebitnih korekcij geometrije merilnega objekta na natančnost meritev. Analize izvajamo z uporabo enodimenzionalnih matematičnih modelov.

Z medsebojno primerjavo analiz po vseh navedenih načinih lahko, glede na deklarirano natančnost vsake od njih, presodimo ustreznost novega ali obstoječega merilnega mesta in predlagamo morebitne korekcije.

The Institute for Hydraulic Research and The Faculty for Geodetic and Civil Engineering - Chair of Fluid Mechanics, with their laboratory, have developed a procedure for discharge measuring site verification. The methodology is useful for analysing existing or planned locations of measuring sites. The procedure can be divided into three main elements:

a) *Verification of accordance with existing standards, technical literature or manufacturer declarations.* The goal is to verify accordance of the discharge measurement site with the requirements of the SIST, ISO, CEN and DIN standards. If the discharge measurement site is not standardised, we use data from literature or from manufacturers' declarations. The result of the analyses is to define the tolerances for the existing measuring site, the theoretical discharge calculation and the geometry of the new measuring site.
b) *Field measurements.* The purpose of field measurements is to analyse actual hydraulic conditions at the measuring site or planned location. Measurements consist of determining a two or three-dimensional velocity field in the measuring profile (ISO 748: method area-velocity) and the integration of the velocity through the profile to determine the discharge (ISO 8363). Field measurement of the discharge is not obligatory if the measurement site is standardised. In such cases, the verification of the geometry and other requirements stated in the standards is verified.
c) *Mathematical modelling of hydraulic conditions.* The goal is to verify the hydraulic boundary conditions of the measurement site. At the measurement sites at which critical flow is requested, an influence of the backwater at the downstream boundary condition is of importance. It is also possible to analyse the influence of geometric corrections to measurement accuracy. We use one-dimensional mathematical models.

Performing the analyses through each of the three steps described above, it is possible, to verify the location of the new or existing measuring site or to propose eventual correction measures.

Postopek je posebej primeren za merilne naprave, ki jih zahteva zakonodaja, veljavna v RS in zakonodaja EU. Čeprav Pravilnik o prvih meritvah in obratovalnem monitoringu odpadnih vod ter o pogojih za njegovo izvajanje (Uradni list RS 35/96) predpisuje uporabo standarda DIN 19559, se v praksi izkazuje, da je v pravilniku (edini) predpisani standard v svojih določilih presplošen. Podrobneje obravnava le Venturijevo merilno korito (DIN 19559-2), ostale merilne metode pa so le na splošno obravnavane in niso podrobneje opredeljene, kot npr. v ISO standardih. Menimo, da je zato uporaba ISO standardov v takih primerih primernejša, kot dopolnitev predpisani metodi pa zelo smiselna.

Potreba po verifikaciji merilnih mest je pomembna tudi z vidika izvajanja nadzornih meritev s strani države ali njene pooblaščene ustanove. V času obratovanja merilnih objektov za merjenje pretoka bo vsekakor treba vzpostaviti tudi sistem nadzora nad izvajalci monitoringa. Postopek verifikacije meritev, ki v primerih ugotavljanja koncentracij različnih snovi v odpadni vodi poteka z medsebojno izmenjavo vzorcev, na področju meritev pretokov ne pride v poštev. Nadzornih meritev namreč ni mogoče izvajati na neustreznem merilnem objektu, ampak je treba merilno mesto predhodno ustrezno verificirati. Šele ko je doseženo, da se meritve (ves čas) lahko ustrezno izvajajo, je mogoč občasen , nadzorni pregled.

5. PRIMERI UPORABE POSTOPKA VERIFIKACIJE

5.1 MERILNIK PRETOKA CČN DOMŽALE

Merjenje pretoka na iztoku CČN Domžale se izvaja s pomočjo Khafagi-Venturi merilnika, širine korita 118 cm, s kratko zožitvijo širine 52 cm. Merilnik je lociran pred iztokom iz CČN v Kamniško Bistrico. Cilj naloge je bil, preveriti delovanje merilnega mesta in določiti krivuljo pretoka. Merilno korito je prikazano na sliki 1.

