APPENDIX A

PROCEDURE TO DETERMINE AND REPORT THE PERFORMANCE OF MARINE FENDERS

1. INTRODUCTION

1.1 A marine fender is an energy-absorbing device that is typically secured against the face of a marine facility for the purpose of attenuating the forces inherent in arresting the motion of berthing vessels safety. Most modern fenders fall into three general classifications based on the material employed to absorb energy:

a) Solid rubber fenders where the material absorbs the energy

b) Pneumatic (air-filled rubber) fenders where air absorbs the energy

c) Foam filled fenders where the foam core absorbs the energy.

1.2 This document establishes the recommended procedures for testing, reporting and verifying the performance of marine fenders. The primary focus in this document is on "solid-type" rubber fenders, used in berthside application for commercial and naval vessels. Appendix B deals with pneumatic fenders. The testing protocol does not address other fender types and materials of construction nor small fendering " bumpers" used in pleasure craft marinas, mounted to hulls of work vessels, military vessels or those used in similar applications. Its primary purpose is to ensure that engineering data reported in manufacturers' catalogues is based upon common testing methods throughout the industry.

1.3 "Solid-type" rubber fenders are available in a variety of basic types with several variations of each type, and multiple sizes and rubber compounds for each variation. Depending on the particular design, "solid-type" rubber fenders may also include integral components of steel, composites, plastics or other materials. Geometrical and component variations of "solid type" rubber fenders should be performance tested and reported according to this protocol. All variations of rubber compounds need not be tested and this is left to the manufacturer's discretion to test an adequate portfolio of compounds to enable a particular compound performance to be predicted.

1.4 This protocol consists of three parts:-

a) Definition of Rated Performance Data (RPD), which defines minimum requirements for manufacturers' published catalogues data;

b) Definition of test apparatus and basic performance-test procedures;

c) Supporting protocols and other tests:
   - i Velocity Factor (VF) determination
   - ii Temperature Factor (TF) determination
   - iii Contact angle effect determination
   - iv. Durability testing
   - v Temperature stabilization
   - vi Verification/quality assurance testing
   - vii Rubber property testing

2. FENDER PERFORMANCE AND REPORTING

2.1 GENERAL

2.1.1 All testing shall define fender performance under linearly-decreasing or sinusoidal-decreasing deflection velocities to simulate actual, vessel-berthing conditions.

Rated Performance Data (RPD), manufacturers' published performance curves and/or tables, shall be based on:

a) Initial deflection (berthing) velocity of 0.15 m/s and decreasing to no more than 0.005m/s at test end;

b) Testing of fully broken-in fenders;

c) Testing of fenders stabilized at 23C±5C;

d) Testing of fenders at zero degree angle of approach;

e) Deflection (berthing) frequency of not less than one hour

2.1.2 Catalogues shall also include nominal performance tolerances as well as data and methodology to adjust performance curves and/or tables for application parameters different from RPD conditions. Adjustment factors shall be provided for the following variables:

a) Other initial velocities: 0.001, 0.05, 0.10, 0.20, 0.25 and 0.30 m/s deflection (approaching) velocity, decreasing to no more than 0.005 m/s at test end;

b) Other temperatures: +50° C, +40° C, +30° C, +10° C, 0° C, -10° C, -20° C, -30° C;

c) Other contact angles: 3, 5, 8, 10, 15 and 20 degrees

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 manufacturer for design assistance.

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

2.2 FENDER TESTING

This document establishes procedures to be able to standardize the performance characteristics of fenders being tested using two methods:

- The traditional and widely used Constant Velocity (CV) Method, and
- Decreasing Velocity (DV) Method

Performance testing to establish design data may use either of two methods:

2.2.1 Method CV – Constant-slow-velocity deflection of full size fenders with performance adjusted by velocity factors developed from scale model tests. This method is the preferred method of a majority of manufacturers.

Test to establish initial performance data by full-size fender under the constant-slow 0.0003-0.0013 m/s (2-8 cm / min) velocity. Establish VF obtaining scale-model test and calculate the RPD of full-size fender.

Establish adjustment factors from scale model test for initial berthing velocities other than 0.15 m/s.

