

BACKGROUND



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SECTION

REGULATIONS AND INTERMODAL FORCES

OVERVIEW

General. Regulations and Intermodal Forces (Section I) summarizes applicable hazardous materials transportation requirements for surface (rail and highway) and maritime intermodal shipments. Further, it provides an overview of the different forces encountered in the various intermodal shipping environments. A thorough understanding of these areas is essential in order to properly conduct load planning.

UNITED STATES AND INTERNATIONAL STANDARDS

GENERAL

Regulations governing the transport of packaged hazardous materials for both interstate and intrastate commerce in the United States are published in Title 49 of the Code of Federal Regulations (CFR), Parts 171-180. The requirements for the safe loading and securing of hazardous materials are located in modal specific parts: Part 174 for rail, Part 176 for water, and Part 177 for highway. Additionally, within the constraints

imposed by 49 CFR 171.22, shipments where part or all of the transport is by water may use the recommendations contained in the International Maritime Dangerous Goods (IMDG) Code, including the loading and securing standards of Chapter 7.5 of the IMDG Code and the IMO/ILO/UNECE Guidelines for Packing of Cargo Transport Units in the IMDG Code Supplement. Regulatory standards are available as follows:

Sources of Supply for U.S. Hazardous Material Transportation Regulations. Like all other federal regulations, Title 49 CFR Parts 100-185 may be purchased from: Superintendent of Documents, U.S. Government Printing Office, 732 North Capital Street NW, Washington, D.C., 20401 [Phone: (202) 512-1800]. Additionally, the World Wide Web provides information concerning hazardous material transportation requirements, including rulemakings, the current edition of Title 49 CFR Parts 100-185, and other useful information (address: <http://hazmat.dot.gov>).

Sources of Supply for International Maritime Organization Standards. A comprehensive listing of distributors of International Maritime Organization (IMO) publications, including the IMDG Code, is provided in the IMO Publications Catalogue available through the IMO, 4 Albert Embankment, London SE1 7SR, United Kingdom [Phone: + 44 (0) 20-7735 7611] or sales@imo.org.



SHIPPER RESPONSIBILITIES

Non-compliance with hazardous materials transportation regulations, including loading and securing standards, pose unnecessary risks to the public, property, and the environment. The failure of shippers and carriers to follow these standards may cause or contribute to the severity of transportation accidents which also may result in disruptions to the transportation system and trade. Consequently, the adequate training of workers preparing hazardous material shipments is not only good business practice, it is the law. While 49 CFR 172 Subpart H describes specific training requirements, the key regulation under which all shippers of hazardous materials in the United States must operate – Section 173.1(b) of Title 49 Code of Federal Regulations [49 CFR 173.1(b)] states:

A shipment of hazardous material that is not prepared for shipment in accordance with this subchapter may not be offered for transportation by air, highway, rail or water. It is the responsibility of each hazmat employer subject to the requirements of this subchapter to ensure that each hazmat employee is trained in accordance with the requirements prescribed in this subchapter. It is the duty of each person who offers hazardous materials for transportation to instruct each of his officers, agents, and employees having any responsibility for preparing hazardous materials for shipment as to applicable regulations in this subchapter.

SPECIAL PERMITS

to the hazardous material transportation regulations are issued by the U.S. Department of Transportation through the Pipeline and Hazardous Materials Safety Administration's Office of Special Permits and Approvals. Special Permits are vital to industry, allowing quick implementation of new technology and evaluation of new operational techniques which often increase productivity and enhance transportation safety. Special Permits not only authorize a person to perform a function that is not otherwise allowed by 49 CFR 171-180, but serve as Competent Authority Approval for the United States under the IMDG Code. A detailed explanation of Competent Authority Approvals and Special Permits is found in 49 CFR Part 107. The recommended point of contact is:

U.S. Department of Transportation

Pipeline and Hazardous Materials Safety Administration
Office of Hazardous Materials Special
Permits and Approvals (PHH-31)
East Building, 2nd Floor
1200 New Jersey Avenue, SE
Washington, DC 20590
Phone (202) 366-4535

