

# **PART VII**

## **Ship Motions**



## CHAPTER 233

### CRITERIA FOR SHIP MOVEMENTS IN HARBOURS

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#### Abstract

Knowledge of ship behaviour at berth is of fundamental importance for the design of harbours and marine terminals. To develop more precise data on acceptable ship movements than available in the literature, a joint research project was undertaken in cooperation between governmental and research institutions in the Nordic countries: Denmark, Faroe Islands, Iceland, Norway and Sweden. The purpose of the project was to establish criteria for acceptable ship movements in harbours for working and for safe mooring conditions.

#### Introduction

Modern maritime transport requires minimum time for loading and unloading in ports and at marine terminal. This requirement is in some ports restricted by ship movements at quay (operational conditions). If the ship movements are too large, damage to the ships and port installations may occur (safe mooring conditions).

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In recent years, changes in cargo-handling methods have resulted in changes of both ships and port installations. All these changes have large economic consequences, and the requirements to fast loading/unloading operations without delays due to ship movements are increasing. The above mentioned changes involve for example the containerization of general cargo and changes of methods of handling fish in fishing ports. The latter is of great importance in the Nordic countries which all have large fishing fleets.

As the new techniques are often more sensitive and vulnerable to ship movements than the conventional methods previously used, it is mandatory for cost benefit analyses of new ports or analysis of existing installations that pertinent criteria for acceptable ship movements be established for use in conjunction with the most modern investigation methods for determining ship movements at quay.

The present paper describes the methods applied and the results leading to recommendations for criteria for acceptable ship movements in harbours.

### Aims and Objectives

The purpose of the project has been to determine criteria for acceptable movements of moored vessels in relation to:

- Efficiency of loading/unloading operations (denoted as working conditions)
- Safe stay at berth (denoted as safe mooring conditions).

The project has primarily concentrated on assessment of criteria for fishing vessels, ferries, coasters (freighters) and container vessels. The project involved the following four phases:

- Literature study.
- Pre-study to identify ports with ship movement problems that could be selected for prototype measurements of ship movements etc.
- Prototype measurements of ship movements and simultaneous interviews with captains and port personnel.
- Supplementary studies comprising interview with port masters and operators etc., and comparison with results from existing hydraulic investigations of the same ports. In two occasions, studies of container operations were also performed.

The prototype measurements of ship movements have been made in Denmark, Faroe Islands, Iceland, Norway and Sweden.

The supplementary study had the purpose of extracting as much information as possible from previous model studies from researchers, planners, port engineers and port users in the Nordic countries. By these interviews, critical situations have been described and compared with already existing knowledge of ship movements or wave agitation in the ports in question. In this way, it has in a number of cases been possible to procure more data on criteria for acceptable conditions in ports than obtained from the field measurements.

Fig. 1 shows the locations of prototype measurements and other studies in the five countries.

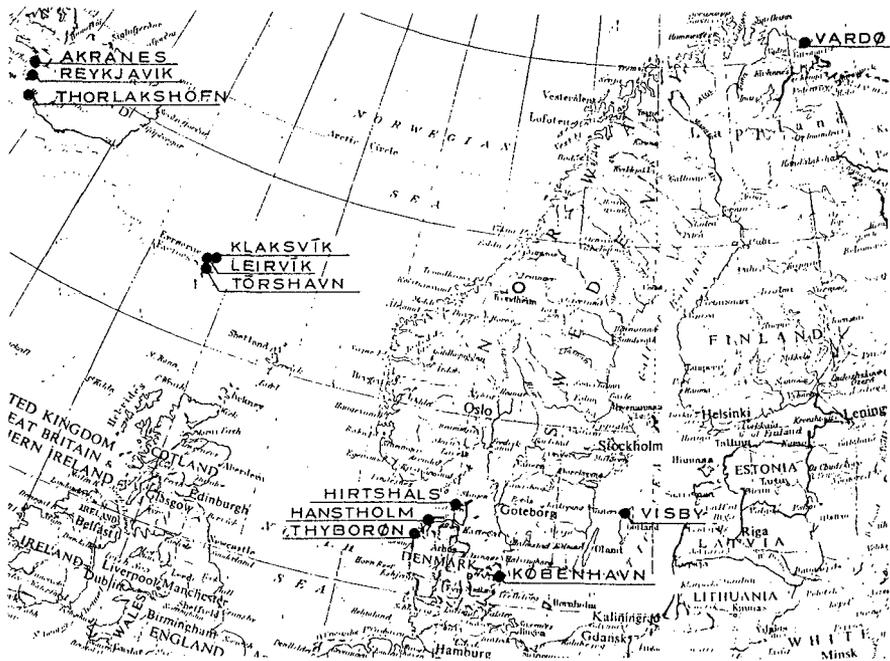


Figure 1. Locations of prototype measurements and other studies.

