Wave induced motions in an articulated fish cage

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WAVE INDUCED MOTIONS IN AN ARTICULATED FISH CAGE

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SUMMARY

This report details experiments conducted on an IMD developed fish cage design. The purpose of the study was to investigate design features which are, or may be, incorporated into cage designs. These features included cylindrical floats, an articulated deck, a lower net ring, motion damping, and various mooring attachment points. The experiments assessed the response of the system to regular waves for different mooring configurations and wave directions and included the effect of joining multiple cage units. The objectives of the program were to quantify the wave induced motions of the articulated flotation collar, to measure the wave induced motions of a lower shape retaining ring, and to determine the effects of some alternate mooring configurations on the motions of the collar and the ring.

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A1B 3T5

CONTENTS

Summary

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Results indicate that the motions of the collar sections are reasonable except for the aftmost section which exhibited a tendency to "kick" as larger waves passed. Joining multiple units resulted in reduced motions overall. In addition the lower ring was found to exhibit large pendular motions as wavelengths increased. Alternate mooring configurations were found to significantly reduce some motion modes but at increased cost in mooring complexity.

Introduction

This report details the evaluation of a prototype model of a Fish Cage Design developed at IMD and a set of wave induced motion experiments conducted on the model. Development of the cage design arose from observation of problems with existing fish cages used by the salmon farming industry in eastern Canada, primarily New Brunswick. The concept was developed as a solution with features for areas where rougher conditions might prevail as the industry moves into more exposed locations.

The intention of this research was not so much to develop a specific design but to investigate features which are or may be incorporated into cage designs. The features incorporated into the design included cylindrical floats, an articulated deck, a lower net ring to provide shape retention for the inner and outer nets and which also provided a degree of motion damping. The experiments assessed the response of the system to regular waves for different mooring configurations and wave directions. In addition the system concept allowed multiple cage units to be assembled as a larger single unit and the experiments evaluated the effect on individual motions of the larger multiple cage units. The objectives of the program were: to quantify the wave induced motions of the articulated flotation collar, to measure the wave induced motions of a lower shape retaining ring, and to determine the effects of some alternate mooring configurations on the motions of the collar and the ring.

Cage Design

The cage built and tested in this program was originally conceived as a design for the salmon industry. The intent was to minimize structural complexity, provide an elevated working deck, a strong structure, minimal wave and current loading and ease of fabrication and assembly. We also intended to improve the shape retention of the net bag and improve predator protection. As developed for this particular design, these aspects may be more or less practical in terms of present-day operational practices. The intention was to evaluate various features from the point of view of environmental loads. The individual features may be useful in themselves without adoption of the whole design.

The cage design consists of a collar or working deck which supports the net and provides access for farmers. The deck is octagonal in plan, with four articulation points, each consisting of a right-angled hinge. The design of the deck is such that it can be fabricated from two basic pieces, a side unit and a hinge unit. Each complete cage requires four each of these two units and an infinite number of cages can be linked together through hinge pins located along the back of each side unit. The basic design of a single unit and a four unit configuration is shown in Appendix 1. Individual drawings of the side and hinge units are included.

The deck is supported by cylindrical floats which provide sufficient buoyancy to support the deck, netting and other structure but not the mooring weight. In addition, the diameter and depth of the floats should be designed, for a full scale installation, to insure that each side unit is hydrostatically stable. This feature provides ease of assembly in the full scale and improved motions in the fully assembled cage. However, due to the differing materials used in model construction, this could only be achieved by adding ballast which was originally intended only to simulate the weight of nets.

To provide stability and shape retention in the net bag and predator protection netting, an octagonal ring is also provided at the bottom of the cage. This ring is fitted with horizontal flat plating to act as a motion damper in addition to its role as a shape retention member.

Late in the development, the potential for raising ground fish in a similar design by providing a fabric bottom and by mooring from the bottom ring to minimize motions at fish-level was raised. This did not require modification of the cage design, but extra tests were incorporated into the program to assess this potential.

Purpose of Testing

The purpose of model testing was to measure the motions of the deck and lower ring under various wave conditions to assess the stability and ultimate workability of the design, particularly in rough seas. The experiments assessed the response of the system to regular waves for different mooring configurations and wave directions and included the effect of multiple cage units. The objectives of the program were: to quantify the wave induced motions of the articulated flotation collar, to measure the wave induced motions of a lower shape retaining ring, and to determine the effects of some alternate mooring configurations on the motions of the collar and the ring.

The testing consisted primarily of regular wave tests at wavelengths corresponding to even fractions and multiples of the cage principal dimension. The motions of two adjacent deck sections were measured with an optical motion tracking system and the motions of the underwater ring were measured using video cameras.

A secondary purpose of the testing was to measure the wave induced drag (or drift force) on the collar. This was achieved by measuring the mean surge deflection of the total cage on the mooring. Since the surge direction stiffness of the surface mooring could be easily calculated from the known spring stiffness of the mooring, the force to cause the measured deflection could also be calculated.

Two configurations were tested, one consisting of a single cage unit and the other consisting of four cage units linked together as they would be in a realistic fish farming configuration.

Netting was not included in any of the tests due to problems in scaling the drag and damping characteristics of netting. Thus these tests are conservative estimates of the motions of the cage structure because inclusion of netting would reduce the motions from those measured.

Model Construction

The deck/collar model was constructed of fibreglass structural sections, rivetted and glued together. The scale was approximately 1:6 based on a full scale cage diameter of about 15 m. Flotation elements were 250 mm lengths of 200 (8 inch) diameter water pipe, capped at both ends and filled with urethane foam. These floats were heavier than a scaled version of a full scale float. The lower ring was aluminum made up of round sections with flat plate welded horizontally. Cables run through the centre of each float supported the ring.

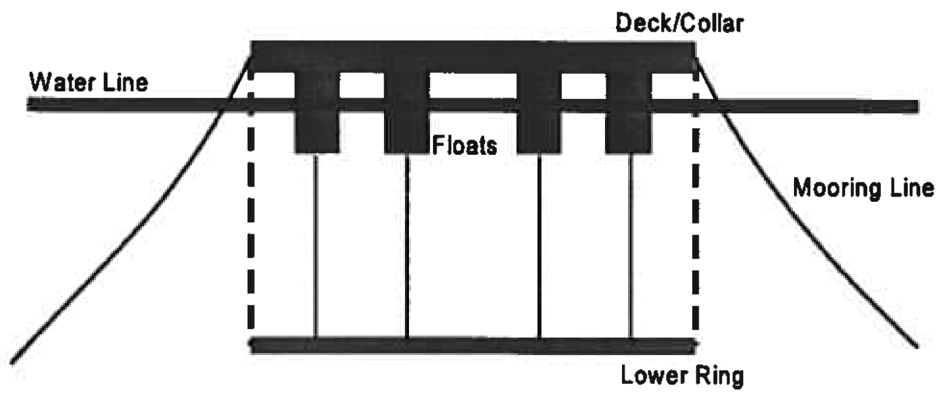
Mooring lines were modelled as light weight cables with in-line springs. These springs simulated the catenary effects in the mooring line.

Mooring Configurations

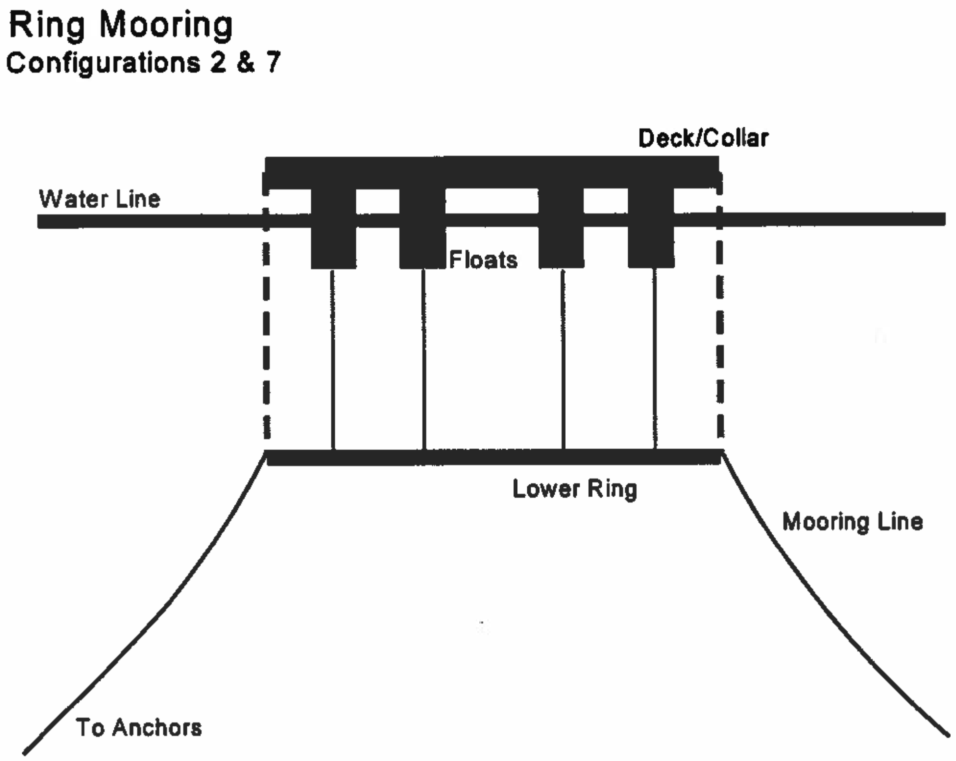
Three basic mooring line configurations were tested to assess the effect of the mooring on the cage motions. These were designated as a Catenary Mooring, a Ring Mooring and a Basket Mooring. In addition a Surface Mooring configuration was used to simulate a catenary mooring with an intermediate float and allow the mean drift force to be measured.

Catenary Mooring

Configuration 1



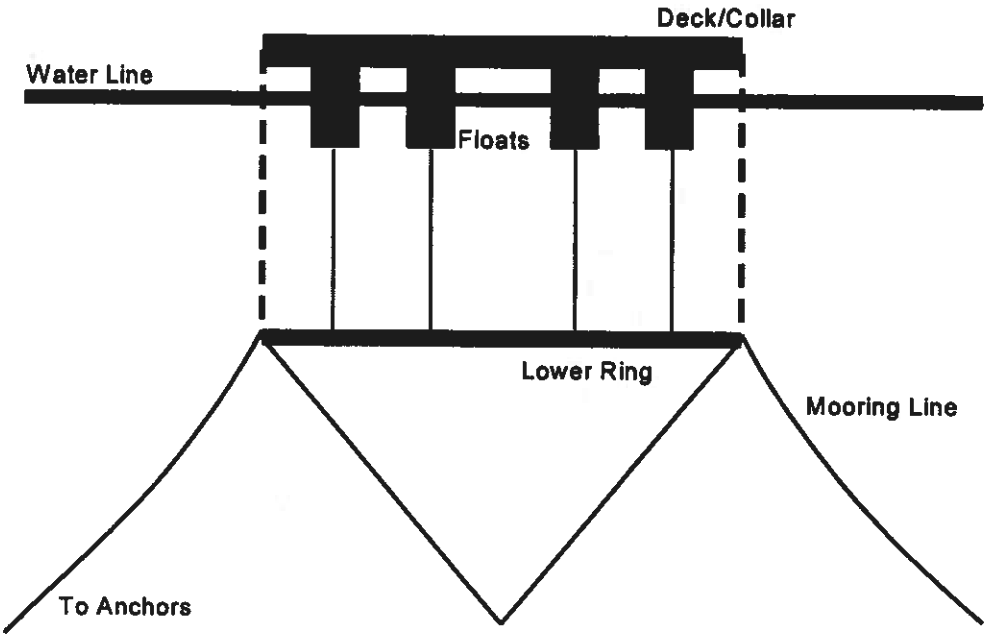
The Catenary Mooring is a conventional cage mooring typical of those presently used in fish farm applications. In the model case, the mooring was attached directly to the cage but in practice an intermediate support float would be used to support the mooring weight. In some of the test configurations the effect of this buoy is modelled by changing the angle at which the mooring line was attached to the collar.



The Ring mooring was simply a catenary mooring in which the mooring lines terminated on the lower ring. This configuration was evaluated as a means of reducing motions in the cage bottom. In this case the system was modelled as if the weight of the mooring was supported by the cage without intermediate floats.

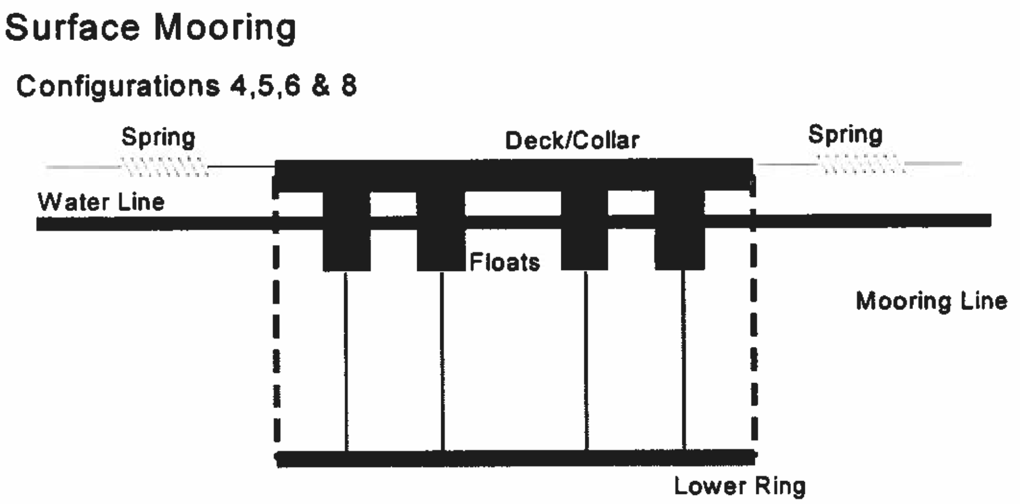
Basket Mooring

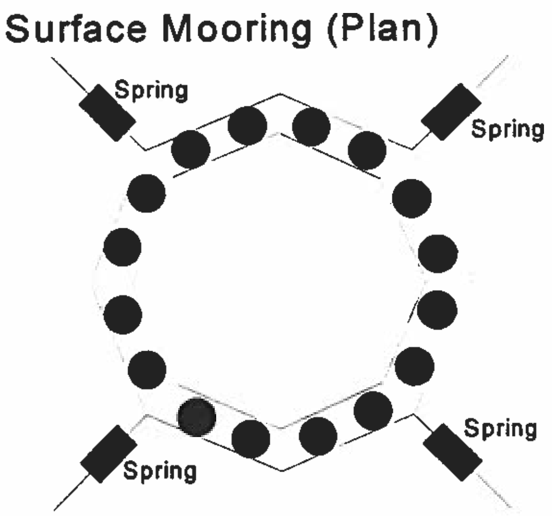
Configuration 3



The basket mooring was an attempt to combine the vertical stiffness of a tension leg mooring with the horizontal stiffness of a catenary mooring as a means of further reducing motions in the cage bottom. This configuration was only tried on the single cage unit.

The surface mooring consisted of four horizontal springs attached to the cage collar. This provided only a horizontal restoring force for which the gross spring constant could be calculated. It also mimicked a properly supported mooring line in that it did not apply any vertical force to the cage collar





Instrumentation

Instrumentation for the experiments consisted primarily of motion measuring devices. For the collar section of the cage, which was above water, two adjacent hinged sections were instrumented to allow a Qualisys Optical Motion Measuring System to measure the motions of those sections of the collars. For the underwater portions of the system, primarily the lower ring, underwater video records of the motions were kept and subsequently analysed using video analysis software to give a measure of the motions of the ring(s). In measuring mean drift forces, calibrated springs were used in the horizontal mooring with a known geometry. The mean surge displacement was derived from the Qualisys data and the average force calculated from the known spring constants and geometry. A brief description of each of the systems follows.

Qualisys Motion Tracking System

Two QUALISYS Position Sensors and Videoprocesors were used with an IBM compatible computer running IMD in-house software to track the six degrees of freedom motion of a model in real-time. Seven reflective markers were placed on a wire frame attached to each of the cage collar segments for a total of fourteen markers on the cage.

To convert camera image coordinates to motions in six degrees of freedom, the information is processed by solving first the photogrammetric equations to obtain the x, y, z coordinates of each marker. This data is then transformed in a least squared sense to surge, sway, heave, pitch, roll and yaw motion of the model relative to a chosen reference frame. Normally this process is only carried out once for a single rigid body. However in this case, the body was articulated and two separate sections had to be analyzed to give the six degree of freedom motions for each segment.

The accuracy of the system depends on the distance of the cameras from the model. For this application, a displacement measurement accuracy of 1 mm, model scale, was realized. In terms of pitch, roll and yaw motions, this corresponds to an angular accuracy of approximately 0.3 degrees.

Video

A single monochrome video camera placed at the same elevation as the lower ring was used to record motions of the underwater portion of the cage. The zoom lens was adjusted to give the best field of view and then maintained for the remainder of the test. The field of view was sufficient to record the heave and surge motions of the ring by insuring that a reference point was always within the field of view.

This reference was then used in subsequent analysis as the measuring point in determining the motions of the cage.
In analysing the video data, the length of cable from the bottom of the float to the attachment point on the ring was used as a check and reference dimension to insure that the focal length of the lens had not been altered during testing.

Calibrated mooring springs
IMD maintains a stock of calibrated springs for use in modelling mooring systems. The springs used in this experiment were approximately 59.3 N/m. The mooring was arranged with an equal length spring in each of four lines arranged in a symmetrical 45 degree pattern. For small angles of displacement this gives a net mooring spring constant of 118.6 N/m.

Experimental Program

The experimental program consisted of eight series of tests as follows:

Configuration & Data Label	Mooring Attachment	Mooring Type	Ballast	No of Cages	Wave Direction
1 (FHW*U1M1)	Collar	Catenary	No	1	Head
2 (FHW*U1M2)	Ring	Catenary	No	1	Head
3 (FHW*U1M3)	Ring	Basket	No	1	Head
4 (FHW*U1M4)	Collar	Horizontal	No	1	Head
5 (FHW*U3M4)	Collar	Horizontal	Yes	1	Head
6 (FHW*U4M1)	Collar	Horizontal	Yes	4	Head
7 (FHW*U4M2)	Ring	Catenary	Yes	4	Head
8 (FQW*U4M1)	Collar	Horizontal	Yes	4	Quarter

A brief description of each configuration is as follows:

1. Single cage unit Catenary mooring in which the cage supported the mooring weight. Head waves.

2. Single cage unit, Ring mooring, Head waves

3. Single cage unit, Basket mooring, Head waves

4. Single cage unit with a surface mooring in which the cage did not support the mooring weight. Head waves

5. Single Cage Unit with extra ballast and a surface mooring in which the cage did not support the mooring weight. Head waves

6. Four Cage unit with extra ballast and a surface mooring in which the cage did not support the mooring weight. Head waves

7. Four Cage unit with extra ballast and a ring mooring. Head waves

8. Four Cage unit with extra ballast and a surface mooring in which the cage did not support the mooring weight. Quartering waves

In each of these configurations the same series of regular waves was run as follows (not all waves were run for all configurations):

Wave Number	Height (cm)	Period (sec)	Wavelength L= 2.5m MS
1	5	0.67	1/4 L
2	10	0.94	½ L
3	10	1.33	L
4	20	1.33	L
5	10	1.88	2L
6	25	1.88	2L
7	5	0.69	1/4 L
8	10	2.32	3 L
9	25	2.32	3 L
0	10 Hsig	Pierson Moskowitz Spectrum	

Results

Full results of motion transfer functions for six degrees of freedom are presented for both the instrumented cage segments in Appendix 3. However the detailed presentation of results for analysis purposes is confined to surge and heave results for a single segment and for the lower ring. In addition the mean wave drift force is derived from the mean surge for cases where the mooring configuration was horizontal and the horizontal plane net spring stiffness of the mooring can be calculated. The detailed analysis is confined to these motions because angular motions such as roll and pitch were relatively small (except for one segment) and motions such as sway and yaw were not evident due to the single wave direction. In addition, surge and heave motions are the most significant wave induced motions in relation to motions experienced by workers or fish and in terms of loads on the moorings. The more detailed results are presented in Appendix 2.

Response Amplitude Operators (RAOs) or Transfer functions are derived from tests of a structure in regular waves. For each steady state sinusoidal wave, the steady state response of the structure is measured. The results are then presented as Response per Unit Wave Height, varying with wave period. In order to scale the results it would be necessary to non-dimensionalise the wave period to the ratio of wavelength to structure length. Mean lines for the data collected are plotted on uniform scales and presented in Appendix 2. These transfer functions can be compared directly or combined with statistical wave descriptions to yield statistics of the structure response in a realistic sea state. Results are discussed by category below.

Collar Segment Surge

The surge motions of the collar are presented for the eight configurations tested. In general the surge motion increased as the wave period (wavelength) increased. The mooring configuration did not have a pronounced effect on the peak amplitude of motion but did tend to induce slight shifts in the wave period (or frequency) where peaks occurred. In comparing the single unit configuration with the four unit cage, the multiple cages exhibited lower surging motion, probably because the wave induced forces on adjacent units tended to cancel each other.

Collar Segment Heave

Heave motions are practically unaffected by the mooring except in the case of the basket mooring which showed better than 50% reduction in collar heave motions. This result was expected due to the nature of the mooring. As with surge, the heave motions tend to increase with increasing wave period (wavelength). In all cases the heave motions did not exhibit a resonant peak but tended to approach a value of one as wavelength increased. This is an expected result for an articulated structure with relatively high heave damping from the cylindrical floats. It also indicates that the structure tends to filter out short waves and contour itself to longer waves. There was no reduction in heave for the multiple unit configuration in comparison to the single unit.

Collar Segment Pitch/Roll

The angular motions of the deck sections do not have a great effect on the average position of the cage but are relevant to wear in the articulation points, stress at the net attachment points and the ability of people to work comfortably on the platform in rough seas. In general the roll/pitch motions of the segments increased in the downwave direction. For a single unit the motions were generally higher than the motions of the segments in the four unit configuration.

Although it is not evident from the motion results because the aft segments were not instrumented, an interesting pitching phenomena was observed from video records of the tests. The last segment of the cage in either the single unit or four unit configurations tended to pitch with relatively high amplitude. This was observed to be due to the passing of a wave crest which tended to lift the aftmost segment as the forward sections were descending the slope of the wave. Because there were no additional segments attached down-wave the last section was rotated sharply about the hinge without restraint leading to much higher pitch motions than those observed on the other cage segments.

Lower Ring Surge

The lower ring exhibited a tendency to surge with the amplitude increasing as the wave length increased. Attaching the mooring directly to the ring reduced the tendency to surge with the basket mooring showing the best suppression of surge motions. For cases where the mooring was attached to the collar, the surge amplitudes became quite large. In these cases, the ring acted as a pendulum excited from the top in which case it tended to amplify the motions from the collar, with the amplification effect increasing with increasing wave length. The net result is that the ring showed larger motion amplitudes than the collar for a given wave condition with the difference increasing as the waves got longer.

A comparison was made with the estimated natural period of a comparable pendulum. Although this natural period induced an apparent local maxima it was not the point of greatest amplitude. Amplitudes continued to increase as wavelength increased, up to the limit of the waves tested.

Lower Ring Heave

The lower ring heave motions were generally less than the collar heave motions. This is due primarily to the fact that the ring was not articulated and to the fact that a damping plate was fitted in the heave direction. As with the other cases, the basket mooring was the most effective in suppressing the heave motions. Atypically, the heave motions of the ring increased for the multiple cage configuration. The reasons for this increase are unclear.

Mean Surge

The mean surge values are used to derive the non-dimensional wave drift forces plotted in Appendix 2. These results are presented in a non dimensional format where the force is represented by $F/h^2\rho g l_s$ (F=force, l_s= structure length, h = wave height, ρ = water density, g = gravitation acceleration) plotted against the ratio of wave length to structure length. Although it is not evident from the plots, due to the non-dimensionalizing, in fact the wave induced drift force peaks when the wave length is equal to the structure length. The four unit configuration showed higher drift forces, although not four times as high but the four unit configuration in the quartering seas exhibited a drift force approximately equal to the single unit. This may be an anomaly or it may indicate that there is some advantage in orienting a structure to a prevailing wave direction.

Conclusions

Some discussion of the results of these tests as it may bear on full scale designs is warranted. The intention of this project was not so much to develop a specific design but to investigate features which are or may be incorporated into cage designs. Our objectives were to see if the collar design offered good wave response and to determine if a lower ring could be used to stabilize the net shape and/or improve the motions of the whole cage under offshore conditions. In addition the intention of investigating various mooring configurations was to give an idea whether motions could be reduced sufficiently to provide a stabilized bottom plane suitable for raising ground fish. Based on an admittedly limited set of tests we draw the following conclusions.

Collar

The articulated collar design provided good wave response and relatively low drift forces. In general the motions of the segments increased in the downwave direction. Also the multiple cage unit showed lower motions in the collar segments than the single unit. This was the expected result as larger marine structures usually exhibit better motions for a given wavelength. One problem was excessive motion in the aftmost segments, particularly in wavelengths approximately equal to the cage length. Although this motion would probably be reduced by the presence of nets, the relatively high motion amplitudes could cause excessive wear in mechanical and other components at an offshore location. The motion would also make it difficult to work on that part of the cage in rough seas.

The design did offer considerable convenience in joining multiple units (even at model scale) and would be a simple design for production purposes with only two basic parts. Hinged cage designs have however been problematic in service and the hinge would need further evaluation.

Bottom Ring

The use of bottom rings has been proposed for a number of existing designs and appears to offer promise in maintaining net shape. However for collar-moored systems there is likely to be large pendular motions in the ring excited by wave action on the collar, Again the presence of nets would undoubtedly damp the lower ring motions but a top excited pendulum is know to act as an amplifier and thus the ring motions can be expected to be larger than the collar motions. This effect appears to increase with increasing wavelength (or period) and the system exhibits a small local maximum at the pendulum period of the suspended ring.

The use of lower rings also presents problems which, while easy to deal with in models, may present problems at larger scale. These concern the ballasting and support of the ring. Generally a ring must be heavy to keep the net down. The model ring was suspended by cables attached to each float which resulted in a sixteen point suspension on the ring. The ring has then to be sufficiently rigid to support its own weight between suspension points. Although this could easily be achieved at model scale with aluminum stock, a full scale cage would require a heavy metal construction to provide a sufficiently rigid ring. The problem is compounded when additional hydrodynamic damping loads are applied as they were in this case by fitting damping plates to the ring.

An alternative would be to use the net as a support which would provide a uniform support for the ring and avoid the point loads of a cable suspension. This would however stress the net and prevent easy removal for cleaning.

Our conclusion is that lower rings offer potential for improved motions and better shape retention but require careful design for structural loads and the development of some means of reducing pendular motions. This is further discussed in the next section on moorings.

Mooring

The location of the mooring attachment and the style of the mooring can be adapted to reduce the motions of the cage system. This however comes at some cost in complexity of mooring and anchoring. The basket mooring developed for this program, combined elements of a tension leg mooring and a conventional catenary attached to the lower ring. Although this mooring offered reductions in the collar and the lower ring motions for a single unit cage, it would be an expensive solution requiring at least one piled anchor capable of resisting substantial uplift and would be a more complicated arrangement for multiple cages. This type would also be complicated for regions with high tidal ranges requiring either motion compensation or a sub-surface grid.

Attaching a simple catenary mooring to the lower ring offered a reduction in the pendular motions of the ring and appears to be a practical method of reducing the swinging problem likely to be encountered in installations with net retaining rings. However this would subject the ring and its support system to the entire mooring load. This load, combined with the required ballast weight to sink the ring and provide a net stabilizing influence would require that such rings be structurally rigid and carefully designed.

Suitability for ground fish

As part of work we were involved in, evaluating schemes for growing groundfish such as halibut and flounder in sea cages, we looked at the possibility of using this design and a stabilising mooring configuration to provide a relatively calm bottom plane suitable for fish more accustomed to being on the ground. The Basket mooring in combination with a structurally rigid bottom ring allows us to conclude that considerable reductions can be had in bottom plane motions, even in relatively rough wave conditions, by using elements of tension leg and catenary moorings. Although the motions are unlikely to be completely eliminated they can be substantially reduced, albeit at increased complexity and cost in mooring and cage components. Whether this reduction is sufficient would have to be the subject of a full scale trial.

There is however a caution. Even if the cage motions are reduced to zero, for a surface cage there is still a great deal of water particle motion in the cage, particularly for long waves. This hydrodynamic activity would exert forces on the fish which may have the same effect as cage motions. Thus even a stable surface cage may not offer a suitable habitat for ground fish. It appears likely that submersible cages or land based tanks offer a better technical solution for groundfish.

Summary

In summary, the features incorporated into this experimental cage design exhibited characteristics which may benefit cage designs. The elevated deck presents advantages in higher waves. Cylindrical floats tend to minimize wave forces and the consequent motions. The articulation scheme was generally good, particularly for multiple cage units but does exhibit some relatively high motions in the aftmost segments. Variations on conventional moorings can be used to reduce motions in the cage unit but do require more complexity in lines and anchoring. Lower rings can be used to improve shape retention but potential problems with support require detailed evaluation for use in full scale situations.

Finally the use of motion reduced sea surface cages for raising ground fish may be practical in terms of wave motion of the cage but still impractical in terms of wave effects on the fish.

APPENDIX 1 Cage drawings

Figure 1-1 Isometric View, Single Unit

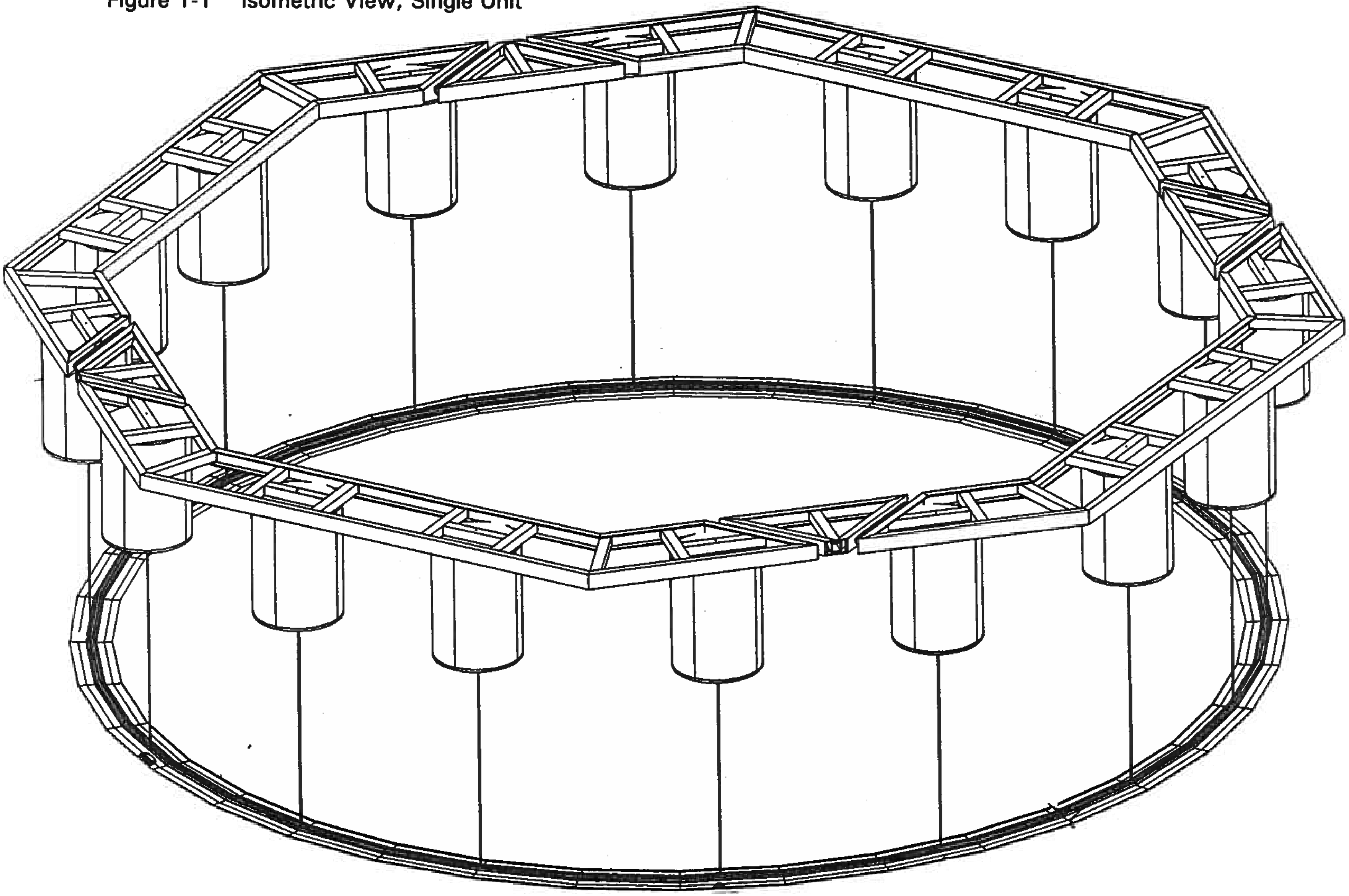


Figure 1-2 Plan View, Four Unit

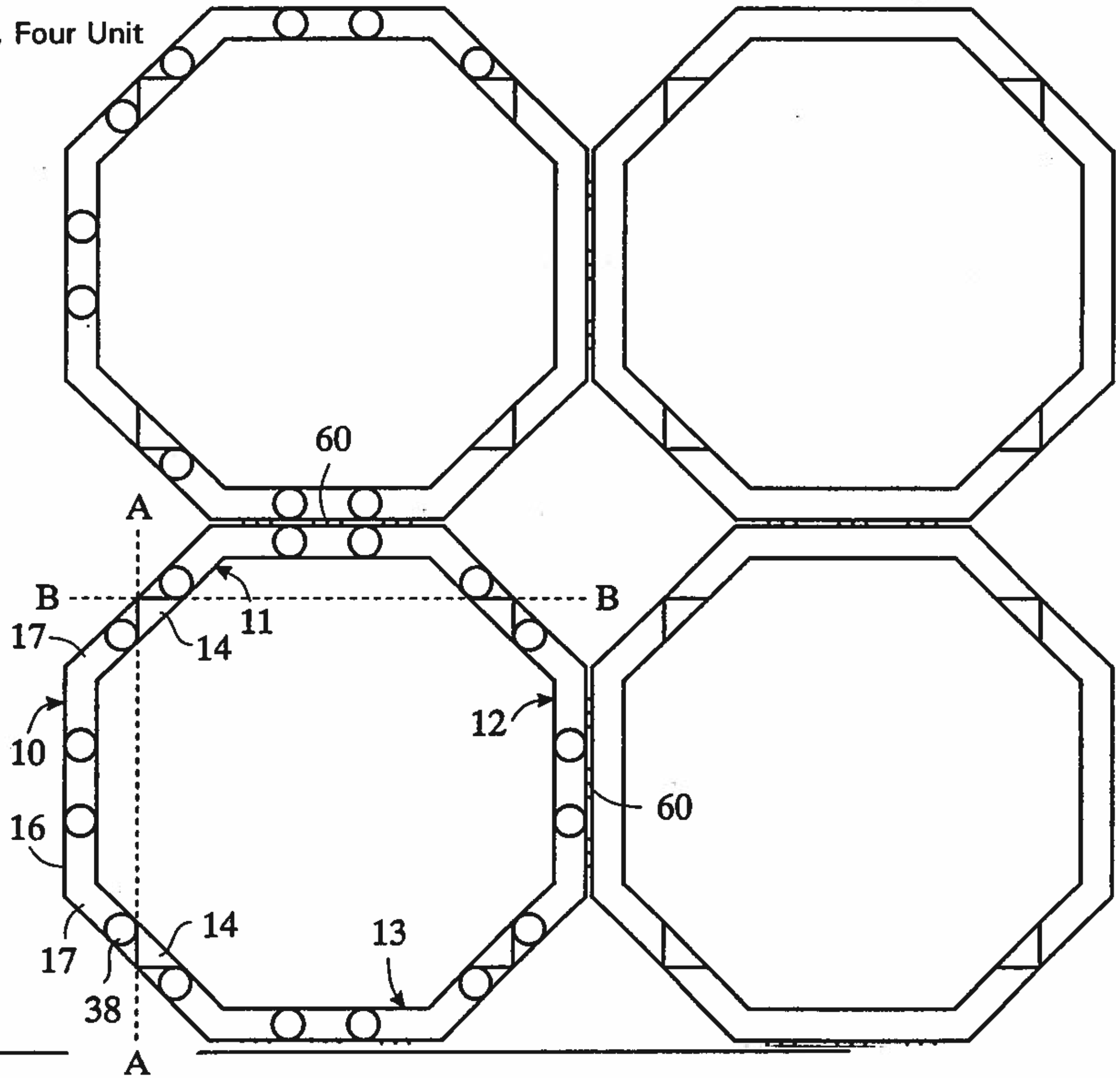


Figure 1-3 Elevation/Section View, Single Unit

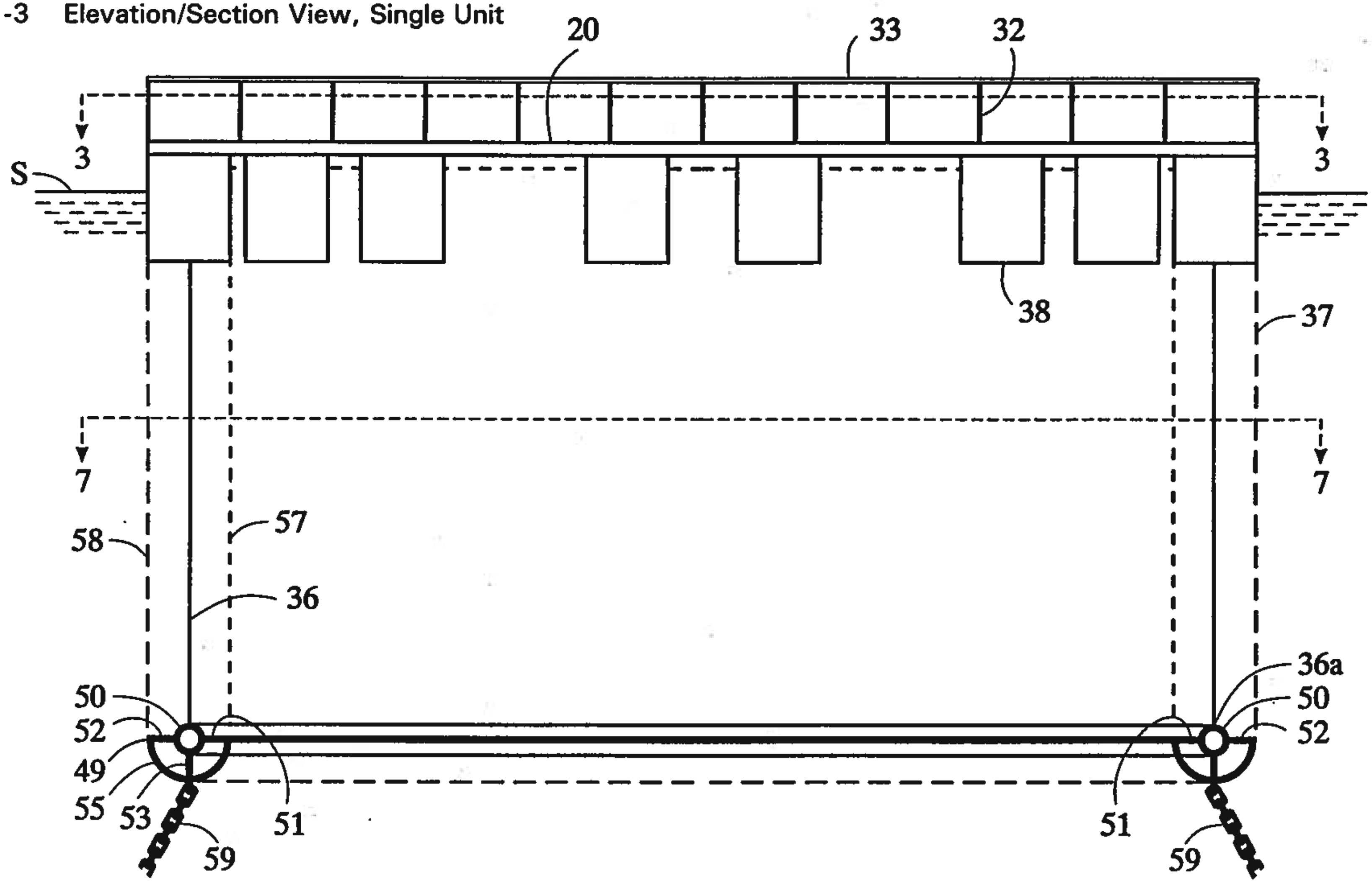


Figure 1-4 Plan & Elevation, Collar Segment

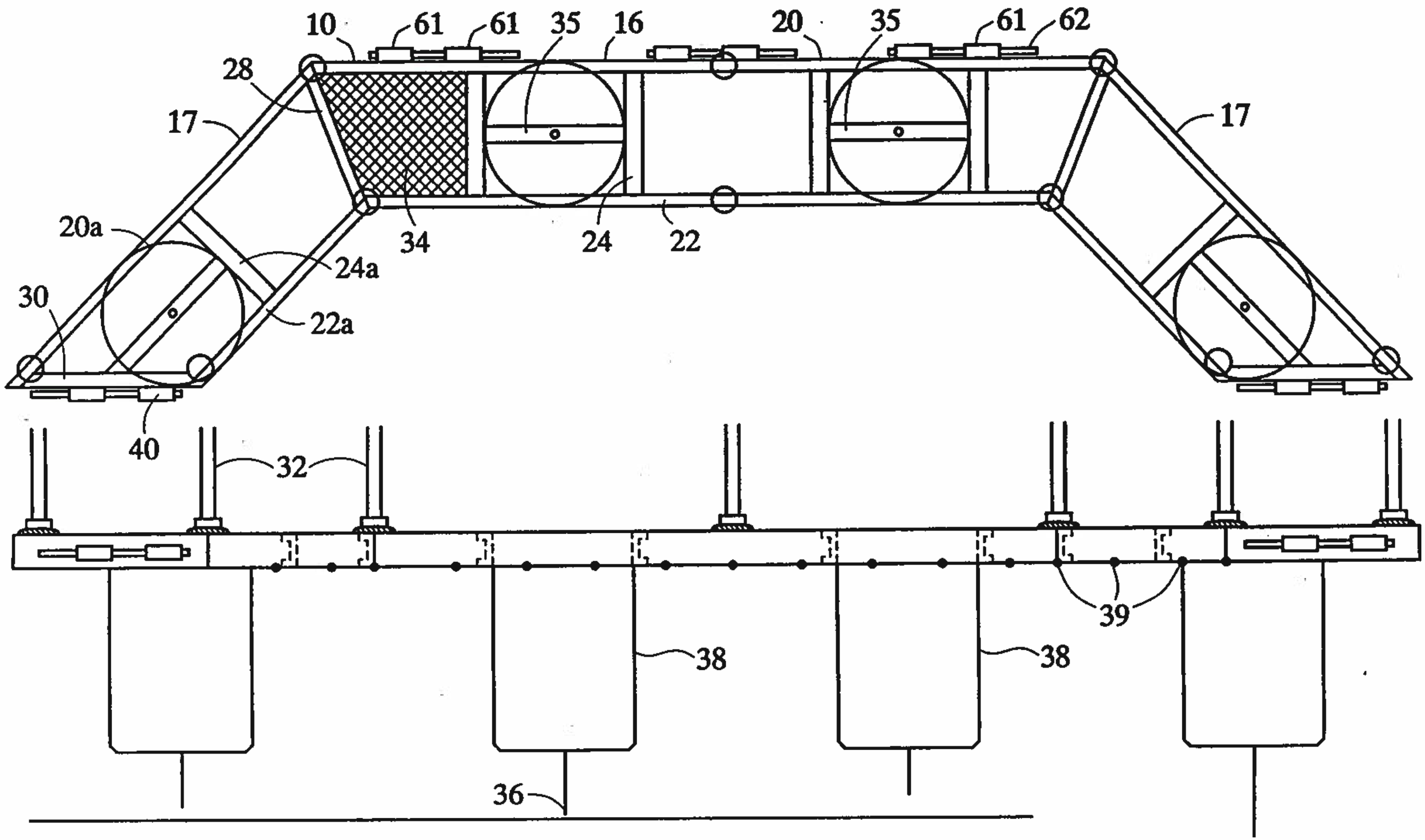
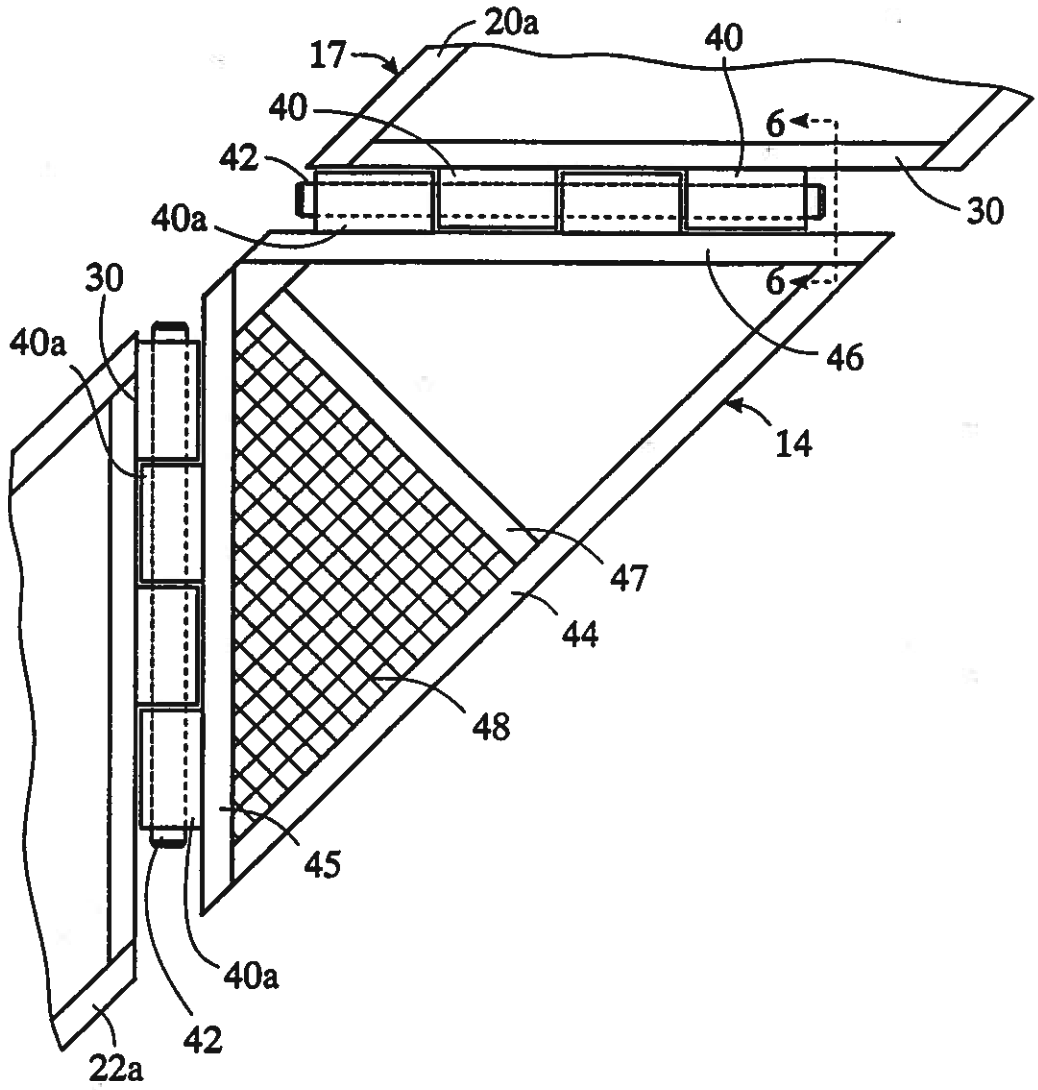


Figure 1-5 Plan, Hinge Element

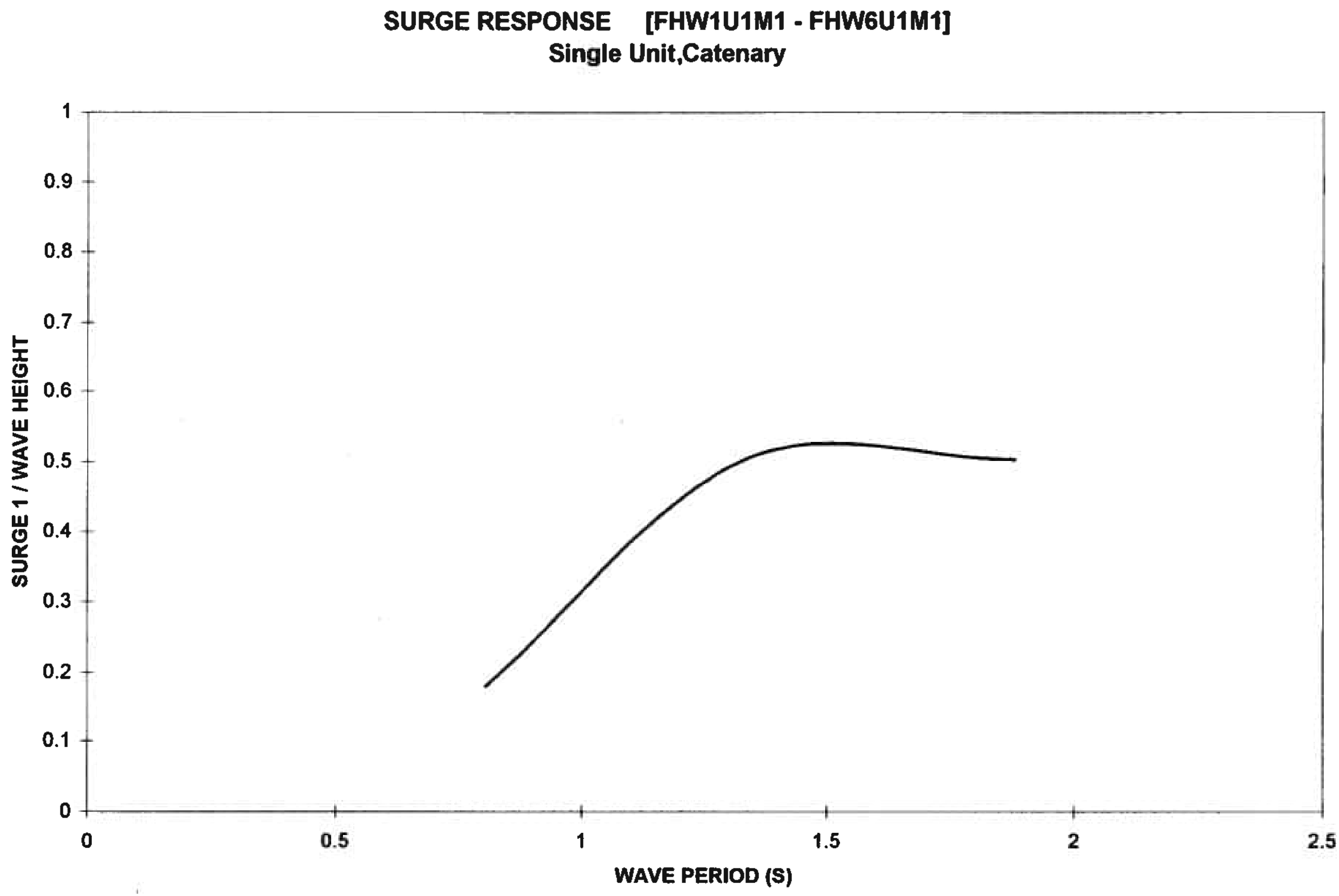


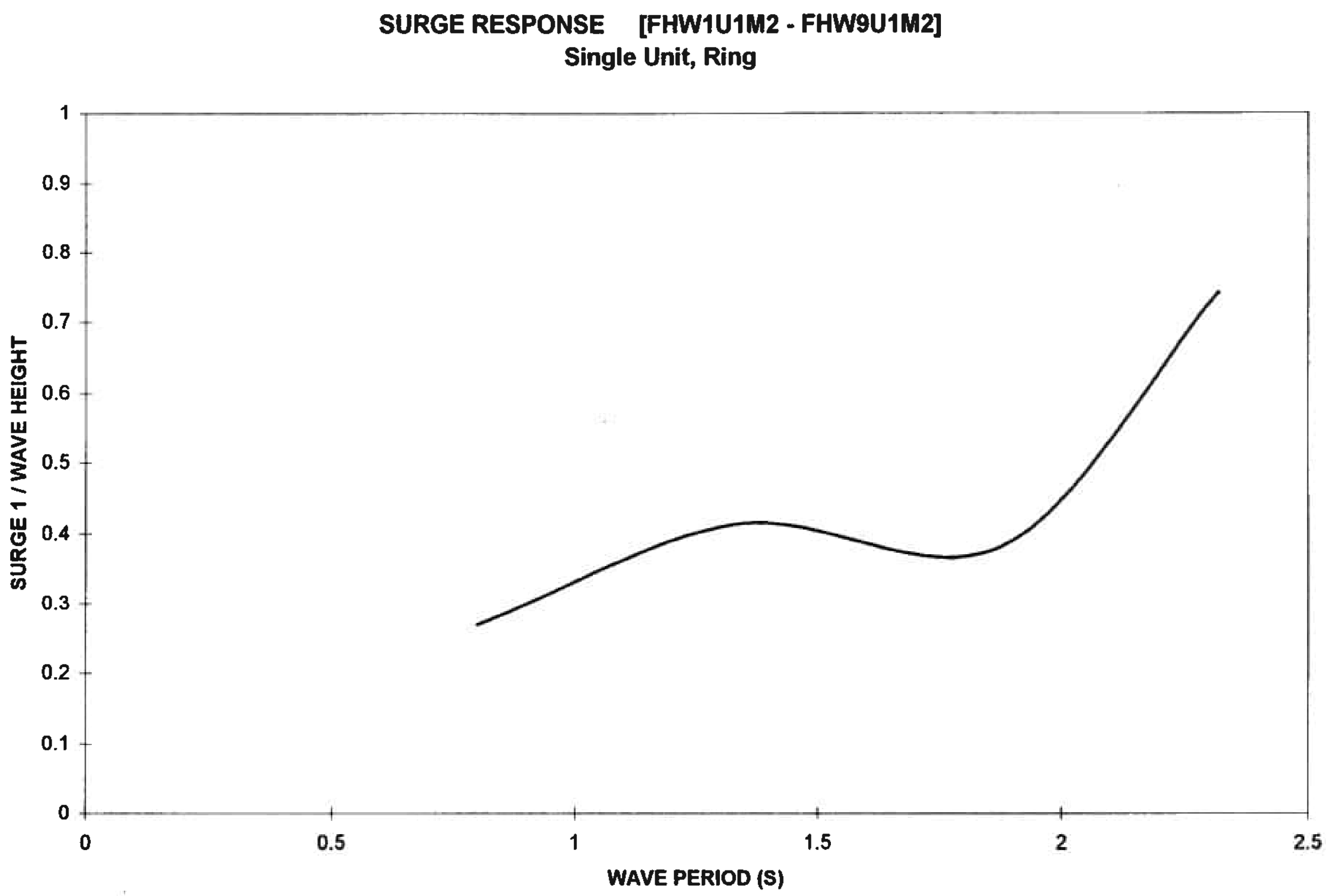
APPENDIX 2 Heave and surge plots

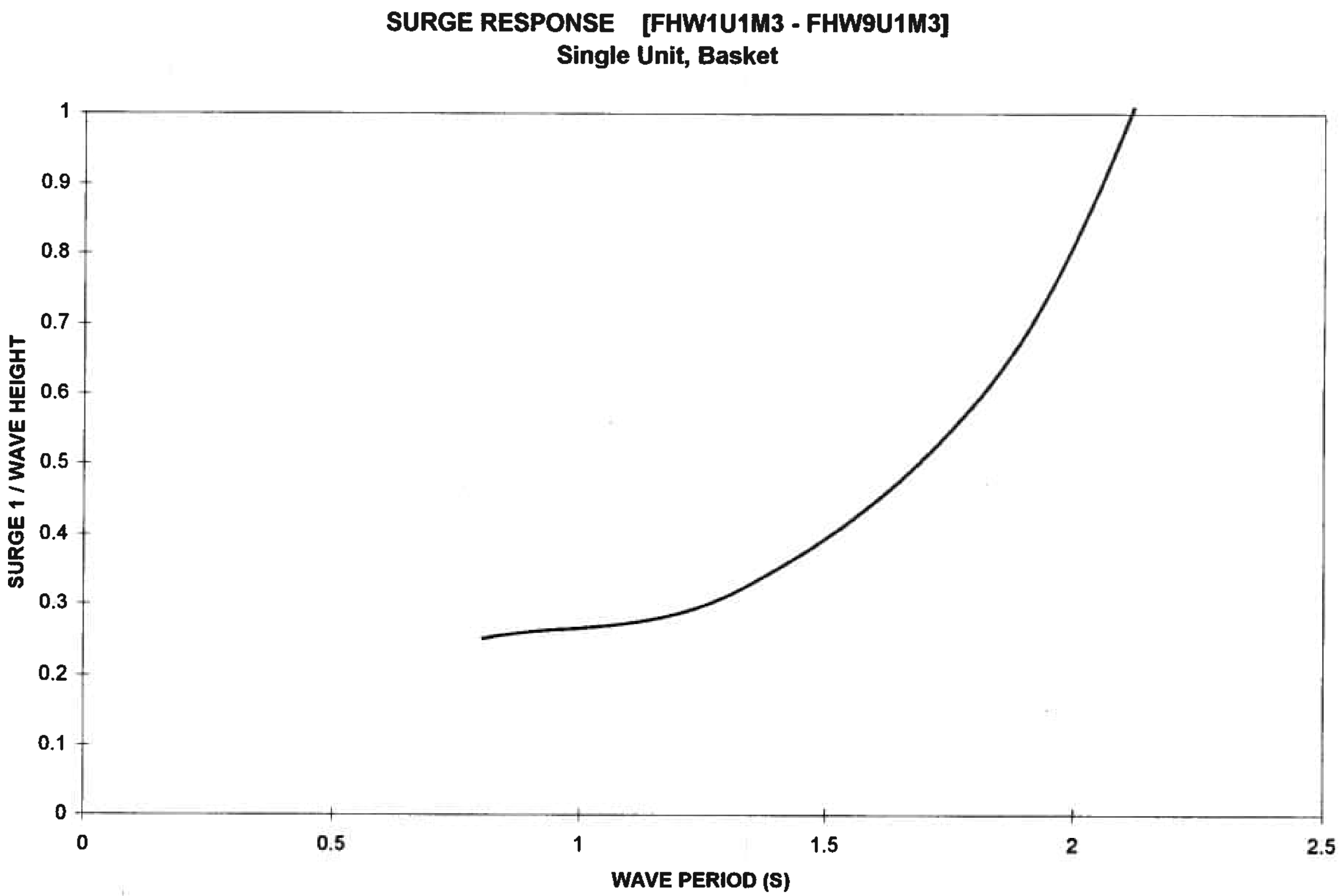
1. Surge RAOs - Collar
2. Heave RAOs - Collar
3. Surge RAOs - Lower Ring
4. Heave RAOs - Lower Ring
5. Mean Wave Drift Force Plots (Horizontal moorings only)

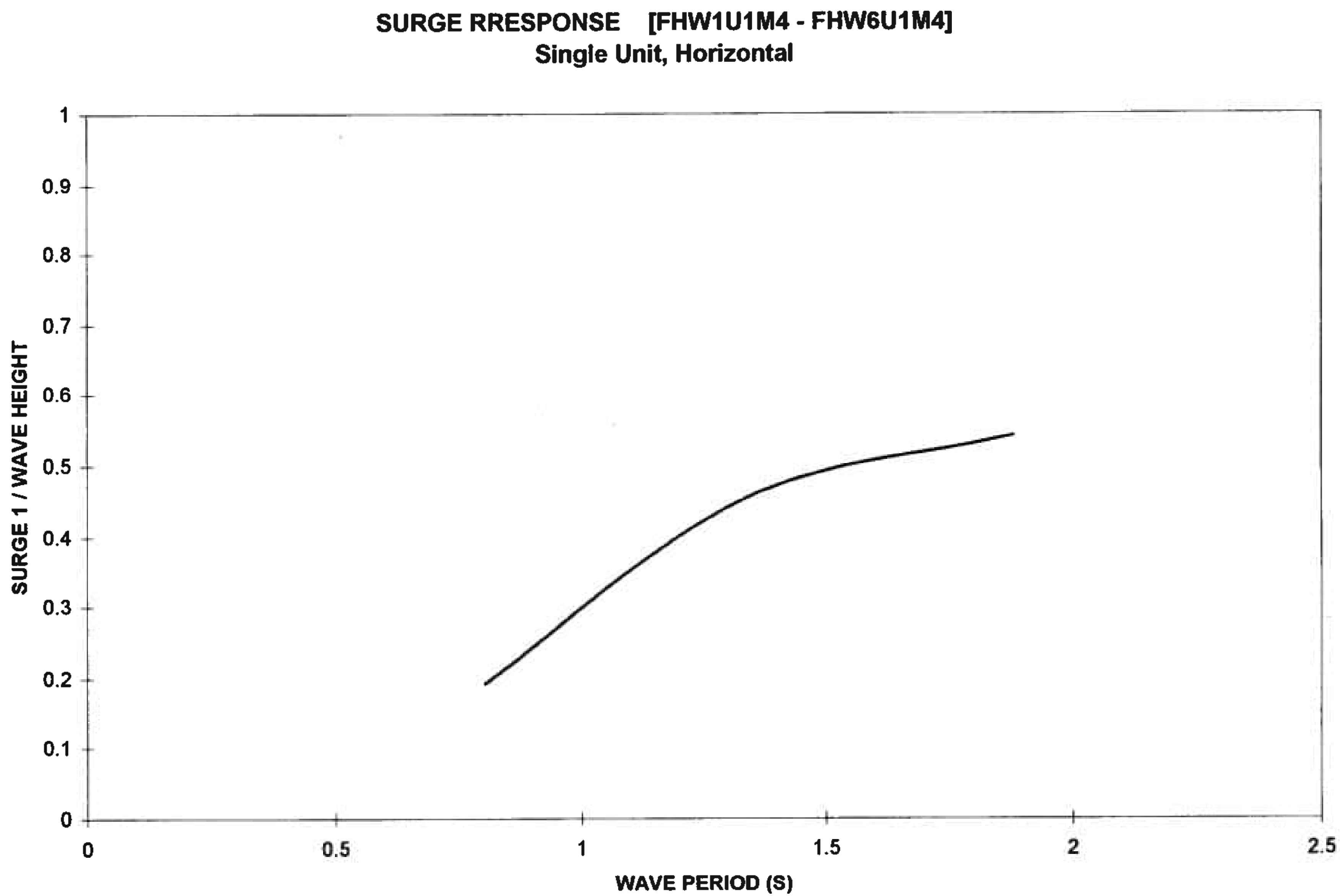
Data Plots are presented in the following order in each section listed above.

