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Simulation of Irregular Waves by CFD

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***Abstract*—**Wave generation methodology has been developed and validated by simulating wave in CFD. In this analysis, Flap type wave maker has been modeled numerically with wave basin to generate waves for marine experimental analysis. Irregular waves are arrived from the wave spectrum, and this wave has been simulated in CFD. Generated irregular wave has been compared with an analytical wave. Simulated wave has been processed for FFT analysis, and the wave spectrum is validated with original wave spectrum.

***Keywords*—**Numerical wave tank, irregular wave, FFT, wave spectrum

NOMENCLATURE

H_s – significant wave height (m)
T_z – the average zero-up – crossing wave period (s)
ω – circular wave frequency (rad/s)
ζ_{an} – amplitude component (m)
ω_n – circular frequency component (rad/s)
k_n – wave number component (rad/m)
ε_n – random phase angle component (rad)
N – number of points taken for FFT analysis
Δt – time interval taken for FFT analysis (s)
T – irregular wave time taken for FFT analysis (s)
S – Stroke length (m)
Af – Flap motion amplitude (m)
hw – water height (m)
he – effective water height

I. INTRODUCTION

SHIP, offshore structure, marine operations are taken for the model test before going for the construction or execution of the operation. To carry out any experiment, it is expensive and time consuming. Therefore, researcher has started working on numerical development which can support in the preliminary stage of design. Initially potential theory was developed for the regular wave analysis which is based on the 2D strip theory. Here fluid is assumed to be inviscid, irrotational and incompressible. Potential theory was quite improved by considering the 3D based theory like Green function method by Iwashita et al[1] and Rankine panel method by Jensen et al [2] and Iwashita [3]. Simulation of non-linear wave has been studied by Ducrozet [4] which is based on potential theory. Though, potential theory is reliable for the analysis of standard structure and with a regular / irregular wave but the simulation of real sea state and analysis of complicated structure are still in developing stage.

Though potential solver is used for many practical application, viscous solver is being used for marine application by many researchers, Park et al [5]; Dong et al [6]; Taylor et al [7]; Joe Longo et al[8]. In this research, ANSYS CFX has been used as a CFD solver and authors have made an effort to simulate the irregular wave for marine structure analysis. Generally, for the wave generation, three kinds of a mechanism are used in practical like a piston, flap and plunger type , Wang [9]; Tommi Mikkola [10]; Elangovan et al [11]. Generation of regular wave has been simulated by the Flap type wave maker by Anant Lal and M.Elangovan [12], and it was validated with theoretical data.

Developed Methodology for the generation of irregular wave by the CFD. Modeling of a wave maker is explained in details with wave maker tank size requirements. Simulated CFD irregular waves are carried for FFT analysis and the wave spectrum is compared with original wave spectrum.

II. METHODOLOGY -WAVE GENERATION

International Association of Classification Society (IACS, 2000) [13] has recommended the Bretschneider wave spectrum (PM) for the wave data for the design and analysis of ship or offshore structure, which is available in that society website.

$$S_{(\omega)} = \frac{H_s^2}{4\pi}\left(\frac{2\pi}{T_z}\right)^4 \omega^{-5}\cdot\exp\left(-\frac{1}{\pi}\left(\frac{2\pi}{T_z}\right)^4 \omega^{-4}\right) \quad (1)$$

IACS has provided the probability sea states table and the maximum number of wave occurrence is noted 7738. For this occurrence, the significant wave height (H_s), 1.5 and the wave period (T_z), 7.5 are noted from that table. Now the wave spectrum shall be generated for the particular H_s and T_z , Dean [14]; Journee[15]; Daoud[16], Ming [17]. It is the requirements to extract the regular wave keeping the frequency interval same and shall be plotted as frequency versus amplitude. Equation for the extraction of regular wave (Journee , 2001) is written as.

$$S_{(\omega n)}d\omega = \frac{1}{2}\zeta_{an}^2 \quad (2)$$

Researcher can set the frequency interval and fix the range of frequency. Analytical way of generation of irregular from the regular wave is done by using the given equation.

$$\zeta(t) = \sum_{n=1}^{N}\zeta_{an}\cos(k_n x - \omega_n t + \varepsilon_n) \quad (3)$$

Keeping the different phase angle for each regular wave, irregular wave can be generated analytically by adding the entire regular wave. The process of a wave generation

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methodology flow chart is developed and wave spectrum analysis also shown in figure (Fig. 1).

