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ISOMAse

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Scope of JOMAse

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Numerical Study on the Effect of Horizontally Installed Corrugated Plate Boundary Condition under Blast Load

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ABSTRACT
Blast hazard load on offshore and marine operation resulting very catastrophic failure. Installation of protection devices needs to be applied. There are active and passive protection available. This paper investigates the use of corrugated plate as a passive protection to resist blast loads based on ASCE (American Society of Civil Engineers) - Design of Blast Resistant Building in Petrochemical Facilities. This paper aims to investigate the response in terms of stress, deformation and energy dissipation of corrugated plate with accounting the effect of boundary condition. The horizontally installed corrugated plate is modeled using well known FEA Software, ANSYS. Numerical simulation is validated using meshing sensitivity study. The plate is then loaded by light, medium, and heavy explosions, represented by uniform pressure. Numerical simulation of non-linear structural analysis is performed. Based on the analysis result, it is concluded that the pinned and fixed boundary condition corrugated plate successfully resists all the blast load variations, but the pinned support gives average better responses.

KEY WORDS: Blast load, corrugated plate, boundary condition, stress and deformation, energy dissipation.

NOMENCLATURE
\( \sigma \) Stress
\( d \) Deformation
\( \theta \) Support Rotation
\( \eta \) Ductility Limit

1.0 INTRODUCTION
The blast hazard is one of the most dangerous accidents that could happen on the offshore structure operation. Blast load consists of rapid change of pressure and mostly followed by massive fire that can abrupt the structural integrity of the structure. There were several cases happened that the topside structure could not withstand the blast and fire load, and it leads to total damage and loss of live [1]. The Piper Alpha explosion was one of the case that the designer did not consider the plan to resist the load from extreme accidental condition, and caused 169 men aboard killed. The rapid change of pressure brought the structure to the total collapse. Several cases happened in Gulf of Mexico. One of the most well-known was on April 10, 2010, when the Deepwater Horizon accident took 11 casualties and caused sea pollution. Again, this accident caused by the structure could not resist the extreme load on potentially harmful location that the explosion could happened.

Several efforts are performed, especially in last decades when the advancing technology of computer simulations made the complex simulations become possible. Rajendran and Lee [2], provide the brief review of analytical solutions of blast loaded plate in both air and underwater conditions. A numerical investigation generated by Kadid [3], Tavakoli [4] and Riyanto [5], by modelling some varied stiffened plates subjected to uniform blast loading. The nonlinear dynamic response of square steel stiffened plates subjected to uniform blast loading was studied. Stiffener configurations and boundary conditions, which affect the dynamic response of the plates subjected to blast loading was considered. Faruqi [6] investigate the response of corrugated plate to resist the time history load.
2.0 MODELLING AND ANALYSIS SETTING

Corrugated plate consists of 3 (three) parts, namely (a) compression flange, (b) diagonal flange, and (c) tension flange, as stated in [6] and shown in Figure 1. This paper uses dimension of each part of corrugated plate, as shown in Table 1. The corrugated plate geometry is modeled using 3D CAD software. There are 4 (four) panels of corrugated plate with dimension of 2 x 1 m for each panel. The panels are installed horizontally with 2 (two) types variation of boundary condition, fixed and pinned boundary conditions. The contact between panels is assumed bonded connection so the tearing between panels is prohibited.

Table 1: Dimension of Corrugated Plate

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>200</td>
<td>mm</td>
</tr>
<tr>
<td>b</td>
<td>200</td>
<td>mm</td>
</tr>
<tr>
<td>c</td>
<td>200</td>
<td>mm</td>
</tr>
<tr>
<td>h</td>
<td>200</td>
<td>mm</td>
</tr>
<tr>
<td>t</td>
<td>10</td>
<td>mm</td>
</tr>
<tr>
<td>s</td>
<td>282</td>
<td>mm</td>
</tr>
<tr>
<td>w</td>
<td>1000</td>
<td>mm</td>
</tr>
<tr>
<td>L</td>
<td>2000</td>
<td>mm</td>
</tr>
<tr>
<td>θ</td>
<td>45</td>
<td>degree</td>
</tr>
</tbody>
</table>

Parameter (a) at corrugated plate is the length of compression flange, whilst parameter (b) is the length of diagonal flange. Parameter (c) denotes the length of tension flange. Parameter (h), denotes the height of the corrugated section.

