

PHILIPPINE NATIONAL STANDARD

PNS/BAFS/PAES 227:2017
ICS 65.060.35

Design of a Small Reservoir Irrigation System



BUREAU OF AGRICULTURE AND FISHERIES STANDARDS

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Foreword

The formulation of this national standard was initiated by the Agricultural Machinery Testing and Evaluation Center (AMTEC) under the project entitled “Enhancement of Nutrient and Water Use Efficiency Through Standardization of Engineering Support Systems for Precision Farming” funded by the Philippine Council for Agriculture, Aquaculture and Forestry and Natural Resources Research and Development - Department of Science and Technology (PCAARRD - DOST).

As provided by the Republic Act 10601 also known as the Agricultural and Fisheries Mechanization Law (AFMech Law of 2013), the Bureau of Agriculture and Fisheries Standards (BAFS) is mandated to develop standard specifications and test procedures for agricultural and fisheries machinery and equipment. Consistent with its standards development process, BAFS has endorsed this standard for the approval of the DA Secretary through the Bureau of Agricultural and Fisheries Engineering (BAFE) and to the Bureau of Philippine Standards (BPS) for appropriate numbering and inclusion to the Philippine National Standard (PNS) repository.

This standard has been technically prepared in accordance with BPS Directives Part 3:2003 – Rules for the Structure and Drafting of International Standards.

The word “shall” is used to indicate mandatory requirements to conform to the standard.

The word “should” is used to indicate that among several possibilities one is recommended as particularly suitable without mentioning or excluding others.

Design of a Small Reservoir Irrigation System

1 Scope

This standard specifies the minimum design requirements of a small reservoir irrigation system.

A small reservoir irrigation system shall be defined as a system with a structure built across a river to store river runoff for immediate and multiple use. It may be built with dam height of 15 m to 35 m.

2 References

The following normative documents contain provisions through which reference in this text constitute provisions in this National Standard:

PNS/BAFS/PAES 217: 2017 Determination of Irrigation Water Requirements

United States Bureau of Reclamation. 2012. Design Standards No.13 – Embankment Dams, Chapter 2: Embankment Design

United States Bureau of Reclamation. 2011. Design Standards No.13 – Embankment Dams, Chapter 4: Static Stability Analysis

United States Bureau of Reclamation. 2012. Design Standards No.13 – Embankment Dams, Chapter 5: Protective Filters

United States Bureau of Reclamation. 2012. Design Standards No.13 – Embankment Dams, Chapter 6: Freeboard

United States Bureau of Reclamation. 2014. Design Standards No.13 – Embankment Dams, Chapter 8: Seepage

United States Bureau of Reclamation. 2014. Design Standards No.13 – Embankment Dams, Chapter 10: Embankment Construction

United States Bureau of Reclamation. 2014. Design Standards No.13 – Embankment Dams, Chapter 11: Instrumentation and Monitoring

United States Bureau of Reclamation. 2014. Design Standards No.14 - Appurtenant Structures for Dams (Spillways and Outlet Works) Design Standard, Chapter 3: General Spillway Design Considerations

3 Definition

For the purpose of this standard, the following definitions shall apply:

3.1

bearing capacity

maximum average contact pressure between the foundation and the soil which should not produce shear failure in the soil

3.2

design irrigable area

maximum area which an irrigation project can serve considering the extent of arable lands and the available water supply

3.3

permeability test

method to determine the rate of flow under laminar flow conditions through a unit cross sectional are of soil under unit hydraulic gradient

3.4

potential irrigable area

area capable of being irrigated, principally as regards to availability of water, suitable soils, and topography of land

3.5

seismicity

occurrence or frequency of earthquakes in a region

4 Preparation and Collection of Initial Design Data

4.1 Survey Data

The following data shall be prepared:

4.1.1 General Layout of Project Area

4.1.2 Location Map

4.1.3 Topographic map of dam site indicating location of dam axis, spillway and outlet works and alignment.

4.1.4 Map showing access roads and location of quarry areas for construction materials.

4.1.5 River bed and banks profile and cross sections at least 2.0 km upstream and downstream from dam axis or as required.

4.1.6 Cross-sections of a river at dam axis and at downstream where required and ideal location for the preparation of tail water rating curve.