### General on Ship Movements at Berth

The movements of a moored ship at berth can be described by the three translatory movements: surge, sway and heave, and the three movements of rotation: pitch, roll and yaw. The movements are defined in Fig. 2.

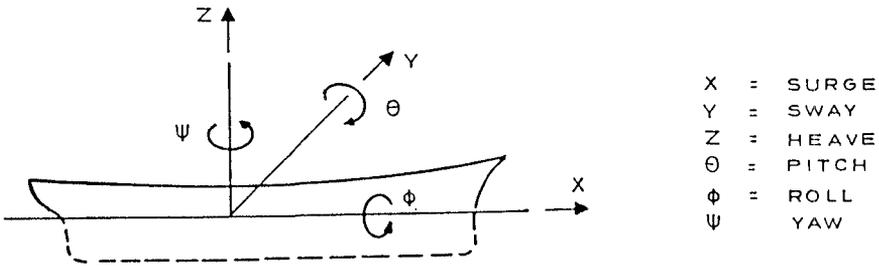


Figure 2. Definition of ship movements.

The movements of rotation, i.e. pitch, roll and yaw, are almost independent of the mooring system. They depend on the resonance period of the ship, the wave spectrum, the berth angle relative to the waves, the reflection pattern for the waves and the type of berth.

The translatory movements of a moored ship depend upon the type of ship, the mooring and fender system (geometry and stiffnesses), the type of berth, and the wave conditions (spectrum, direction of berth relative to the waves).

Typically, the natural periods of motion of the planar motions of a moored ship are for large vessels almost one order to magnitude larger than rotational movements, i.e. approximately 100 s to be compared with 10 s.

The various types of ship movements may, when they become excessive, cause different kinds of damages. Large surge movements may as an example cause breaking of mooring lines and collision with other ships aft or for. Yaw and sway movements may also cause breaking of mooring lines, but also in many cases damage to quay and fenders or to the ship itself.

It is, however, important to notice that ship movements are only one of several parameters influencing the conditions (ease and speed) of loading and unloading operations and safe stay at berth for a moored ship. Of major importance is also:

- Loading/unloading equipment and the level of skill and experience of the personnel,
- Type of goods to be handled,
- Type of vessel,
- Waiting time due to lacking capacity or efficiency at the quay front or for transport in the port,
- Wind,
- Snow, ice,
- Rain,
- Light.

The acceptable movements of a ship in a certain port are dependent on a number of factors:

- Local conditions,
- Loading/unloading methods, i.e. cranes on ship or quay, other devices for bulk or liquid products or Ro-Ro type operations,
- Movement pattern of the vessel, i.e. acceptable movement depends on not only the magnitude of movements but also on their composition,
- Mooring and fender system.

#### Possibility for Escape and Alternative Ports

Another very important factor to be considered for the safety of harbours is whether it is possible for a vessel experiencing excessive movements to leave the port and survive the storm either at sea or in an alternative harbour. In some ports, the manoeuvring conditions in the harbour entrance are so difficult that ships cannot enter or leave the port once a storm has reached the site. In such a port, the aspect of safe mooring at berth becomes even more important as the vessels have no other choice but to stay in the port.

#### Summary of Harbour Problems

The following Fig. 3 schematically presents an impression of the parameters which influence and might cause problems for mooring of vessels in a port.

#### Field Measurements

The measurements included ship movements, mooring forces, wind, waves off the port and inside the port and, in one occasion, fender deflections. The field measurements of ship movements were carried out with two different types of equipment developed in Iceland/Faroe Islands and Norway, respectively. Figs. 4 and 5 show the principles of the two different measuring systems. The Icelandic instrumentation was a further development of the Norwegian type to allow for measuring larger movements.