World Wide Web Address:

www.phmsa.dot.gov/hazmat/regs/sp-a

COMPLIANCE INSPECTIONS

All hazardous material shipments are subject to routine compliance inspections by U.S. Department of Transportation (DOT) administrations including the Federal Highway Administration (FHWA), Federal Railroad Administration (FRA), U.S. Coast Guard (USCG), and Pipeline and Hazardous Materials Safety Administration (PHMSA). Inspectors may detain containers until corrective action is completed and/or initiate civil penalty action for violation of these hazardous materials regulations. Civil penalties can be assessed in amounts up to \$55,000 per violation per day. Criminal penalties -- for willful violation of the regulations -- are subject to Title 18, United States Code and/or 5 years imprisonment except in the case of a violation involving death or bodily injury is subject to 10 years. When configuring loads, and the blocking and bracing to secure those loads, keep in mind inspectors may need to visually inspect the shipment. To avoid undue delays, configure the loads such that the contents, and the required labels and markings, can be seen from the doors.

LOADING AND SECUREMENT REQUIREMENTS

The following excerpts of the October 2009 edition of Title 49 CFR cover only general loading and bracing requirements for

hazardous materials (other than explosives) for shipment by rail, highway, and the water modes. For certain hazard classes, there are additional loading and securement requirements within each modal section of the regulations. Consult the current edition of Title 49 CFR Parts 100-185 (the federal hazardous material transportation requirements for rail, highway, and maritime modes) for updates and specific additional requirements. For questions, use the DOT points of contact listing provided in Appendix A of this guide.

SURFACE (RAIL AND HIGHWAY) REQUIREMENTS

SUMMARY OF RAIL REGULATIONS

A summary of federal transportation regulations for the loading and securement of hazardous material cargoes for rail transportation follows:

49 CFR Part 174, Carriage by Rail Highlights

§174.55 General requirements. (a) Each package containing a hazardous material being transported by rail in a freight container or transport vehicle must be loaded so that it cannot fall or slide and must be safeguarded in such a manner that other freight cannot fall onto or slide into it under conditions normally incident to transportation. When this protection cannot be provided by using other freight, it must be provided



by blocking and bracing. For examples of blocking and bracing in freight containers and transport vehicles, see Bureau of Explosives Pamphlet Nos. 6 and 6C. **Must be loaded, blocked and braced. Each hazmat package must be loaded so that it cannot fall or slide and must be safeguarded so other freight cannot fall or slide into it.**

(b) Each package containing a hazardous material bearing package orientation markings prescribed in Sec. 172.312 of this subchapter must be loaded within a transport vehicle or freight container to remain in the correct position indicated by those markings during transportation. **Comply with orientation markings when securing packages.**

(c) The doors of a freight container or transport vehicle may not be used to secure a load that includes a package containing a hazardous material unless the doors meet the design strength requirements of Specification M-930 (for freight containers) and M-931 (for trailers) in the AAR's specification for "Specially Equipped Freight Car and Intermodal Equipment" (incorporated by reference see 171.7 of this subchapter) and the load is also within the limits of the design strength requirements for the doors.

§174.61 Transport vehicles and freight containers on flatcars.

(a) A transport vehicle, freight container, or package containing a hazardous material must be designed and loaded so that it will

not become damaged to an extent that would affect its integrity under conditions normally incident to transportation. Each unit must be secured on a flatcar so that it cannot permanently change position during transit. Packages of hazardous materials contained therein must be loaded and braced as provided by §§174.101, 174.112, 174.115 and 174.55. Placards must be applied when prescribed by Part 172 of this subchapter and Part 174.

Cargo Transport Units must be adequate. TOFC or COFC must be adequately secured on flat car.