4.1.7 Profile and cross-sections of spillway and diversion or outlet conduit at center line.

4.2 Validation of Land Resources Data

4.2.1 Existing irrigated, rainfed and new area for inclusion under the system shall be delineated.

4.2.2 Potential irrigable area as identified on land classification map, soil map and land use map shall be validated

4.3 Conduct of Hydrological Studies

4.3.1 Evaluate soils, hydrology and meteorology parameters through the succeeding procedures.

4.3.2 Develop a cropping calendar or review if there is an existing cropping calendar being practiced within the project area. Cropping calendar development is specified in PNS/BAFS/PAES 217: 2017 – Determination of Irrigation Water Requirements.

4.3.2 Determine the diversion water requirement for the identified design irrigable area as specified in PNS/BAFS/PAES 217: 2017 – Determination of Irrigation Water Requirements.

4.3.3 Conduct sedimentation analysis and determine reservoir sedimentation rate. Establish the reservoir sediment storage or dead storage capacity based on the estimated economic life of the infrastructure. Procedures are shown in Annex A.1.

4.3.4 Determine reservoir demand in case of multipurpose dam. Procedures are shown in Annex A.2.

4.3.5 Determine reservoir losses. Procedures are shown in Annex A.3.

4.3.6 Conduct reservoir operation simulation studies. Procedures are shown in Annex A.4.

4.3.7 Carry out initial project hazard and risk assessment.

4.3.8 Establish inflow design flood magnitudes and determine the corresponding inflow design flood discharge or peak discharges for the spillway and outlet works.

4.3.9 Prepare the inflow design flood hydrograph, elevation-area-capacity curve and tailwater rating curves. Procedures are shown in Annex A.5.

4.3.10 Perform inflow design flood routing for spillway and outlet works. Procedures are shown in Annex A.6.

4.3.11 Conduct dam break simulation and analysis for environmental impact assessment and hazard level and category assessment. The ADB Environmental Assessment Guidelines and the EIA Review Manual by the Environmental Management Bureau may be used.

4.3.12 Formulate the emergency preparedness action plan to include flood warning system.

4.4 Assessment of Geological Data

The following data shall be prepared:

4.4.1 Regional geology, geologic map of the project area, seismic map and geohazard map of the locality

4.4.2 Geologic map of the reservoir area, dam foundation and rim indicating geological information and details, locations of fault line, reflecting the locations of bore/drill holes and borrow pits

4.4.3 Log of bore or drill holes - A minimum of 5 holes located along the dam axis and at the dam foundation upstream and downstream area shall be required. Depth of boreholes shall be approximately equal or greater than the proposed dam height. A minimum of three drill holes shall be required for both spillway and diversion outlet.

4.4.4 Geologic profile of dam axis, spillway, diversion and outlet works

4.4.5 Seismicity of the dam site and reservoir area

4.4.6 Confirm the permeability or water tightness of the reservoir area, surrounding rim/flanks and foundation at the dam axis.

4.4.7 Confirm reservoir rim/flanks slope stability.

4.5 Review and Testing of Materials

4.5.1 Confirm the quality and availability of embankment materials.

4.5.2 Determine the physical and engineering properties of available materials.

4.5.3 Perform grain size analysis and permeability test.

5 Design Procedure

5.1 Dam Foundation and Location

5.1.1 Set the cutoff trench alignment, width and depth requirement and base center line offset from the dam axis.

5.1.2 Dam, spillway and outlet works foundation excavation plan and profile

5.1.3 Dam foundation treatment, grouting plan and profile details

5.1.4 Fault line shear strength and bearing capacity improvement.

5.1.5 Spillway and outlet works foundation treatment plan and details.

5.1.6 Provisions for operation and maintenance facilities and appurtenances as dictated by design requirements.

5.2 Dam Design

5.2.1 Confirm values for minimum dead storage capacity based on sedimentation studies, normal capacity based on operation simulation studies and maximum reservoir surface levels based on inlet discharge flood studies.

5.2.2 Determine the dam crest width, camber and protection requirements. Procedures are detailed in United States Bureau of Reclamation Design Standards No.13 – Embankment Dams, Chapter 2: Embankment Design

5.2.3 Determine cutoff trench alignment, width and depth requirements.

5.2.4 Determine required height of upstream and downstream permanent and temporary coffer dams and rock toe including freeboard requirement.

