Simulation and Validation of Piston Type Wave Maker by CFD

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Abstract

Earlier days, experimental verifications / validations are done for new ship design / offshore structure in towing tank and now it has been done at wave maker where the realistic sea state can be created. Practically to create the sea state in the experimental tank is more complicated and it is expensive. A Reynolds Averaged Navier Strokes Equation (RANSE) based model is presented to analysis the wave maker. Piston type wave maker is identified to generate the small wave. Generated waves compared with theoretical wave maker theory and it is agree well. Dependency was carried out for time period, stroke length and water height. Force on the piston was studied for different cases and it was suggested that piston type wave maker should be used for lesser water height where the small wave can be generated. As a conclusion of the present research, it is confirmed that piston type wave maker can be simulated by computational fluid dynamics (CFD) software and the regular waves can be generated for different wave amplitude & wavelength. Over all this simulation can replace the piston type wave maker for the regular wave.

Keywords: wave maker, piston type, seakeeping, numerical analysis, CFD.

Nomenclature

Ap = piston stroke
Aw = wave amplitude
H = wave amplitude
S = stroke length
x, y, z = Cartesian co-ordinate system
u, v, w = Velocity vector
η = Wave elevation
hw = Water height
t = Time period

Subscripts
p = piston
w = wave

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Introduction

In marine engineering field, due to the development of technology and computation power, ship or offshore structure problems are solved and analyzed by developed computational program. Though the numerical results are validated and compared with experimental results for particular model, it is unavoidable to go for experimental confirmation for any new design or operation. In experimental setup, suitable waves are generated to keep the model in physical sea state to predict the reliable seakeeping information. Most of the institute has their own experimental wave maker tank [1-4] and there are many researchers working with numerical wave analysis [5-7]. Now a day's efforts are being spent for experimental techniques to get the accurate prediction of experimental results. In experimental technique, the primary step is to generate the required wave and simulate the sea state in the tank.

Generally, there three kinds of wave makers are used for the wave generation, which are piston type, plunger type and flap type. Flap type makers are used to generate high amplitude wave and sufficient water depth can be maintained to do model test. Similarly in plunger type wave makers are used to do generate the high amplitude wave, which are used in many institute / laboratories. Piston type maker is used mainly for the study of wave characteristics and analysis of marine model.

Understanding the importance of wave maker, here the piston type wave maker is simulated using RANSE model and solved by ANSYS CFX software. Study has been made for the generation of suitable wave and limitations are also studied. Relations between the stroke length, time period and water height are studied. From the simulation, it is concluded that practical piston type wave maker can be simulated by CFD software.

Formulation of Problem

Present analysis, author has identified the piston type wave maker from the various practical wave makers considering the generation of small waves. New tank with practical dimension has been arrived to simulate the wave from the practical wave maker. Initial effort was made to generate the regular wave, which is common for many model tests. Schematic diagram of the wave maker is shown in Fig: 1, which includes the piston, end wall, beach, side wall, tank top and tank bottom. In any wave maker, tank will have suitable wave damping at the end of the tank to damp the wave and avoid the reflection from the end wall. Here the beach was introduced to damp the waves. If suitable beach is not provided then the reflection can change the behavior of the wave and result also will be disturbed. Present analysis, slope ratio of beach height to beach length was taken as 1:3.0, 1:4.5 & 1:6.0 and its effect has been studied & verified on wave damping. In practical usage, there are different kind of wave damping is used.

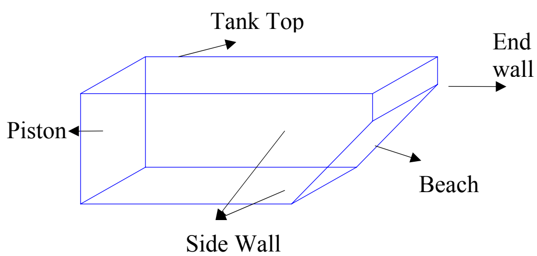

Figure 1: Diagram of Wave Maker

Fig: 2 show the nomenclature that has been used in the analysis and it is marked in the tank profile view with wave to understand easily. Though the piston motion is shown as in a horizontal path but it will have the sinusoidal velocity.