Velocity Factor shall be the ratio of performance-test results of scale models under the following conditions:

a. a constant slow strain rate similar to the strain rate of full-size fender at its test speed

b. decreasing-speed deflection with initial strain rate similar to that of the full-size fender RPD and other deflection conditions

2.2.2 Method DV – Linearly or sinusoidally-decreasing-velocity deflection of full-size fenders

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. TEST APPARATUS

3.1 The test apparatus shall be equipped with a calibrated load measuring device such as load cell(s) or pressure transducer and linear transducer(s) for measuring displacement 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 0.01H-0.05H, where H is a fender's nominal height, and storing manually-entered inputs The following information shall include, as a minimum:

a. Serial number and description of test item

b. Date, time at start and time at end of test

c. Location of test facility and test apparatus ID

d. Stabilization temperature of test specimen

e. Test ambient temperature

f. Graphic plot(s) and tabular printout(s) of:
   - i. Deflection velocity vs deflection (optional) (If not plotted, deflection velocity and its characteristics shall be separately noted)
     Applicable to Method DV only:
   - ii. Reaction vs. deflection
   - iii. Energy vs. deflection.

3.2 For fender tests, all equipment used to measure and record force and deflection shall be calibrated, and certified accurate to within ±1 (one) percent 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 checked annually by a qualified third-party organization, using instrumentation, which is traceable to a certified, national standard.

3.3 The test apparatus shall deflect specimens according to the Test Protocol, (Section 4.0) below.

4. TEST PROTOCOL

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

4.1 METHOD CV

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

b. Remove load from specimen and allow it to "recover" for at least one hour

c. Before conducting performance test, stabilize fender temperature, see Section 5.1. Temperature stabilizing time can include time for preceding steps 4.1.a. and 4.1.b

d. Deflect specimen once at constant slow 0.0003-0.0013m/s (2-8 cm/min) deflection

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

f. Adjust performance to rating temperature (23°C±5°C), if required, or to desired application temperature by multiplying both energy and reaction results by Temperature Factor, TF (Section 5.3).

g. Adjust performance to desired initial berthing velocity, by adjusting both energy and reaction results by Velocity Factor, VF (Section 5.2)

4.2 METHOD DV

a) Break-in specimen by deflecting three or more times to its rated deflection or more, as recommended by the manufacturer

b) Remove load from specimen and allow it to "recover" for at least one hour.

c) Before conducting performance test, stabilize fender temperature in accordance with Section 5.1 Temperature stabilizing time can include time for preceding steps 4.2.a. and 4.2.b.

d) Deflect specimen once at a linearly-decreasing or sinusoidally-decreasing variable deflection velocity as defined in the equations below:

$$V = V_o(D-d)/D \qquad \text{[EQ. 4.1]}$$

or 0.005 m/s whichever is greater

or

$$V = V_o\cos(\pi d/2D) \qquad \text{[EQ. 4.2]}$$

or 0.005 m/s whichever is greater

where:

V = Instantaneous deflection velocity of fender
V_o = Initial deflection velocity (actual berthing condition)
d = Instantaneous deflection of fender
D = Rated deflection of fender

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

f) Adjust performance to rated temperature (23°C±5°C), if required, or to desired application temperature by multiplying both energy and reaction results by Temperature Factor, TF (Section 5.3)

5. SUPPORTING PROTOCOLS

5.1 TEMPERATURE STABILIZATION

5.1.1 Test temperature for full-size specimens is defined as the same as the stabilization temperature, as long as ambient temperature at the test apparatus is within ±15° C of the stabilization temperature and testing is completed within two hours

5.1.2 To stabilize rubber temperature, store specimen at a constant temperature ±15° C. Record air temperature of the space where specimen is stored within 3m of specimen surface, either continuously or twice a day, no less than ten hours apart.

5.1.3 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 metres).

5.2 VELOCITY FACTOR, VF

One of the following protocols shall be followed to determine the Velocity Factors, VF, for every combination of fender configuration, initial velocity other than RPD velocity, fender height and energy-absorbing material. Specimens for determining VF may be either full-size fenders or models, as noted below, provided they are not smaller than 0.1m in height

5.2.1 Method CV – Testing of scale model maintaining strain rates as described in 2.2.1 a) and 2.2.1 b).

The model should be accurately scaled to the model proposed for sale.

a) Test model sized fenders as per Section 4.2 at n x 0.15 m/s initial velocity at 23° C±5° C (n : model height / actual height)

b) Repeat step a (above) at other initial velocities (including the constant slow velocity).

