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RELATIONAL DATABASE OF THREE PRECISE LEVELLING CAMPAIGNS IN POLAND

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Key words: data base, levelling network.

Abstract

Four precise levelling campaigns were carried out in Poland: in 1926–1937, 1953–1955, 1974–1982, 1997–2003. The levelling data from these campaigns is stored in printed catalogues, text files and spreadsheets. A comprehensive analysis of this data requires its compilation in a standardized form (a database). First attempts at the standardization of precise levelling data format date back to 2002 at the University of Warmia and Mazury in Olsztyn (ŁYSZKOWICZ et al. 2002). The authors of this paper, in turn, have collected the complete data from the last three precise levelling campaigns in Poland, which gives an opportunity to standardize the levelling database structure. The subject of the paper is to provide a theoretical background and to offer a relational database of the precise levelling network in Poland, with the data from each campaign. The paper describes the data, database schemas and examples of retrieving information with SQL queries.

RELACYJNA BAZA DANYCH SIECI NIWELACJI PRECYZYJNEJ OBSZARU POLSKI Z KOLEJNYCH KAMPANII

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Słowa kluczowe: baza danych, sieć niwelacyjna.

Abstrakt

W Polsce przeprowadzono cztery kampanie niwelacji precyzyjnej: 1926–1937, 1953–1955, 1974–1982, 1997–2003. Materiał niwelacyjny z tych prac jest przechowywany w katalogach papierowych, plikach tekstowych oraz arkuszach kalkulacyjnych. W celu przeprowadzania szerszych analiz tych wyników należy zebrać cały materiał w jednolitej formie (bazie danych). Pierwsze próby ujednolicenia formy przechowywania danych z niwelacji precyzyjnej podjęto na Uniwersytecie Warmińsko-Mazurskim w 2002 roku (ŁYSZKOWICZ i inni 2002). Obecnie nadarzyła się okazja ujednolicenia struktury bazy danych niwelacyjnych dzięki zgromadzeniu przez autorów kompletnego materiału z trzech ostatnich kampanii niwelacji precyzyjnej w Polsce. Przedmiotem niniejszego opracowania było przygotowanie teoretyczne i praktyczne relacyjnej bazy danych sieci niwelacji precyzyjnej obszaru Polski z kolejnych kampanii. Praca zawiera opis danych z poszczególnych kampanii niwelacji precyzyjnej oraz schematy budowy tej bazy, a także przykłady uzyskiwania różnych informacji za pośrednictwem zapytań SQL.

Introduction

The analysis of contemporary vertical crustal movements and their forecasting has long been a focus of interest for geodesists, geologists and geophysicists. These movements result from the changes of the Earth's shape, size and location in space. The changes can be determined on the basis of different measurement data (geological, seismic observation, sea level observation, GPS observation, levelling data). The most precise measurement method is geometric precise levelling.

Precise levelling campaigns are carried out rarely, every 20 years on average. In Poland four precise levelling campaigns took place: in 1926–1937, 1953–1955, 1974–1982, 1997–2003. The data obtained in these campaigns is stored in the Centre for Geodesic and Cartographic Documentation (Centralny Ośrodek Dokumentacji Geodezyjnej i Kartograficznej) in the form of catalogues. The catalogues are analog and/or digital, depending on the available recording possibilities during measurement. A comprehensive analysis of this data requires its compilation in a standardized form (a database). First attempts at the standardization of precise levelling data storage date back to 2002 at the University of Warmia and Mazury in Olsztyn (ŁYSZKOWICZ et al. 2002). This database contained very small data sets from three levelling campaigns. The data was not standardized, mainly due to the different numbering of lines and benchmarks, different levelling routes, different types of adjustments and different storage media (printed documents, text files). During the work on a model of vertical crustal movements in Poland (KOWALCZYK 2006a), the complete data from the last two levelling campaigns (unadjusted height differences without normal corrections) was collected and converted to a common digital form (xls format). The data from 1939 (*Katalog* 1939) and 1960 (*Katalog* 1960) catalogues was also digitized, however it only contained adjusted height differences, which, given the analysis method (KOWALCZYK 2006b), did not provide a suitable levelling data for the research on vertical crustal movements.

The model of vertical crustal movements in Poland (KOWALCZYK 2006a) is a static model. To create a kinematic model requires the data from at least three levelling campaigns. Therefore, the goal of the work presented in this paper has been to collect this data, standardize it, and place it in one common levelling database, as well as to organize the database optimally for the aforementioned purpose.

An important part of the research into crustal vertical movements is data without normal corrections and unadjusted data. Unfortunately, the records from the first and second precise levelling campaigns do not contain such data. In 2008, courtesy of the personnel of the Centre for Geodesic and Cartographic Documentation in Warsaw, unadjusted data from survey logs from the second precise levelling campaign was obtained. This created an opportunity to standardize the database structure of the three campaigns. While merging the data from 1974–1982, 1997–2003 did not constitute a major problem (similar work had been carried out in the Centre (SEKOWSKI 2005)), standardizing all three campaigns was a serious challenge both logistically and in terms of programming. The paper describes the available levelling data, presents the existing source data sets which contain the levelling data and describes the problems faced in the standardization process. As a result, a complete database has been created, containing unadjusted results from three levelling campaigns: 1953–1955, 1974–1982, 1997–2003. This data will allow in a near future to determine a kinematic model of vertical crustal movements in Poland. Currently, work is in progress on augmenting the database with results from the first precise levelling campaign in Poland, which took place before the World War II.

Levelling data

Levelling campaign of 1926–1937

Class I levelling network from 1926–1937 was referenced to a tide gauge in Gdynia, built in 1931. The lines were designed along class I roads, and sometimes along rail road tracks (WYRZYKOWSKI 1988).

Table 1

Geometric specifications of the 1926–1937 network

Line length [km]	Number			Mean length [km]		
	traverses n_F	lines n_L	sections n_R	Loop F	line L	sections R
10 046	36	121	5 907	445	83	1.7

The survey was conducted with Zeiss precise levels, type III, with optical flat, telescope 35× and reversible level 8’’–10’’/2 mm. 3-metre levelling rods with 2 graduation lines on an invar tape were used (RANIECKI 1932).