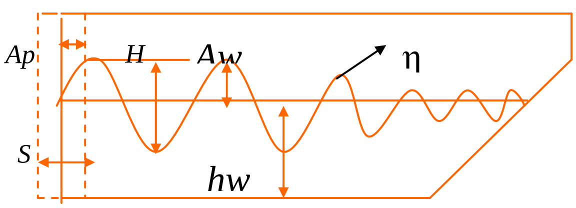

Figure 2: Tank Profile view and Wave Elevation

In the piston type wave maker, to generate the sinusoidal wave with small amplitude, the relationship between the stroke, wave height and water height are given [8,1] by wave maker theory as

$$S = H\frac{\sinh 2kh + 2kh}{2(\cosh 2kh - 1)}$$

Where S is the stroke length, *H* is the wave height, and *h* is the water height. This has been derived from the linear wave maker theory. Here *S* is equation to double the amplitude of *Ap*.

Giving suitable stroke length with required linear velocity to the piston, it is possible to generate the wave. It is more complicated to get the relation between each other. Still author has made effort to bring the relation and it will be discussed in the coming section.

CFD Simulations

This is the most important in the CFD where we need to implement the exact modeling to display and analyze the physical objects. We have used ANYSY CFX software for the modeling and analysis. Fig: 3 show the meshing of the wave maker. Meshing is taken care well in the modeling because density of the mesh also can effect the result to some extend. Near water level the meshing density was quite high to predict the maximum accuracy and it can be visualized in the Fig: 3.

For the piston, sinusoidal motion was given by the relation $Ap\sin(\omega t)$ where *Ap* is the piston stroke and ω is the angular velocity.

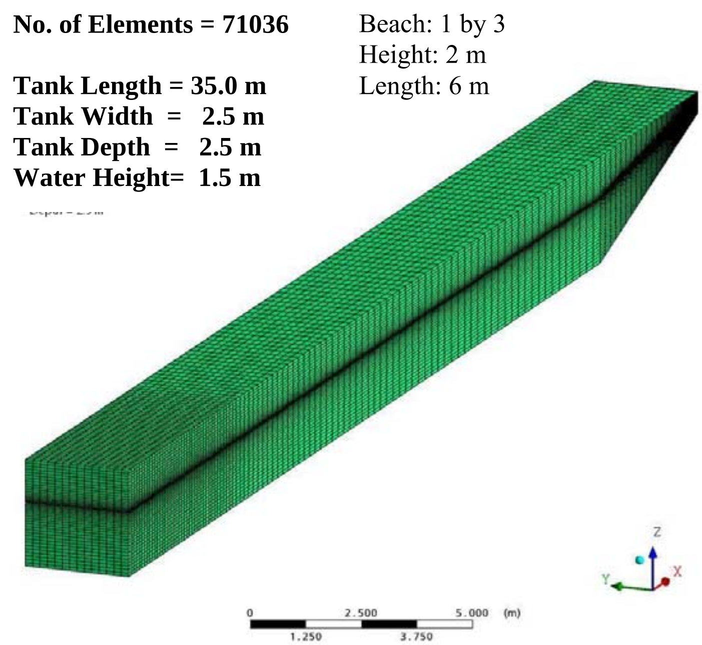

Figure 3: Computational Grid used for CFD Simulation

Table: 1 show the data which has been used for the generation of wave for the relation of changing water height, time period and piston stroke.

hw [m]	*t* [s]	*Ap/t* [m/s]	*Ap* [m]
0.10 0.25 0.50 0.75 1.00 1.25	1.5 2.0 2.5 4.0 4.5 5.0	0.0625	0.10 0.15 0.20

Table 1: Data used for Dependency Study.

RESULTS AND DISCUSSIONS:

Grid Density Evaluation

It is necessary for numerical analysis to evaluate the accuracy of result by changing the density of elements for the particular modeling. Table 2 shows the element type and density of mesh used for the evaluation.