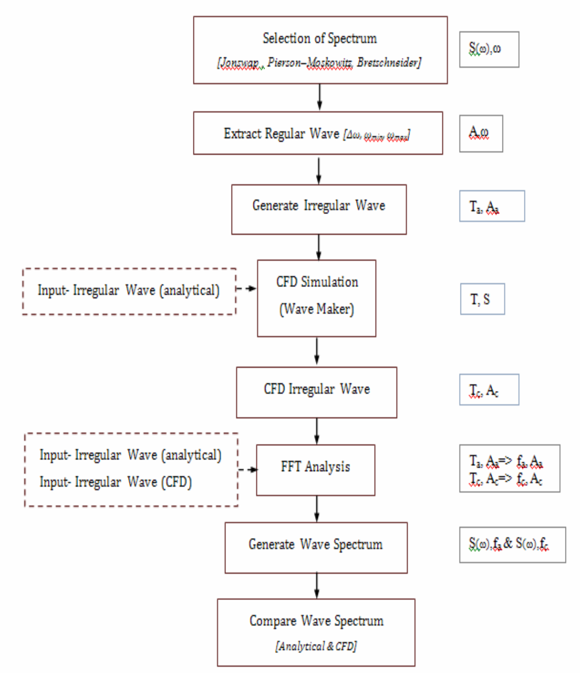

Fig..1 Methodology of Irregular Wave Generation Analysis

Analytically generated wave will be used as an input to the CFD wave maker. In CFD, stroke length with respect to the time is given in the form of analytical irregular wave. Now irregular wave can be measured in numerical wave tank and can be compared with analytical wave. In addition to the comparison of irregular wave, FFT analysis shall be carried out for analytical irregular wave and CFD irregular wave. FFT will be carried out for the irregular waves and then spectrum will be generated to validate the generation of irregular wave.

III. Numerical Modeling

IN the previous section, methodology was discussed to generate the wave analytically as well as computationally. Here we will discuss about the modeling of the CFD wave maker. Experimental tank size was selected from the existing practical wave maker tank. Tank length is extended from 35 m of a practical experimental tank to 100 m with the breadth of 2.5 m and the height is 3.0 m, refer figure (Fig. 3). The water is filled about 2.0 m with effective height of 1.5 m for the analysis in this research. In CFD, domain must be created with inlet, out let, side wall, top and bottom. Here is the critical decision to select the suitable boundary condition to impose the physical condition on the domain surface. Considering our experimental tanks, inlet is the Flap, outlet is the end wall. Side wall is kept as symmetry and the beach is placed before the end of the tank, refer figure (Fig 2). Tank top is kept open similar to the practical which will be useful to avoid numerical instability.

TABLE I
Numerical Model

Parameter	Setting
Model	Turbulence
Multiphase Model	Homogeneous
Analysis Type	Trasnsient
Spatial Discretization	High Order
Time Discretization	1 2nd Order
Convergence Criteria	RMS < 1E-7
Run Mode	Serial

A. Wave Makers – Flap Type

For the simulation of regular wave, constant stroke length will be provided and the Flap will move in z-direction sinusoidally. In that situation, whole water is moved by the Flap in the tank. Schematic view of working principle of Flap type is drawn in figure (Fig 3) and applied numerical settings are shown in Table I.

