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DIKE BREACHES IN THE CARPATHIAN BASIN

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Abstract

Hungary is situated in the part of Europe drained by the Danube, in the deepest part of the hydrographic unit called the Carpathian Basin. Her territory covers 93000 km^2 and represents 11.4% of the 817 000 km^2 large Danube catchment. The Carpathian Basin is bounded to the west by the 2000–3000 high ranges of the Alps, to the north and east by the Carpathian Range the peaks of which rise to over 1000–2000 m above sea level. In contrast thereto, 70% of the territories are plains below 200 m, while hardly 1% consists of hills higher than 500 m AMSL. The eastern parts of the country are the deepest, the lowlands here being between 80–100 m AMSL only. Owing to this topography, an area of round 21 200 km^2, that is 23% of the territory of Hungary is below the flood level of the rivers. This fact alone presents flood defence problems which are unique in Europe and comparable in order of magnitude perhaps to those in the Netherlands alone [9].

Keywords: dike breach, historical data, failure mechanism, flood origin, risk assessment, failure probability.

1. Introduction

The first evidences of local flood embankment construction date back to medieval times. Construction work on local flood embankments was started again along the Danube, the River Tisza and their tributaries towards the end of the 18th and early in the 19th centuries. In 1840 the total length of flood embankments in Hungary was 792 km, of which 464 km were in the Danube valley and 328 in the Tisza valley. This initial period of flood defence development lasted until 1846.

The growing market for cereals in Western Europe, the recurring inundations and especially the 1845 flood on the River Tisza prompted the landowners to join their forces in flood defence associations. Large-scale river regulation and parallel thereto the flood embankment projects extending to entire flood plain sections were thus launched in 1846. The first 11 km long embankment section was built on the initiative of Count István Széchenyi according to the designs of the engineer Pál Vásárhelyi along the cut through the meander at Tiszadob.

Fig. 1. Surány in 09. August 1991. (Hungary)

2. Failure Probability of Dikes

There are several approaches conceivable to estimating the failure probability of flood levees [7]. The results differ in their accuracy and the methods can be classified according to reliability into the following groups:

1. Rough estimation must be resorted to if no basic data are, or can be made available. A certain level of quantification can nevertheless be achieved by reviewing systematically the information available. In doing so, the magnitude of exposure, the mechanism of failure and the consequences thereof must be considered. The critical mechanism of failure is identified by the following procedure:
   - Review of the potential failure mechanism.
   - Estimation from the failure data of the probability of each mechanism.
   - Identification of the critical failure mechanism.
   - Estimation from the critical mechanism of the most probable one.
   - Starting there from the most probable failure value is determined, whence
   - The failure probability is estimated.

   The failure mechanisms may be sequences of events on the basis of which the abnormal circumstances leading to failure can be traced.

2. Identification by processing historical data. The causes, location, size, etc. of earlier failures must be examined. This approach will be dealt with more in detail later.
3. Using an event tree, starting from the potential failure mechanisms. In the wake of the Teton Dam disaster and some minor dam failures, experts in the U.S. proposed inclusion of the failure probability in the risk analysis of new projects. Also, they proposed using a designated annual failure probability of 10^{-4} in the absence of other information concerning the safety of the project [1].

For performing the calculations, the experts proposed in the early 80s, two mutually supplementary methods for approximating the probability of failure [10]:

- use of a decision-making tree, which presents a pattern and framework of the classification process,
- a set of criteria, which offers guidance at each bifurcation of the decision tree for assessing the potential alternative choices,

The statistics of earlier dam failures can also used to advantage in the application of the decision tree.

4. Detailed investigations, involving observations, measurements, calculations and the evaluation thereof. Methods of analysis are available in civil engineering practice by which the stability of a dam and the probability of failure thereof can be estimated. These quantifiable methods rely on rapid, non-destructive geophysical tests, soil mechanical explorations, geotechnical and hydraulic analyses. Methods are available for determining [5, 6]
   - slope stability,
   - hydraulic subsoil failure, and
   - seepage pressure.

The failure probability of flood levees can be calculated in cases, where basic data of the quality and quantity necessary for estimating resistance are available. The calculations rely for their soundness on the reliability of the basic data. No trustworthy results can be expected from false, or inaccurate data.

The probability of failure can be determined by the combined application of the foregoing methods. In any method the result of another one can be used, or the methods can supplement each other. Thus e.g.