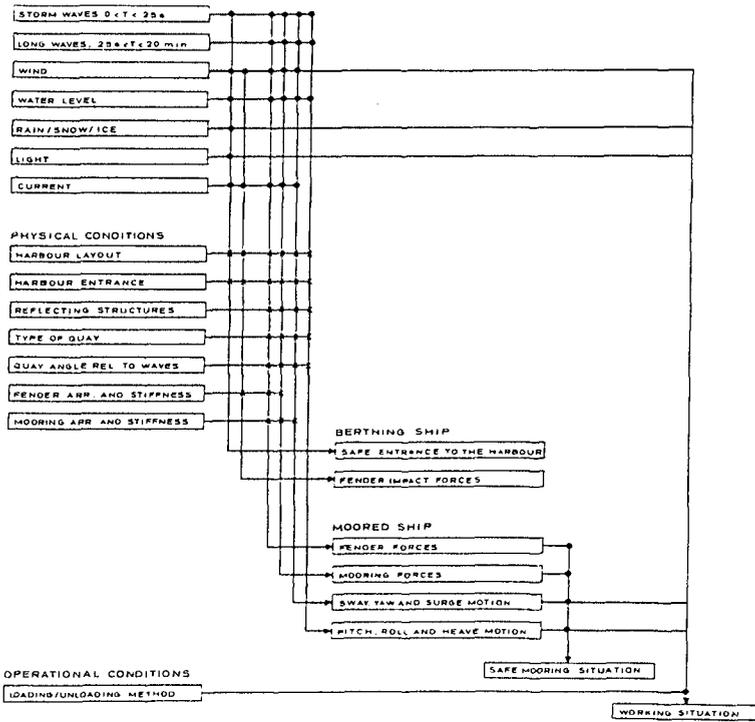
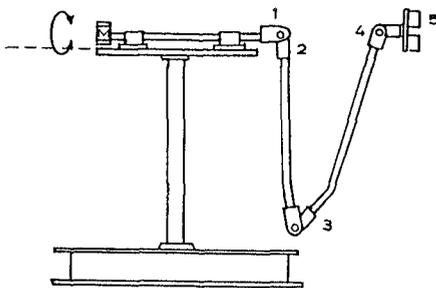


Figure 3. Parameters of importance for the conditions for a moored vessel.



- M: ROTATION (Pitch movement)
- 1: Angle in the horizontal plane
- 2: Angle in the vertical plane
- 3: Angle in the vertical plane
- 4: Angle in the vertical plane
- 5: Angle in the horizontal plane

Figure 4. Principle of Norwegian instrument.

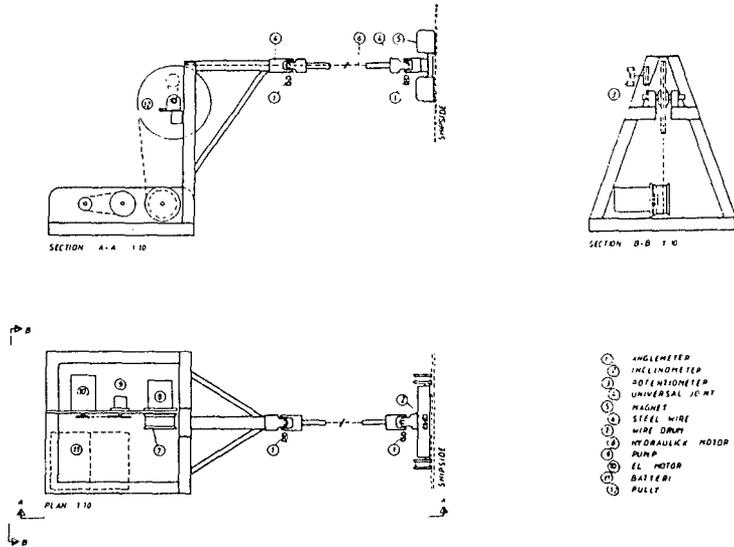


Figure 5. Principle of Islandic instrument.