The measurements were taken with the telescope in the horizontal position, using “from the middle” method, with aiming line distance 50 m. The results were adjusted using two criteria. The first criterion determined the maximal deviation of height difference between two points in two measurements, the second criterion determined the maximum mean error for 1 km of the levelling line.

Results were adjusted for levelling rods’ systematic errors and with normal orthometric corrections. Before adjustments mean error for the whole network was estimated and the results are shown in Table 2.

Table 2

Mean error before adjustment, mean probable errors, mean error after adjustment (survey 1926–1937) [mm/km]

Mean error before adjustment			Mean errors		Mean error after adjustment
			random	systematic	
m_1	m_2	m_3	η	m_0	m
±0.45	±0.73	±1.04	±0.31	±0.05	±1.04

Legend:
m_1 – mean deviation for two measurements between two points, m_2 – mean deviation for two line measurements, m_3 – mean traverse perimeter error, mean probable errors were calculated with Lallemand’s formulae.

Linia 7.

L. p.	Rodzaj reperu	Niwelowana odległość między reperami km	OPIS POŁOŻENIA REPERU: Km szosy, kolei	OPIS POŁOŻENIA REPERU: Nazwa miejscowości i budynku (obiektu), na którym umieszczony jest reper	Wysokość nad poziomem morza w Amsterdamie m
				szosa: Wejherowo — Linia Zakrzewo.	
39	B	2.67	33.23	**Linia,** szkoła powszechna, w ścianie od strony szosy.	**175.649**
40	B	2.16	30.56	**Tłuczewo,** szkoła powszechna, w ścianie od strony szosy.	**126.340**
41	NK	2.50	28.40	Kamień niwelacyjny.	**142.894**
42	B	0.49	26.39	**Strzepcz,** dom Bazylego Lewińskiego (zarząd gminy), w ścianie od strony szosy.	**160.861**
43	B	2.79	25.90	**Strzepcz,** szkoła powszechna, w ścianie od strony drogi do Miłoszewa.	**153.216**
44	T	—	25.90	**Strzepcz,** szkoła powszechna, w ścianie od strony drogi do Miłoszewa.	**154.497**
45	B		23.11	Pobłocie, przepust.	**136.625**

Fig. 1. Sample page from the 1929 catalogue

Thereafter the network was adjusted using conditional method. The so called Normal-Null (N.N.) datum was selected as the benchmark for the height of network points. The height of network benchmarks was referenced to the so called Normal-Null (N.N) datum, i.e. the Normal Amsterdam Level. For network adjustment, the height of an old first order German benchmark, located on a town hall wall in Torun (m) was selected.

The final results were collected in a catalogue of points in a first order levelling network (*Katalog* 1939). For each line the following were given: type and description of benchmarks' location, distances between them, and their height with an accuracy of 1 mm. The catalogue of the levelling campaign 1926-1937 has a traditional, printed form (*Katalog* 1939). The author obtained a copy (Fig. 1) of this catalogue from the Topography Board of the Polish Army (350 scanned images). 292 pages of the catalogue were converted, resulting in 121 spreadsheet pages (xls).

Levelling campaign of 1953–1955

The main factors considered in the design of this campaign's first order levelling network were good stabilization and the possibility of using the already present network elements. The geometric specifications of the network are shown in table 3. The first order levelling network was initially not referenced to Polish tide gauges on the Baltic coast. This was done several years later, by means of second order levelling lines (WYRZYKOWSKI 1993).

Table 3

Geometric specifications of the 1952–1955 network

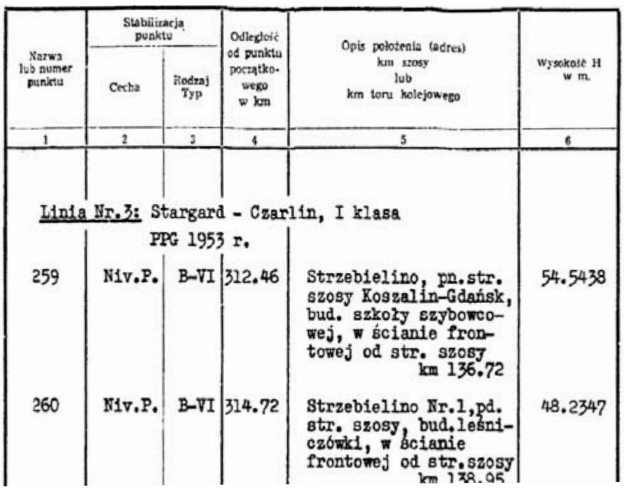
Line length [km]	Number			Mean length [km]		
	traverses n_F	lines n_L	sections n_R	Loop F	line L	sections R
5 778	12	60	about 4500	609	96	1.3

Measurements for this network were taken using precise levels such as Aerogeopribor NA – 1, with telescope 44×, reversible level 10''/2 mm, with optical flat and an elevation screw, or Wild N III with similar specifications, telescope 44×, reversible level 6''/2 mm. In both cases 3-metre wooden levelling rods were used, with an invar tape with 2 graduation lines displaced against each other. The measurements were carried out using "from the middle" method, with the maximum length of the horizontal aiming line 40 m. The measurement results were adjusted for levelling rods' systematic errors and, in the first stage (i.e. preparation for the independent adjustment), normal orthometric corrections. In the second stage, i.e. preparation of Polish data for the joint adjustment of the international network, normal corrections were introduced (WYRZYKOWSKI 1988). Mean error of the network before adjustment was also estimated using Lallemand's formulae and the results are shown in Table 4.

Table 4

Mean error (1953–1955 survey) [mm/km]

Mean probable error		Mean error after adjustment
random	systematic	
η	m_0	m
±0.37	±0.13	±0.78



Narwa lub numer punktu	Stabilizacja punktu: Cecha	Stabilizacja punktu: Rodzaj Typ	Odległość od punktu początkowego w km	Opis położenia (adres) km szosy lub km toru kolejowego	Wysokość H w m.
1	2	3	4	5	6
Linia Nr.3: Stargard - Czarlin, I klasa PPG 1953 r.					
259	Niv.P.	B-VI	312.46	Strzebielino, pn.str. szosy Koszalin-Gdańsk, bud. szkoły szybowcowej, w ścianie frontowej od str. szosy km 136.72	54.5438
260	Niv.P.	B-VI	314.72	Strzebielino Nr.1,pd. str. szosy, bud.leśniczówki, w ścianie frontowej od str.szosy km 138.05	48.2347

Fig. 2. Sample page fragment from the 1960 catalogue

The adjustment was calculated twice. The first adjustment was based on – as in the previous network – the height of Torun – Townhall benchmark, referenced to Normal Amsterdam Level. The second adjustment was based on the zero point of Kronstadt tide gauge (WYRZYKOWSKI 1988). Standard deviation value after adjustment is shown in Table 4.