Cases:	Type:	No. of Elements:
Case1	Coarse	5,115
Case2	Normal	9,246
Case3	Fine	15,921

Table 2: Element Types and Number of Elements.

Wave elevation has been plotted in Fig: 4 for three cases and the difference is not remarkable. Therefore our further simulations are done by normal mesh and it is extended for three dimensional modeling.

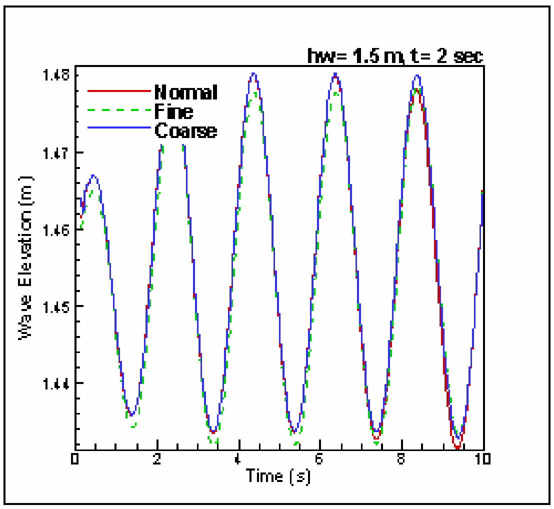

Figure 4: Wave Elevation for different Mesh Types and Mesh Density

Turbulence Model Study

Study is made to select the suitable turbulence model for the present analysis. We have taken three model i.e., Laminar, k-ε, SST and wave elevation results are shown in Fig:5. From the graph, it is understood that the difference is not remarkable for the three-turbulence model.

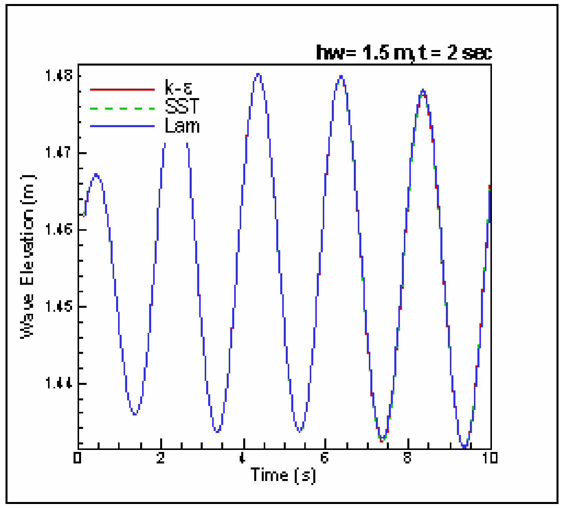

Figure 5: Wave Elevation for Different Turbulence Model

Validation of CFD Wave Maker

From the wave maker theory, practical wave maker was compared and it is published by Patrick J Hudson et al [1]. We have taken that drawing as a reference and our predicted CFD result is plotted in the same drawing, Fig: 6. In that figure, it is noted that wave maker theory and experiment show some difference when the *kh* relation become higher and it leads up to 20% difference. But the CFD results are plotted by red circle, which shows that it has good agreement with wave maker theory. That means CFD can produce better wave for the analysis of any model with suitable wave.

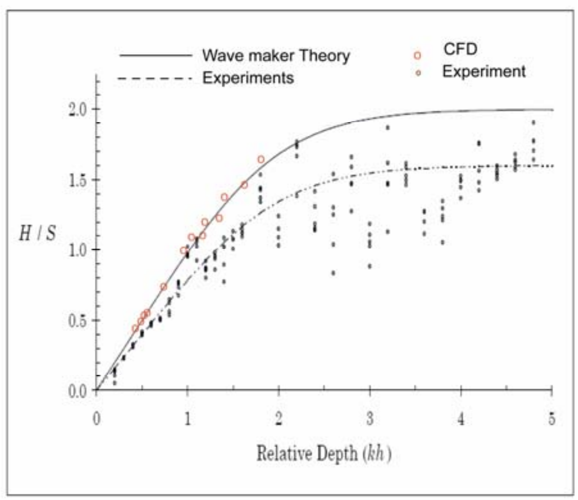

Figure 6: Comparison of Wave Maker Theory, Experiment and CFD

Stroke Dependency

Effort is made to study the dependency of piston stroke i.e., changing only the piston stroke for particular time period and water height. Refer Fig: 7 & 8, it was found that wave height is increasing when the piston stroke increases at the same time the wavelength is also getting increase. Wave elevation is shown in Fig: 13 for the different piston stroke with respect to time.