The measurements were analysed to determine representative parameters, such as:

- $T^S$  : the significant period determined by Z-crossing  
 $T^m$  : the mean period determined by Z-crossing  
 $T_{mo2}^m$  : a characteristic period determined through spectral analysis.  $T_{mo2}^m = 2\pi\sqrt{m_0/m_2}$   
 $T_P$  : the peak period determined through spectral analysis  
 $H_s$  : a significant value determined as the average of the highest third  
 $H^m$  : the mean value determined by Z-crossing  
 $H^{max}$  : the maximum value determined by Z-crossing  
 $H_o$  : 4 x the rms-value determined through spectral analysis  $H_o = 4\sqrt{m_0}$   
 $H_{rms}$  : 4 x the rms-value determined by Z-crossing.

### Questionnaire

A questionnaire was used in parallel with the measurements in order to quantify the results of the measurements. However, the questionnaire was also used in situations where measurements did not take place. This was done in order to obtain more data and to obtain a more complete knowledge of conditions in certain ports.

The questionnaire contained four main items:

- Information on harbour, quay, ship (incl. moorings etc.),
- Evaluation by ship personnel of the situation during the measurements,
- Evaluation by ship personnel of whether it is necessary to interrupt the operations,
- Evaluation by ship personnel of critical mooring situations.

### Results of Field Measurements

A total of 117 measurement sequences were carried out with 11 in Denmark (Hirtshals and Hanstholm), 22 at the Faroe Islands (Torshavn, Lervik and Klaksvik), 24 in Iceland (Reykjavik, Thorlakshöfn and Akranes), 43 in Sweden (Visby) and 17 in Norway (Vardö).

The measurements were carried out on different types of vessels: large passenger and car ferries, cargo vessels, trawlers, smaller fishing vessels and container vessels. In national reports, more detailed information on the ships, i.e. type and size of ships, loading/unloading equipment, mooring arrangement, etc., are presented.

Fig. 6 shows as an example results of measurements on a 27.4 m long vessel in Torshavn, Faroe Islands.

Fig. 7 shows the analyses of the same data.

In Fig. 8, results from nearly all the measurements of ship movements have been related to the length of the ship. It has been distinguished whether it was possible to load/unload or whether the movements were excessive for operations, but still allowed the ship to stay at berth.

### Supplementary Investigations

Supplementary investigations were carried out including studies of the actual conditions in ports and harbours in which hydraulic model tests had been undertaken within the last 10-15 years using irregular natural waves for testing.

Fig. 9 shows an example from Visby in Sweden comparing field measurements of ship movements, mooring forces and wave disturbance with the results of hydraulic model tests of ship movements made at DHI.

