

SECTION 01 81 13.13 - PHYSICAL MODEL FOR FILLING AND EMPTYING SYSTEM

1.01 SUMMARY:

- A. ^{A19}As part of the design of the filling and emptying (F-E) system for the Works, the Contractor shall construct a physical model, which shall physically reproduce the Contractor's intended design of the functioning of all the hydraulic scenarios of the F-E system for the triple-lift locks with a set of corresponding Water-Saving Basins (WSBs), Gatun Lake access channel and access channels for the Atlantic and Pacific ocean entrances.^{A19} ^{A16}The reproduction shall include Operations with and without vessels in the lock chambers and other design, performance, and test criteria required in Section 01 81 13 (*Filling and Emptying Systems*).^{A16}
- B. ^{A19}Prior to the Contract, the Employer has contracted the services of a recognized hydraulic laboratory to provide physical modeling studies for the conceptual hydraulic design of the new locks. The results of these studies have been provided to the Contractor purely for his information (refer to Volume VI, Part 8). As part of the design of the Works, the Contractor must validate his proposed F-E design for the Works using his own modeler for 2-D or 3-D numerical models. The Contractor shall validate the F-E design at its own selected laboratory or may contract the Employer's selected laboratory to do so.^{A19}
- C. The physical model to validate the F-E system design and performance is only required after the ^{A17}Commencement Date. The Employer's selected laboratory may not be used as a consultant during the Tender period, although the Contractor may directly contact this laboratory during the tendering period to discuss test plans and pricing in order to directly engage, if so proposed, the Employer's selected laboratory after the Commencement Date.
- D. ^{A19}The proposed laboratory and detailed work plan for physical modeling of the F-E system shall be provided with the Contractor's Technical Proposal, which shall include, but not be limited to, laboratory and modeler experience with similar lock models, proposed scale and corresponding calculations, measurement instrumentation, tests scenarios, number and reporting schedules, a sketch of the proposed model, the fabricator of the model vessel, and planned output data^{A19}
- E. ^{A19}Prior to construction of the Contractor's physical model, he shall submit for review to the Employer's Representative the proposed design of the physical model, to include but not limited to, scale verification, detailed drawings, instrumentation to be used, data acquisition, model construction work schedule, test schedule, model vessel, and report format.^{A19}
- F. ^{A19}The Contractor shall notify the Employer's Representative of all tests to be performed on the physical model at least 28 days in advance. The Contractor shall allow and coordinate with the Employer to witness all tests. Subject to the provisions of this Section 01 81 13.13, the physical tests shall be conducted in accordance with Sub-Clauses 7.4 (*Testing*), 7.5 (*Rejection*) and 7.6 (*Remedial Work*) of the Conditions of Contract.^{A19}

- G. ^{A19}Test results of the Contractor's physical model must comply with the F-E system performance requirements stated in Paragraph 1.06, below. The Contractor shall submit a report comprising all test results and contemporaneous records of such tests for approval by the Employer's Representative within 21 days of the completion of the tests. ^{A19}
- H. ^{A19}The Contractor shall not proceed with the construction of any part of the F-E system until such time as the Employer's Representative has approved in writing that all the tests of the Contractor's physical model have been passed and demonstrate full compliance with the F-E system performance requirements as stated in Paragraph 1.06 below. ^{A19} The Contractor, ensuring that appropriate precautions are taken to accommodate F-E system once approved, at its own risk, may begin preliminary construction activities for elements of the F-E system, as long as precautions are taken to fit the approved F-E system.
- I. ^{A20}The Contractor shall thereafter design and construct the Works' F-E system in accordance with the physical model as tested and approved as aforesaid. ^{A20} Should the Contractor desire to make changes to its design of F-E system design, after the Employer's Representative has approved construction to proceed as stated in Paragraph 1.01 F. and G., the proposed changes shall be submitted to the Employer's Representative for approval in accordance with Sub-Clause 5.2 (*Contractor's Documents*) of the Conditions of Contract but only after such changes have been reflected in the F-E physical model and re-tested and paragraphs 1.01 D., 1.01 E. and 1.01 F. above have been complied with in respect to such re-tests. ^{A19}

1.02 SCOPE OF WORK:

- A. ^{A19}The Contractor's physical model shall simulate all F-E functions of the Works:
1. F-E from lake to lock, chamber to chamber, lock to ocean, chamber to WSB, and WSB to chamber.
 2. F-E for all operating scenarios for vessels transiting in both Up Lockages and Down Lockages.
 3. The physical model shall reproduce the use of the WSBs as part of normal operations, as well as lock operations without the use of WSBs.
 4. The tests shall be conducted without use of model vessel to measure water slopes and with model vessel in lock chamber to measure hawser forces. Analysis of tests results with these two variables shall be correlated and report submitted to Employer's Representative for verification.
 5. The physical model shall reproduce all combinations of high, mean and low levels at Gatun Lake and oceans, the total lift is illustrated in the below table. The Contractor shall calculate the high, mean and low water heads to be tested in the physical model and submit to the Employer for verification. All test conditions, partial and final results and calculations for lake, lock chamber, ocean and WSB filling and emptying tests in physical model shall be submitted to the Employer. All water head combinations shall be modeled for the Pacific locks.