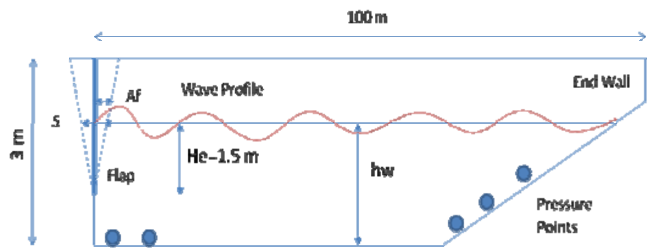

Fig.. 3 Falp Type Wave Maker

In the process of irregular wave simulation, analytical irregular wave with function of time will be given as an input stroke for the Flap. It is also possible to give the stroke amplitude with time in the table format.

B. CFD computational Performance and Accuracy

For any numerical analysis, performance of the numerical computation and the accuracy of data can be improved by many factors like, numerical method, boundary conditions, grid size, time interval, etc. In this analysis only grid size, time interval and the turbulence are taken care for improvement which can be modified by the researcher in the numerical computation analysis. In earlier research [12], authors have made a comparison for the different turbulence like k-ε, k-ω, SST. It was found that SST model can capture well for near and far flow turbulence for the present application. Therefore, in this analysis also, we have used SST model. Present analysis, number of element is 150000 and time interval is 0.01 second. Near the free surface, the grid density has been increased to capture the free surface well. That way, our accuracy and performance are controlled / maintained well.

C. Numerical Wave Tank -Wave Damping

In the practical experimental tank, wave absorber is provided at the end of the tank and in some places, beach is provided. To damp the wave, different kind of damper are used like beach slop, net type iron gril, frigate panel etc. some Presently, we have introduced the beach at the end of the tank which will be used for the absorption of wave, and it avoids the reflection. We have analyzed for different slope like 1:3, 1:4.5 & 1:6. Single wave has been plotted on the beach at same location with different slope, refer figure (Fig 4). It can be observed that without beach, the wave amplitude was quite high when comparing to the other cases. Between the three slope, 1by 3.0 shows much smaller amplitude because it can damp well for same location. As a conclusion, it decided that slope 1:6 is better because higher slope can damp the wave slowly and can break the wave to avoid the reflection or disturbance. Whereas for the higher slope case, the damping is done quickly but small disturbance is observed. Considering all, authors have decided that lower slope will be better for wave damping [12].

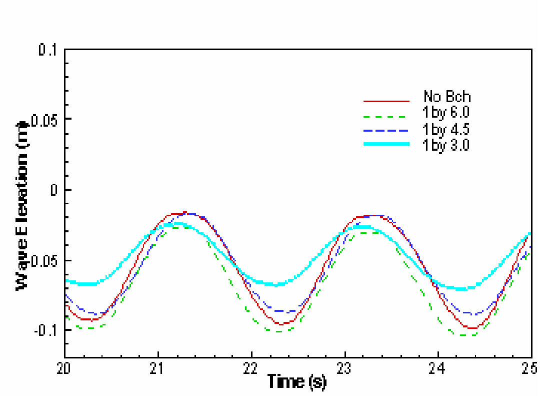

Fig.. 4 Analysis of Wave Damping

IV. Numerical Simulation of Irregular Wave

Use Taking into account of practical application in the marine field, the Bretschneider spectrum is selected for the analysis, and it is also possible to replace with any wave spectrum. As per the IACS statistical wave data, H_s & T_z has been taken respectively as 1.5 & 7.5. Taking this value, spectrum is developed, and it is shown in figure (Fig 5). From this spectrum, 15 regular waves have been extracted keeping equal angular frequency interval. Now all the fifteen waves have been added with different phase angle and the irregular wave was generated, refer figure (Fig 6). It is observed that wave amplitude is ranging from -5 to 5 m.