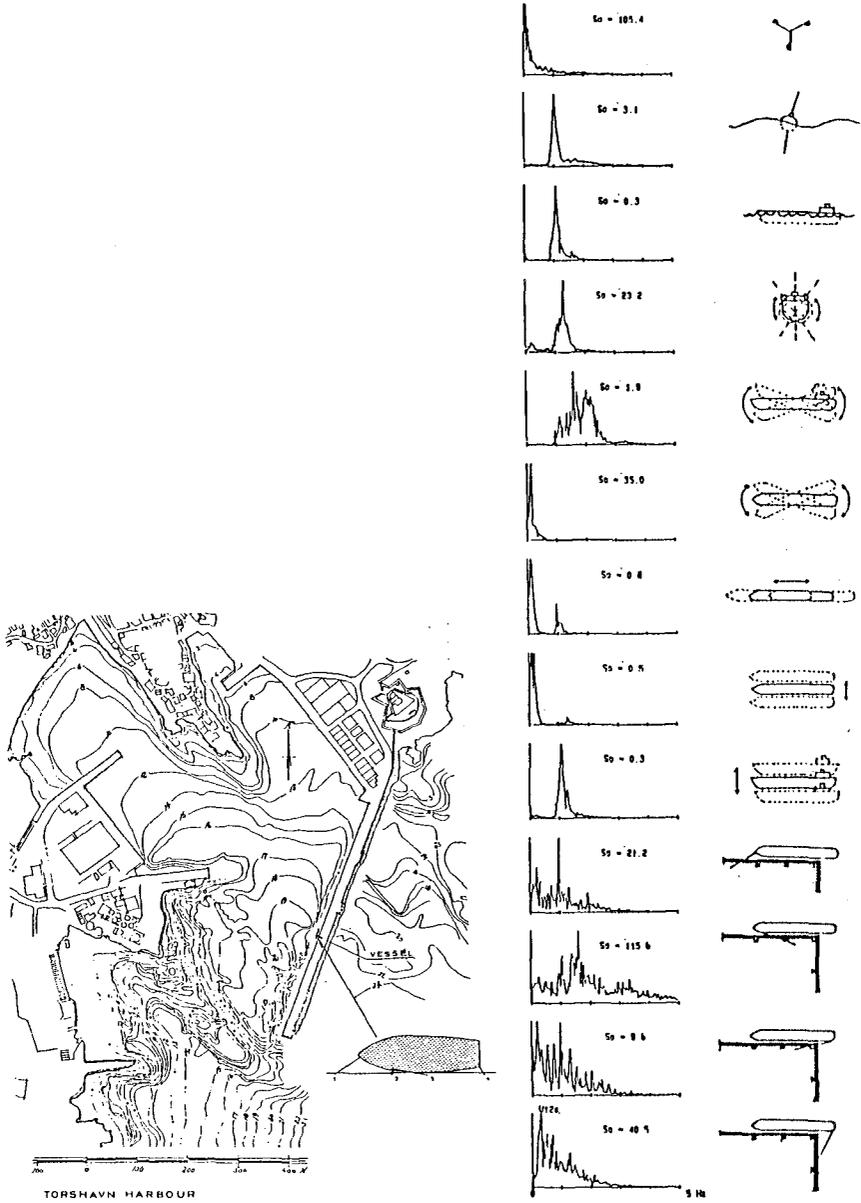


Figure 6. Example of field measurements in Torshavn, Faroe Islands.