§174.63 Portable tanks, IM portable tanks, intermediate bulk containers, cargo tanks, and multi-unit tank car tanks. (a)

A carrier may not transport a bulk packaging (e.g., portable tank, IM portable tank, intermediate bulk container, large packaging, cargo tank, or multi-unit tank car tank) containing a hazardous material in container-on-flatcar (COFC) or trailer-on-flatcar (TOFC) service except as authorized by this section or unless approved for transportation by the Associate Administrator for Safety, FRA. **Applies to bulk packages that can be loaded into freight containers and transport vehicles. Requires FRA approval if the conditions of 174.63 (b) or (c) cannot be met.**

(b) A bulk packaging containing a hazardous material (including IM 101 and IM 102 when appropriate according to dimensions and weight distribution) may be transported in a fully closed transport vehicle or fully closed freight container provided it is properly

secured with a restraint system that will prevent it from changing position, sliding into other packages, or contacting the side or end walls (including doors) under conditions normally incident to transportation.

(c) When not transported in conformance with and subject to paragraph (b) of this section, a bulk packaging may be transported in COFC service or TOFC service subject to the following conditions as applicable: **(1)** The bulk packaging contains a material packaged in accordance with §§173.240, 173.241, 173.242, or 173.243 of this subchapter; **(2)** The tank and flatcar conform to requirements in AAR 600 of the AAR Specifications for Tank Cars, entitled "Specification for Acceptability of Tank Containers"; **(3)** For TOFC Service, the trailer chassis conforms to requirements in paragraphs 3, 4, 5, and 6 of AAR Specification M-943 "Container Chassis For TOFC Service" of the AAR specification for "Specially Equipped Freight Car and Intermodal Equipment"; **(4)** For COFC service, the container support and securement systems conform to requirements in Specification M-952 "Intermodal Container Support and Securement for Freight Cars", of the AAR specification for "Specially Equipped Freight and Intermodal Equipment"; **(5)** If transported in a well car- **(i)** The tank is not in a double-stacked configuration (i.e., no freight container or portable tank is placed above or below the tank); and **(ii)** The tank is transported in the well with its outlet valve facing outward

towards the end of the well and away from any adjacent tank or container; and **(6)** All securement fittings shall be fully engaged and in the locked position, provided; however, if the tank is transported in a well car, it must be loaded into a well appropriate for the length of the container and any void filling device present must be secured in its designed appropriate position.

(d) An approval in effect on February 28, 1991 for the transportation of portable tanks or IM portable tanks in TOFC or COFC service expires on the date stated in the approval letter or June 15, 1995, whichever is later.

SUMMARY OF HIGHWAY REGULATIONS

A summary of federal transportation regulations for the loading and securement of hazardous material cargoes for highway transportation follows:

49 CFR Part 177, Carriage by Public Highway Highlights

§177.804 Compliance with Federal Motor Carrier Safety Regulations. Motor carriers and other persons subject to this part shall comply with 49 CFR parts 383, and 390 through 397 (excluding §397.3 and 397.9) to the extent those regulations apply. **Compliance with 49 CFR 383 and 390-397 are required.**



§177.834 General requirements. (a) Packages secured in a vehicle. Any package containing any hazardous material, not permanently attached to a motor vehicle, must be secured against shifting, including relative motion between packages, within the vehicle on which it is being transported, under conditions normally incident to transportation. Packages having valves or other fittings must be loaded in a manner to minimize the likelihood of damage during transportation. **Packages of hazardous materials must be secured against movement and package valves and fittings must be protected.**

SURFACE SEGREGATION REQUIREMENTS

Hazardous materials transported by rail or highway must not be loaded or stored together in the same cargo transport unit except as provided by 49 CFR 174.81 (rail) or 177.848 (highway). In cases of a multi-modal shipment where segregation requirements differ, the shipper should use the most restrictive standard. In particular, if the shipment will include a maritime leg, use the maritime segregation requirements which are generally more stringent than corresponding surface requirements. (See Maritime Requirements in this section for a more complete discussion of maritime segregation requirements).