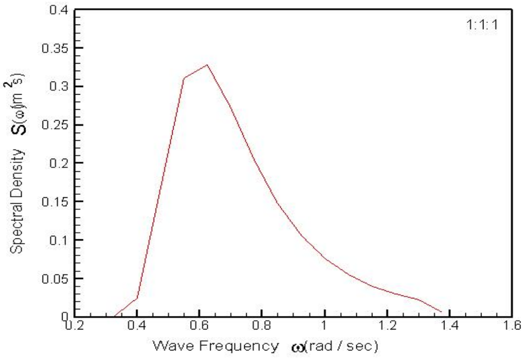

Fig.. 5 The Bretschneider Wave Spectrum [H_s = 1.5 & T_z = 7.5]

In wave simulation, stroke must be given up to 10 m to generate this wave but practically it is very difficult to simulate. To simulate in the CFD also, it is very expensive in terms of domain size and the number of grid elements. Considering all the points, it was decided to scale the extracted regular wave amplitude keeping the wave steepness fixed to suit the practical experimental case as well as CFD simulation capacity. To overcome this issue, generated wave have been scaled down to get our required amplitude ex. 1:5, 1:10 and 1:15. The above scaling has been implemented to accommodate the wave in the practical wave tank / numerical wave tank. Present analysis, scale 1:5 has been taken and used for further analysis.

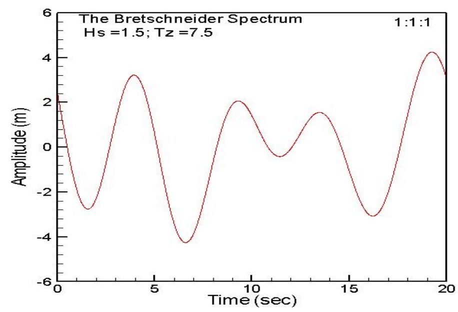

Fig.. 6 Extracted Analytical wave for 1:1:1 from PM Spectrum

Present analysis, spectrum scale 5 has been considered for further analysis and it is identified that required amplitude range wave can be generated. In most of the cases, CFD generated irregular wave, may not match with analytical irregular wave. To match with analytical irregular wave, it is necessary to give some scale at the CFD input to get the required irregular wave. Therefore, all the drawing will have two scales. For example, 1:5:1.6, here '5' is the scale of the spectrum to accommodate in wave tank and the '1.6' is the scale of the irregular wave to CFD as an input to match with analytical wave. This system is followed in the research paper for better understanding. CFD irregular wave depends on the kind of mechanism used for the wave generation. That means generated waves are function of stroke length, water height in the tank and the time interval of the wave. Considering all the points, a researcher can decide some transfer function / scale [15] for the input stroke of the CFD to get the required irregular wave. Present analysis for the particular H_s and T_z, transfer function 1.6 is matching well for the generation of irregular wave to suit the analytical wave. With the present scale, the spectrum shows a large difference when compare to the original spectrum. It is also noticed that the irregular waves not coming closure to the analytical wave spectrum. Then, it is decided to go for a input scale to reduce the difference in the irregular wave.From the scaled spectrum (1:5:1), extracted regular wave added together keeping different phase for the generation of irregular wave. Then this irregular wave can be given as input stroke to the CFD wave maker. After the CFD simulation, irregular wave profile is extracted for the required location in post-processing. Initially, the analytical irregular wave has been given as input without adding any scale to the input value at the CFD. It was found in the FFT analysis that generated spectrum is much smaller than the original spectrum.

It was found out that the amplitudes of CFD generated wave was nearly 2~3 times less than that of input wave. Therefore, in the next step to get the CFD wave profile similar or very closer to analytical wave, scale ranges have been simulated from 1.5 to 3, and it was found that 1.6 scale CFD simulation data matched well with original spectrum.

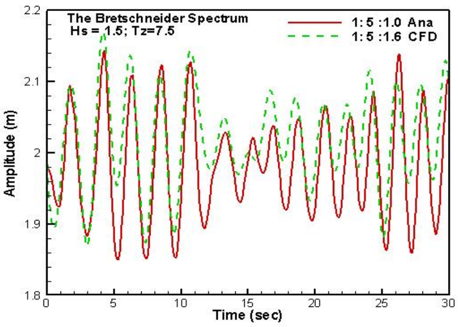

Fig. 7 Comparison of Analytical Vs CFD Irregular Wave for 1:5.1.6

Irregular wave has been generated analytically from the wave spectrum and the CFD irregular waves are plotted in figure (Fig 7). It is understood that scale 1:5:1.6 is matching or coming closer to the analytical wave. Therefore, this case is taken for detailed FFT analysis.