Water Height Dependency

In this section, we have changed the water height for particular piston stroke and time period. This has been plotted in the Fig: 9 & 10. Here the wavelength increases when we increase the water depth. In the wave height graph, it was found that it is getting increase but after certain water depth, there is a saturation phenomena occurs. Few cases, when we reduce the water level, the waves are not generated. Wave elevation plot is shown in Fig: 15 and it is noticed that wave height is increased when the water height is increased and this is measured at particular point.

Time Dependency

In this section, the piston stroke duration is keep changing while the water height and the piston stroke is maintained same. Here the quite different phenomenon was detected. Fig: 11 show the wave height plot for the different time period, it is noticed that peak value is occurred for a particular time period. Then it comes down to low. That means every water height particular peak value of wave height can be achieved for particular time period. Fig: 12 show the wavelength graph while changing the time. It is found that wave length increases when the time duration is increasing. Wave elevation is shown in Fig: 14 where the wave amplitude is getting increase when the time duration is increased but it will comes down after reaching the peak and this is illustrated in Fig: 11. Wave profile for the different time duration is shown in fig: 18. The wave elevation and wave length can be easily viewed for different time duration.

Pressure and Forces

Pressure and forces are estimated for different case during the above dependency, it was found that water pressure and forces are directly proportional to the piston water surface area. Therefore for higher water height, piston type can not be used because very high load. It is also concluded that piston can be used for a small wave generation.

Piston at Constant Velocity

It is decided to verify the behavior of the wave when changing the piston stroke but the velocity is kept remains same. Because some time, it is very difficult to produce the wave for the combination of piston stroke, time period. Keeping the same velocity and for the different piston strokes, the waves are generated. It is found that keeping the constant velocity can generate nice wave. This property is shown in fig: 16.

Wave Damping

It is understand that any wave maker will have wave damping at the end of the tank but the kind damping will be different depends on the requirements. Here we have made effort to damp the wave by introducing beach at the end. Beach height and length ratio was tried for three cases like 1:3, 1:4.5 and 1:6. Waves are generated for with out beach and with beach for three options. It is found the wave can be damped by introducing suitable beach, please refer Fig: 17. To verify the damping of wave, simulation was done for 50 second time period because the wave reach the end wall by 10 seconds. If the piston is working higher than 10 second then the reflection should come in the moving wave. It was found that wave disturbance occur near end of tank and it is not disturbed the other area. Fig 19 a) shows the wave near the wave maker at particular location. Similarly the wave elevation away from the wave maker is plotted for different location up to end wall. It is plotted in Fig 19, b) - e).

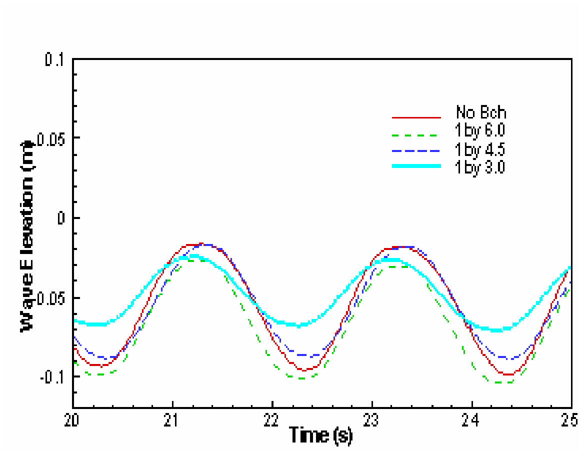

Figure 17: Wave Damping at Beach

Though the maximum damping occurs when the slope is high and it is also noticed that higher amplitude of wave will be generated initially because of high angle of slope. It is suggested that low slope can give damping in the smooth manner i.e., without making higher wave amplitude due to beach disturbance.