5.2.5 Adjust freeboard and camber requirement considering wind and seismic induced wave height and run-up, embankment consolidation and settlement. Procedures are detailed in United States Bureau of Reclamation Design Standards No.13 – Embankment Dams, Chapter 6: Freeboard

5.2.6 Determine the expected maximum tolerable design seepage flow rate based on the embankment and foundation established permeability. Procedures are detailed in United States Bureau of Reclamation Design Standards No.13 – Embankment Dams, Chapter 8: Seepage

5.2.7 Determine the required filter drains size. Procedures are detailed in United States Bureau of Reclamation Design Standards No.13 – Embankment Dams, Chapter 5: Protective Filters

5.2.8 Determine seepage collector and conveyance channel capacity and size dimensions.

5.3 Embankment Stability Analysis

Provide a summary of calculated critical values of factor of safety for all loading conditions, location coordinates of center of radius of slip circle and corresponding values. Details are discussed and described in United States Bureau of Reclamation Design Standards No.13 – Embankment Dams, Chapter 4: Static Stability Analysis.

5.4 Dam Instrumentation

Adequate dam instrumentation shall be provided in order to monitor and measure the structural behavior of the dam and its appurtenant structures. Details on each type and method of analysis and presentation are shown in Annex B. A more comprehensive discussion is detailed in United States Bureau of Reclamation Design Standards No.13 – Embankment Dams, Chapter 11: Instrumentation and Monitoring.

5.5 Design of Outlet, Spillway and Related Appurtenances

Details are discussed and described in United States Bureau of Reclamation Design Standards No.14 – Appurtenant Structures for Dams (Spillways and Outlet Works) Design Standard, Chapter 3: General Spillway Design Considerations

6 Construction

The following data shall be included in the technical specifications for the construction of the embankment dam and appurtenant structures. Scope, classification, method of construction and basis of payment for

- Clearing and grubbing
- Diversion and care of river during construction and unwatering of foundation
- Excavation and foundation preparation
- Channel excavation
- Structure excavation
- Drilling and grouting
- Overhaul
- Borrow haul
- Side borrow
- Embankment construction and compaction
- Structure and backfill
- Roads
- Concrete structures
- Rubble masonry
- Concrete joints and joint materials
- Dowels
- Reinforcing steel bars

7 Design of Access and Service Roads

7.1 The following shall be determined for the design of access roads:

- Road grade lines/ gradient requirements
- Traverse elements, horizontal and vertical curve elements
- Design road lane and width requirements
- Cross-sections and details
- Drainage and provision of side drains

7.2 Provide the following dam appurtenances:

- Access path to control gates
- Inspection pathways
- Footbridge
- Safety railings, fences and cages

8 Summary of Data

Table 1. Summary of Data

Component	Unit	Value
DAM		
Type		
Height above streambed		
Crest length		
Crest width		
Dam crest level		
Normal reservoir level		
Maximum reservoir level (with surcharge)		
Top of inactive storage		
SPILLWAY		
Type		
Design Capacity		
Crest Length		
Crest Level		
IRRIGATION OUTLET WORKS		
Type		
Design Capacity		
Barrel Size		
Conduit Length		
CONSTRUCTION DIVERSION		
Type		
Design Capacity		
Barrel Size		
Conduit Length		

8 Bibliography

PNS/BAFS/PAES 225: 2017 Rainwater and Runoff Management - Small Water Impounding System

PNS/BAFS/PAES 220:2017 - Conveyance Systems – Performance Evaluation of Open Channels – Determination of Conveyance Loss by Inflow-Outflow Method.

De Vera, M.R. 1981. Assessment of Sediment Yield Using the Universal Soil Loss equation, Erosion and Sediment Transport in Pacific Rim

National Irrigation Administration. n.d. Design Procedure for Reservoir Dams.

Saplala, V.R.S. 2014. National Irrigation Administration Lecture Notes on the Operation and Maintenance of Dams and Dam Safety.

United States Bureau of Reclamation. 1967. Design of Small Dams.

United States Bureau of Reclamation. 2008. Erosion and Sedimentation Manual.