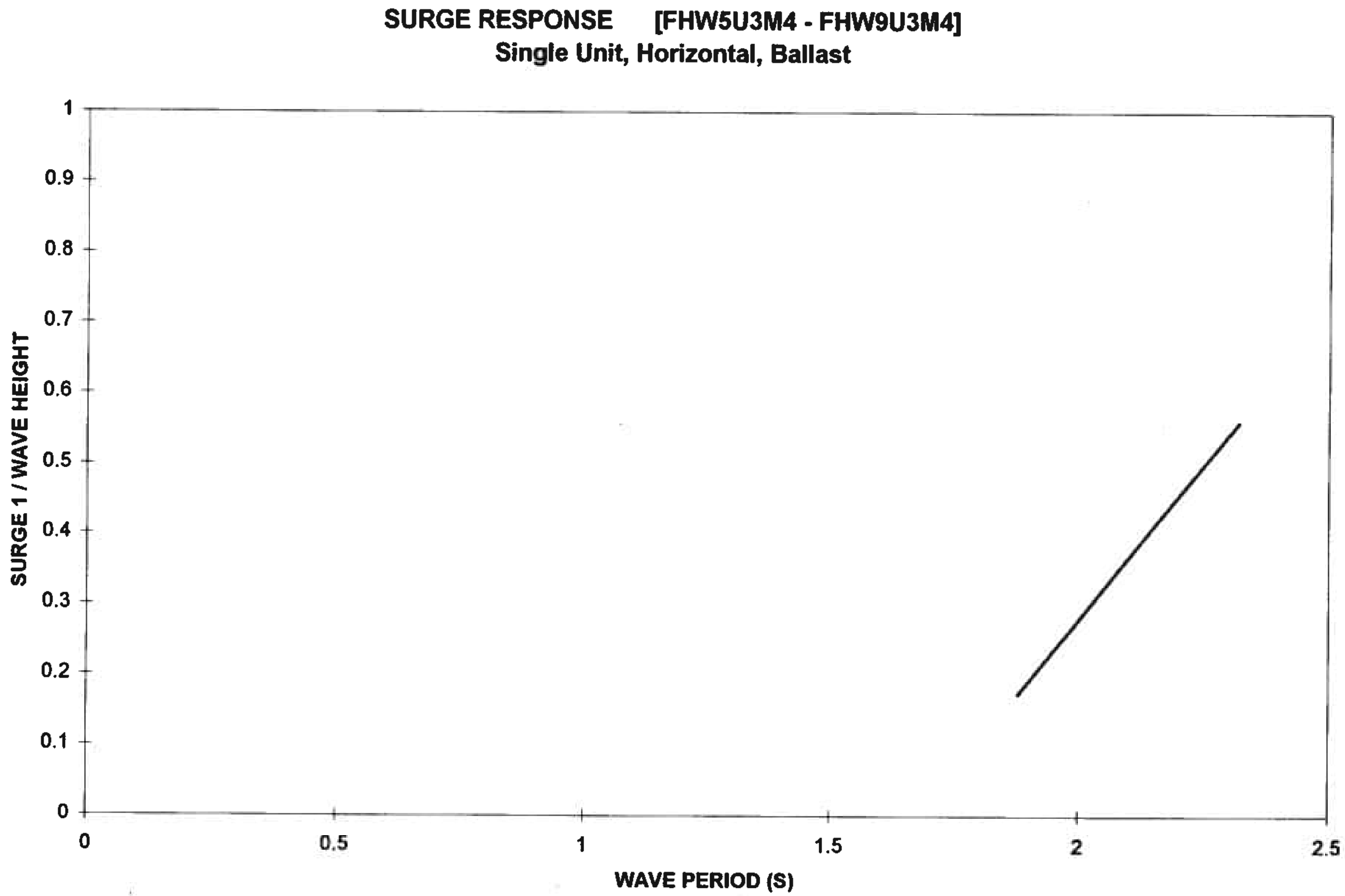
Config No.	Data Label	Title	Description
1	FHW*U1M1	Single Unit Catenary	Single cage unit, Catenary mooring in which the cage supported the mooring weight. Head waves.
2	FHW*U1M2	Single Unit Ring	Single cage unit, Ring mooring, Head waves
3	FHW*U1M3	Single Unit Basket	Single cage unit, Basket mooring, Head waves
4	FHW*U1M4	Single Unit Horizontal	Single cage unit with a surface mooring in which the cage did not support the mooring weight. Head waves
5	FHW*U3M4	Single Unit Horizontal Ballast	Single Cage Unit with extra ballast and a surface mooring in which the cage did not support the mooring weight. Head waves
6	FHW*U4M1	Four Unit Horizontal	Four Cage unit with extra ballast and a surface mooring in which the cage did not support the mooring weight. Head waves
7	FHW*U4M2	Four Unit Ring	Four Cage unit with extra ballast and a ring mooring. Head waves
8	FQW*U4M1	Four Unit Horizontal Quartering	Four Cage unit with extra ballast and a surface mooring in which the cage did not support the mooring weight. Quartering waves


SURGE RESPONSE [FHW1U1M1 - FHW6U1M1]
Single Unit,Catenary
SURGE 1 / WAVE HEIGHT
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.5
1
1.5
2
2.5
WAVE PERIOD (S)

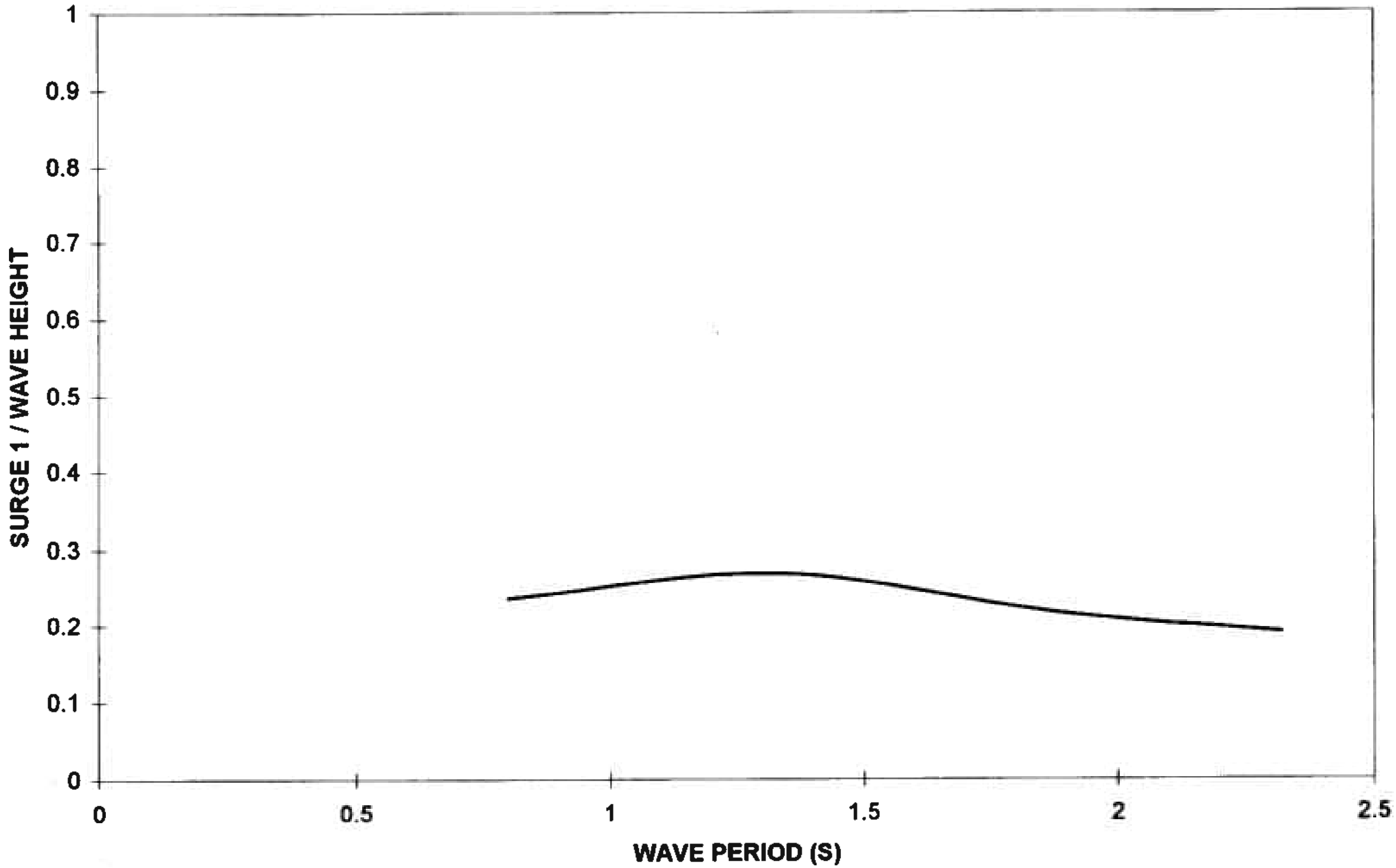

SURGE RESPONSE [FHW1U1M2 - FHW9U1M2]
Single Unit, Ring
SURGE 1 / WAVE HEIGHT
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.5
1
1.5
2
2.5
WAVE PERIOD (S)

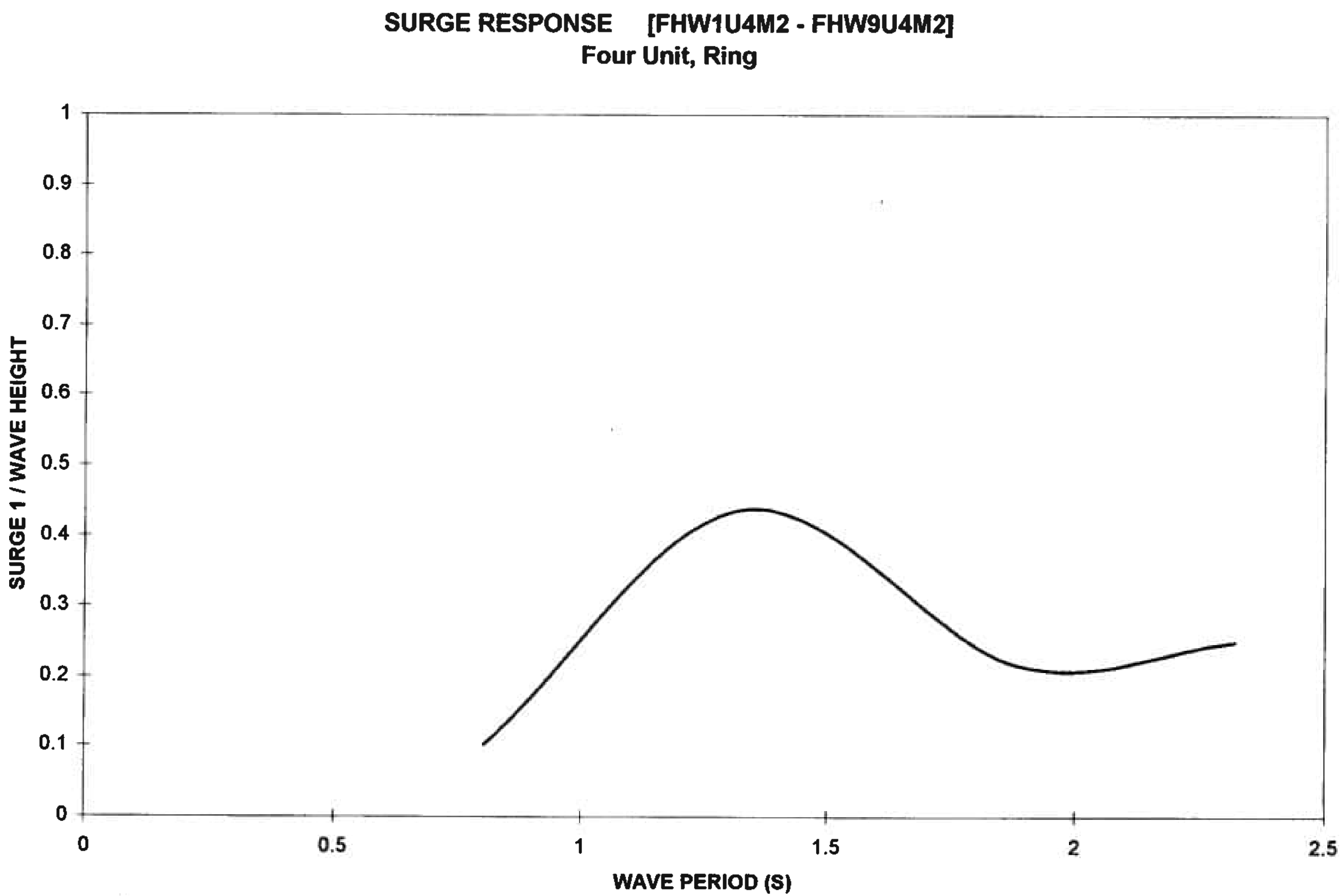

SURGE RESPONSE [FHW1U1M3 - FHW9U1M3]
Single Unit, Basket
SURGE 1 / WAVE HEIGHT
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.5
1
1.5
2
2.5
WAVE PERIOD (S)


SURGE RRESPONSE [FHW1U1M4 - FHW6U1M4]
Single Unit, Horizontal
SURGE 1 / WAVE HEIGHT
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.5
1
1.5
2
2.5
WAVE PERIOD (S)

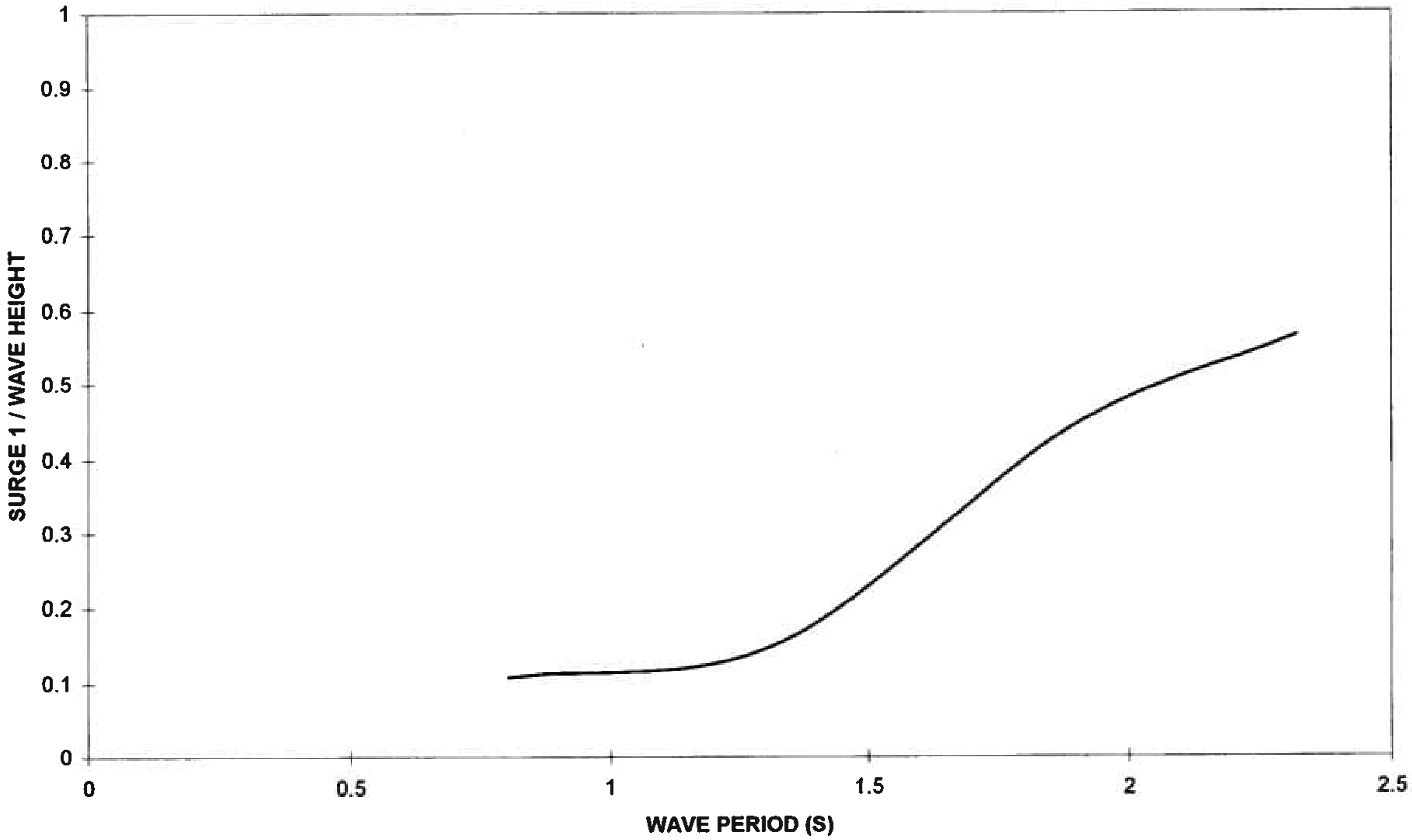

SURGE RESPONSE [FHW5U3M4 - FHW9U3M4]
Single Unit, Horizontal, Ballast
SURGE 1 / WAVE HEIGHT
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.5
1
1.5
2
2.5
WAVE PERIOD (S)

SURGE RESPONSE [FHW1U4M1 - FHW9U4M1]
Four Unit, Horizontal

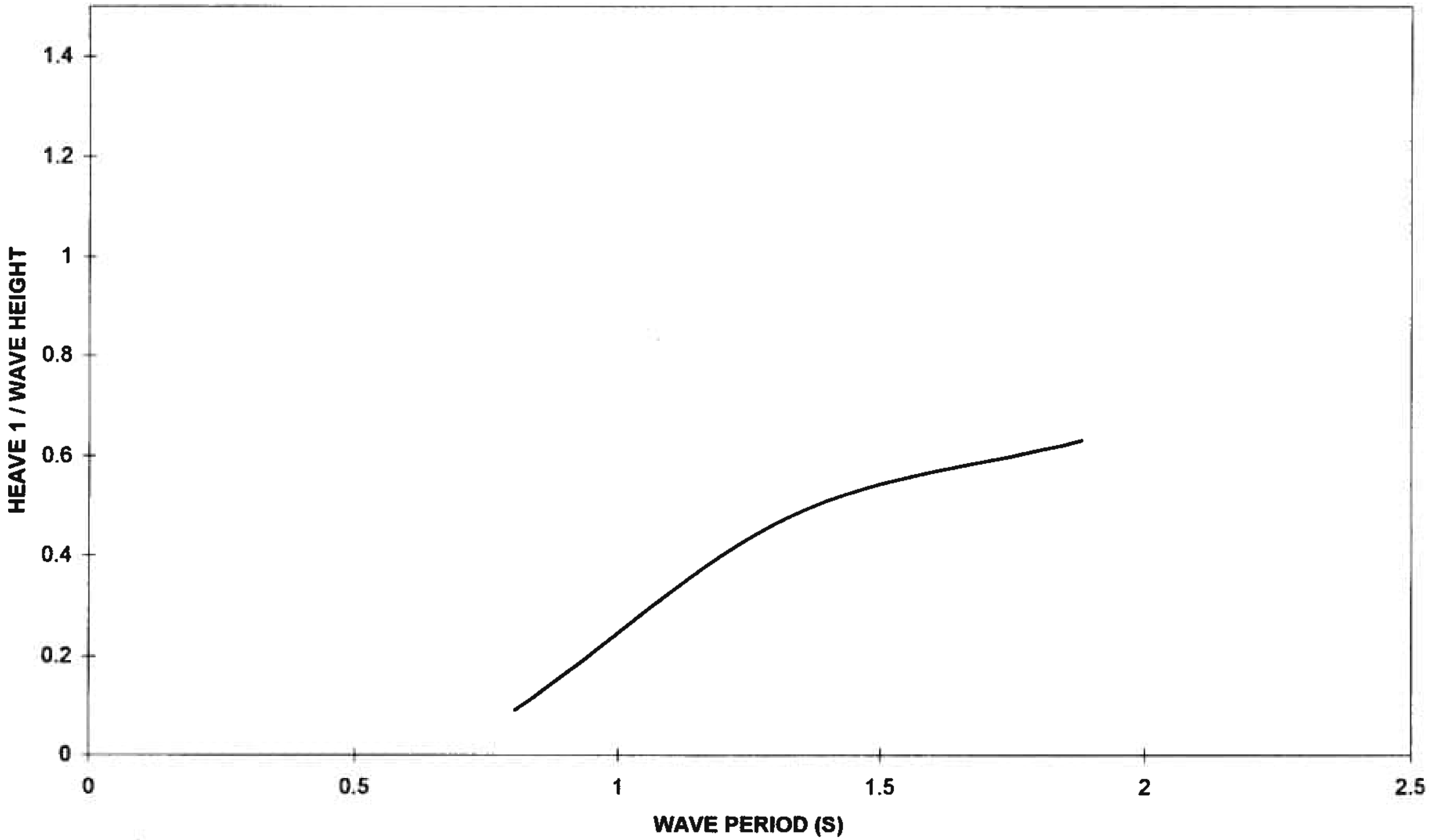



SURGE RESPONSE [FHW1U4M2 - FHW9U4M2]
Four Unit, Ring
SURGE 1 / WAVE HEIGHT
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.5
1
1.5
2
2.5
WAVE PERIOD (S)

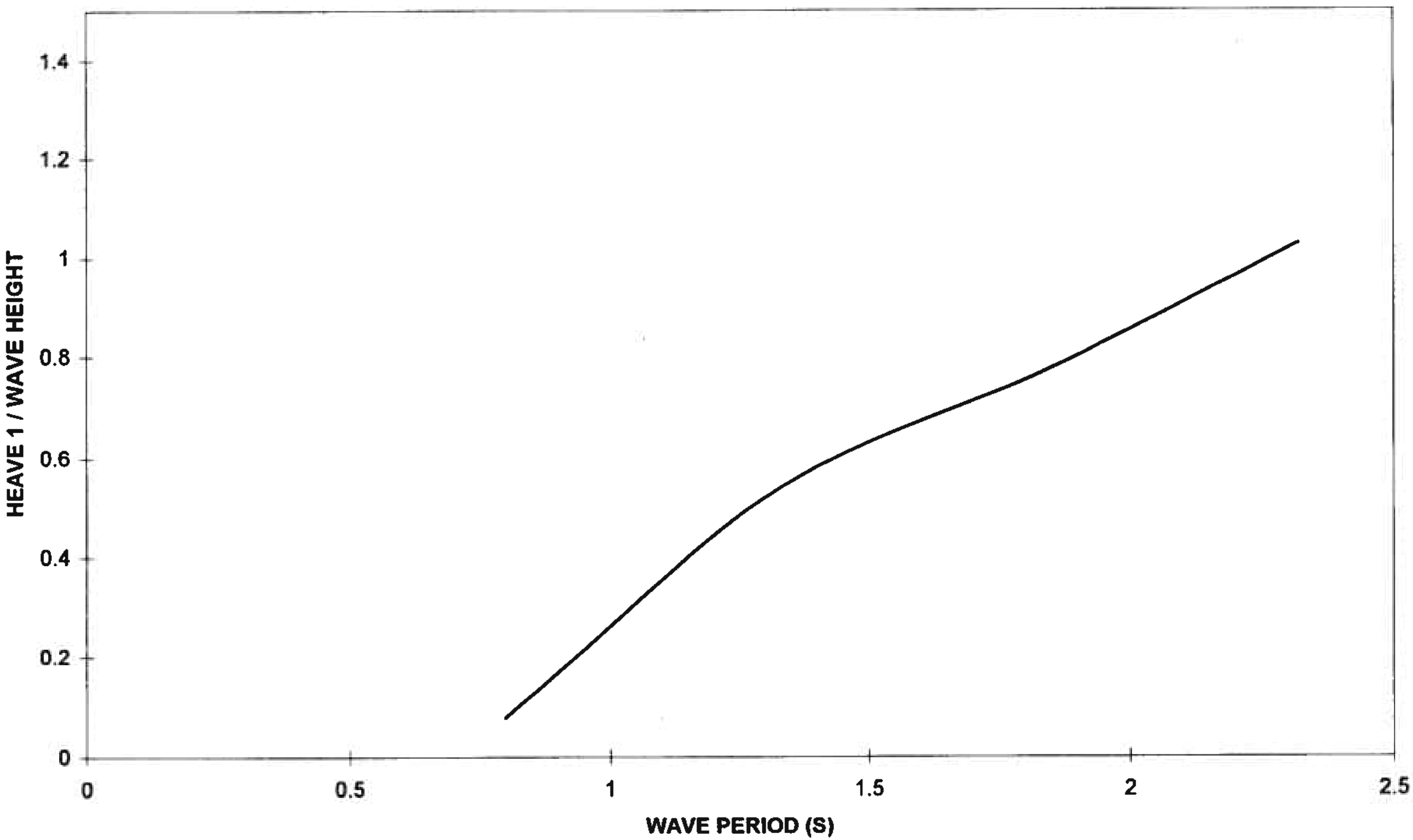
SURGE RESPONSE [FQW1U3M4 - FQW9U3M4]
Four Unit, Horizontal, Quartering



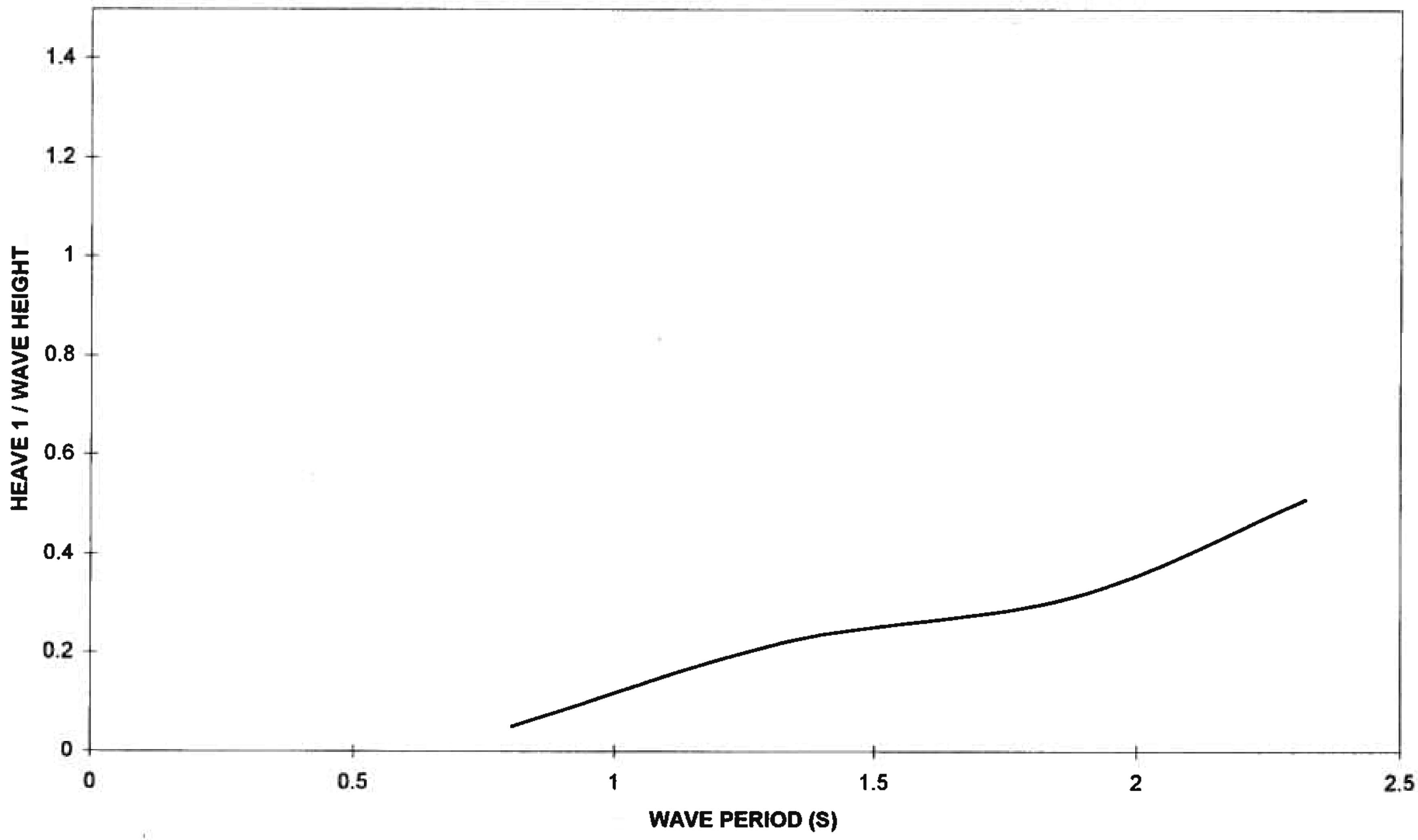
HEAVE RESPONSE [FHW1U1M1 - FHW6U1M1]
Single Unit, Catenary



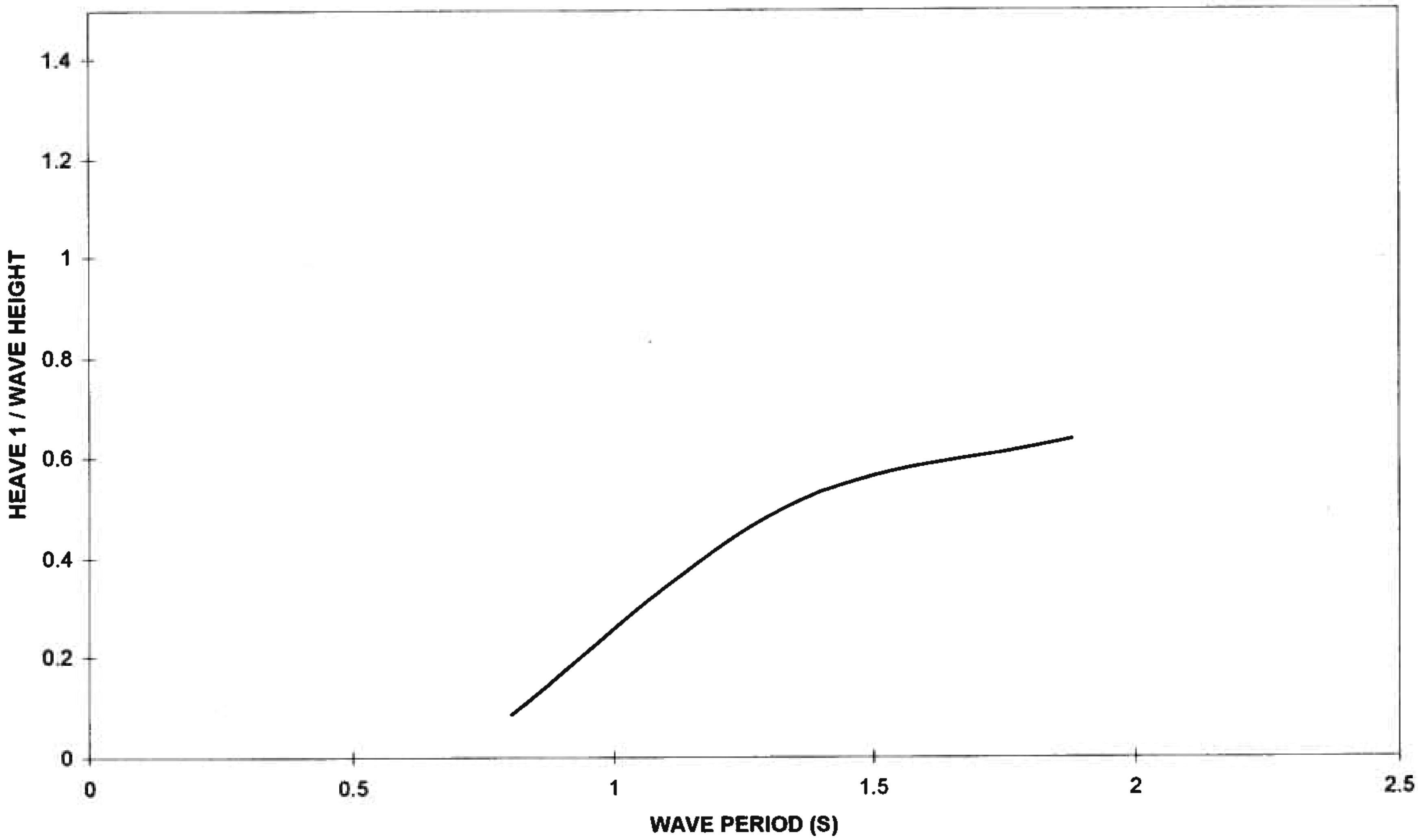
HEAVE RESPONSE [FHW1U1M2 - FHW9U1M2]
Single Unit, Ring

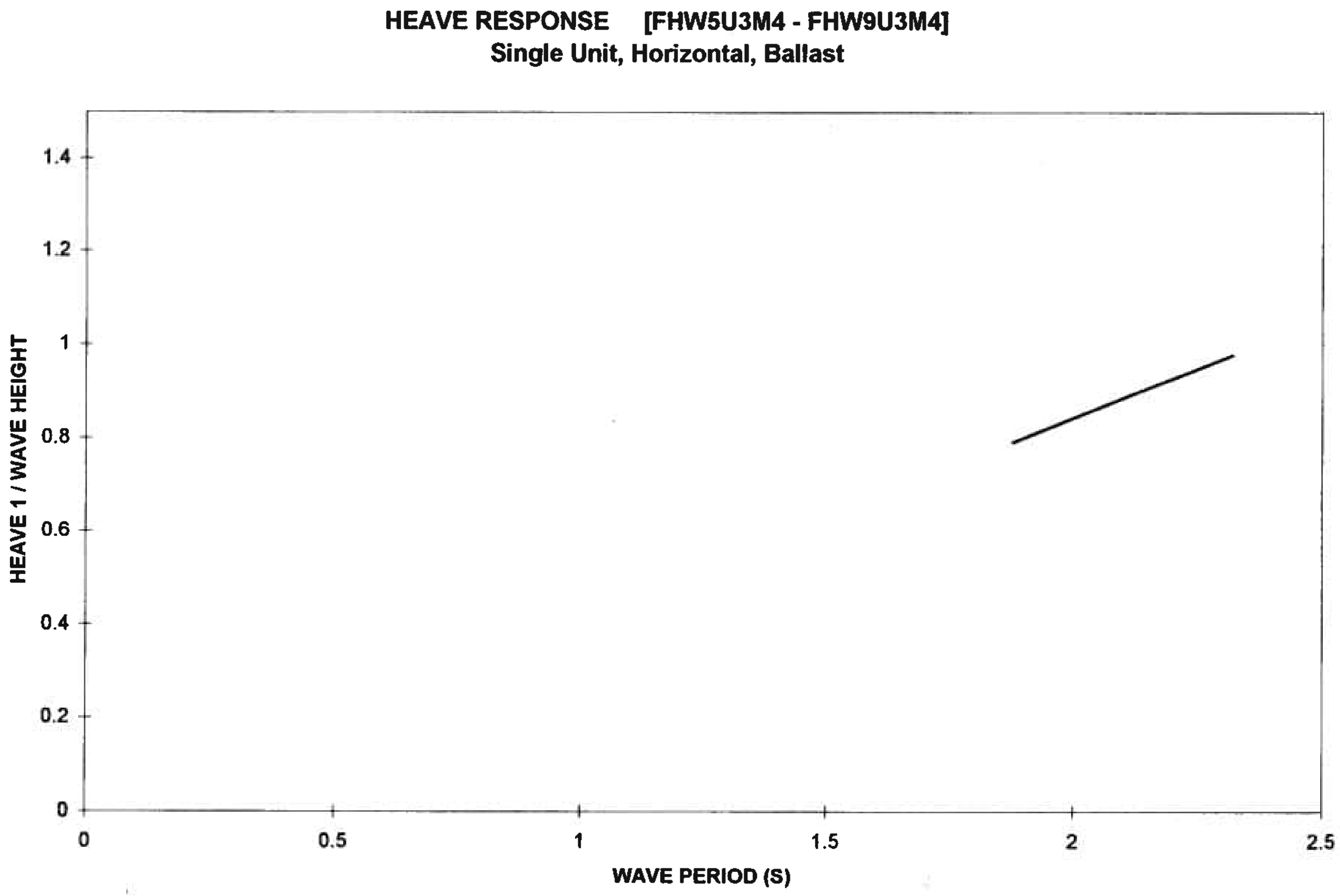


HEAVE RESPONSE [FHW1U1M3 - FHW9U1M3]
Single Unit, Basket

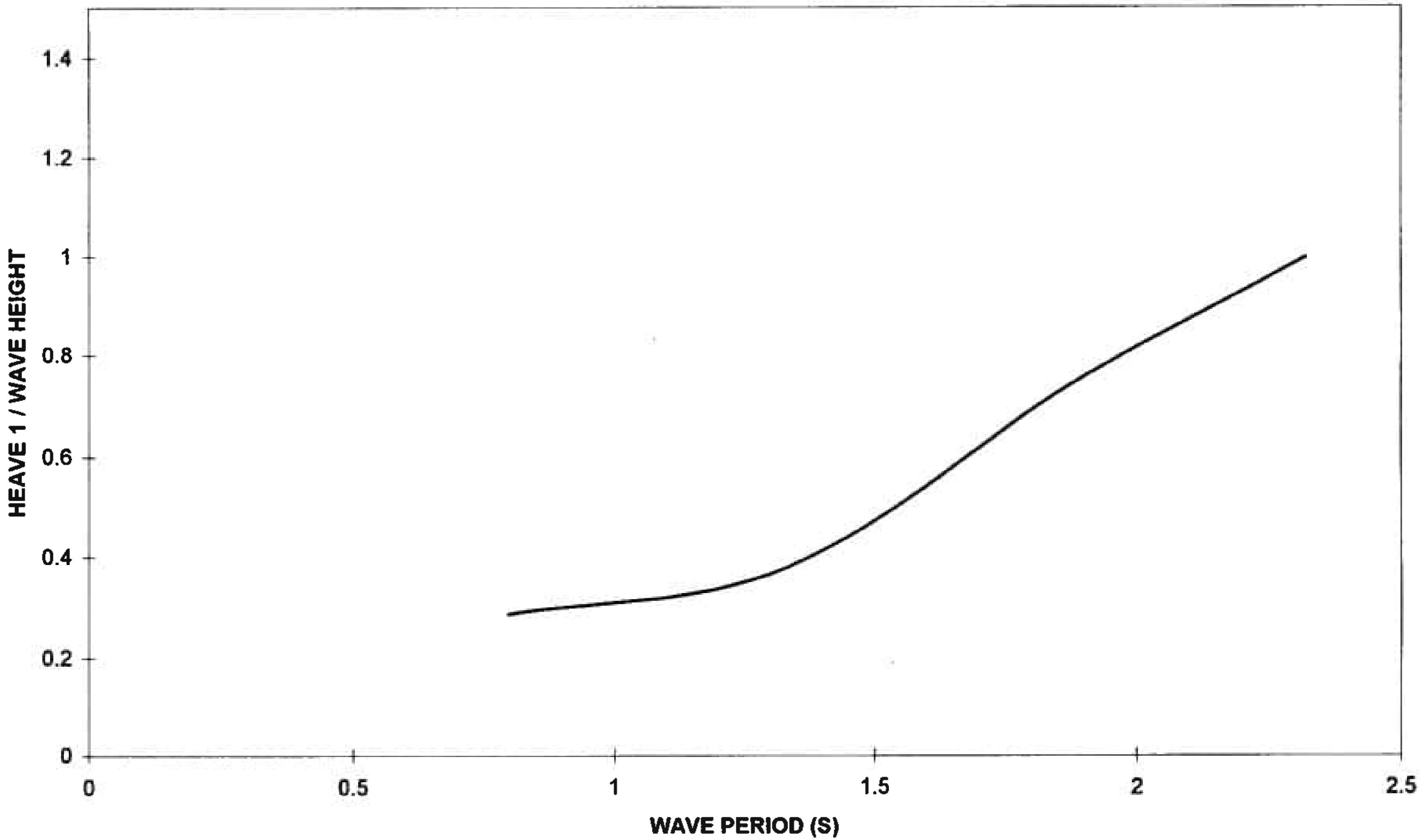


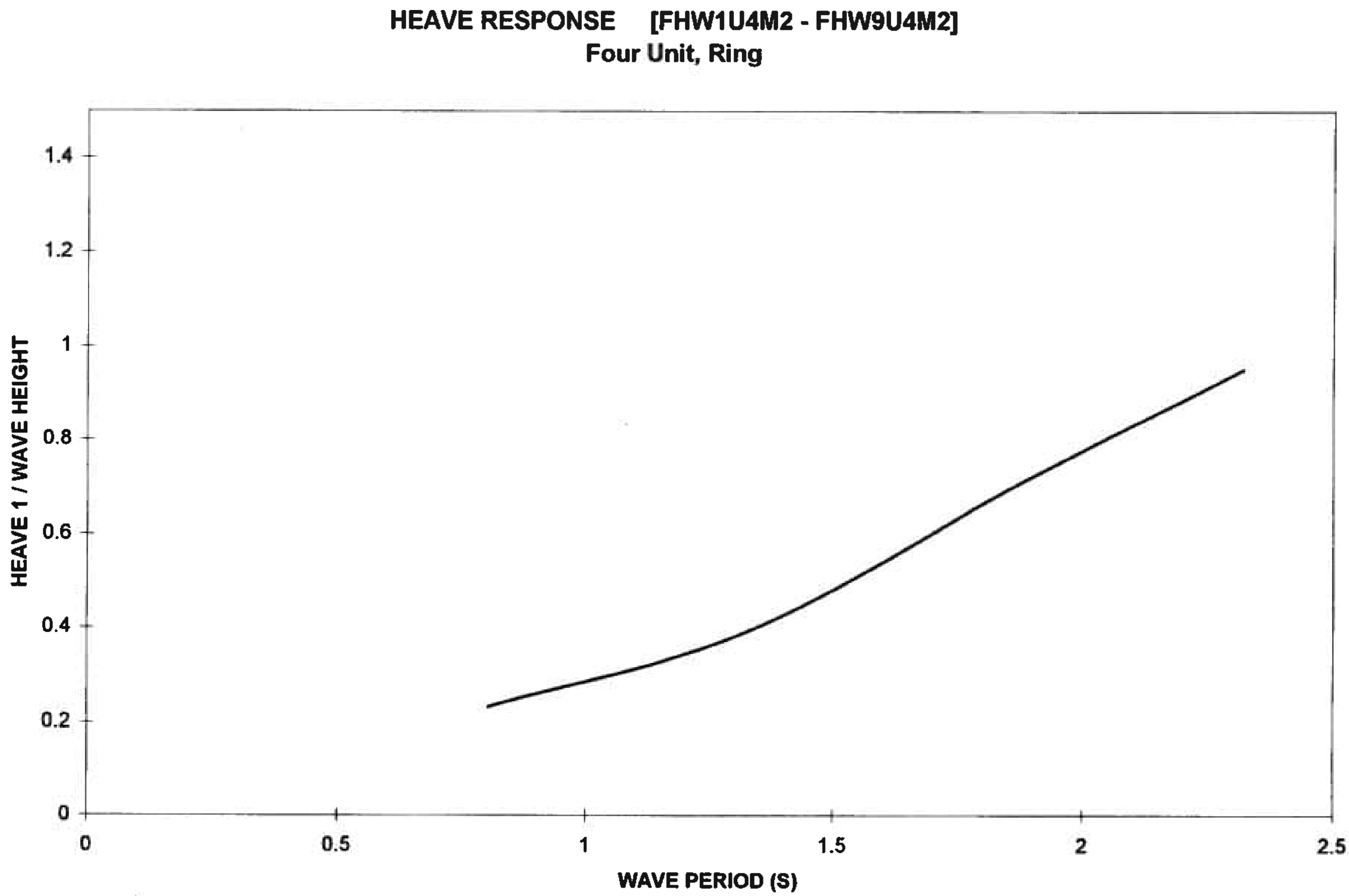
HEAVE RESPONSE [FHW1U1M4 - FHW6U1M4]
Single Unit, Horizontal

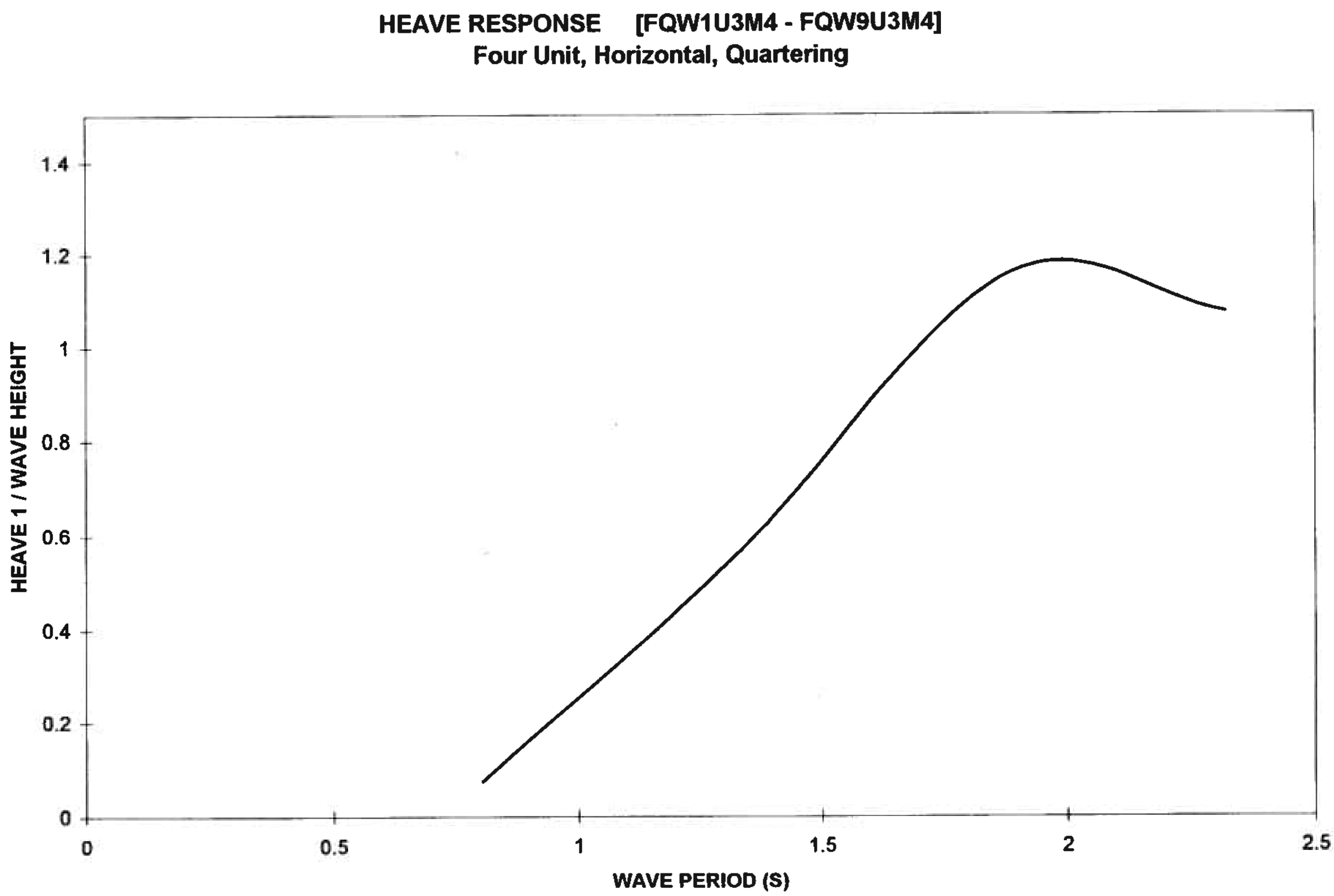


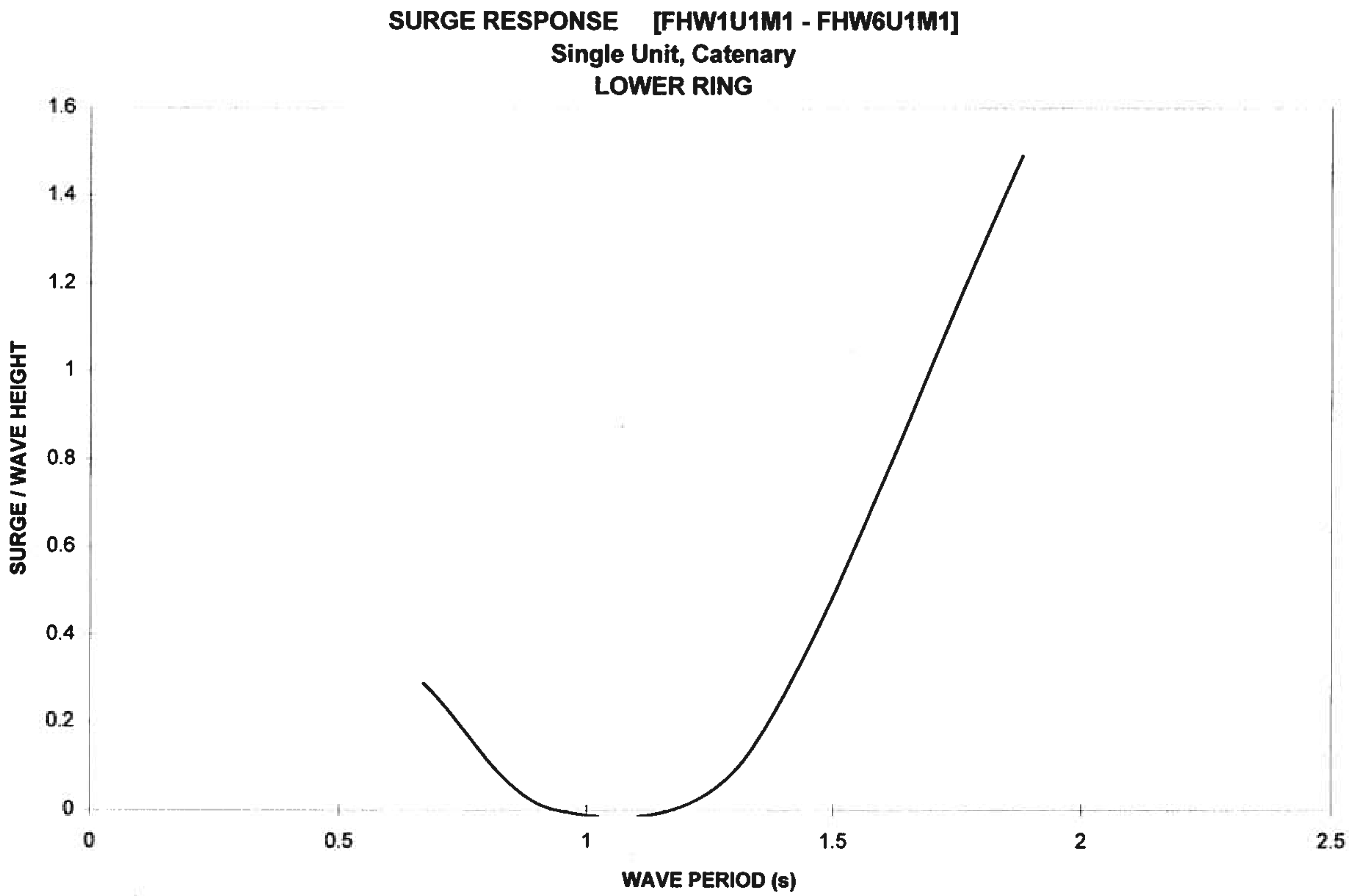

HEAVE RESPONSE [FHW5U3M4 - FHW9U3M4]
Single Unit, Horizontal, Ballast
HEAVE 1 / WAVE HEIGHT
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.5
1
1.5
2
2.5
WAVE PERIOD (S)