Numerical Finite Element Analysis (FEA) is performed with regarding the material nonlinearity. Structural steel resistance curve is an elastic-perfectly plastic curve with strain hardening. High-strength steel is selected. The material properties are presented in Table 2, whilst the resistance curve is shown in Figure 2.

Table 2: Material Properties.

<table>
<thead>
<tr>
<th>No.</th>
<th>Properties</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Elastic Modulus (MPa)</td>
<td>$2.1 \times 10^5$</td>
</tr>
<tr>
<td>2</td>
<td>Poisson’s Ratio</td>
<td>0.3</td>
</tr>
<tr>
<td>3</td>
<td>Density (kg/m³)</td>
<td>7850</td>
</tr>
<tr>
<td>4</td>
<td>Yield Strength (MPa)</td>
<td>585</td>
</tr>
<tr>
<td>5</td>
<td>Ultimate Tensile Strength (MPa)</td>
<td>725</td>
</tr>
<tr>
<td>6</td>
<td>Max Strain</td>
<td>0.04</td>
</tr>
</tbody>
</table>

2.1 Meshing Sensitivity Analysis

Pinned support corrugated plate is selected for numerical validation. Natural period is the parameter used for numerical model validation using meshing sensitivity analysis method. In dynamic analysis, natural period consists of important parameters, namely mass and stiffness parameters. Meshing sensitivity study is performed by varying the meshing size from 200 to 10 mm. Hexahedral meshing type is selected. 3D CAD model is displayed in Figure 3.

Only 1st mode natural period is captured and compared, to produce fair comparison. It is discovered that 40 mm meshing size and hexahedral meshing type are the optimum configurations. The 1st mode natural period reaches its convergence in 40 mm meshing size, in 0.0854 seconds. The results can be seen in Figure 4.
3.0 BLAST LOADING

The blast source consists of 5, 20, and 50 kg of TNT to represent light, medium, and heavy explosions, respectively, [7] with 10 m blast radius. The blast loading detonation empirical function as provided by Bangash [8] is used, as shown at (1):

\[ P(t) = P_0 + P_s \left( 1 - \frac{t}{t_p} \right) e^{-\frac{t}{a}} \]  

(1)

Where:
- \( P(t) \) = Overpressure at time \( t \) (kg/m\(^2\))
- \( P_s \) = Maximum Overpressure (kg/m\(^2\))
- \( t \) = Time (s)
- \( t_p \) = Blast duration (s)
- \( a \) = Negative time constant

The maximum overpressure, \( P_s \) and blast duration, \( t_p \), are determined by scaled distance method as stated in [8]. Scaled distance calculation is shown at (2):

\[ Z = \frac{R}{W^{1/3}} \]  

(2)

Where:
- \( Z \) = scaled distance (ft/lb\(^{1/3}\))
- \( R \) = explosion distance (ft)
- \( W \) = explosives weight (lb)

The cube root term results from geometric scaling laws in which charge radius varies in proportion to all distances, and thus the charge weight is proportional to the cube of the charge diameter. For detailed scaled distance curve, please refer to [8].

To use these empirical curves, one computes the scaled distance by dividing the explosion radius from the charge to the point of interest by the cube root of the charge weight, in this case, explosion radius is the blast radius, 10 m.

Due to the maximum blast load duration calculated from scaled distance curve is 1.348 seconds at M05, therefore maximum analysis time is set into 2 (two) seconds with 0.04 timestep. The blast loads result is displayed in Figure 6.

4.0 RESULT AND DISCUSSION

From the analysis result, it is discovered that the corrugated plate could resist all the blast load from light to high explosion without undergoing material erosion.

4.1 Deformation Response

Deformation for the case of fixed boundary condition tends to be higher than the pinned boundary condition; overall deformation response is displayed in Figure 7 and Figure 8.
Both for pinned and fixed boundary conditions, the higher the blast load, the higher the response and the oscillation after the blast load ends. Fixed support gives better response in light explosion, whilst in medium and high explosion, pinned support gives better responses. Pinned support gives 8.18 % better in maximum deformation response, averagely. The graphical comparison is displayed in Figure 9.

