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STATISTICAL ANALYSIS OF FLOOD RISK FACTORS

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The durability of hydrotechnical structures, especially flood embankments, depends largely on the correct identification of natural phenomena occurring in both the embankment body and the foundation. Such a phenomenon - particularly important from a flood protection viewpoint – is water filtration through the embankment. It turns out that it can be effectively reduced by applying various types of anti-filtration barriers in the embankment fill material and the foundation.

In the paper the results of statistical analysis of the impact of the sealing technology on the level of water in the piezometers (installed on both sides of the seal) and findings on the relationship between the water level height in a flood embankment area and the type of seal, and the period (month) of a given hydrological year are presented.

Keywords: Lubuskie section of the Odra River, flood protection, statistical analysis

1. INTRODUCTION

One of the overriding problems associated with the development of the Odra River basin is effective flood protection. It is mainly accomplished by means of flood embankments.

On the territory of the present Voivodeship of Lubusz, the construction of flood embankments began as early as in prehistoric times, when dykes were constructed to combat flooding, i.e. in a hasty manner, which did not ensure their proper technical condition. Additionally, the quality of these dykes deteriorated during subsequent floods, and the processes of erosion and the improper use of dykes.

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The millennium flood, which occurred in the Odra River basin in July 1997 caused large damages to the embankments. In the Voivodeship of Lubusz alone, 3.57 km of the embankments were completely destroyed by caving in and as many structures underwent deformation.

Upon the receding of the flood waters, the repair of embankments began.

In many places, the embankments underwent a thorough modernization with the use of modern insulating materials, such as: biodegradable non-woven fabrics, geosynthetics, C-Loc sheet piling and PVC film, as well as natural mineral raw materials, including silts, clays, and bentonites [4, 6, 7, 9, 10, 12 et al.]

Embankments of a length of 75.4 km were modernized in the Voivodeship of Lubusz in the years 1998-2009. However, only 39.9 per cent of the structures are in a good condition, while 36.8 per cent are in a medium condition, and 23.3 per cent are in bad a condition until today. The embankments of a length of at least 146.9 km along the Odra River within the boundaries of the Voivodeship of Lubusz are in need of repair or upgrading.

The last flood (of 2010) was another test of the condition of the flood protection in the Lubusz region, showing on the one hand good practices and flood protection techniques, and on the other hand - permanent neglect.

2. CHARACTERISTICS OF STUDY SITE

The study was conducted at the Rąpice – Urad 10P section located on the right bank of the Odra river, at a chainage of 546.0 to 564.8 km. It is a Class II embankment and it protects farmland and built-up areas with a total area of 4,330 hectares, including the valuable natural Uradzka Valley, against flooding.

It is likely that the section was built in the days of the king's Superintendent for the construction of hydraulic structures and embankments in the Lower and Upper Silesia and Dyke Associations, when the so called Związki Wałowe were active (i.e. after 1846). However, the basic shape was given to the section in 1905 (the so-called Odra River Act came into force) and after the flood in 1985. The Big Flood in 1997 caused much damage to the structure. The embankment inspection made in 1998 revealed that the embankment did not fulfil its functions owing to a too low crest and the occurrence of leakage, and numerous deformations. Therefore, in the year 2000 its complete refurbishment was accomplished [5, 10]. In order to reduce the water filtration through the embankment and increase the flood safety in the area, anti-filtration barriers have been installed during the refurbishment of that embankment section [1, 2]. Depending on the geological structure of the body and foundation and the distance of the embankment from the riverbed, four sealing technologies were applied:

- PVC foil for sealing the embankment body,
- PVC foil for sealing the embankment body, combined with the C-Loc sheet piling for sealing the embankment foundation
- Bentonite mat for sealing the embankment body,
- Bentonite mat for sealing the embankment body, combined locally with a clayey wall for sealing the embankment foundation.

The inspections performed from 2004 to 2008 proved that the embankment is in a good technical condition.