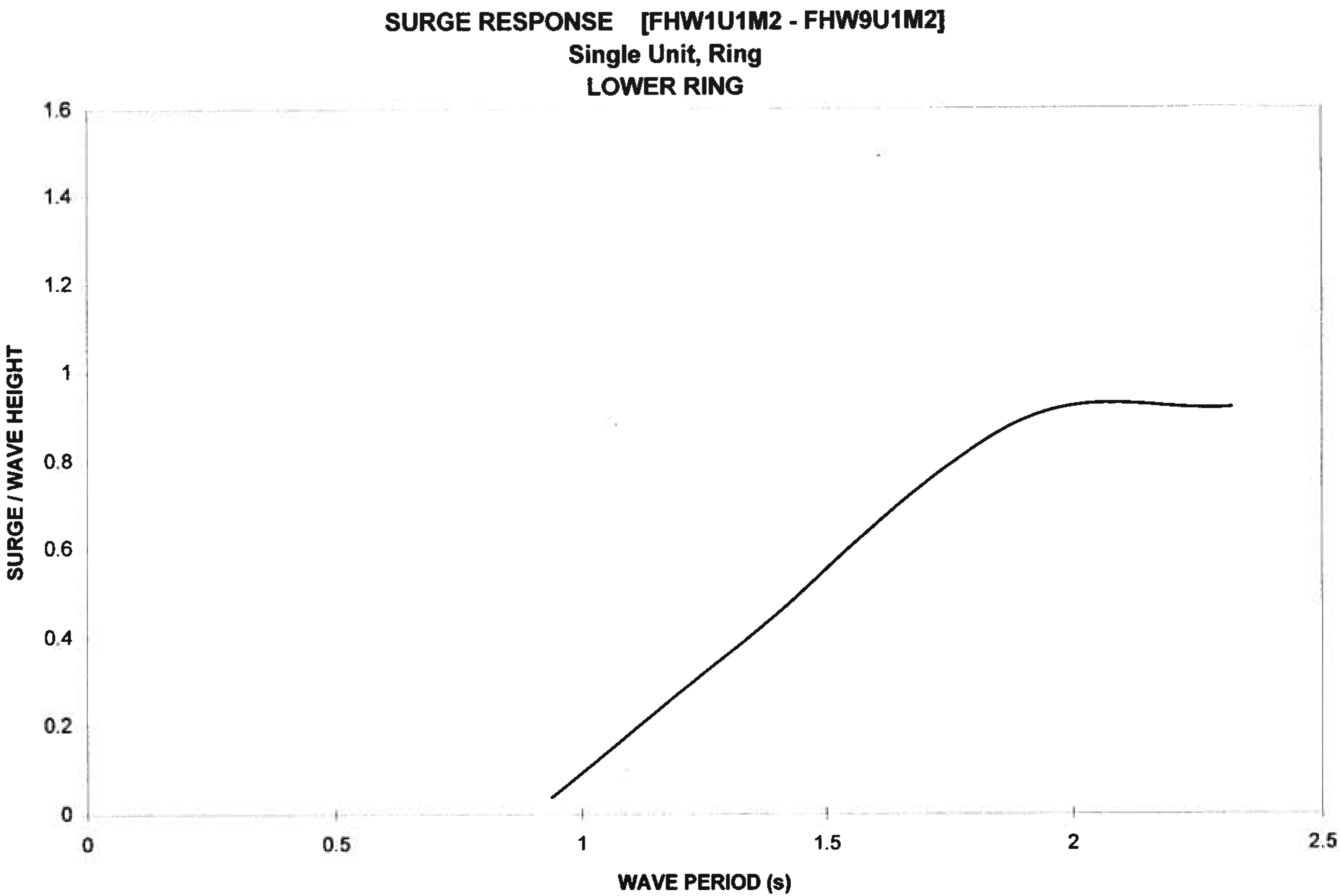
HEAVE RESPONSE [FHW1U4M1 - FHW9U4M1]
Four Unit, Horizontal

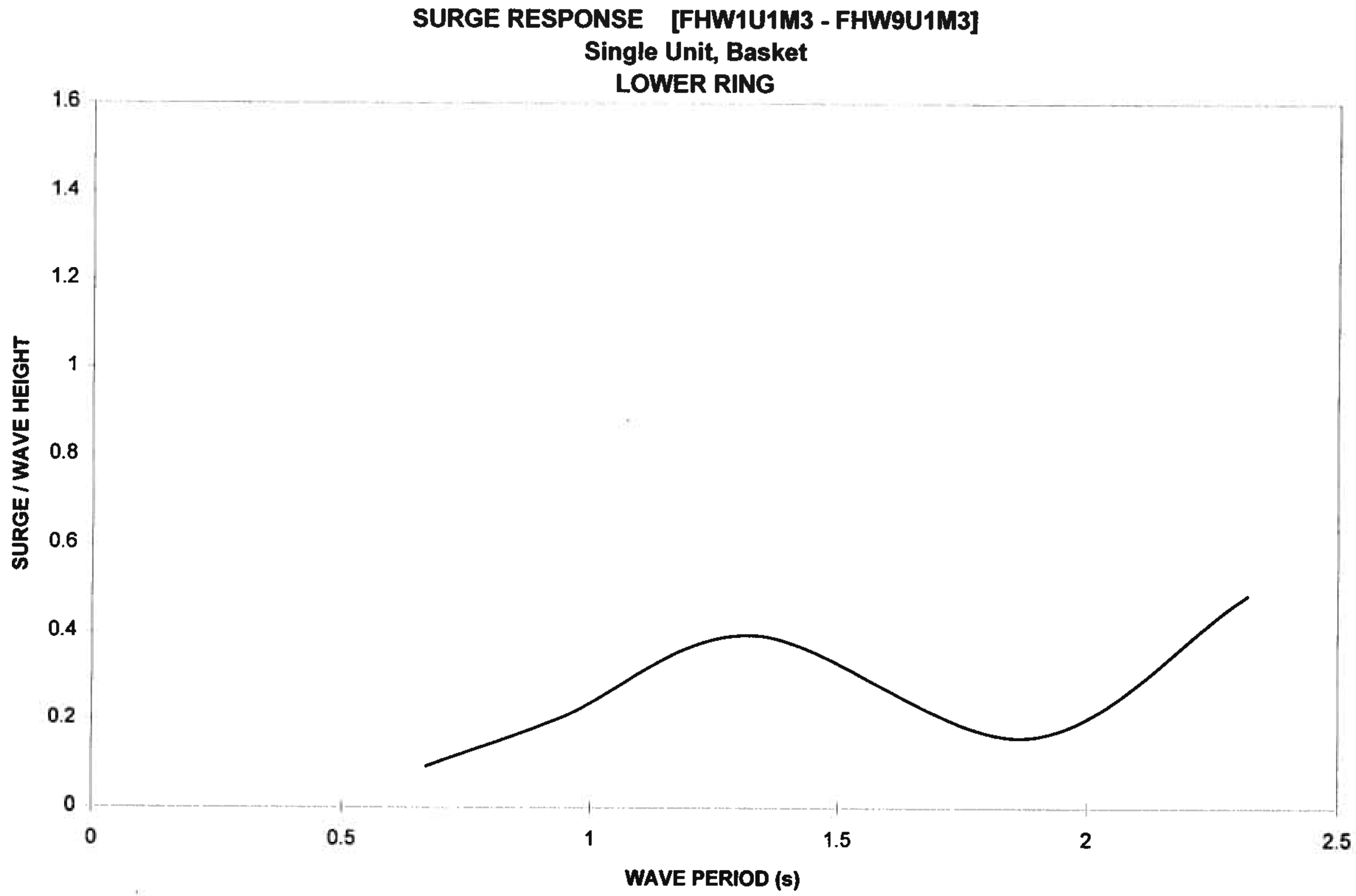


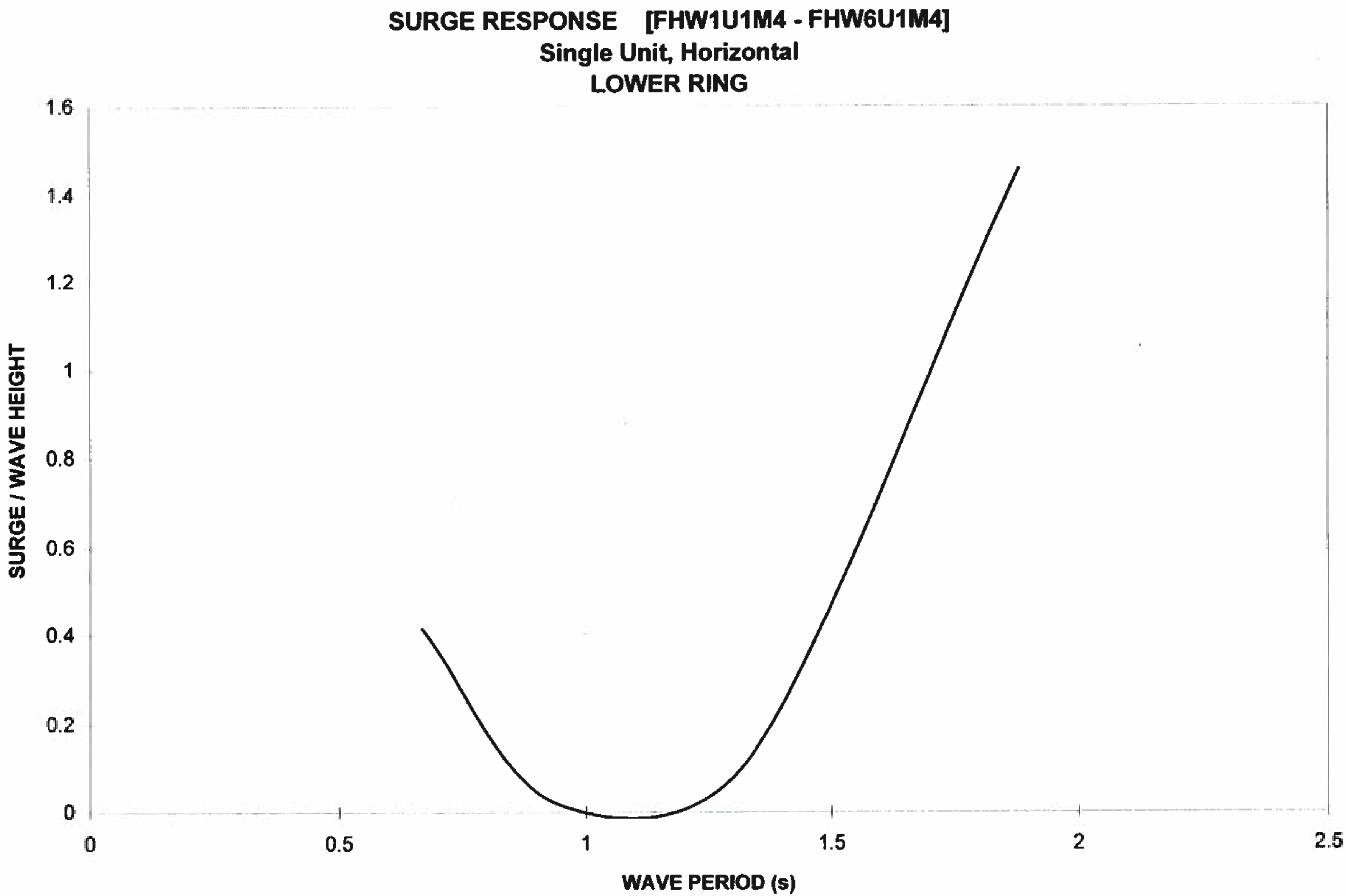

HEAVE RESPONSE [FHW1U4M2 - FHW9U4M2]
Four Unit, Ring
HEAVE 1 / WAVE HEIGHT
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.5
1
1.5
2
2.5
WAVE PERIOD (S)

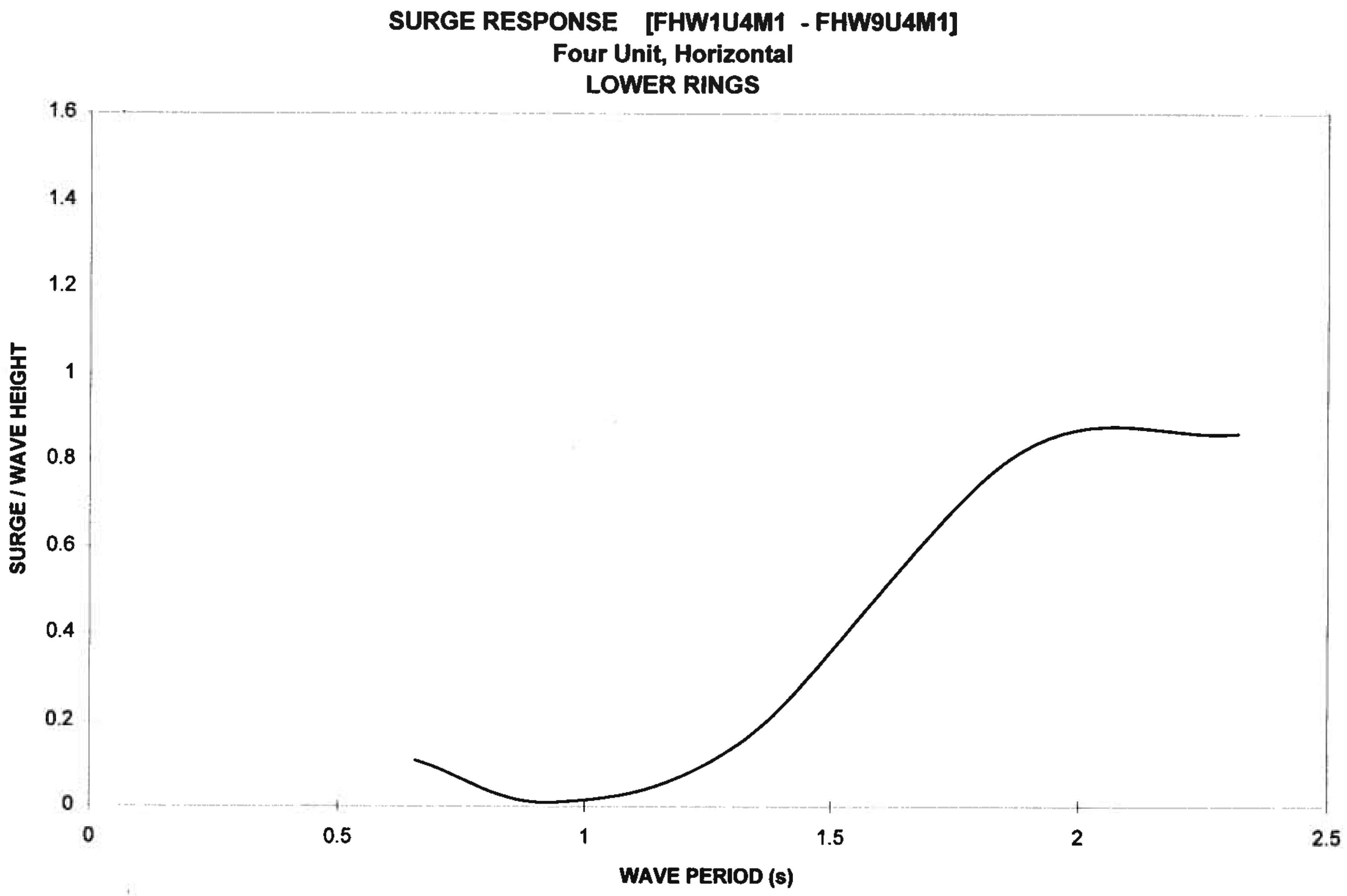

HEAVE RESPONSE [FQW1U3M4 - FQW9U3M4]
Four Unit, Horizontal, Quartering
HEAVE 1 / WAVE HEIGHT
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0.5
1
1.5
2
2.5
WAVE PERIOD (S)


SURGE RESPONSE [FHW1U1M1 - FHW6U1M1]
Single Unit, Catenary
LOWER RING
SURGE / WAVE HEIGHT
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.5
1
1.5
2
2.5
WAVE PERIOD (s)

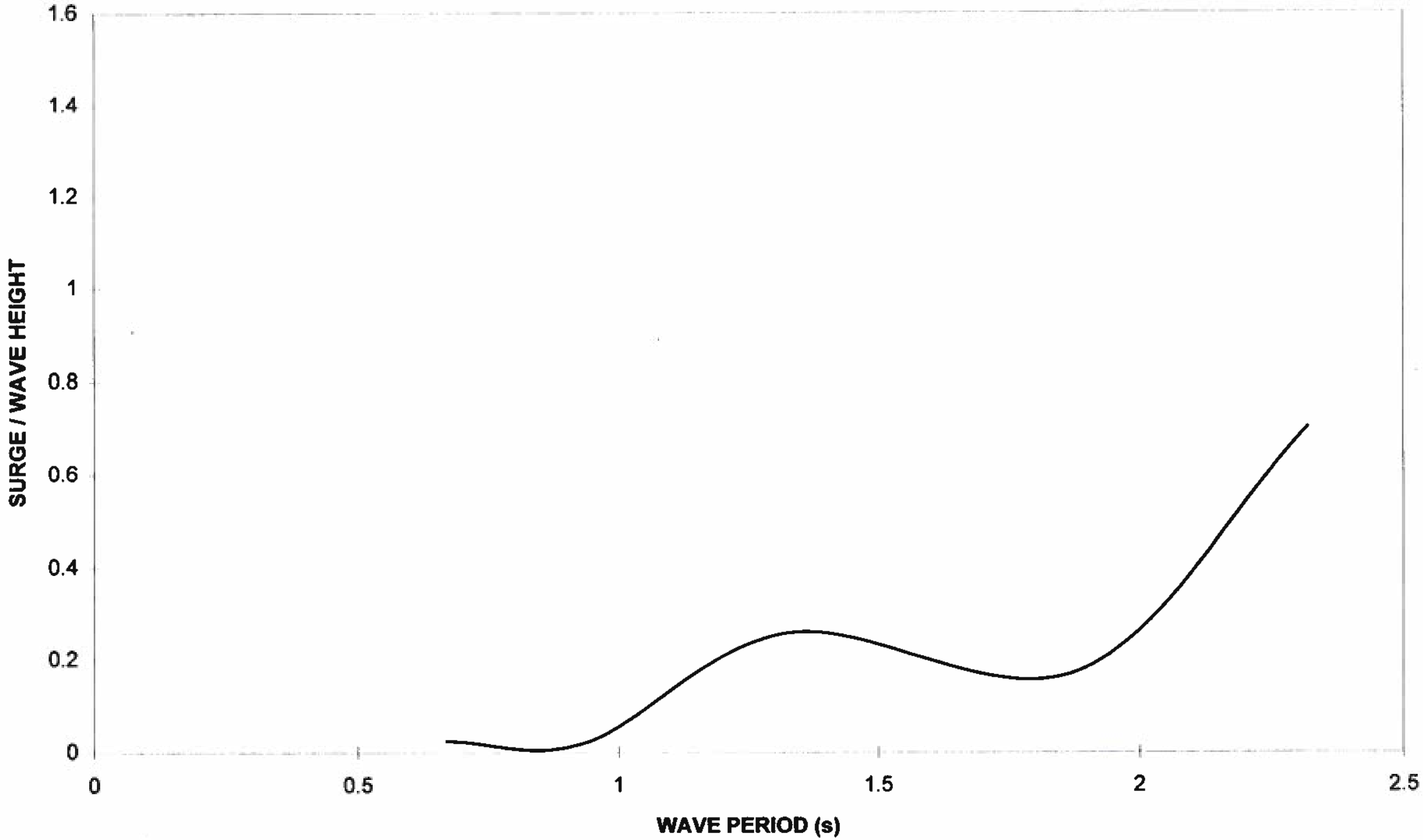

SURGE RESPONSE [FHW1U1M2 - FHW9U1M2]
Single Unit, Ring
LOWER RING
SURGE / WAVE HEIGHT
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.5
1
1.5
2
2.5
WAVE PERIOD (s)

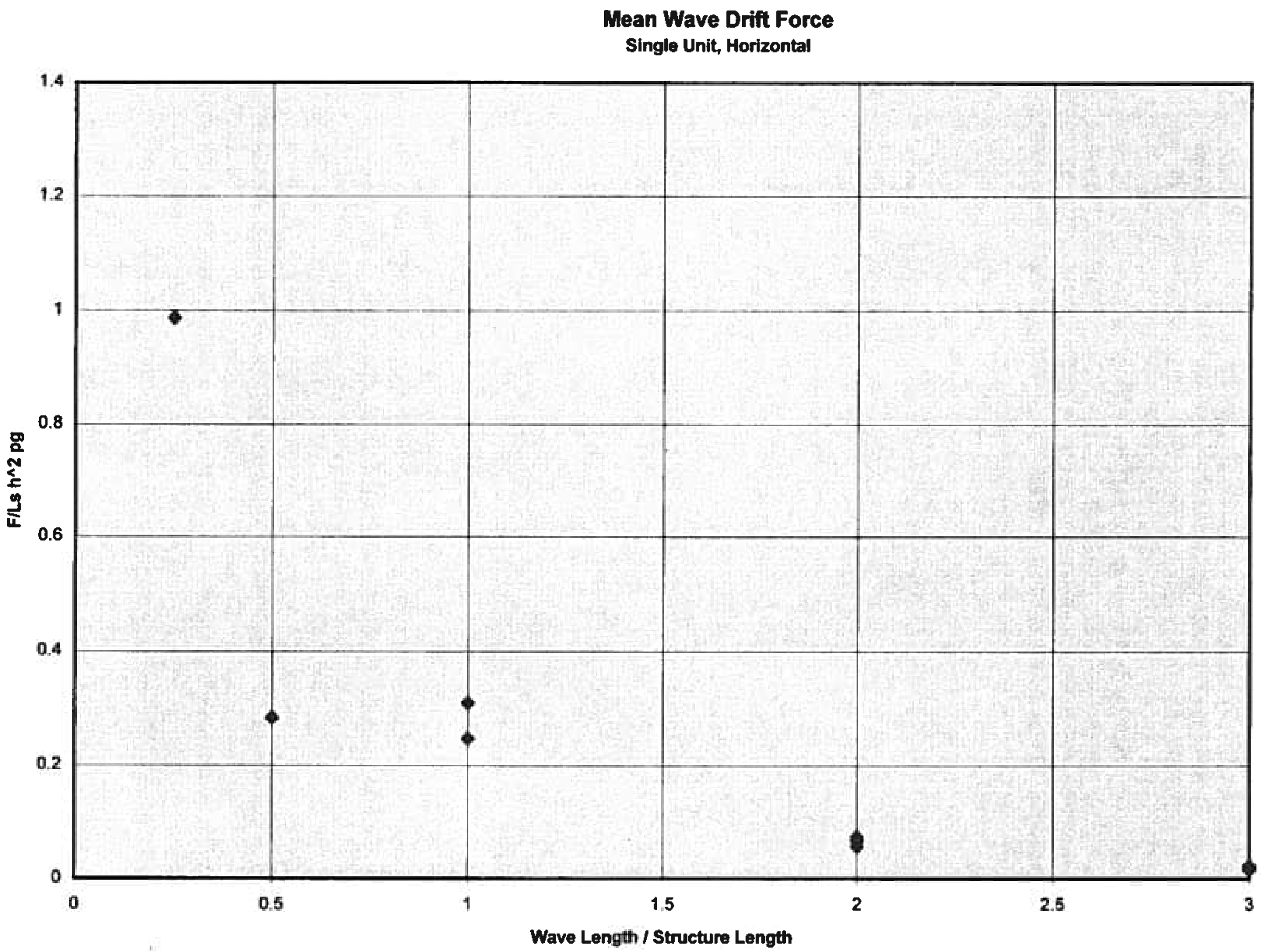

SURGE RESPONSE [FHW1U1M3 - FHW9U1M3]
Single Unit, Basket
LOWER RING
SURGE / WAVE HEIGHT
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.5
1
1.5
2
2.5
WAVE PERIOD (s)

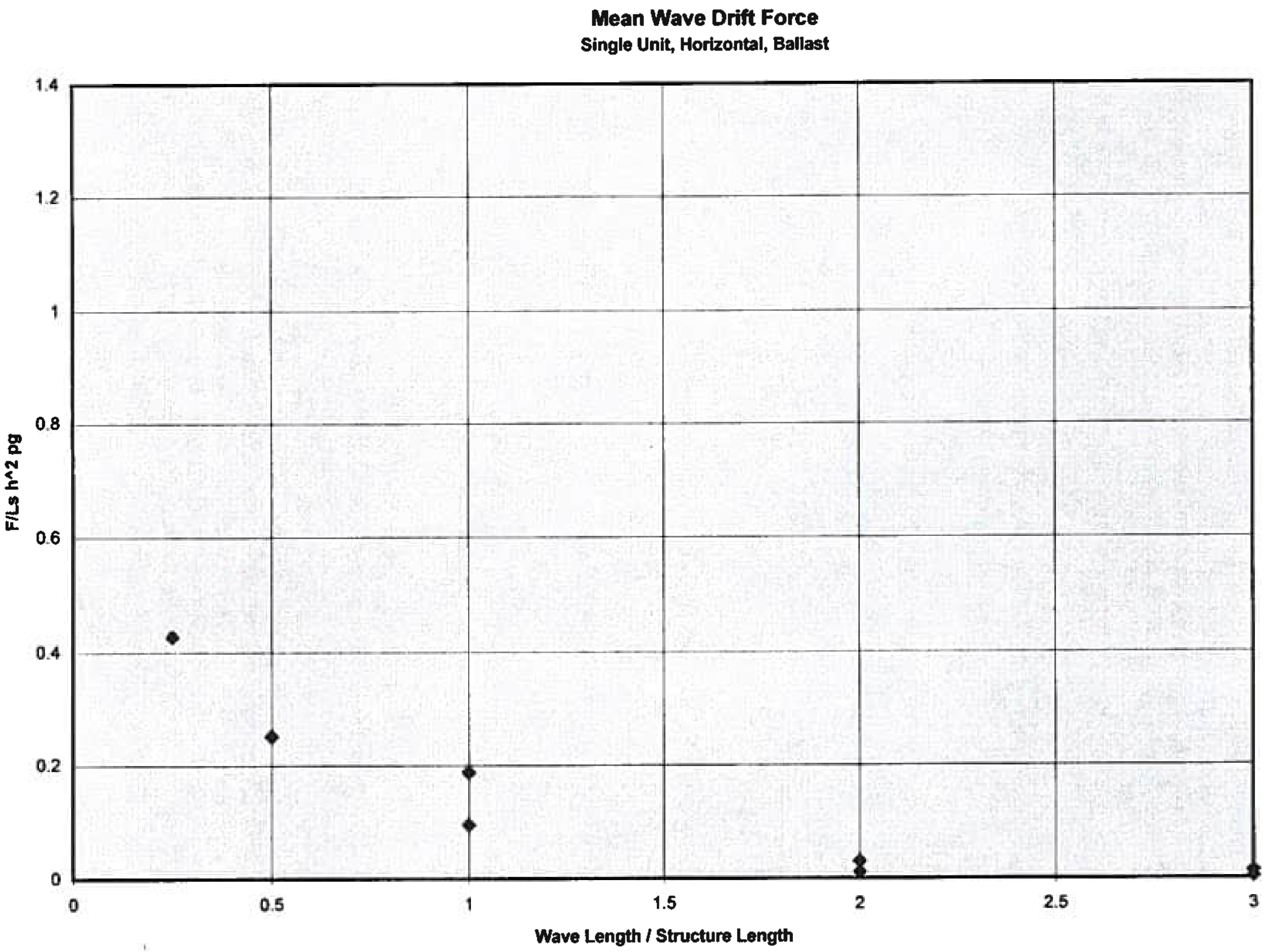

SURGE RESPONSE [FHW1U1M4 - FHW6U1M4]
Single Unit, Horizontal
LOWER RING
SURGE / WAVE HEIGHT
WAVE PERIOD (s)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
0.5
1.5
2
2.5

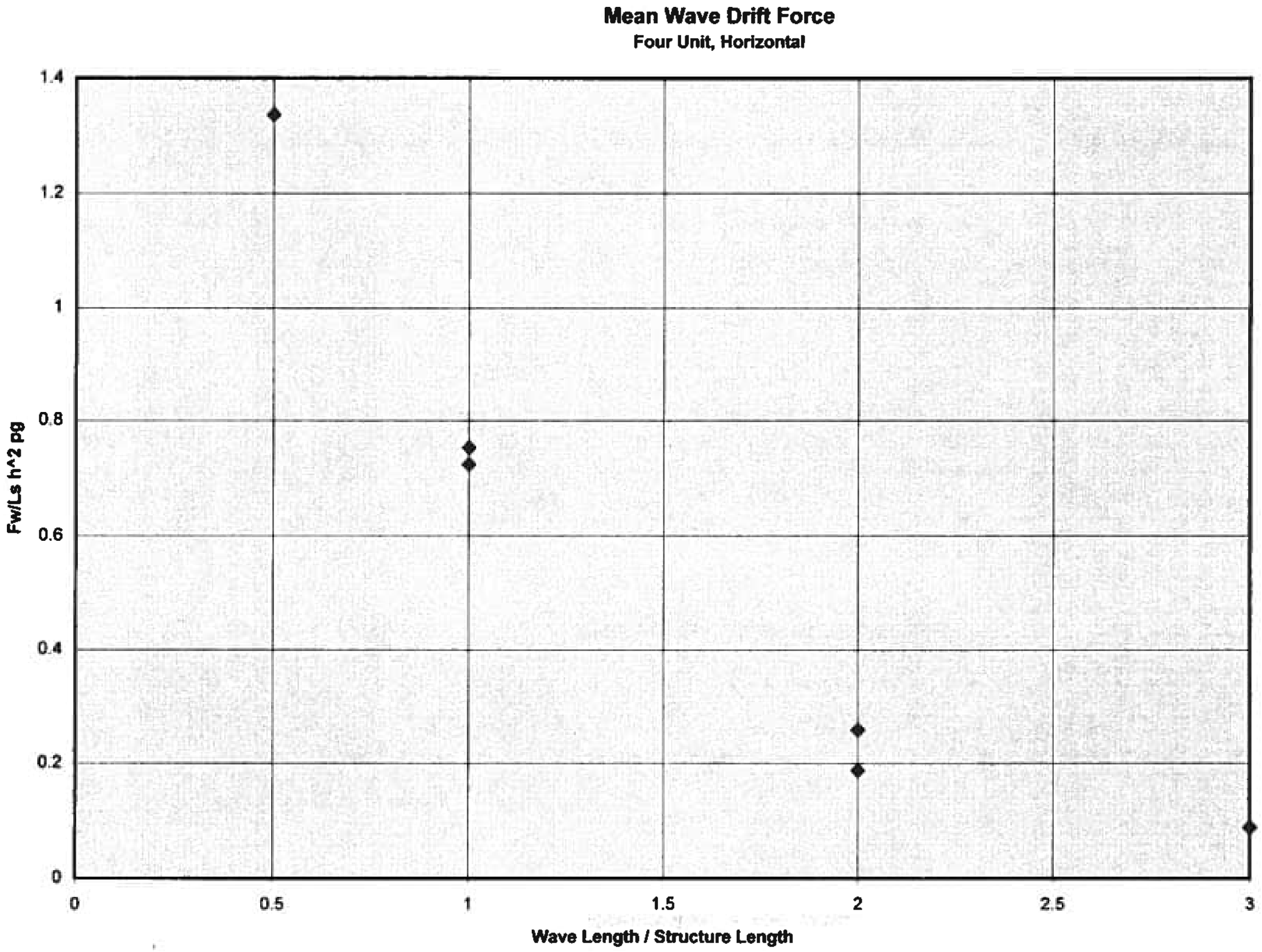

SURGE RESPONSE [FHW1U4M1 - FHW9U4M1]
Four Unit, Horizontal
LOWER RINGS
SURGE / WAVE HEIGHT
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0.5
1
1.5
2
2.5
WAVE PERIOD (s)

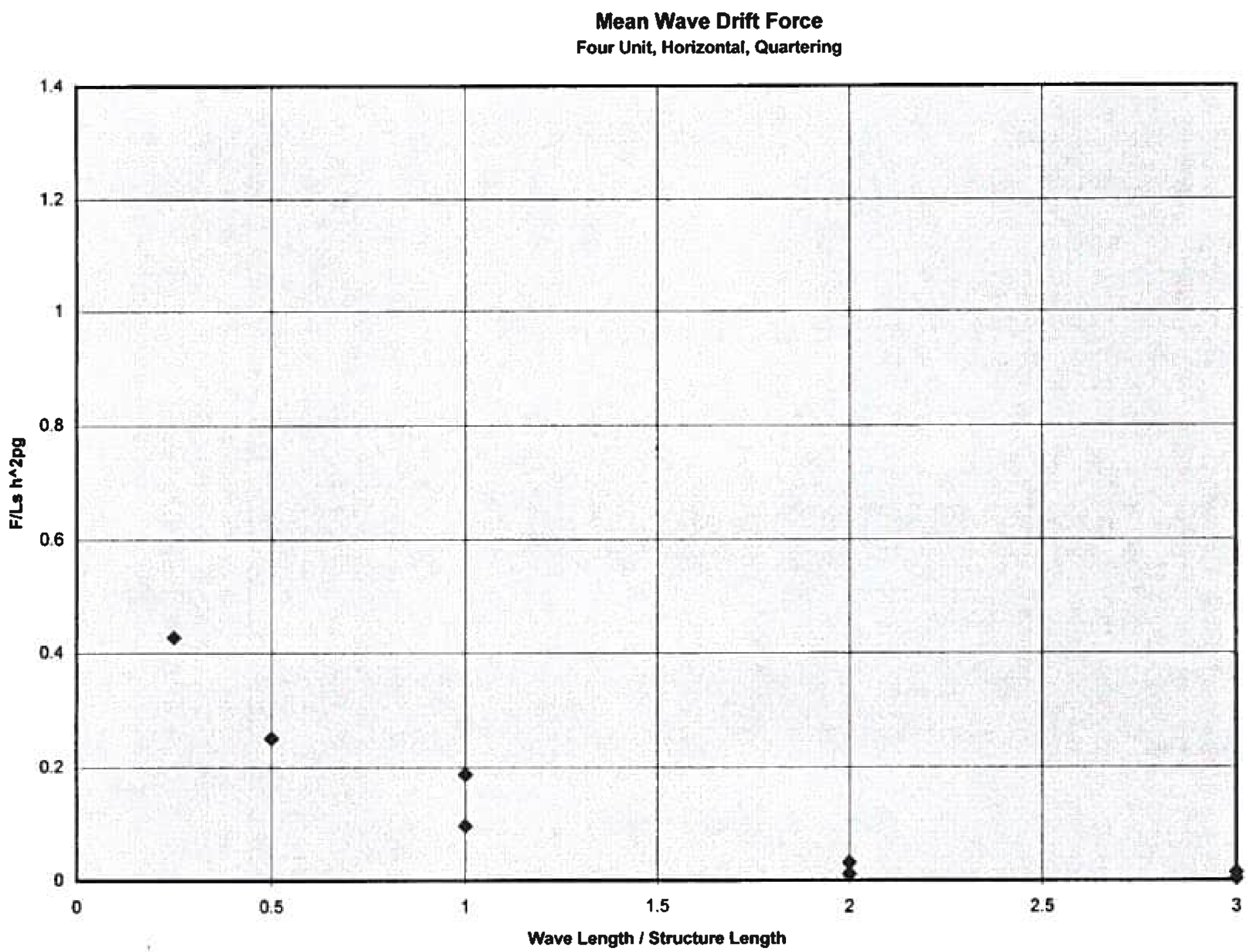
SURGE RESPONSE [FHW1U4M2 - FHW9U4M2]
Four Unit, Ring
LOWER RINGS




Mean Wave Drift Force
Single Unit, Horizontal
1.4
1.2
1
0.8
0.6
0.4
0.2
0
F/Ls h^2 pg
0
0.5
1
1.5
2
2.5
3
Wave Length / Structure Length


Mean Wave Drift Force
Single Unit, Horizontal, Ballast
F/Ls h^2 pg
0
0.2
0.4
0.6
0.8
1
1.2
1.4
0
0.5
1
1.5
2
2.5
3
Wave Length / Structure Length


Mean Wave Drift Force
Four Unit, Horizontal
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Fw/Ls h^2 pg
0
0.5
1
1.5
2
2.5
3
Wave Length / Structure Length


Mean Wave Drift Force
Four Unit, Horizontal, Quartering
F/Ls h^2pg
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.5
1
1.5
2
2.5
3
Wave Length / Structure Length

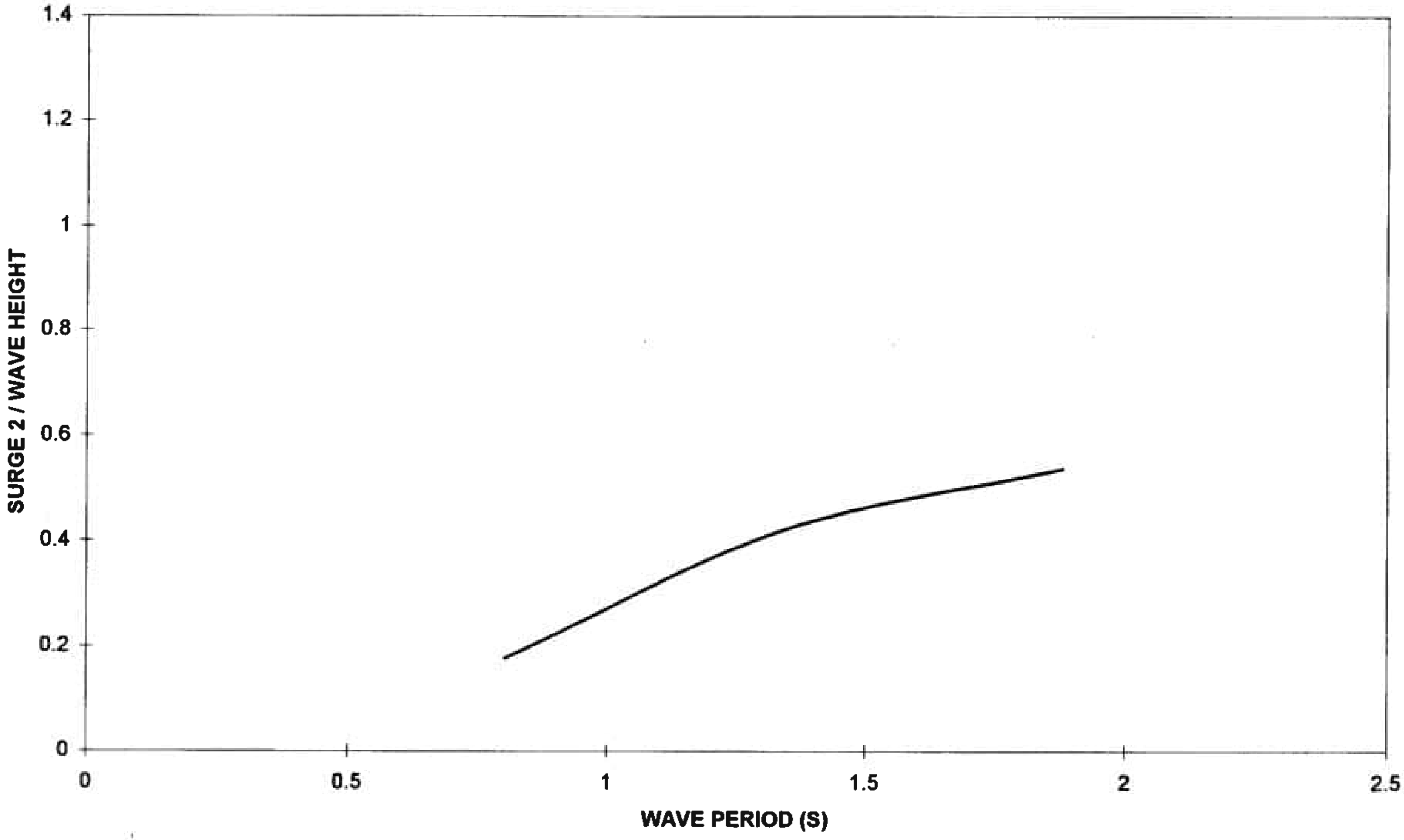
APPENDIX 3 Six degree of freedom data

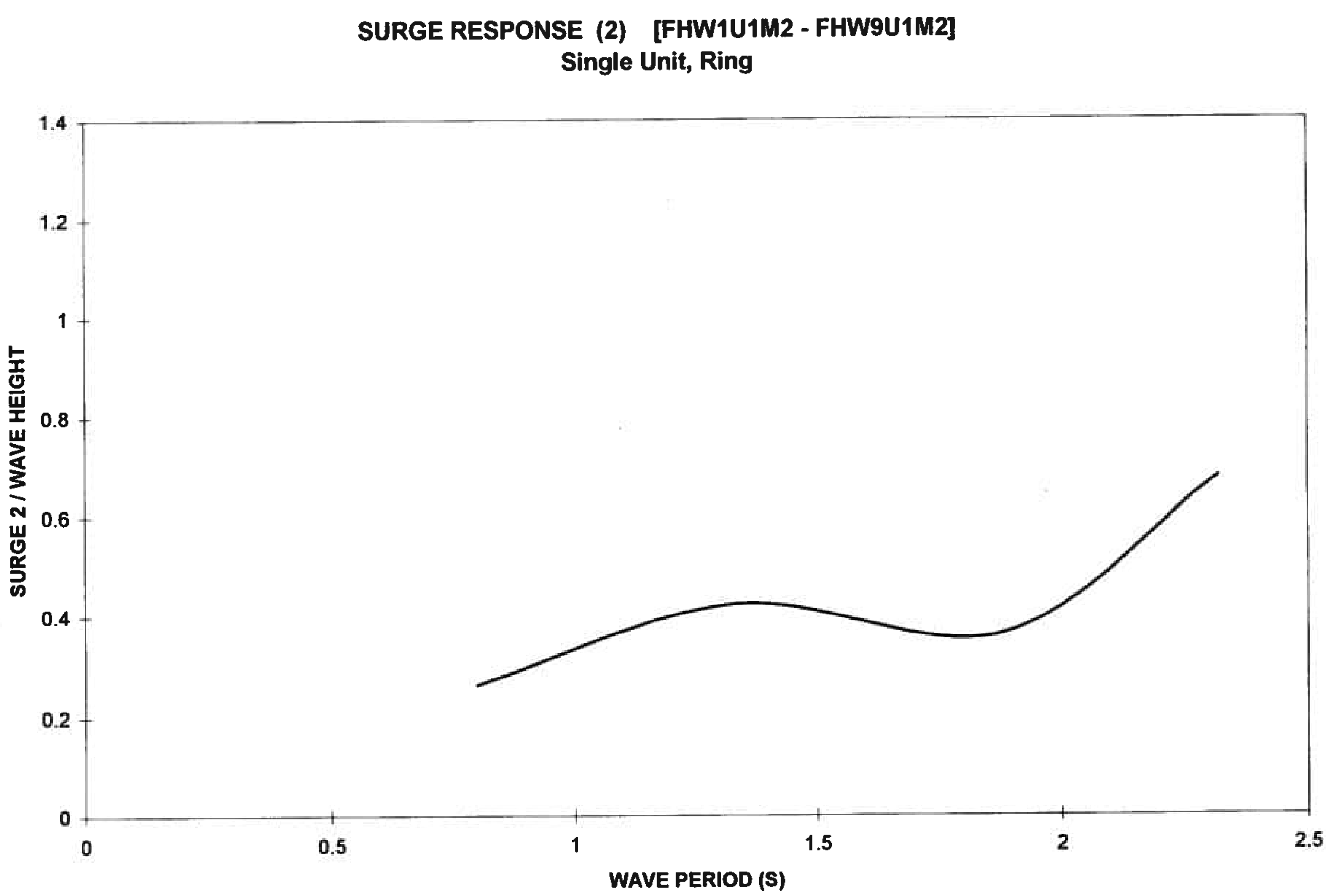
1.	Surge RAOs	Collar Section 2
2.	Heave RAOs	Collar Section 2
3.	Sway RAOs	Collar Section 1
4.	Sway RAOs	Collar Section 2
5.	Roll RAOs	Collar Section 1
6.	Roll RAOs	Collar Section 2
7.	Pitch RAOs	Collar Section 1
8.	Pitch RAOs	Collar Section 2
9.	Yaw RAOs	Collar Section 1
10.	Yaw RAOs	Collar Section 2

The following data sets are contained in Appendix 2

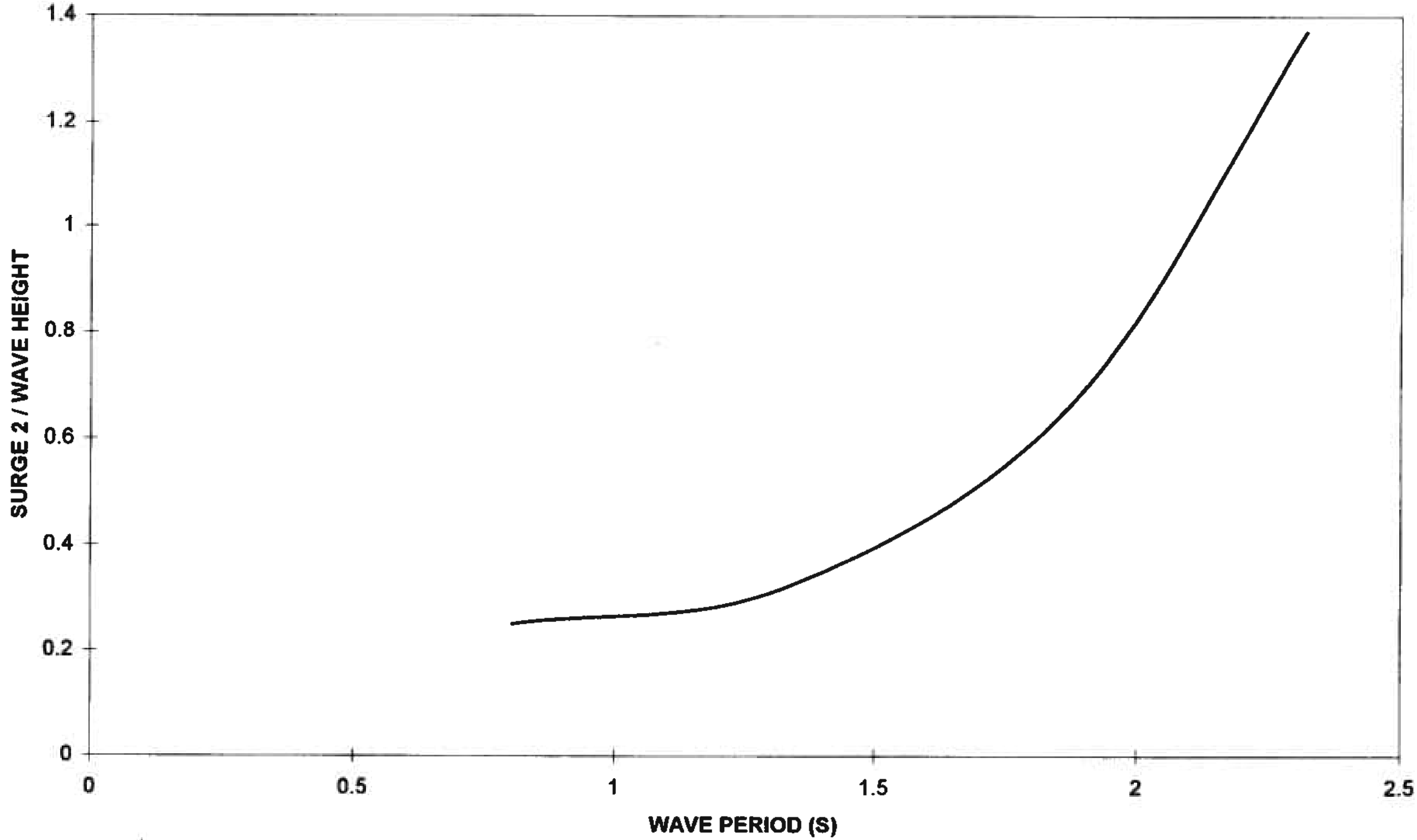
1.	Surge RAOs	Collar Section 1
2.	Heave RAOs	Collar Section 1
3.	Surge RAOs	Lower Ring
4.	Heave RAOs	Lower Ring

SURGE RESPONSE (2) [FHW1U1M1 - FHW6U1M1]
Single Unit, Catenary

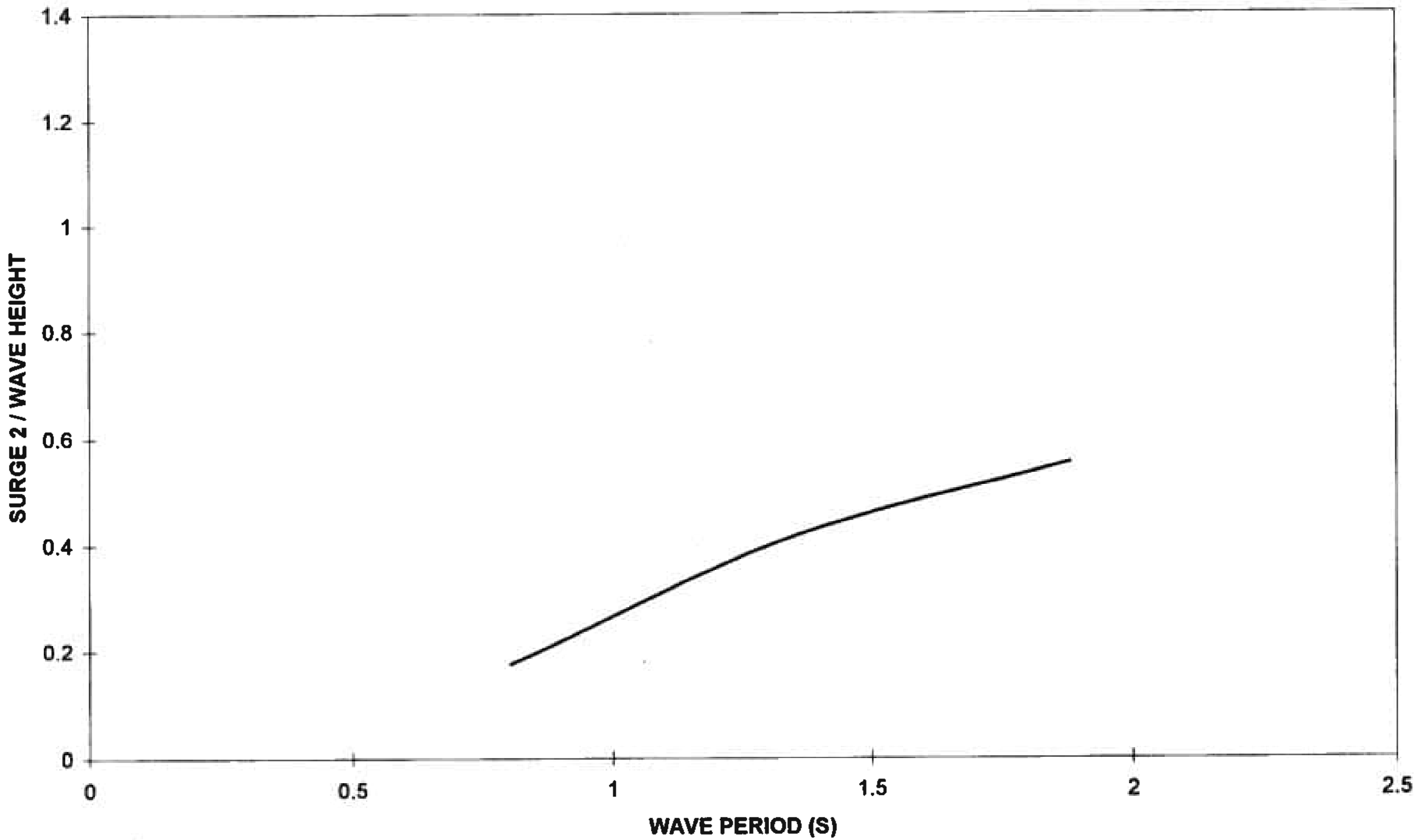



SURGE RESPONSE (2) [FHW1U1M2 - FHW9U1M2]
Single Unit, Ring
SURGE 2 / WAVE HEIGHT
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.5
1
1.5
2
2.5
WAVE PERIOD (S)

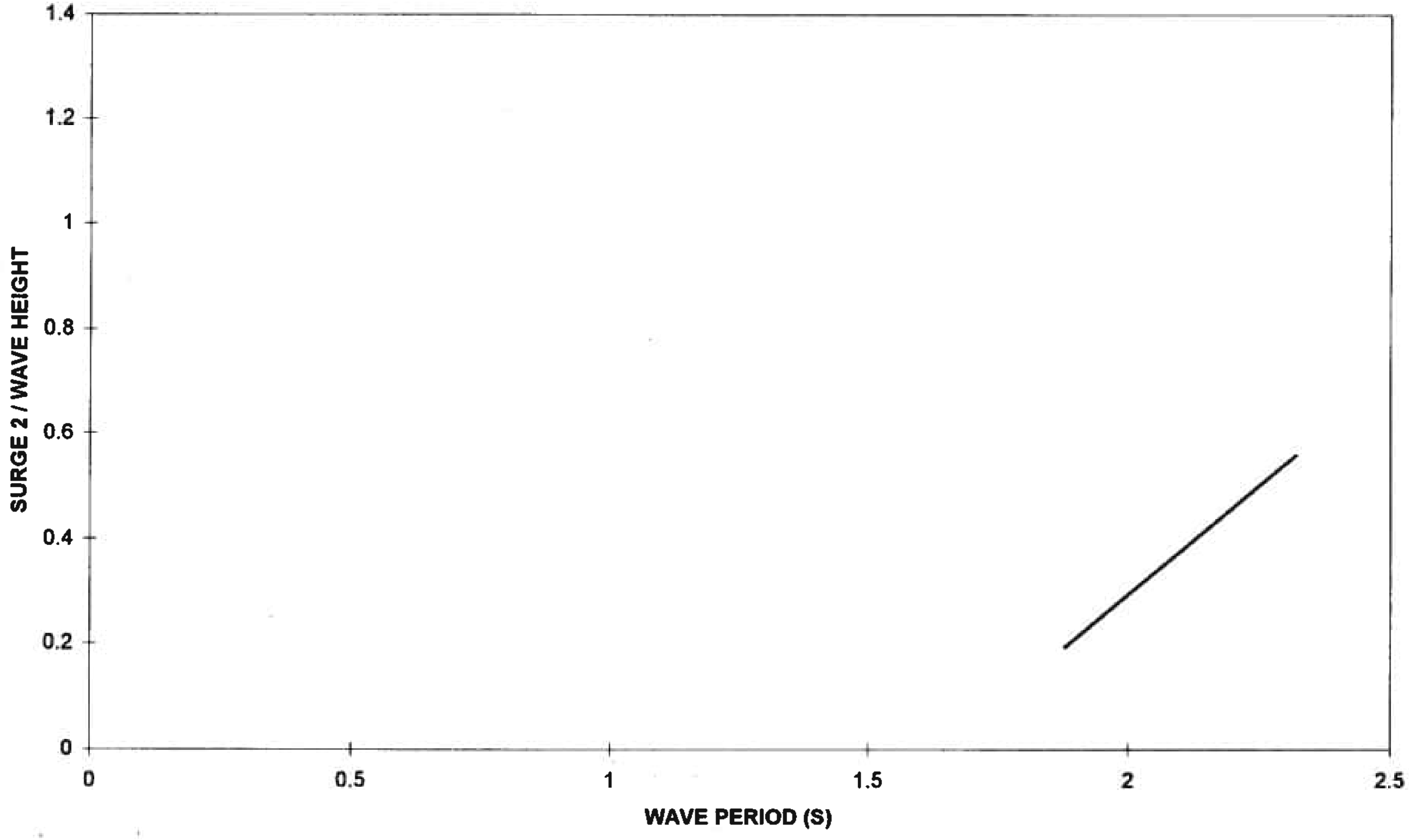
SURGE RESPONSE (2) [FHW1U1M3 - FHW9U1M3]
Single Unit, Basket