A minimum of 10% of water head combinations for the Atlantic locks shall be modeled for compliance.^{A19}

^{A19} Table 1 – 01 81 13.13		
Gatun Lake levels (meters PLD)		
Low	Mean	High
24.70	25.91	27.13
Pacific Ocean levels (meters PLD)		
High	Mean	Low
+2.14	-0.09	-2.32
Total Lift from Pacific Ocean to Gatun Lake (meters)		
Minimum	Mean	Maximum
22.56	26.00	29.45
Atlantic Ocean levels (meters PLD)		
High	Mean	Low
+0.17	+0.03	-0.12
Total Lift from Atlantic Ocean to Gatun Lake (meters)		
Minimum	Mean	Maximum
24.53	25.88	27.25 ^{A19}

- B. ^{A16}The main objective of the study with the Contractor's physical model shall be to validate his design of the F-E system selected after the numerical modeling study performed by the Contractor. ^{A19}See Section 01 81 13 (*Filling and Emptying Systems*) for parameters to be validated. The F-E design shall be optimized for two main objectives: maximizing vessel throughput (by minimizing hydraulic times) and ensuring vessel safety (with acceptable water slopes and hawser forces).^{A19}
- ^{A19}Validating hydraulic data related to lock characteristics (for example, discharge versus head curves). Validating F-E times in conformance with Section 01 81 13 (*Filling and Emptying Systems*). Determining lock-operating procedures and valve opening schedules for standard lockage conditions.
 - Validating water slopes and hawser forces in conformance with Section 01 81 13 (*Filling and Emptying Systems*).
 - Validating percentage of water saved with the use of WSB versus not using them in conformance with Section 01 81 13 (*Filling and Emptying Systems*).
 - Validating water velocities and pressures in culverts, conduits, intakes, discharges, ports, etc. in conformance with Section 01 81 13 (*Filling and Emptying Systems*).
 - Validating that there shall be no cavitation, nor water hammer, nor air entrapment in the F-E system in conformance with Section 01 81 13 (*Filling and Emptying Systems*).^{A19}
- C. ^{A19}The design of the Contractor's physical model shall be based on the results achieved in the numerical modeling study. The Contractor's physical model studies shall then be used to confirm and further refine the final geometries and characteristics of all the

elements and to improve the performance of the F-E system, in particular the physical model shall yield:^{A19}

1. ^{A19}The dimensions of the lock chambers including gates and niches, and WSBs.
2. The elevations of the lock chambers and WSB bottoms (floors) and tops (of walls), floor slopes, and dividing walls.
3. The dimensions and shapes of the culverts, conduits, transitions and connections.
4. The dimensions, shapes, number, and positions of side ports in lock chambers.^{A19}
5. The range of the heads between the lake and upper chambers, between the lower chambers and oceans, between chambers, and between chambers and WSBs.
6. The full range of F-E times.
7. ^{A19}The water intakes from the lake and WSBs.
8. The water outlets to the ocean.
9. The valves for WSBs and lock chambers.
10. Water slopes in lock chambers and dynamic measurement of hawser forces on vessels shall be conducted.^{A19}

D. ^{A16}Once the F-E system has been validated by the Contractor's physical modeling, further optimization and assessment of special operating conditions shall be conducted using his own numerical models, refined based on his physical model validation, and confirmed using the physical model.^{A16} ^{A19}These additional tests are not required prior to final approval of F-E physical modeling and acceptance to proceed with construction of F-E system. These additional tests shall be carried out by Contractor and reported to Employer within 84 days from acceptance of F-E physical model tests. Additional tests in physical model have the following objectives:^{A19}

1. ^{A19}Assessing special operating conditions for different equipment availability scenarios, such as gates, culverts, or valves out of service and its effect to F-E times, water slopes and hawser forces.
2. Determining lock-operating procedures and valve opening schedules for special lockage conditions and its effect to F-E times, water velocities in culverts, water slopes in lock chambers and hawser forces.
3. Collecting data relative to the lock characteristics on both sides (discharge versus head, discharge versus valve-opening ratio, and pressure versus head).
4. Measuring hawser forces for types and sizes of vessels other than the Design Vessel defined in Section 01 42 16 (*Definitions*).
5. (Reserved)^{A19}

E. ^{A19} (Reserved) ^{A19}

F. ^{A19} (Reserved) ^{A19}

1.03 REQUIREMENTS:

A. **Precision:** The precision expected from the prototype shall be in the range of:

1. **Level:** < 50 mm actual.
2. **Time:** < 10 seconds.
3. **Velocity:** 0.35 m/s (5% of maximum average velocity at any point).