The procedure is very suitable for measuring sites requested by regulation adopted in Slovenia and the European Union. Experiences from the implementation of the Regulation of the first measurements and operational emission monitoring of wastewater (Official Gazette of Republic Slovenia No. 35/96), which adopted DIN 19559, have shown that this standard has guidelines which are too general for the use of different measuring methods, with exception of the Venturi flume, which is described in part 19559-2. We consider the use of ISO standards to be more reasonable than the completion of the adopted DIN method.

Verification of discharge measurement sites is an important and necessary task with the aim of supervising the discharge measurements which are usually performed by the polluters themselves, or by authorised institutions. During the operation of discharge measurement sites it is also necessary to establish a supervising system.. Verification of the pollution concentration measurements through the exchange of wastewater samples is applied for the verification of measurements in the field of pollution monitoring. The same mechanism is impossible to apply in the field of discharge measurement. It is therefore necessary to perform the verification of any discharge measurement structure before it is commissioned to its use. After the verification, it is necessary to perform a periodical verification of the measurement structure within a regular time interval.

5. CASE STUDIES

5.1. FLOW MEASUREMENTS AT THE WWTP, DOMŽALE

Discharge at the outlet of the WWTP, Domžale was measured with a Khafagi Venturi flume with a width of 118 cm and a short contraction of a width of 52 cm. The device was located at the outlet from the WWTP to the Kamniška Bistrica River. The goal of the project was the calibration and verification of the measuring site. The measurement flume is showed in Figure 1.

Slika 1. Khafagi Venturi korito na iztoku CČN Domžale.
Figure 1. Khafagi Venturi flume on the Domžale WWTP outflow.

V prvi fazi naloge so bili natančno izmerjeni in preverjeni geometrijski podatki korita in ugotovljena odstopanja oz. tolerance. Pri tem so bile smiselno uporabljene zahteve standarda DIN 19559-2, ki takšnega primera sicer ne obravnava, temveč le klasično Venturijevo korito z dolgo zožitvijo. Na podlagi podatkov iz strokovne literature smo določili teoretično krivuljo pretoka.

Terenske meritve pretoka smo izvajali v merilnem profilu pred zožitvijo. Uporabljali smo način omerosojanja merilnega mesta, z metodo merjenja hitrosti v posameznih točkah prereza in integracijo hitrosti po prerezu, za izračun pretoka v skladu s smernicami

In the first phase of the project, the geometrical data of the flume were inspected and measured and deviations were recognised. We used the requirements of the standard DIN 19559-2, which describes the classical Venturi flume with a long contraction. We also defined a theoretical discharge curve from the literature.

Field measurements were carried out in the measuring profile before the contraction. We used a measuring site calibration with a method of measuring velocities in profile, and an integration of them in the profile, to calculate the discharge according to the guidelines of standards ISO 8363 and ISO 748.

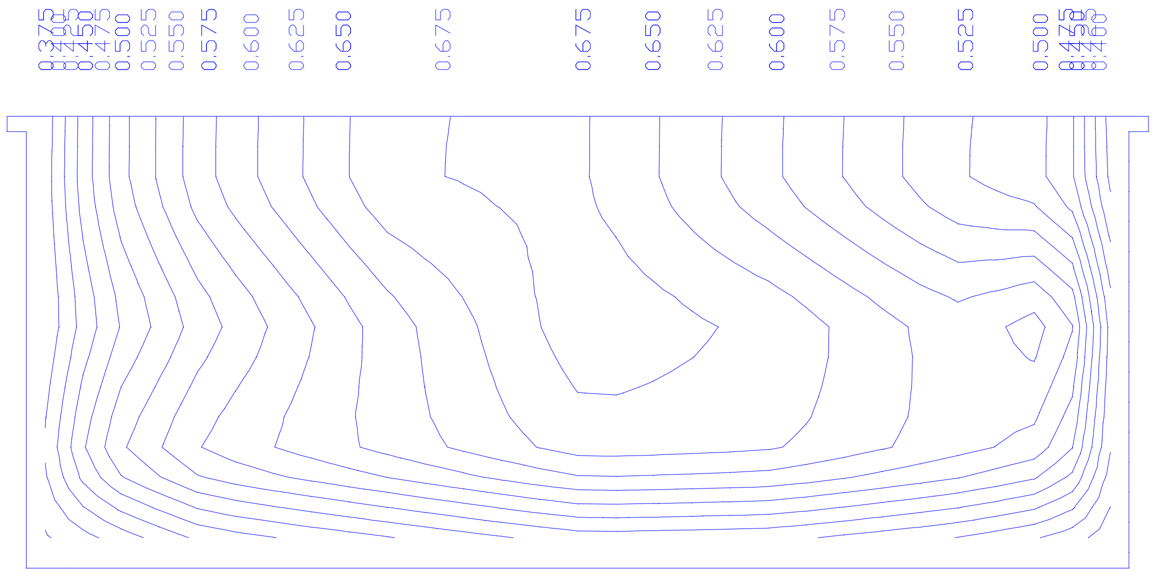
standardov ISO 8363 in ISO 748.