MARITIME REQUIREMENTS

Shipments of hazardous materials by vessel within the jurisdiction of the United States must comply with the requirements found in Title 49, Code of Federal Regulations. However, Title 49 authorizes the use of the IMDG Code under the criteria described in 49 CFR 171.22. While the Federal hazardous materials regulations in Title 49 CFR generally agree with the IMDG Code recommendations for the transport of dangerous goods aboard vessels, there are differences. 49 CFR §§171.22, 171.23, 171.25 and 176.11 set forth the specific conditions and limitations under which hazardous materials may be transported by vessel in the United States under the provisions of the IMDG Code in lieu of Title 49 requirements. Note that although 49 CFR 171.22 is titled “Authorization And Conditions For The Use Of International Standards And Regulations” the provisions of 49 CFR §§171.23 and 171.25 may be applied when all or part of the transport is by vessel, including domestic vessel transport and rail or highway movement, which also includes a maritime transport leg. Because of the wide recognition and application of the IMDG Code in international maritime transport by both foreign Administrations and vessel operators, it is recommended that it be followed whenever an import or export shipment is being planned.

INTERNATIONAL REQUIREMENTS

SOLAS. The International Convention for the Safety of Life at Sea, 1974 (SOLAS), as amended, deals with various aspects of maritime cargo transportation including: Regulation 3 of Part A of Chapter VII of SOLAS prohibits the carriage of dangerous goods in packaged form except in accordance with the provisions of the IMDG Code.

Competent Authority Designation for the United States. Within the IMDG Code, allowance is made in certain situations for approvals, permits or certificates to be issued by the Competent Authority of a member government. Competent Authority designations for the IMDG Code are listed in Chapter 7.9 of Volume I. The Competent Authority designated for the United States is the Associate Administrator for Hazardous Materials Safety (PHH-1), Pipeline and Hazardous Materials Safety Administration, U.S. Department of Transportation. The recommended point of contact is:

U.S. Department of Transportation

Pipeline and Hazardous Materials Safety Administration
Office of International Standards (PHH-70)
East Building / PHH-70
1200 New Jersey Avenue, S.E.
Washington, D.C. 20590-0001

Phone: (202) 366-0656

World Wide Web Address: www.hazmat.dot.gov/

U.S. Coast Guard Assistance: In addition, the following office may be contacted to facilitate Competent Authority actions:

U.S. Coast Guard

Hazardous Materials Standards Division (CG-3PSO-3)

2100 Second Street SW

Washington, D.C. 20593-0001

Phone: (202) 372-1420 or (202) 372-1426

Other International Maritime Publications. A comprehensive listing of distributors of International Maritime Organization (IMO) publications, including the IMDG Code, is provided in the *IMO Publications Catalogue* available through the IMO, 4 Albert Embankment, London SE1 7SR, United Kingdom

Email: info@imo.org; Fax: +44 207587 3120.



SUMMARY OF MARITIME REGULATIONS

A summary of federal and international transportation regulations for the loading and securement of hazardous material cargoes for maritime transportation follows:

49 CFR Part 176, Carriage by Vessel (IMDG Code Reference Highlights)

§176.27(c) Certificate. (1) A person responsible for packing or loading a freight container or transport vehicle containing hazardous materials for transportation by a manned vessel in ocean or coastwise service, must provide the vessel operator, at the time the shipment is offered for transportation by vessel, with a signed container packing certificate, at a minimum that—
(i) The freight container or transport unit is serviceable for the materials loaded therein, contains no incompatible goods, and is properly marked, labeled or placarded, as applicable; and (ii) When the freight container or transport unit contains packages, those packages have been inspected prior to loading, are properly marked, labeled or placarded, as applicable; are not damaged; and are properly secured. **Volume I: Section 5.4.2 Container/Vehicle Packing Certificate Requirement.**

(2) The certification may appear on a shipping paper or on a separate document as a statement such as “It is declared that the packing of the container has been carried out in accordance with

the applicable provisions of [of 49 CFR], [of the IMDG Code], or [of 49 CFR and the IMDG code].”