B. ^{A16}The requirements in terms of precision that can be expected in the Contractor's scale model of the locks shall be in the range of: ^{A16}

1. **Level:** 1 mm for continuous measurements with an acquisition frequency higher or equal to 100 Hz.
2. **Maneuvering time:** 1 second.
3. **Velocity:** 50 mm/s.
4. **Pressure:** 0.0001 bar for continuous measurements with an acquisition frequency higher or equal to 100 Hz.

C. ^{A19}For all measurements, data and reporting of physical model tests "ASTM E29 Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications" shall be used with the rounding method. ^{A19}

1.04 GENERAL DESIGN:

A. ^{A19}The Contractor's choice of the model scale shall be governed by the model's physical laws of similarity. It must take into account the desired degree of precision for the results and the size of the elements to be modeled. The Contractor's lock models shall be built taking into account Froude's similitude to ensure that the viscosity forces are negligible compared with other forces (gravity, inertia, and turbulence). Nonetheless, the Contractor shall ensure that the prototype turbulent flow regime is reproduced well by his model so that the head losses, velocities, flows, F-E times, water surface slopes in lock chambers, and the forces on the hawsers are accurately modeled. The chosen scale shall be at least 1:30; for example, a scale of 1:25 is acceptable, while a scale of 1:40 is not acceptable. ^{A19}

B. ^{A17}The ^{A17} model shall comprise at least:

1. Two lock chambers (with possible adjustable bottoms or floors) and corresponding main culverts, sideports, valves, intakes, and discharges ^{A17} to reproduce all lock chamber to lock chamber F-E tests. ^{A17}
 - ^{A8}2. Water-Saving Basins WSBs with corresponding conduits and valves ^{A8} ^{A17} to reproduce all WSB to lock chamber F-E tests. ^{A17}
 3. Reproduce at least 250 m of access channel on the Gatun Lake side, ^{A12} including approach areas ^{A12} ^{A17} to reproduce lake to lock chamber filling tests. ^{A17}
 4. Reproduce at least 250 m of access channel on the ocean side, ^{A12} including approach areas ^{A12} ^{A17} to reproduce all lock chamber to ocean emptying tests. ^{A17}
- C. The WSBs shall be built on the downstream chamber. WSBs at the downstream chamber will be subjected to more severe constraints due to the heads generated by the tide, especially on the Pacific side. The optimization of the elements associated with the WSBs (water intakes in the basins, valve chambers, connections of conduits with the culverts, minimum depth of the basins, and slope of the basins versus the water intakes) shall therefore be done with these basins and shall be verified for the basins of the two other lock chambers.
- D. ^{A16} The Contractor's physical model shall be designed for testing on the Pacific ^{A16} ^{A17} side. ^{A17} The Atlantic side shall be validated by a series of tests once the optimization has been finalized on the Pacific side. ^{A20} Both Pacific and Atlantic physical model tests shall be completed and reported by the Contractor and accepted by the Employer before commencement of construction of the F-E system on either Pacific or Atlantic locks. ^{A20}
- E. ^{A19} Reference per-chamber F-E time without the use of WSB: 10 minutes. ^{A19}
- F. ^{A19} Reference per chamber F-E time with the use of WSB: 17 minutes total; reference time for each WSB of 4 minutes; and reference time for remaining water in lock chamber of 5 minutes. ^{A19}
- G. ^{A19} The Contractor shall facilitate information and access to facilities of Employer's Personnel and hydraulic experts to meet with the Contractor's hydraulic designer and modeler to comment, discuss and review the design, models, results and reports as they are developed and produced. Full responsibility for the F-E system design and performance shall remain with the Contractor. See Section 01 40 00 (*Quality Requirements*). ^{A19}
- H. ^{A19} All Contractor's hydraulic design, reports, drawings, test results, data and information shall be submitted in accordance with Section 01 33 00 (*Submittal Procedures*). ^{A19}
- 1.05** ^{A16} **MODEL EQUIPMENT:** The Contractor's model shall be equipped with sensors to measure at least the following parameters. ^{A16} ^{A19} The number, location and precision of sensors shall be provided to the Employer with the physical model design report. The Contractor may suggest to measure additional parameters. ^{A19}
- A. Water levels in lock chambers, WSBs, and access channels.