Meritve dvodimenzionalnega polja hitrosti so bile izvedene v 21 točkah prereza pri 7 različnih pretokih. Uporabljena je bila brezkontaktna sonda za točkovno meritev dvodimenzionalnega vektorja hitrosti ADVLab–2D, z nazivno natančnostjo 0,5 odstotka merilnega območja in resolucijo 0,1 mm/s, proizvajalca Nortek AS. Prednost uporabe te sonde je poleg njene natančnosti tudi ta, da nima gibljevih delov, kot npr. mersko krilo.

Za izračun pretokov smo uporabili program PRETOK7, ki izvaja integracijo merjenih hitrosti po prerezu s funkcijo spline, ob upoštevani polno razviti turbulenci v merjenem profilu (slika 2).

Two-dimensional velocity fields were measured at 21 points in the profile at seven different discharges. A non-contact probe for the point measurement of the two-dimensional velocity vector ADVLab–2D, with an accuracy 0,5 % of measuring range and a resolution 0,1 mm/s from the manufacturer Nortek AS, was used. Besides having good accuracy, the probe has no moving parts, which is an advantage if we compare it with usual current meters.

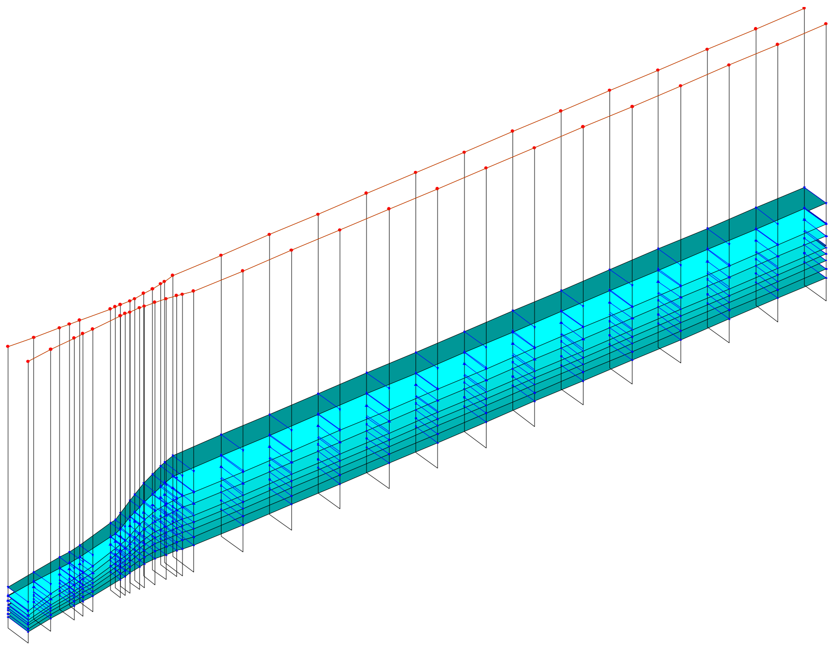
We calculated the flow using the in-house software PRETOK7. It executes the integration of measured velocities through the profile with the spline function at full developed turbulence in the measuring profile (Figure 2).