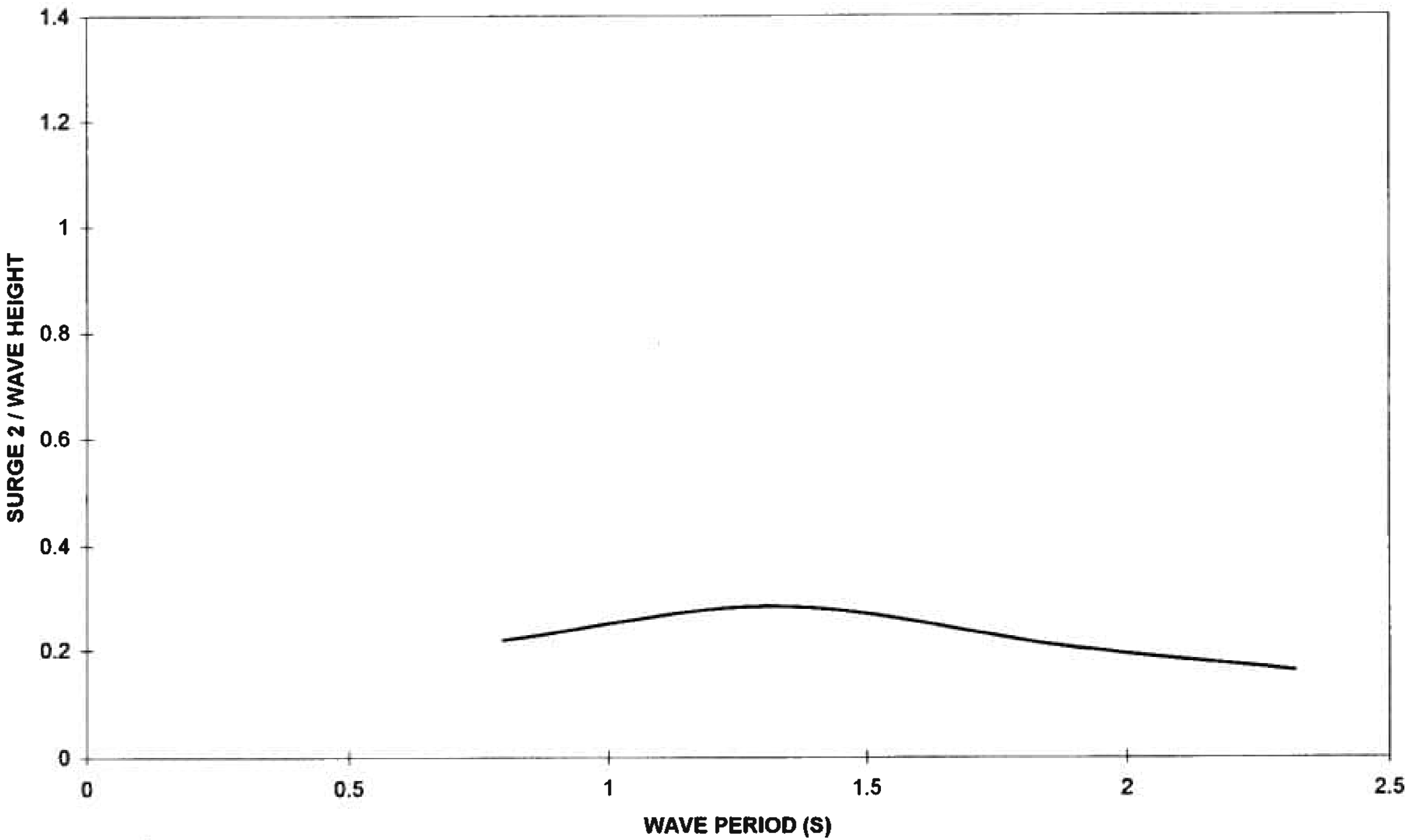
SURGE RESPONSE (2) [FHW1U1M4 - FHW6U1M4]
Single Unit, Horizontal

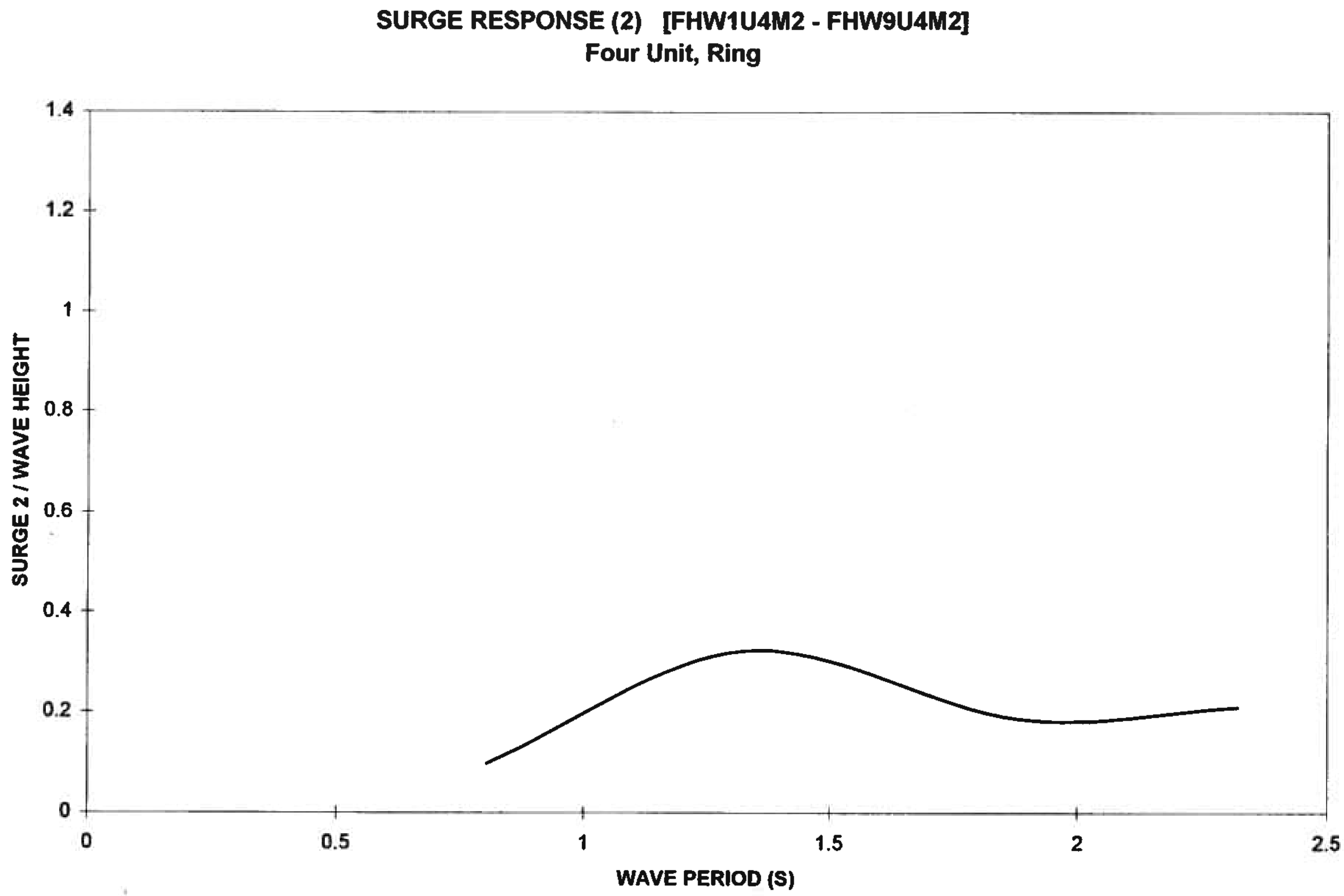


SURGE RESPONSE (2) [FHW5U3M4 - FHW9U3M4]
Single Unit, Horizontal, Ballast

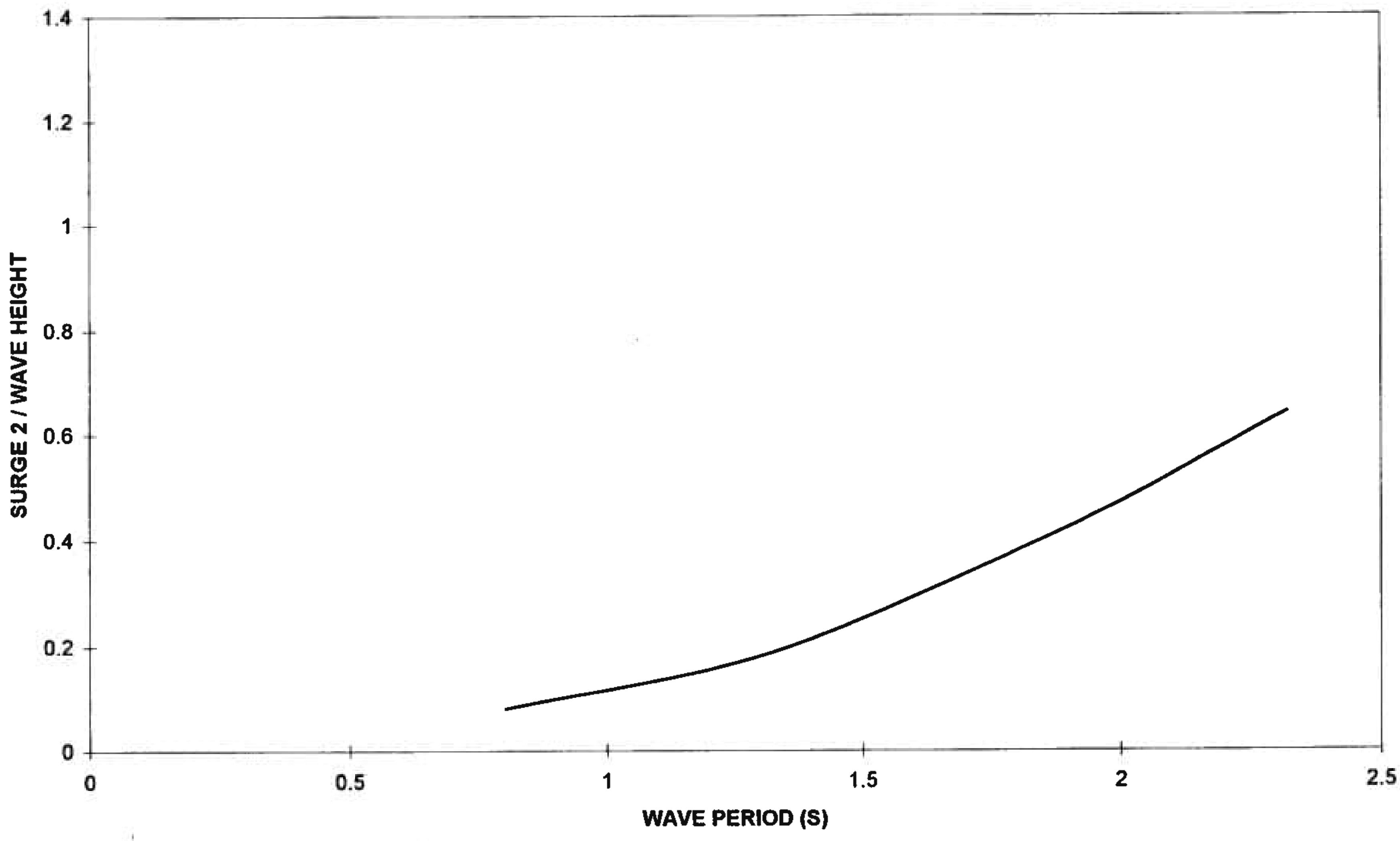


SURGE RESPONSE (2) [FHW1U4M1 - FHW8U4M1]
Four Unit, Horizontal

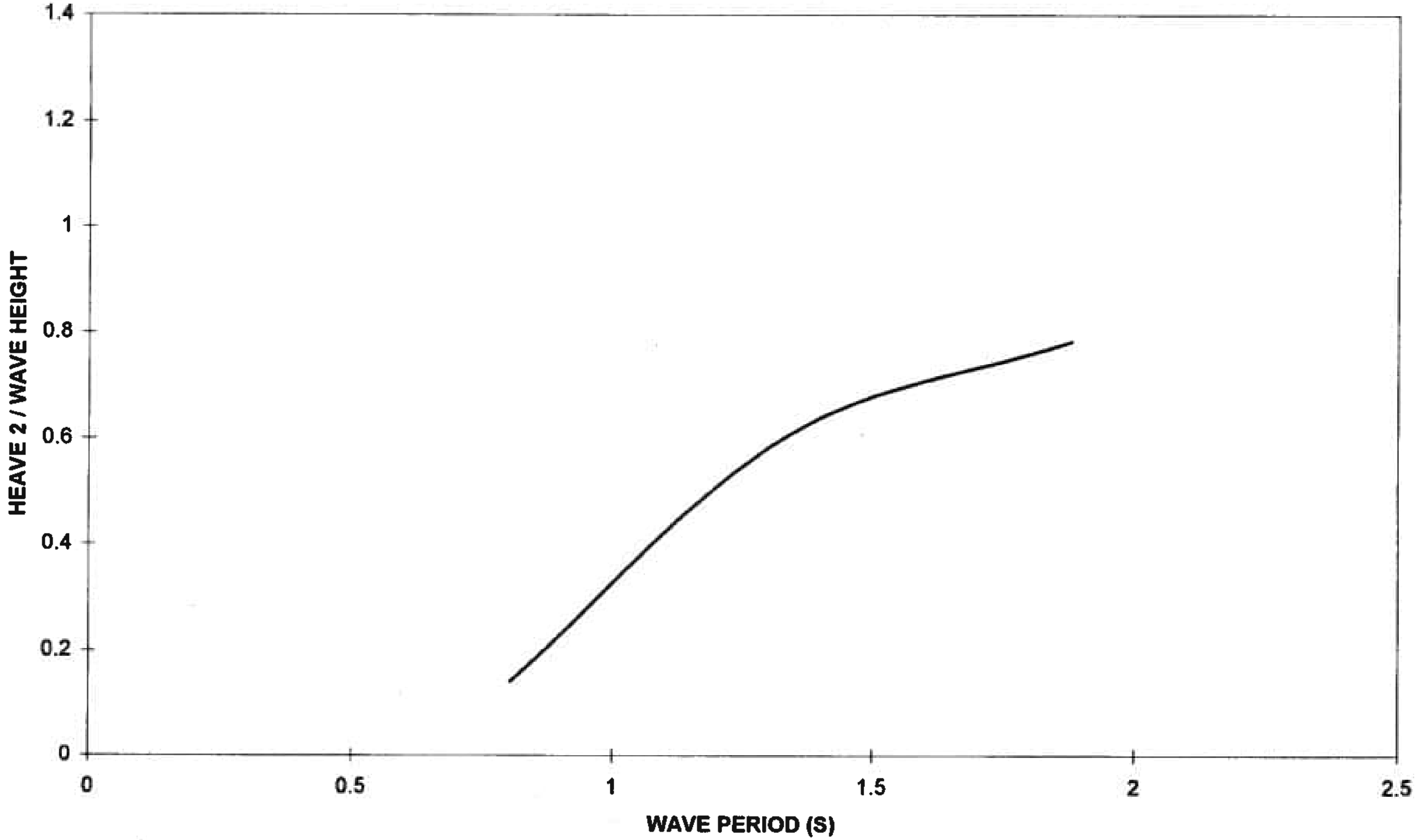



SURGE RESPONSE (2) [FHW1U4M2 - FHW9U4M2]
Four Unit, Ring
SURGE 2 / WAVE HEIGHT
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.5
1
1.5
2
2.5
WAVE PERIOD (S)

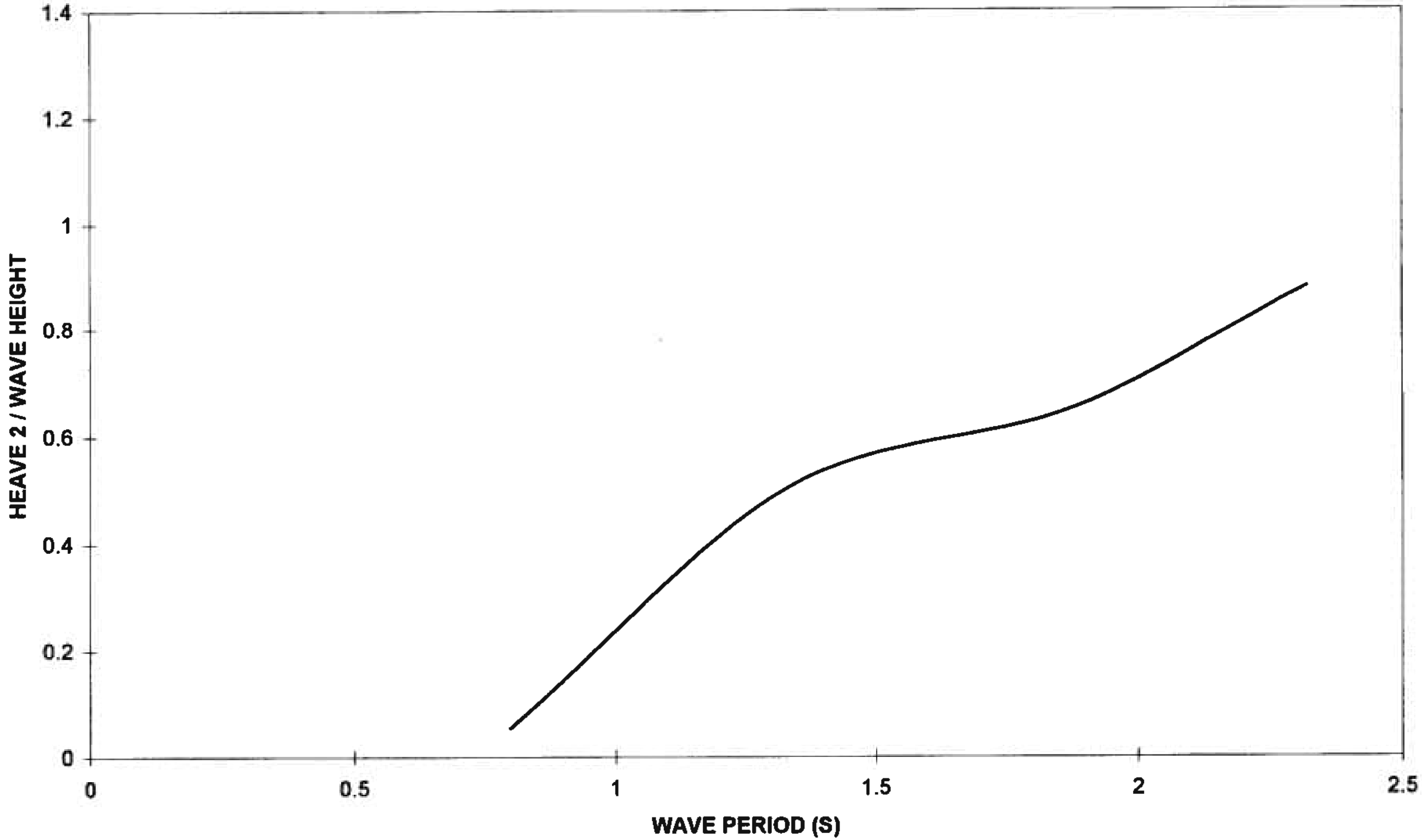
SURGE RESPONSE (2) [FQW1U3M4 - FQW9U3M4]
Four Unit, Horizontal, Quartering

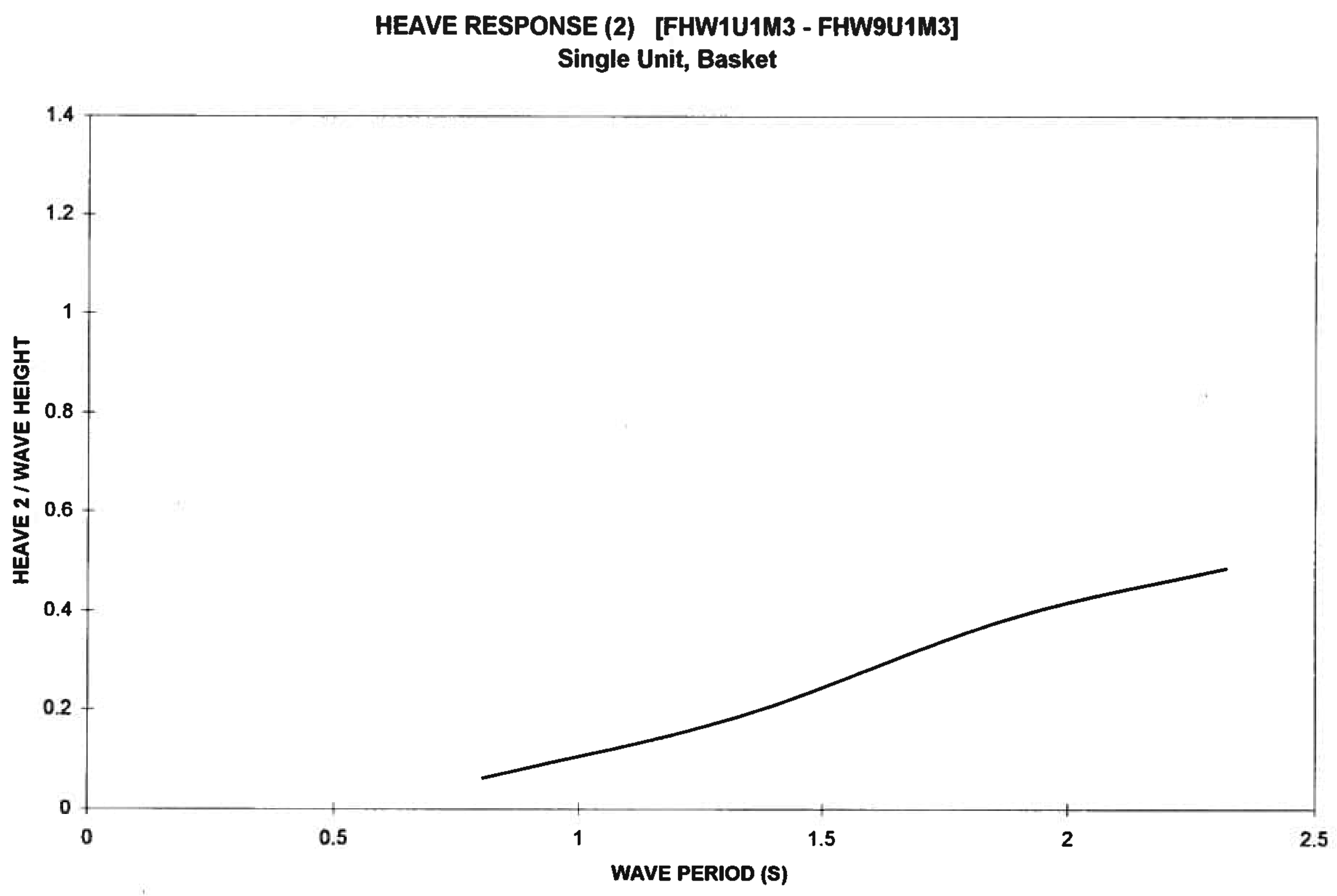


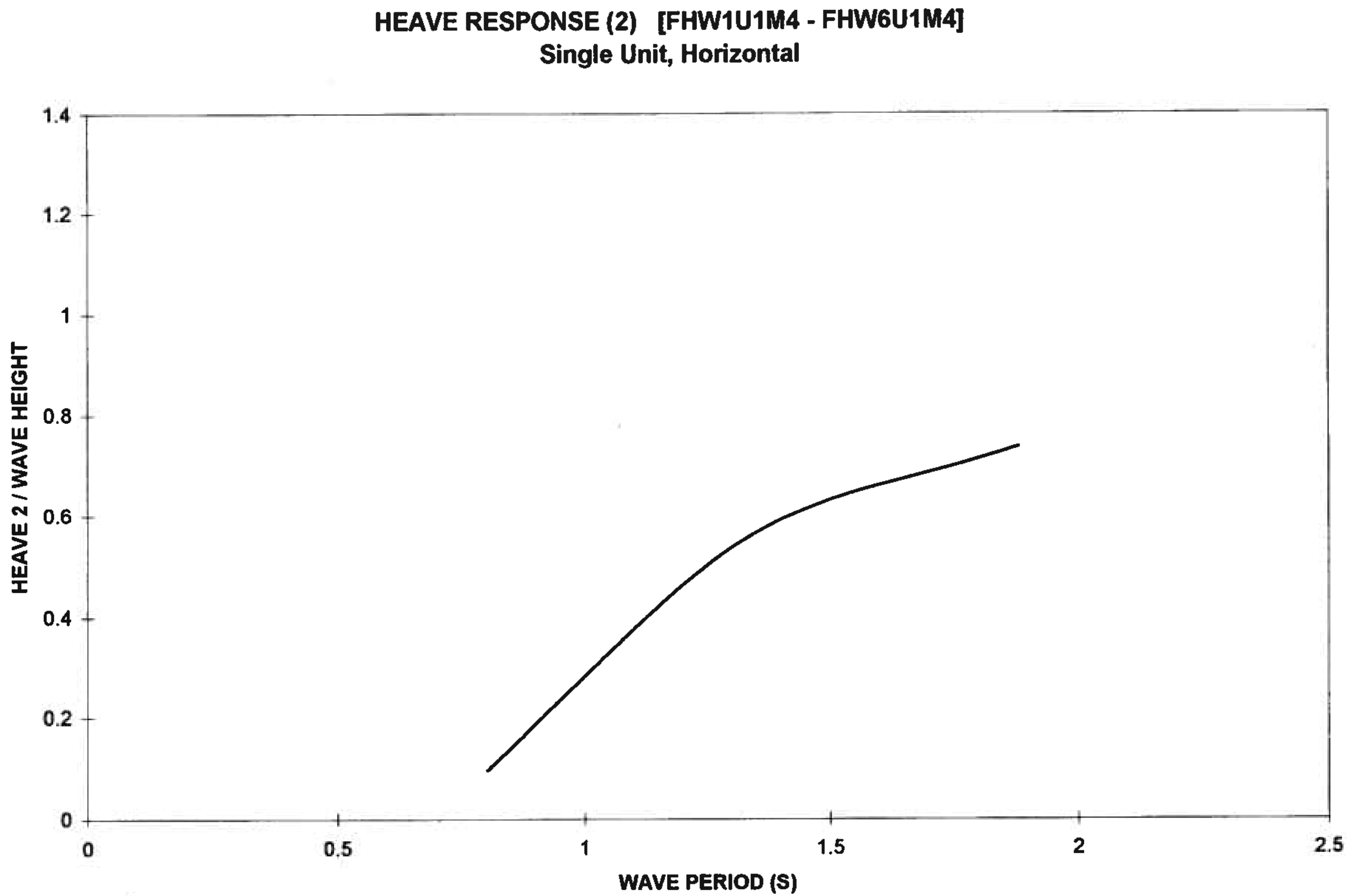
HEAVE RESPONSE (2) [FHW1U1M1 - FHW6U1M1]
Single Unit, Catenary



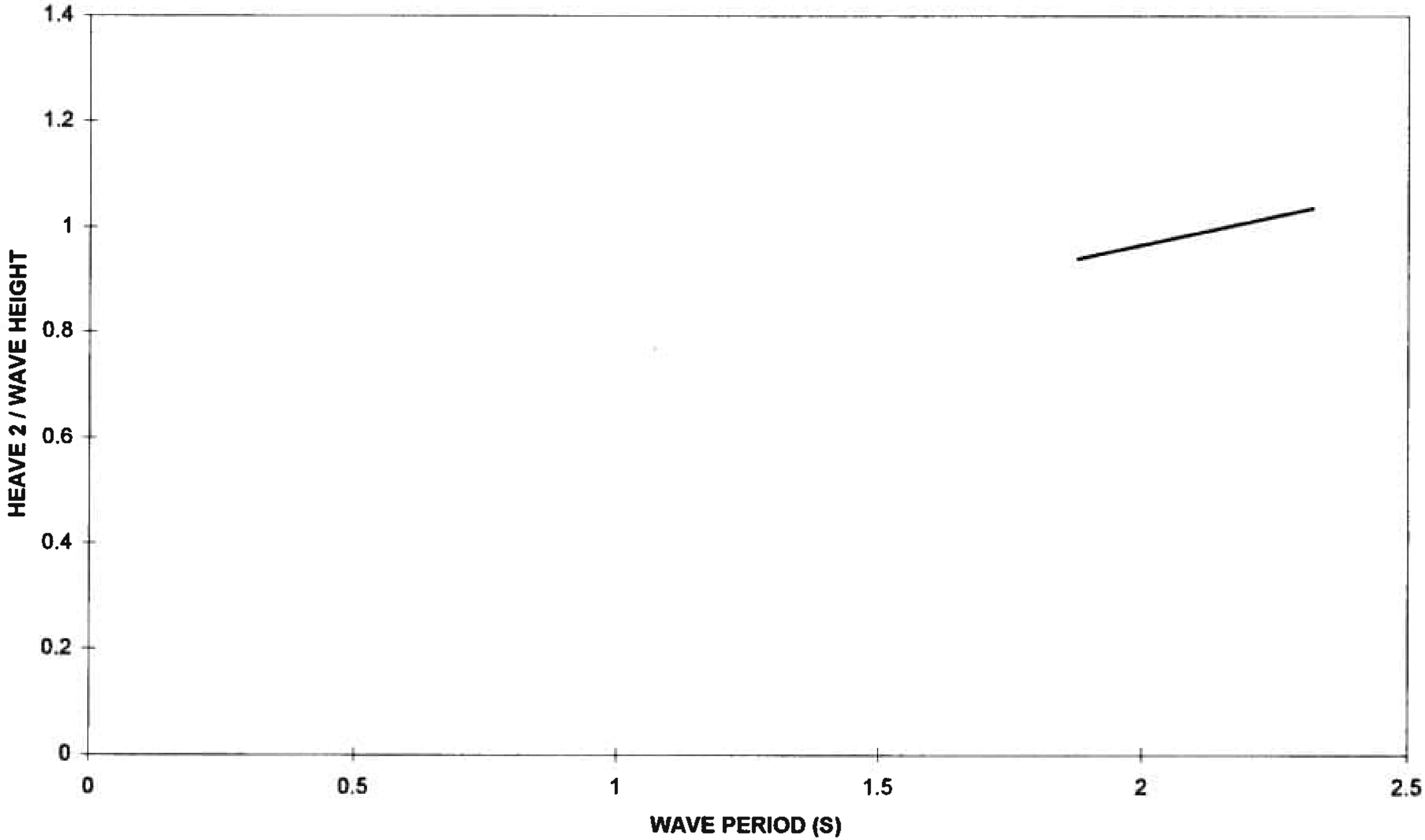
HEAVE RESPONSE (2) [FHW1U1M2 - FHW9U1M2]
Single Unit, Ring



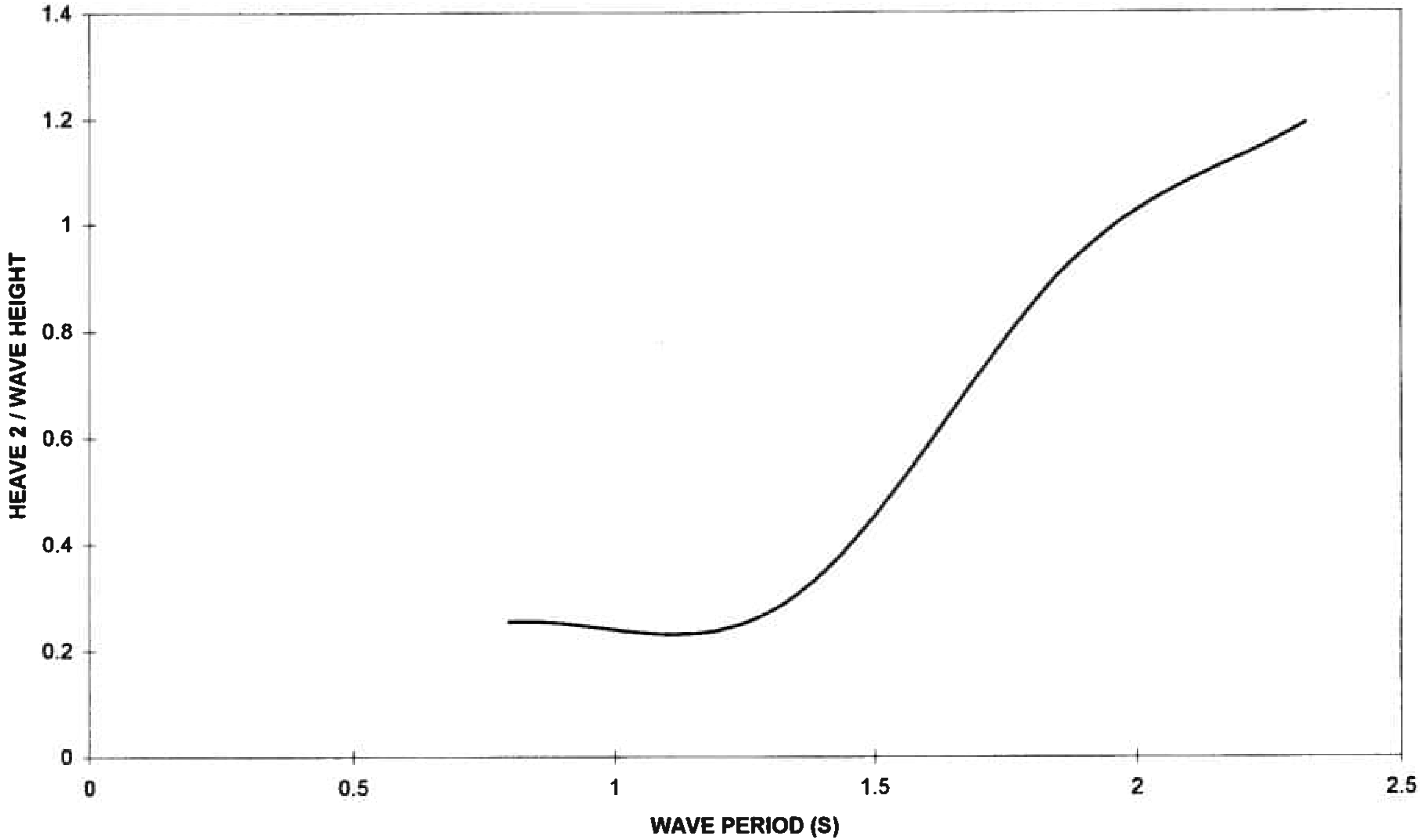

HEAVE RESPONSE (2) [FHW1U1M3 - FHW9U1M3]
Single Unit, Basket
HEAVE 2 / WAVE HEIGHT
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.5
1
1.5
2
2.5
WAVE PERIOD (S)

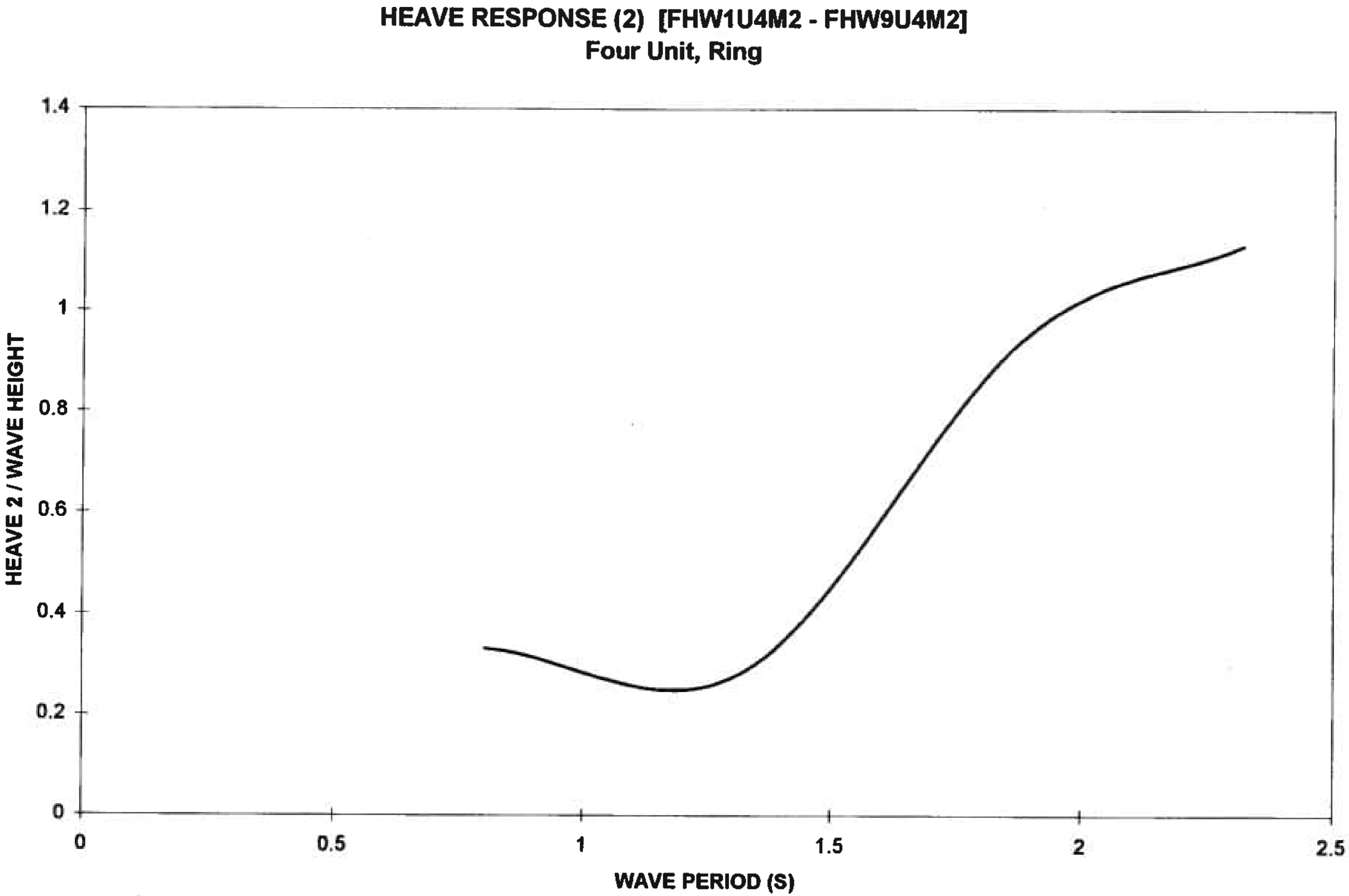

HEAVE RESPONSE (2) [FHW1U1M4 - FHW6U1M4]
Single Unit, Horizontal
HEAVE 2 / WAVE HEIGHT
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.5
1
1.5
2
2.5
WAVE PERIOD (S)

HEAVE RESPONSE (2) [FHW1U3M4 - FHW9U3M4]
Single Unit, Horizontal, Ballast

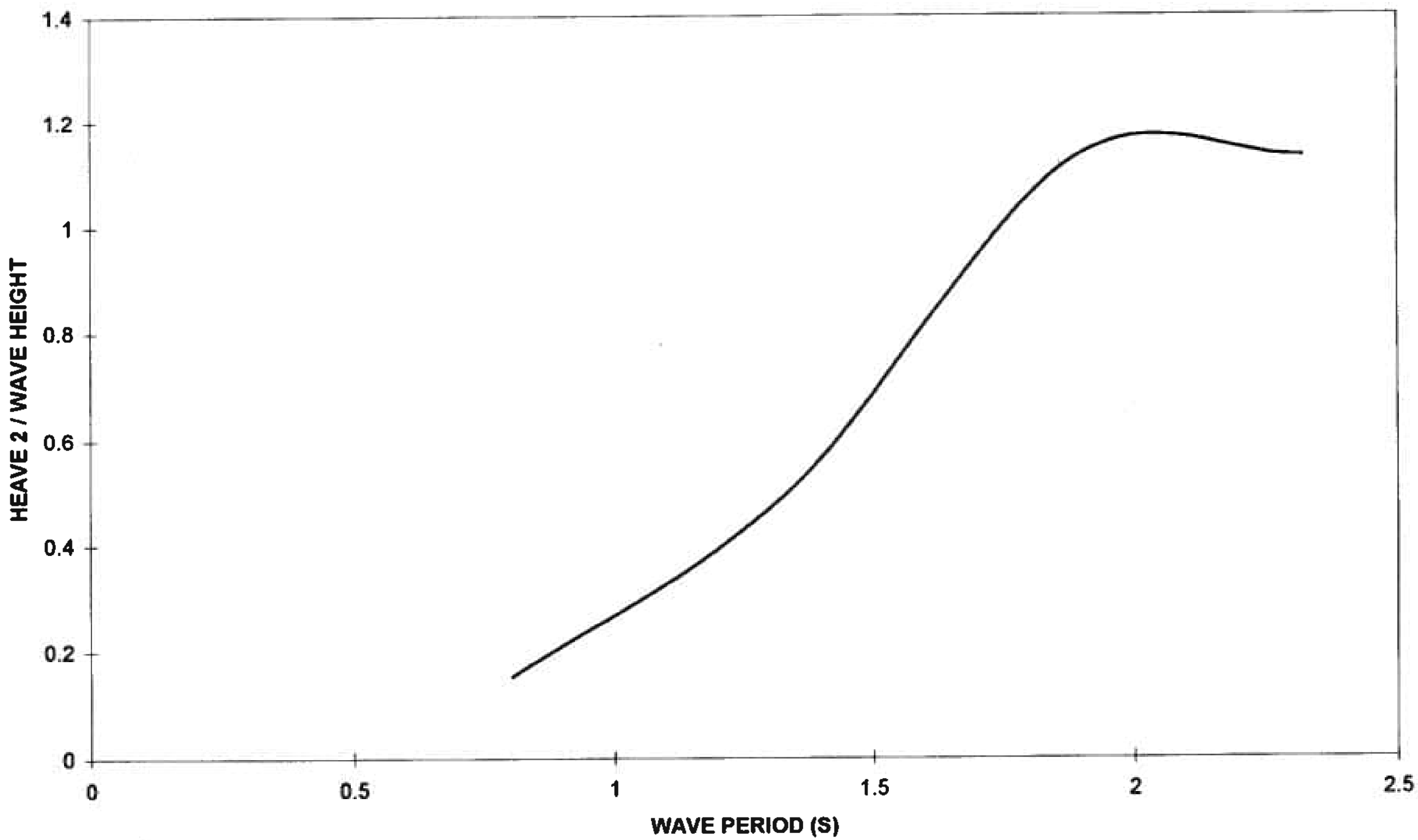


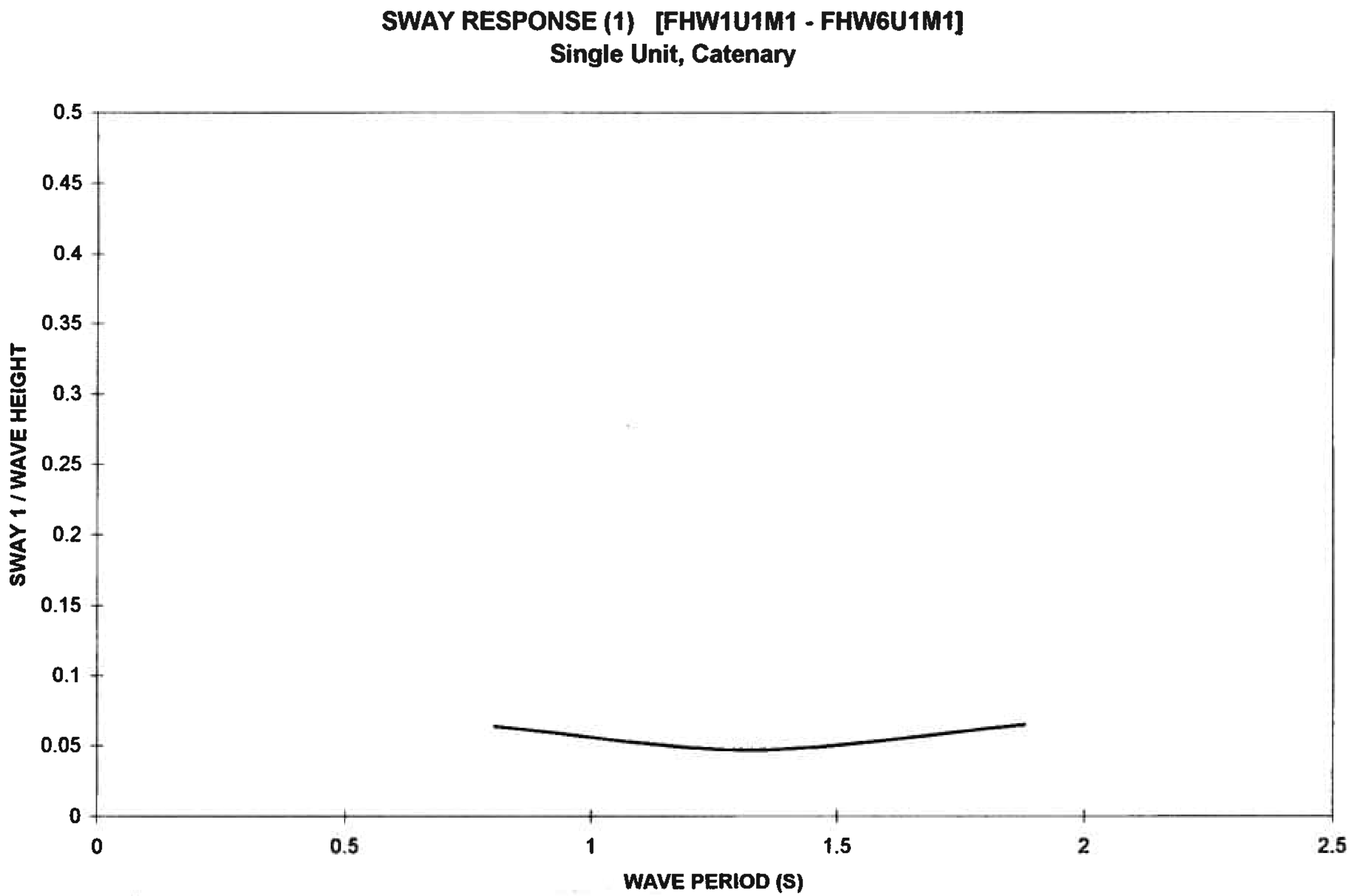
HEAVE RESPONSE (2) [FHW1U4M1 - FHW9U4M1]
Four Unit, Horizontal



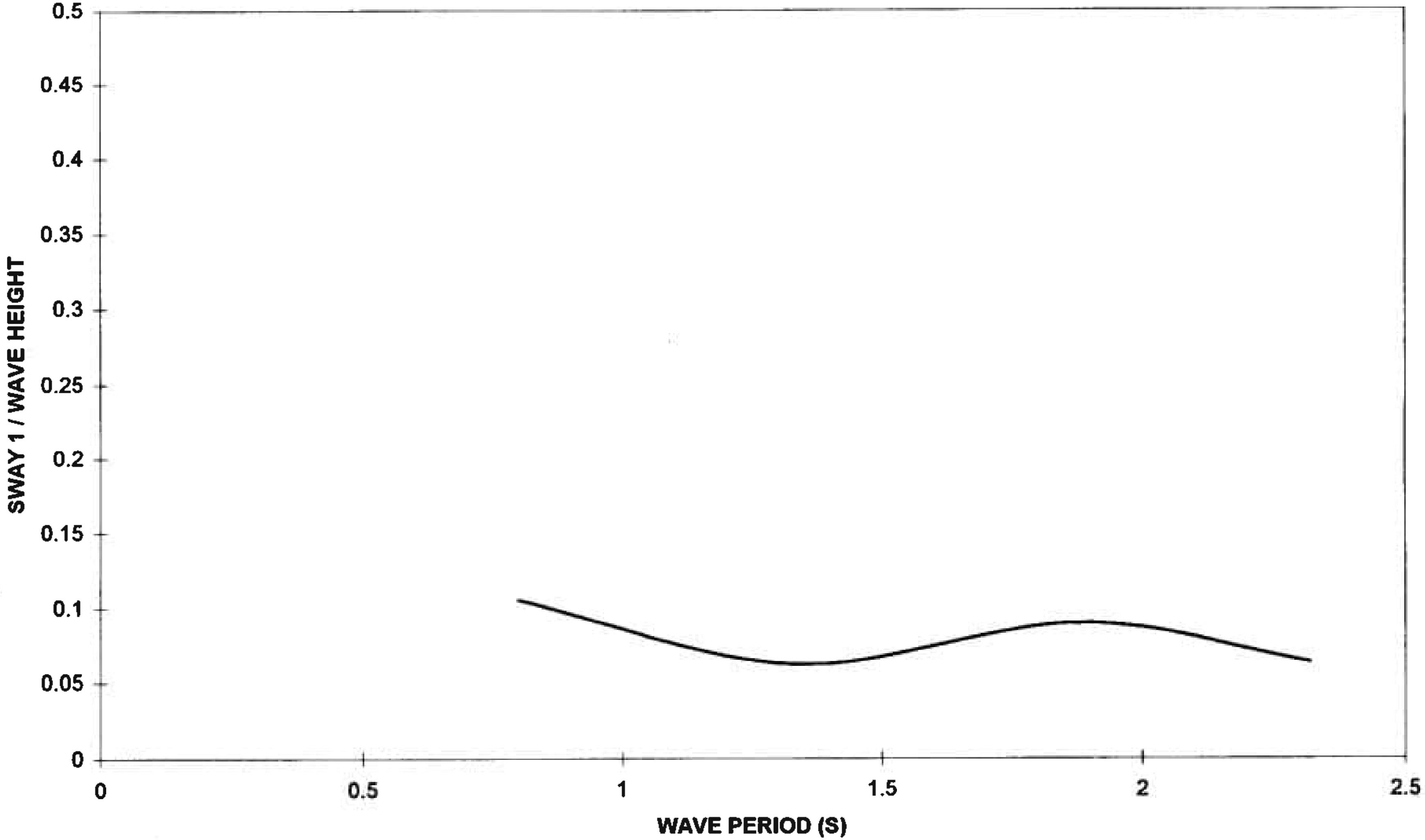

HEAVE RESPONSE (2) [FHW1U4M2 - FHW9U4M2]
Four Unit, Ring
HEAVE 2 / WAVE HEIGHT
WAVE PERIOD (S)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.5
1
1.5
2
2.5

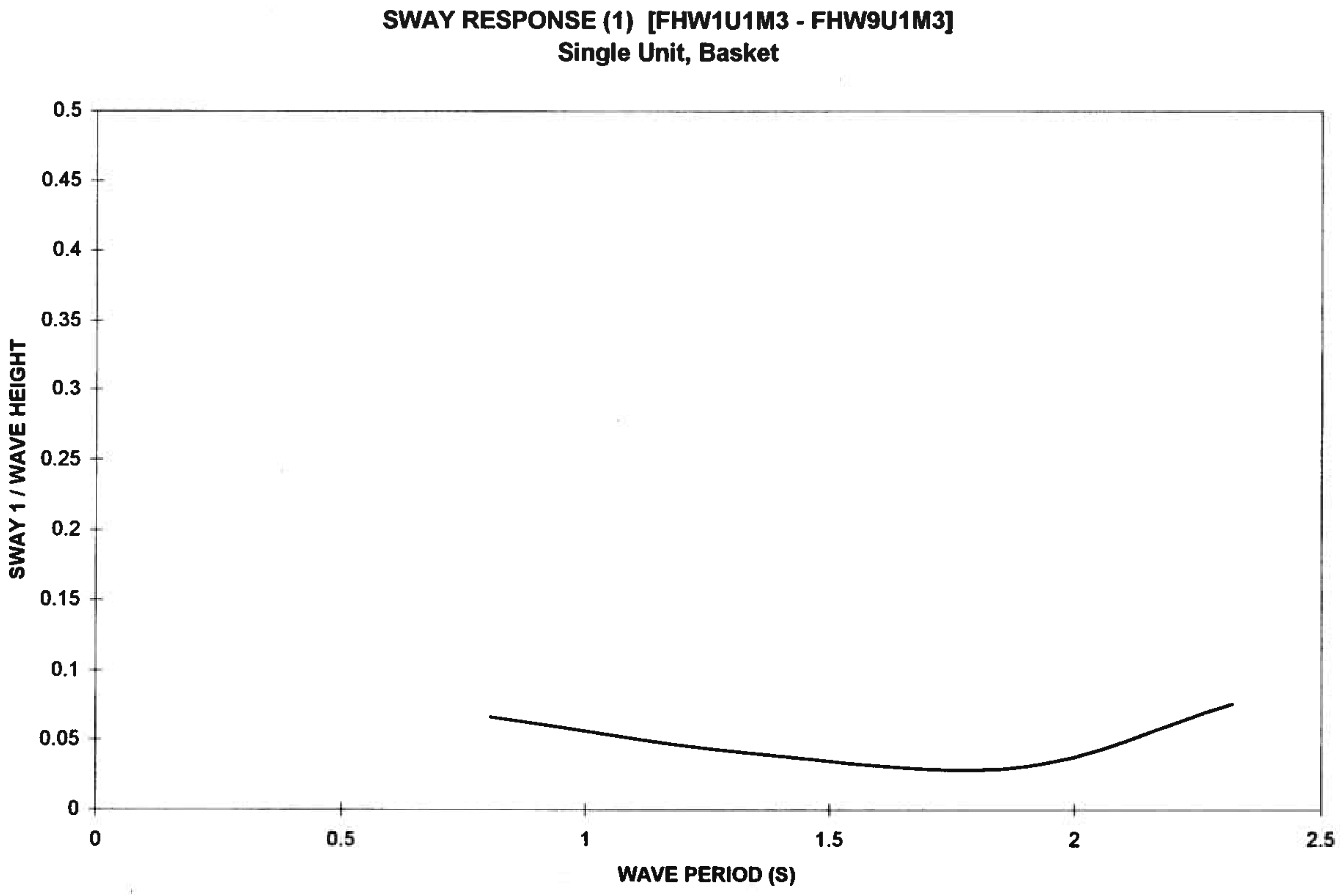
HEAVE RESPONSE (2) [FQW1U3M4 - FQW9U3M4]
Four Unit, Horizontal, Quartering



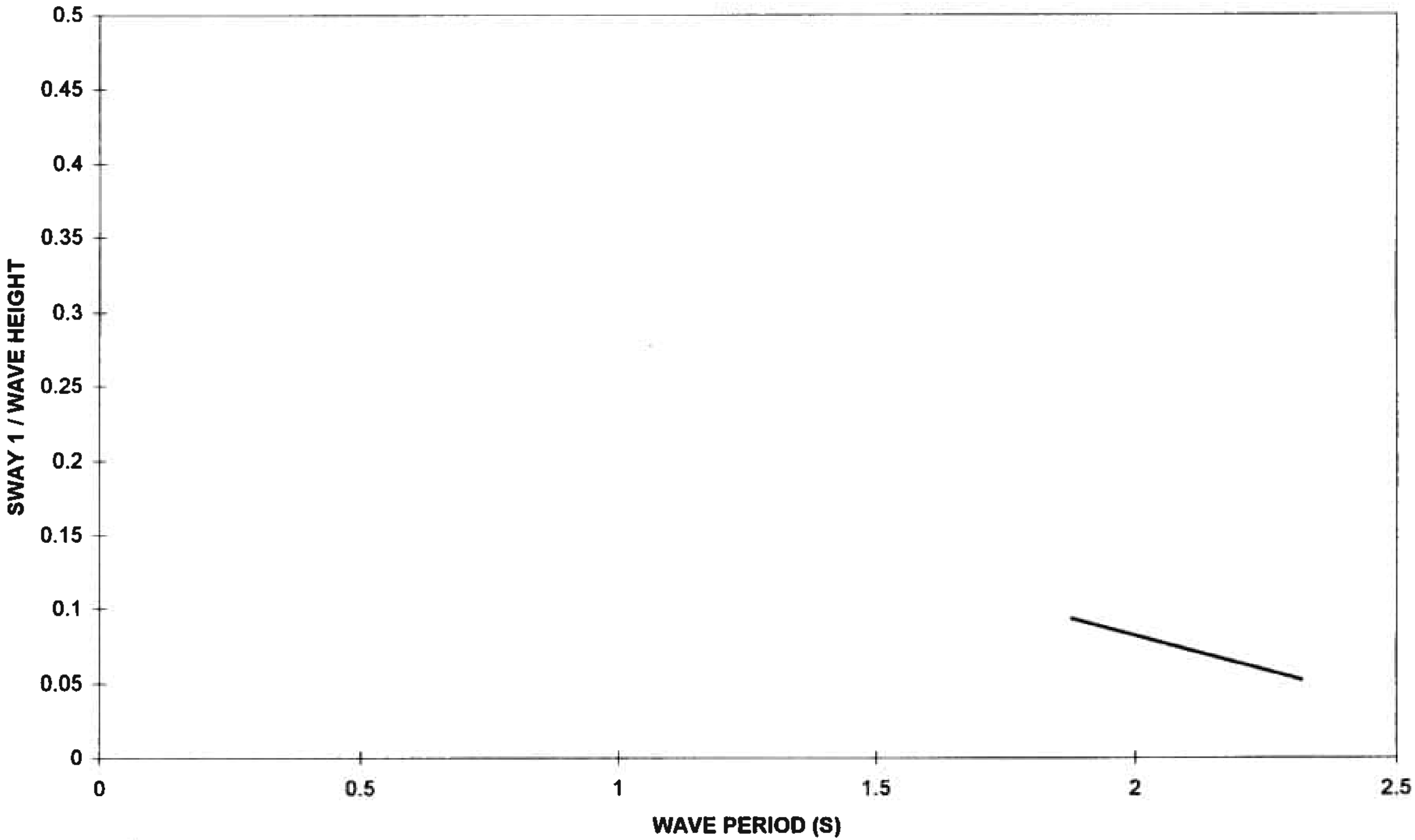

SWAY RESPONSE (1) [FHW1U1M1 - FHW6U1M1]
Single Unit, Catenary
SWAY 1 / WAVE HEIGHT
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.5
1
1.5
2
2.5
WAVE PERIOD (S)