Conclusions

Piston type wave maker designed and simulated well by CFD. It is verified with experimental data and wave maker theory data. It is found that CFD data's shows good agreement with experiment as well as wave maker theory. It is also suggested to use the piston type for the generation of small wave due to heavy loads on piston. It is concluded that simulations were done with good accuracy and can be used for model analysis with regular wave.

Acknowledgements

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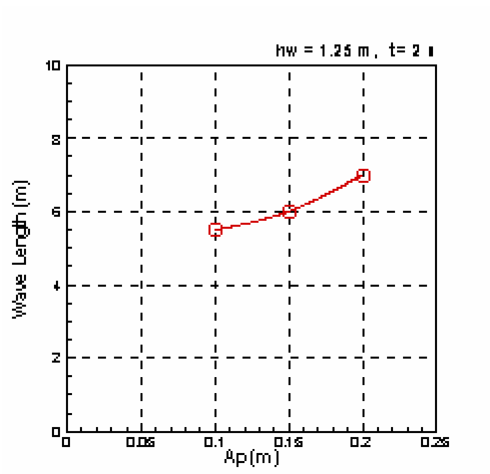

Figure 7: Wave Length Vs Piston Stroke

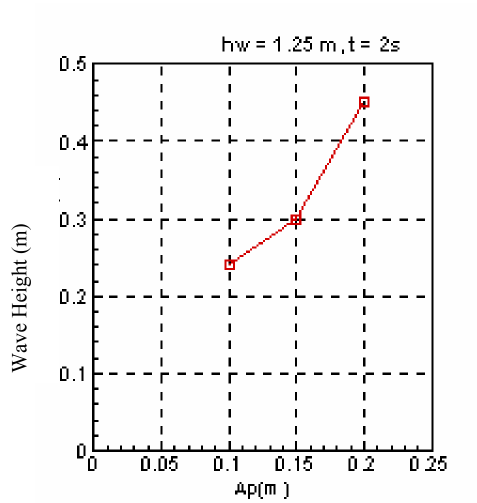

Figure 8: Wave Height Vs Piston Stroke

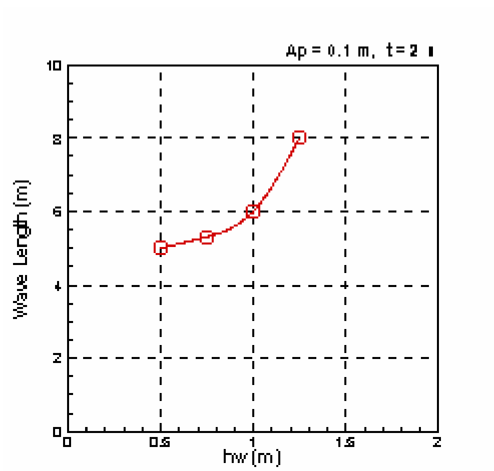