At the end of the analysis (t = 2 seconds), the deformation is captured. In all blast load condition, the plate undergo plastic deformation, even the maximum stress hasn’t been reached the maximum plastic stress. Just as the maximum deformation response, the end deformation response for fixed support at light explosion gives better result. The comparison can be seen in Figure 10.

4.2 Stress Response
Stress on the fixed boundary condition case tends to be higher than the pinned boundary condition one; overall stress response is displayed in Figure 11 and 12. At light explosion blast load, the maximum stress is 228.44 MPa and 269.72 MPa for fixed and pinned condition, respectively. The stress result gives different tendency in medium and high blast load, in medium explosion blast load, the maximum stress is 397.02 MPa and 304.31 MPa for fixed and pinned condition, respectively. Whilst the maximum stress at high explosion load is 558.14 MPa and 427.27 MPa for fixed and pinned condition, respectively.
excessive vibration subsequent to the blast loading. Fixed support gives better response in light explosion, whilst in medium and high explosion, pinned support gives better responses. As shown in Figure 13 the pinned support gives 16.69% better in maximum stress response, averagely.

Despite all the maximum stress hasn’t been reached its plastic stress, however the response still gives nonzero end time deformation. It is probably due to the unfinished vibration at the analysis time. In other words, for further analysis, the simulation time should be extended.

Figure 13: Maximum Stress Comparison

4.3 Performance Criteria for Blast Resistant Wall

ASCE: Design of Blast Resistant Building in Petrochemical Facilities [3] gives 4 (four) levels of protection from explosion loads. In order to give safe protection to the occupant, whilst still in the range of reasonable economic consideration, the performance criteria is set at Level II: Damage is expected, such that the building is not likely to be economically repairable, but progressive collapse is unlikely.

The response parameters define the structure damage level, namely ductility limit (µ) and support rotation (θ). The equation of ductility limit is shown in (3).

\[
µ = \frac{X_m}{X_y}
\]

Where:
- \(X_m\) = Maximum deformation
- \(X_y\) = Static deformation at yield stress

Whilst the support rotation equation is shown in (4) as depicted in Figure 14.

\[
θ = \tan^{-1}\left(\frac{X_m}{L_{min}}\right)
\]

Where:
- \(X_m\) = Maximum deformation
- \(L_{min}\) = Shortest distance from maximum deformation to support

Figure 14: Support rotation [1]

Performance criteria limits the maximum value of µ and θ onto following, as stated in Table 3.

Table 3: Performance Criteria for Level II Protection

<table>
<thead>
<tr>
<th>Component</th>
<th>µ_max</th>
<th>θ_max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel Plates</td>
<td>10</td>
<td>6</td>
</tr>
</tbody>
</table>

The ductility limit calculation requires static stress at maximum yield stress. Table 4 and 5 shows the calculation result summary of the corrugated plate static stress, under uniform pressure.

Table 4: Stress and Deformation at Yield (Fixed)

<table>
<thead>
<tr>
<th>Pressure (MPa)</th>
<th>Stress (MPa)</th>
<th>Deformation (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0864</td>
<td>584.99</td>
<td>91.416</td>
</tr>
</tbody>
</table>

Table 5: Stress and Deformation at Yield (Pinned)

<table>
<thead>
<tr>
<th>Pressure (MPa)</th>
<th>Stress (MPa)</th>
<th>Deformation (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.08636</td>
<td>584.97</td>
<td>91.275</td>
</tr>
</tbody>
</table>

Calculation result shows that the horizontally installed corrugated plate only successfully resists the light explosion from 10 m distance, both in fixed or pinned boundary condition as can be seen in Table 6 and 7. Although all the ductility limit results satisfy the criteria, but the support rotation failed to comply the minimum requirement. It is statutory that both criteria should be satisfied in order to produce a blast resistant wall.

Therefore, this type of corrugated plate should only be used if the designated blast load is in light explosion range.