SWAY RESPONSE (1) [FHW1U1M2 - FHW9U1M2]
Single Unit, Ring

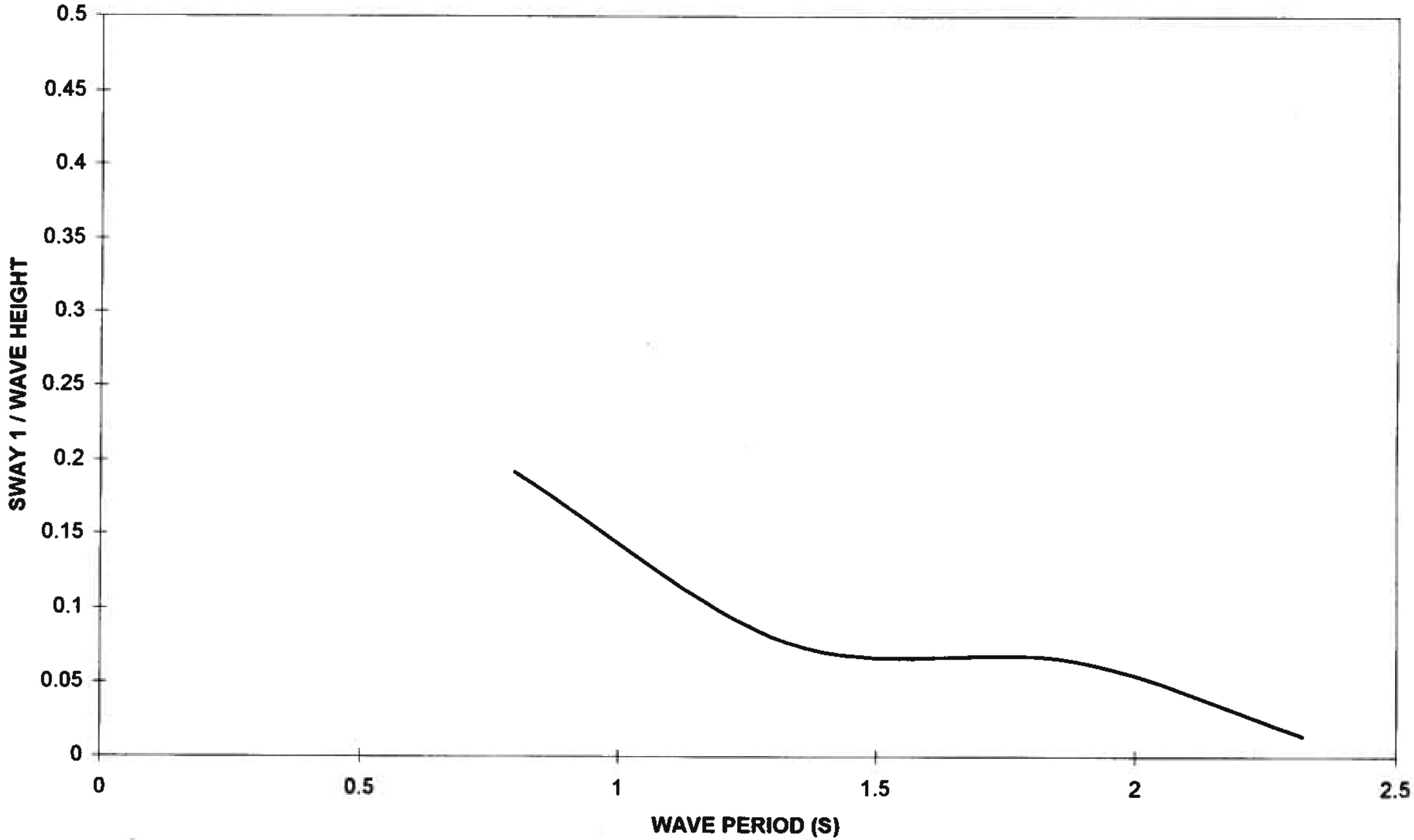


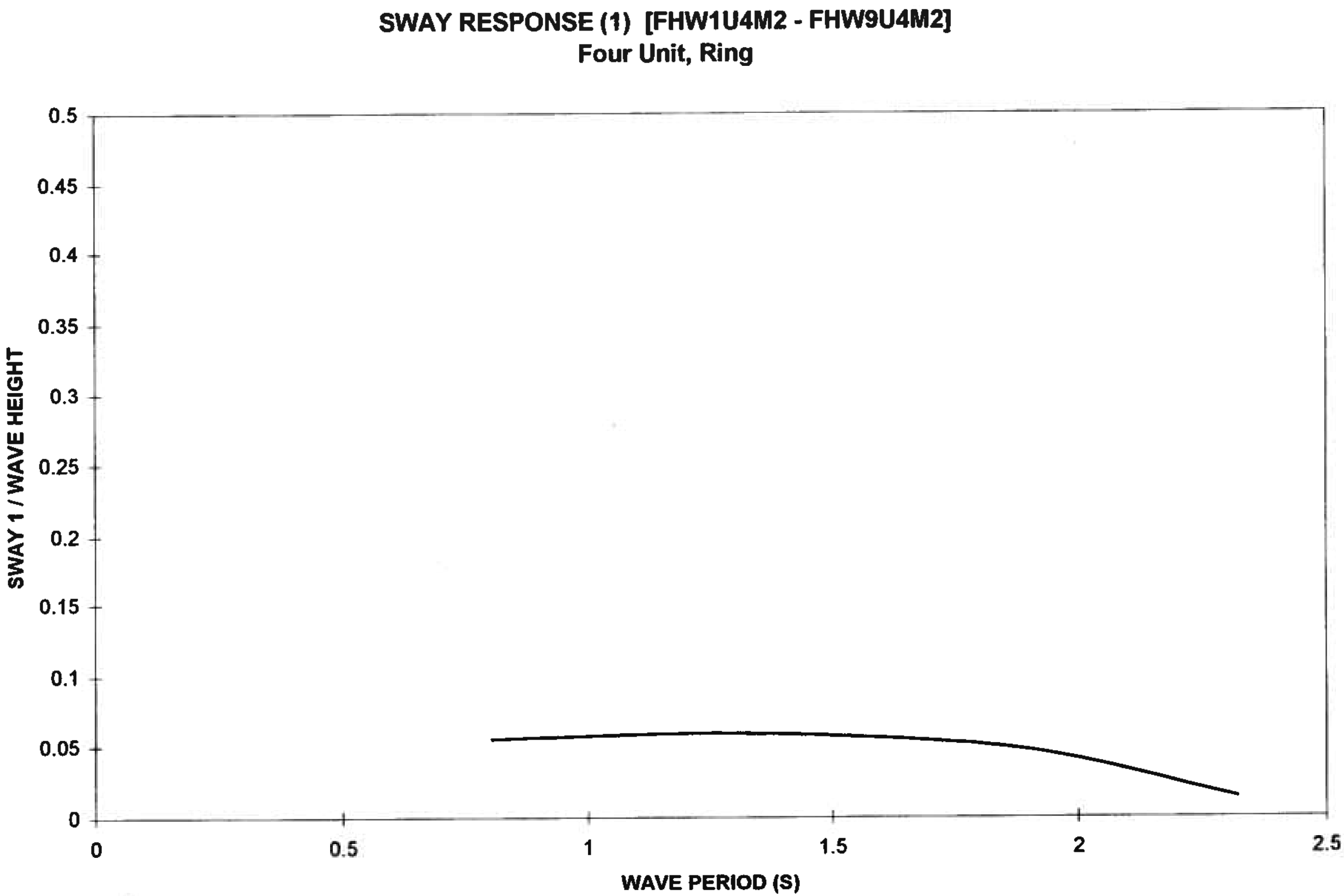

SWAY RESPONSE (1) [FHW1U1M3 - FHW9U1M3]
Single Unit, Basket
SWAY 1 / WAVE HEIGHT
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.5
1
1.5
2
2.5
WAVE PERIOD (S)

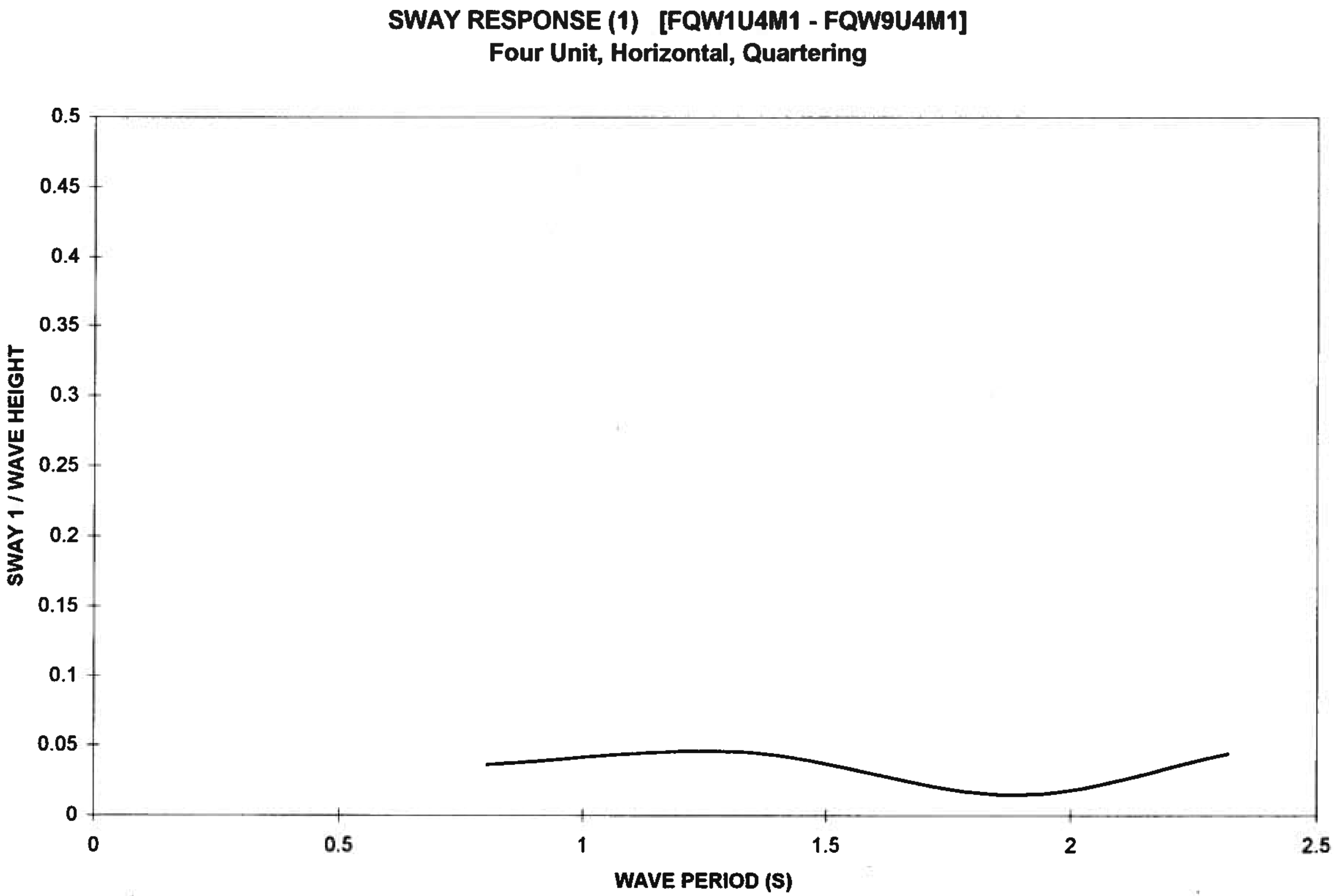
SWAY RESPONSE (1) [FHW5U3M4 - FHW9U3M4]
Single Unit, Horizontal, Ballast



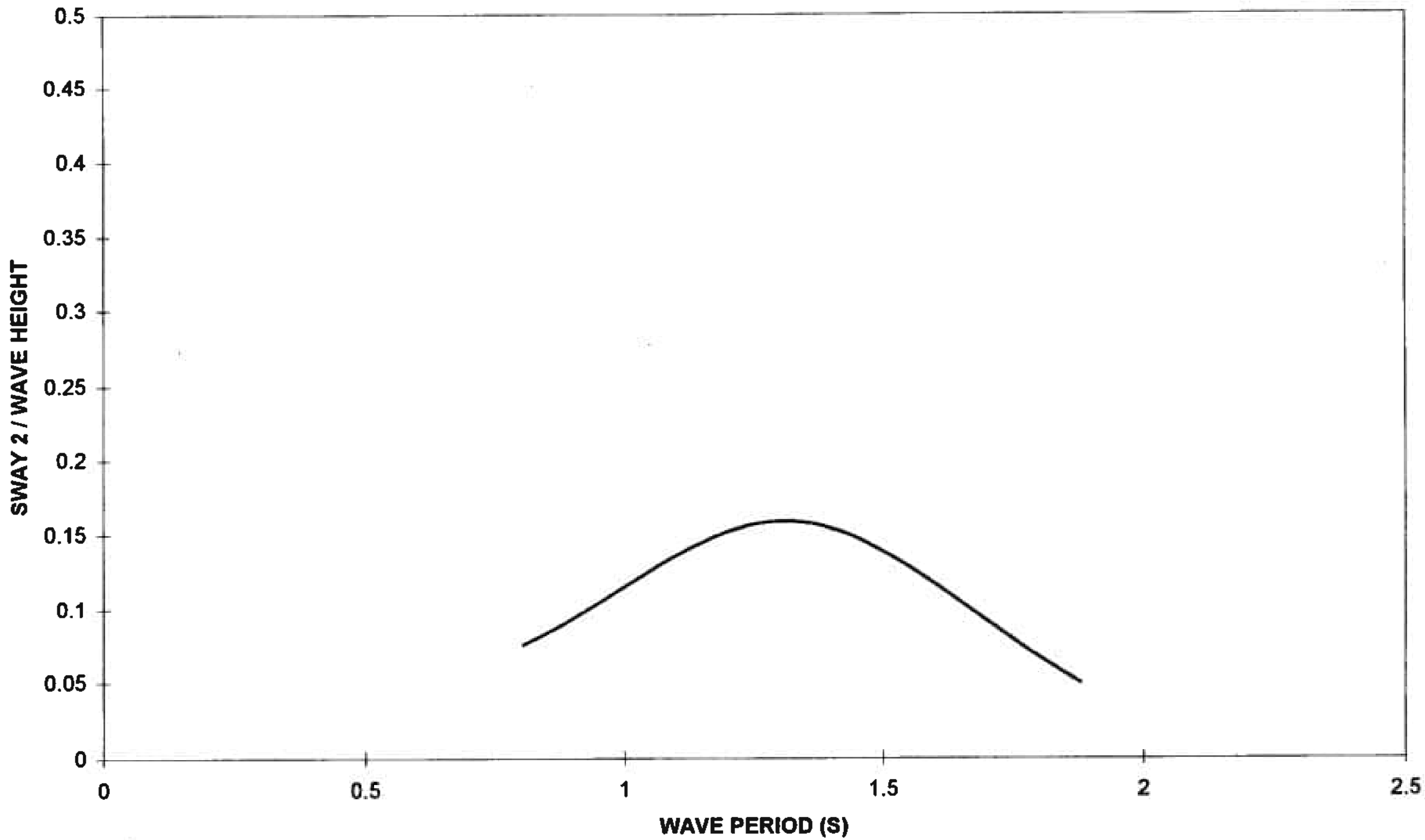
SWAY RESPONSE (1) [FHW1U4M1 - FHW9U4M1]
Four Unit, Horizontal

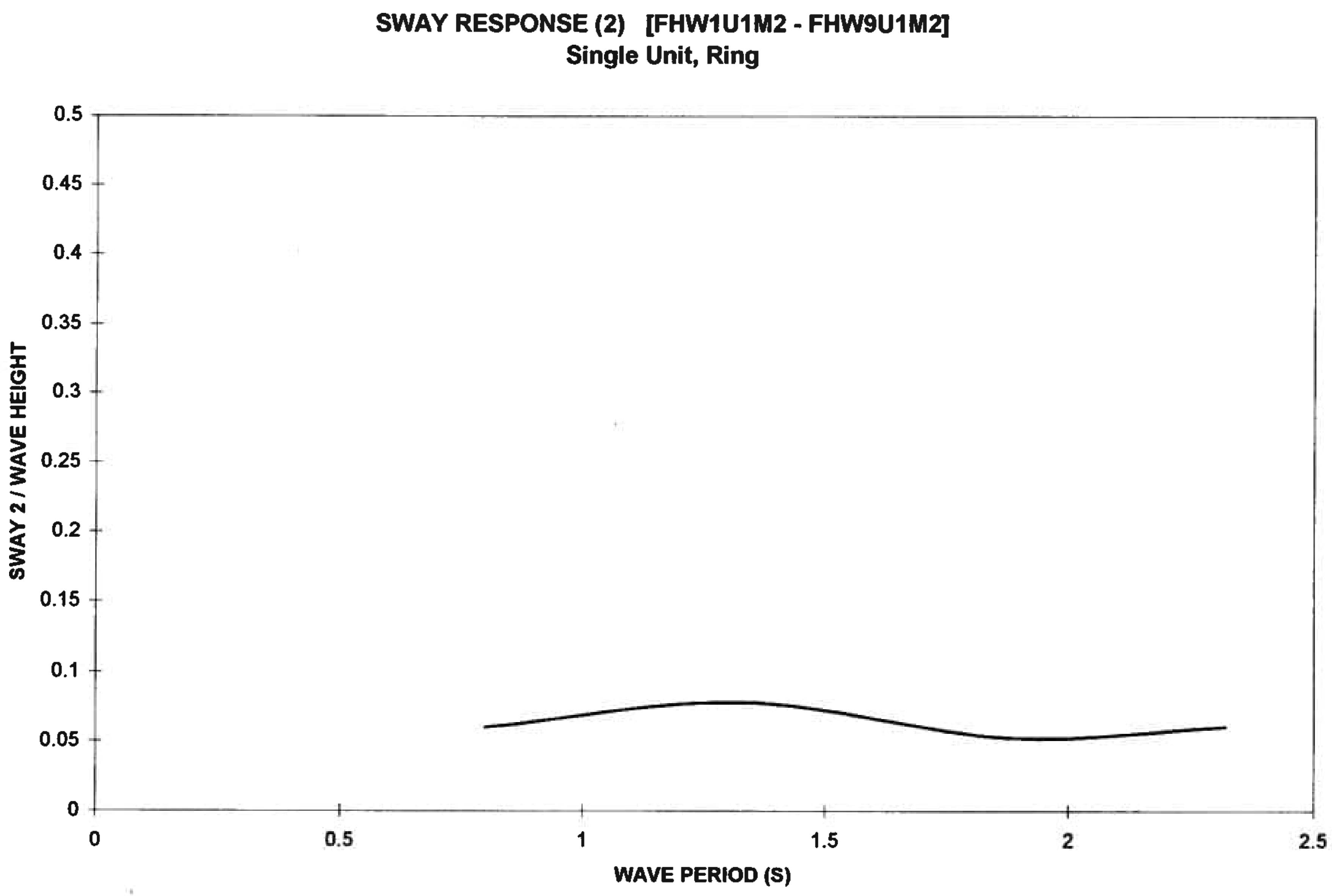



SWAY RESPONSE (1) [FHW1U4M2 - FHW9U4M2]
Four Unit, Ring
SWAY 1 / WAVE HEIGHT
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0
0.5
1
1.5
2
2.5
WAVE PERIOD (S)

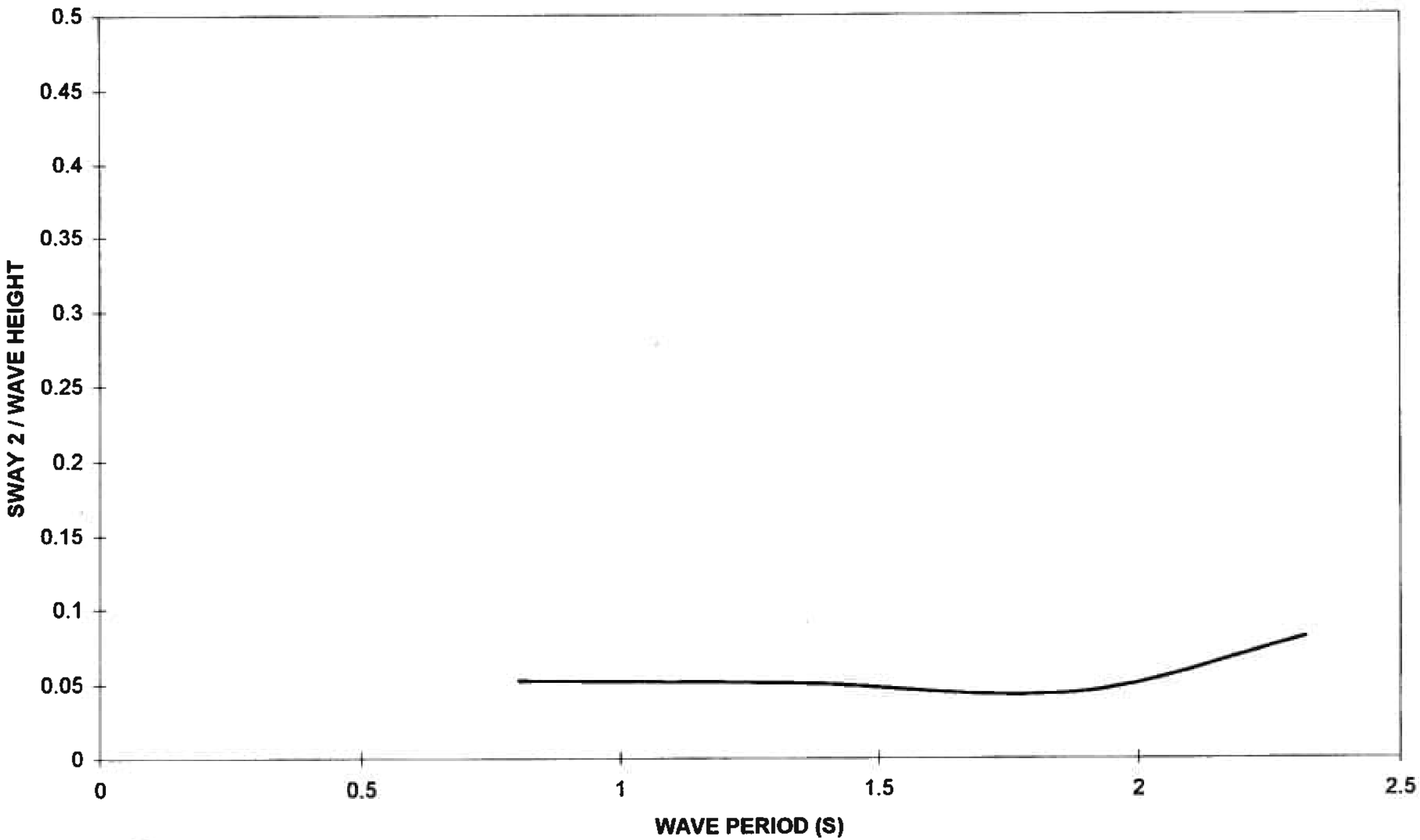

SWAY RESPONSE (1) [FQW1U4M1 - FQW9U4M1]
Four Unit, Horizontal, Quartering
SWAY 1 / WAVE HEIGHT
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.5
1
1.5
2
2.5
WAVE PERIOD (S)

SWAY RESPONSE (2) [FHW1U1M1 - FHW6U1M1]
Single Unit, Catenary

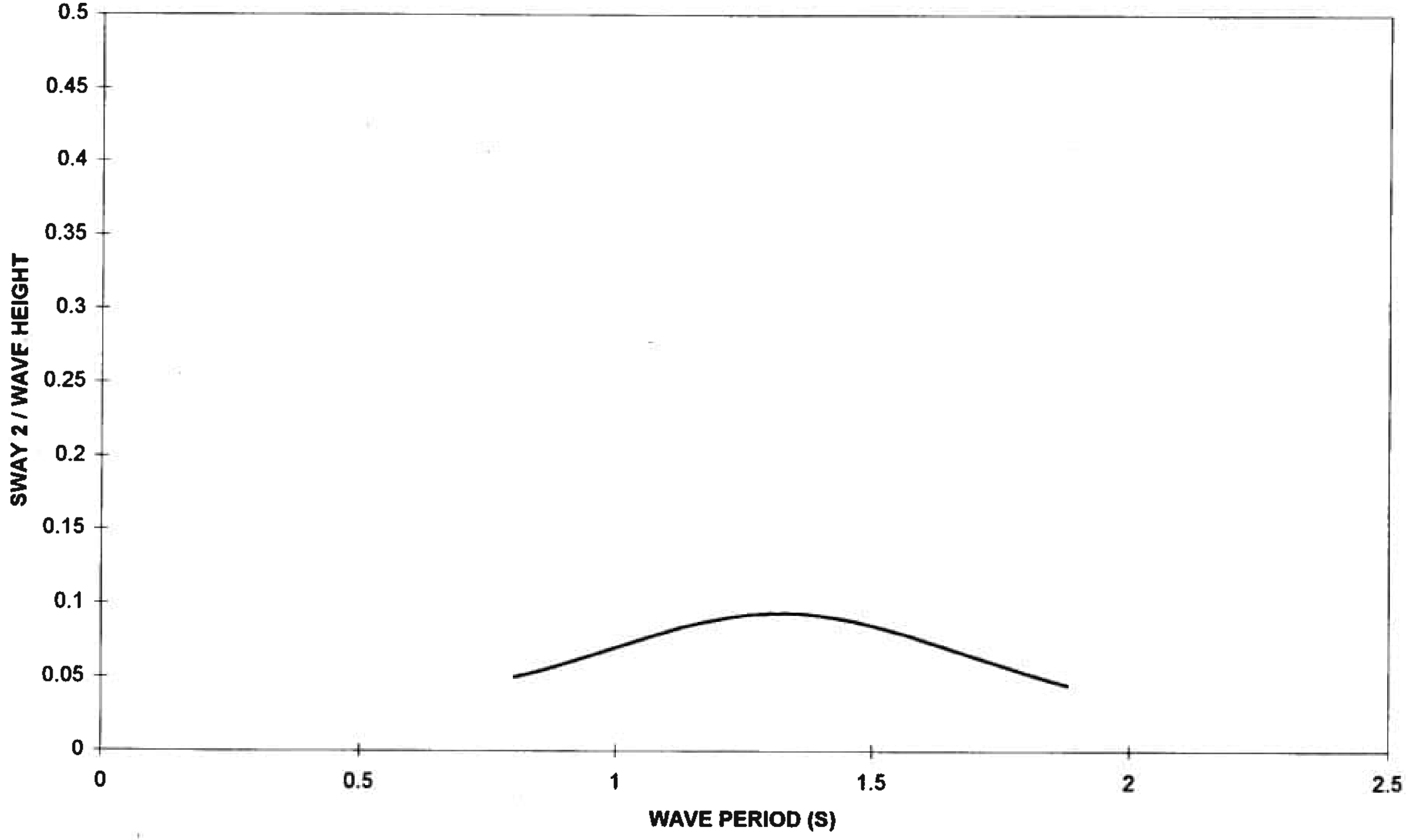



SWAY RESPONSE (2) [FHW1U1M2 - FHW9U1M2]
Single Unit, Ring
SWAY 2 / WAVE HEIGHT
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.5
1
1.5
2
2.5
WAVE PERIOD (S)

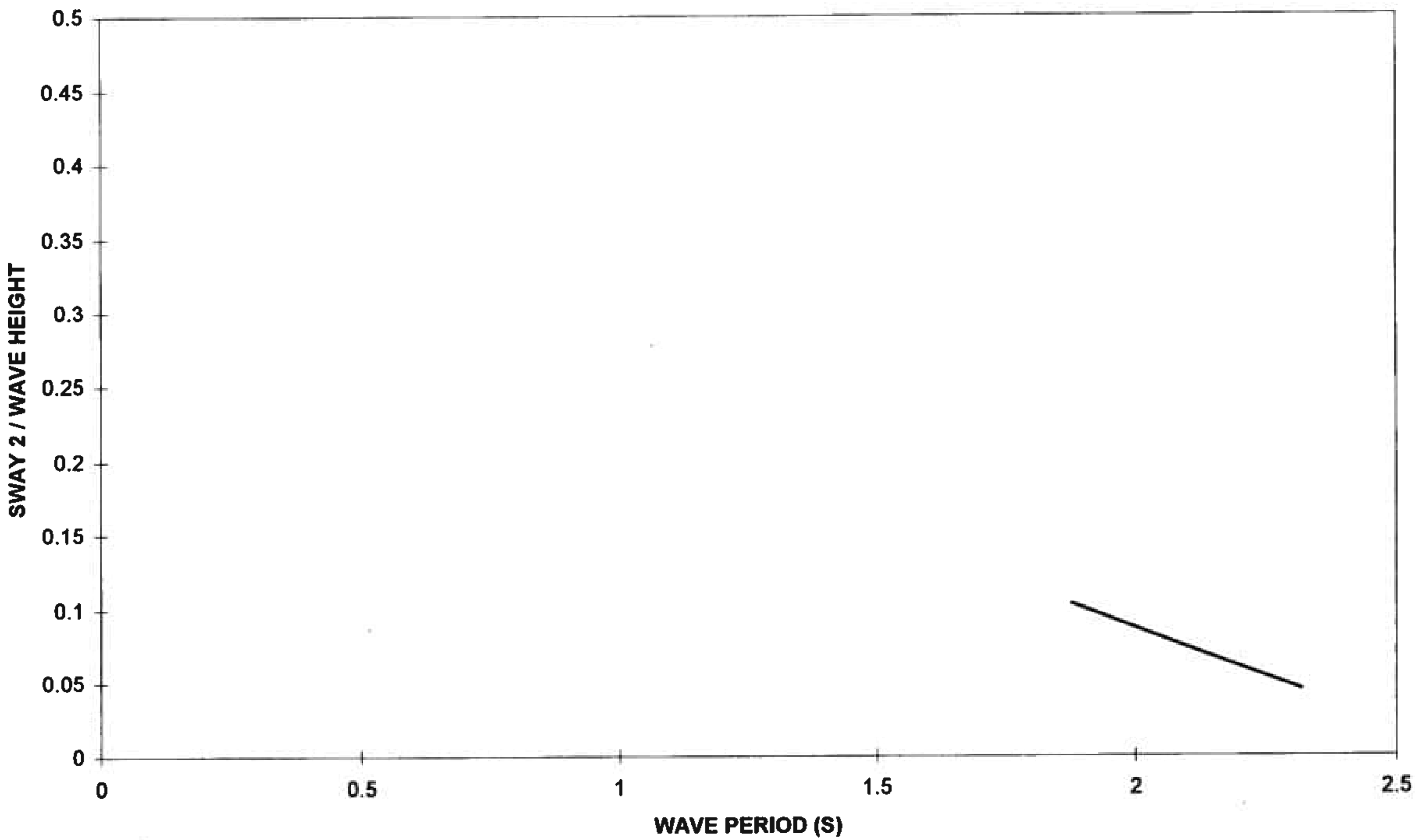
SWAY RESPONSE (2) [FHW1U1M3 - FHW9U1M3]
Single Unit, Basket



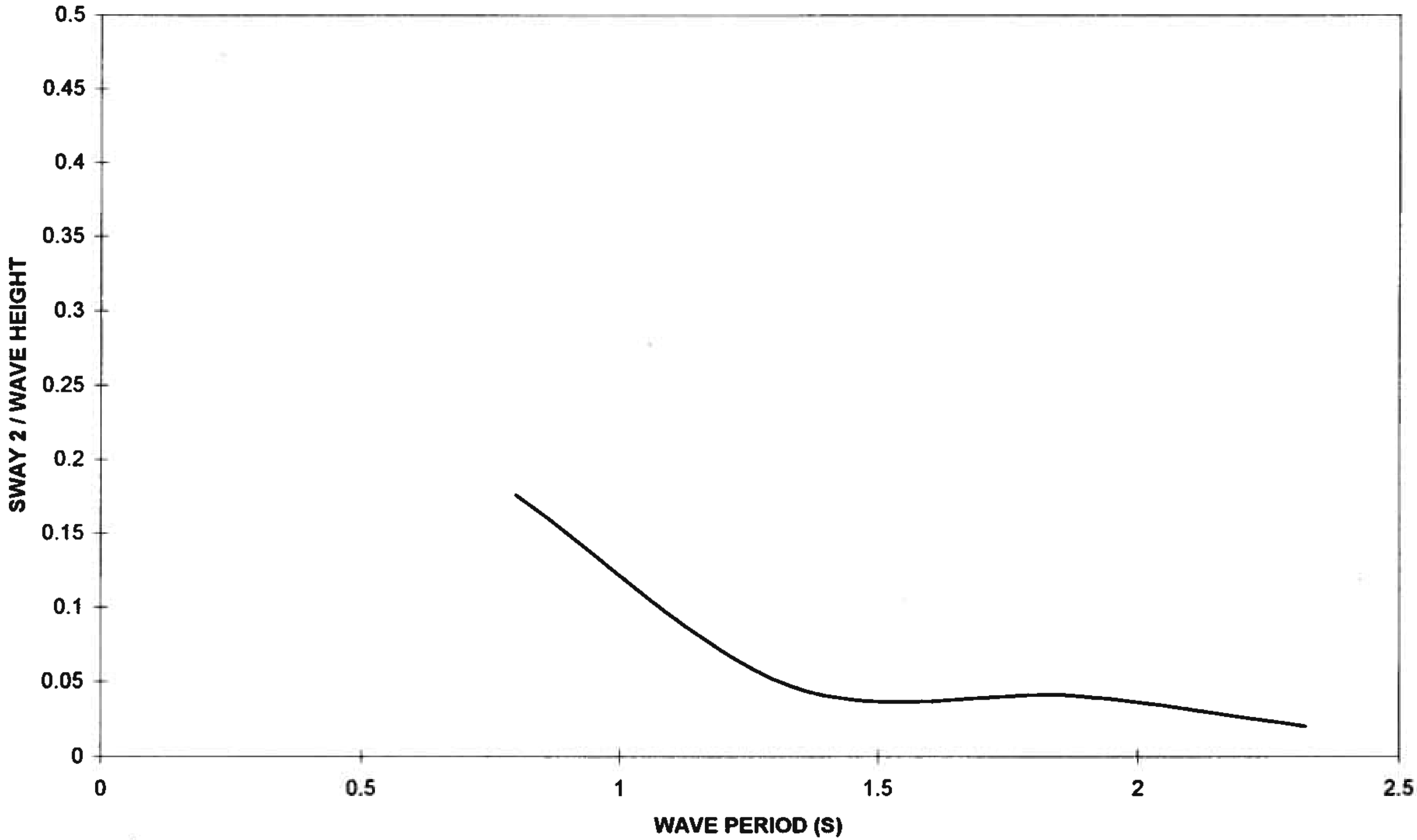
SWAY RESPONSE (2) [FHW1U1M4 - FHW6U1M4]
Single Unit, Horizontal

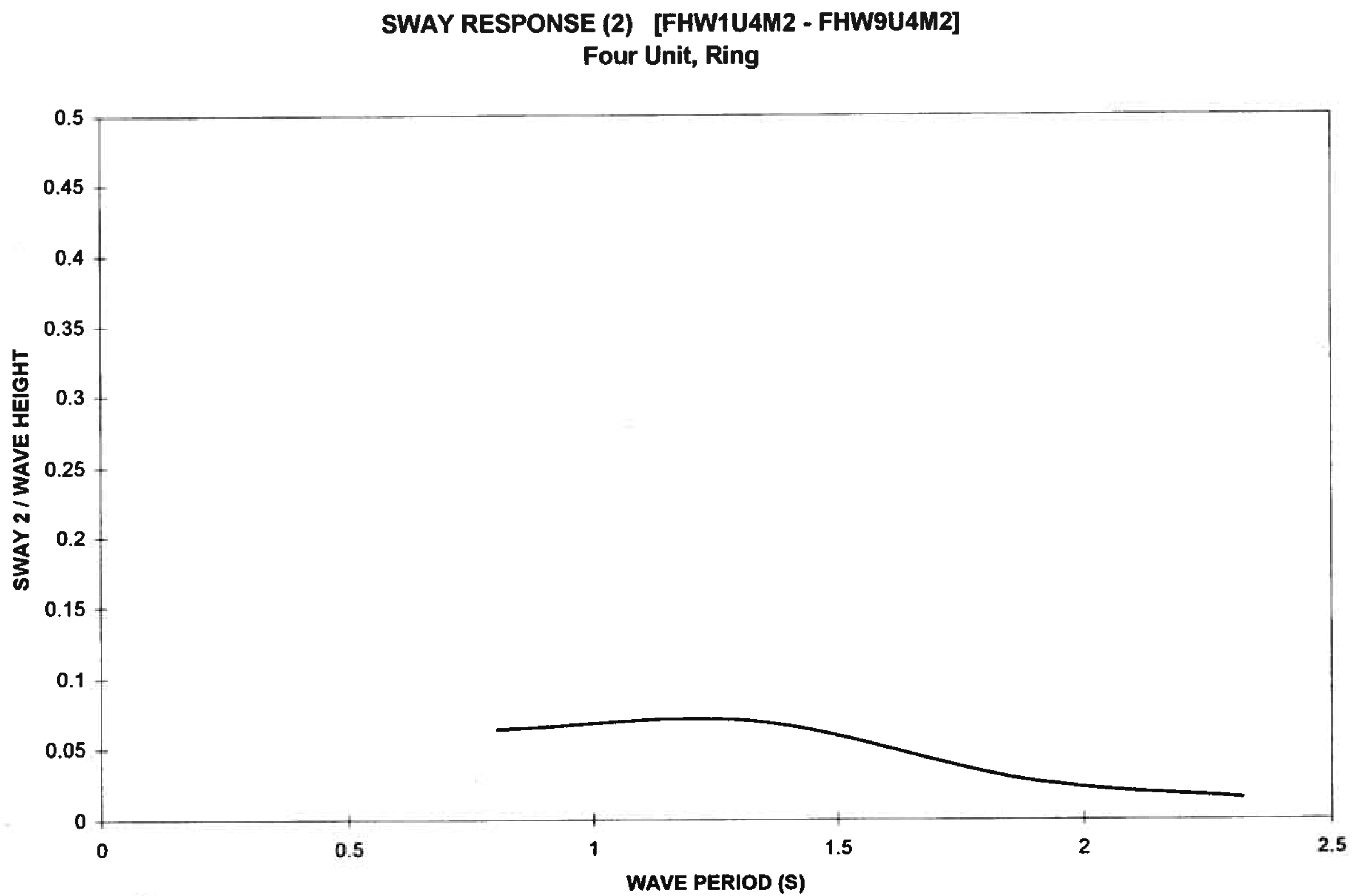


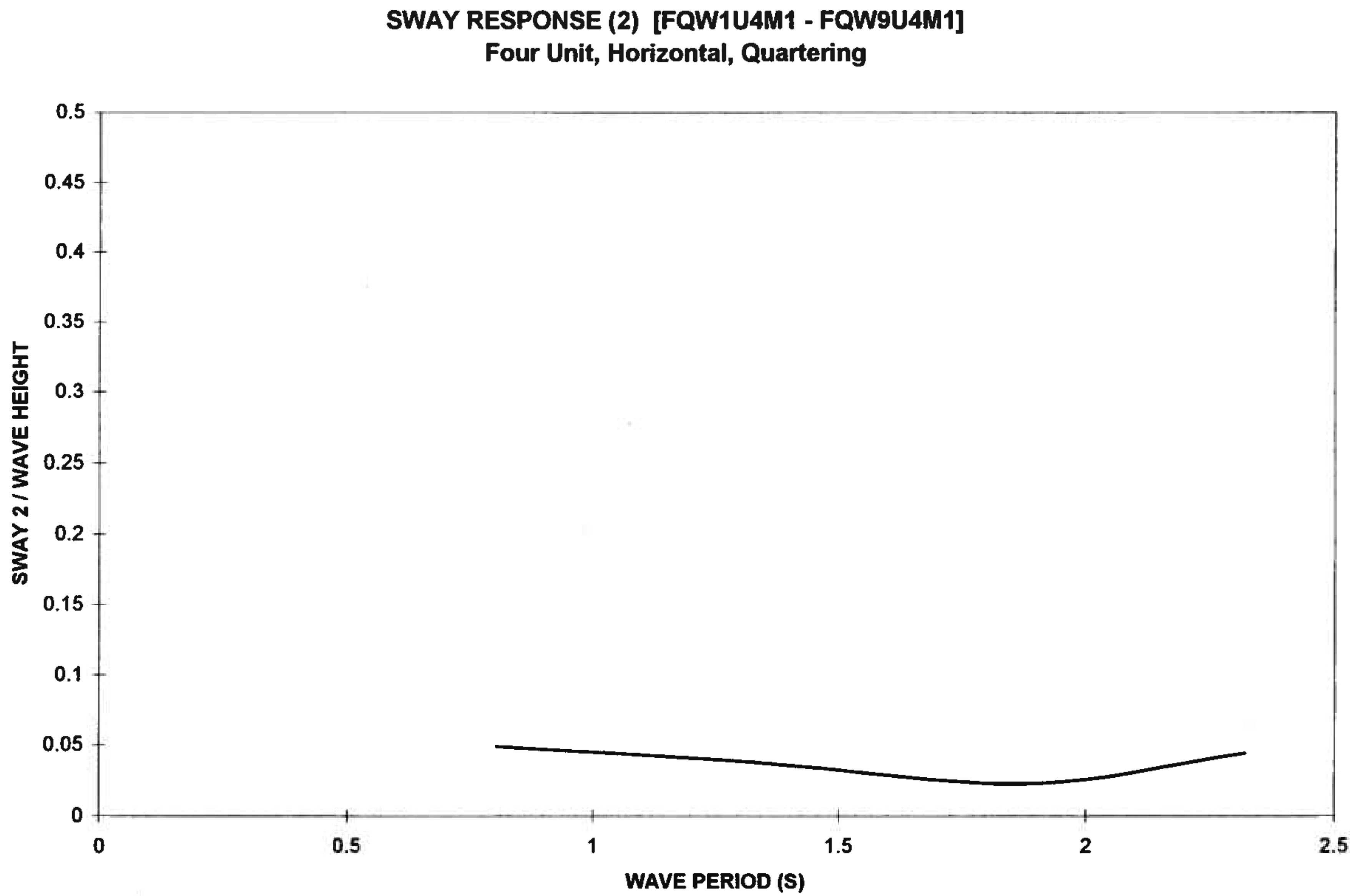
SWAY RESPONSE (2) [FHW5U3M4 - FHW9U3M4]
Single Unit, Horizontal, Ballast



SWAY RESPONSE (2) [FHW1U4M1 - FHW9U4M1]
Four Unit, Horizontal

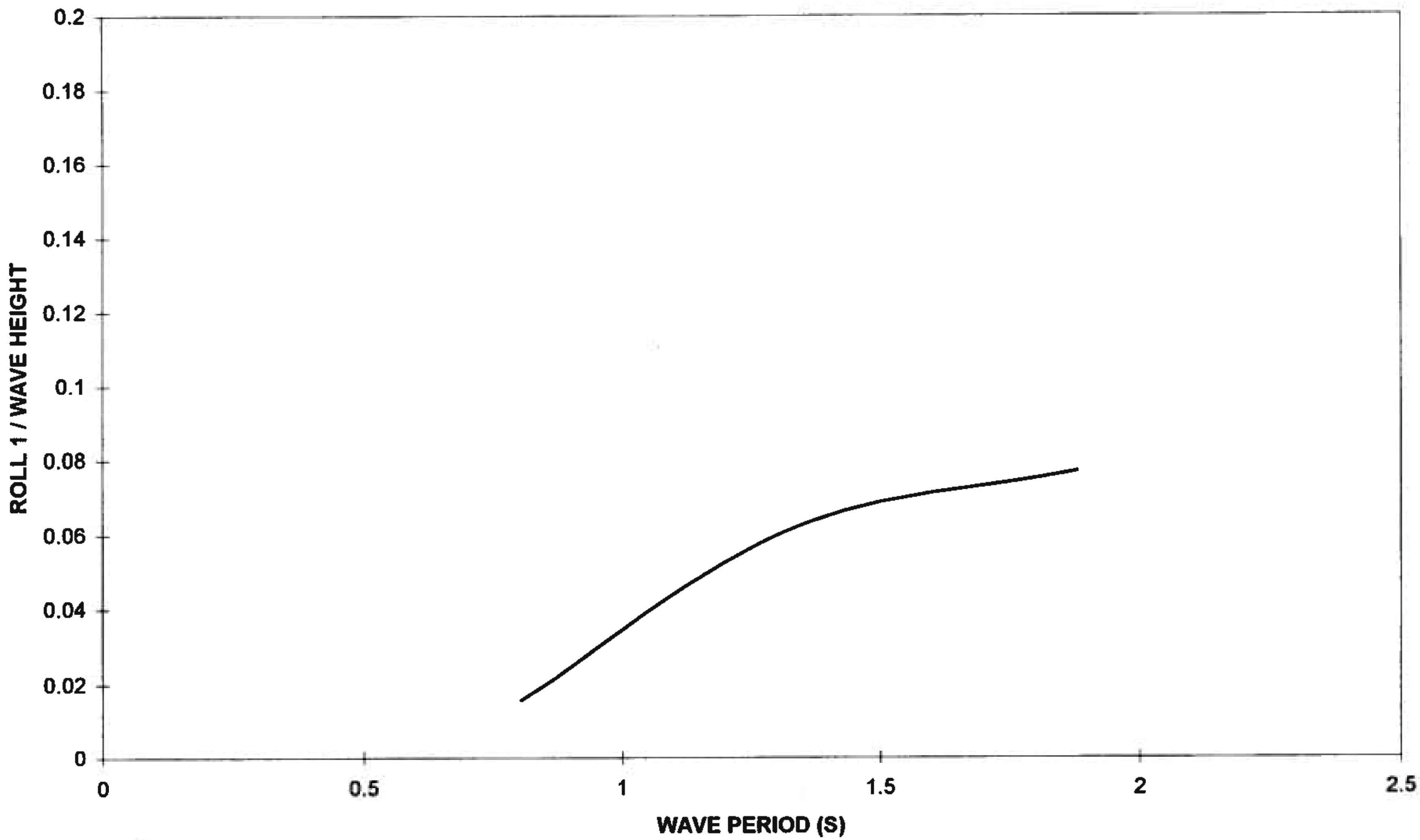


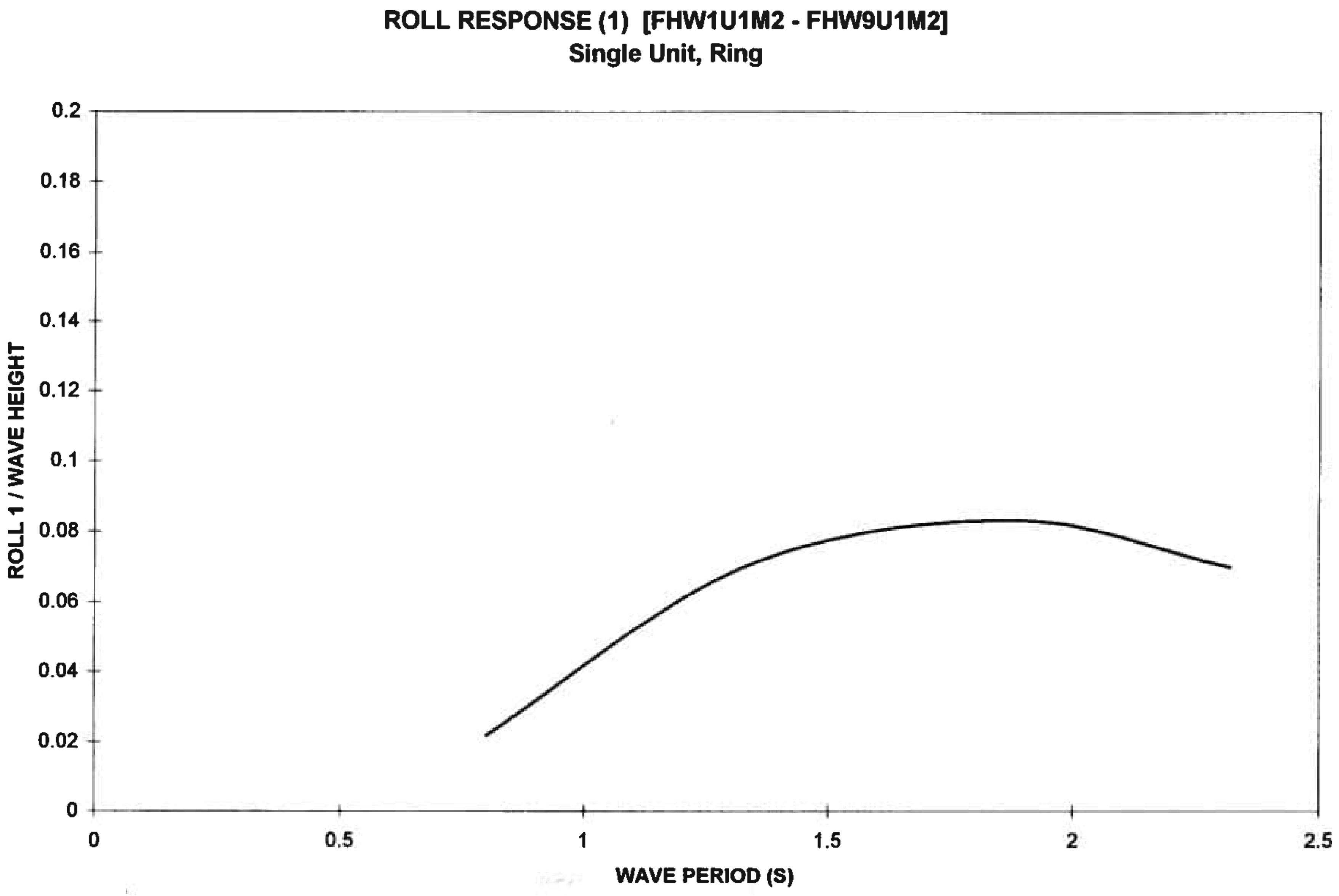

SWAY RESPONSE (2) [FHW1U4M2 - FHW9U4M2]
Four Unit, Ring
SWAY 2 / WAVE HEIGHT
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.5
1
1.5
2
2.5
WAVE PERIOD (S)

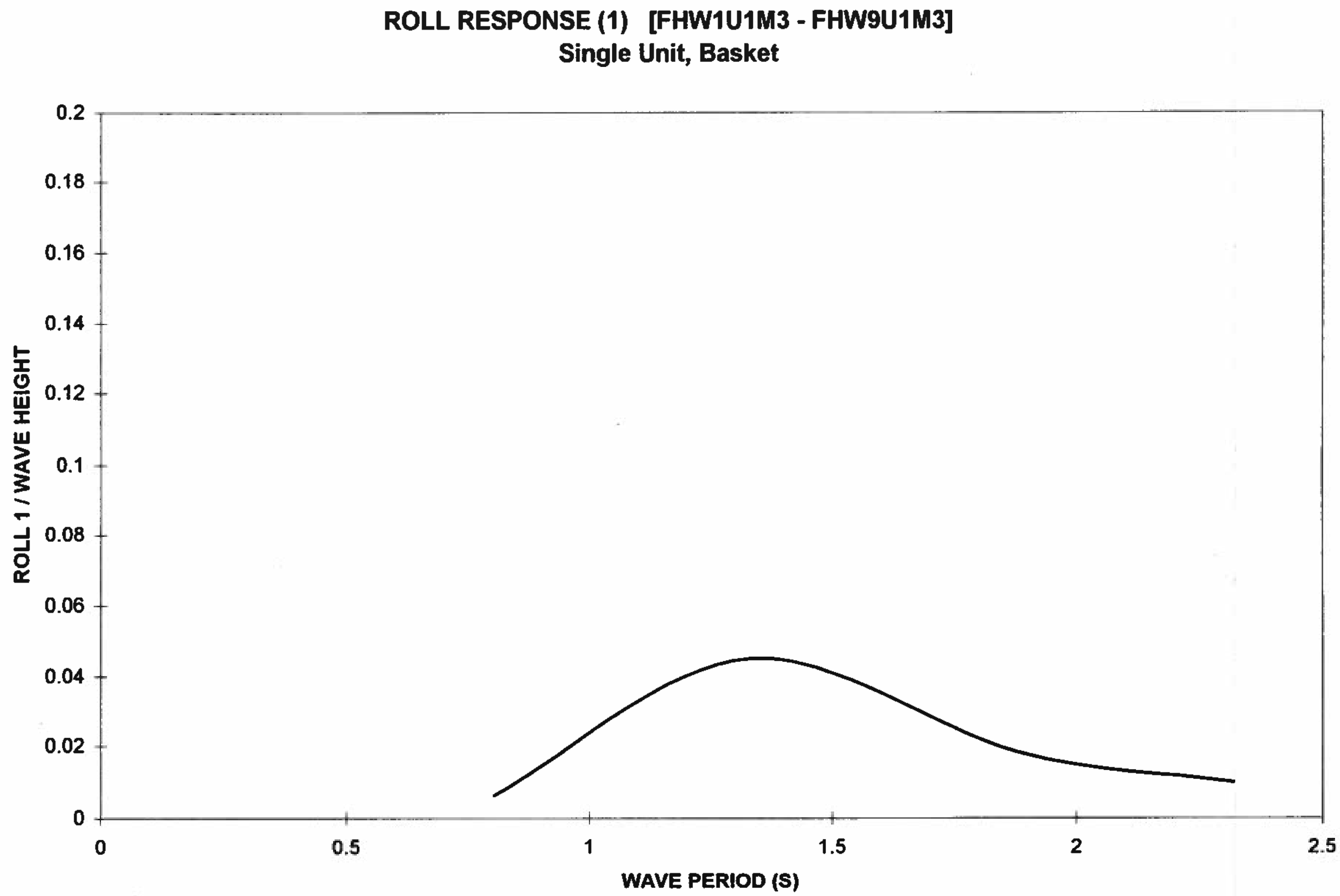


SWAY RESPONSE (2) [FQW1U4M1 - FQW9U4M1]
Four Unit, Horizontal, Quartering
SWAY 2 / WAVE HEIGHT
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0.5
1
1.5
2
2.5
WAVE PERIOD (S)

