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An American National Standard

Standard Test Method for Determining and Reporting the Berthing Energy and Reaction of Marine Fenders[1]

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INTRODUCTION

A marine fender is an energy-absorbing device that is typically secured against the face of a marine facility or a ship's hull for the purpose of attenuating the forces inherent in arresting the motion of berthing vessels safely. Most modern fenders fall into three general classifications based on the material used to absorb energy: (*1*) solid rubber fenders in which the material absorbs the energy, (*2*) pneumatic (air-filled) fenders in which air absorbs the energy, and (*3*) foam-filled fenders in which the foam core absorbs the energy.

1. Scope

1.1 This test method establishes the recommended procedures for quantitative testing, reporting, and verifying the energy absorption and reaction force of marine fenders. Marine fenders are available in a variety of basic types with several variations of each type and multiple sizes and stiffnesses for each variation. Depending on the particular design, marine fenders may also include integral components of steel, composites, plastics, or other materials. All variations shall be performance tested and reported according to this test method.

1.2 There are three performance variables: berthing energy, reaction, and deflection. There are two methods used to develop Rated Performance Data (*RPD*) and published performance curves for the three performance variables.

1.3 The primary focus is on fenders used in berthside and ship-to-ship applications for marine vessels. This testing protocol does not address small fendering "bumpers" used in pleasure boat marinas, mounted to hulls of work boats, or used in similar applications; it does not include durability testing. Its primary purpose is to ensure that engineering data reported in manufacturers' catalogues are based upon common testing methods.

1.4 The values stated in SI units are to be regarded as the standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method[2]

3. Significance and Use

3.1 *General*:

3.1.1 All testing shall define fender performance under velocities that decrease linearly or that are proportional to the square root of percent of remaining rated energy.

3.1.2 Rated performance data (*RPD*) and manufacturers' published performance curves or tables, or both, shall be based on: (*1*) initial deflection (berthing) velocity of 0.15 m/s and decreasing to no more than 0.005 m/s at test end, (*2*) testing of fully broken-in fenders (break-in testing is not required for pneumatic fenders), (*3*) testing of fenders stabilized at 23 ± 5°C (excluding pneumatic fenders; see 6.3), (*4*) testing of fenders at 0° angle of approach, and (*5*) deflection (berthing) frequency of not less than 1 h (use a minimum 5-min deflection frequency for pneumatic fenders.).

3.1.3 Catalogues shall also include nominal performance tolerances as well as data and methodology to adjust performance curves or tables or both for application parameters different from *RPD* conditions. Adjustment factors shall be provided for the following variables: (*1*) other initial velocities: 0.05, 0.10, 0.20, 0.25, and 0.30 m/s; (*2*) other temperatures: +50, +40, +30, +10, 0, −10, −20, −30; and (*3*) other contact angles: 3, 5, 8, 10, 15°. In addition, *RPD* shall contain a cautionary statement that published data do not necessarily apply to constant-load and cyclic-loading conditions. In such cases, designers are to contact fender manufacturers for design assistance.

[1] This test method is under the jurisdiction of ASTM Committee F25 on Ships and Marine Technology and is the direct responsibility of Subcommittee F25.07 on General Requirements.

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[2] *Annual Book of ASTM Standards*, Vol 14.02.

3.1.4 Adjustment factors for velocity and temperature shall be provided for every catalogue compound or other energy absorbing material offered by each manufacturer.

3.2 *Fender Testing*—Performance testing to establish *RPD* must use either one of two methods:

3.2.1 *Method A*—Deflection of full-size fenders at velocities inversely proportional to either (*1*) the percent of either (*a*) rated deflection or (*b*) remaining rated energy or (*2*) the square root of the percent of rated energy absorbed. Test parameters shall be as defined for published *RPD*. *RPD* tests shall start at 0.15 m/s. Tests to establish adjustment factors for initial berthing velocities other than 0.15 m/s shall start at those other initial velocities.

3.2.2 *Method B*—Deflection of full size fenders at constant velocity with performance adjusted by velocity factors developed from model tests. Velocity factors shall be the ratio of performance test results of models under the following conditions: (*1*) a constant strain rate similar to the strain rate of the full-size fender at its test speed, and (*2*) decreasing speed deflection with initial strain rate similar to that of the full-size fender under *RPD* deflection conditions.

3.2.3 The *RPD* for pneumatic fenders shall be determined using either Method A or Method B with miniature-size fenders; in which case, the compression performance of air shall be directly extrapolated from the test data of reduced scale models.