The results after the second adjustment were accepted as final. The data was collected in a catalogue of levelling points (*Katalog* 1960). The author obtained a copy of this catalogue, about 500 scanned images (Fig. 2) from the Geological Exploration Company in Warsaw, as well as copies of calculation logs from the archives of the Centre for Geodesic and Cartographic Documentation (about 450 photographs). The data was then digitized into over 60 spreadsheet pages in .xls format, which contain the complete unadjusted levelling data.

Levelling campaign of 1974–1982

The levelling campaign of 1974–1982 was carried out in two stages. The first stage was a survey in 1974–1979, part of the network was then merged with the Unified Vertical Reference Network. The second, complementary survey, took place in 1980-1982. The geometric specifications of the network are shown in Table 5.

Table 5

Geometric specifications of the 1974–1979 network

Line length [km]	Number			Mean length [km]		
	traverses n_F	lines n_L	sections n_R	traverse perimeter F	line L	sections R
10 438	47	173	ok. 9700	354	64	1.1

For the first time the measurements were taken using self levelling levels. Initially, Opton levels type Ni 1, made in West Germany, were used, but in 1977 they were replaced with Zeiss levels type Ni 002, made in East Germany. In the case of Ni 1, 3-metre wooden levelling rods with an invar tape with 1 cm graduation were used, in the case of Ni 002 – similar levelling rods, with 2 graduation lines of 0.5 cm displaced against each other. The following adjustments were made: temperature adjustment and the adjustment for the levelling rods' systematic errors; for daily changes of the vertical caused by the Moon and the Sun; and normal adjustments (I and II). First order levelling network was directly referenced to seven Polish tide gauges: in Swinoujscie, Kolobrzeg, Ustka, Leba, Wladyslawowo, Hel and Gdansk – Nowy Port. Mean error before adjustment and mean error after adjustment are shown in Table 6.

Table 6

Mean error before adjustment, random and systematic mean errors and mean error after adjustment (1974–1979 survey) [mm/$\sqrt{\text{km}}$]

Mean error before adjustment			Mean errors		Mean error after adjustment
			random	systematic	
m_1	m_2	m_3	η	m_0	m
±0.29	±0.55	±0.94	±0.28	±0.09	±0.91

* before levelling correction

A supplemental survey was carried out in the years 1980–1982. The measurement method and the equipment remained the same. Also, the same adjustments were made as in 1974–1979. Specifications of the network are shown in Table 7.

Table 7

Geometric specifications of the 1980–1982 network

Line length [km]	Number			Mean length [km]		
	traverses n_F	lines n_L	sections n_R	traverse perimeter F	line L	sections R
17 015	135	371	15 827	221	46	1.1

Mean error before adjustment, mean probable error and mean error after adjustment are shown in Table 8.

Table 8

Mean error before adjustment, mean probable error, mean error after adjustment (1980–1982 survey) [mm/$\sqrt{\text{km}}$]

Mean error before adjustment			Mean errors		Mean error after adjustment
			random	systematic	
m_1	m_2	m_3	η	m_0	m
±0.29	±0.53	±0.92	±0.28	±0.08	±0.84

* before levelling correction

The data from 1974–1982 campaign are stored in a digital form (Fig. 3). They were obtained from the Centre for Geodesic and Cartographic Documentation in Warsaw andconverted into 376 spreadsheet pages (Fig. 4).

```
=========================================================================
|Lp | Nr punktu |   [R]  |Przew.popr.| PN I  | PN II | Wysokosc |Sr.bl.wys.|
|   |---------------------------------------------------------------------|
|   | Rodzaj    |  Typ   | Kod stab. |Glowica| Grupa |  Wsp. X  ,  Wsp. Y  |
|   |---------------------------------------------------------------------|
|Opis  polozenia  punktu                                                  |
=========================================================================
| 25|   30530022|  22.59|    1.50182|     -4|      1|  28.5995|      0.000|
|   |B          |VIA    |870        |AP 6105|A      | 6132550.0, 3591000.0|
|SWARZEWO,NR 185,BUD.MSZK.A.GAPPA,KM 21.05
|-------------------------------------------------------------------------|
| 26|   30530023|  23.39|   -5.37329|     -2|     -2|  23.2262|      0.000|
|   |BK         | IV    |713        |AB 2807|A      | 6133350.0, 3591050.0|
|WLADYSLAWOWO,KAM.NIW.PODZ.NA MIEDZY J.GALA I STRUGA,KM 21.801
|-------------------------------------------------------------------------|
| 27|   30530024|  24.39|   -7.71709|     -1|     -2|  15.5091|      0.000|
```