Slika 2. Izotahe merjenega profila pri pretoku 285 l/sek.
Figure 2. Velocity profile at discharge 285 l/sec.

Preverjanje hidravličnih robnih pogojev smo izvedli s pomočjo programa HEC-RAS, ustreznega za izračun stalnega, zvezno se spreminjajočega toka. Upoštevali smo dejansko geometrijo korita, analizirali pa smo tudi vpliv korekcij geometrije korita na izračun poteka gladin in pretokov (slika 3.)

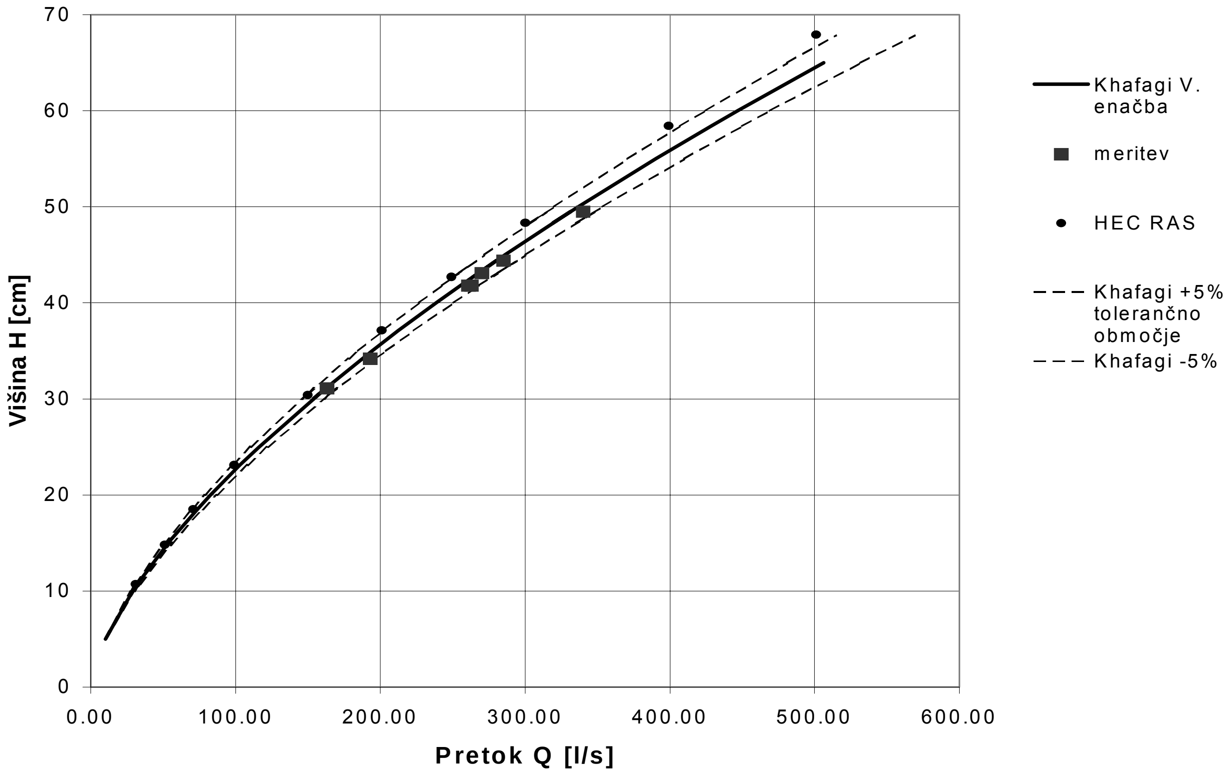
Verification of hydraulic boundary conditions were carried out by using the program HEC-RAS 2.2, developed for the calculation of steady and continuously changing unsteady flow. We calculated the flow with actual geometry, and analysed the influence of geometric corrections on the water levels and discharges (Figure 3).



Slika 3. Aksonometričen prikaz izračunanih gladin s programom HEC-RAS ver.2.2.
Figure 3. Acsonometric view of water levels computed with HEC-RAS ver.2.2.