4. Apparatus

4.1 The test apparatus shall be equipped with load cell(s) and linear transducer(s) capable of providing continuous monitoring of fender performance. The test apparatus shall be capable of recording and storing load-cell and transducer data at intervals of $<0.01\ H$, where H is a fender's nominal height, and storing manually entered inputs. Output information shall include, as a minimum:

4.1.1 Serial number and description of test item,

4.1.2 Date, time at start, and time at end of test,

4.1.3 Location of test facility and test apparatus ID,

4.1.4 Stabilization temperature of test specimen,

4.1.5 Test ambient temperature, and

4.1.6 Graphic plot(s) of: (*1*) deflection velocity versus deflection (optional) (If not plotted, deflection velocity and its characteristics shall be separately noted.), (*2*) reaction versus deflection, and (*3*) energy versus deflection.

4.2 For fender tests, all equipment used to measure and record force and deflection shall be calibrated and certified accurate to within ±1 %, in accordance with ISO or equivalent JIS or ASTM requirements. Calibration shall be performed within one year of the use of the equipment, or less, if the normal calibration interval is shorter than one year. Calibration of test apparatus shall be performed by a qualified third-party organization, using instrumentation that is traceable to a certified, national standard.

4.3 The test apparatus shall deflect specimens according to Section 5.

5. Procedure

5.1 The performance test shall deflect specimens according to either of the two methods listed below. Clear and unambiguous calculations must be provided for any adjustments made to the test results.

5.2 *Method A*:

NOTE 1—Steps 5.2.1 and 5.2.2 do not apply to pneumatic fenders. Step 5.2.3 may be omitted for pneumatic fenders, provided internal pressure is adjusted to the manufacturer's specified value for the ambient test temperature.

5.2.1 Break in the specimen by deflecting it three or more times to its rated deflection, or more, as recommended by the manufacturer.

5.2.2 Remove load from specimen and allow it to "recover" for 1 h or more, as recommended by manufacturer.

5.2.3 Before conducting performance test, stabilize fender temperature in accordance with 6.1. Temperature-stabilizing time can include time for 5.2.1 and 5.2.2.

5.2.4 Deflect specimen once at a continuously decreasing deflection velocity as defined in one of the equations below:

$$V = V_0 (D - d)/D \text{ or } 0.005 \text{ m/s whichever is greater} \quad (1)$$

or

$$V = V_0\sqrt{(E - e)/E} \text{ or } 0.005 \text{ m/s whichever is greater} \quad (2)$$

where:

V = instantaneous deflection velocity of fender,
V_0 = initial deflection velocity, where V_0 = 0.05, 0.10, 0.15, 0.20, 0.25, or 0.30 m/s,
D = rated deflection,
d = instantaneous deflection,
E = rated energy absorption of fender, and
e = instantaneous running total of energy absorbed.

Initial velocity shall be appropriate for particular testing purpose.

5.2.5 Stop test when deflection reaches rated deflection, or more, as recommended by the manufacturer.

5.2.6 Adjust performance to rating temperature (23 ± 5°C), if required, or to desired application temperature by multiplying both energy and reaction results by temperature factor (*TF*) (see 6.3).

5.3 *Method B*:

NOTE 2—Steps 5.3.1 and 5.3.2 do not apply to pneumatic fenders. Step 5.3.3 may be omitted for pneumatic fenders, provided internal pressure is adjusted to the manufacturer's specified value for the ambient test temperature.

5.3.1 Break in specimen by deflecting three or more times to its rated deflection, or more, as recommended by the manufacturer.

5.3.2 Remove load from specimen and allow it to "recover" for 1 h or more, as recommended by manufacturer.

5.3.3 Before conducting performance test, stabilize fender temperature in accordance with 6.1. Temperature-stabilizing time can include time for 5.3.1 and 5.3.2.

5.3.4 Deflect specimen once at a constant deflection velocity.

5.3.5 Stop test when deflection reaches rated deflection, or more, as recommended by the manufacturer.

5.3.6 Adjust performance to rated temperature (23 ± 5°C), if required, or to desired application temperature by multiplying both energy and reaction results by temperature factor (*TF*) (see 6.3).

5.3.7 Adjust performance to *RPD* initial deflection velocity (0.15 m/s) or to desired initial berthing velocity, if required, by multiplying both energy and reaction results by velocity factor (*VF*) (see 6.2).