Fig. 3. Sample text file with the data from the 1974–1982 campaign

A	B	C	D	E	F	G	H	I	J	K
nr linni	lp	nr punktu	R w km	dh+popr N	popr N 1	popr N 2	dh	H wyrównane	średni błąd	rodzaj stabilizac
1	1	31340032	0	0	0	0	0	20.4037	8.4	F
1	2	31340077	0.62	-2.77415	-1	-5	-2.77409	17.6296	0	B
1	3	31340078	0.81	0.97048	0	2	0.97046	18.6	0	B
1	4	31340079	1.26	-0.203	0	0	-0.203	18.397	0	B
1	5	31340080	1.96	0.56443	0	1	0.56442	18.9615	0	B
1	6	31340081	2.82	-1.13962	-1	-2	-1.13959	17.8218	0	B
1	7	31340082	3.08	1.68817	0	3	1.68814	19.51	0	B
1	8	31320010	3.59	8.00282	-1	16	8.00267	27.5128	0	B
1	9	31320011	5.33	-5.57143	-2	-11	-5.5713	21.9414	0	B
1	10	31320012	5.51	4.21671	0	9	4.21662	26.1581	0	B
1	11	31320013	6.41	15.23723	-2	34	15.23691	41.3953	0	BK
1	12	31320014	6.7	-0.57919	-1	-1	-0.57917	40.8162	0	BK
1	13	31320015	7.5	-11.41717	-2	-27	-11.41688	29.399	0	BK
1	14	31320016	8.52	-3.53707	-2	-8	-3.53697	25.8619	0	BK
1	15	31320017	8.76	-0.28072	0	0	-0.28072	25.5812	0	BK
1	16	31320018	9.6	-6.12983	-1	-15	-6.12967	19.4514	0	B
1	17	31320019	11.63	-1.06308	-1	-3	-1.06304	18.3883	0	BK
1	18	31320020	12.13	4.38638	-1	12	4.38627	22.7747	0	BK
1	19	31320021	12.45	0.78761	-1	2	0.7876	23.5623	0	BK
1	20	31320022	12.49	-0.83638	0	-2	-0.83636	22.7259	0	BK
1	21	31320023	13.43	-6.55388	0	-19	-6.55369	16.172	0	B
1	22	31320024	14.77	-5.6105	-1	-17	-5.61032	10.5615	0	B
1	23	31320025	15.43	7.86364	0	25	7.86339	18.4252	0	BK
1	24	31320026	16.81	-2.67338	0	-8	-2.6733	15.7518	0	B
1	25	31320027	17.86	-9.53487	-1	-33	-9.53453	6.2169	0	B
1	26	31320028	19.33	-4.50539	0	-16	-4.50523	1.7115	0	BK
1	27	31320029	19.37	2.57364	0	9	2.57355	4.2852	0	B
1	28	31320030	20.01	-0.78918	0	-3	-0.78915	3.496	0	B
1	29	31320031	20.05	-0.30177	0	-1	-0.30176	3.1942	9.21	B

Fig. 4. Sample of converted data from the 1974–1982 campaign

Levelling campaign of 1997–2003

The measurements for the 1997–2003 were taken between April 1999 and June 2002. Incorporated into the network was also the line measured in May and June 1997 and October 2003. The measurements were mainly carried out along the same lines as in 1974–1982, with minor modifications. A number of reference benchmarks were stabilized in different places, most of them near Wroclaw, Lublin and Grudziadz. Polish levelling network was connected with the neighbouring countries' networks via 28 reference benchmarks. The network includes 8 Polish EUVN points (European Vertical Reference Network), as well as major tide gauges on the Polish coast: in Swinoujscie, Kolobrzeg, Ustka, Leba and Wladyslawowo. The first order precise levelling network was measured using self levelling Zeiss Ni002 levels (about 66% of the network), and digital self levelling Zeis DiNi11 levels (about 31%) and Topcon levels (about 3%) (ŁYSZKOWICZ, JACKIEWICZ 2005). Network specifications are shown in Table 9.

Table 9

Geometric specifications of the 1997–2003 network

Line length [km]	Number			Mean length [km]		
17 516	traverses n_F	lines n_L	sections n_R	traverse perimeter F	line L	sections R
	138	382	16 150	217	45.8	1.085

Parametric method was used for network adjustment (GAJDEROWICZ 2005). All measurements were carried out in two stages. In the first stage error equations were formed for each line's height differences, with the calculated parameters being heights of nodal points. In the second stage, adjustments were calculated for the heights of benchmarks in each line, separately for every line. The values of mean errors obtained in this way (ŁYSZKOWICZ, LEONCZYK 2005) are shown in Table 10.

Table 10

Mean error before adjustment, mean probable error, mean error after adjustment (survey 1997–2003) [mm/$\sqrt{\text{km}}$]

Mean error before adjustment			Mean probable error			Mean error after adjustment
			random	systematic		
				for lines	for traverses	
m_1	m_2	m_3	η	m_0	σ	m
±0.28	±0.52	±0.83	±0.26	±0.08	±0.10	±0.88

Data structure

In order to standardize the data from the levelling campaigns, the information has been compared with respect to whether it is present in the catalogues available to the author. Each catalogue contains slightly different data. Table 11 shows the structure of the available data from each levelling campaign.

The following measurement dates have been adopted:

– in campaign 4 the table information,
– in campaign 3 mean measurement date, converted to decimal,
– in campaign 2 year of measurement as given in the catalogue, plus half a year (which reduces measurement difference to a maximum of 5 months),
– in campaign 1 year of measurement as given in the catalogue, plus half a year (which reduces the measurement difference to a maximum of 5 months).

Accuracy of the measurement date in campaign 4 was 1 day; in campaign 3 (accuracy 1 month) in the date conversion to decimal the following convention was adopted:

– for even months – 15^{th} day of the month,
– for odd months – 30^{th} day of the month.

Example:

– measurement date between 11.1978 and 12.1978 – adopted date 30.11.1978 = 1978.92,

– measurement date between 10.1978 and 12.1978 – adopted date 15.11.1978 = 1978.88.

Table 11

Content of the catalogues and survey logs

Specification	Campaign 1 1926–1937	Campaign 2 1953–1955	Campaign 3 1974–1982	Campaign 4 1997–2003
Normal correction				
Line number				
Benchmark number				
Benchmark type				
Section length				
Mileage				
Head				
Benchmark height				
Description				
Coordinates		Sporadically		
Adjusted height difference				
Unadjusted height difference plus levelling rod adjustment				
Atrtribute				
Measurement date				
Benchmark ID				
Line ID				
Stabilization code				
Group				

Relational database concept for levelling campaigns

Analog data – converted to a digital form – together with the data from campaign 4 were used to create a standardized relational database. The database created in such a way integrates campaigns 2, 3 and 4. For each campaign the data collected is structured differently. The first version of the database was designed to make comparisons between campaigns possible without major modifications to the structure of the data. The design ensures scalability as well, so that the database can be expanded in the future with the data from the missing campaign 1, future campaigns or by adding attributes to objects such as points or lines. This gives a data set which makes a wide range of analyses possible and at the same time is easy to modify.