Table 6: Performance Criteria Result (Fixed)

<table>
<thead>
<tr>
<th>Blast Load</th>
<th>µ</th>
<th>θ (degree)</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td>0.804</td>
<td>4.406</td>
<td>OK</td>
</tr>
<tr>
<td>Medium</td>
<td>1.552</td>
<td>8.466</td>
<td>FAILED</td>
</tr>
<tr>
<td>High</td>
<td>2.070</td>
<td>11.358</td>
<td>FAILED</td>
</tr>
</tbody>
</table>

Table 7: Performance Criteria Result (Pinned)

<table>
<thead>
<tr>
<th>Blast Load</th>
<th>µ</th>
<th>θ (degree)</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td>0.973</td>
<td>5.148</td>
<td>OK</td>
</tr>
<tr>
<td>Medium</td>
<td>1.289</td>
<td>7.040</td>
<td>FAILED</td>
</tr>
<tr>
<td>High</td>
<td>1.821</td>
<td>10.008</td>
<td>FAILED</td>
</tr>
</tbody>
</table>
5.0 CONCLUSION

There are several conclusions could be drawn based on the analysis result:

1. In light explosion, response of the fixed support case is better than the pinned support case. Reversely, in medium and high explosion, response of the pinned support is better than the fixed support.
2. The pinned support case gives 8.18 % better in maximum deformation response, and 16.69 % better in maximum stress response, averagely.
3. The horizontally installed corrugated plate should only be used if the designated blast load is in light explosion range. Based on performance criteria stated on ASCE: Design of Blast Resistant Building in Petrochemical Facilities codes, this configuration only successful to resist light explosion.

6.0 FURTHER WORKS

Further analysis could be performed, based on this paper unsolved problems:

1. The resonance effect needs to be analyzed to investigate the cause of excessive vibration subsequent to the blast loading.
2. The simulation time needs to be extended beyond 2 (two) seconds, in order to investigate the end time of the excessive vibration.
3. Strengthening plan should be configured in order to increase the performance.
4. Considering to install the plate vertically, in order to obtain better response result.

REFERENCES

Production Process of Traditional Ship in Bintan-Indonesia

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ABSTRACT
Indonesia is the world's largest archipelagic country in the world, demand for marine transportation is very important. Marine transport being very strategic because it plays a role in connecting one island to another island. Marine transport is a tool for economic activity. Global industrialisation causes traditional shipyard less competitive, causing reduction in the number of traditional ships, which are urgently needed to support economic activity. Proper production management planning at the shipyard is expected to help improve the quality of traditional shipbuilding for competitive. This paper discusses current issues of traditional shipyards in Kepulauan Riau-Indonesia and implementation of IDEF models as tool for solving the problem by taking the following factors into account: concept design, perform preliminary design, contract design, detail design and building of ships.

KEY WORDS: Traditional Ship; Production Planning; Wooden Shipbuilders.

1.0 INTRODUCTION
Indonesia is the world's largest archipelagic country with more than 17,504 islands the number of pieces, a long coastline more than 81,000 km and 2/3 of the entire region is water. Under this geographical condition, the role of sea transport for Indonesia is very strategic and vital especially as a trigger for economic development.

Ships is being very strategic because it plays a role in connecting one island to another island that economic activity can be run properly. Ships play a role in stimulating economic growth in underdeveloped areas and as a means of supporting the economy the growing area. Thus the important on ships to play a role in providing shipping freight accessibility is essential, and irreplaceable to fulfill basic necessities society the role of maritime transport depends on the quality of ships operating as well as the number of ships that used to cover broad Indonesia country consisting of many islands. Good quality of shipbuilders is essential to provide good quality of the ships. Traditional shipbuilders empowerment existed in Indonesia should be developed, because, the empowerment of traditional shipbuilders will help the society who depends on marine resources such as fisherman. This will improve the quality and performance for chancing fish, indirectly helps for increasing the government income.

This paper discusses the current problem of traditional shipbuilders in Kepulauan Riau-Indonesia, and then analyze using IDEF model. As case study, the research carried out by visiting three wooden shipbuilders as follows: Kijang-Bintan Island, Kelong island and Mana island in Kepulauan Riau, Indonesia as shown in Fig.1. All information and data are collected through interview and documentation.
2.0 TYPICAL TRADITIONAL SHIPBUILDERS IN INDONESIA

Based on the function of traditional shipyard in Indonesia, traditional shipyard is divided into several classifications: wooden shipbuilding, oriented, building fishing vessels, wooden shipbuilding, oriented, building passenger ships and wooden shipbuilding, building a dry cargo ship.

2.1 Traditional shipbuilding layout

![Diagram of traditional shipbuilding layout]

**Explanation:**

A: Material Storage
B: Ship construction
C: Drying Wood place
D: equipment Storage
E: timber and wood process
F: office and Accommodation

Figure 2: Typical traditional shipbuilder layout in Kepulauan Riau, Indonesia.