- The failure probability of structures can be estimated on the basis of paragraphs 1, 2 or 3;
- The analysis of hydraulic subsoil failure is possible on the basis of paragraphs 1, 2, or 4;
- There are scarce data available on the failure of levees, so that the probability of their failure can be estimated using for instance the event tree.

Care should be taken to ensure that the investigations form a system and that the results should be compatible. In analysing failures (or levee breaches), the compatibility of the failure categories is extremely important. The results should be examined for any trends, or regularities [7].

In classifying failures the following groups are distinguished:

- Grouping according to the hydrological, meteorological causes triggering the flood: ice-jam flood, snowmelt and/or storm flood.
- Grouping according to a mistake causing failure: poor design, neglect of construction specifications, poor owner's attitude, unskilled emergency measure, etc.
- Grouping according to specific failure cause: a structure crossing the embankment, the levee body, or the subsoil

The latter item can be subdivided further according to the failure mechanisms, as e.g. subsoil failure may be caused by hydraulic soil failure, erosion by a boil, etc.

3. Estimation of the Dikes Failure Probability from the Statistics of Past Failures

The use of failure statistics to estimate the probability of levee failures presumes that

- the circumstances underwent no changes during the decades, centuries elapsed, and
- true data are available on the past events.

Data collection is a laborious, slow process. Even the data of events later than 1945 are difficult to trace and identify. According to a survey report of 1993, the floods between 1945 and 1993 have caused 84 failures [2]. The causes thereof were grouped as follows:

- Overtopping: 59 (52 during the 1956 ice-jam flood on the Danube),
- Hydraulic soil failure: 13,
- Embankment saturation, loss of stability: 10,
- Leakage along structures: 2
- Unidentified positively: 8.

The statement that information could be collected on 84 failures would have been more appropriate. Research on historical sources of information always involves the possibility of discovering new data not included in previous reviews. In the present case the data of some levee failures on minor Hungarian rivers had emerged after the previous report was published [3]. The floods during the past 55 years have thus caused 140 levee failures, grouped as:

- Overtopping: 83 (52 of which during the 1956 ice-jam flood on the Danube),

- Hydraulic soil failure: 23,
- Embankment saturation, loss of stability: 10
- Leakage along structures: 2
- Other identified: 11
- Unidentified positively: 14.

The total obtained is 143 instead of 140, what is explained by the fact that in three cases different mechanisms of failure were named, which could not be judged as to their correctness. Evidently, the completeness of the list cannot be guaranteed.

Owing to the often-conflicting records, the collection of historical data on levee failures is a time-consuming task requiring close attention. During the past 200 years over 2200 embankment failures have been reported in the Carpathian Basin. The data on most of these are incomplete in the source documents.

4. The Philosophy of Data Collection

The sources were reviewed with the aim of finding the following data on levee failures [8]:

1. Year
2. River of failure
3. Failure mechanism
4. Location (river, bank, stationing)
5. Origin of the flood causing failure
6. Length of breech
7. Overtopping without failure
8. Size of area inundated
9. Losses according to contemporary assessment
10. Number of casualties
11. Exact time of failure
12. Existence of a scour pit
13. The floodplain section affected
14. Other circumstances, notes.

The data collected were processed taking the following considerations into account [8]:

- The data were tabulated in the sequence: Year, River, Flood plain section
- In the table the Carpathian Basin comprises the Dévény-Iron Gates Danube section and her tributaries
- Relatively little information is available on the flood on the River Maros in the 20^{th} century, on the Dráva and Száva rivers, further on the floods after 1920 beyond the present boundaries. For more information on these co-operation with the neighbouring countries is necessary.

- The expression "through-flow" mentioned in the earlier failure records was interpreted as overtopping.
- The time of failure had to be estimated often from the shape of the flood level hydrograph
- The failure mechanism was classified into the following eight groups:

overtopping,	hydraulic soil failure,	deliberate cutting,
wave scour,	crossing structure,	loss of stability,
other known,	unidentified.	

- The deliberate cuts do not include officially approved diversions to emergency reservoirs to lower peak stages. Evidently, neither the cuts to drain these after the flood belong to this group.
- The group of 'crossing structure' contains the failures related to deteriorated culverts, etc. and leakage in their surroundings.