- B. Differential water levels in lock chambers (difference between upstream and downstream levels during F-E operations).
- C. Flow rates and velocities in culverts.
- D. Pressure in the culverts and downstream of the valves.
- E. Valve positions.
- F. ^{A7}Lock chamber water slopes and hawser^{A7} forces.
- G. ^{A19}Filling and emptying times. ^{A19}
- H. ^{A19}Instrumentation calibration report. ^{A19}

1.06 TESTS ^{A19} - PHYSICAL MODEL FOR F-E SYSTEMS. ^{A19}

- A. ^{A17}For each scenario proposed, the Contractor's tests shall consist of verifying that the F-E times specified in Paragraphs 1.03 and 1.04 of ^{A17} ^{A16}Section 01 81 13 (*Filling and Emptying Systems*) are reached for all critical and mean scenarios for normal and maintenance Operations from mathematical modeling and ensuring compliance with the objectives of acceptable water slopes, hawser forces and maximum throughput. ^{A16} The measurement of the ^{A7}water slopes and ^{A7} hawser forces shall be made initially with the extreme hydraulic conditions and also for all operating scenarios.
- B. ^{A19}The objectives of acceptable time, water slopes, hawser forces and maximum throughput shall be achieved by, but not be limited to: ^{A19}
 - 1. Adjusting the opening and closing schedule of the valve in order to reduce the turbulence in the lock chamber.
 - 2. ^{A20}Modifying the hydraulic shapes, number, location and size of some elements, such as culverts, conduits, water intakes or outlets, connections between culverts, and ports, in order to minimize head losses. ^{A20}
- C. ^{A19}The Contractor shall report all data, measurements and results obtained from physical model, including executive summary, analysis, explanations, notes, clarifications, conclusions and recommendations for approval by the Employer. ^{A19}
- D. ^{A19}The F-E times shall be measured from the moment the valves start to open to let water in or out of the chamber, until the water level in the chamber is fully equalized between two adjacent lock water bodies, the valve is closed, so that the next valve in sequence can be opened. ^{A19}
 - ^{A19}1. Time-measurement tolerance shall be no more than $\pm 0.1\%$ of the stated value.
 - 2. Lock chamber equalization is achieved when the water pressure is equal on the upstream and downstream sides of the water body. ^{A19}

- E.. ^{A19}The Contractor shall report all F-E system times for lake, lock chambers, oceans and WSB. The hydraulic sequence of Up Lockage and Down Lockage times shall be calculated and compared to the corresponding not-to-exceed F-E times. ^{A19}
- ^{A19}1. A specific F-E system physical model performance test shall be deemed to have failed if the time obtained from the model tests exceeds the corresponding NTET specified in this section or if other relevant criteria outlined in this Section 01 81 13.13 are not met. ^{A19}
2. ^{A19}The Contractor shall provide calculations for Up Lockage from ocean to lake by adding the filling time for:
- a. Lower lock chamber filling with water from the middle chamber.
 - b. Middle lock chamber filling with water from the upper chamber.
 - c. Upper lock chamber filling with water from Gatun Lake.
 - d. In normal operating mode the upstream lock gates are closed during equalization. ^{A19}
3. ^{A19}The Contractor shall provide calculations for Down Lockage from lake to ocean by adding the emptying time for:
- a. Upper lock chamber emptying water to the middle chamber.
 - b. Middle lock chamber emptying water to the lower chamber.
 - c. Lower lock chamber emptying water to the ocean.
 - d. In normal operating mode the downstream lock gates are closed during equalization. ^{A19}
- F. ^{A19}The Contractor shall conduct a minimum of two runs for each test performed in the physical model. Additional tests shall be performed if the results vary by more than 5% among the run values for the same test. The resulting differences shall be explained, discussed and reconciled in the test report. ^{A19}
- G. ^{A19}**Not-to-Exceed Filling and Emptying Times with Use of Water-Saving Basins:** The not-to-exceed times (NTET) are for the hydraulic times for filling or emptying all lock chambers and corresponding WSBs in the full sequence of hydraulic operation for vessel to be raised or lowered from ocean to lake. For the Up Lockages the upstream set of lock gates shall be closed and for the Down Lockages the downstream set of lock gates shall be closed according to Section 01 92 00 (*Facilities Operations*). ^{A19} ^{A20}Maximum, mean and minimum lifts are provided in Table 1 – 01 81 13.13, paragraph 1.02 of this section. ^{A20}
1. ^{A19}**Case 1:** The not-to-exceed F-E times (in minutes) for an Up Lockage (Northbound) in the Pacific locks for combinations of Gatun Lake and Pacific Ocean levels (in meters PLD) with the use of WSBs are:

- a. **NTET for Maximum Lift:** 52.41 minutes
 - b. **NTET for Mean Lift:** 50.46 minutes
 - c. **NTET for Minimum Lift:** 48.44 minutes^{A19}
2. ^{A19}**Case 2:** The not-to-exceed F-E times (in minutes) for a Down Lockage (Southbound) in the Pacific locks for combinations of Gatun Lake and Pacific Ocean levels (in meters PLD) with the use of WSBs are:
 - a. **NTET for Maximum Lift:** 49.32 minutes
 - b. **NTET for Mean Lift:** 46.52 minutes
 - c. **NTET for Minimum Lift:** 43.66 minutes^{A19}
3. ^{A19}**Case 3:** The not-to-exceed F-E times (in minutes) for an Up Lockage (Southbound) in the Atlantic locks for combinations of Gatun Lake and Atlantic Ocean levels (in meters PLD) with the use of WSBs are:
 - a. **NTET for Maximum Lift:** 51.17 minutes
 - b. **NTET for Mean Lift:** 50.39 minutes
 - c. **NTET for Minimum Lift:** 49.61 minutes^{A19}
4. ^{A19}**Case 4:** The not-to-exceed F-E times (in minutes) for a Down Lockage (Northbound) in the Atlantic locks for combinations of Gatun Lake and Atlantic Ocean levels (in meters PLD) with the use of WSBs are:
 - a. **NTET for Maximum Lift:** 47.54 minutes
 - b. **NTET for Mean Lift:** 46.43 minutes
 - c. **NTET for Minimum Lift:** 45.31 minutes^{A19}
- H. ^{A19}**Not-to-Exceed Filling and Emptying Times Without Use of Water-Saving Basins:**
The not-to-exceed times (NTET) are for the hydraulic times for filling or emptying all lock chambers in the corresponding sequence of operations for vessel to be raised or lowered from ocean to lake. For the uplockages the upstream set of lock gates shall be closed and for the downlockages the downstream set of lock gates shall be closed according to Section 01 92 00 (*Facilities Operations*). All Gatun Lake and Ocean water levels in meters PLD.^{A19}
 1. ^{A19}**Case 5:** The not-to-exceed F-E times (in minutes) for an Up Lockage (Northbound) in the Pacific locks for combinations of Gatun Lake and Pacific Ocean levels without the use of WSBs are:
 - a. **NTET for Maximum Lift:** 28.76 minutes

- b. **NTET for Mean Lift:** 26.70 minutes
 - c. **NTET for Minimum Lift:** 24.53 minutes^{A19}
- 2. ^{A19}**Case 6:** The not-to-exceed F-E times (in minutes) for a Down Lockage (Southbound) in the Pacific locks for combinations of Gatun Lake and Pacific Ocean levels without the use of WSBs are:
 - a. **NTET for Maximum Lift:** 28.47 minutes
 - b. **NTET for Mean Lift:** 26.42 minutes
 - c. **NTET for Minimum Lift:** 24.26 minutes^{A19}
- 3. ^{A19}**Case 7:** The not-to-exceed F-E times (in minutes) for an Up Lockage (Southbound) in the Atlantic locks for combinations of Gatun Lake and Atlantic Ocean levels without the use of WSBs are:
 - a. **NTET for Maximum Lift:** 27.46 minutes
 - b. **NTET for Mean Lift:** 26.63 minutes
 - c. **NTET for Minimum Lift:** 25.79 minutes^{A19}
- 4. ^{A19}**Case 8:** The not-to-exceed F-E times (in minutes) for a Down Lockage (Northbound) in the Atlantic locks for combinations of Gatun Lake and Atlantic Ocean levels without the use of WSBs are:
 - a. **NTET for Maximum Lift:** 27.17 minutes
 - b. **NTET for Mean Lift:** 26.35 minutes
 - c. **NTET for Minimum Lift:** 25.51 minutes^{A19}

1.07 ^{A19} (Reserved)^{A19}

1.08 ^{A10}**QUALITY ASSURANCE:** The Contractor's quality management system shall comply with Section 01 40 00 (*Quality Requirements*).^{A10}

END OF SECTION