2.2 Problem in Indonesia Traditional shipbuilding

<table>
<thead>
<tr>
<th>Description</th>
<th>Problem</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concept Design</td>
<td>Does not have a concept, the ship is built only based on experience. Do not have a data base of ship Just have a template to make concept on shipbuilding process</td>
</tr>
<tr>
<td>Preliminary Design</td>
<td>Lack of development of the concept The design is monotonous, less innovative</td>
</tr>
<tr>
<td>Contract Design</td>
<td>Do not have a market Less support from Government The contract just from owner There is no tender</td>
</tr>
<tr>
<td>Detail Design</td>
<td>There is no drawing such as lines plan There is no layout Manual calculation based on experience There is no use CAD (Computer Aided Design) method</td>
</tr>
<tr>
<td>Productivity</td>
<td>Less Innovation to development the ship Limited to produce big ship No technological deepening of ship production process</td>
</tr>
<tr>
<td>Labour</td>
<td>Their expertise based on experience There is no deepest knowledge</td>
</tr>
<tr>
<td>Equipment</td>
<td>Less equipment, and traditional Shipyards are still modest Working with manual instrument Most of the work carried out manually Lack of technology Small Machineries</td>
</tr>
<tr>
<td>Management</td>
<td>There is no management procedure There is no cost management features Product monitoring functionality not observed There is no management to manage material process Poor production management method</td>
</tr>
</tbody>
</table>

Figure 3: Traditional shipbuilding condition.

3.0 IDEF MODEL CONCEPT FOR TRADITIONAL SHIPBUILDING

According to Karaszeweski Zhigniew J (1991), IDEF methodology is used to gain an understanding of the present condition of the system being scrutinized. This understanding is achieved through the creation of a structured functional model that identifies activities and how they relate to one another.

The arrows entering and leaving the boxes on the left and right represents inputs and outputs, respectively. Inputs represent elements that are needed to perform the function. Outputs show the data that is produced as a result of the function. The function transforms the inputs into the outputs.
Arrows which enter from the top indicate controls, or things which constrain or govern the function. Arrows entering the bottom of the boxes are mechanisms. Mechanisms can be thought of as the person or device which performs the function.

IDEF models to describe the traditional process on Shipbuilding in detailing the different functions at every level. Every function will be discussed in detail and comments that support the existence and structure of each function that has been provided.

3.1 Concept Design Improvement
At the design concept of traditional shipbuilding in Indonesia, the customer plays an important role in making decisions on ships design concepts. Most of the major decisions on the proposed customer who is technical information about the parameters of the desired ships, the most important dimension is the principle and function of ships to be built.

In the design concept phase, the traditional shipbuilders should achieve performance requirement from the owner and society by taking into account the following factors such as: customer objectives and technical information. The shipbuilders require improve qualification of staffs, database system, facilities and equipments.

The factors should be controlled under in which forecast the start of a design which is a technical feasibility study to establish the traditional ship that aims to fulfill the desired requirements, so that ships are built to have the appropriate criteria to be operated, as required ships speed, type of wood material used, etc.

The traditional ship yard has a budget problem due less the loan provided by the other party.

3.2 Perform Preliminary Design
Preliminary design involves the development and refinement of the principal characteristics of a ship with greater precision than that required during the concept design stage. These characteristics include principal ship dimensions, selection of material such as wooden and timber, determination of the size and type of propulsion plant. This design solution must continue to satisfy customer requirements such as capacity, service speed, etc. Other things to be considered in the preliminary design are reviewing a concept design package to verify that the requirements have been appropriate. Traditional shipbuilding in preliminary designs has to conduct drawing such ship line.

3.3 Contract Design
Contract design which is performed in traditional designs shipbuilding, is a contract between the customer and shipbuilder, rarely there is the addition of other parties that support the ship construction. No tender is performed. The design contract agreement is just approved by the customer with the shipyard.

As the existing traditional ship construction contract is carried out only by morality, rules and regulation rare aspect is necessary to be added to the design contract.

The importance of regulation and rules in the traditional shipbuilding aims to improve the productivity of traditional Shipbuilding. Government support is required to construct a
traditional ship, performed by providing a rule as a basis of cooperation and partnership in the traditional ship building.