c) Derive VF's, from the data in steps 5.2 1a. and 5.2.1 b (above) per the following method:

i Energy Velocity Factor and Reaction Velocity Factor by Method CV

VF_{ea} and VF_{ra}, shall be defined by the following equations:-

$$VF_{ea} = E_{vM} / E_{RPD} \qquad [EQ\ 5.1]$$

$$VF_{ra} = E_{vM} / R_{RPD} \qquad [EQ\ 5.2]$$

where:

E_{vM} = Energy absorption at other initial velocities than as 5.2.2.b
E_{RPD} = Energy absorption at the initial velocity than as 5 2 2 a at the model
E_{vM} = Reaction at other initial velocities per section 5.2.2.b
R_{RPD} = Reaction at the RPD initial velocity per section 5 2 2 a at the model

ii. Corrected energy and reaction performance is then calculated by the following formulas:

$$E_a = E_{RPD} \times VF_{ea} \qquad [EQ.5.7]$$

$$R_a = R_{RPD} \times VF_{ra} \qquad [EQ\ 5\ 8]$$

where:
E_a = Energy absorption at alternative initial velocity
R_a = Reaction at alternative initial velocity
E_{RPD} = Energy at RPD initial velocity
R_{RPD} = Reaction at RPD initial velocity

5 2 2 Method DV - Testing of full size fender at decreasing-rate deflection velocity

a) Test full-size fender models per Section 4 1 at 0.15m/s initial velocity 23°C+5°C.

b) Repeat step a (above) at other initial velocities.

c) Derive the VFIs from the data in steps 5.2.1 a and 5 2 1.b.(above) per the following method:

i Energy Velocity Factor and Reaction Velocity Factor by Method A DV

$$VF_{ea} = E_v / E_{RPD} \qquad [EQ.\ 5.1]$$

$$VF_{ea} = R_v / R_{RPD} \qquad [EQ\ 5\ 2]$$

where:
E_v = Energy at other initial velocity per Section 5.2 1.b.
E_{RPD} = Energy at the RPD initial velocity per Section 5 2 1 a
R_v = Reaction at other initial velocity per Section 5 2.1.
R_{RPD} = Reaction at the RPD initial velocity per Section 5.2 1.a

ii Corrected energy and reaction performance is then calculated by the following formulas:

$$E_a = E_{RPD} \times VF_{ea} \qquad [EQ\ 5\ 3]$$

$$R_a = R_{RPD} \times VF_{ra} \qquad [EQ\ 5.4]$$

where:
E_a = Energy at alternative initial velocity
R_a = Reaction at alternative initial velocity
E_{PRD} = Energy at RPD initial velocity
R_{RPD} = Reaction at RPD initial velocity

5.3 TEMPERATURE FACTOR, TF

The following shall be completed for every rubber compound.

5.3.1 Tests of the rubber compound and fender type at each of the following temperatures:

-30°C, -20°C, -10°C, 0°C, 10°C, 23°C, 30°C, 40°C, 50°C

5.3 2 The preliminary Temperature Factor, TFp, for each rubber at each temperature shall be its shear modulus at that temperature divided by its shear modulus at 23°C

5.3 3 Confirm the TFp's by conducting standard performance tests, either Method CV or Method DV, Stabilize specimens at the temperature per Section 5 1.2. and 5.1.3 Specimens may be either full-size fenders or models not smaller than 0 1m in height Test specimens in test apparatus maintained at test temperature for duration of test

Test specimens shall be stabilized at –20°C, 0°C, and +23°C Divide the results at –20°C and 0°C by the result at +23°C If these results corroborate the shear-modulus results within +5%, the TFp's shall be the TF's.

5.3.4 If the performance tests do not corroborate the shear-modulus data, further tests shall be conducted on specimens stabilized in temperature-controlled environments at the following temperatures:

-30°C, -20°C, -10°C, 0°C, +10°C, +23°C, +30°C, +40°C and +50°C. The TF's for each of these temperatures, Tft's, shall then be calculated by the following formula:

$$TF_t = R_t/R_{23} \qquad \text{[EQ 5.9]}$$

where:

R_t = Reaction at temperature other than 23°C (highest reaction below 35% deflection)

R_{23} = Reaction at 23°C (highest reaction below 35% deflection)

However, in the case of fenders whose reaction does not drop after a peak around 30% deflection in low temperature, TF shall be based upon the ratio of maximum reactions when energy absorption specified by the fender manufacturer is achieved

6. VERIFICATION/QUALITY ASSURANCE TESTING

6.1 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 3.

Samples for verification testing shall be actual fender elements fabricated for the project location.