In CFD wave simulation, wave generation depends on stroke length, time period of the wave and the water height in the tank. Therefore, a researcher must have a strong overview on the wave simulation to decide the wave amplitude, time period and the water height required.

V. Analysis Numerical Results

Simulation of irregular wave from the particular wave spectrum by analytically as well as by the CFD have modeled and waves are generated. Here, it will be discussed to get the wave spectrum from the generated irregular wave. Presently, we have used the MATLAB for FFT analysis. FFT analysis depends on the wave's time interval, number of points and the duration of wave considered for the analysis. For the simulated wave, FFT has been carried out and compared with original wave spectrum, refer figure (Fig: 8). Original wave spectrum and the CFD wave spectrum are matching well in the lower frequency range. However, in the higher frequency, there is a large difference. Author can understand from the earlier research that times the interval between the simulations must be much lower. Now it has taken as 0.01 and better result can be achieved by reducing much lower i.e., 0.001 or 0.0001**.**

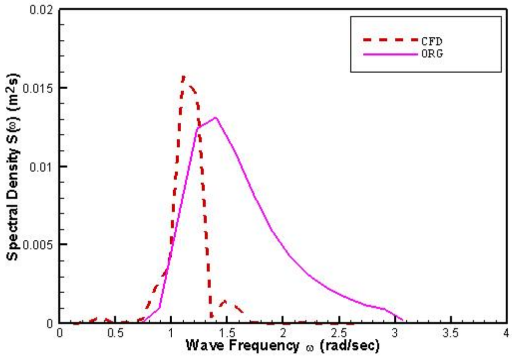

Fig.. 8 Comparision of Wave Spectrum for 1:15:1

FFT analyses are equally important as the simulation of irregular wave by CFD. Therefore, effort has been made FFT analysis for different cases by changing the number of data points, time duration and the time interval between two data points. FFT analysis for the analytical wave has been compared with CFD spectrum, refer figure (Fig. 9) and there is no remarkable difference. Only one place, the peak has small difference. This difference can be seen in the irregular wave itself because there is peak difference exist in the wave amplitude (Fig.7).

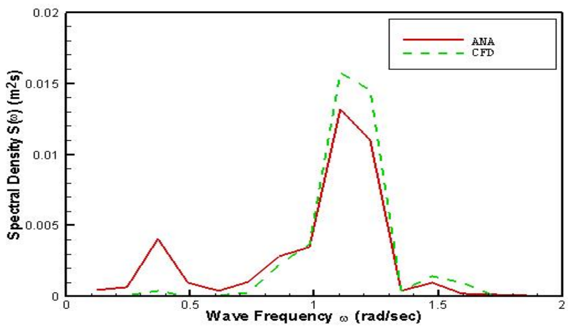

Fig.. 9 Comparision of Wave Spectrum for 1:20:1

FFT has been carried out for different interval like 2048, 1024, 512. It is concluded that better result can be achieved by covering maximum time period and with minimum of 512. FFT analysis, Δt is taken as 0.01 to 0.05 with the interval of

0.01. Even in small change in the interval also can make higher difference in the spectrum analysis.

VI. Conclusion

For the given wave spectrum, Irregular wave can be generated for the particular significant wave height and wave period. Developed methodology for the simulation of wave by the CFD is validated for the Bretschneider wave spectrum. FFT analysis also discussed for the different interval of frequency, time period and number of points for the analysis. The comparison of the wave spectrum shows some difference but this can be reducing the simulation interval. Wave damping characteristics was discussed introducing beach to avoid the reflection of waves. It is concluded that required irregular waves can be generated by the CFD giving suitable scaling at the input, and it will be useful for the analysis of marine structure numerically.

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