3. STUDY METHODS

Water level measurements in the examined section of the flood embankments were performed in four lines of piezometers. At the same time, hydrological phenomena were monitored at the water level measurement stations located closest to the analysed embankment section, i.e. in Połęcko and Słubice. The level of water in the Odra River, at the height of the piezometers installed was determined by interpolation [3]. Readings of water level were taken from level water-level gauge profiles, as well as from particular piezometers once a month for a period of four hydrological years, i.e. from November 2004 to October 2008. The record sheet takes into account the relationship that exists between the water level in the River and piezometers located on both sides of the seal, and a given month in the hydrological cycle. The location of piezometer lines was set so that they cover each of the four sealing technologies and are placed on both sides of the sealing diaphragm. Particular lines consisted of three or four piezometers, installed in the following way:

- Piezometer No. 1 – located on the embankment on the water side, at a distance of 30-50 m from the embankment toe,
- Piezometer No. 2 – lokated in the embankment crest,
- Piezometer No. 3 – located on the embankment on the land side, at a distance of 20-50 m from the embankment toe,
- Piezometer No. 4 – located on the embankment on the land side, at a distance of 70-100 m from the embankment toe.

4. STUDY RESULTS

In addition to the basic statistical parameters (mean, sum, minimum and maximum), the analysis of correlation and a multi-factor analysis of the variance of variables at the level of significance $\alpha < 0.01$ and $\alpha < 0.05$, and calculations of the half-width of the confidence intervals (margins of error) NIR were made.

As demonstrated by the analyses, the level of water in the Odra River was correlated with water levels in individual piezometers at a highly significant level, this being proved statistically by the correlation coefficient (Fig. 1-4).

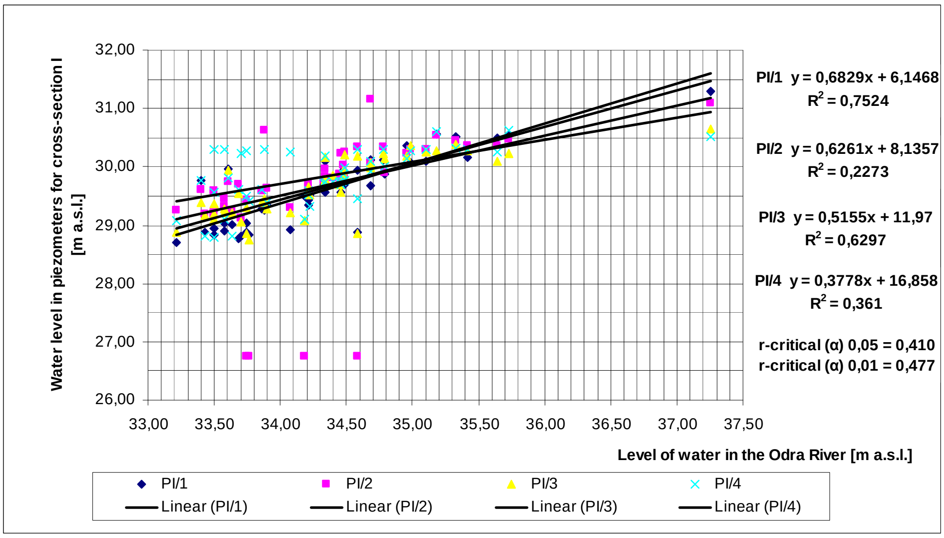

Fig. 1. Interdependence of the water level in individual piezometers in the PI cross-section and the level of water in the Odra River