The analysis of the collected data, at the stage of designing entities and determining relationships for the subsequent database design, was based on characteristic properties of these data sets. Topological relationships between nodes and edges, as well as time of measurement, were considered most significant differentiating attributes. However, the way the data from survey logs is recorded directly into database tables makes the nodal points appear in the database several times – depending on how many lines starts and ends at a given nodal point. Moreover, most benchmarks are the shared by different campaigns. A simple arrangement of this data in a common set causes redundancy. So, first of all, some data is redundant – the information related to reference points is unnecessarily repeated. Secondly, this may cause anomalies during modification – a change or an update will necessitate changes in all records related to a given point. On one hand it overworks the system, on the other it may cause loss of data integrity. It may also cause deletion anomalies – the deletion of the line containing a given point will also delete the information about the point.

Based on the above reasoning, the following tables have been designed: points, lines, sections and benchmarks. Table *punkty* (points) contains the data on all the levelled points. Table *linie* (lines) contains the data on the levelling lines. Table *repery* (benchmarks) contains the data on the adjusted heights. Each line consists of a starting point and the end point. Table *odcinki* (sections) contains the data on sections within the lines. Each section has a starting point and the end point, and is assigned to a levelling line. Measurement time is divided between levelling campaigns. Each campaign took place in a certain time span; in the first version of the database this gave rise to three separate tables for lines, sections and heights adjusted in each campaign. Table names include the appropriate campaign number (e.g. *linie2* – lines from campaign no. 2, *sections3* – sections from campaign no. 3, *repery4* – adjusted heights from campaign no. 4). There is one table *points*, common for all the campaigns. This is the first version of the database. By analogy to the object-oriented approach, one can treat *punkty*, *linie* and *odcinki* tables as containing objects. Class names of these objects are identical with the table names. The objects have descriptive attributes, graphic attributes and topology. Descriptive attributes are recorded in the columns, graphic attributes are the points' coordinates and the topology is the aforementioned relationships between lines, sections and points. These relationships have been physically created by assigning each point's identifier to the lines and sections which contain the point. In the relational model adopted here, these are equivalent to relationships between tables.

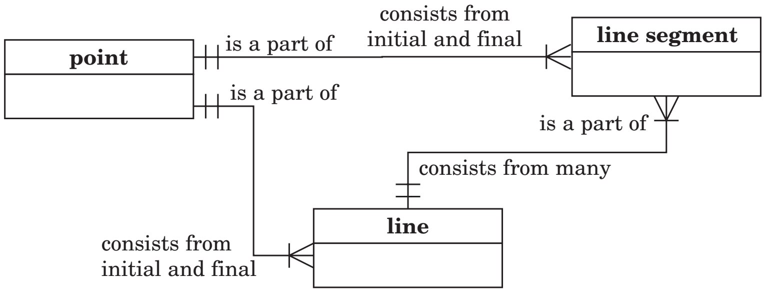


Fig. 5. Relationships between entities

The separation of the data into campaigns, as described above, makes it easier to remove information from data sets without the necessity to modify the original structure, based on the source catalogues. It is a good solution, especially for demonstration purposes – for viewing and analysing the data from each campaign separately. For analyses comprising all the campaigns simultaneously, joining the tables containing objects of the same class may be more practical. This will produce e.g. one table *linie*, by joining three tables for separate campaigns: *linie2*, *linie3*, *linie4*. Tables containing sections should be treated similarly. In order to be able to differentiate the objects from different campaigns, they should be assigned an additional attribute: campaign number. For example, each line, apart from the attributes such as line number, starting point and end point, should also be assigned the number of the campaign during which it was measured. This method has been used to produce the second version of the database.

Table joining gives access to all the campaigns simultaneously with one simple query. In the first version, obtaining information from all three campaigns required at least three queries – for each table, or, in some cases, using a join. It is easier in the first version to add or remove a whole campaign, irrespectively of the data set structure. Only minimal requirements on the data integrity must be met – the proper assignment of point and line identifiers. There are no constraints on other attributes. In the second version, the addition of a new campaign necessitates adding new columns, which contain attributes specific only for a given campaign. In this situation, records from these columns in other campaigns will remain empty. The only solution is to select a set of attributes common to all campaigns. This however entails a loss of some data, which is undesirable.

Generally, the first version is better optimized for performance – the data is divided into smaller parts, which often speeds up searching. There are no