**ANNEX A
(informative)**

Hydrological Studies

A.1 Sedimentation Analysis

The rate of deposition and the period of time before the sediment obstructs the useful function of the dam shall be determined. The following methods can be used to estimate the sediment inflow in the reservoir:

A.1.1 Universal Soil Loss Equation by Wischmeier and Smith – use of sediment yield rate factors. Table A.1 may be used in estimating sediment yield based on the drainage area of the site. However, it must be noted that the values below are results of sediment rate study for basins in Central Luzon

Table A.1. Sediment Yield Estimation for Various Drainage Areas

Drainage Area, km²	Soil Loss, ton/km²	Sediment Yield, ton/km²
52	345	345
90	223	85
112	332	312
165	276	256
191	654	970
232	365	400
240	431	585
253	424	566
258	296	209
274	665	1420
285	1017	2213
312	808	1262
347	291	195
353	562	2049
512	415	539
709	335	374
764	351	363
1177	278	182

SOURCE: De Vera, M.R. 1981. Assessment of Sediment Yield Using the Universal Soil Loss equation, Erosion and Sediment Transport in Pacific Rim

A.1.2 Reservoir Resurvey Data –measurement of sediment accumulation to compare the storage capacity with an earlier survey where the difference is the sediment accumulation.

A.1.3 Sediment Sampling Data – determination of sediment inflow by suspended sediment sampling in combination with total load computations.

A.2 Reservoir Demand

Reservoir demand can be estimated according to the methods described in Annex A of PNS/BAFS/PAES 225:2017 - Rainwater and Runoff Management - Small Water Impounding System

A.3 Reservoir Losses

Reservoir losses can be estimated according to the methods described in Annex A of PNS/BAFS/PAES 225:2017 - Rainwater and Runoff Management - Small Water Impounding System

A.4 Reservoir Operation Simulation

A simple reservoir operation simulation is presented in Annex A of PNS/BAFS/PAES 225:2017- Rainwater and Runoff Management - Small Water Impounding System

A.5 Inflow

Estimation of inflow can be estimated according to the methods described in Annex A of PNS/BAFS/PAES 225:2017 - Rainwater and Runoff Management - Small Water Impounding System

A.6 Flood Routing

A.6.1 The following methods can be used:

- a. Muskingum
- b. Convex
- c. Direct Translation
- d. Storage-Discharge (Modified Puls)
- e. Kinematic Wave
- f. Diffusion Wave
- g. Dynamic Wave
- h. Muskingum-Cunge

A.6.2 A simple process for flood routing is presented in Annex A of PNS/BAFS/PAES 225:2017 - Rainwater and Runoff Management - Small Water Impounding System

ANNEX B (informative)

Dam Instrumentation

B.1 Dam instrumentation is composed of various devices which are intended to monitor the performance and structural behavior of a dam and its appurtenant structures.

B.2 Instrumentation shall be provided to indicate the distress spots in the reservoir and embankment which require remedial measures.

B.3 Proper collection, reduction, recording, plotting, analysis and interpretation of the data from the different instruments provided in the dam is required in order to determine that the dam and its appurtenant structures are performing in a safe manner as they have been designed.

B.4 The instrumentation data shall be completed by regular and timely visual inspections.

B.5 General Types of Dam Instrumentation

B.5.1 Piezometers - provide data on the water pressure at selected points within an embankment dam or foundation

B.5.1.1 Pneumatic piezometer

B.5.1.1.1 Usually buried within the embankment dam and connected with tube lines to the reading point on the downstream slope

B.5.1.1.2 Measures the pore water pressure acting on one side of a flexible diaphragm by applying an equal pneumatic pressure to the backside of the diaphragm which is applied by pumping nitrogen (the recommended gas) or carbon dioxide to the diaphragm through the tube lines

B.5.1.1.3 Uses a readout unit to take pore water pressure reading

B.5.1.2 Standpipe piezometer

B.5.1.2.1 Open-well piezometers (installed in the embankment) and groundwater observation wells (installed on the abutments or foundations)

B.5.1.2.2 Measures the water level within a casing using an electrical probe called a dipmeter

B.5.1.2.3 Does not require readout units

B.5.1.2.4 Requires to flush out or rod the casings clear should they become plugged, or to redrill if unsuccessful

B.5.2 Flow Measuring Devices - measure the total seepage and the seepage from selected locations. Various types of flow measuring devices are detailed in Annex A of PNS/BAFS/PAES 220:2017 - Conveyance Systems – Performance Evaluation of Open Channels – Determination of Conveyance Loss by Inflow-Outflow Method.