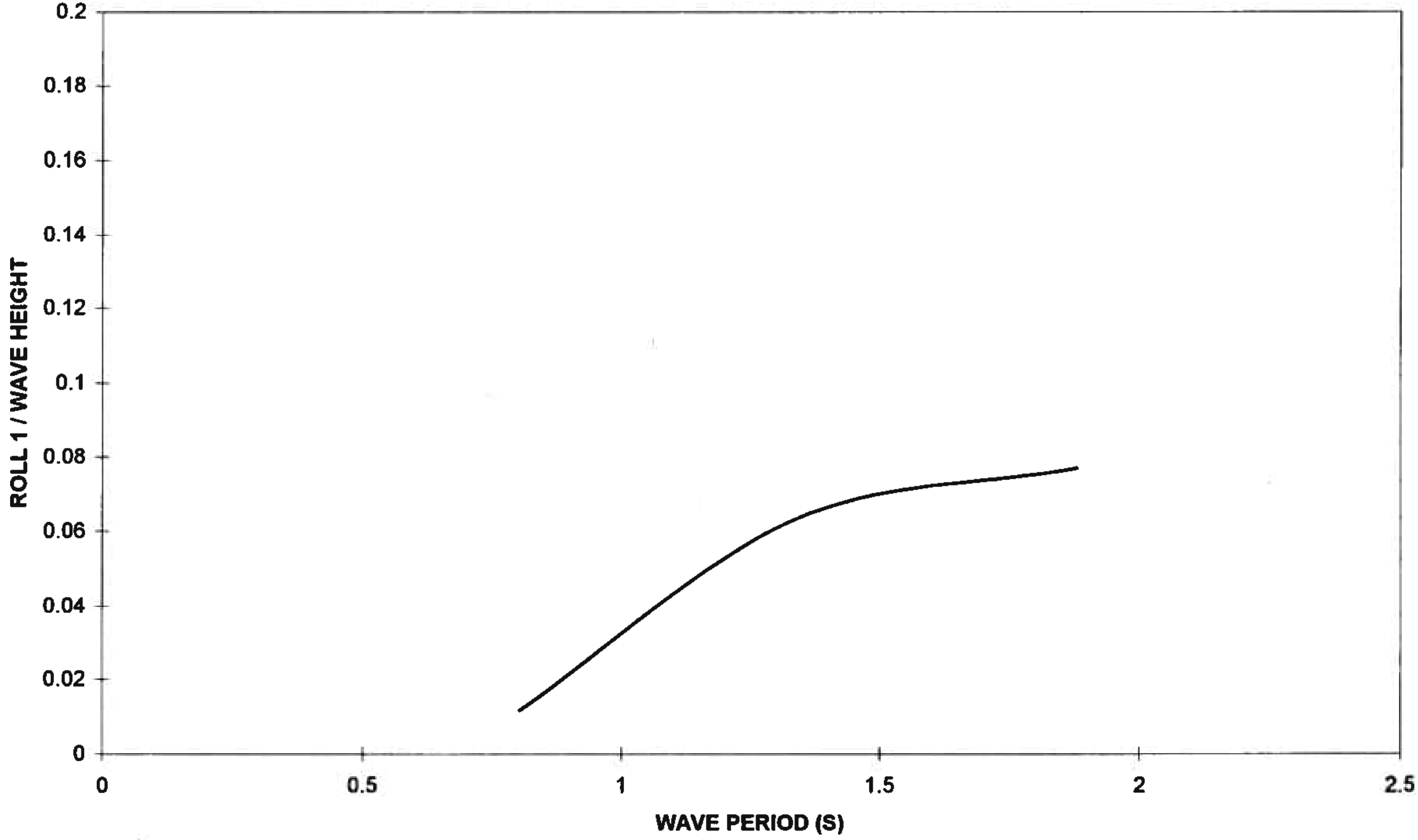
ROLL RESPONSE (1) [FHW1U1M1 - FHW6U1M1]
Single Unit, Catenary



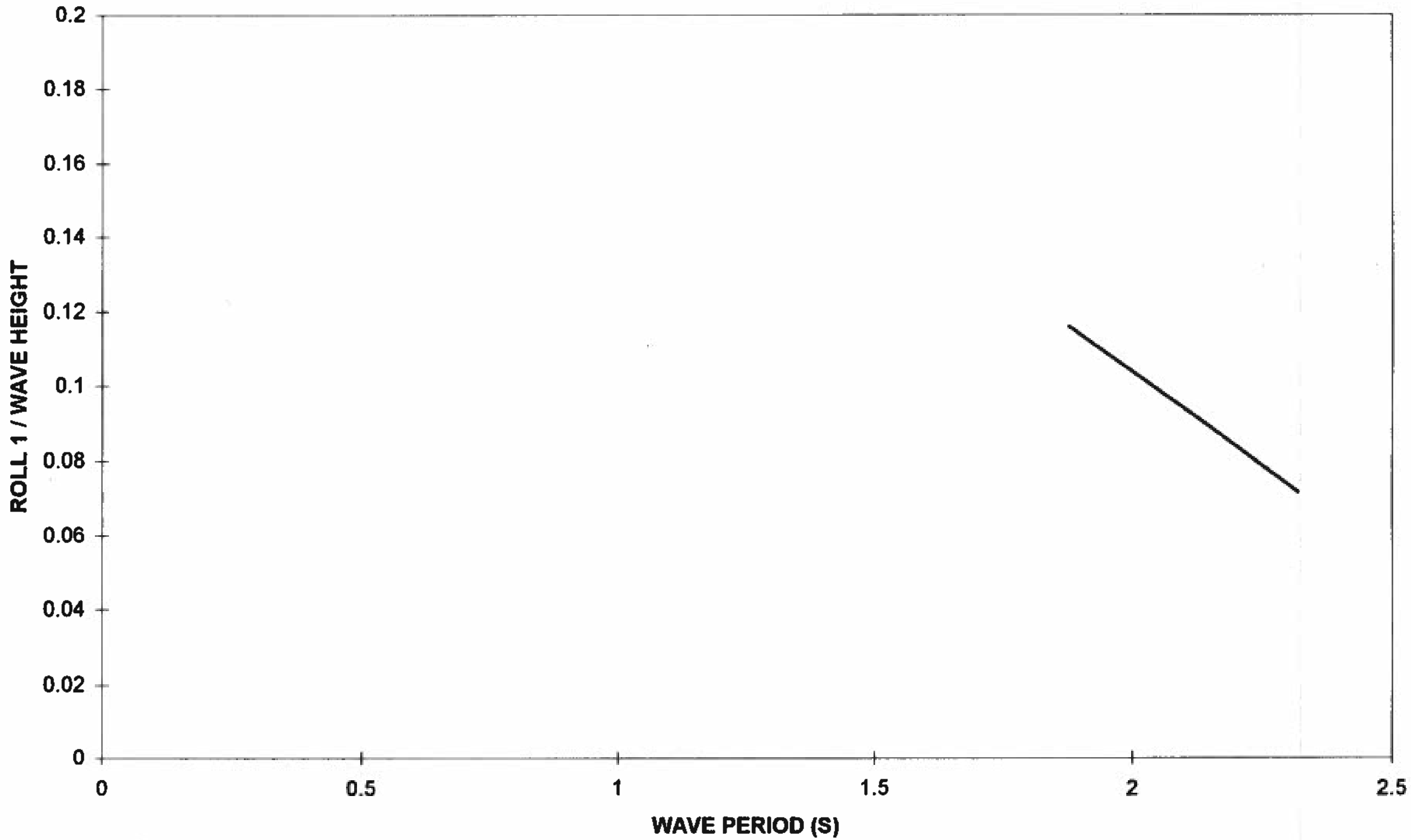

ROLL RESPONSE (1) [FHW1U1M2 - FHW9U1M2]
Single Unit, Ring
ROLL 1 / WAVE HEIGHT
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0.5
1
1.5
2
2.5
WAVE PERIOD (S)


ROLL RESPONSE (1) [FHW1U1M3 - FHW9U1M3]
Single Unit, Basket
ROLL 1 / WAVE HEIGHT
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
0.5
1
1.5
2
2.5
WAVE PERIOD (S)

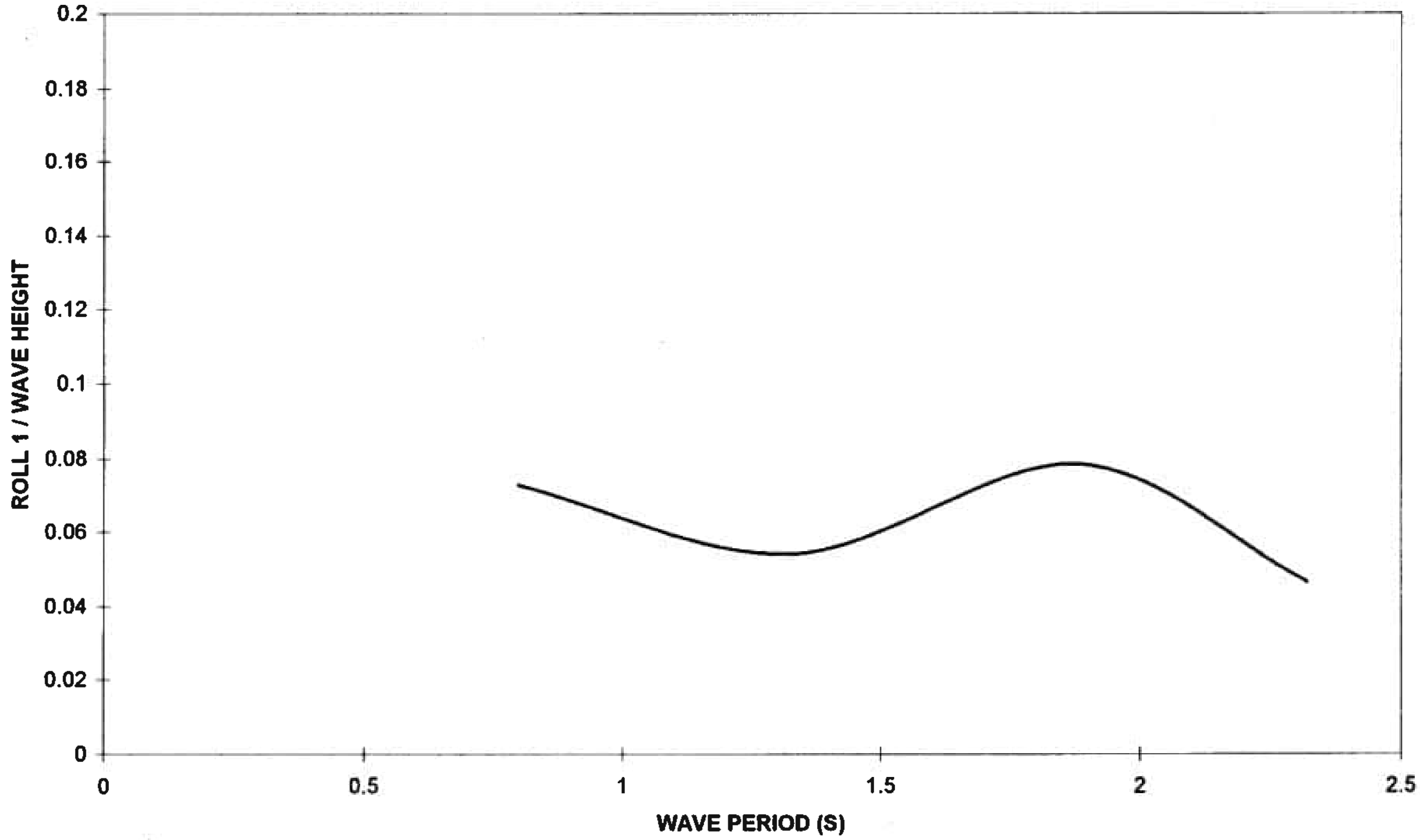
ROLL RESPONSE (1) [FHW1U1M4 - FHW6U1M4]
Single Unit, Horizontal



ROLL RESPONSE (1) [FHW5U3M4 - FHW9U3M4]
Single Unit, Horizontal, Ballast



ROLL RESPONSE (1) [FHW1U4M1 - FHW9U4M1]
Four Unit, Horizontal



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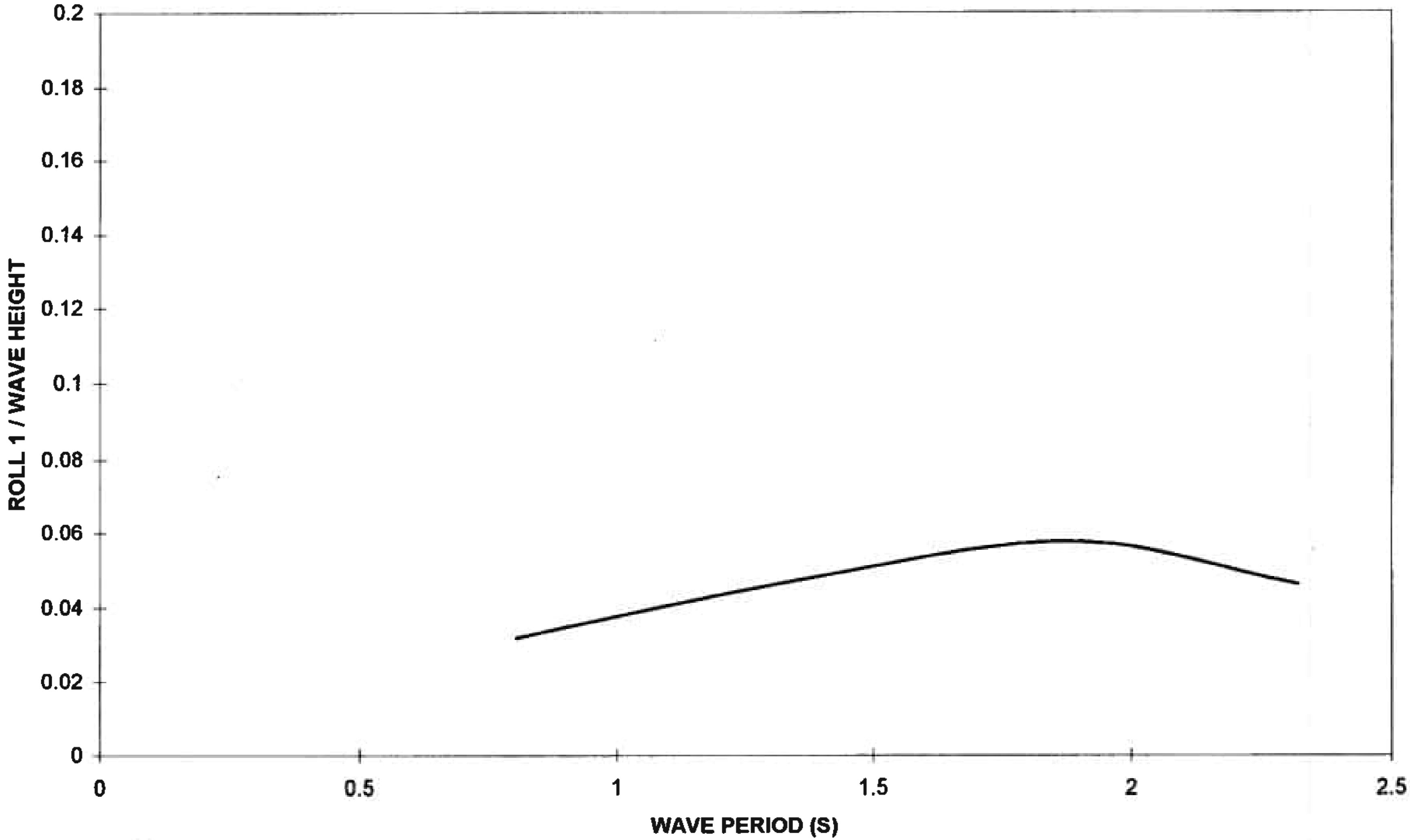
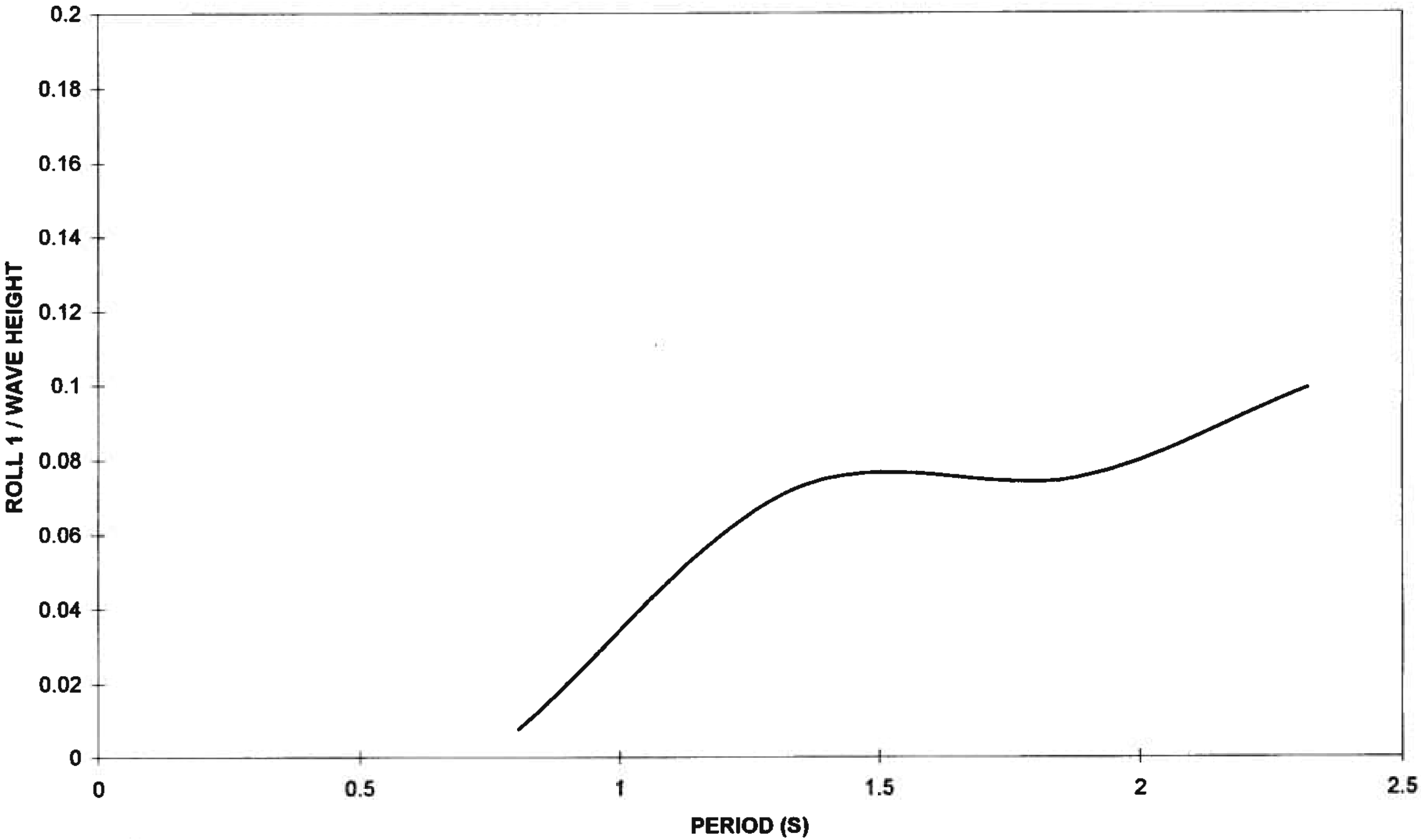
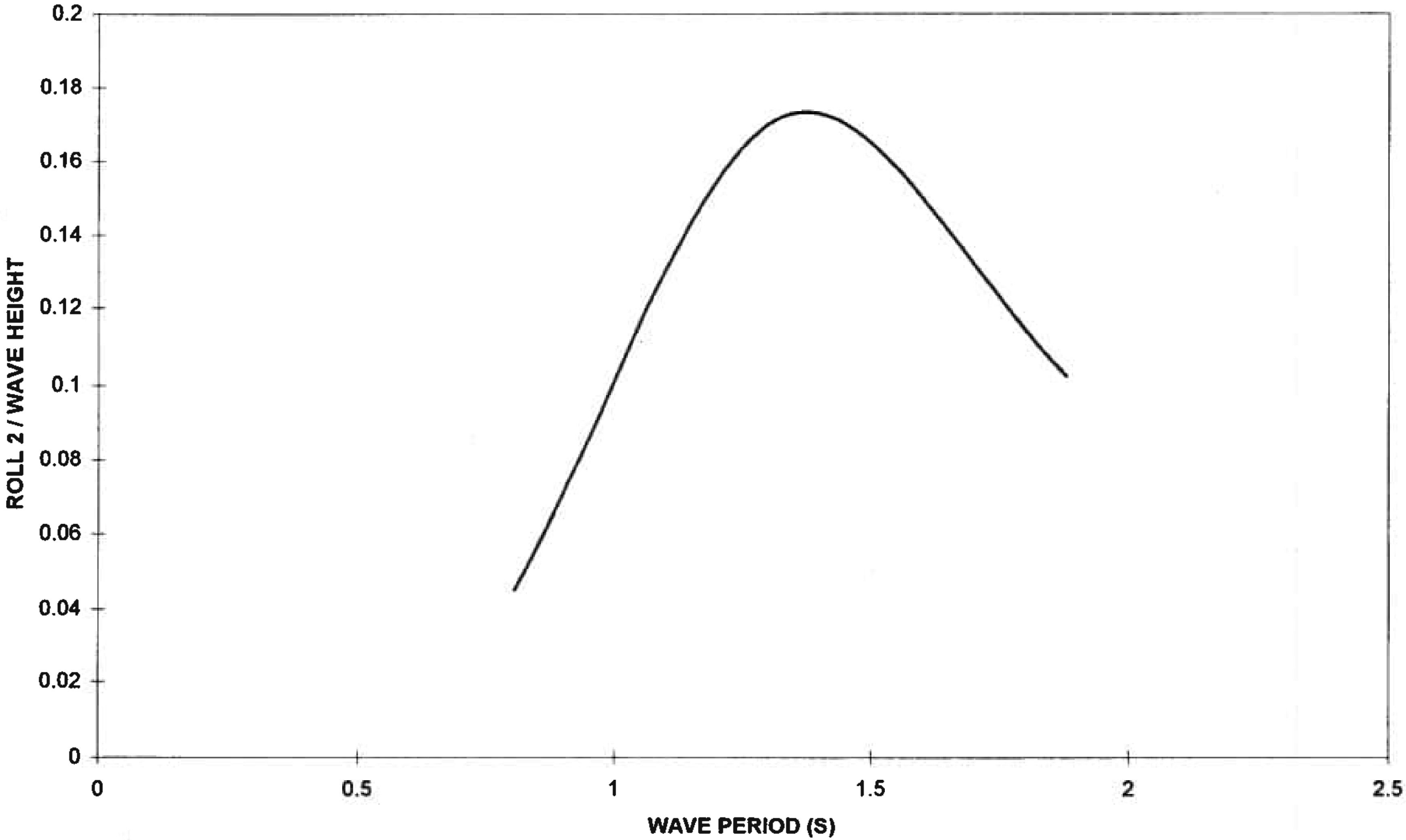
ROLL RESPONSE (1) [FHW1U4M2 - FHW9U4M2]
Four Unit, Ring

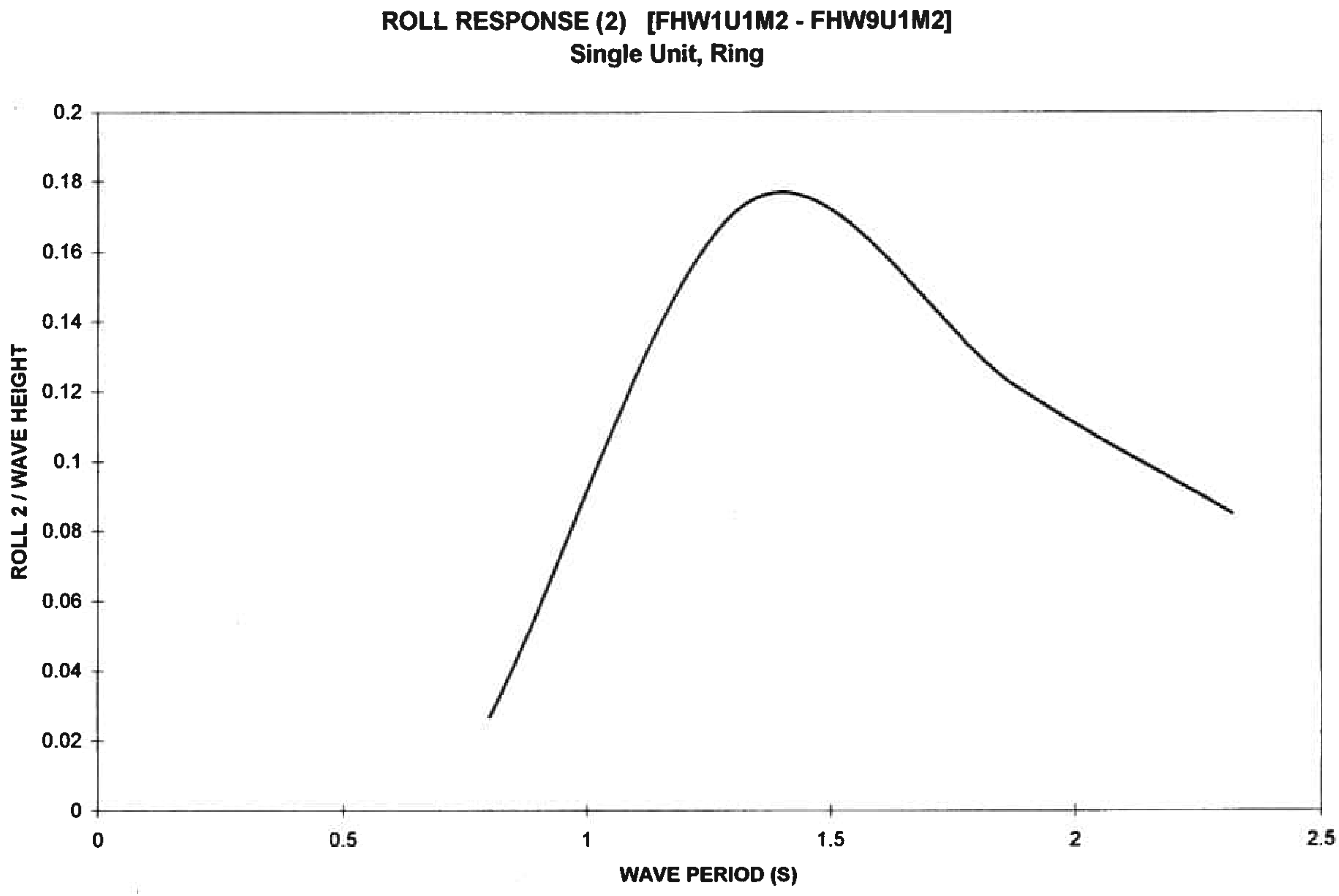


ROLL RESPONSE (1) [FQW1U4M1 - FQW9U4M1]
Four Unit, Horizontal, Quartering

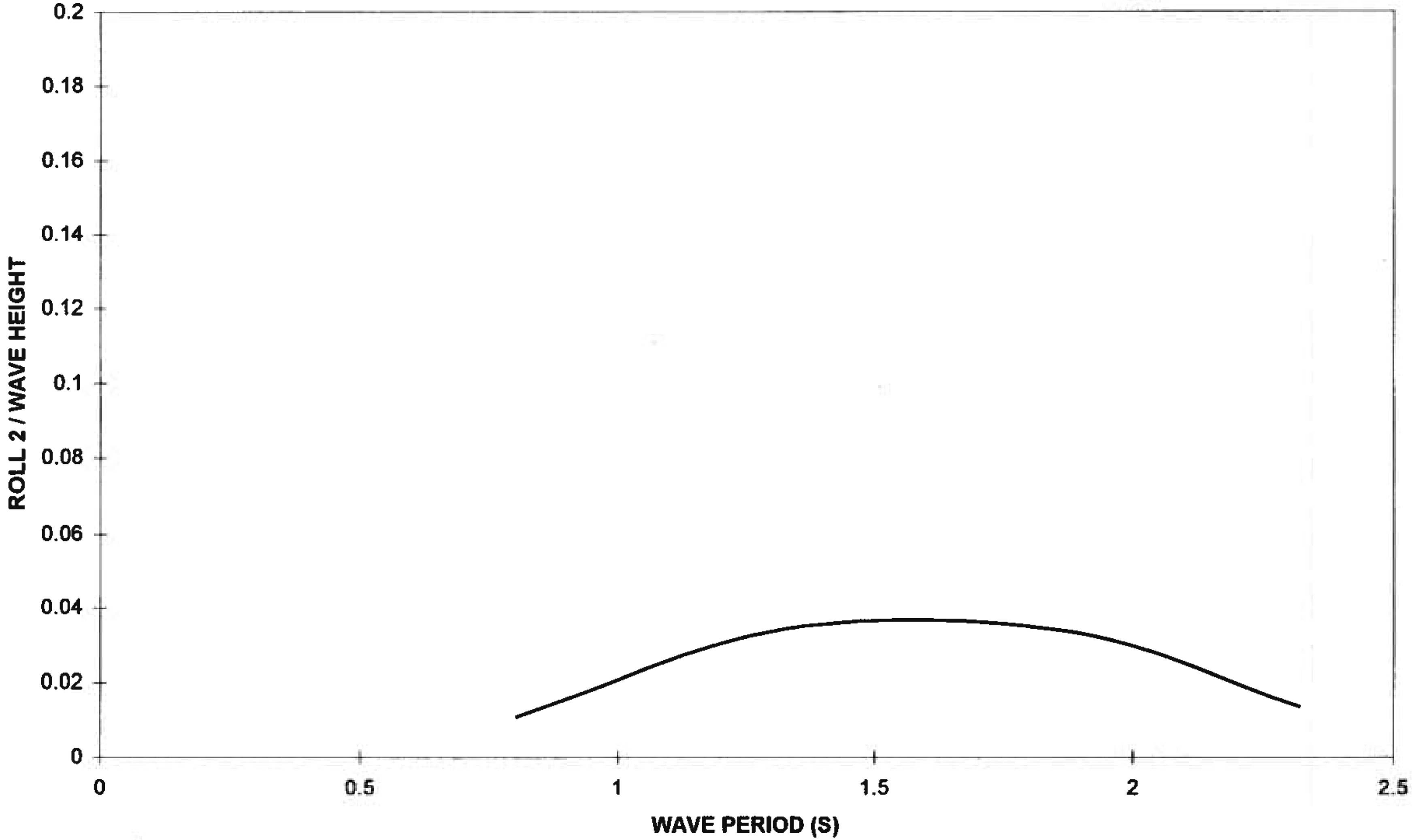


ROLL RESPONSE (2) [FHW1U1M1 - FHW6U1M1]
Single Unit, Catenary

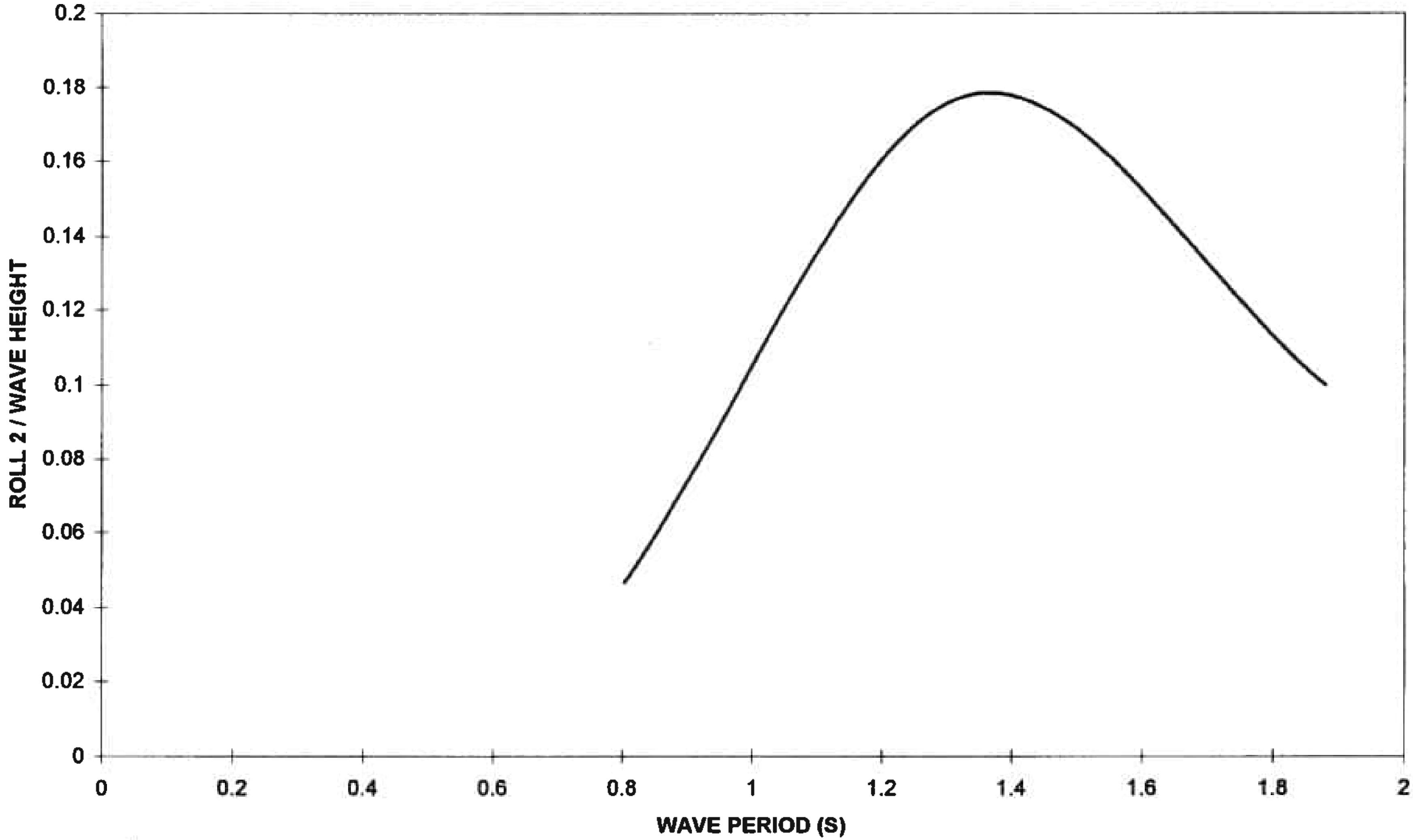


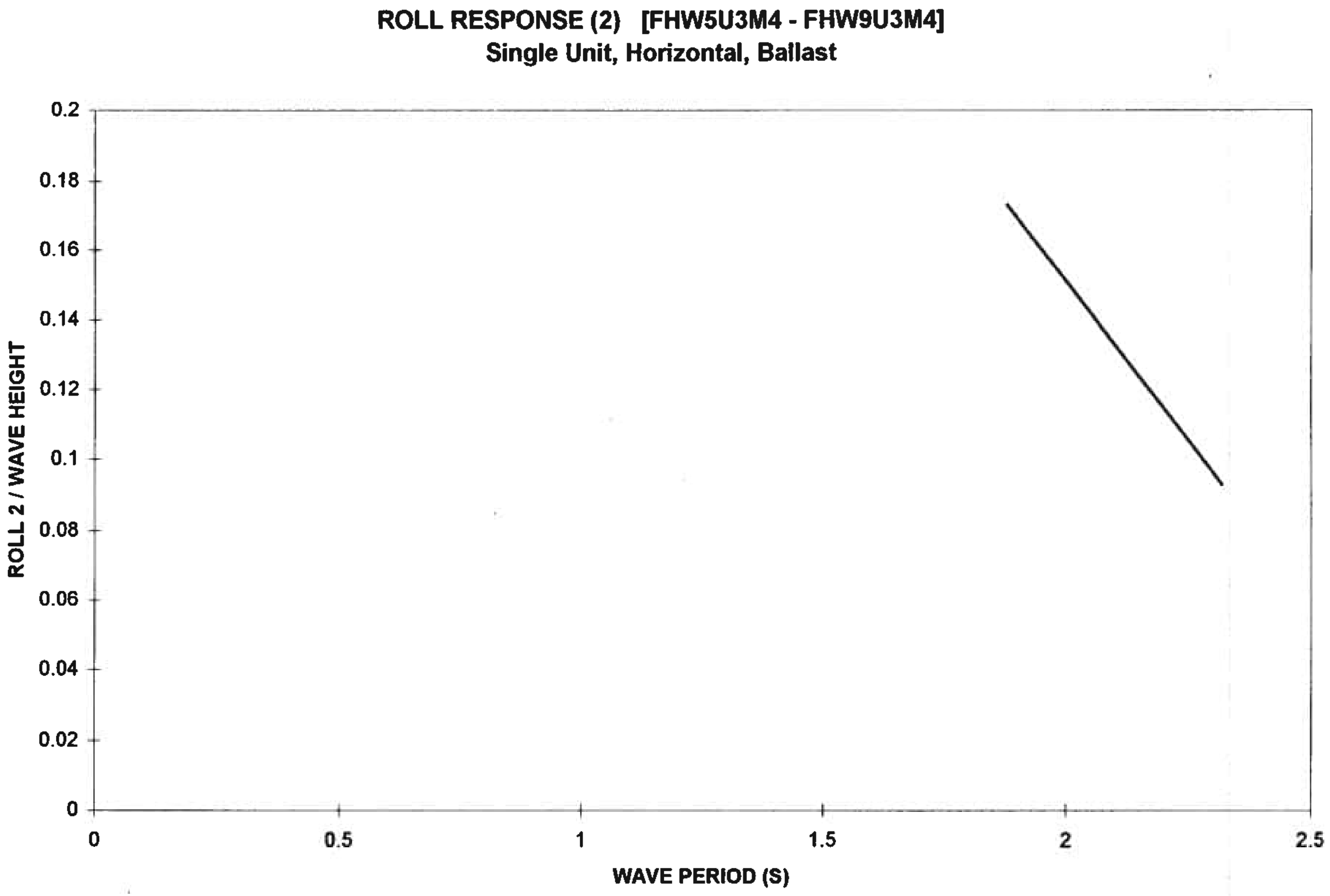

ROLL RESPONSE (2) [FHW1U1M2 - FHW9U1M2]
Single Unit, Ring
ROLL 2 / WAVE HEIGHT
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0
0.5
1
1.5
2
2.5
WAVE PERIOD (S)

ROLL RESPONSE (2) [FHW1U1M3 - FHW9U1M3]
Single Unit, Basket

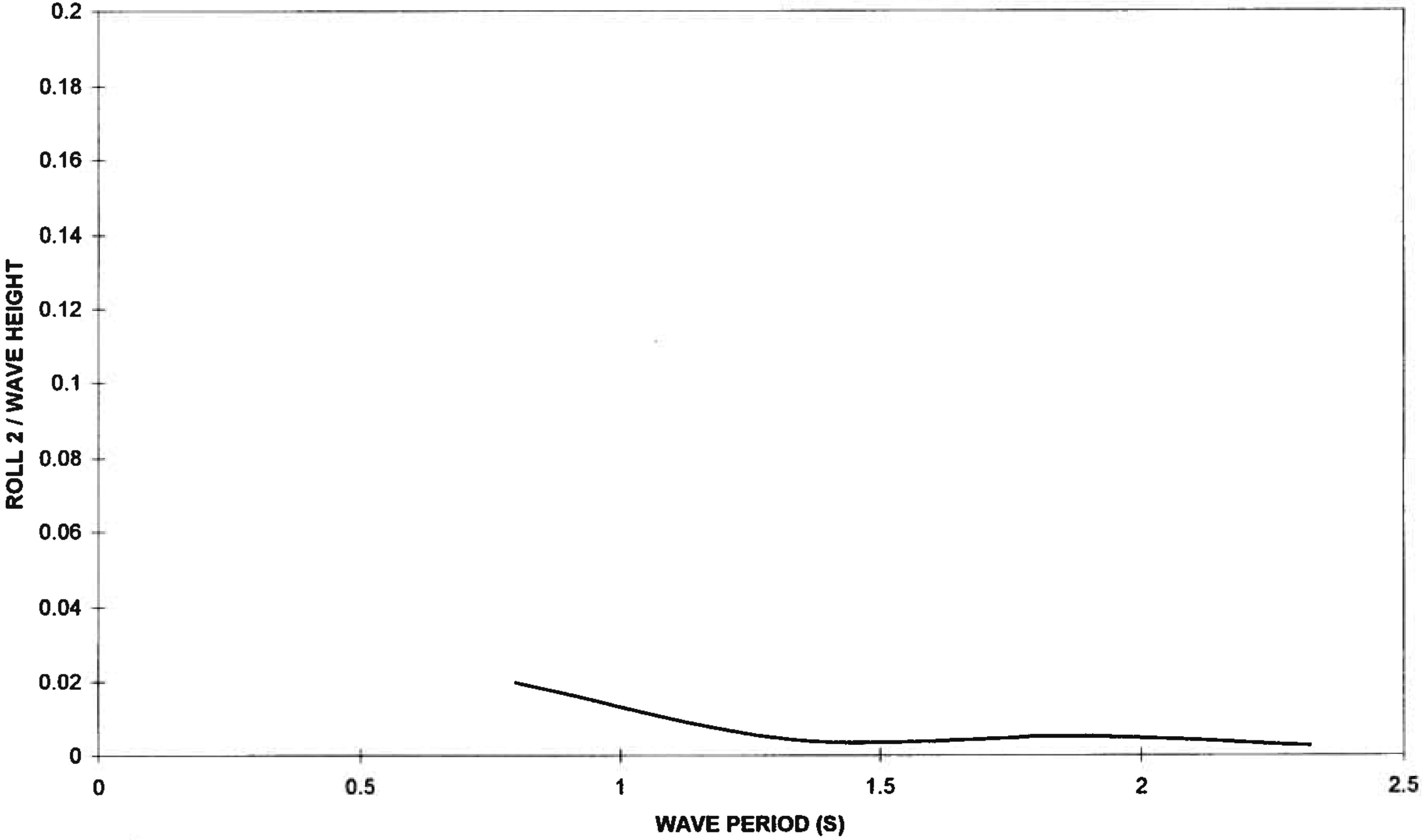


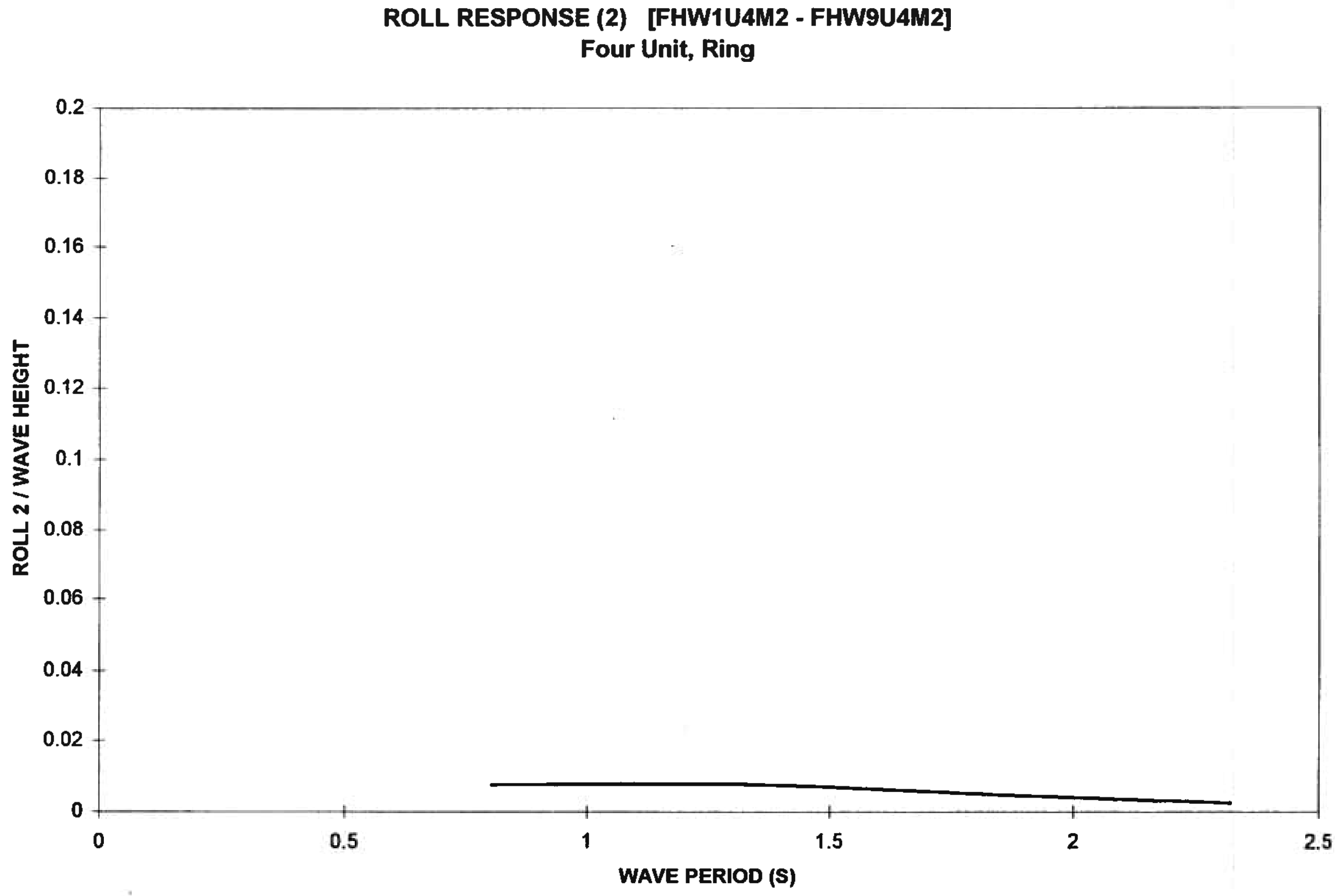
ROLL RESPONSE (2) [FHW1U1M4 - FHW6U1M4]
Single Unit, Horizontal

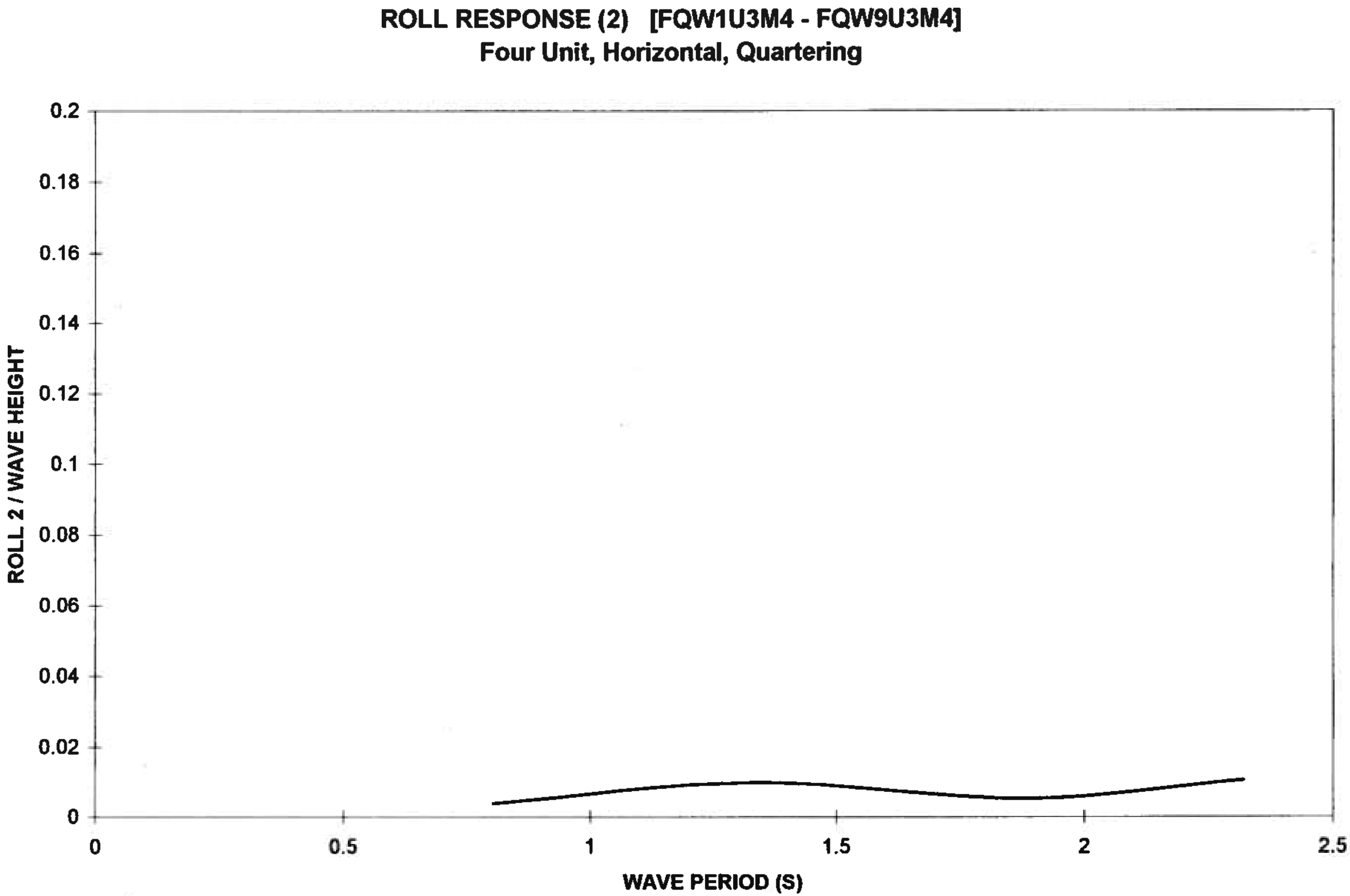


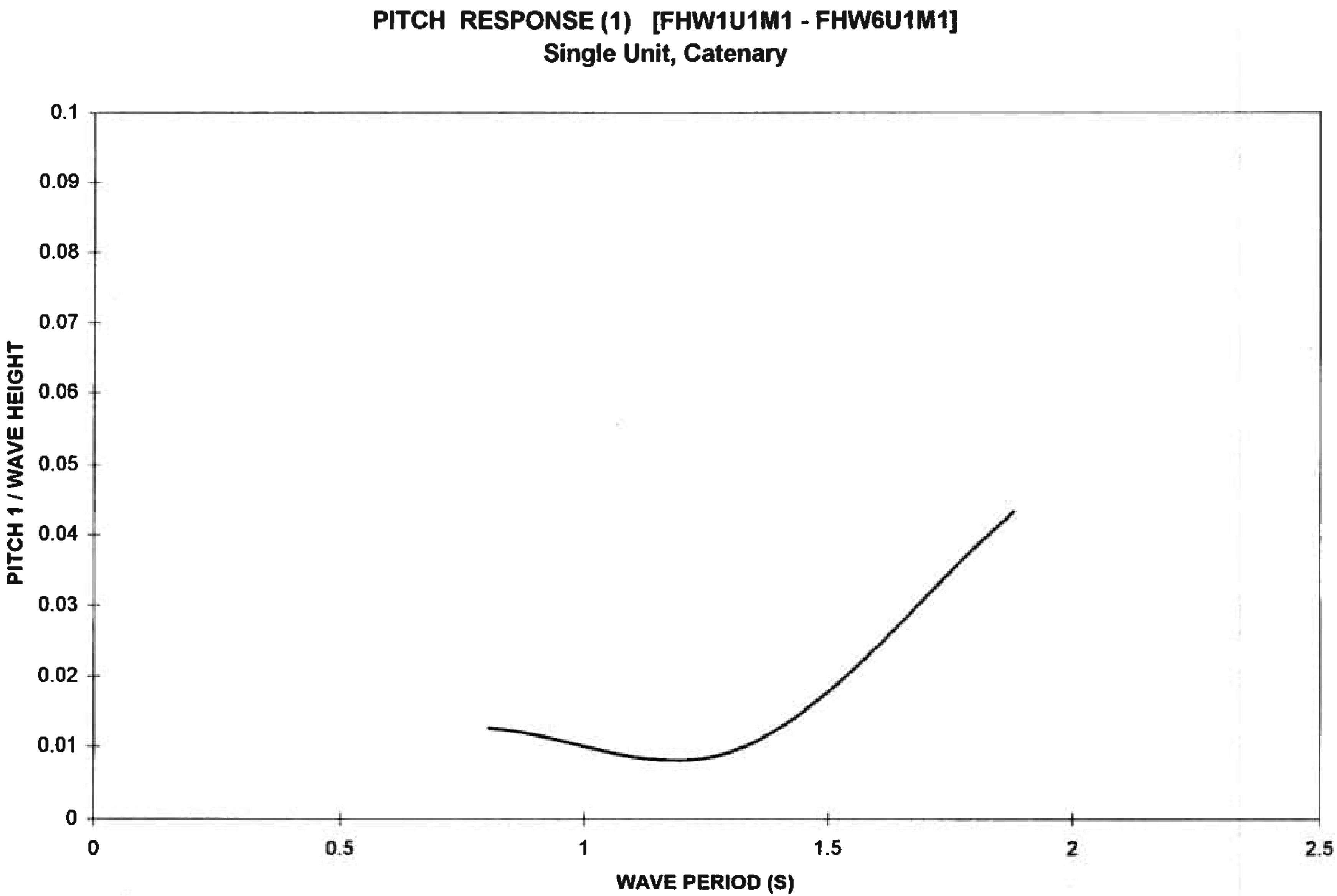

ROLL RESPONSE (2) [FHW5U3M4 - FHW9U3M4]
Single Unit, Horizontal, Ballast
ROLL 2 / WAVE HEIGHT
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0.5
1
1.5
2
2.5
WAVE PERIOD (S)

ROLL RESPONSE (2) [FHW1U4M1 - FHW9U4M1]
Four Unit, Horizontal

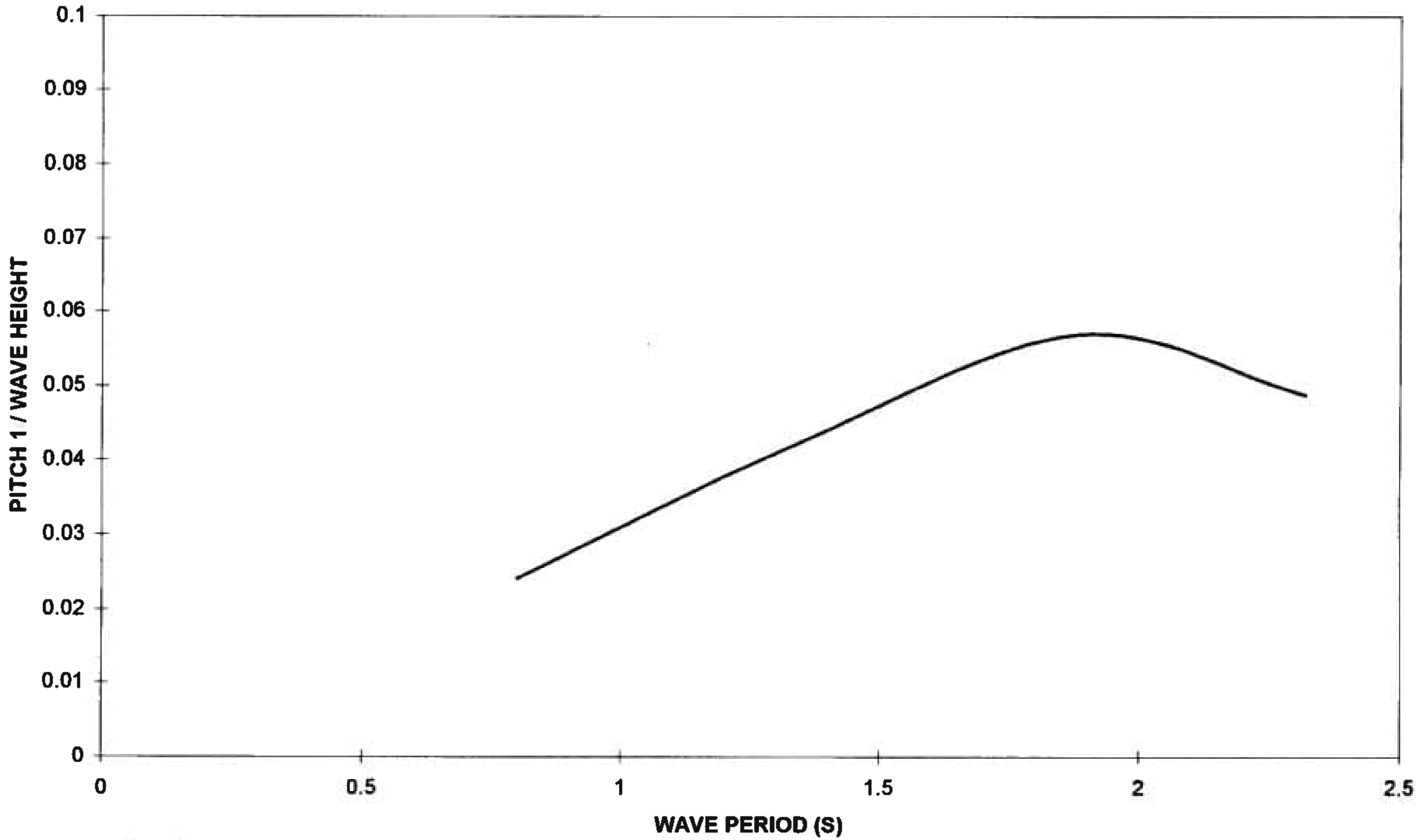



ROLL RESPONSE (2) [FHW1U4M2 - FHW9U4M2]
Four Unit, Ring
ROLL 2 / WAVE HEIGHT
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0.5
1
1.5
2
2.5
WAVE PERIOD (S)