Rezultati navedenih treh vrst analiz so prikazani grafično (slika 4).

Results of all different analyses are presented graphically (Figure 4).



Slika 4. Q-H diagram – primerjava rezultatov.
Figure 4. Q-H curves analysis.

Iz slike 4 je razvidno dobro ujemanje rezultatov meritev pretokov z izračunom po teoretični enačbi, saj odstopanja niso znašala nikjer več kot 3 odstotke. Izračun s programom HEC RAS je bil namenjen predvsem preverjanju robnih pogojev, zato koeficient hrapavosti ni bil natančneje kalibriran. Rezultati so zato le indikativni.

Kot končni rezultat naloge lahko strnemo, da smo z meritvami in izračuni dokazali, da je merilni objekt ustrezno izveden, da so robni pogoji ustrezni in je merilni objekt ustrezno umeščen na iztoku iz čistilne naprave. Zato se lahko kot kalibracijska krivulja v območju meritev uporabi teoretična krivulja pretoka Khafagi-Venturi korita, kot ustrezno nadomestilo določbam Pravilnika o prvih meritvah in obratovalnem monitoringu odpadnih vod ter o pogojih za njegovo izvajanje (Uradni list RS 35/96).

5.2. MERILNIK PRETOKA NA KANALIZACIJSKEM SISTEMU KAMNIK DOMŽALE

Merilnik pretoka je lociran na meji med občinama Kamnik in Domžale in je namenjen ugotavljanju dotoka odpadne vode iz občine Kamnik. Merilni objekt je klasično Venturijevo korito, širine korita 70 cm z dolgo zožitvijo širine 47 cm.

Uporabljena je bila enaka metodologija dela, končni rezultati analiz pa so prikazani na sliki 5.

Odstopanja opravljenih meritev od teoretično izračunanih pretokov so nekoliko večja, vendar še vedno v okviru dovoljene tolerančne meje po standardu DIN 19559-2. Na podlagi te ugotovitve je bila v območju meritev verificirana uporaba pretočne krivulje po DIN standardu.

From Figure 4 we can identify a good accordance of measured values with the theoretical equation calculation, as difference in the whole range of measurements is not larger than 3%. Calculation with the program HEC RAS served primarily for the controlling of boundary conditions, so we didn't calibrate the roughness coefficient, and the results are only indicative.

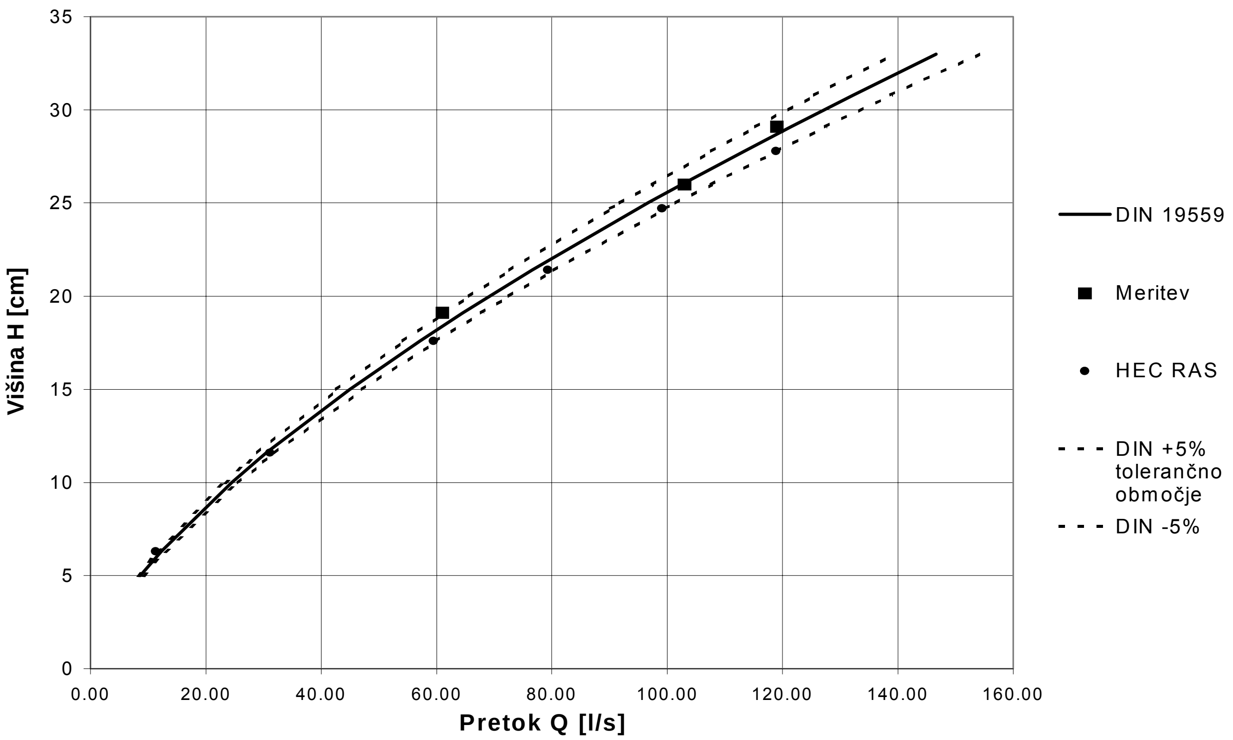
In conclusion, we proved with measurements and calculations that the measuring site is properly constructed with proper boundary conditions. The measuring object is also suitably located on the outlet of the WWTP. We can use, in the range of measurements, a theoretical stage discharge equation for the Khafagi Venturi flume, as an adequate substitution of the guidelines of Regulation of the first measurements and operational emission monitoring of wastewater (Official Gazette of Republic Slovenia No. 35/96).