6.1.1 Test Sample according to Method CV (Section 4.1.) or Method DV (Section 4.2.), adjusting performance to Required Performance as specified in Sections 4.1.f or 4.1.g and 4.2.f

6.1.2 A fender provides 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 Section 6.1.1:

a Velocity-and-temperature-adjusted energy absorbed in equal to or greater than Required Energy multiplied by the nominal energy tolerance (low end) specified in its catalogue data

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

6.1.3 The fender samples for energy/reaction verification testing shall be selected according to a sample scheme agreed between the customer and fender manufacturer. If a specific sampling scheme has not been noted, a minimum of ten percent of the fender order shall be tested for compliance with energy/reaction requirements.

6.2. BREAK-IN DEFLECTION

Break-in deflection of actual elements should be at least manufacturer' rated deflection. At least one cycle should be performed

6.2.1 Break-in deflection shall be mandatory for all fenders with catalogue reaction rating of 100 tonnes or more to be installed on monopiles or pile-supported pier structures. Break-in deflection of other fenders shall be as stipulated by the customer.

6.3 OTHER TESTING

Production fenders may be tested for conformance with specified material properties, alternate performance requirements, and/or durability characteristics.

6.3.1 Verification/quality assurance testing of production fenders may be requested by the customer to insure product conformance with specified contact angle performance, durability, and/or material property characteristics

6.3.2 Other testing requirements, including selection of sampling scheme, shall be as agreed between customer and fender manufacturers.

7. OTHER TESTS

7.1 EFFECT OF CONTACT ANGLE

7.1.1 Manufacturers shall include graphs or tables defining the effect of deflecting fenders at the contact angles listed in Section 2.1.2.c. 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.

7.1.2 The following is the procedure for defining the effect of each contact-angle/configuration combination. The test shall be made on the two major axes of the fender unit:

a Using a test apparatus as described in Section 3, execute the steps of the test procedure defined in Section 4.1. or 4.2.

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

c. Allow the specimen to recover outside the test apparatus for at least one hour or more as recommended by manufacturer

d. Simulate the desired contact angle and repeat the test cycle only of step 7 1 2 a

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

f. The contact-angle factor is the energy determined in the step 7 1 2e divided by that determined in step 7.1 2 b

This factor is applied to energy only. No factor need be applied to reaction, since the maximum reaction is as defined by the zero-degree-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 if the factors for both directions are different.

7.2 DURABILITY

7.2 1 Each combination of fender type and energy-absorbing material shall be tested for durability to insure its suitability to withstand repeated deflections without enough recovery time to return to original performance characteristics.

7.2.2 The test specimen may not be smaller than the smallest fender of the same basic design offered for sale. The specimen L/H ratio may not be less than the lowest ratio of any catalogues model of the same, basic design

7.2.3 Before the test begins, stabilize the specimen's temperature to +23°C+5°C per Section 5.1, Temperature Stabilization. Do not artificially cool the specimen during the test

7.2 4 The test shall consist of 3 000 deflections of the specimen to its rated deflection at a maximum period of 150 seconds.

7.2.5 The criterion for successful completion of the durability test is no cracks or defects visible to the naked eye after the 3.000 deflections.

7.3 PHYSICAL PROPERTIES OF RUBBER

The properties recommended in this section are those that help assure acceptable resistance to the effects of aging and environmental attack. The following physical properties of rubber are recommended as standard requirements:

Resistance to heat aging:

Test tensile strength, elongation and hardness per JIS, ASTM or ISO standards. Then place a second set of samples into an oven maintained at 70°C+/-1°C for a period of 96 hours. After removing the samples from the oven, repeat the same tensile strength, elongation and hardness tests. Compare the results before and after heat aging. The following are the minimum requirements for satisfactory aging resistance:

a Tensile Strength after aging: not less than 80% of original value.

b Elongation after aging: not less than 80% of original value

c Hardness after aging: not more than 8 points Shore A of increase from original value

Resistance to ozone:

Conduct a standard, ozone-exposure chamber ozone-exposure test per one of the following standards:

_ JIS K 6259 40°C, 20% elongation and 50 pphm ozone level

_ ASTM D 1171, ozone exposure, method A, 38°C

_ ISO 1431-1, procedure A 40°C, 20% elongation and 50 pphm ozone level.

After 72 hour's exposure, there shall be no visible cracking of the test strips.

7.4 DIMENSIONS

Fenders shall meet manufacturer's specified dimensional tolerances