B.5.2.1 Measures seepage both through and under the dam

B.5.2.2 Weirs are placed at strategic locations to separate flows intercepted from cracks from the general seepage flows, such that the seepage water is collected in an open channel and directed to a conventional sharp-crested V-notch weir

B.5.2.3 When the flows are too small to measure accurately with weirs, ordinary flow pipes or small stone drop structures are used

B.5.3 Total Pressure Cells - measure the total vertical pressure at selected locations within the embankments

B.5.3.1 Cells measure the combination of water pressure and effective earth pressure where a piezometer is placed beside each total pressure cell

B.5.3.2 Usually pneumatic and operate on the same principle as the pneumatic piezometers where the pressure in an incompressible fluid, contained between two plates welded together at their circumference is measured pneumatically

B.5.4 Cross-arm Settlement Devices - measure internal settlements in an embankment dam and in foundations

B.5.4.1 Devices in embankments are placed during construction and the construction, as well as long-term

B.5.4.2 Consists of a series of horizontally placed cross-arms which are installed along 50-millimeter diameter vertical tubing in such a manner that the cross-arms are free to move independently to each other

B.5.4.3 Locations or elevations are determined by lowering a cylindrical torpedo, attached to a steel measuring tape, down the vertical tubing. As it is lowered, the torpedo engages each succeeding measuring point.

B.5.4.4 The measuring points are the lower ends of the 40-millimeter pipes attached to each cross-arm by means of spring-loaded pawls which project out from the body of the torpedo. At the bottom of the 50-millimeter diameter tubing the torpedo is tapped against the latching plate which forces the pawls back into the body of the torpedo enabling it to be withdrawn from the pipe after completing the measurements. The depths down the vertical tubing to each measuring point is then related to the surveyed elevation of the top of the dam.

B.5.5 Surface Settlement and Deflection Points - surface monuments placed on the dam crest and slopes to measure long term settlement and horizontal deflection

B.5.5.1 These settlement and deflection points are simply steel pins set in concrete blocks embedded on the embankment fill which are surveyed from time to time using precise survey methods and instruments.

B.5.5.2 As soon as the embankment is completed, the survey monuments are installed and baseline readings are taken on which future readings are referred to.

B.5.6 Seismic Instruments - usually installed in a large dam or its vicinity to measure the effects of strong earthquakes and seismic activity at the site

B.5.6.1 Strong Motion Accelerograph

B.5.6.1.1 A high precision, battery operated earthquake recorder specifically designed to measure ground accelerations resulting from a strong local earthquake.

B.5.6.1.2 Triggerred by an earthquake of a certain magnitude at which it is set and provides automatic triaxial photo recording of all major local earthquake events and subsequent aftershocks

B.5.6.1.3 Basic parts:

- Seismic triggers - sensitive to vertical accelerations which senses the vertical component of the initial strong earthquake ground motion (wave) and is actuated to full operation within less than 50 milliseconds. It operates for as long as the seismic trigger detects earthquake and up to a few seconds after
- Accelerometers - triaxial flexure type and act in the x, y, and z directions
- Camera - records the acceleration traces and timing reference traces

B.5.6.2 Auxiliary Short Period Accelerograph System

B.5.6.2.1 Monitors any crustal disturbance at the damsite by recording low motion seismic events

B.5.6.2.2 Operates around the clock and all the seismic events are recorded.

B.5.6.2.3 Basic parts:

- drum recorder
- amplifier
- seismometer - provides sufficient amplification to record any minor local earthquake event, thus providing a continuous record of local seismic activity during the construction of the dam, filling of the reservoir and dam operation

B.6 Instrumentation Data Collection, Reduction and Presentation

Reading/Measurement	Frequency of Reading
Piezometer	monthly or weekly depending on the difficulty (or ease) of taking them
Seepage	daily
Total pressure cells	every six months
Settlement/deflection	every six months
Strong motion accelerographs	during a strong earthquake
Short period accelerographs	daily
Special Event*	within several hours
<p>NOTE: Special event can occur at any of the following:</p> <ul style="list-style-type: none"> •Anytime the rise or fall in the reservoir level is excessive. •At any time during the life of the dam when a strong earthquake is felt or otherwise recorded by the seismic instruments. •At any time during the life of the dam when an unusually large flood occurs and the spillway discharge is large. 	