Figure 9: Wave Length Vs Water Height

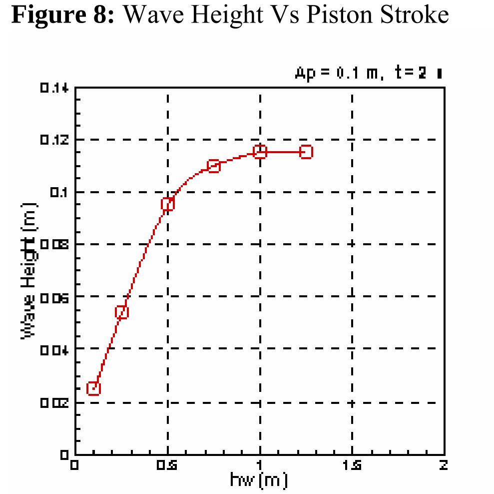

Figure 10: Wave Height Vs Water Height

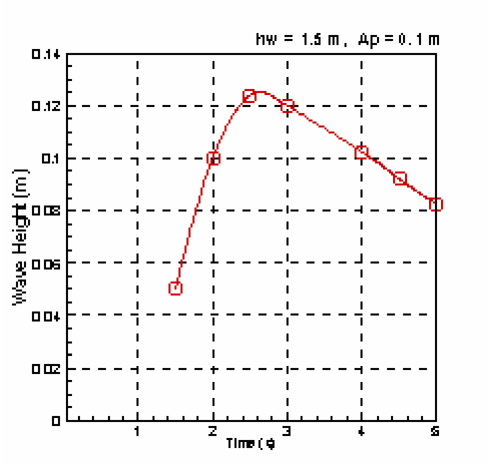

Figure 11: Wave Height Vs Time Period

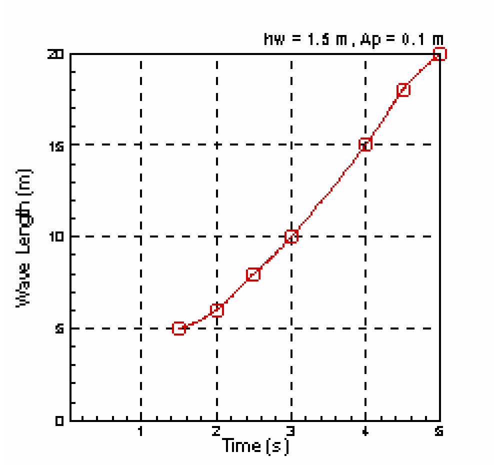

Figure 12: Wave Length Vs Time Period

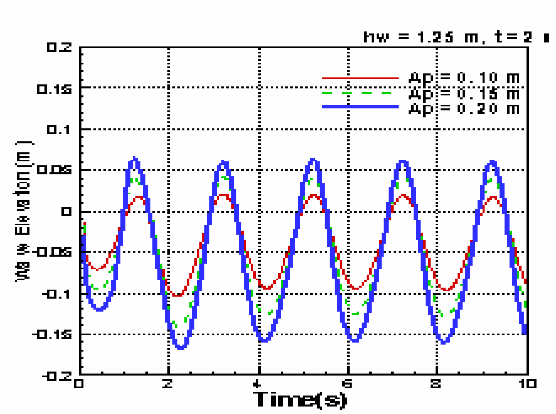

Figure 13: Wave Elevation with Respect to Piston Stroke

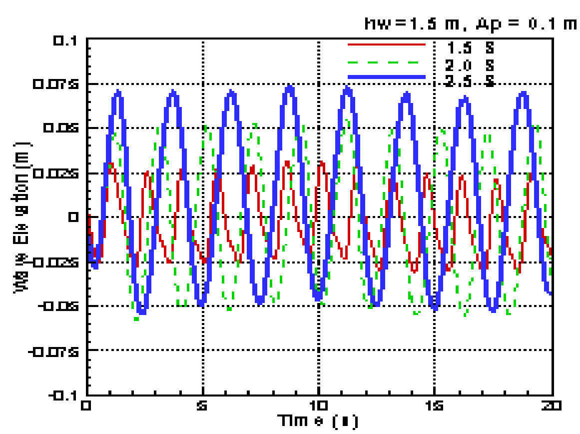

Figure 14: Wave Elevation with respect to Time Period

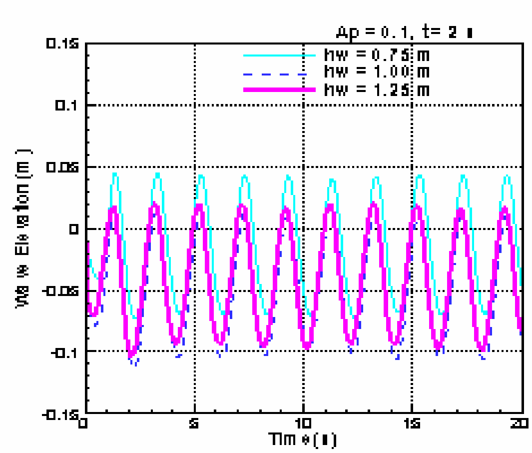

Figure 15: Wave Elevation with Respect to Water Height

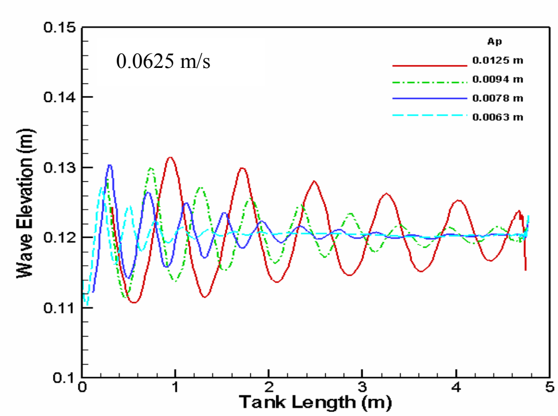

Figure 16: Wave Profile for different Stroke Length for Constant Velocity of Piston