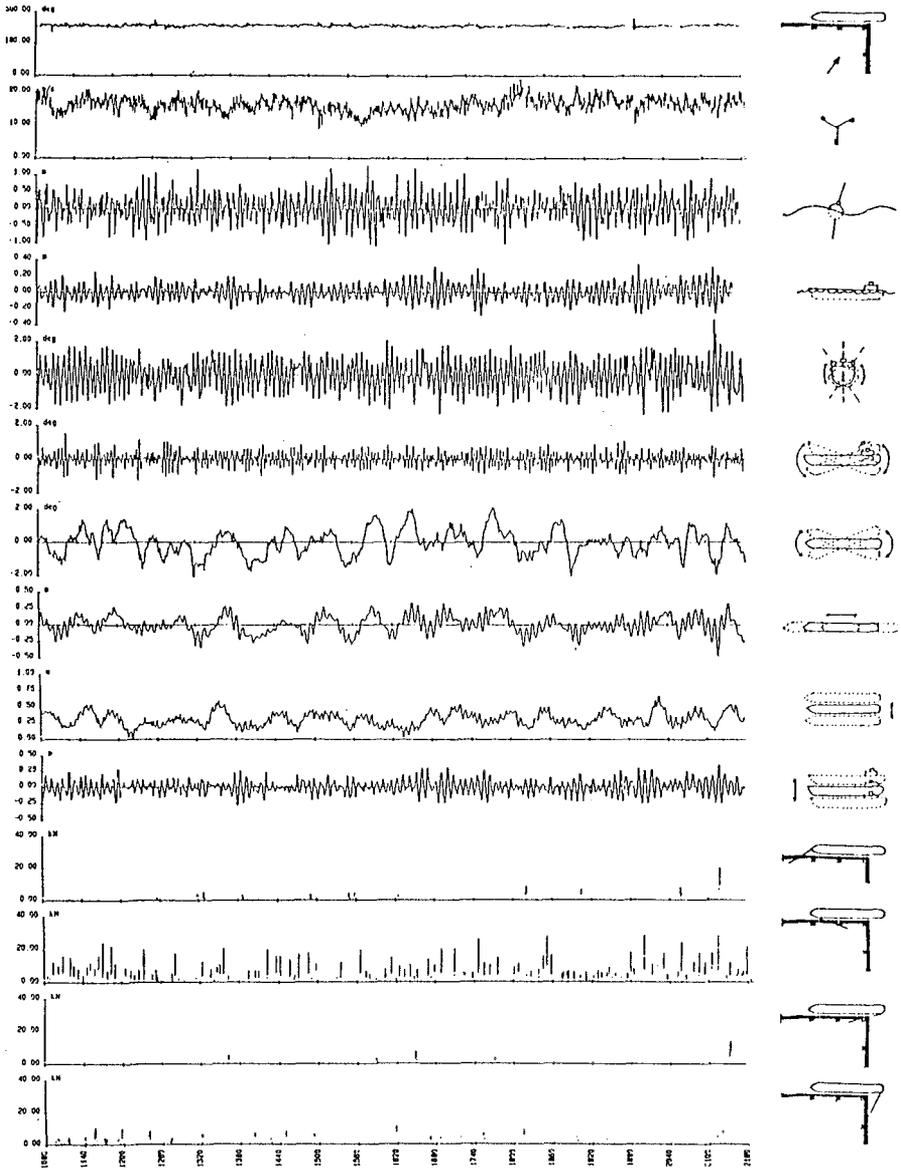


Figure 7. Results of field measurements in Torshavn, Faroe Islands.

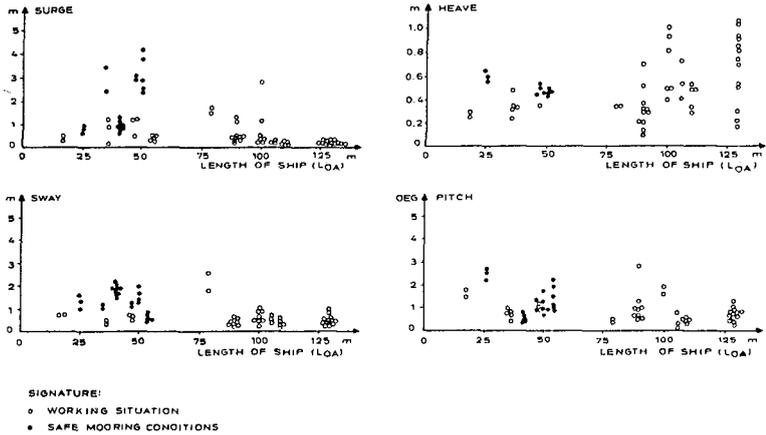


Figure 8. Ship movements in relation to the length of the ship.

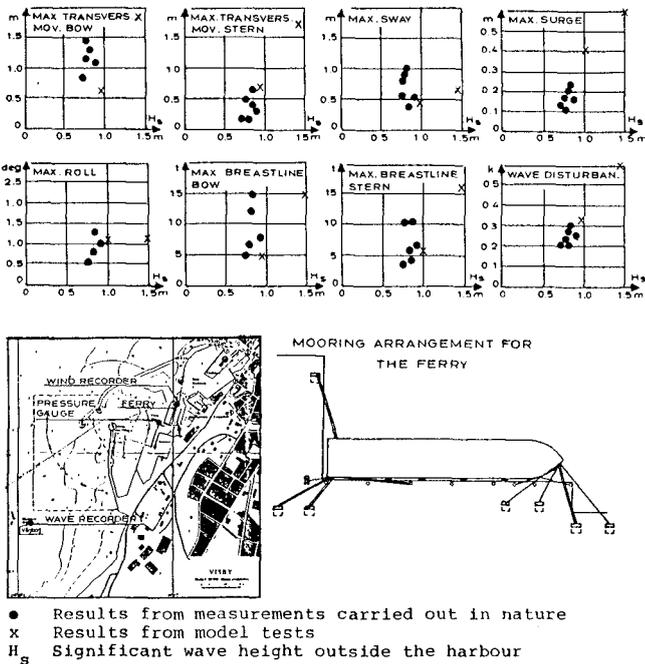


Figure 9. Example from Visby (Sweden).

It appears that there is a reasonable agreement between the field and model measurements. The differences found is believed to be caused by uncertainty about the stiffness and pretensioning of the mooring lines in nature.

### Criteria for Acceptable Ship Movements

The following definitions have been adopted:

#### Interrupted Working Situation:

This situation is characterised by movements causing an interruption or a substantial reduction of the effectiveness of the loading/unloading operations. For this critical movement, analysis of the frequency of occurrence were undertaken. The results depend to a certain extent upon type of vessel and loading/unloading operations.

The investigations carried out have shown that on the average, a harbour in which operations have to be stopped for a total of up to 1 week/year may normally be regarded as having acceptable conditions for loading/unloading operations.