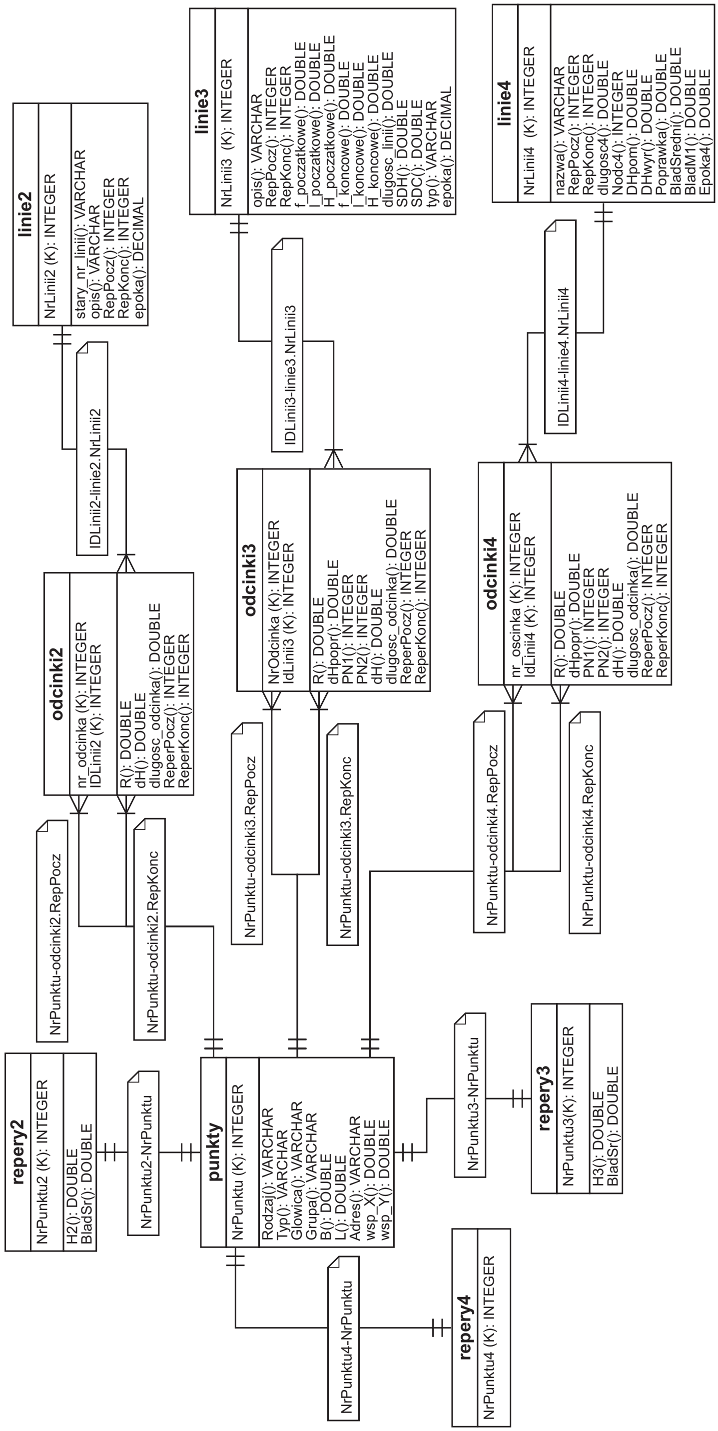


Fig. 6. First version of the database schema

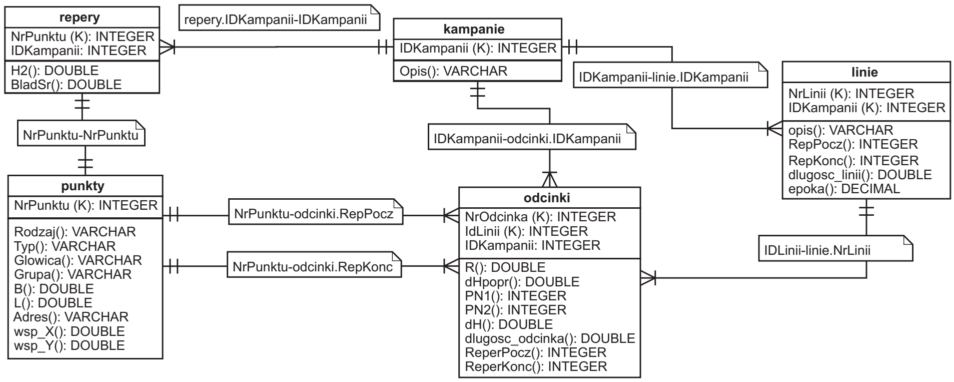


Fig. 7. Second version of the database schema

redundant records and the campaign information can be easily placed in a structure similar to the original. SQL queries for this structure are usually fairly complex, but in some cases (example 2 and 2a in the chapter *Using the database*) they can be simpler than in the second version. The second version of the database is better optimized for functionality. First of all, joining the data in a large set makes it possible to build simpler and more intuitive queries, although examples 2 and 2a below show that it is not always the case. On the other hand, joining the data and the creation of redundant records associated with this procedure (a result of joining sets of different structures), slows down searching, which is also evident in the discussed examples. Both database structures – first and second – have their advantages and drawbacks, which result from technological possibilities and limitations, as well as the limitations of relational databases.

Currently there are two versions of the database schema. The logical division of the data set into entities is identical for both versions. The basic difference in the physical build of the databases is – as described above – joining of benchmark, section and line tables respectively, as well as the introduction of an additional table *kampanie* for campaigns in the second version. Which version is optimal for future vertical movements research is yet to be determined.

Data transfer

The next step after the database design is creating a physical database. The procedure described in this chapter has been applied to the first version of the database schema. The second version was created by conversion of the first version (imported and controlled).

The database schema can be implemented in any relational database management system. At this stage, the most important task was to transform the source data sets to a form which could be used in the schema. the original data was initially digitized and saved as MSExcel files. This involved only campaigns 2 and 3 – campaign 4 had already been saved as MSAccess database file. Due to the formatting of the source data, the conversion was carried out in MSAccess system, using MSOffice programming tools, with MS Visual Basic for Applications as the programming language. All the procedures performed on the database during conversion were automated, which means that the import of data for the schema is a repeatable process.

The first step was the import of data to MSAccess system, for each campaign in the form of two tables: *Kampania* and *linie*. The former contains the information about all the reference points measured during the campaign, placed in lines, according to the mileage – i.e. in the same way as in the survey log or the catalogue. The latter contains the information about the lines themselves, numbered. In the case of campaign 4 the data was practically ready to import. Campaigns 2 and 3 were formatted in such a way, that each line was in a separate MSExcel spreadsheet page. Therefore, it was necessary to unify the data sets with respect to the type of data and to merge the spreadsheets into one table. Own program was used for this purpose, written in MSVBA for Applications.

The second step was to create appropriate tables in the system – SQL queries were used to do that. The next step was to transfer the data from *kampania* table to the structure created. The information on the reference points and sections was transferred to the appropriate tables by means of queries. Table *odcinki* contains additionally section lengths, starting point identifiers, end point identifiers and section numbers within lines. This data was created using a designated program written in MSVBA for Applications.

This stage's work resulted in the database structure described above, filled with the data from each campaign and linked with relationships.

Using the database

The functionality of the database is determined by the possibility to retrieve different information by means of SQL queries. A few examples of such queries are given below. More complex analyses would require dedicated applications utilizing the data from the database.

Example 1. Asking in which lines, of which campaign and in which epochs, point no. 10230015 is a starting point (query for the first version of the database):

```
SELECT nr_punktu, linie2_epoka, linie3_epoka, linie4_epoka,
NrLinii2, NrLinii3, NrLinii4
FROM p_pocz_linii_wszystkie1kampanie
WHERE NrPunktu=10230015;
```

Result:

nr_punktu	linie2.epoka	linie3.epoka	linie4_epoka	NrLinii2	NrLinii3	NrLinii4
10230015		1976,33	2001,55		42	249
10230015		1978	2001,55		180	249
10230015		1976,33	2001,62		42	248
10230015		1978	2001,62		180	248