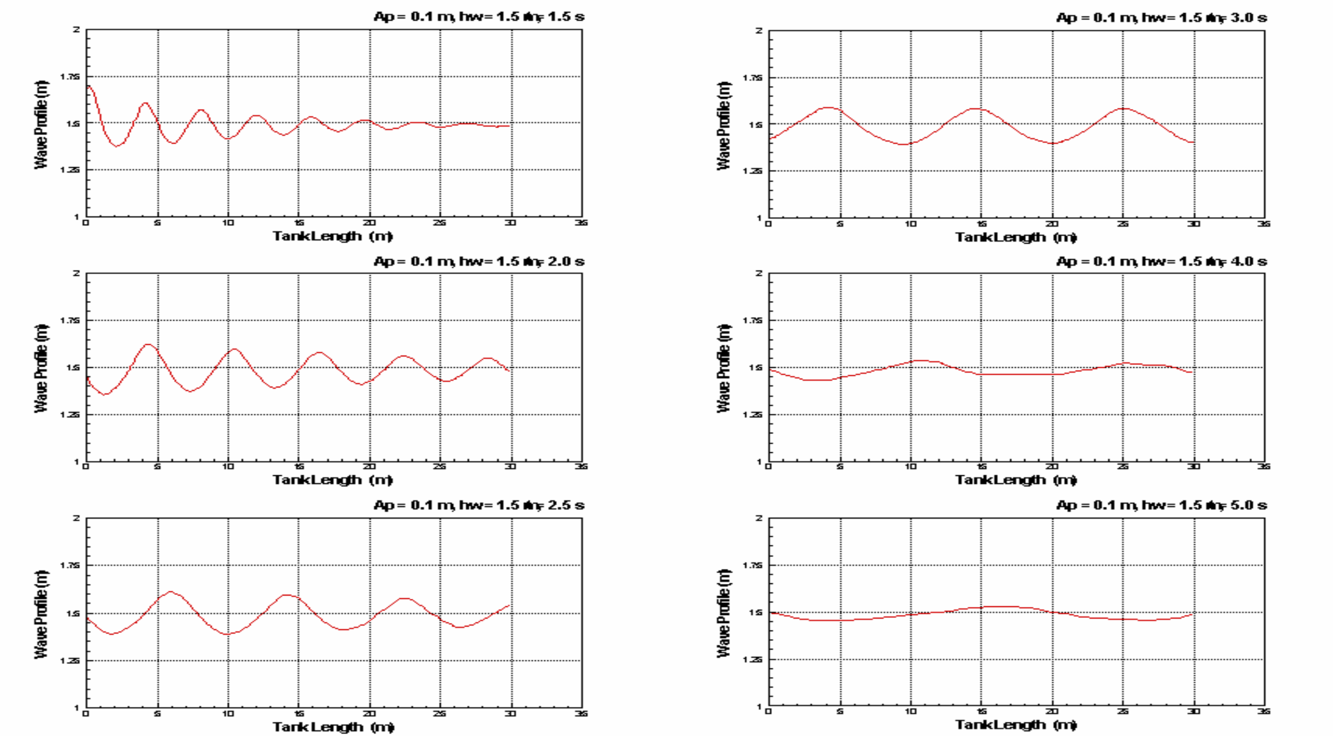

Figure 18: Wave Profile along the Tank for different