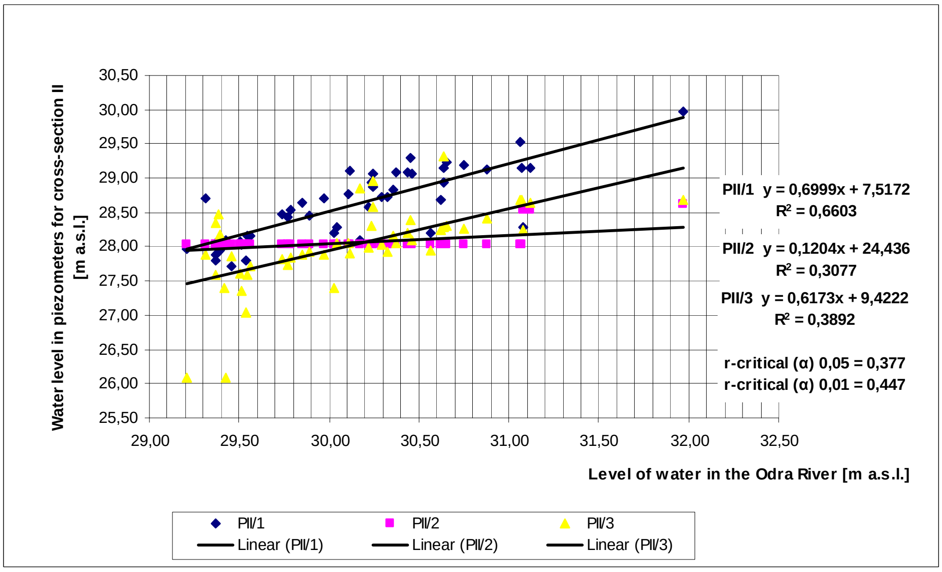

Fig. 2. Interdependence of the water level in individual piezometers in the PII cross-section and the level of water in the Odra River

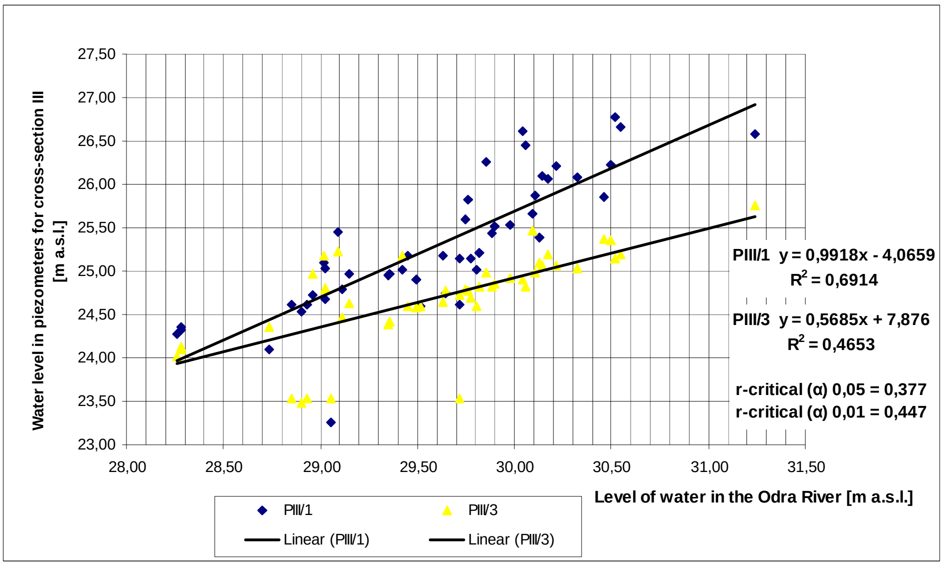

Fig. 3. Interdependence of the water level in individual piezometers in the PIII cross-section and the level of water in the Odra River