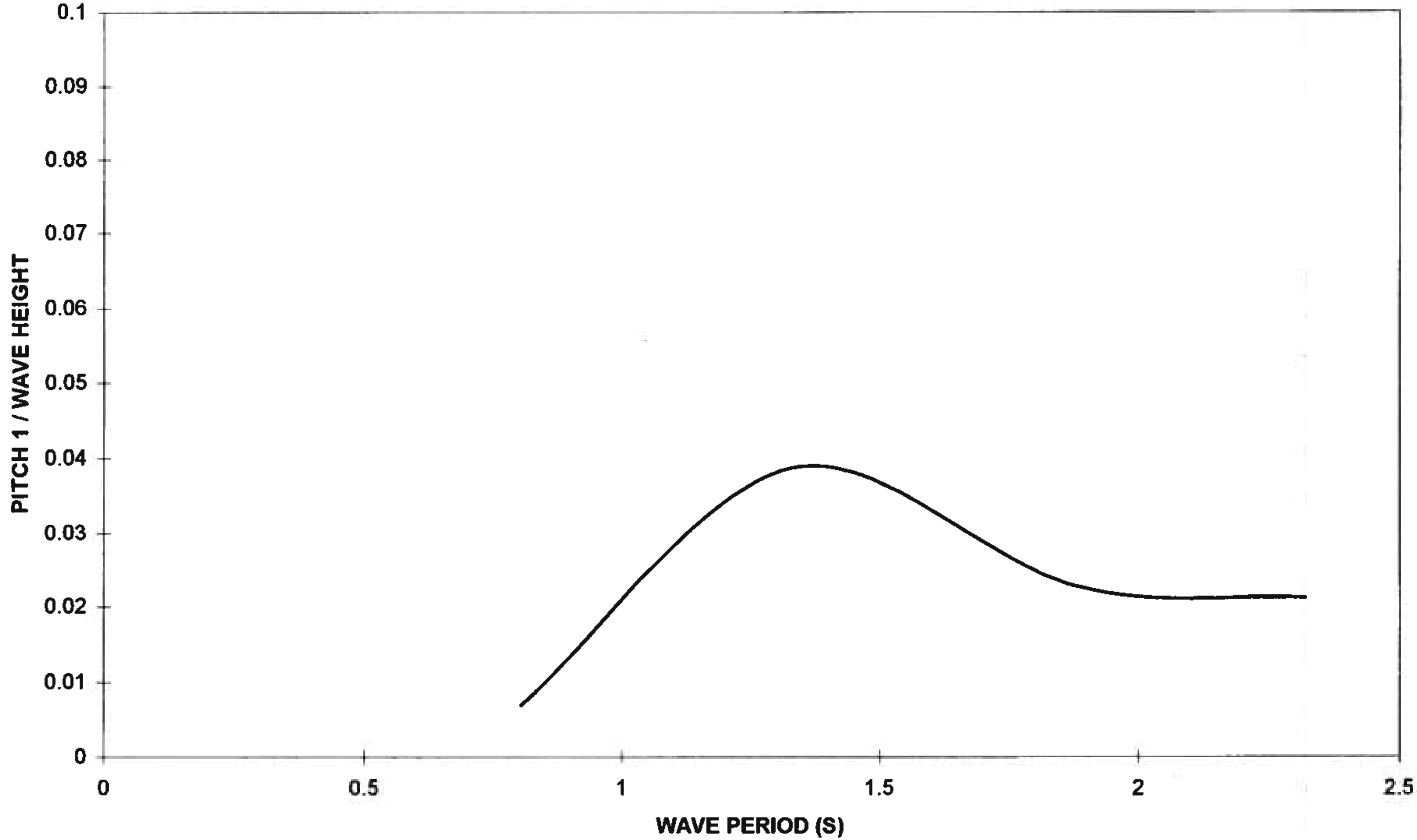

ROLL RESPONSE (2) [FQW1U3M4 - FQW9U3M4]
Four Unit, Horizontal, Quartering
ROLL 2 / WAVE HEIGHT
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0.5
1
1.5
2
2.5
WAVE PERIOD (S)


PITCH RESPONSE (1) [FHW1U1M1 - FHW6U1M1]
Single Unit, Catenary
PITCH 1 / WAVE HEIGHT
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0.5
1
1.5
2
2.5
WAVE PERIOD (S)

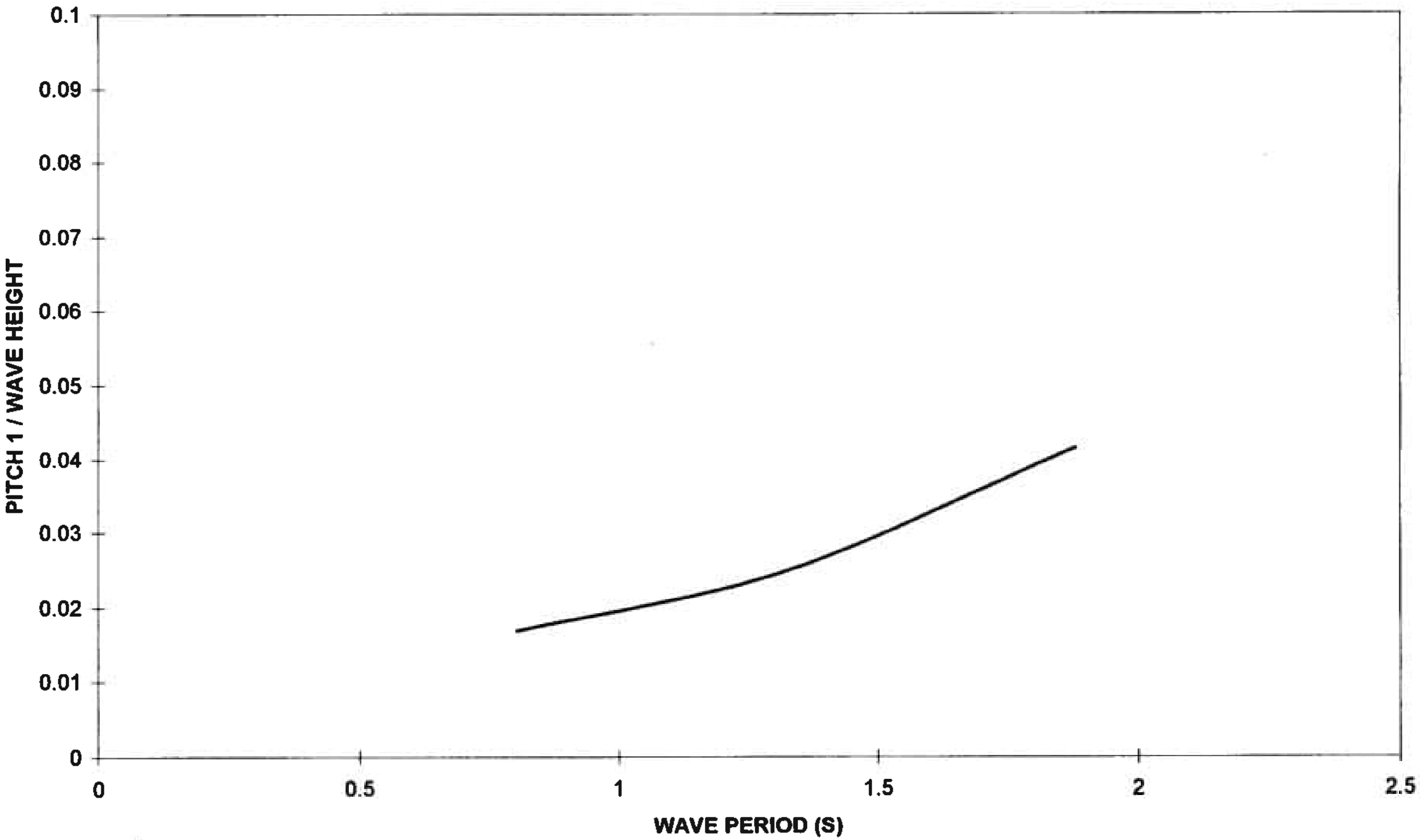
PITCH RESPONSE (1) [FHW1U1M2 - FHW9U1M2]
Single Unit, Ring



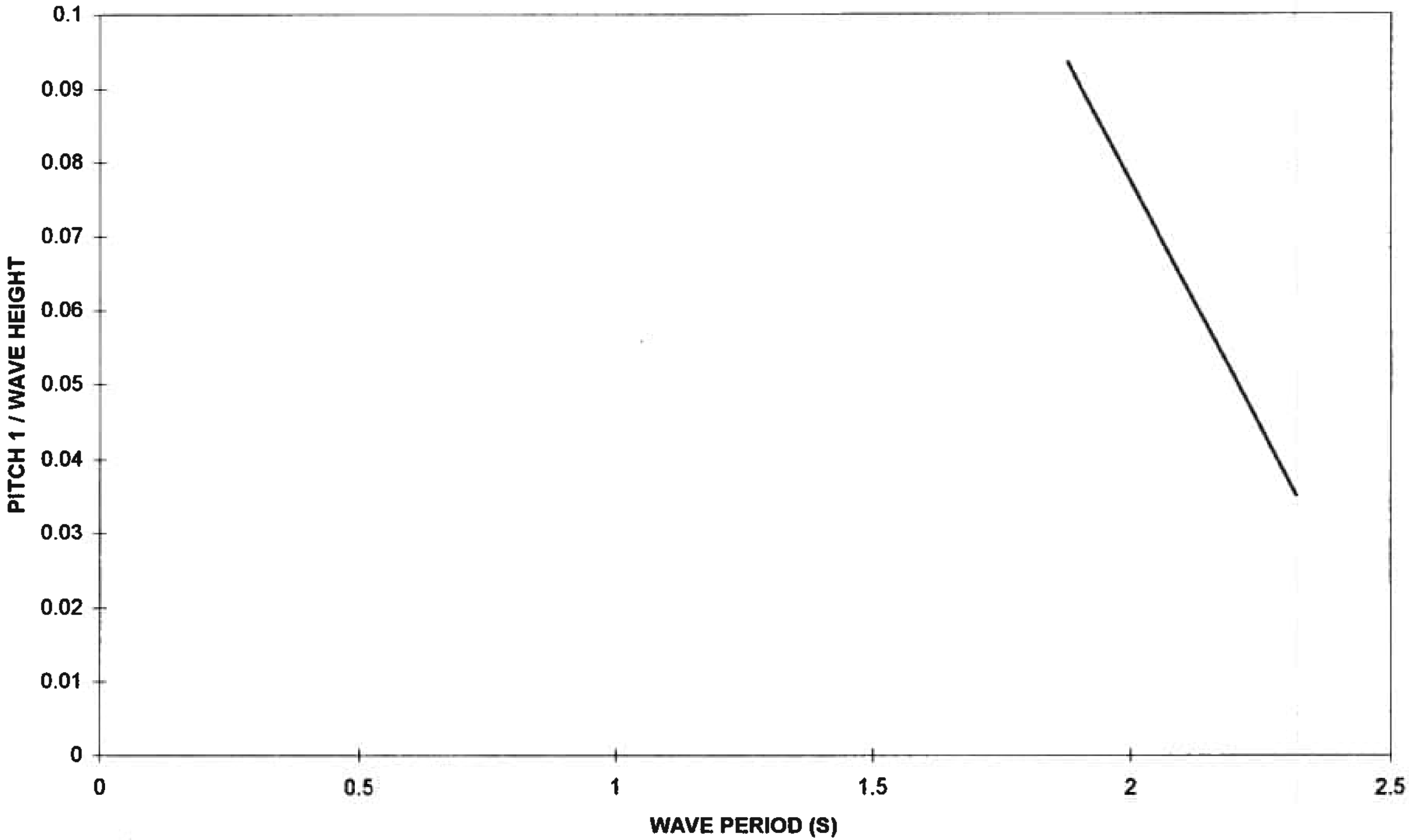
PITCH RESPONSE (1) [FHW1U1M3 - FHW9U1M3]
Single Unit, Basket



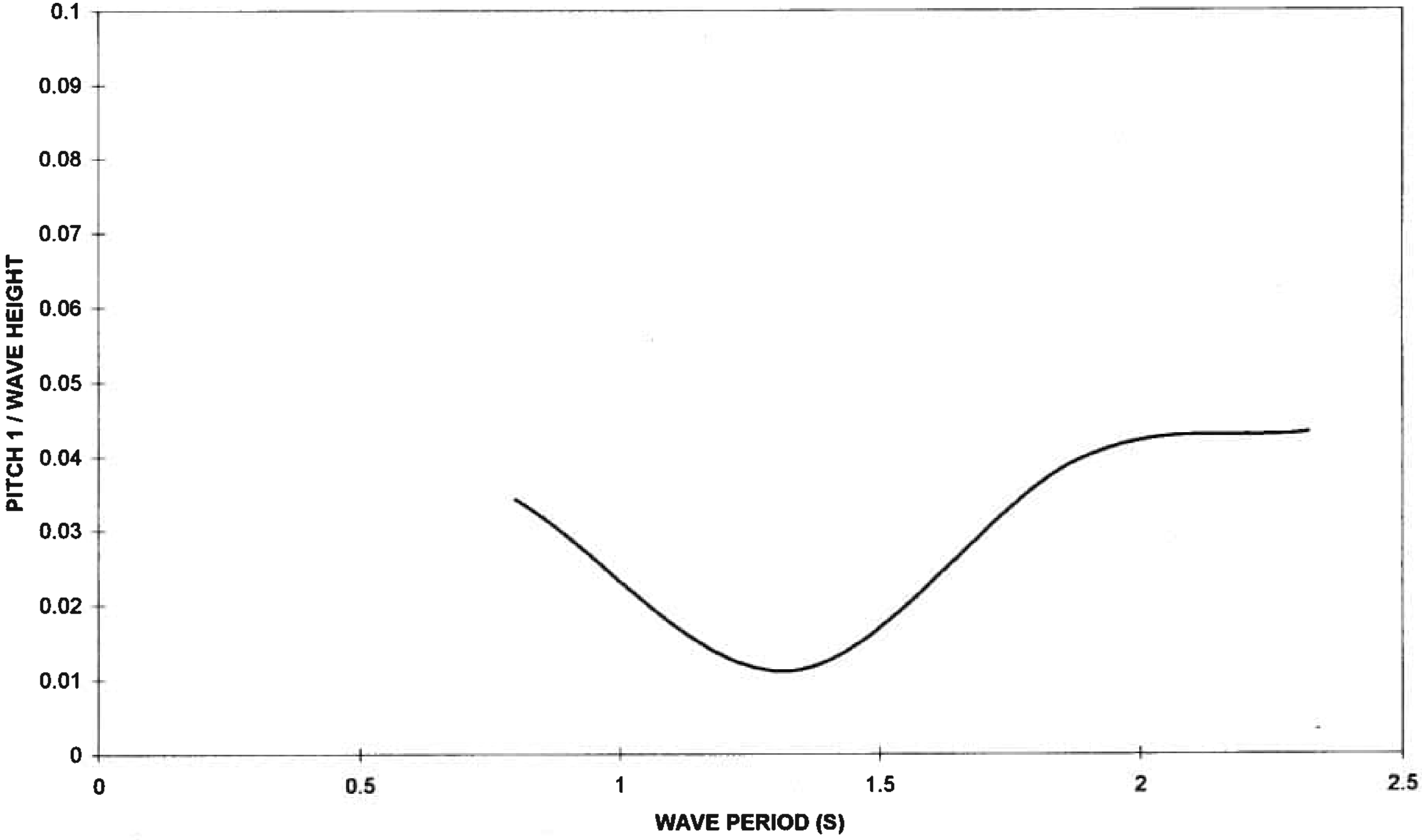
PITCH RESPONSE (1) [FHW1U1M4 - FHW6U1M4]
Single Unit, Horizontal



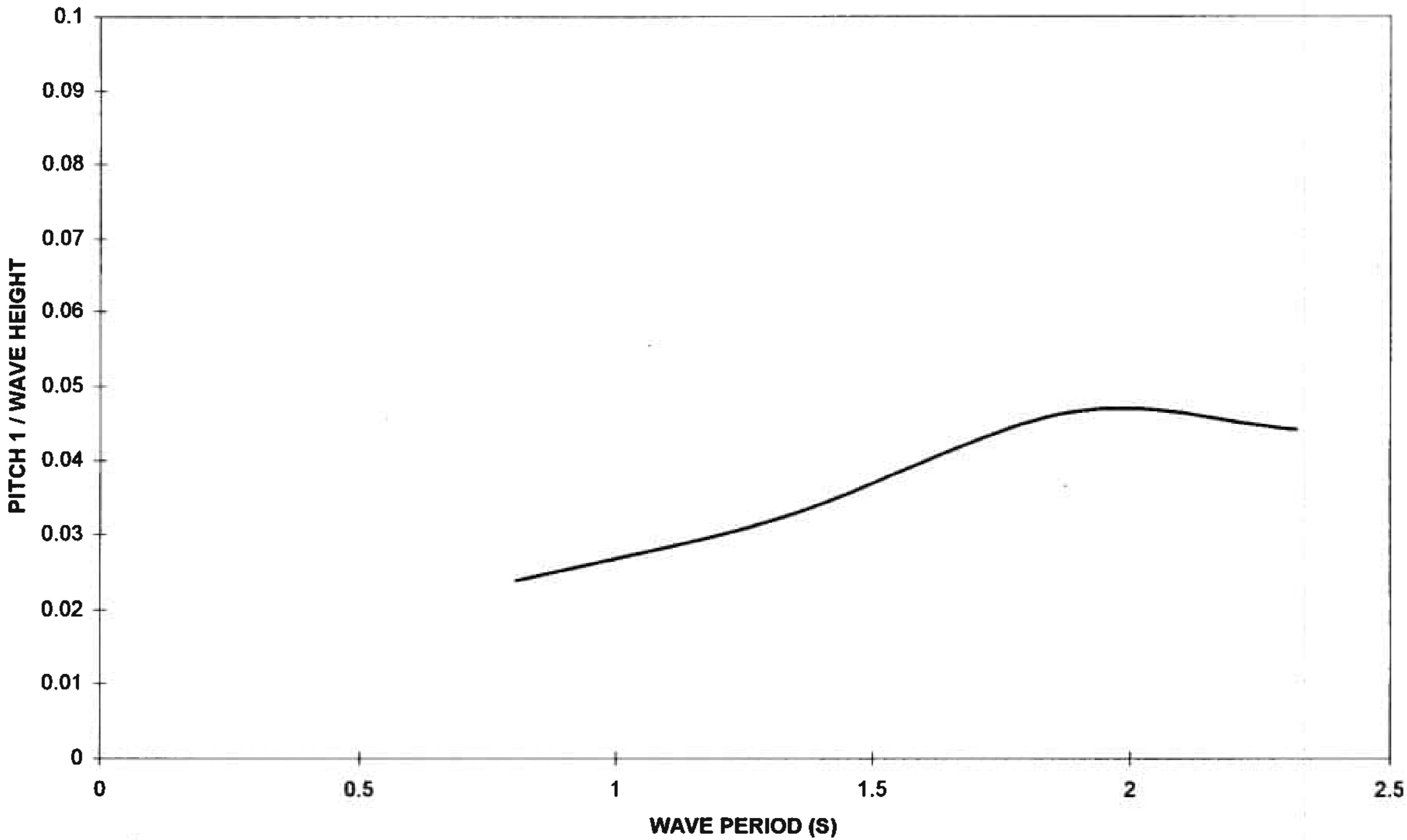
PITCH RESPONSE (1) [FHW5U3M4 - FHW9U3M4]
Single Unit, Horizontal, Ballast

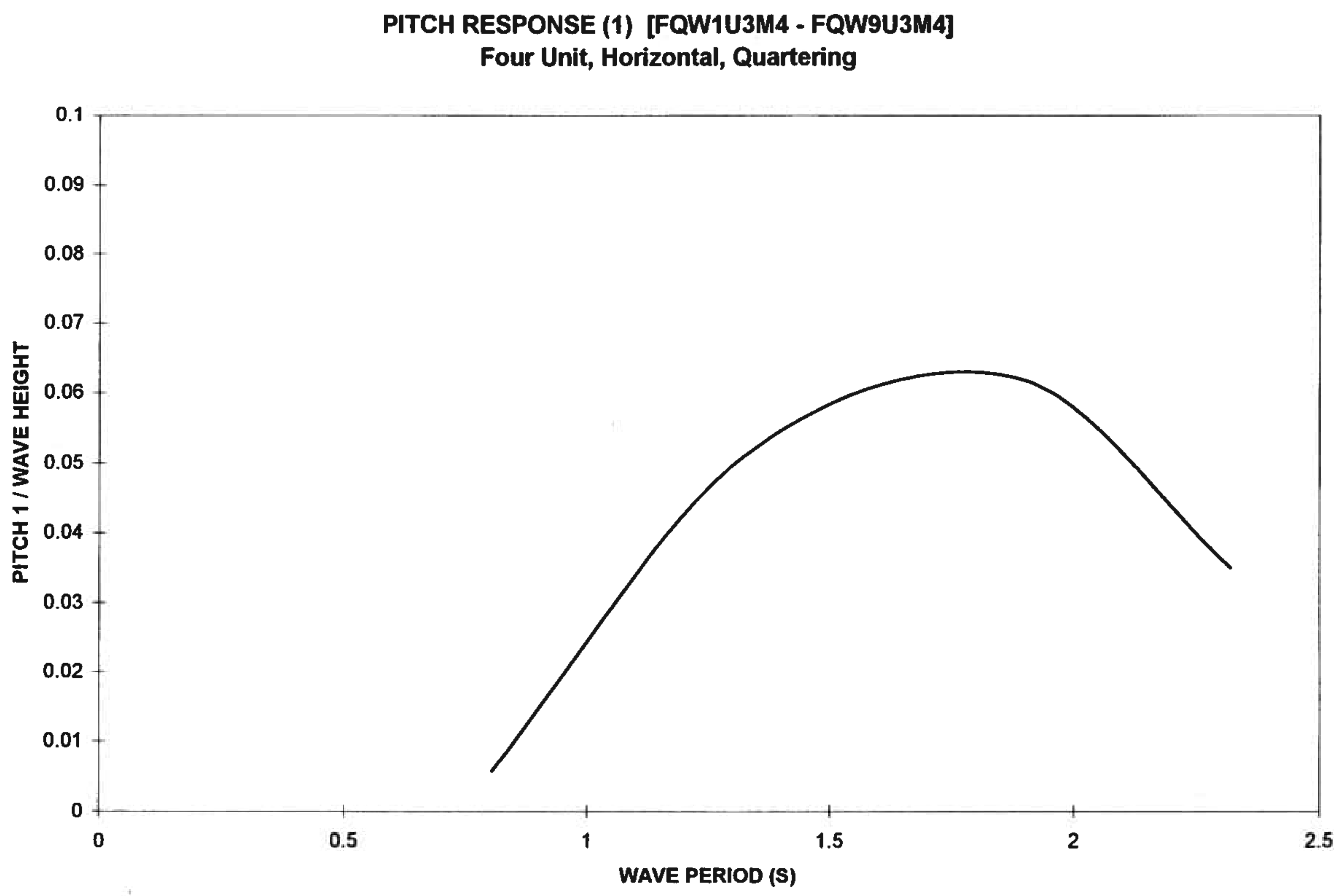


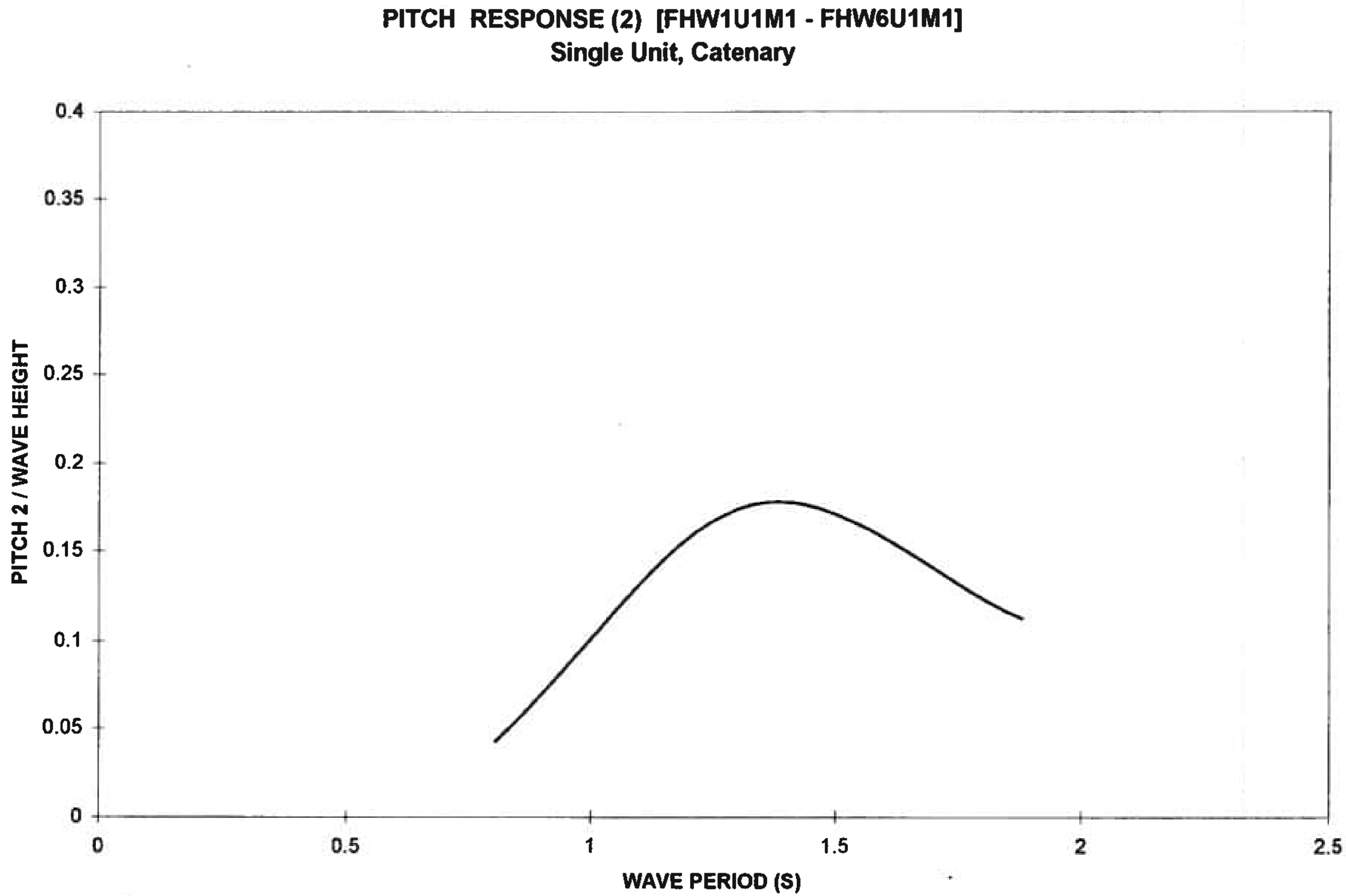
PITCH RESPONSE (1) [FHW1U4M1 - FHW9U4M1]
Four Unit, Horizontal

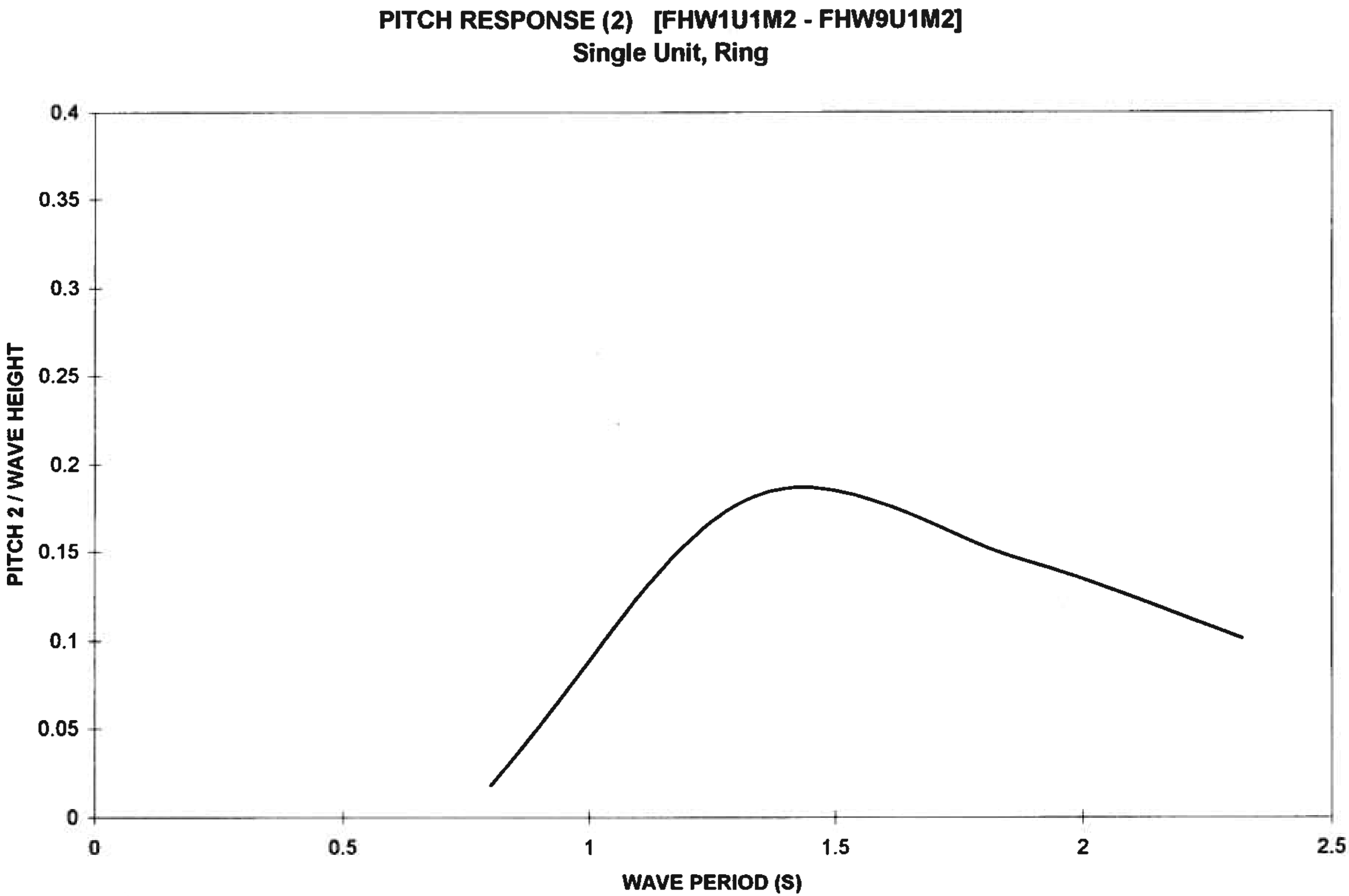


PITCH RESPONSE (1) [FHW1U4M2 - FHW9U4M2]
Four Unit, Ring

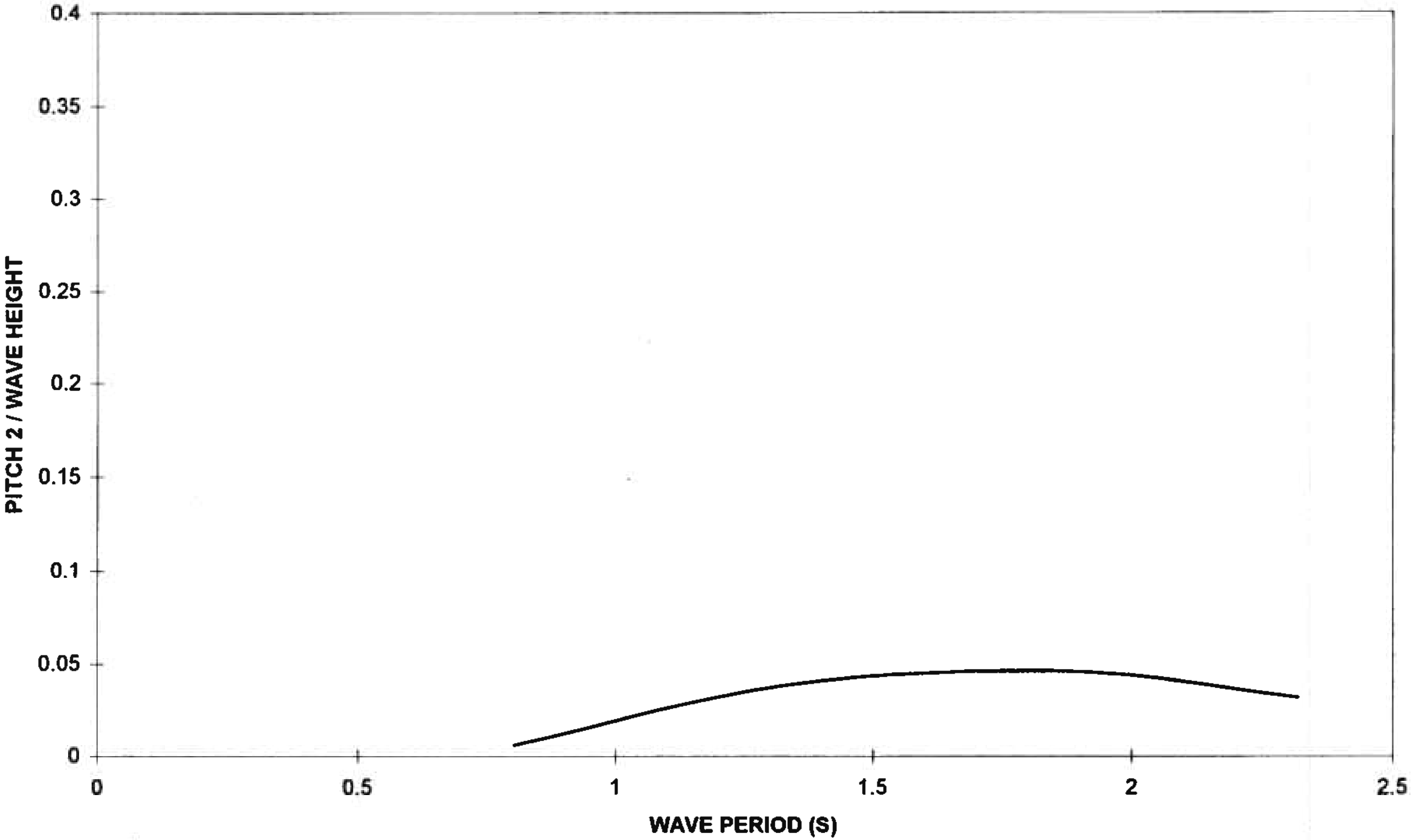


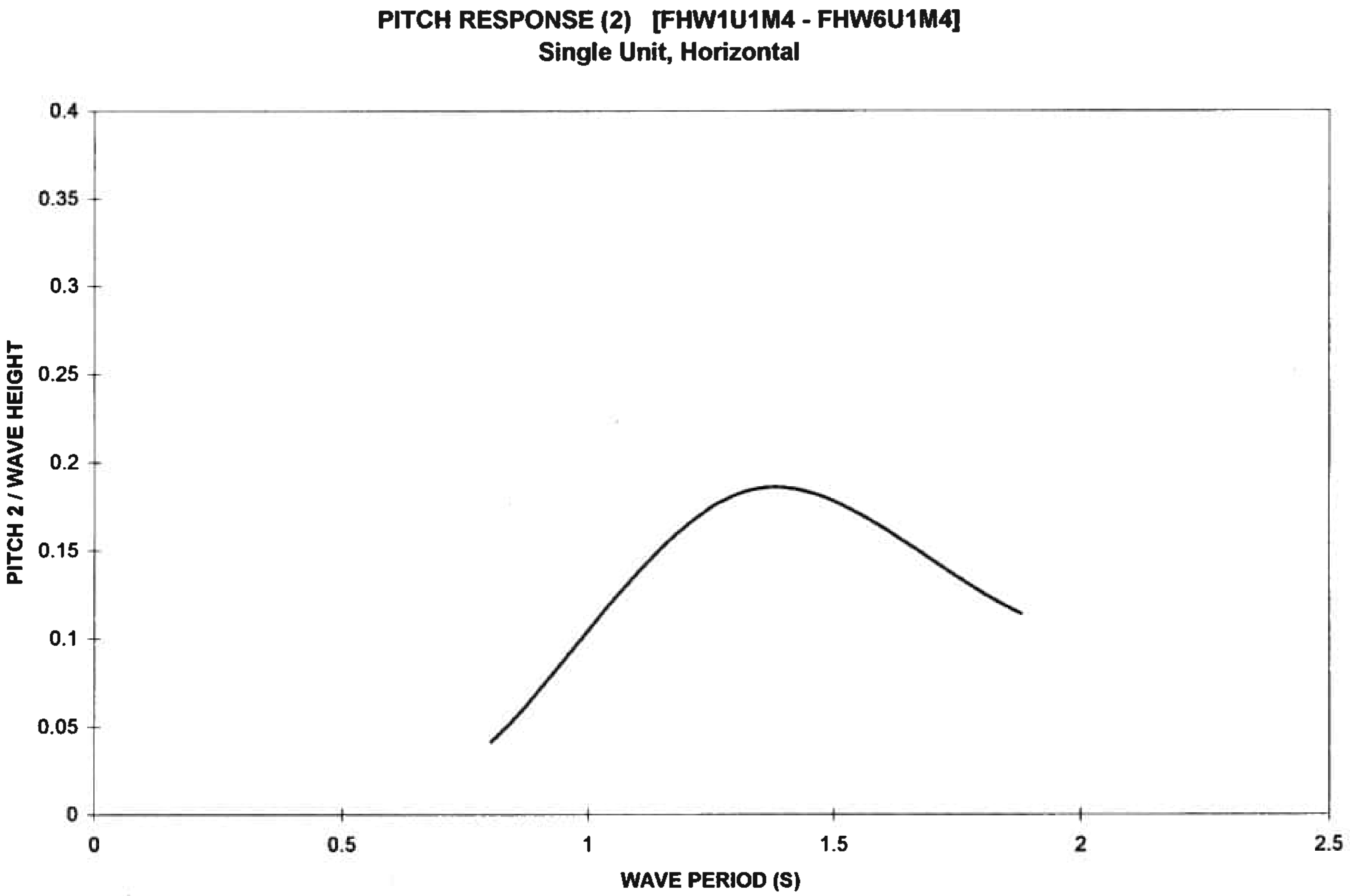

PITCH RESPONSE (1) [FQW1U3M4 - FQW9U3M4]
Four Unit, Horizontal, Quartering
PITCH 1 / WAVE HEIGHT
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
0.5
1
1.5
2
2.5
WAVE PERIOD (S)

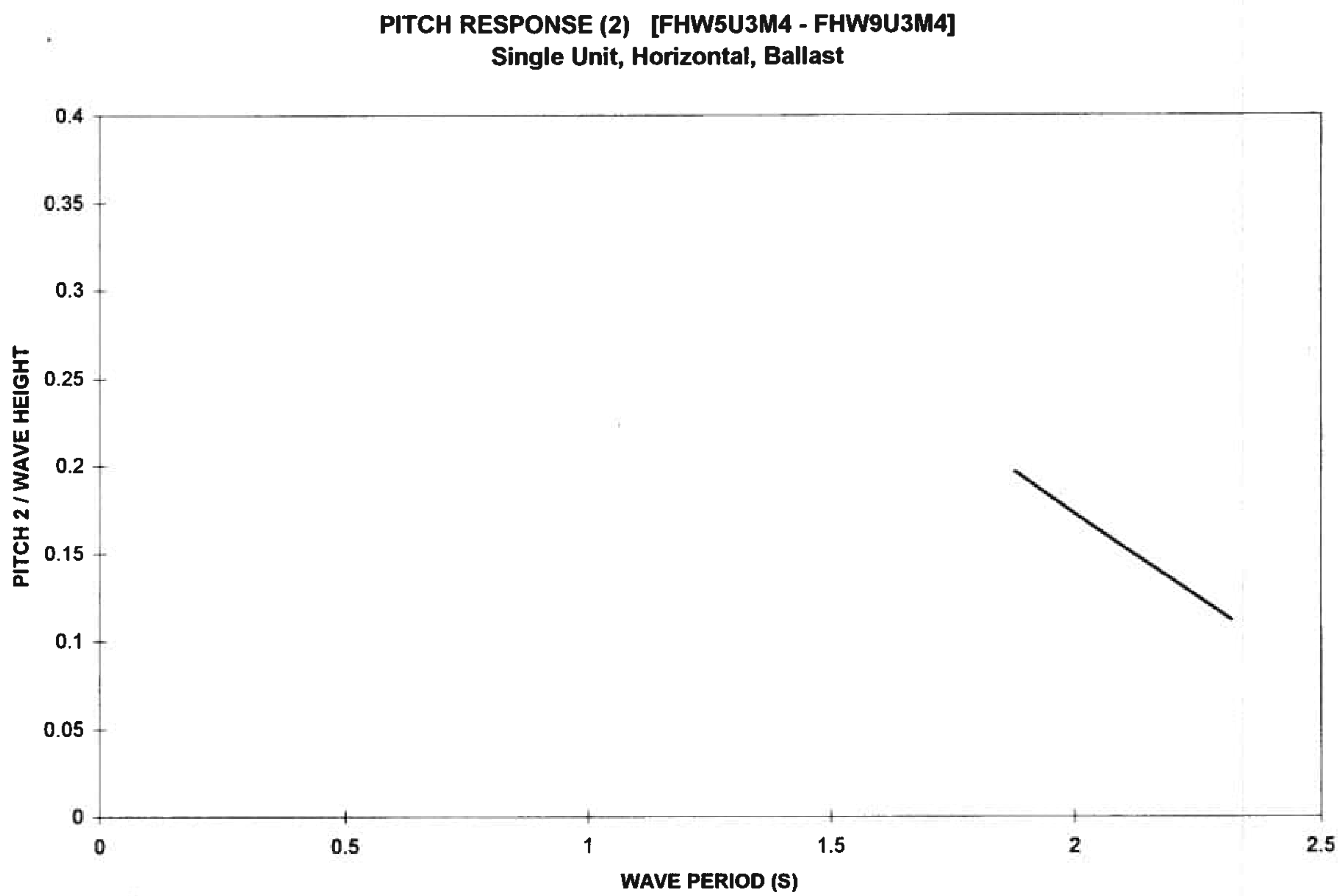

PITCH RESPONSE (2) [FHW1U1M1 - FHW6U1M1]
Single Unit, Catenary
PITCH 2 / WAVE HEIGHT
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.5
1
1.5
2
2.5
WAVE PERIOD (S)

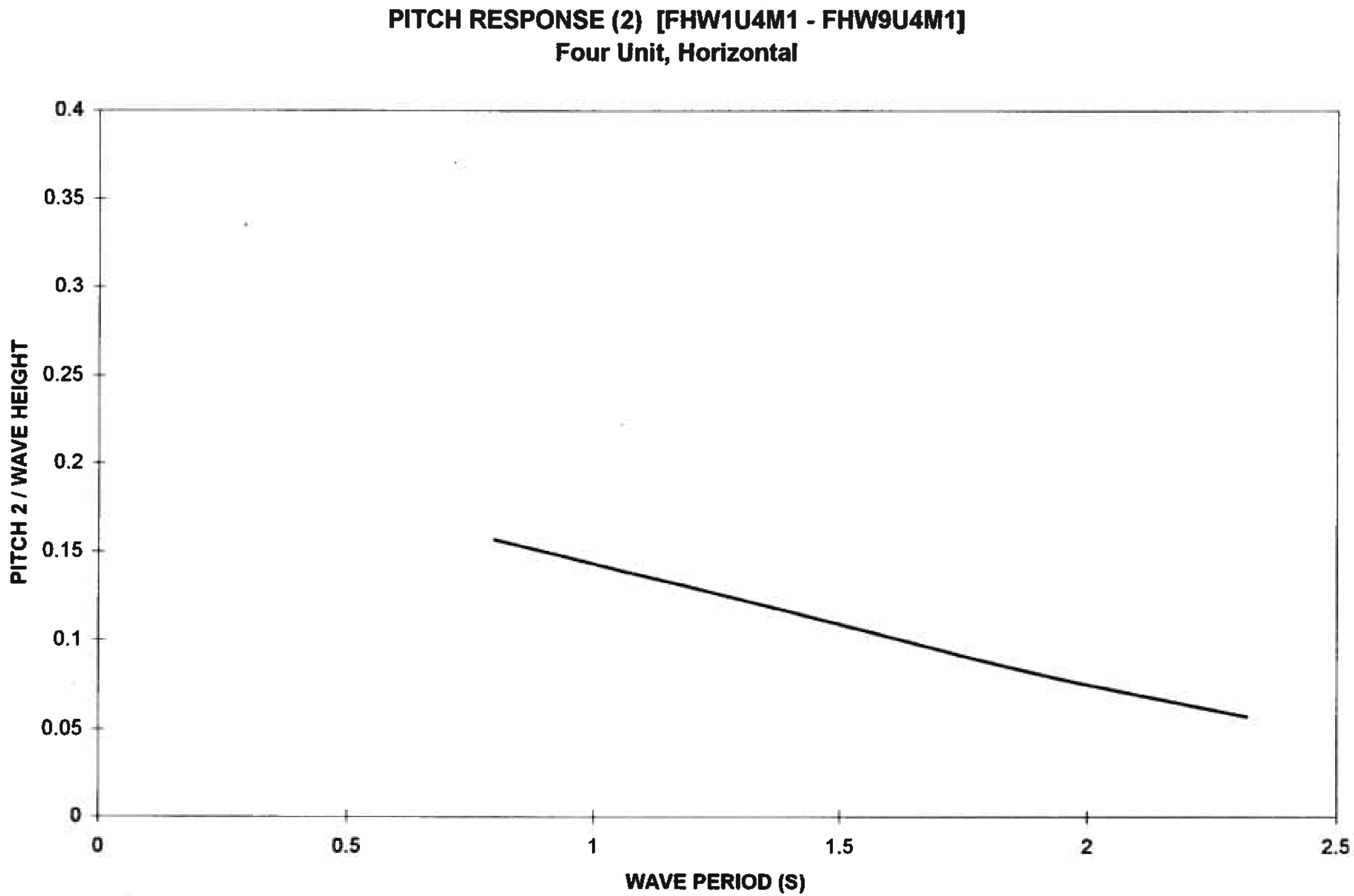

PITCH RESPONSE (2) [FHW1U1M2 - FHW9U1M2]
Single Unit, Ring
PITCH 2 / WAVE HEIGHT
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.5
1
1.5
2
2.5
WAVE PERIOD (S)

PITCH RESPONSE (2) [FHW1U1M3 - FHW9U1M3]
Single Unit, Basket

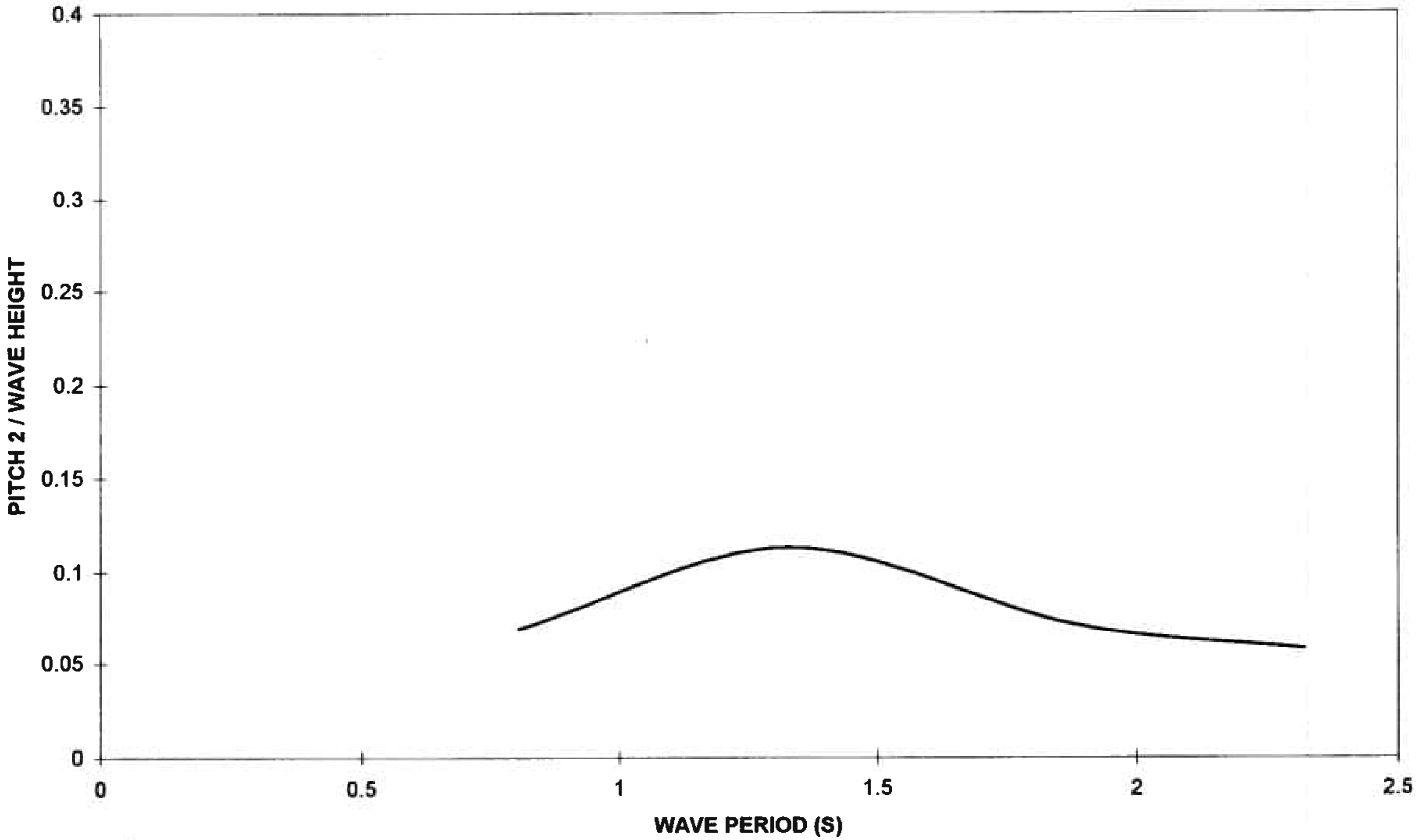



PITCH RESPONSE (2) [FHW1U1M4 - FHW6U1M4]
Single Unit, Horizontal
PITCH 2 / WAVE HEIGHT
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.5
1
1.5
2
2.5
WAVE PERIOD (S)

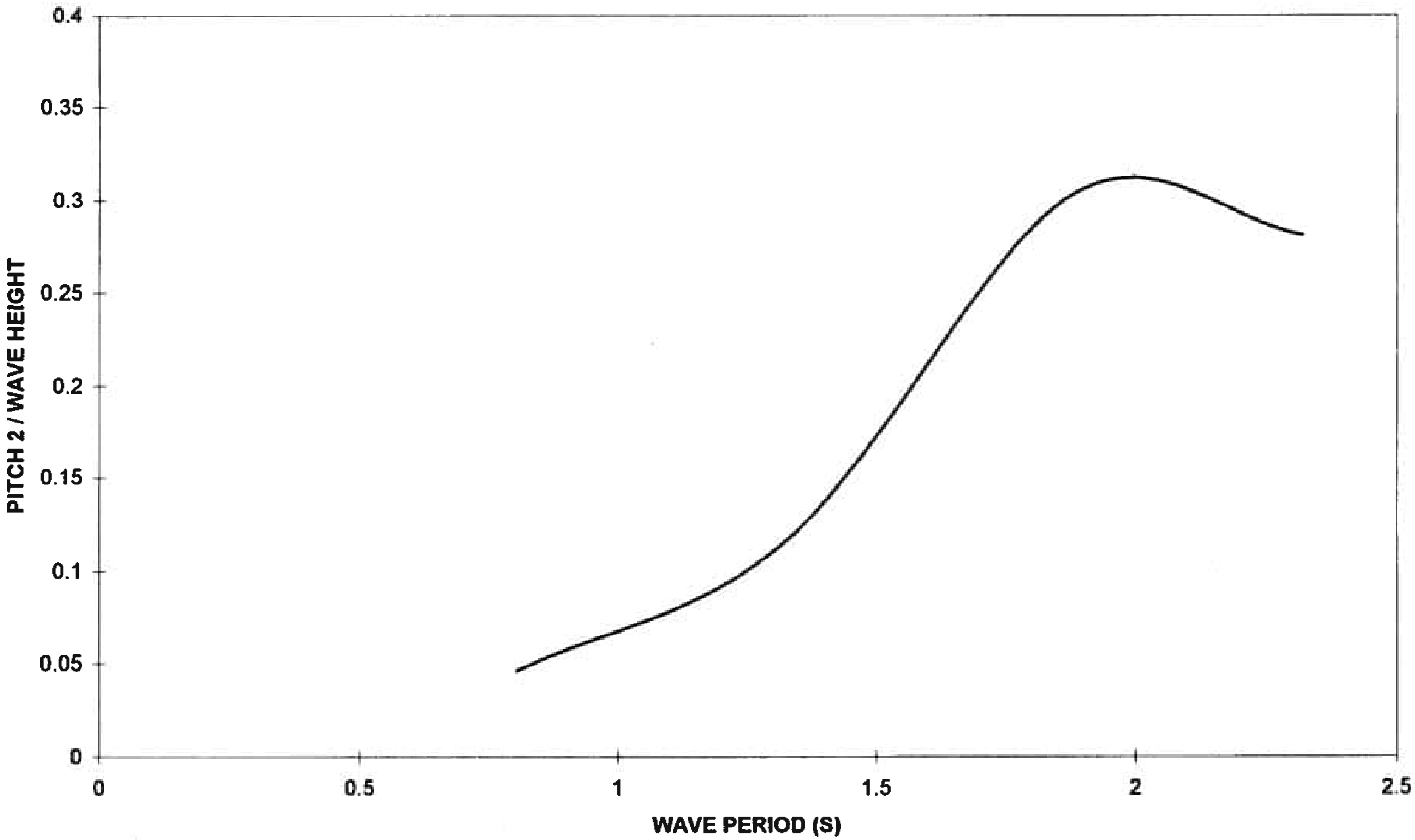

PITCH RESPONSE (2) [FHW5U3M4 - FHW9U3M4]
Single Unit, Horizontal, Ballast
PITCH 2 / WAVE HEIGHT
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.5
1
1.5
2
2.5
WAVE PERIOD (S)

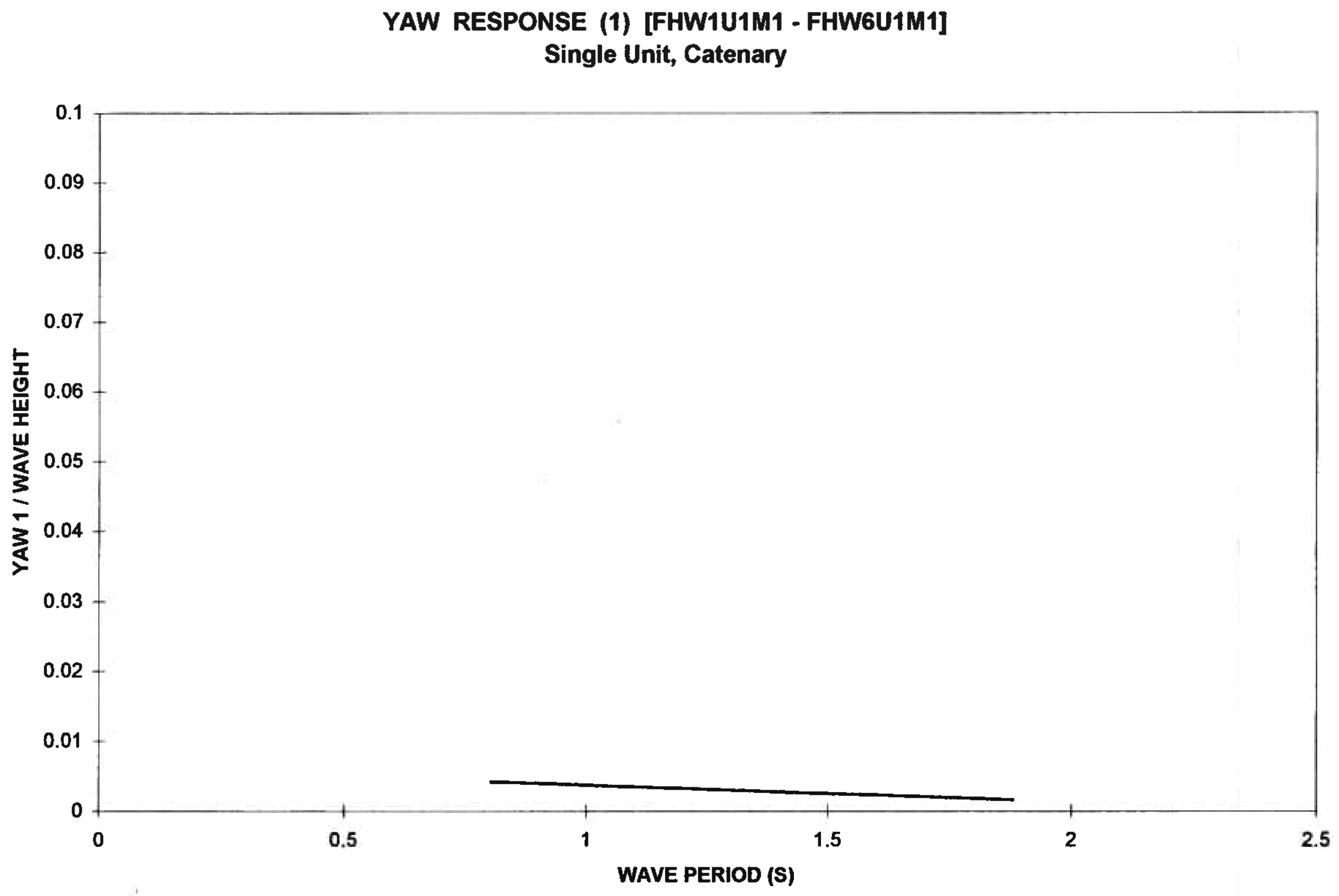

PITCH RESPONSE (2) [FHW1U4M1 - FHW9U4M1]
Four Unit, Horizontal
PITCH 2 / WAVE HEIGHT
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.5
1
1.5
2
2.5
WAVE PERIOD (S)