6. Supporting Procedures

6.1 *Temperature Stabilization*:

6.1.1 Test temperature for full-size specimens is defined as the same as stabilization temperature, as long as ambient temperature at test apparatus is within ±15°C of stabilization temperature and testing is completed within 2 h of the specimen's removal from the temperature-controlled environment.

6.1.2 To stabilize temperature, store specimen at a constant temperature ±5°C. Record air temperature of space where specimen is stored within 3 m of specimen surface, either continuously or twice a day, no less than 10 h apart.

6.1.3 Stabilization time shall be not less than $20x^{1.5}$ days or more as recommended by the manufacturer, rounded to the next whole day (x = dimension of greatest rubber thickness, in meters), after curing plus $20x^{1.5}$ days, rounded to the next whole day, after being in an ambient temperature differing from stabilization temperature by more than 10°C for more than 8 h.

6.2 *Velocity Factor (VF)*—One of the following protocols shall be followed to determine *VF* for every combination of fender configuration, initial velocity other than *RPD* velocity, fender element standoff and energy-absorbing material. Specimens for determining *VF* may be either full-size fenders or models, as noted below. Pneumatic fenders do not require a *VF*.

6.2.1 *Method A*—Testing of full-size fenders at actual, decreasing rate deflection velocity.

6.2.1.1 Test full-size fenders per 5.2 at 0.15-m/s initial velocity and 23 ± 5°C.

6.2.1.2 Repeat at other initial velocities.

6.2.1.3 Derive the *VF*s from the data in 6.2.1.1 and 6.2.1.2 per the following method:

(*1*) Energy velocity factor and reaction velocity factor by Method A, VF_{ea} and VF_{ra}, shall be defined by the following equations:

$$VF_{ea} = E_v/E_{RPD} \tag{3}$$

$$VF_{ra} = R_v/R_{RPD} \tag{4}$$

where:
E_v = energy at other initial velocity per 6.2.1.2,
E_{RPD} = energy at the *RPD* initial velocity per 6.2.1.1,
R_v = reaction at other initial velocity per 6.2.1.2, and
R_{RPD} = reaction at the *RPD* initial velocity per 6.2.1.1.

(*2*) Corrected energy and reaction performance is then calculated by the following equations::

$$E_a = E_{RPD} \times VF_{ea} \tag{5}$$

$$R_a = R_{RPD} \times VF_{ra} \tag{6}$$

where:
E_a = energy at alternative initial velocity,
R_a = reaction at alternative initial velocity,
E_{RPD} = energy at *RPD* initial velocity, and
R_{RPD} = reaction at *RPD* initial velocity.

6.2.2 *Method B*—Testing of model at both constant and decreasing strain rates.

6.2.2.1 Calculate the strain rate of the full-size fender when it is deflected at the constant velocity of 0.0003 to 0.0013 m/s (2 to 8 cm/min).

6.2.2.2 Test the model, per 5.3, at 23 ± 5°C, at the strain rate calculated in 6.2.2.1 (±10 %).

6.2.2.3 Calculate the initial strain rate of the full-size fender when it is deflected at the desired initial berthing velocity.

6.2.2.4 Test the same model used in 6.2.2.2 per 5.3, at 23 ± 5°C, beginning at the initial strain rate calculated in 6.2.2.3 (±10 %).

6.2.2.5 Derive velocity factors for energy and reaction, VF_e and VF_r, from the data in 6.2.2.2 and 6.2.2.4 per the following equations:

$$VF_r = R_v/R_{test} \tag{7}$$

$$VF_e = E_v/E_{test} \tag{8}$$

where:
E_v = energy per 6.2.2.4,
E_{test} = energy per 6.2.2.2,
R_v = reaction per 6.2.2.4, and
R_{test} = reaction per 6.2.2.2.

6.3 *Temperature Factor (TF)*—Temperature factors (*TF*) for pneumatic fenders may be calculated using ideal gas laws. For every urethane, foam or rubber compound, the *TF*s shall be determined by the following procedure.

6.3.1 Conduct standard performance tests on temperature-stabilized specimens using either Method A or Method B, per one of the two methods described below:

6.3.1.1 (*A*)—Stabilize specimens at test temperature per 6.1.2 and 6.1.3. Specimens shall be either full-size fenders or models not smaller than 0.1 m in height. Test specimens in test apparatus maintained at test temperature for duration of test.

6.3.1.2 (*B*)—Stabilize specimens at test temperature per 6.1.2 and 6.1.3. Specimens shall be either full-size fenders or models not smaller than 0.3 m in height. Test specimens at room temperature. Test must be completed within 15 min of sample's removal from temperature-controlled environment.