5. Discussion

The list compiled is probably an incomplete one. Nevertheless, some conclusions of potential interest not only for professionals can already be achived:

- A unique attempt has been launched at reviewing the history of flood levee failures in a hydrographic unit shared by several countries.
- The number of failures surpasses all former expectations.
- The collection of this type of historical data is a time-consuming and laborious task.
- Considerable difficulties have been encountered in identifying ancient, no more used names of communities, sections, etc. mentioned by two authors under different names. This problem may have resulted in some overlaps in the table.
- The data tend to become more ambiguous with time, though, unfortunately, the records on failures during the last three dates are also far from perfect.
- At the time of closure (end of the year 2000) the review contains information on more than 2200 failures in the Carpathian Basin. The number for the present territory of Hungary is 1174. The number of failures per five-year periods demonstrates clearly that the large-scale flood control project launched in 1845 was not fully successful up to the turn of the century (*Fig. 2*).
- Early in the 19th century isolated areas were protected by levees of 340 km total length, which increased to 720 km by 1850. The low number of failures before 1850 is attributable to the shortness of the levees.
- Over 100 failures occurred annually during a few disastrous years in the second half of the 19th century. The majority of these were caused by the large floods on the River Tisza in 1876, 1881 and 1888 [8].
- In the second half of the 19th century only three years were found thus far in which no levee failure was registered (1852, 1863, 1898).

- The largest number of failures, over 200, was recorded in 1888.
- Most of the failures (375) occurred in the Körös Valley, where a total of 82 were recorded in 1879.

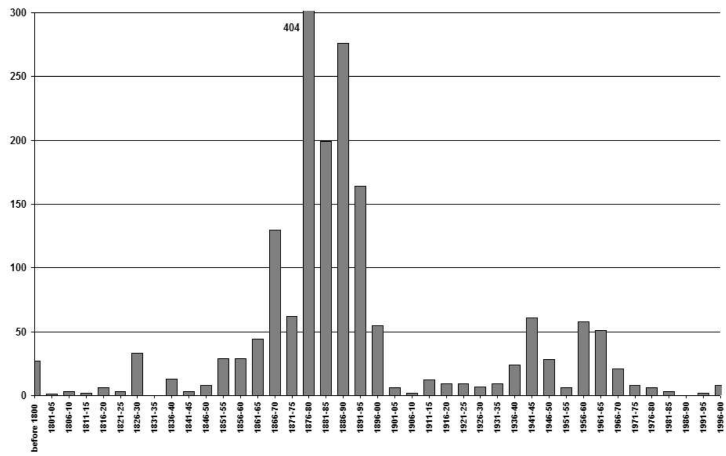

Fig. 2. Five years distribution of dike failures

Failures were especially numerous along the Tisza tributaries at their emergence from the mountain reaches onto the plains.

- Along the Fekete Körös 132 failures occurred between 1868 and 1887, 36 in 1869, 35 in 1879, 11 in 1881 and 11 in 1887,
- The right-hand levee along the River Szamos failed on 205 occasions during the 32 years between 1864 and 1896, e.g. at 49 points in 1881 and at 31 in 1888.
- The left-hand levee along the River Szamos failed on 75 occasions between 1864 and 1896, e.g. at 18 points in 1881 and at 9 in 1888.
- In the Tisza Valley 74 failures were registered up to 1850. From 1851 to 1900 The Tisza levees failed on 150 occasions. High banks (considered safe) were overtopped 35 times.
- Of the 16 failures along the Tisza between 1901 and 1950, only 10 were on the present territory of Hungary.
- Along the Körös and Berettyó rivers 85 failures occurred in 1879.

In the Carpathian Basin high level water is caused by three things: ice jam on the plain section of river Danube, heavy rainfall on the smaller rivers and on the upper sections of larger rivers, and snowmelt in spring. The largest floods become when the snowmelt appears with a heavy rainfall. The distribution of the flood origin can be seen in *Fig. 3* [8]:

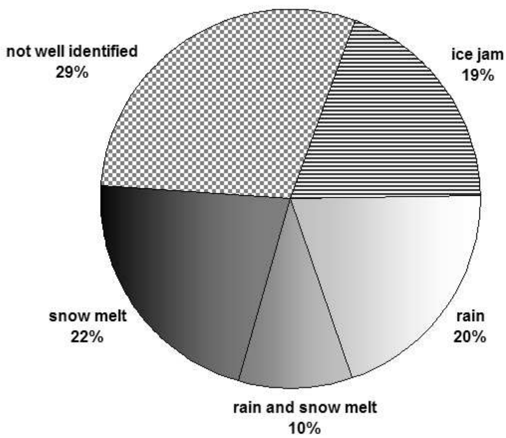

Fig. 3. Distribution of flood origin

The failure mechanism is known in 525 cases, that is 29% of the total [8]. The distribution of those known is illustrated in *Fig. 4*.