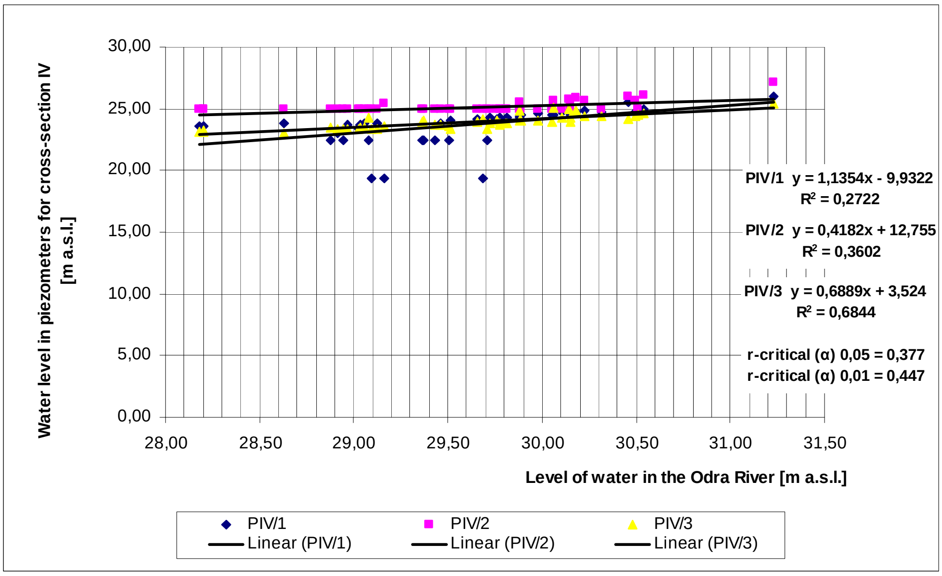

Fig. 4. Interdependence of the water level in individual piezometers in the PIV cross-section and the level of water in the Odra River

The relationship between the level of water in the Odra River and water levels in piezometers located in the PI cross-section (PVC foil for sealing the embankment body, combined with the C-LOC sheet piling for sealing the embankment foundation) indicates that the coefficient of correlation between the River and the first piezometer (PI/1) was: $R^2 = 0.7524$ (r = 0, 8674), the second piezometer (PI/2): $R^2 = 0.227$ (r = 0.4768), the third piezometer (PI/3): $R^2 = 0.6297$ (r = 0.7935) and fourth piezometer (PI/4): $R^2 = 0.3610$ (r = 0.6008), at the assumed levels of significance shows a highly significant relationship. Similar relationships were shown in cross-sections PII, PIII and PIV.

For piezometer PIII/2, it was not possible to perform the analysis of correlation owing to very low water levels during the period of study (the water level below the measuring range of the piezometer).

To test the significance of the influence of major factors, such as the level of water in the Odra River, water level in piezometers, type of seal used and study period (months of a given hydrological year) as well as their combinations, a three-factor analysis of variance was performed. It was found that interactions, which can exist between the major factors suggest the presence (or absence) of an additional influence of a combination of factors on an examined statistical characteristic [8, 13]. In other words, it was checked by using the analysis of variance test, the so-called null hypothesis, stating that the examined factor does not affect the value of the analysed characteristics.

In order to determine which of the examined factors significantly or very significantly affects the variation of an examined observational characteristic, as in the case of correlation analysis, the value of the level of significance – "α" was used, taking the following criteria for the limit (critical) value of the level of significance:

$\alpha<0.05$ – meaning that a particular factor significantly affects the examined characteristics,

$\alpha<0.01$ – meaning that a particular factor very significantly affects the examined characteristics.

The comparison of the significance of differences between the values of the level of water in the Odra River and water levels in individual piezometers, depending on the type of seal used in a cross-section and study period (four hydrological years), is presented in Table 1.

Table 1. Results of three-factor analysis of ariance

Type of variation	Sum of squared deviations	Number of degrees of freedom	Mean square	Value of statistic F-calculated	Level of significance F – Fisher's tables	
					α<0.05	α<0.01
Total	6482.72	-	-	-	-	-
Blocks	9.24	-	-	-	-	-
Structures of factor I	3341.57	3	1113.86	3902.50^{XX}	2.62	3.83
Structures of factor II	120.51	11	10.96	38.38^{XX}	1.81	2.29
Co-operation of structures of factor I and II	10.13	33	0.31	1.08	1.49	1.74
Structures of factor III	2475.86	3	825.29	2891.47^{XX}	2.62	3.83
Co-operation of structures of factor I and III	314.38	9	34.93	122.38^{XX}	1.90	2.46
Co-operation of structures of factor II and III	15.41	33	0.47	1.64^{X}	1.49	1.74
Co-operation of structures in of three factors	31.22	99	0.32	1.10	1.32	1.47
Error	164.40	576	0.29	-	-	-

xx – highly significant correlation

Next, ratios of the variation of individual factors were calculated and a NIR (least significant difference test) test was performed. Its idea consists in determining the so-called least significant differences and comparing them with the differences of averages. This is a test least prone to the increase in the number of multiple comparisons, because the level of significance relates to a single comparison:

– for sealing technologies 0.17 m above seal level (a.s.l.),
– for months 0.36 m a.s.l.,
– for piezometers 0.17 m a.s.l.,

- for sealing technologies x piezometers 0.42 m a.s.l.,
- for months x piezometers 0.59 m a.s.l.

The analysis of variance has shown a very significant effect of all three examined factors on the water level in piezometers. The biggest effect was shown by sealing technologies. For this factor, the NIR was 0.17 m a.s.l. Piezometers (i.e. the location of the test point in the embankment) demonstrated a smaller effect on the examined characteristics, in this case, the half-width of the confidence interval (margin of error - NIR) amounted to 0.17 m a.s.l. Individual months of the technological year exhibited the smallest effect on the examined characteristics (in 'very significant' range), in this case, the half-width of the confidence interval (margin of error - NIR) amounted to 0.16 m a.s.l.

The study has shown the existence of interactions between factor I and III, i.e., between the sealing technology used and piezometers. In this case, the NIR amounted to 0.42 m a.s.l., and factor III, i.e. piezometers, and factor II, i.e. the month of the hydrological year - in this case, the half-width of the confidence interval (margin of error) was equal to 0.52 m a.s.l.

The absolute value of the difference of averages of the sample is larger than the so-called least significant difference (NIR), hence we can say that it is statistically significant.

5. SUMMARY

One of the most popular forms of protection against flooding is the construction of flood embankments. However, many years of experience in different countries, including Poland, show that the existence of these hydrotechnical structures in the river valleys, does not guarantee effective protection against flooding in the region.

The study conducted by the author showed that sealing technologies built into the embankment constitute an important factor determining the flood defence of the region. The effectiveness of those protection measures is very strongly affected by the season and distance of the embankment from the riverbed.

A way to reduce water filtration through the embankment is the proper selection of the type of sealing technology, depending on local conditions, the distance of the embankment from the riverbed, and the development of the inter-embankment zone.

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REFERENCES

1. Asani A.: *Zastosowanie bentomaty i ścianki ilastej jako ekranów przeciwfiltracyjnych w wałach przeciwpowodziowych*, w: Zeszyty Naukowe Uniwersytetu Zielonogórskiego nr 133, red. A. Greinert, U. Kołodziejczyk, Zielona Góra, Oficyna Wydawnicza Uniwersytetu Zielonogórskiego 2007, 21-30.
2. Asani A.: *Uszczelnienie wałów przeciwpowodziowych przegrodą szczelną w postaci folii PVC i ścianki C-LOC*, w: Antropogeniczne oddziaływania i ich wpływ na środowisko wodne, red. M. Maciejewski, M.S. Ostojski, Warszawa, Wydawnictwo IMGW 2009, 100-106.
3. Asani A.: *Napełnienie koryta rzecznego a poziom wody w rejonie wałów przeciwpowodziowych*, w: Ochrona Środowiska i Zasobów Naturalnych. Enviromental Protection and Natural Resources nr 37, red. B. Gworek, Warszawa 2008, 64-71.
4. Bieberstein A., Brauns J.: 2002, *Technischer Hochwasserschutz - Erfordernisse aus geotechnischer Sicht*, Geotechnik 25, Nr. 4 (2002), 239-248.
5. Bobowska A., Kołodziejczyk U.: *Die Modernisierung der Flussdeiche auf der lubuschen Strecke der Oder*, w: Zeszyty Naukowe Uniwersytetu Zielonogórskiego nr 131, red. A. Greinert, U. Kołodziejczyk, Zielona Góra, Oficyna Wydawnicza Uniwersytetu Zielonogórskiego 2004, 21-30.
6. Borys M.: *Metody modernizacji obwałowań przeciwpowodziowych z zastosowaniem nowych technik i technologii*, Falenty, Wydaw. IMUZ 2006.
7. Borys M.: *Projektowanie i wykonawstwo ekranów przeciwfiltracyjnych z geomembran i mat bentonitowych w wałach przeciwpowodziowych i obwałowaniach małych zbiorników wodnych*, Falenty, Wydaw. IMUZ 2009.
8. Drab M.: *Wybrane zagadnienia statystyki matematycznej i doświadczalnictwa w inżynierii środowiska*, Zielona Góra, Oficyna Wydawnicza Uniwersytetu Zielonogórskiego 2007.