§176.69 General stowage requirements for hazardous materials. (d) Packages of hazardous materials must be secured and dunnaged to prevent shifting in any direction. Vertical restraints are not required if the shape of the package and the stuffing pattern preclude shifting of the load. (e) Packages of hazardous materials must be braced and dunnaged so that they are not likely to be pierced by the dunnage or crushed by a superimposed load.

§176.76 Transport vehicles, freight containers, and portable tanks containing hazardous materials. (a) Except as provided in paragraphs (b) through (f) of this section, hazardous materials authorized to be transported by vessel may be carried on board a vessel in a transport vehicle or freight container subject to the following conditions (see additional requirements concerning the transport of Class 1 (explosive) materials in §176.168 through §176.172 of this subchapter: **Volume I: Parts 4 and 7.**

(1) The material must be in proper condition for transportation according to the requirements of this subchapter. **Volume I: Section 5.1.1.2**

(2) All packages in the transport vehicle or freight container must be secured to prevent movement in any direction. Vertical

restraint is not required if the shape of the packages, loading pattern, and horizontal restraint preclude vertical movement of the load within the freight container or transport vehicle. **Volume I:Section 7.5.2; Supplement: IMO/ILO/UNECE Guidelines for Packing of Cargo Transport Units; Section 4 Additional advice on the packing and securing of dangerous goods**

(3) Bulkheads made of dunnage which extend to the level of the cargo must be provided unless the packages are stowed flush with the sides or ends. **Supplement: IMO/ILO/UNECE Guidelines for Packing of Cargo Transport Units; Section 4 Additional advice on the packing and securing of dangerous goods**

(4) Dunnage must be secured to the floor when the cargo consists of dense materials or heavy packages. **Supplement: IMO/ILO/UNECE Guidelines for Packing of Cargo Transport Units; Section 3.2.2 Ladings, such as those transported in full size drums, are subject to this requirement.**

(5) Each package marked in accordance with 172.312(a)(2) of this subchapter must be stowed as marked. **Supplement: IMO/ILO/UNECE Guidelines for Packing of Cargo Transport Units; Sections 3.2.11 and 4.3.6 Package Orientation within freight container.**

(6) Any slack spaces between packages must be filled with dunnage. **Supplement: IMO/ILO/UNECE Guidelines for Packing of Cargo Transport Units; Section 3.2.3** No voids. Place any

required labels and markings in such a way as to make visual inspection easier for inspectors. It may save time and expense.

(7) The weight in a container must be distributed throughout as evenly as possible and the maximum permissible weight must not be exceeded. **Supplement: IMO/ILO/UNECE Guidelines for Packing of Cargo Transport Units; Section 3.2.5 Even load; Distributed.**

(8) Adjacent levels of bagged and baled cargo must be stowed in alternate directions so that each tier binds the tier above and below it.

(10) The lading must be contained entirely within the freight container or vehicle body without overhang or projection except that oversized machinery such as tractors or vehicles with batteries attached may overhang or project outside the intermodal container provided all of that portion of the lading that consists of hazardous materials is contained entirely within the freight container. No open bed container or vehicle is permitted to carry hazardous materials unless it is equipped with a means of properly securing the lading. **Supplement: IMO/ILO/UNECE Guidelines for Packing of Cargo Transport Units; Section 3.1.9 Hazardous materials must be within freight container or vehicle body. Open bed containers must be equipped with restraint capability.**

(b) A transport vehicle containing hazardous materials may be carried only on board a trailer ship, ferry vessel or car float.



§176.83 Segregation. (d) Segregation in transport units: Two hazardous materials for which any segregation is required may not be stowed in the same transport unit. **Volume I: Chapter 7.2.2 Segregation required for incompatible hazardous materials.**

MARITIME SEGREGATION REQUIREMENTS

Maritime segregation requirements are considerably more stringent than their surface transportation counterparts in many respects. Therefore, if an intermodal shipment includes a maritime leg, shippers should ensure the appropriate maritime segregation requirements are met. In most respects, the segregation requirements contained in the Federal Regulations are consistent with those found in the IMDG Code.