The term subsoil or hydraulic soil failure was coined in the 20^{th} century in connection with flood levees, so that its application to earlier incidents is a retrospective interpretation.

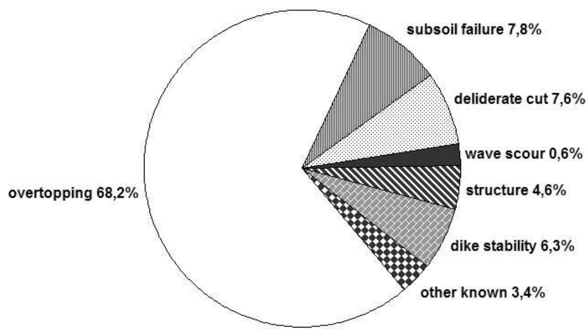

Fig. 4. Distribution of failure mechanism

The figures on deliberate (illegal) cuts, wave scouring and culvert failures are probably correct, as special cases, these were mentioned repeatedly in the contemporary and more recent press and in the professional literature.

The calm period following the turn of the century was interrupted by the failures in 1942, 1945, 1954 and finally by the 58 ones during the Ice-jam flood on the Danube in 1956.

The stock of emergency materials and tools kept around the middle of the 19th century was inadequate to build a sub-levee basin around a medium-sized boil, or a crest dike along one-tenth of a levee range.

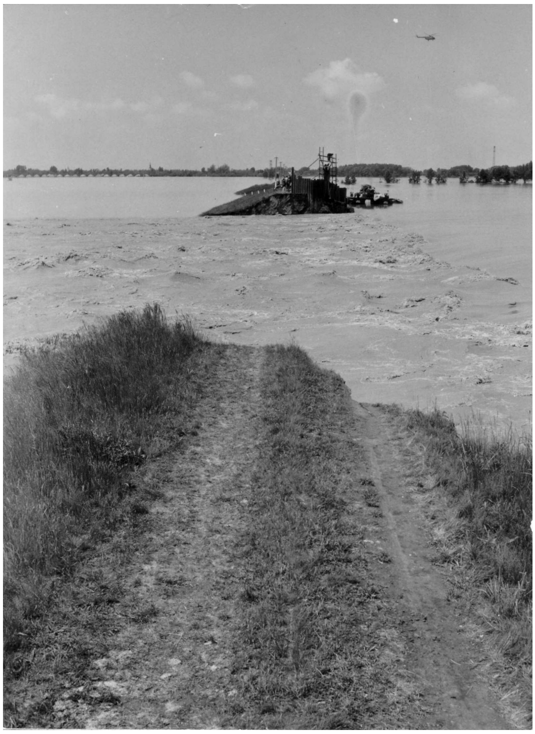

Fig. 5. 1970 Szamos left bank at Tunyogmatolcs (Hungary)

6. Conclusion

Owing to the continuous efforts at raising and strengthening the flood levees in Hungary, the failure thereof has become rare in recent times. A review of the historical records may offer welcome help in the analysis of such rare events. The data thereon must be examined critically in the light of the contemporary conditions. It should be noted that the historical data are often inaccurate, but the role of such inaccuracies is likely to diminish, as the database becomes wider.

The data available for estimating the probability of failure are often scarce and in such cases rough estimation must be resorted to. Historical data on levee failures may offer valuable help in this respect.

Of the over 2200 levee failures registered during the past 200 years in the Carpathian Basin, close to 1200 have occurred on the present territory of Hungary.

Collection of the data on past levee failures have been started several years ago and will be continued as long as a reasonably complete database can be composed.

The main conclusions achieved from the statistics of past levee failures [3] are summarized as follows:

- As the result of methodical improvements on the flood defences, the number of levee failures has dropped drastically in the 20th century;
- The diminishing number of failures implies that flood control in Hungary has attained a fairly high level, though not all hazards have been eliminated yet;
- The proportion of failures caused by overtopping has decreased and reveals a diminishing trend;
- The likelihood of failures caused by overtopping, however small, is confined presently to streams carrying a small flow (the probability thereof being practically nil along the Danube and Tisza rivers);
- The probability of failures associated with the subsoil (boils and hydraulic soil failure) is liable to grow;
- Owing to the growing number of structures (e.g. gated culverts) and the poor maintenance thereof, the failures of the structures and in the vicinity thereof are also liable to increase in number.

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