9. Herrmann R. A., Jensen J.: *Sicherung von Dämmen und Deichen: Handbuch für Theorie und Praxis*, Hrsg., Siegen, Universitätsverlag 2003, 14-23.
10. Kołodziejczyk U.: *Geologiczno-inżynierskie badania wałów przeciwpowodziowych i ich podłoża jako metoda prognozy zagrożeń powodziowych na lubuskim odcinku Odry,* Zielona Góra Oficyna Wydawnicza UZ 2002.
11. Kołodziejczyk U.: *Effectiveness of assessing flood hazards along the Lubuski Section of the Oder,* w: Civil and Environmental Engineering Reports, No 2 (2007), 37-47.
12. Ševčenko K.I.: *Gabiony – nadežnaja zaščita gruntom ot erozji*, Gidrot. Stroit no 5 (1996), 33-37.
13. Sobczyk M.: *Statystyka,* Warszawa, Wydawnictwo Naukowe PWN 2008.

ANALIZA STATYSTYCZNA CZYNNIKÓW RYZYKA POWODZIOWEGO

S t r e s z c z e n i e

Trwałość budowli hydrotechnicznych, w tym szczególnie wałów przeciwpowodziowych, zależy w dużym stopniu od właściwego rozpoznania zjawisk naturalnych zachodzących zarówno w korpusie, jak i podłożu wału. Takim zjawiskiem – szczególnie istotnym z punktu widzenia ochrony przeciwpowodziowej – jest filtracja wody przez wał. Okazuje się, że można ją skutecznie ograniczyć poprzez zastosowanie w nasypie i podłożu wału różnego rodzaju przegród przeciwfiltracyjnych.

W pracy przedstawiono wyniki modelowych badań wpływu technologii uszczelnienia na poziom wody w piezometrach (zainstalowanych po obu stronach uszczelnienia) i ustalenia zależności pomiędzy wysokością poziomu wody w rejonie wału przeciwpowodziowego i rodzajem uszczelnienia, a także okresem (miesiącem) danego roku hydrologicznego. Badania przeprowadzono na odcinku zlokalizowanym na prawym brzegu Odry w od 546,0 do 564,8 km jej biegu. W celu ograniczenia filtracji wody przez wał i zmniejszenia ryzyka wystąpienia powodzi w rejonie, w ramach prac modernizacyjnych, na przedmiotowym odcinku wałów, zostały zainstalowane cztery różne technologie uszczelnienia: a) folia PVC uszczelniająca korpus wału, b) folia PVC uszczelniająca korpus wału połączona ze ścianką szczelną C-LOC uszczelniającą podłoże wału, c) bentomata uszczelniająca korpus wału, c) bentomata uszczelniająca korpus wału, lokalnie połączona ze ścianką ilastą uszczelniającą podłoże wału.

Otrzymane wyniki badań wskazują na możliwość ograniczenia filtracji wody przez wał poprzez zastosowanie różnych ekranów przeciwfiltracyjnych oraz opisują zależność pomiędzy technologią uszczelnienia, okresem w roku hydrologicznym a poziomem wody w rejonie wału.