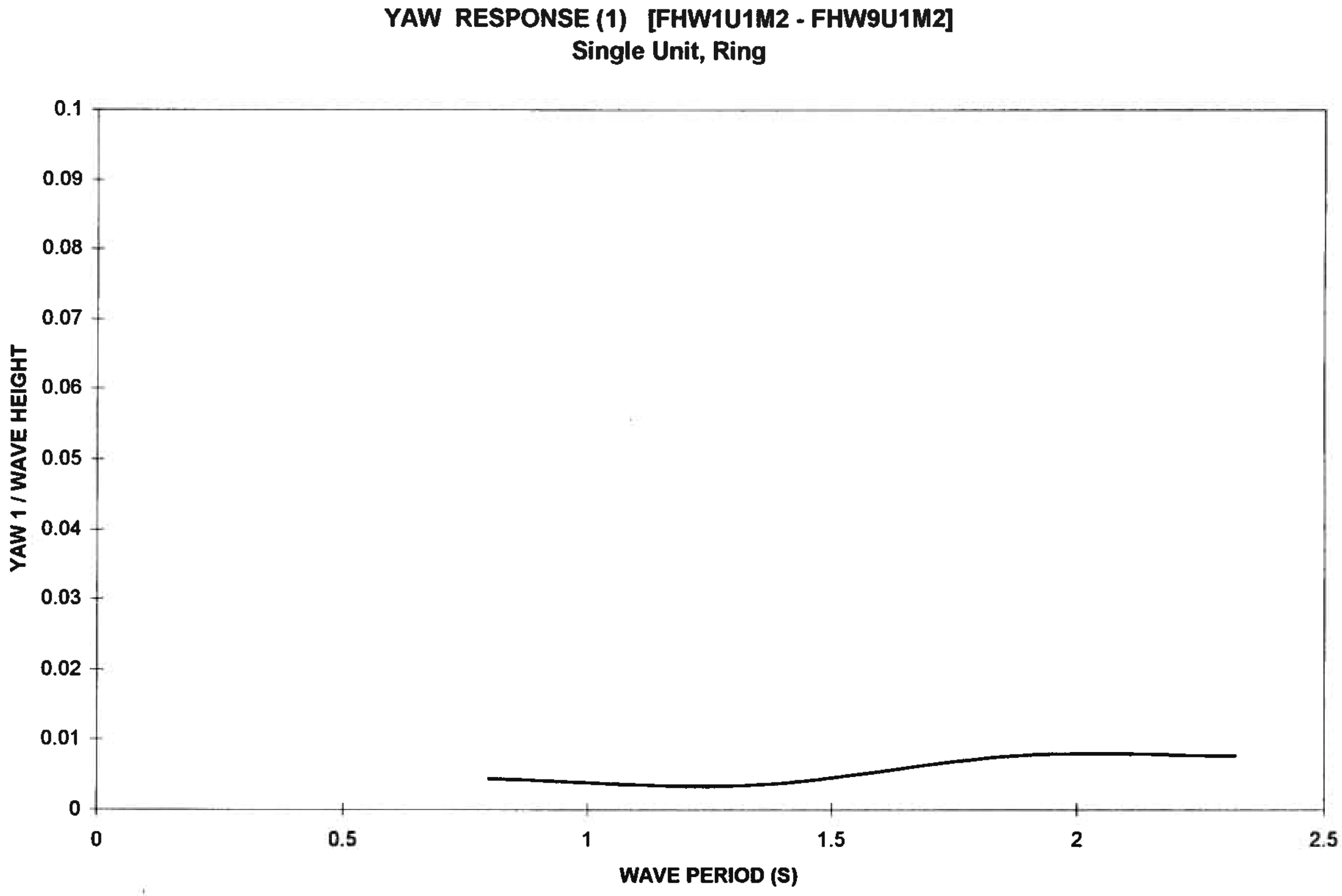
PITCH RESPONSE (2) [FHW1U4M2 - FHW9U4M2]
Four Unit, Ring

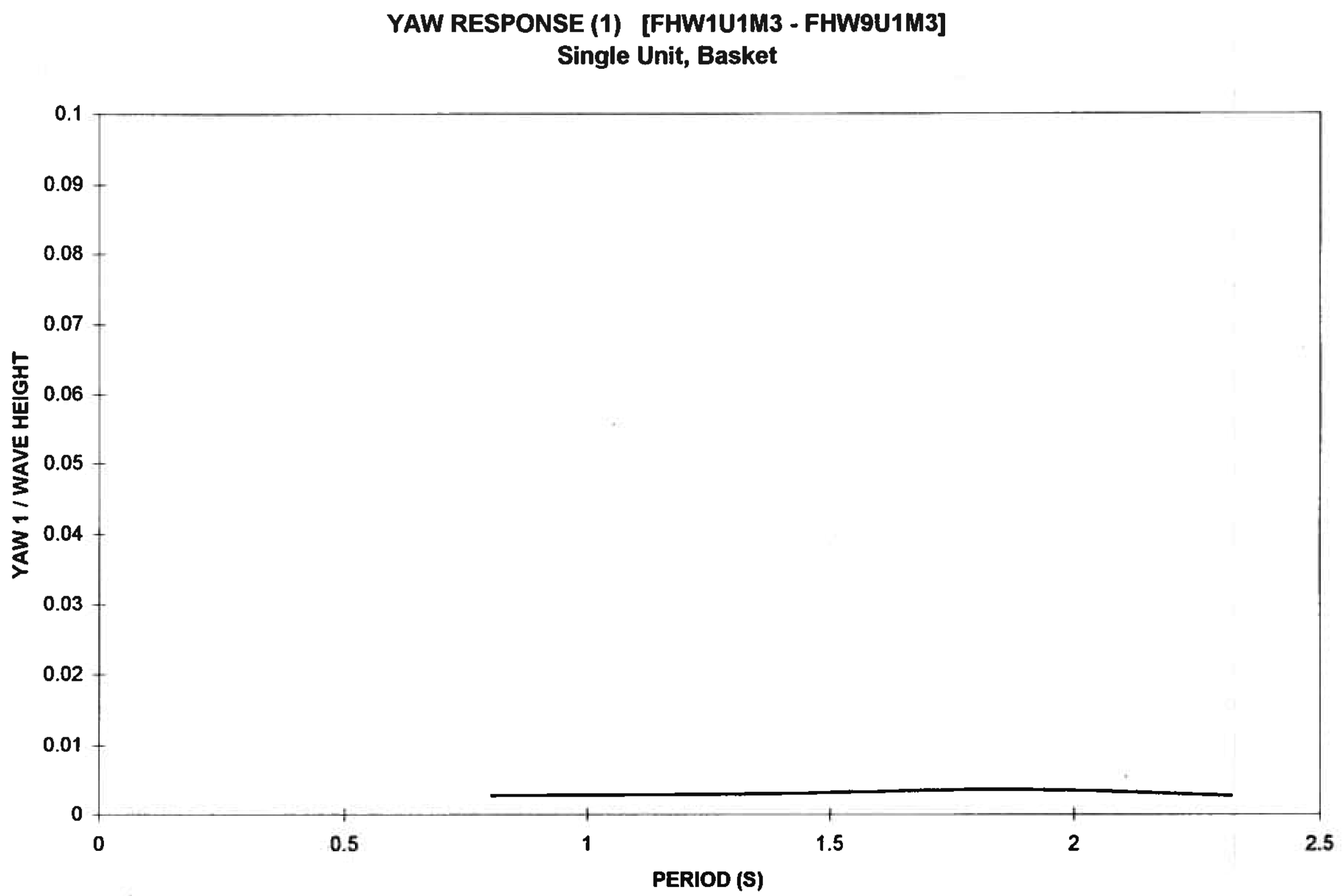


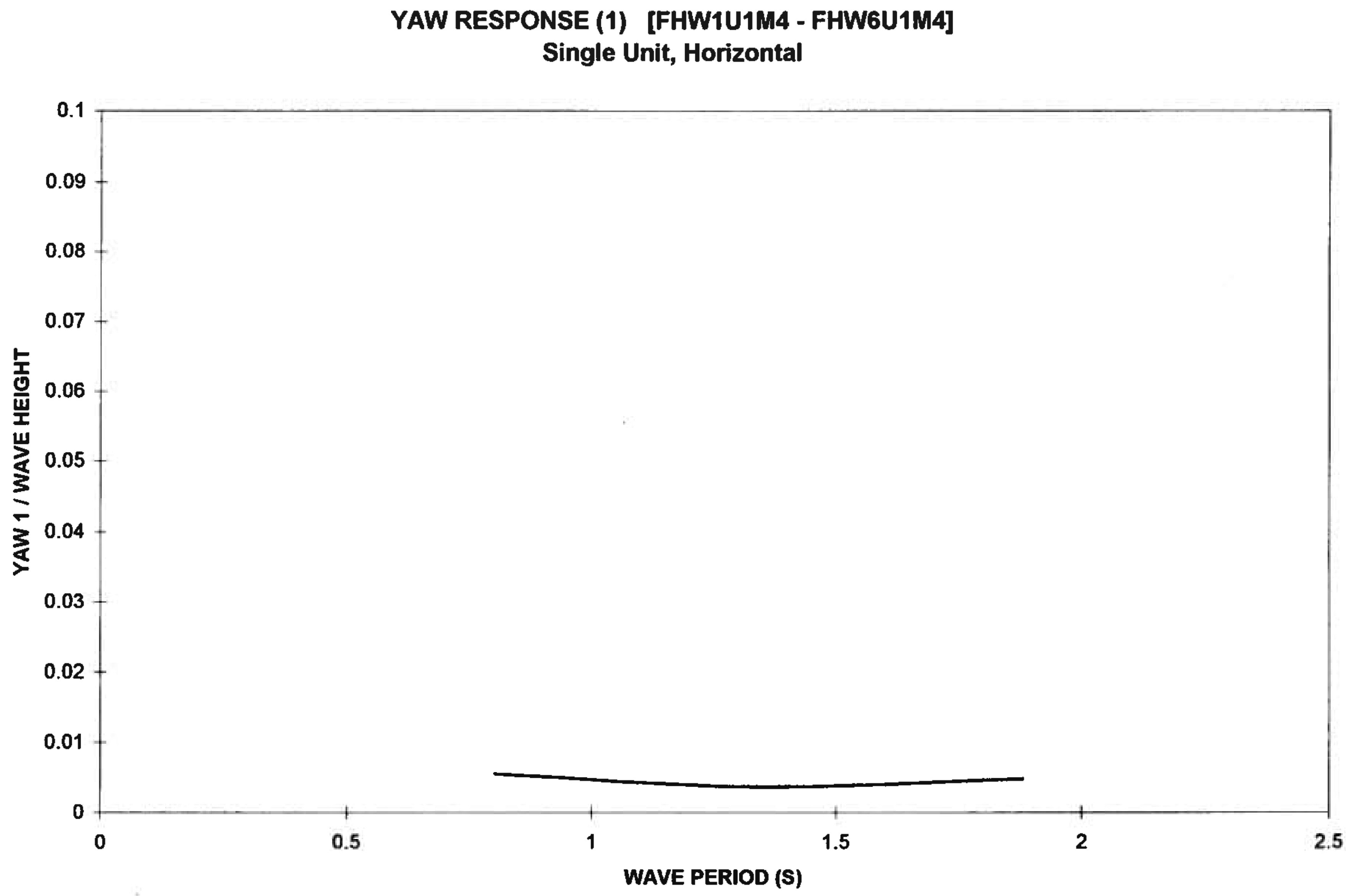
PITCH RESPONSE (2) [FQW1U3M4 - FQW9U3M4]
Four Unit, Horizontal, Quartering

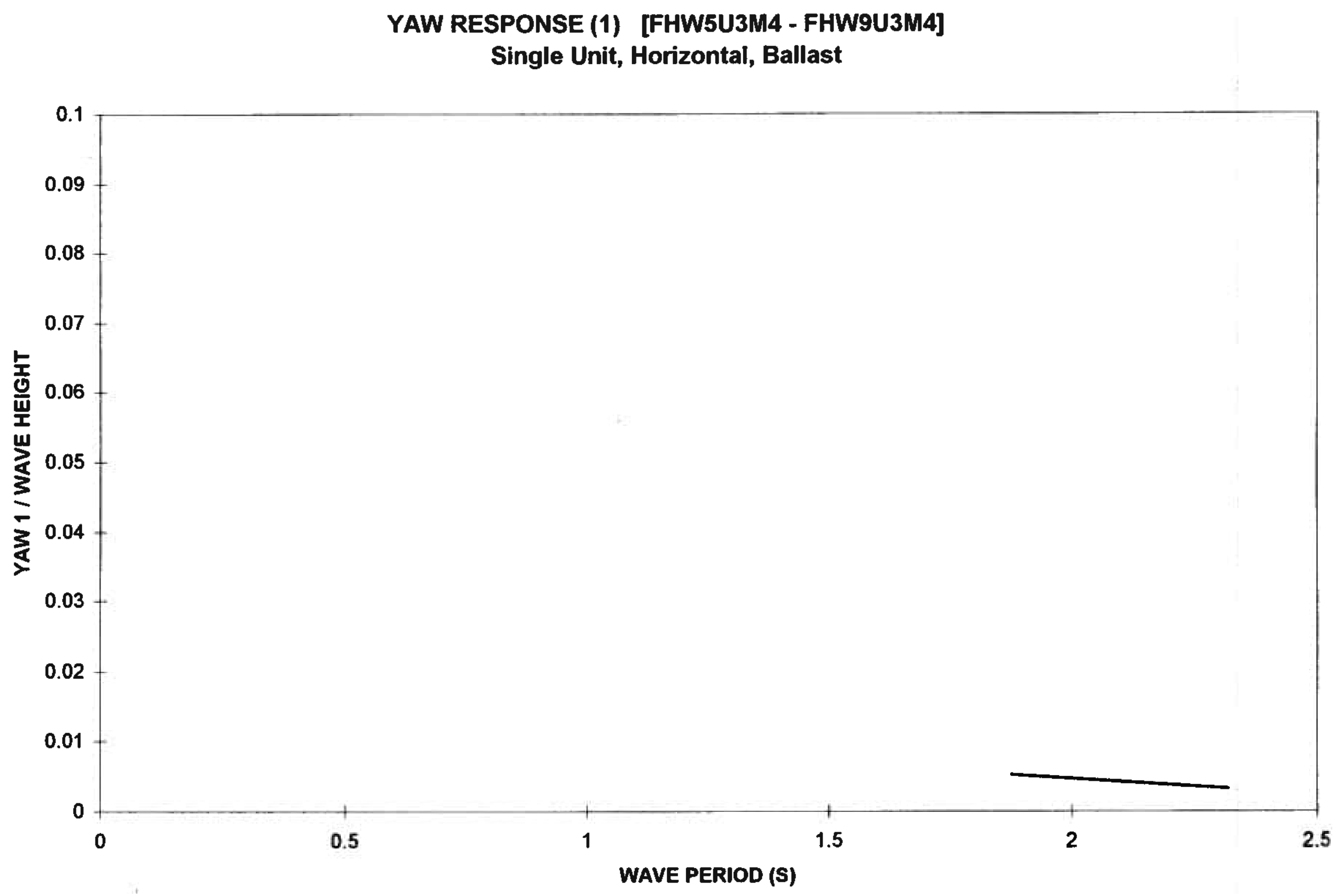


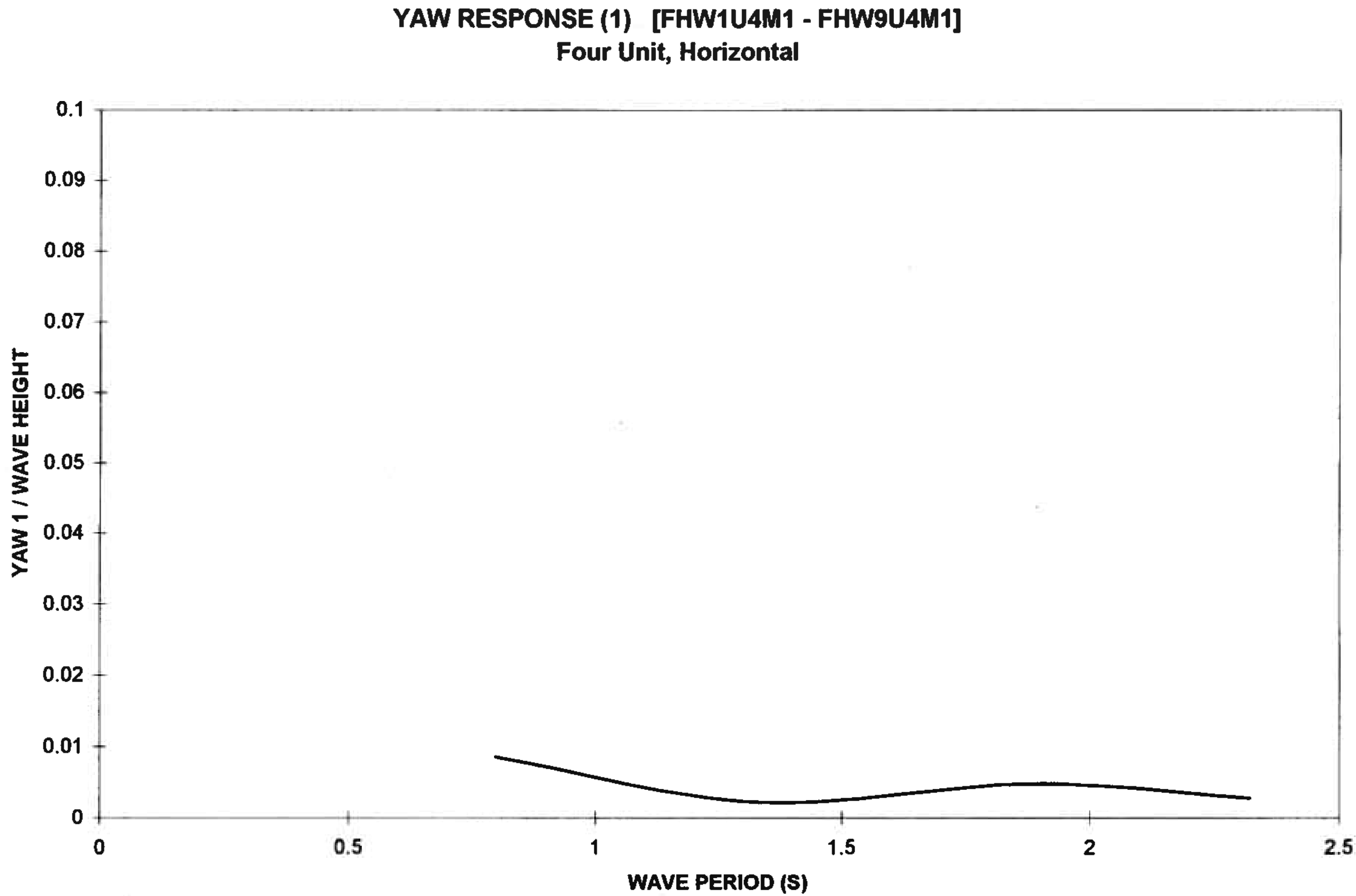

YAW RESPONSE (1) [FHW1U1M1 - FHW6U1M1]
Single Unit, Catenary
YAW 1 / WAVE HEIGHT
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0.5
1
1.5
2
2.5
WAVE PERIOD (S)


YAW RESPONSE (1) [FHW1U1M2 - FHW9U1M2]
Single Unit, Ring
YAW 1 / WAVE HEIGHT
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
0.5
1
1.5
2
2.5
WAVE PERIOD (S)

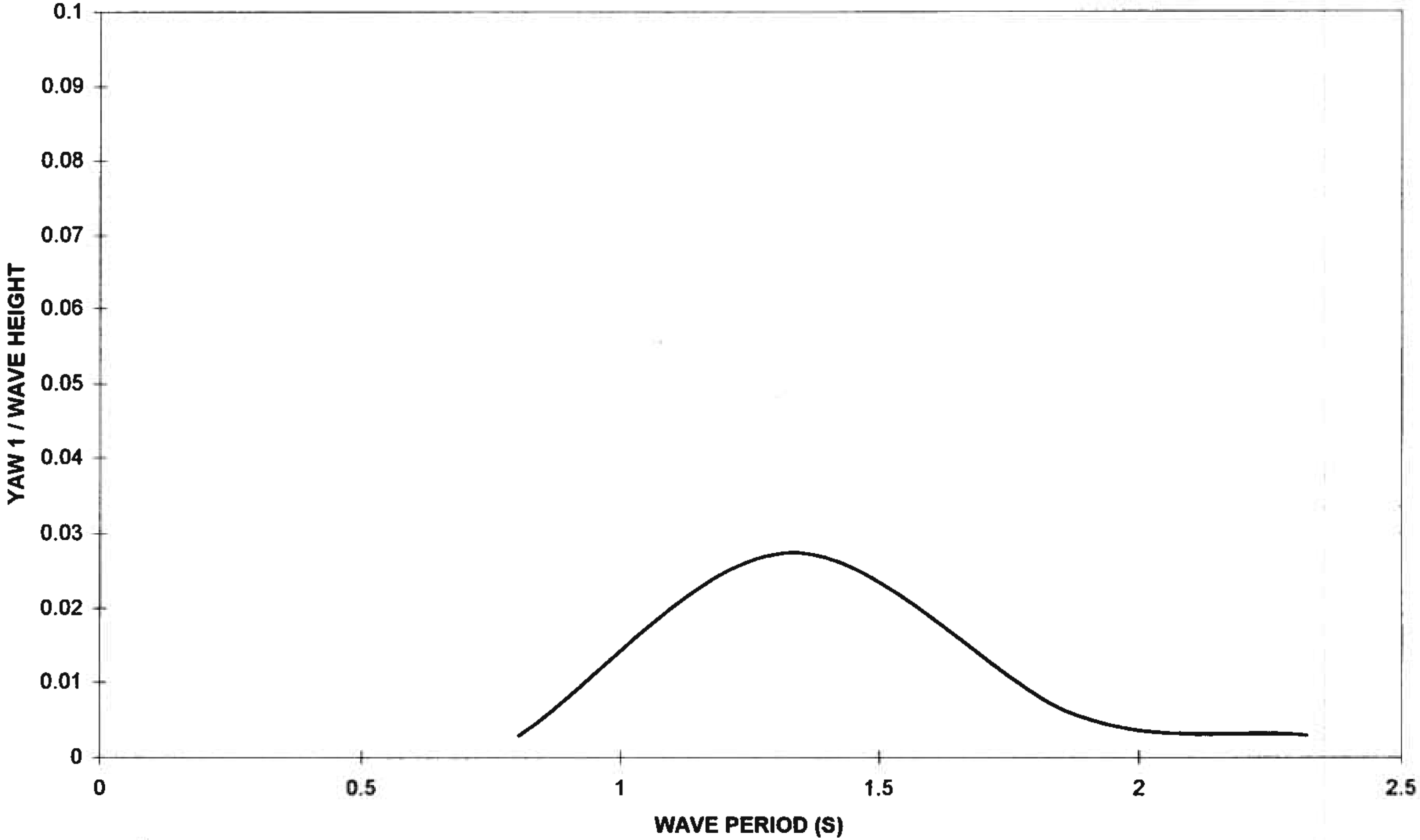

YAW RESPONSE (1) [FHW1U1M3 - FHW9U1M3]
Single Unit, Basket
YAW 1 / WAVE HEIGHT
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0.5
1
1.5
2
2.5
PERIOD (S)


YAW RESPONSE (1) [FHW1U1M4 - FHW6U1M4]
Single Unit, Horizontal
YAW 1 / WAVE HEIGHT
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0.5
1
1.5
2
2.5
WAVE PERIOD (S)

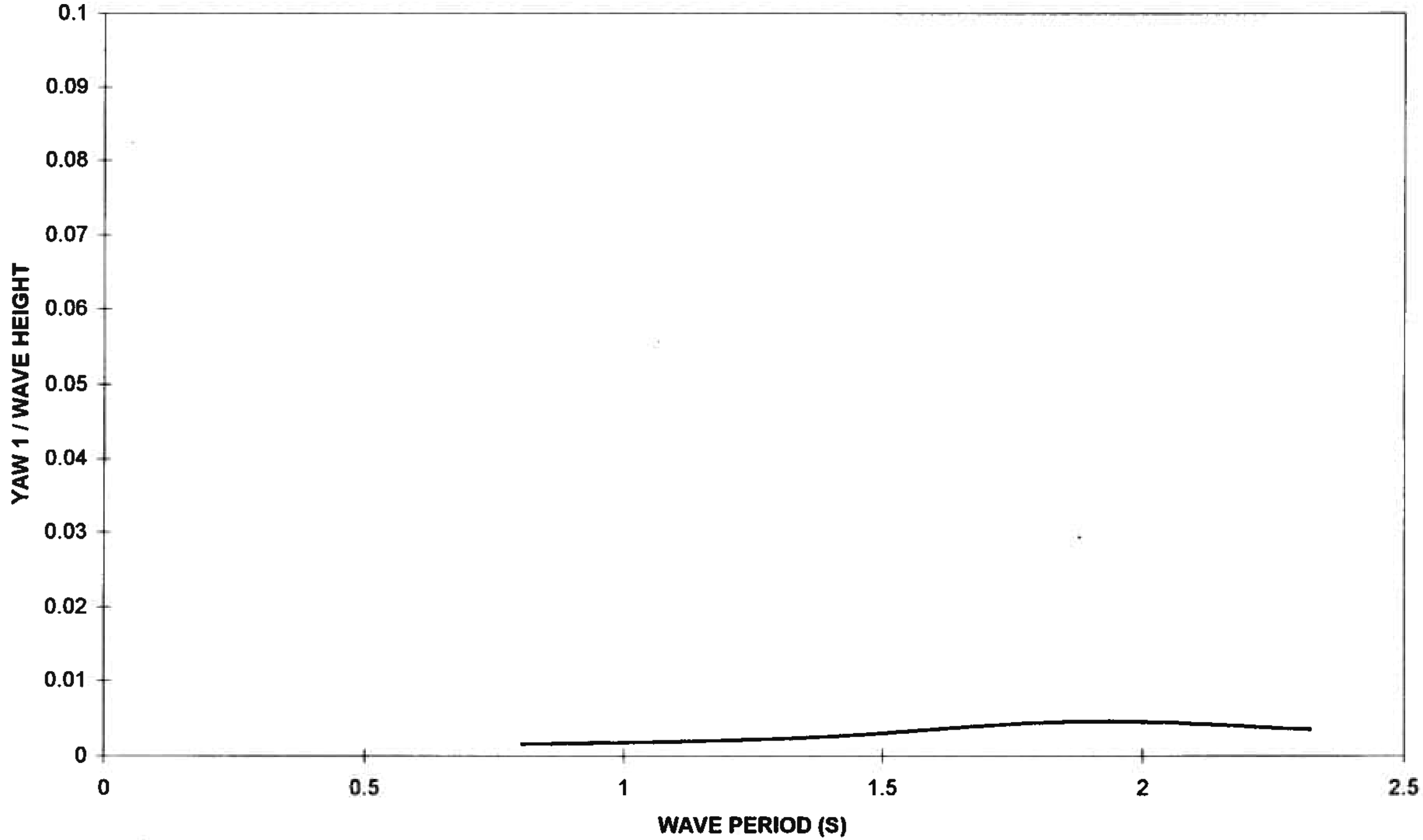

YAW RESPONSE (1) [FHW5U3M4 - FHW9U3M4]
Single Unit, Horizontal, Ballast
YAW 1 / WAVE HEIGHT
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0.5
1
1.5
2
2.5
WAVE PERIOD (S)

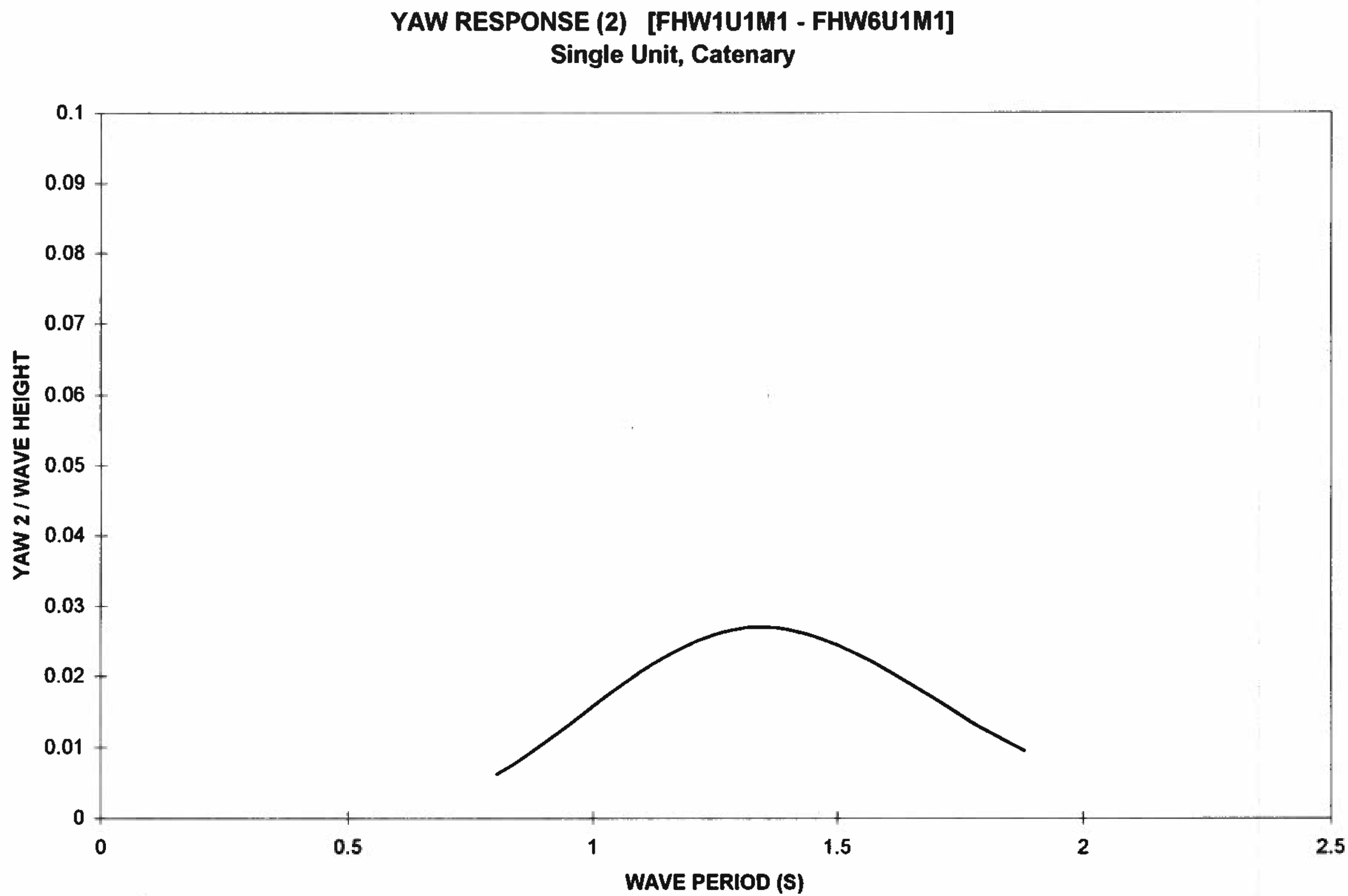

YAW RESPONSE (1) [FHW1U4M1 - FHW9U4M1]
Four Unit, Horizontal
YAW 1 / WAVE HEIGHT
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0.5
1
1.5
2
2.5
WAVE PERIOD (S)

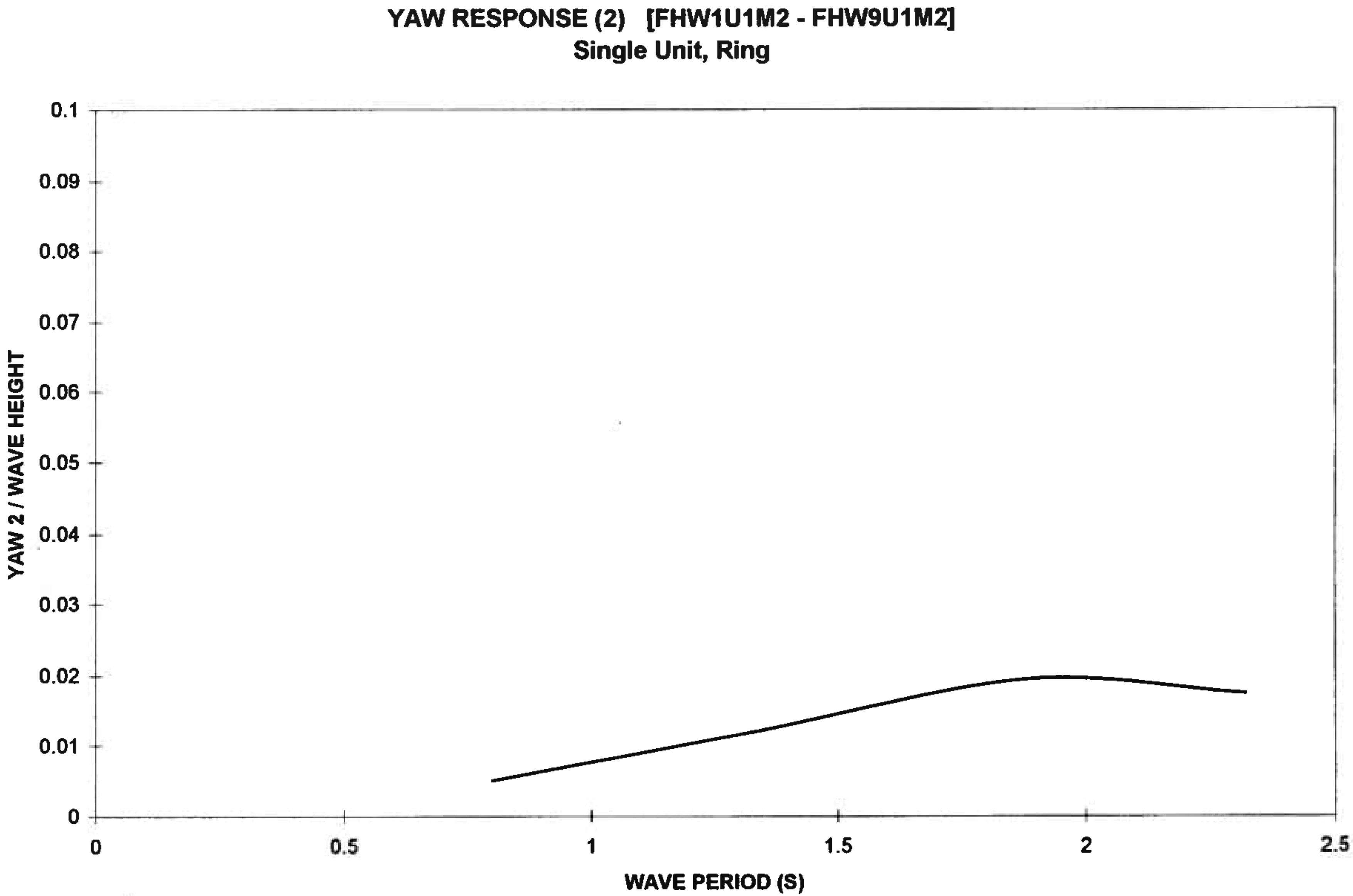
YAW RESPONSE (1) [FHW1U4M2 - FHW9U4M2]
Four Unit, Ring



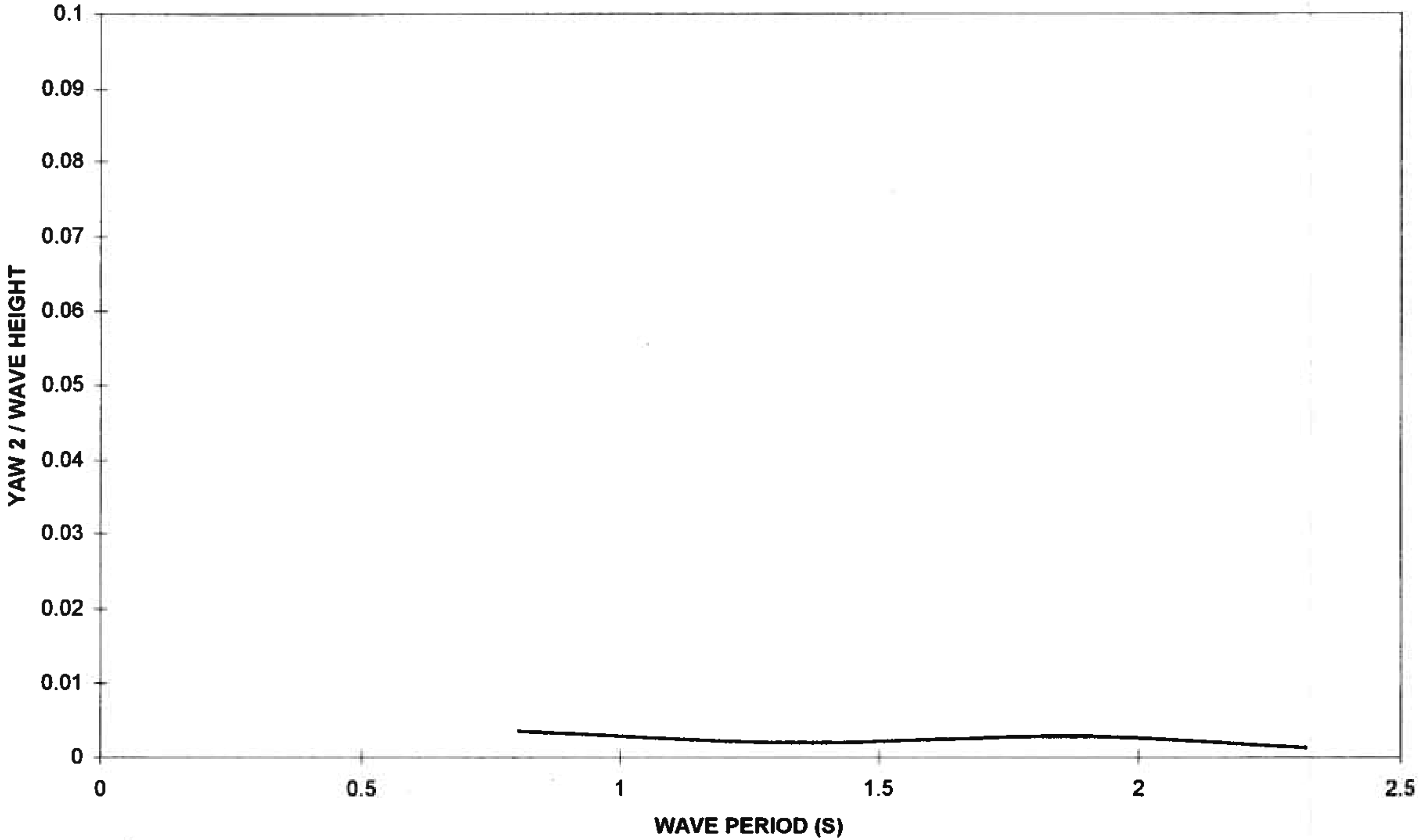
YAW RESPONSE (1) [FQW1U3M4 - FQW9U3M4]
Single Unit, Horizontal, Quartering



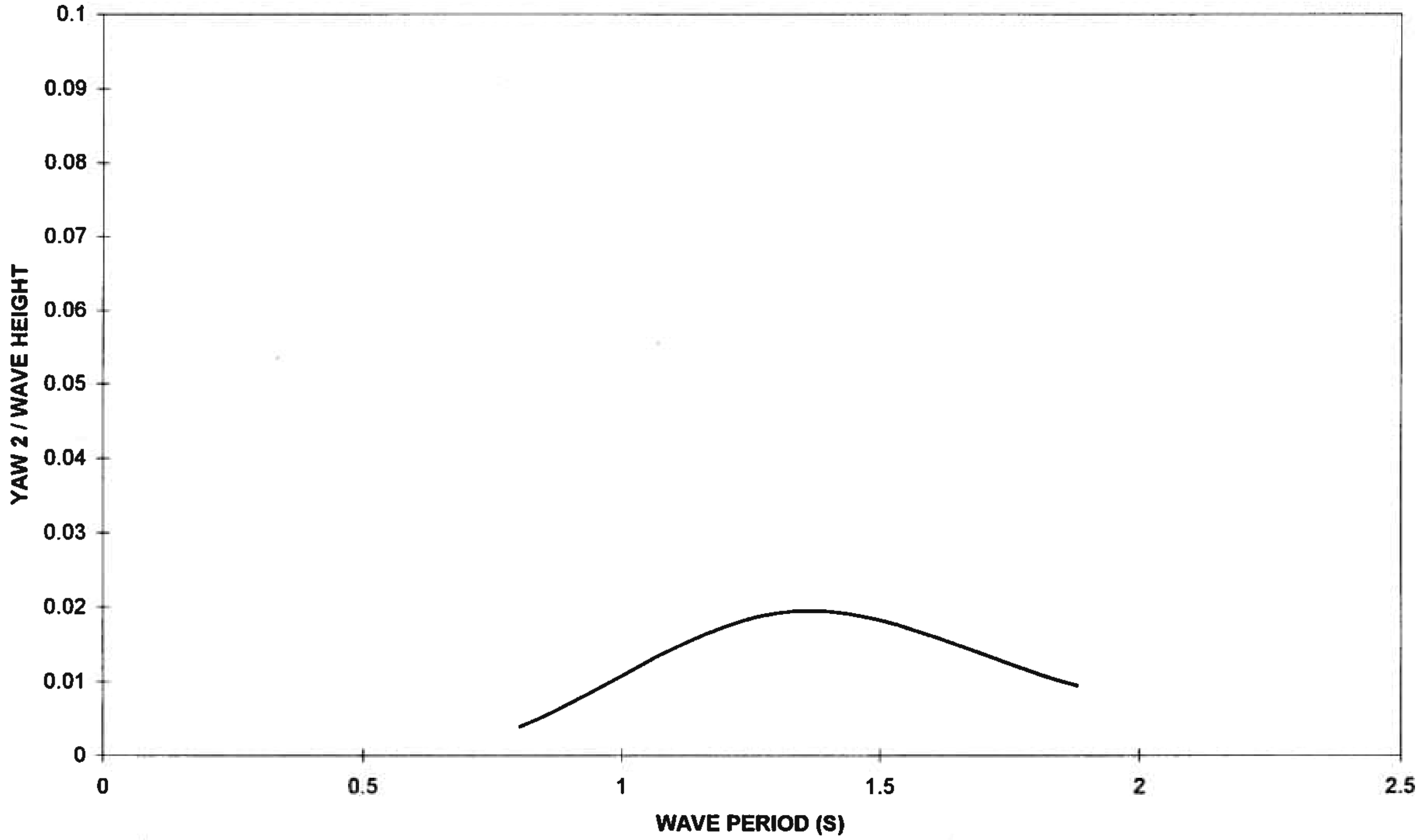

YAW RESPONSE (2) [FHW1U1M1 - FHW6U1M1]
Single Unit, Catenary
YAW 2 / WAVE HEIGHT
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0.5
1
1.5
2
2.5
WAVE PERIOD (S)

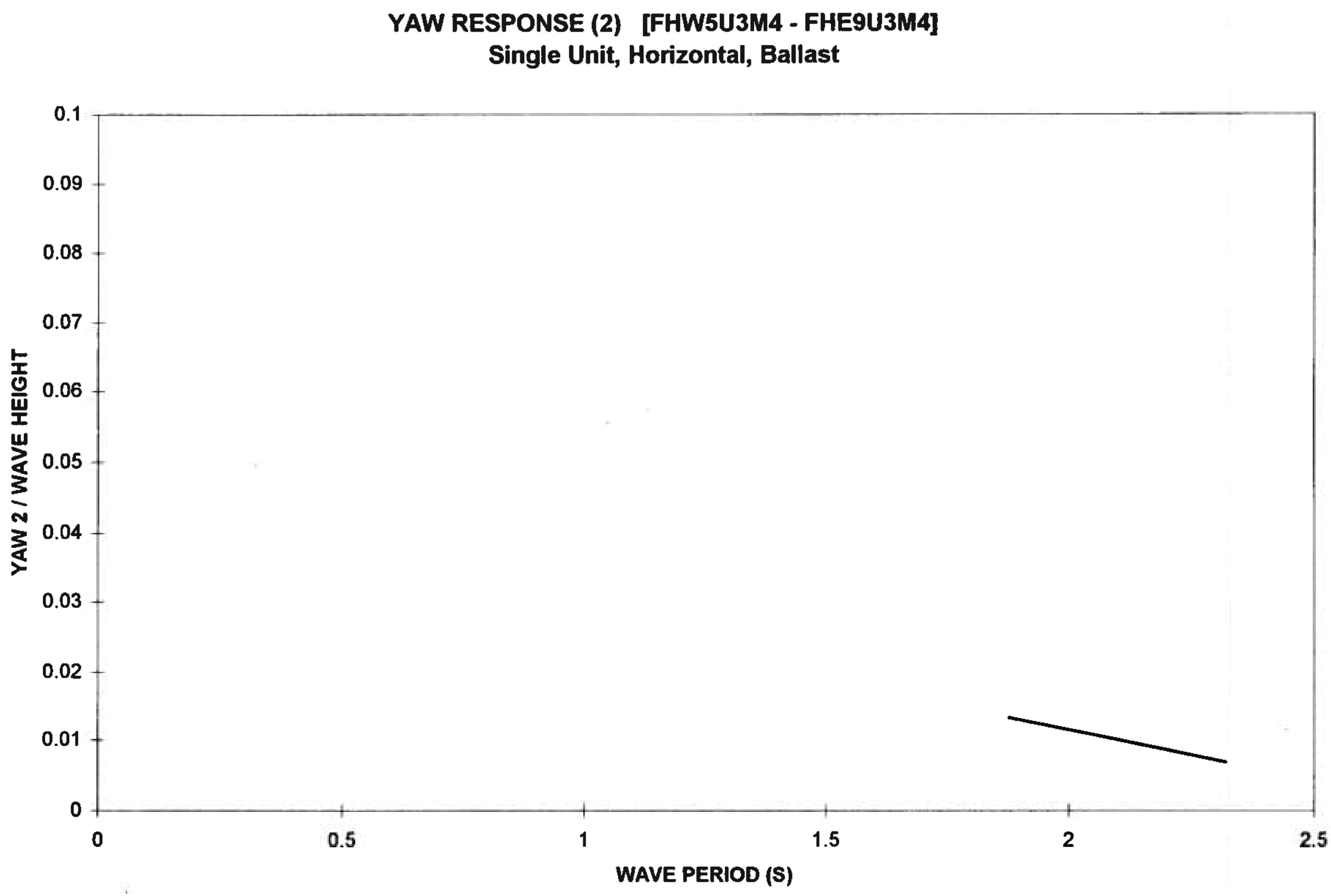

YAW RESPONSE (2) [FHW1U1M2 - FHW9U1M2]
Single Unit, Ring
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
YAW 2 / WAVE HEIGHT
0
0.5
1
1.5
2
2.5
WAVE PERIOD (S)

YAW RESPONSE (2) [FHW1U1M3 - FHW9U1M3]
Single Unit, Basket

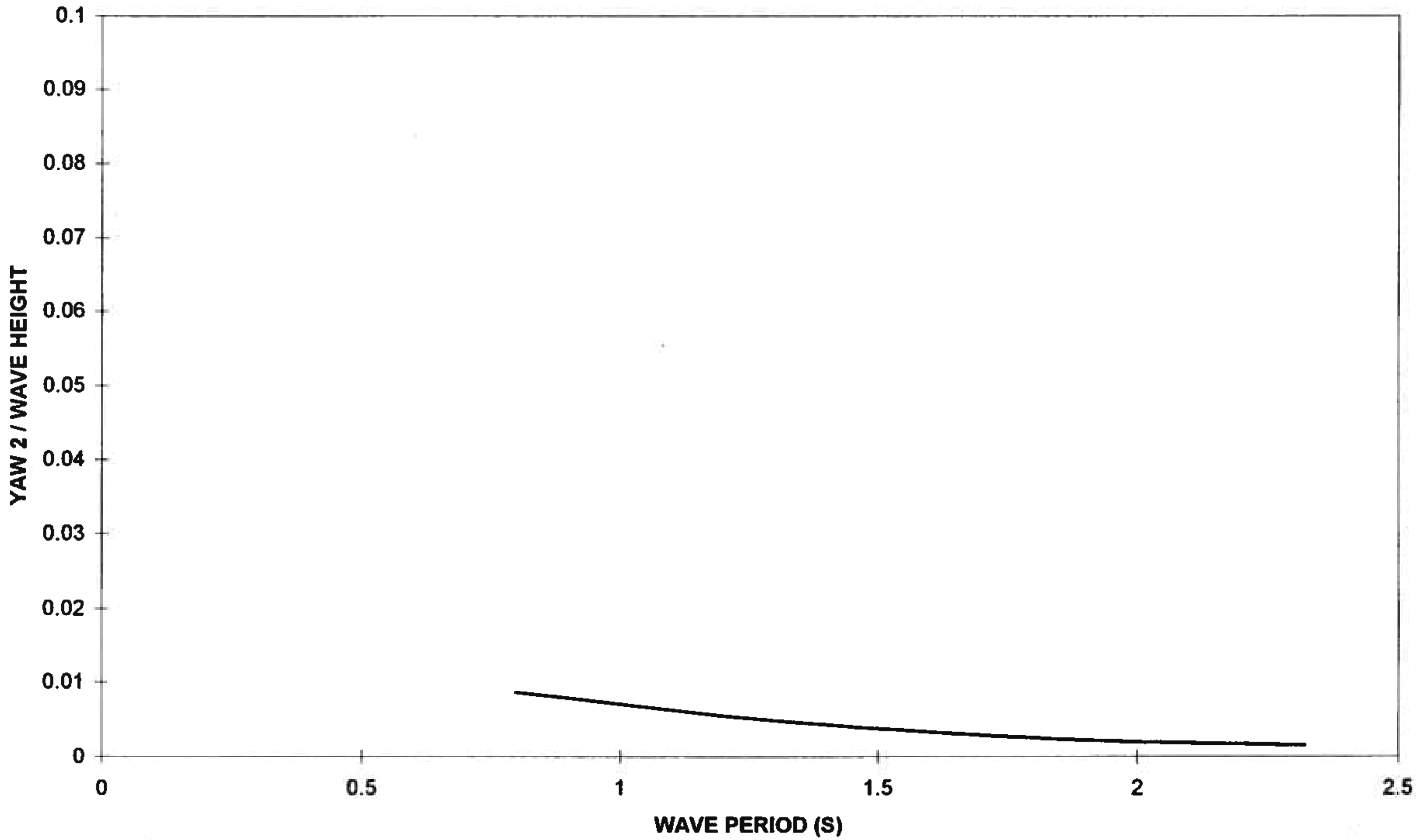


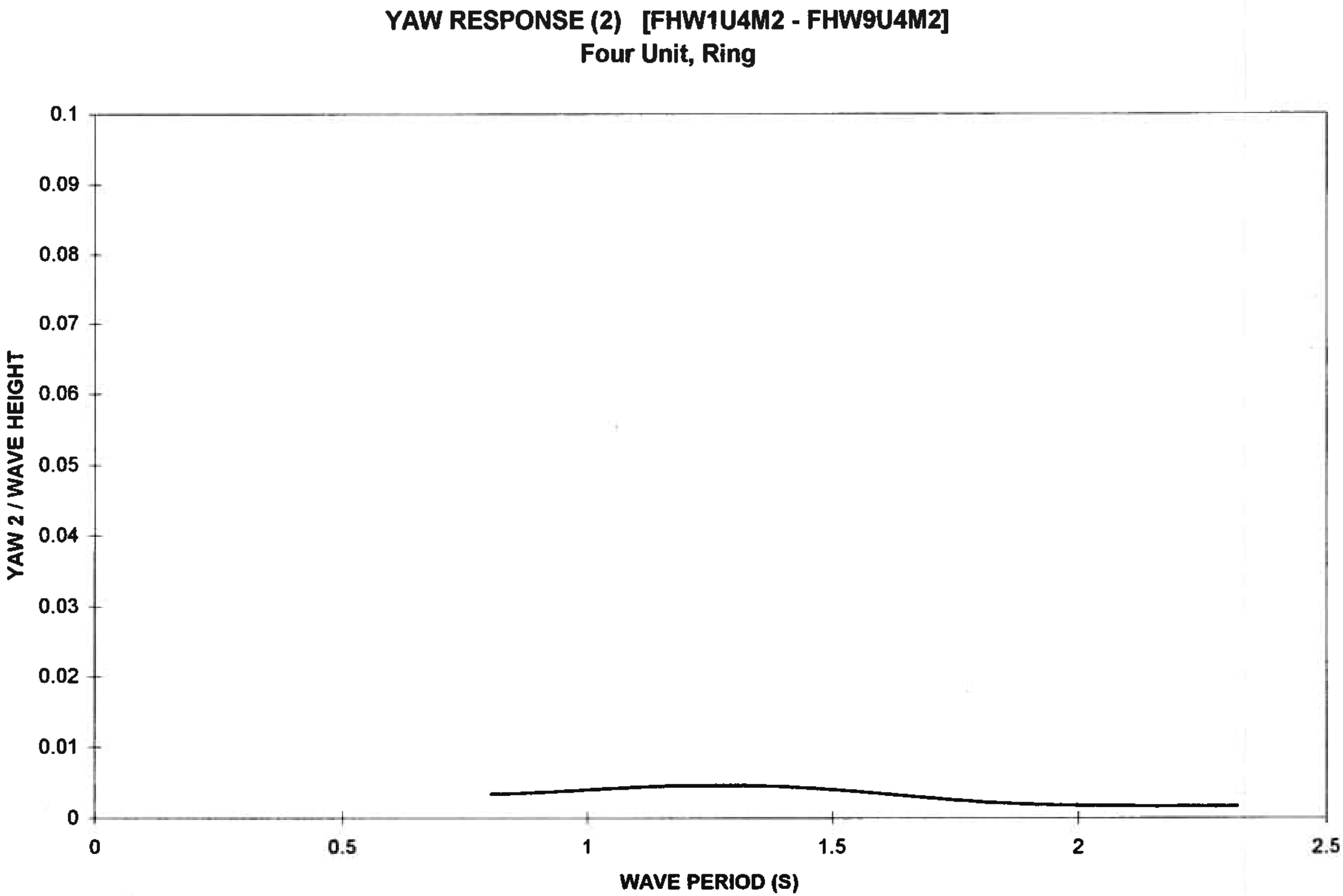
YAW RESPONSE (2) [FHW1U1M4 - FHW6U1M4]
Single Unit, Horizontal




YAW RESPONSE (2) [FHW5U3M4 - FHE9U3M4]
Single Unit, Horizontal, Ballast
YAW 2 / WAVE HEIGHT
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
0.5
1
1.5
2
2.5
WAVE PERIOD (S)

YAW RESPONSE (2) [FHW1U4M1 - FHW9U4M1]
Four Unit, Horizontal




YAW RESPONSE (2) [FHW1U4M2 - FHW9U4M2]
Four Unit, Ring
YAW 2 / WAVE HEIGHT
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
0.5
1
1.5
2
2.5
WAVE PERIOD (S)

YAW RESPONSE (2) [FQW1U3M4 - FQW9U3M4]
Four Unit, Horizontal, Quartering