Federal Regulations. Maritime segregation requirements are found in 49 CFR Part 176, Subpart D-General Segregation Requirements with additional requirements for explosives segregation found in sections 176.140 through 176.146. Of particular relevance to this guide is 49 CFR 176.83 (d), which prohibits the stowage of incompatible hazardous materials within the same cargo transport unit. Consequently, any hazardous materials which must be stowed “away from”, “separated from”, “separated by a complete bulkhead from”, “separated longitudinally by an intervening complete compartment or hold from” as summarized in 49 CFR Table 176.83(b), and other applicable segregation or stowage requirements identified in the

Hazardous Materials Table in 49 CFR 172.101 may not be stored in the same cargo transport unit.

IMDG Code. Chapter 7.2 of Volume I of the IMDG Code contains the principal segregation provisions. Additional provisions are contained in 7.1.1.12 (with reference to 3.4.3) for shipments of limited quantities materials and in 2.1.2 of Class 1-Explosives. Paragraph 7.2.2.2.1 of the IMDG Code corresponds to 49 CFR 176.83 (d) and generally prohibits the stowage of incompatible hazardous materials within the same cargo transport unit. Although paragraph 7.2.2.3 allows hazardous materials that should be segregated “away from” each other to be carried in the same cargo transport unit with the approval of the Competent Authority, the United States Competent Authority has never authorized this approach. One other item of possible difference between 49 CFR and the IMDG Code is the treatment of dangerous goods that are packaged as limited quantities. While in both rules, relief is granted from the prohibition of stowage of incompatible materials within the same cargo transport unit, there are some differences in the definitions for what constitutes a limited quantity.

THE SHIPPING ENVIRONMENT

The first step in load planning is to understand the forces to which the cargo will be subjected in transit. Each mode of transport presents a different shipping environment that must be accommodated in the load plan. A container carried on a chassis (highway), for example, will be subject to different forces than that carried on a rail flat car, and thus may require a different system of securing the load. Consequently, for intermodal cargo movements, all transportation environments to be encountered should be considered and cargo secured for the most severe transportation mode to be encountered. An intermodal shipment may combine all three transportation modes, as follows:

- Shipper loads a container which is then transported by highway to a rail head;
- Container is transferred to rail car and transported by rail (COFC) to a seaport;
- Container is transferred to freight vessel (containership or RORO) and transported across the ocean to the port of destination;
- Container is transferred to surface transportation mode(s) and received by the consignee and unloaded.

FORCES AFFECTING CARGOES IN SURFACE AND MARITIME TRANSPORTATION

GENERAL

While each method of transportation presents its stresses and hazards to cargo in transport, some cross modal boundaries. During the design of a load plan, the types and degrees of stress most likely to be encountered should be considered. Some of the publications that discuss transportation forces and provide blocking and bracing guidelines are provided in the Bibliography of this guide. Additionally, a representative intermodal standard is provided as Table I.1 below:

***Source: American Bureau of Shipping, Rules for the Certification of Cargo Containers

Note: The ABS standard is representative of several similar standards. However, some differences in acceleration values exist among the standards. e.g., IMO/ILO/UN/ECE's "Guidelines for the Packing of Cargo Transport Units" use a 4G longitudinal acceleration value for rail. Acceleration values are expressed as multiples of the standard acceleration (1G) due to gravity of 32 feet per second² (9.8 meters per second²). As an example of the effect of acceleration on a cargo load, consider a cargo weighing 4000 pounds experiencing a 2G acceleration. The resulting force would be 4000 pounds x 2G = 8,000 pounds.