3.4 Detail Design

Detail design to plan activities that will be conducted in a traditional ship building. As for the activities undertaken during detail design are the drawing - ship lines, material specification, information for plan and specification, construct the traditional ship information

Problems that arise in traditional Shipbuilding in Indonesia, one of which is construct the ship, not based on the lines plan, but mostly do not use a drawing. Drawing is very important for a traditional ship building to be developed. Drawing serves as a data base, drawing plays an important role in the improvement and the performance of Shipbuilding with a drawing, it is expected that customers can trust performed Shipbuilding performance in building ships.

All of work performed in the traditional shipyard in Indonesia, is a manual method. A simple computational method in the traditional shipyard in Indonesia is to help in maximizing work time, include simple computational methods that can help traditional ship yards are make a drawing, support calculation, make a simple management system.

3.5 Build a ship

The last stage in the traditional construct a ship is building a ship. The stage is performed by looking at the detail design has been implemented. Databases must address satisfying in building ships quality traditionally relied heavily on human resource and expertise of labor, because the tendency of traditional shipbuilding in Indonesia is based on the manual worker, not much assistance in machine. Labor skills possessed a very important role in the quality of the ship will be built.

Availability of facilities and good management system enables the construct in a traditional ship building. Delay in material is often faced by a traditional ship yard due to lack of government support in helping to develop the traditional shipyard, large tax, minimal regulation, sabotage by a large shipbuilding industry is still hit by the problems of traditional ship building.
Support from government is very desirable for small businesses such as traditional shipbuilding. Government plays an important role for giving out easy for small businesses to grow. Reducing the tax is also one of the government supports for small businesses.

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Projection of Ocean Wave Climate Change Based on Numerical Simulations

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ABSTRACT

This study aims to analyze global wave climates of present and future time by using the WAM model. The analysis is performed based on wind climate data from the JMA/MRI-AGCM3.2 climate change projection. We analyze two 6-hourly wind data sets, covering two periods: the present climate ranging from 1979-2003 and future climate extending from 2075-2099. These wind data are used to implement the WAM model for producing the outputs of wave characteristics. Subsequently, the outputs from each period were used to study global wave climate in the future. The analysis showed that the wave climate is strongly dependent on the geographical position of regions from mid to high latitude and low latitude. This includes regions where the climate induced changes for present to future climate. The largest increases of significant wave height which reached approximately 5% occur in the southern parts of the Indian, Pacific and Atlantic Oceans and in the Antarctic Ocean. The decreases in the same magnitude around 5% occur especially in the North Atlantic Ocean.

KEY WORDS: Climate Change, Wind Climate, Wave Climate, WAM

1.0 INTRODUCTION

Waves and the general conditions of the oceans affect coastal regions and marine activities on a daily basis and bring impacts for all over the world. It is increasingly apparent that human activity is affecting not only the atmospheric climate, but also the characteristics of our oceans. As the composition of the atmosphere changes and the concentration of greenhouse gases increases, the whole environment gets the impacts.

The ocean climate is affected by the increasing temperatures in many different ways. A static side-effect of global warming, for example, causes thermal expansion in the oceans which raises sea levels. The effects of this phenomenon can already be seen in many coastal regions, where coastal erosion and inundations are becoming the common problems. According to IPCC (2007) the sea-level has risen for 1.7 ± 0.3 mm/year since the second half of the 19th century. This rising rate seems to have increased during the last decade as reported by Church and White, (2006).

The dynamic side-effects of the warming climate are predictable changes of the behavior of ocean waves, storm surges and other extreme events (IPCC, 2007). Reports on the increasing extreme climate in many parts of the world highlight the importance of understanding and assessing the effects of climate change. Today, these reports put more concern on the effect of climate greater than in the past. The numbers of coastal and marine activities which are dependent on reliable and long-term information about wind term and wave climate are also constantly increasing. Therefore, studies on predicting and forecasting future development are required. There have been numerous studies performed to assess the effects of future climate change. These studies analyze both, the static effects such as sea level rise and the dynamic side-effects. These effects include the change of wave climates. A large part of these studies focuses on the development of future extreme events, such as tropical storms and cyclones (Caires., et al., (2006), Weisse and von Storch (2009),
Murakami et al. (2011), Kitoh et al (2009)). However, there are still very few studies conducted on the global scale effects of climate change on ocean waves.