5.2. MEASUREMENT SITE ON THE SEWAGE SYSTEM OF KAMNIK AND DOMŽALE

The flow measurement device is located on the border between the communities of Kamnik and Domžale, and serves to divide the costs of the WWTP operation between the two communities. The measuring structure is a classical Venturi flume of 70 cm width, and a length contraction of 47 cm width.

Equal methodology was used; the final results of the analyses are presented in Figure 5.

The deviations of measured values from theoretical calculated values were slightly larger, but still within the range of permitted tolerance according to the guidelines of the standard DIN 19559-2. According to this statement, the usage of the DIN standard stage discharge curve in the range of measurements was verified.



Slika 5. Q-H diagram – primerjava rezultatov
Figure 4. Q-H curves analysis.

6. ZAKLJUČEK

Ugotovitve lahko strnemo takole :

- meritve pretokov morajo biti kakovostno izvajane in zahtevajo specifična znanja,
- priporočljiva je uporaba standardov pri načrtovanju merilnih objektov, oceni izvedenega stanja in izvajanju meritev pretokov,
- verifikacija merilnih mest je potrebna pred začetkom izvajanja monitoringa pretokov,
- elementi verifikacije obsegajo preverbo skladnosti merilnega objekta s standardi, meritve pretokov in matematično modeliranje hidravličnega delovanja objekta,
- postopek verifikacije je v praksi pokazal široko uporabnost, od verifikacije ureditev do predlogov za premestitve oz. sanacije, pa tudi vprašanj o razgradnji objektov, ki jih ni mogoče primerno usposobiti,
- Verifikacijo meritev (nadzorne meritve) pretokov je mogoče izvajati na verificiranih merilnih mestih.

6. CONCLUSIONS

We can conclude with the following remarks:

- To perform discharge measurements, specific knowledge is needed.
- The usage of standards is necessary for the planning of new discharge measurement sites, the analyses of existing sites, and for the discharge measurements for the calibration procedure.
- Verification of the measurement site is necessary before the structure begins operation.
- Elements of measurement site verifications must be in accordance with the standards, field discharge measurements and the mathematical modelling of the hydraulics.
- Procedure of verification is very useful in praxis, from verification to the reconstruction of the sites, but also opens questions about the decomposition of the measuring sites which don’t work properly,
- The verification of measurements (supervising measurements) are only able to be performed on verified measuring sites.

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