#### Safe Stay at Berth:

This condition is limited by the largest movements for which no damage occurs to vessel or quay, provided that the vessel is reasonably well moored and the quay is well equipped with fenders.

For acceptable condition in a harbour, attempts should be made to keep the frequency of occurrence of this situation less than once a year.

### Criteria for Ship Movements

Tables 1 and 2 present the main results of the joint Nordic project in terms of criteria for acceptable ship movements for the working situation as well as for safe mooring conditions at berth.

The criteria for safe mooring conditions at berth are also given as critical velocities, as the velocity and the mass of the vessel are important parameters which determine the dynamic forces which may cause damage to the quay and/or the vessel.

Type of vessel	Surge (m)	Sway (m)	Heave (m)	Yaw (deg)	Pitch (deg)	Roll (deg)
<u>Fishing vessels</u> <sup>1)</sup>						
(L <sub>oa</sub> = 25-60 m)						
LO-LO	1.0-1.5	1.0-1.5	0.4-0.6	3-5	4	3-5
Elevator crane	0.15	0.15				1.5
Suction pump	2.0-3.0	1.5-2.0				
<u>Freighters, Coasters</u> <sup>1)</sup>						
(L <sub>oa</sub> = 60-130 m)						
Crane on the vess.	1.0-2.0	1.2-1.5	0.6-1.0	1-3	1-2	2-3
Crane on the quay	1.0-2.0	1.2-1.5	0.8-1.2	2-4	1-2	3-5
<u>Ferries</u> <sup>2)</sup>						
(L <sub>oa</sub> = 100-150 m)						
		0.8	1.0	1.0	1.0	2.0
<u>Container Vessels</u> <sup>1)</sup>						
(L <sub>oa</sub> = 100-200 m)						
90-100% efficiency	0.6-1.0	0.6-0.8	0.6-0.9	0.5	1.5	3.0
50% efficiency	2.0	2.0	1.2	1.5	2.5	6.0

1) Frequency of these movements should be less than 1 week/year (2% of time)

2) Frequency of these movements should be less than 3 hours/year (0.03% of time).

Table 1. Criteria for ship movements (loading/unloading operations). The movements are maximum peak-peak.

Type of vessel	Surge (m)	Sway (m)	Heave (m)	Yaw (deg)	Pitch (deg)	Roll (deg)
<u>Fishing vessels</u>						
(L <sub>oa</sub> = 25-60 m)						
Movement	1.2-1.5	1.0-2.0	0.6-1.0	6	4	8
<u>Freighters, Coasters</u>						
(L <sub>oa</sub> = 60-120 m)						
Movement	1.0-2.0	1.5-2.0	1.0-1.5	3-5	2-3	6
<u>Velocity</u>						
Size of vessel						
about 1000 DWT	0.6 m/s	0.6 m/s		2.0 deg/s	2.0 deg/s	
about 2000 DWT	0.4 m/s	0.4 m/s		1.5 deg/s	1.5 deg/s	
about 5000 DWT	0.3 m/s	0.3 m/s		1.0 deg/s	1.0 deg/s	

Table 2. Criteria for vessel movements for safe mooring conditions at berth. The movements are peak-peak values. For the berth to be acceptable, the frequency of these movements should be less than 3 hours/year.

Criteria for Wave Height

Wave height criteria for safe mooring conditions at berth were also established. Table 3 presents the main result.

Ship type	$L_{oa}$ (m)	$H_s$ (m)
Open boats	5-12	0.20
Other boats	5-12	0.30
Small fishing vessels	15-30	0.30
Coasters (<2,000 DWT)		0.45

$H_s$  is the significant wave height equal to the mean value of the highest one-third of the waves in a wave train. This criterion is valid only if wind waves are causing the disturbance. In harbours where seiching/long periodic waves are significant, the indicated wave height cannot be regarded as a criterion for acceptable conditions.

Table 3. Wave height criteria for safe mooring conditions.

Further Studies

PIANC decided upon review of the study report of the Nordic Research Project to set-up a new international working group for the study of Criteria for Ship Movements in Harbours and related problems. The group is chaired by the first author of this paper and three of the authors are members of the PIANC Working Group. Contributions and suggestions from firms, institutions and individuals on the subject of Ship Movements will be graciously acknowledged.

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NOTE: Five national reports available.

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