One of these studies is presented by Mori et al. (2010). Mori et al. (2010) used the wind fields simulated by MRI/JMA-AGCM3.1 to model the past, close future and future average and extreme wave in the SWAN model. After comparing the averaged values of the significant wave height over the periods of 1979-2003, 2015-2031 and 2075-2099, Mori et al. (2010) find that the changes in wave climate over the observed time indicate a strong latitude dependency. The findings show that the mean wave heights will increase both in the mid-latitudes areas and in the Antarctic Ocean, while the equatorial region and the coastal areas in Japan will experience decreasing average wave heights. However, in the proximity of the Japanese islands, this area is predicted to experience increasing magnitudes of extreme waves because of tropical cyclones.

Another study analyzing the future development of significant wave height is conducted by Wang et al. (2004). They apply a statistical model to the output of the CGCM2 (Canadian Centre for Climate Modelling and Analysis) coupled atmosphere-ocean model for three different emission scenarios. Their analysis was limited to the future wave fields of the North Atlantic Ocean. It is found that the monthly wave height in the north-east Atlantic Ocean and in the south-western North Atlantic will increase towards the end of the 21st. It is projected that the mid-latitudes will experience some decreases.

The aim of this present study is to evaluate the effects of climate change and compare wave climates between simulations for the present and the future climate. The wave simulations are analyzed on the basis of a global scale, with the main focus on observing the evolution of the average wave fields, which is affected by the changing climate. The wave predictions that are used for the analysis is modeled by WAM numerical wave model and using input wind fields from JMA/MRI-AGCM3.2. JMA/MRI-AGCM3.2 is an Atmospheric General Circulation Model, from which the second version was recently developed through the collaboration between Japanese Meteorological Agency, JMA and Meteorological Research Institute, MRI.

### 2.0 WIND CLIMATE DATA

This study projected future wind fields by adopting JMA/MRI-AGCM3.2. It is used as the input for developing WAM model to simulate wave fields within the periods of 1979-2003 and 2075-2099. The AGCM3.2 is the most recent version of the model developed by Meteorological Research Institute (MRI) in collaboration with Japanese Meteorological Agency (JMA). This model is designed for simulating climate and predicting weather (Mizuta, et al., 2006). The model can, for example, provide information on possible future changes of tropical cyclones, the East Asian Monsoon, extreme events and other changes induced by global warming (Mizuta, et al., 2011).

JMA/MRI-AGCM3.1 was the previous version of JMA/MRI-AGCM3.2. It was the first climate model that could stand long-time integration while being able to conserve mass and simulate realistic high-resolution global climate. This model can simulate global climate with a horizontal grid size of around 20 km, a grid size which is normally only employed for Regional Circulation Models (RCMs) (Mizuta, et al., 2011). One advantage with a high-resolution global model is that problems with lateral boundary conditions can be avoided. Moreover, the AGCM provides information on regions that cannot be provided by a RCM simulation (Mizuta, et al., 2006). The MRI-AGCM3.2 were simulated under Special Report on Emissions Scenarios (SRES) A1B for the IPCC Fifth Assessment Report (AR5) in which computations were covering two periods: the present climate ranging from 1979-2003 and future climate extending from 2075-2099. (Kitoh et al., 2009).

The first version of the model, 3.1, was developed from JMA operational numerical weather prediction model. This model was constructed based on observed Sea Surface Temperature (SST). In the second version, 3.2, only smaller changes, including new parameterization schemes, were made in order to increase the accuracy of the model performance (Mizuta, et al., 2011). As reported by Mizuta et al (2011), the results of the experiments showed that the AGCM, especially the current version, 3.2, can simulate the global climate in a realistic manner. After comparing the models standard deviations and correlation coefficients to those of an observed climatology, it is found that most variables were better in the AGCM3.2.