Stroke Duration

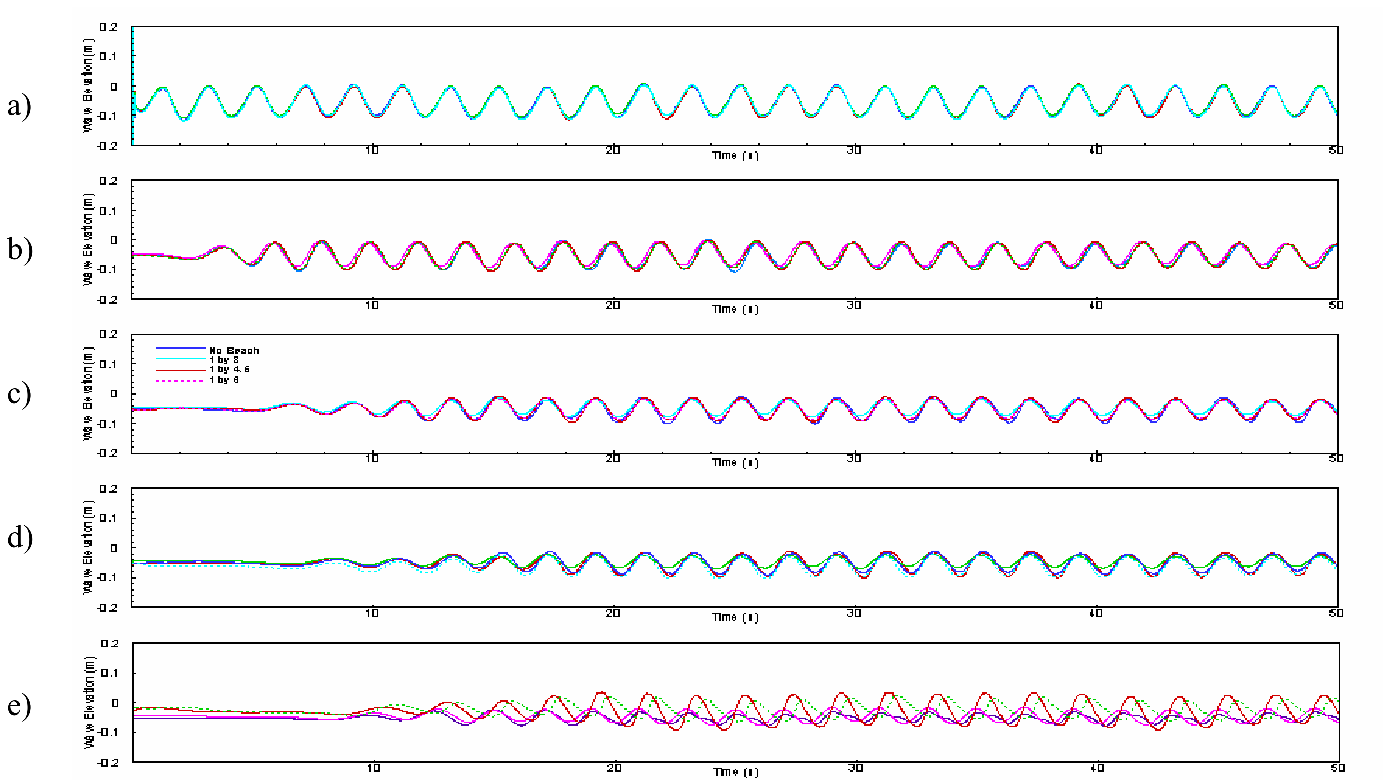

Figure 19: Wave Height Vs Piston Stroke