B.6.1 The data obtained shall be recorded in specific forms for each instrumentation.

B.6.2 The data recorded on the forms shall be reduced and compiled into a readily understandable format.

B.6.3 The data shall be presented graphically to facilitate an evaluation of the overall dam complex performance or performance of a particular dam feature. Plot the readings on the y scale with the corresponding date when it was taken on the x scale.

B.6.4 Similar data, organized on a dam feature basis, should be summarized on one sheet to facilitate comparison and evaluation of historical trends.

B.7 Instrumentation Data Analysis and Interpretation

The analysis and interpretation of dam instrumentation data shall be done only by qualified technical staff who are highly experienced in dam operation and maintenance and familiar with the features of the specific dam. If, after reviewing instrumentation data in accordance with the proper steps, there is any indication that an abnormal condition is developing, higher authorities shall be informed immediately so that a thorough investigation can be undertaken immediately.

B.7.1 Piezometers - evaluation depends on consideration of the type and location of instrument and should be generally based on historical trends rather than specific limits for each instrument

B.7.1.1 Embankment Piezometers - There should be a reduction in piezometric head as water seeps through embankment zones. In relative terms, the piezometric head should be as follows:

- Upstream of the embankment core - the head should be equal to, or nearly equal to, the elevation of the reservoir.
- Through the core - there should be a substantial drop in head across the core.
- Downstream of the core - should be only slightly higher than the piezometer tip. When the tailwater (downstream) level is lower than the tip, the piezometers downstream of the core should indicate very nearly zero water pressures.

B.7.1.1.1 Piezometer readings (other than those upstream of the core), which change at the same rate as the reservoir fluctuations would indicate direct links between the reservoir and the instrument location.

B.7.1.1.2 Piezometer readings should follow a historical trend in response to the reservoir elevation.

B.7.1.2 Foundation Piezometers -These are subject to the same general considerations and comments as embankment piezometers as follows:

- The piezometric head should drop gradually from the upstream to the downstream side of the core contact. Foundation piezometers located at or near the downstream toe of the embankments should indicate piezometric head very close to or even below the tailwater level.
- Downstream piezometers may or may not respond quickly to reservoir level changes.
- Historical trends in head relative to reservoir levels and response times must be established. If unexplained changes in these occur, further investigations should be undertaken and higher authorities should be notified.

B.7.1.3 Groundwater Observation Wells - These are subject to the same general considerations and comments as Foundation Piezometers.

B.7.2 Flow Measuring Devices - As for other data, historical trends related to reservoir levels and rainfall should be established.

B.7.2.1 An increase in quantity (not related to rainfall) in excess of 10 percent as compared to the historical flow quantity for the particular level must be considered unusual and should be reported to higher authorities.

B.7.2.2 If the described increase occurs, or the discharge color changes from clear to turbid, "Special Events" frequency of readings shall be instituted.

B.7.3 Total Pressure Cells - Readings shall be compared with historical data and if unexplained changes occur, the companion piezometers shall be re-read and the verified results from the cells and the piezometers reported to higher authorities.

B.7.4 Cross-arm Settlement Devices - Settlement of the embankment would mostly occur during construction, becoming less during the initial years of its life and nearing zero after several years of operation. At that point, if the trend towards zero settlement changes, higher authorities shall be informed. Any changes in the trend will most likely occur suddenly after on-site earthquake-induced accelerations.

B.7.5 Surface Settlement and Deflection Points - The trend of measurements recorded should be towards small to zero settlement changes. If any excessive changes occur, the data shall be cross checked with other instrumentation data for indications of abnormal behavior. If there is any abnormal condition, higher authorities shall be notified immediately.

B.7.6 Seismic Instrumentation - Whenever the Strong Motion Seismograph is triggered, the readings shall be transmitted to higher authorities who will then decide on whether a "Special Event" instrument reading frequency should be initiated. Similar action shall be taken if historically unusual data is obtained from the Short Period Accelerographs.

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National Standard for Design of a Small Reservoir Irrigation System**

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