Fig. 8. Result of SQL query for the first version of the database – example 1

The query is based on the query: *p_pocz_linii_wszystkie_kampanie*, which retrieves the starting points for the lines in all the campaigns. It is a multiple join of table *points* with tables *linie2*, *linie3* and *linie4*:

```
SELECT DISTINCT punkty.*, linie4.epoka, linie2.epoka, linie3.epoka,
linie4.NrLinii4, linie3.NrLinii3, linie2.NrLinii2
FROM ((punkty LEFT JOIN linie4 ON punkty.NrPunktu = linie4.RepPocz)
LEFT JOIN linie2 ON punkty.NrPunktu = linie2.RepPocz)
LEFT JOIN linie3 ON punkty.NrPunktu = linie3.RepPocz
WHERE
(((linie4.epoka) Is Not Null)) OR (((linie2.epoka) Is Not Null))
OR (((linie3.epoka) Is Not Null));
```

Result:

NrPunktu	Rodzaj	Typ	KodStab	Głowica	Grupa	B	L	Adres	wsp_X	wsp_Y	linie2.epoka	linie3.epoka	linie4_epoka
10230015	F	III	700	AA 8920	D	52,25609	19,17286	KROŚNIEWICE	5650150	4506550		1978,13	2001,53
10230015	F	III	700	AA 8920	D	52,25609	19,17286	KROŚNIEWICE	5650150	4506550		1976,92	2001,53
10230015	F	III	700	AA 8920	D	52,25609	19,17286	KROŚNIEWICE	5650150	4506550		1978,13	2001,47
10230015	F	III	700	AA 8920	D	52,25609	19,17286	KROŚNIEWICE	5650150	4506550		1976,92	2001,47
11240014	B	VI	860	AA 8270	D	51,95966	19,3025	OZORKÓW,UL	5616950	4514600		1980,92	2001,55
11240014	B	VI	860	AA 8270	D	51,95966	19,3025	OZORKÓW,UL	5616950	4514600		1978	2001,55
11240014	B	VI	860	AA 8270	D	51,95966	19,3025	OZORKÓW,UL	5616950	4514600		1980,92	2001,55
11240014	B	VI	860	AA 8270	D	51,95966	19,3025	OZORKÓW,UL	5616950	4514600		1978	2001,55
11310027	B	VI	860	AA 7104	D	52,11951	19,95109	ŁOWICZ,UL.AR	5633850	4559450		1976,92	2001,42
11610016	F	II	700	AA 7373	D	52,00105	22,76894	MIĘDZYRZEC I	5621400	4752750	1954,5	1977,33	2001,52
11610016	F	II	700	AA 7373	D	52,00105	22,76894	MIĘDZYRZEC I	5621400	4752750	1954,5	1975,29	2001,52
11610016	F	II	700	AA 7373	D	52,00105	22,76894	MIĘDZYRZEC I	5621400	4752750	1954,5	1977,33	2001,43
11610016	F	II	700	AA 7373	D	52,00105	22,76894	MIĘDZYRZEC I	5621400	4752750	1954,5	1975,29	2001,43
11610016	F	II	700	AA 7373	D	52,00105	22,76894	MIĘDZYRZEC I	5621400	4752750	1954,5	1977,33	2001,52
11610016	F	II	700	AA 7373	D	52,00105	22,76894	MIĘDZYRZEC I	5621400	4752750	1954,5	1975,29	2001,52
11610016	F	II	700	AA 7373	D	52,00105	22,76894	MIĘDZYRZEC I	5621400	4752750	1954,5	1977,33	2001,43
11610016	F	II	700	AA 7373	D	52,00105	22,76894	MIĘDZYRZEC I	5621400	4752750	1954,5	1975,29	2001,43
11620017	F	III	700	AB 1451	D	52,036	23,36788	ZALESIE,PN.S	5626400	4793750		1975,33	2001,55
11710010	F	II	700	AA 7324	D	52,08273	23,61322	TERESPOL,ZA	5632150	4810400	1954,5		
12140013	F	III	700	AA 8158	A			Sieradzul.Sienk	5577600	4474200		1977,33	
12140034	B	VI	860	AJ 4030	D	51,59595	18,73341	SIERADZ,UL.S	5577600	4474200			2001,82
12220037	F	III	700	AA 8449	D	51,73812	19,46392	ŁÓDŹ,PD-WSC	5592050	4525150		1978,04	2001,58
12220037	F	III	700	AA 8449	D	51,73812	19,46392	ŁÓDŹ,PD-WSC	5592050	4525150		1978,62	2001,58

Fig. 9. Result of SQL query *p_pocz_linii_wszystkie_kampanie* – multiple join

Example 1a. This is an example of a query for the second version of the database, which retrieves the same data as in example 1. The query in the second version is much simpler and does not require an additional query joining the data from several tables:

```
SELECT punkty.nr_punktu, linie.IDkampanii, linie.NrLinii, linie.epoka
FROM punkty INNER JOIN linie ON punkty.NrPunktu4 = linie.reppocz
WHERE (((punkty.NrPunktu4)=10230015));
```

Result:

nr_punktu	IDkampanii	NrLinii	epoka
10230015	3	180	1978
10230015	4	249	2001,55
10230015	4	248	2001,62
10230015	3	42	1976,33

Fig. 10. Result of SQL query for the second version of the database – example 1a

Example 2. Retrieval of the points which are present in all the campaigns simultaneously (set intersection) as starting points for lines – query for the first version of the database:

```
SELECT DISTINCT punkty.*
FROM
((punkty INNER JOIN linie2 ON punkty.NrPunktu = linie2.RepPocz)
INNER JOIN linie3 ON punkty.NrPunktu = linie3.RepPocz)
INNER JOIN linie4 ON punkty.NrPunktu = linie4.RepPocz;
```

Result:

NrPunktu	Rodzaj	Typ	KodStab	Glowica	Grupa	B	L	Adres	wsp_X	wsp_Y
11610016	F	II	700	AA 7373	D	52,00105	22,76894	MIĘDZYRZEC PODL.,F.P.W.PRZED WARSZT.SAM.,I	5621400	4752750
13430030	F	II	700	AA 7581	D	51,10306	20,8413	SKARŻYSKO-KAMIENNA,BZIN,UL.KRAKOWSKA,F.F	5520200	4620050
16330035	F	II	700	AA 6826	D	50,03232	19,9519	KRAKÓW,UL.H.KAMIEŃSKIEGO,F.P.W.PO PN.STR.	5401700	4555950
18310020	F	III	700	AA 9076	D	49,62188	19,95981	RABKA,UL.KRAKOWSKA,F.P.W.OBOK KAPLICZKI,I	5356050	4555829
18310053	F	II	700	AA 6870	D	49,48237	20,03274	NOWY TARG,RYNEK,F.P.W.NA SKWERZE PRZED I	5340459	4560879
18330027	F	II	700	AA 7147	D	49,36551	19,80676	CHOCHOŁÓW,F.P.W.96.3M OD GRANICY PAŃSTW/	5327720	4544285
18410028	F	II	700	AA 7919	D	49,6254	20,94707	GRYBÓW,RYNEK,F.P.W.NA TERENIE ZAKŁADU OF	5355839	4627156
18510012	F	II	700	AA 8286	D	49,6337	21,78654	MIEJSCE PIASTOWE,UL.DUKIELSKA,F.P.W.ZNAK (	5356993	4687793
20230018	F	II	700	AA 7494	D	54,38553	19,83025	BRANIEWO,UL.KRÓLEWIECKA,F.P.W.,NA PLACU F	5961250	4494350
22240019	F	II	700	AA 8096	D	53,77861	20,48704	OLSZTYN,F.P.W.,UL.DĄBROWSZCZAKÓW,NA PLA(	5892900	4536050
26330081	F	I	690	5	D	52,23038	20,95019	W-WA WOLA,UL.WOLSKA,F.P.W.W PARKU IM.SO\	5720300	4565250
32530036	F	II	700	AA 8162	D	54,04825	18,75838	CZARLIN,F.P.W.,PD.STR.SZOSY STAROGARD GDA	6052150	3615600
34140026	B	VI	880	NIV.P.	D	53,33714	15,04798	STARGARD SZCZECIŃSKI,UL.MARIACKA,KATEDRA	5973400	3370450
41140018	B	VI	880	NIV.P.	D	52,59991	15,50315	SKWIERZYNA,RYNEK,BUD.URZĘDU MIASTA I GMIN	5731000	3623800
42440019	F	II	700	AA 7912	D	52,23003	18,23127	KONIN,UL.POZNAŃSKA,F.P.W.,PN.STR.ULICY,PRZ	5690350	3809500
42440034	F	II	703	AA 8089	D	52,20902	18,25615	KONIN,UL.3-GO MAJA,F.P.W.,NA PLACU KOŚCIOŁA	5688050	3811250
43140020	F	II	700	AA 8852	D	51,93925	15,50652	ZIELONA GÓRA,UL.KOSCIELNA,F.P.W.PRZY KOŚC	5657500	3622850
46210014	F	II	700	AA 8086	D	51,05223	16,19153	JAWOR,PLAC WOLNOŚCI,F.P.W.,NA SKWERKU,ZN	5558300	3669300
47240024	B	VI	880	HM	D	50,43919	16,65744	KŁODZKO,PL.B.CHROBREGO,RATUSZ,ŚCIANA WS	5490000	3701950
47330030	B	VI	880	HM	D	50,46342	17,00814	PACZKÓW,UL.KOŚCIELNA,KOŚC.KAT.P.W.ŚW.JAN	5492750	3726850
47330067	B	VI	860	AA 0094	D	50,44662	16,89046	BŁOTNICA NR 52,BUD.LEŚNICZÓWKI NADL.BARDO	5490850	3718500
48410056	F	III	700	AA 8775	D	50,19596	17,83538	GŁUBCZYCE,UL.RACIBORSKA,F.P.W. PRZED BUD.	5463600	3786050
54130024	F	III	700	AA 9145	D	49,75051	18,63571	CIESZYN,PL.LONDZINA,F.P.W.OBOK KOŚCIOŁA	813150	213750
54140041	F	III	700	AA 8682	D	49,6869	19,1863	ŻYWIEC,UL.WESOŁA,F.P.W.OBOK KAPLICZKI	806050	253450

Fig. 11. Result of SQL query for the first version of the database – example 2

Example 2a. Retrieval of the same information as in example 2, but from the second version of the database.

```
SELECT DISTINCT punkty.NrPunktu, punkty.Rodzaj, punkty.Typ,
punkty.KodStab, punkty.Glowica, punkty.Adres
FROM punkty INNER JOIN linie ON punkty.NrPunktu = linie.reppocz
WHERE
punkty.nrpunktu IN (SELECT punkty.NrPunktu
FROM punkty INNER JOIN linie ON punkty.NrPunktu = linie.reppocz
WHERE linie.idkampanii=2)
AND
punkty.nrpunktu IN (SELECT punkty.NrPunktu
FROM punkty INNER JOIN linie ON punkty.NrPunktu = linie.reppocz
WHERE linie.idkampanii=3)
AND
punkty.nrpunktu IN (SELECT punkty.NrPunktu
FROM punkty INNER JOIN linie ON punkty.NrPunktu = linie.reppocz
WHERE linie.idkampanii=4);
```

It is evident that this query is more complex. A set intersection requires calling three sub-queries for the same table. The resulting set is exactly the same as in example 2, but the execution of the query takes considerably longer (a few dozen seconds).

In the nearest future the database will be improved and augmented with more data. One of the first improvements will be to add more data on the localization of reference points. At present, points from campaign 4 have geodesic coordinates (system 42), points from campaign 3 have coordinates in system 65, while only few points from campaign 2 do have coordinates. The addition and standardization of the coordinates will make it possible to create a graphical representation of the data from all the campaigns as well as facilitate spatial analysis and import to other formats.

Summary

The integration of the data from levelling campaigns permits the analysis of the information from several campaigns simultaneously. This has been demonstrated above in the discussion of SQL queries. Additional solutions, such as dedicated computer programs, may further increase the usefulness of the database. Computer technology gives practically unlimited opportunities, from adding new information to the database and recalculating (adjusting) the coordinates, to structure modification depending on the needs. Thus it is possible to tackle diverse analytical problems by easily selecting relevant data

sets. Moreover, the data existing in a relational database can be transferred to any other relational database management system, which makes it independent of the physical storage format. Additionally, the data can be converted to any other format, for example any GIS system format, like the popular ESRI shapefile, or an object or object-relational database.

Undertaking the work of digitizing this data has undoubtedly been well-justified and will help make a better use of the precise levelling data in Poland.

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