Table 1.1, American Bureau of Shipping (ABS) Intermodal Acceleration Standard ¹

Mode	Longitudinal Acceleration	Lateral Acceleration	Vertical Acceleration	
			Down	Up
Rail	2.0G	0.3G	1.7G	1.7G
Highway	0.7G	0.2G	1.7G	0.5G
Maritime	0.4G	0.6G	1.8G	1.8G
Terminal Handling	None	None	2.0G	None

RAIL

While there are some differences in the shipping environments of Trailer on Flat Car (TOFC) and Container on Flat Car (COFC) rail shipments, they are considered to be the same for the purposes of this guide. Rail transportation subjects the cargo primarily to longitudinal shocks. Trailers or containers may be carried in backwards or reverse direction. Therefore, impact can come from either direction - to the nose or the doors of the container - and load planning must prepare for impact from both directions. Rail loads characteristically experience stresses from the following:

- **Coupler slack** can lead to individual cars accelerating or decelerating at rates different from the whole train. This causes longitudinal forces on the load.
- **Coupling impact or shock** causes longitudinal forces on the load.
- **Suspension system and track dynamic vibration**, which can produce frequencies as high as 5 cycles/sec with 'G' forces up to 1.25.
- **Sway or side to side motion** from curves or uneven track causes lateral forces on the load.

HIGHWAY

The characteristic forces on lading during highway transport are due to the following:

Primary hazards. Major hazards include:

- **Vertical shocks** from surface irregularities from rough roads, bridge crossings, etc.
- **Vibrations**, particularly vertical, from road conditions, speed, and vehicle/cargo characteristics.

Secondary hazards. Less significant hazards include:

- **Longitudinal shocks** from impacts against loading docks, coupling impacts, braking, and accelerations.
- **Lateral shocks and sway** from running over curbs or other abrupt surface irregularity encountered by one side of the trailer

CARGO HANDLING AT THE PORT INTERFACE

The port interface is the waterfront facility where the maritime and surface transportation modes converge. Characteristic forces are dependent upon the method of freight handling required for the vessel type:

Roll on/Roll Off vessels (ROROs) generally impose less severe container movements than that for container ships during loading and off loading. Instead of being handled by cranes, trailers and rail cars roll directly onto specially fitted ships and consequently experience the forces of the surface modes of transportation while being loaded or unloaded.

Container ships require specially designed handling equipment at waterfront facilities, such as yard haulers and container cranes, resulting in cargoes experiencing the following forces:

- **Vertical shocks** from lifting and landing containers at the facility and the container ship.
- **Vibrations**, particularly vertical, from road conditions, speed, and vehicle/ cargo characteristics.

Longitudinal shocks from braking, and accelerations by container handling equipment.



VESSEL MOTIONS AT SEA

Shipments are typically subject to a number of independent forces from ship movement. A ship at sea may move in all of the following six directions at once due to wave action (see Figure 1.1, Forces Affecting Maritime Shipments, below):

- **Roll** (motion about the vessel's longitudinal axis).
- **Pitch** (motion about the vessel's transverse axis).
- **Heave** (vertical bodily motion of the vessel).
- **Yaw** (motion about the vessel's vertical axis).
- **Surge** (longitudinal, fore and aft, bodily motion).
- **Sway** (lateral, side to side, bodily motion).

Furthermore, there are two common combination movements:

- **Slamming** (a combination of heaving, surging, and swaying).
- **Pounding** (a combination of heaving and pitching).

In addition, loads can be affected by:

- **Wave** impact (shocks to the vessel from heavy seas).
- **Water** entry (faulty container).
- **Condensation** (from lading or container).

Through movements such as those described above, cargo may be subjected to vertical, athwartship, and fore/aft shifting within the freight container. Because a freight container may be stowed on a ship with its longitudinal axis in the athwartship direction as well as in the more common longitudinal configuration, the possible effects on a container and its lading from ship movement are many. Further, their repetitiveness tends to break down cushioning and bracing. Tight loading and adequate bracing is imperative to prevent damage.