6.3.2 Specimens shall be stabilized at the following temperatures: −30, −20, −10, 0, +10, +23, +30, +40, and +50°C. The *TF*s for each of these temperatures, TF_t, where $_t$ is the number designating the reference temperature, shall then be calculated by the following equations:

$$TF_t = R_t/R_{23} \tag{9}$$

$$TF_e = E_t/E_{23} \tag{10}$$

where:
R_t = reaction at temperature other than 23°C (highest reaction below 0.35 *H* deflection),
R_{23} = reaction at 23°C (highest reaction below 0.35 *H* deflection),
E_t = energy at temperature other than 23°C, and
E_{23} = energy at 23°C.

7. Verification/Quality Assurance Testing

7.1 *Energy/Reaction Compliance Testing*—Verification/quality assurance testing to determine compliance with either *RPD* or other customer-specified energy and reaction requirements (required performance) shall be performed in a test apparatus, as described in Section 4. Samples for verification testing shall be actual fender elements fabricated for the project location. For cylindrical foam, pneumatic, and hydropneumatic fenders larger than 1800-mm diameter by 3600-mm long, the tests of a 1200-mm diameter by 2000-mm long or larger fender may be scaled to demonstrate the energy and reaction ratings of the fender. The projected fender and the test fender shall both be constructed with the same materials, have the same general configurations of the ends, and have the same skin thickness-to-diameter ratio. Scaling shall be conducted per the following equations:

$$\text{Energy} = \text{test fender energy} \times \text{diameter ratio squared} \times \text{overall length ratio} \tag{11}$$

$$\text{Reaction Force} = \text{test fender reaction} \times \text{diameter ratio} \times \text{overall length ratio} \tag{12}$$

7.1.1 Test sample according to Method A (5.2) or Method B (5.3), adjusting performance to required performance as specified in 5.2.6 or 5.3.6, and 5.3.7.

7.1.2 A fender provides the required performance (required energy and reaction) within production tolerances if it meets both the following requirements simultaneously at any point during the test described in 7.1.1:

7.1.2.1 Velocity-and-temperature-adjusted energy absorbed is equal to or greater than the required energy multiplied by the nominal energy tolerance (low end) specified in its catalogue data.

7.1.2.2 Velocity-and-temperature-adjusted reaction is no more than the required reaction multiplied by the nominal reaction tolerance (high end) specified in its catalogue data.

7.2 *Other Testing*—Other testing requirements, including selection of sampling scheme, shall be as agreed between customer and fender manufacturers.

8. Effect of Contact Angle Testing

8.1 Manufacturers shall include graphs or tables defining the effect of deflecting fenders at the contact angles listed in 3.1.3 (*3*). This data may be generated mathematically or by testing performed on either actual fender elements or on scale models or arrays. It must reflect the effect of angle contact on an entire fender assembly, not just an individual element.

8.2 The following is the procedure for defining the effect of each contact angle/configuration combination. The test shall be made on the horizontal and vertical axes of the fender unit:

8.2.1 Using a test apparatus as described in Section 4, execute the steps of the test procedure defined in 5.2 or 5.3.

8.2.2 Determine the base-case energy rating for 0° contact angle of the specimen at the deflection or reaction limit recommended by the manufacturer.

8.2.3 Allow the specimen to recover outside the test apparatus for at least 1 h or more as recommended by the manufacturer.

NOTE 3—A 5-min recovery period is sufficient for pneumatic fenders.

8.2.4 Attach a "wedge" to the test apparatus' moveable surface to simulate the desired contact angle and repeat the test cycle only of 8.2.1.

8.2.5 Determine the energy rating of the specimen in the contact angle test at the manufacturer's recommended deflection or reaction limit.

8.2.6 The contact-angle factor is the energy determined in 8.2.5 divided by that determined in 8.2.2.

8.3 This factor is applied to energy only. No factor need be applied to reaction, since the maximum reaction is as defined by the 0° contact-angle performance. For combined horizontal and vertical contact angles, multiply the contact-angle factor for the horizontal direction by the contact-angle factor for the vertical direction.

9. Precision and Bias

9.1 No information is presented about either the precision or bias of Test Method F 2192 measuring the performance of fenders. The precision and bias information is being determined and will be available on or before May 2006 following Practice E 691.

10. Keywords

10.1 berthing; berthing energy; deflection; energy absorption; fender; fender testing; rated performance data; reaction; temperature factor; velocity factor