### 3.0 WAM MODEL

The numerical model used in this study is the third-generation wave prediction system, called WAM model (WAMDI Group, 1986. Komen et al., 1994). The model was developed with the purpose of operational prediction of waves over the whole globe, making it well suited for this global climate study (Janssen, et al., 1994). The WAM model is based on the following energy balance equation read as follows:

\[
\frac{\partial}{\partial t} F + (\cos \phi)^{-1} \frac{\partial}{\partial \phi} (\phi \cos \phi F) + \frac{\partial}{\partial \lambda} (\lambda F) + \frac{\partial}{\partial \theta} (\theta F) = S_{\text{tot}}
\]  

where \( F(\lambda, \theta, \phi, t) \) is the wave spectrum described by the frequency \( \lambda \) and the wave direction \( \theta \) as function of latitude and longitude on the spherical earth and \( S \) is the source term given by

\[
S_{\text{tot}} = S_{\text{in}} + S_{\text{nl}} + S_{\text{dis}}
\]  

where the terms on the right hand side represent the physics of wind input, nonlinear wave-wave interaction and dissipation due to whitecapping, respectively.

In this study, WAM model operates on regular longitude/latitude global grid with a fixed resolution of 1 degree, extending from 75° south to 65° north. The spectral domain is discretized in 25 frequency bins from 0.041 Hz to 0.411 Hz, and in the direction-space, a full circle is used with resolution of 15°. WAM model is run in deep water mode and bottom fiction is disregarded. WAM model is run in every 6 hours using sea surface wind field at 10 m height above the sea surface from JMA/MRI-AGCM3.2.
4.0 RESULTS

The following chapter presents the results of the global analysis and the comparison between present and future wave climates. The aim of this assessment is to give an overview on the spatial patterns related to the global distribution of significant wave height, and to evaluate and locate possible changes between the present and future climate.

Figure 1 presents the period averaged distribution of significant wave height numerically is modeled by WAM model. The top part represents the present period and the bottom part presents the future climate. Figure 1 clearly illustrates a strong latitude dependence of the distribution of the average significant wave height distribution. The largest significant wave height (approximately 5 m and above) occurs in the high-latitude regions. These regions extend approximately within the range of 40°N-60°N and 40°S-70°S respectively. These regions include the Southern Indian, Pacific and Atlantic Oceans as well as in the Antarctic Ocean. The average significant wave height in the mid-latitude regions, both north and south, are slightly smaller than in the high latitude regions. They range from 1-1.5 m. The calmest averaged wind conditions are found in the equatorial region: e.g. around the Indonesian archipelago and of the west coastal region of Central America.
Figure 2 shows that the overall spatial distribution pattern of the averaged significant wave height from the climate simulation of the present period is relatively similar to the overall spatial distribution of the future period. However, the magnitudes of the averaged significant wave height change in many places between the two periods. To explain these quantitative transformations of the wave climate, the change between the two periods is plotted and represented in Figure 2. The change is measured, both in meters (the upper figure) and percentages (the bottom figure).

The largest increases occur in the Southern Atlantic, Indian and parts of the Pacific Ocean and in the Antarctic Ocean. In these regions, the changes in average significant wave height for the local scope increases up to 5%, and 2.5% and it is widely spreaded (relating to changes of average wave height of 0.1-0.2 m). Compared to the change in wind speed, the areas where large increases occur considerably more extensive. It is also found that the large area of significantly lower future wave heights includes the North Atlantic Ocean. A greater part of this region shows decreases of 5% and above.

Interestingly, the north western region of the Pacific Ocean, the tropical cyclone intense area off the coastal region of Japan, shows a significant decrease in the mean significant wave height. This is relevant to the earlier discussion, which mentions that tropical storms are likely to increase in the region, in warmer climate in the future. Therefore, it is important to highlight the fundamental differences of the processes for creating the daily average climate and the processes behind extreme events. Thus,
these phenomena should always be analyzed and evaluated separately.

5.0 CONCLUSION

This study presented projected future changes in global wave climate fields derived from the wind field output of JMA/MRI-AGCM3.2 model. The wave fields are numerically modeled by WAM model for a resolution of 1 degree. This study aims to give an overview of forthcoming changes in wave climate from present to future which focuses on the effects of climate change. The results shows that there is no unanimous trend in the increasing or decreasing wave height since the evolution of the wave climate is very strongly related to location. The regions which experience significant future changes of wave climate are found to be in the mid- to high latitudes. This significant increases reaches 5%, in the Southern Hemisphere and local regions of the northern Pacific Ocean. The decreases in the same magnitude occurs especially in North Atlantic Ocean. Large parts of the world appear to be unaffected by the projected climate change. Therefore, It is important to remember that this analysis is mostly limited to the average wave climate. This study does not taken into account the possible changes in the events which are outside the range of normal climate conditions.

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