Chapter 10 Self Weight and Surcharge

Public Notice

Self Weight and Surcharge

Article 20

1 Self weight shall be appropriately set based on the unit weight of the material.

2 Surcharge shall be appropriately set by considering the assumed usage conditions of the facilities and others.

[Technical Note]

1 General

(1) When verifying the performance of port facilities, self weight and surcharge shall be considered, as necessary.

(2) Self weight and surcharge are defined respectively as follows.

① Self weight: the weight of the structure itself

② Surcharge: the weight loaded on top of the structure. This is divided into static load and live load.

(a) Static load
The actions such as general cargo and bulk cargo loaded on aprons, transit sheds, and warehouses are included in static load. In regions with heavy snowfall, the snow on the aprons is regarded also as a kind of static load.

(b) Live load
The following shall be considered as live load as necessary, when verifying the performance of port facilities.

1) train load

2) vehicle load

3) cargo handling equipment load

4) sidewalk live load

(3) The self weight and surcharge used in the performance verification of port facilities must be set in due consideration of the type of actions on the objective facilities and their loading conditions. In particular, the self weight and surcharge have a large effect on the performance verification of circular slip failure of quaywalls, beams and slabs of piers. Therefore, sufficient care should be taken when determining the types and sizes of self weight and surcharge.

2 Self Weight

(1) Self Weight
In the performance verification of the facilities to which the technical standards apply, the self weight must be appropriately set based on the unit weight of the material.

(2) As the characteristic values of the unit weight used in the calculation of self weight, the values given in **Table 2.1** [1] may be generally used. However, in cases where the unit weight can be specified in preliminary survey or other ways, the values in **Table 2.1** are not always applicable.

(3) Unit weights of stone, sand, gravel, and rubble depend on the stone quality, while unit weights of materials other than metals such as steel and aluminum vary according to individual cases. When using these materials, the characteristic values for unit weight must be decided with care.

Table 2.1 Characteristic Values of Unit Weights of Materials [1)]

Material	Characteristic values of unit weight (kN/m^3)
Steel and casting steel	77.0
Casting iron	71.0
Aluminum	27.5
Reinforced concrete	24.0
Un-reinforced concrete	22.6
Timber	7.8
Asphalt concrete	22.6
Stone (granite)	26.0
Stone (sandstone)	25.0
Sand, gravel, and rubble (dry)	16.0
Sand, gravel, and rubble (wet)	18.0
Sand, gravel, and rubble (saturated)	20.0

References

1) Japan Port Association: Handbook of Construction of port facilities, p,140, 1959

3 Surcharge

3.1 Static Load

(1) Surcharge
Surcharge used here means the actions such as static load, snow load, train load, vehicle load, cargo handling equipment load, and sidewalk live load, and when setting them it is necessary to appropriately consider the assumed usage conditions of the facility.

(2) Characteristic values of surcharge shall be set appropriately, considering the usage conditions of port facilities, such as the type, volume and the handling methods of the cargo handled.

(3) Static Load

① Static load in permanent situation

(a) When determining the characteristic values static load in permanent situations, it is preferable to adequately consider the factors such as type of cargo handled, type of packing, volume, handling methods, and loading time.

(b) Generally, in the performance verification, a mean value for each section in an apron, a shed, or a warehouse is used as the static load. However in the performance verification of structural materials, the static load itself is often used. The static load acting on an apron has a large effect on the stability verification of mooring facilities, so it is necessary to consider it separately from the static loads on other facilities such as sheds and warehouses. For an apron, the mean value of the static load per one block usually stays constant by the scale of the mooring facility and the type of cargo handled, and the mean value may be determined with reference to the previous examples of verifications. In the case of general-purpose wharves, the values from about 10 to 30 kN/m^2 are often used as the characteristic values of the static load acting on aprons. As for the aprons where heavy cargo such as containers and steel is handled, it is preferable to determine the value of the static load based on the study of usage conditions.

(c) The characteristic values of unit weights for bulk cargo have been obtained based on surveys of the past actual conditions, which are listed in **Table 3.1.1**. [1)]

Table 3.1.1 Characteristic Values of Unit Weights for Bulk Cargo [1)]

Commodity	Characteristic values of unit weight (kN/m^3)
Coke	4.9
Coal (lump)	8.8-9.8
Coal (fine)	9.8-11.0
Iron ore	20.0-29.0
Cement	15.0
Sand, gravel and rubble	19.0

② Static load during ground motion

(a) It is preferable to determine characteristic values of the static load during ground motion in variable and accidental situations by adequately predicting whether a static load will act or not when the design earthquake occurs in future. Existence or nonexistence of a static load differs from the facilities including sheds, warehouses, open storage yards and aprons. It is assumed that the size of the static load during design ground motion is under control of a probabilistic concept.

(b) Static load during ground motion for sheds, warehouses, open storage and yards may be set according to their types of usage. On the other hand, for facilities such as aprons used as cargo handling facilities where cargo is only placed temporarily, the static load will vary tremendously depending on whether cargo loading operations are underway or not. Moriya and Nagao [2)] performed on-site measurements to study the moment-to-moment change of the static load of bulk cargo that was loaded on an apron, and evaluated the design values for static load during ground motion. According to their results, if the design value for static load during ground motion is calculated in accordance with ISO2394 and Eurocodes, the value becomes 0kN/m^2, but adoption of 0 kN/m^2 as the design value for static load during ground motion results in underestimation of the static load.[2)] Therefore, when using static load during ground motion for a level 1 reliability based design method, it is preferable to assume the mean value of the static load as the characteristic value and to multiply this value by the partial factor 0.5.

③ Unevenly Distributed Load

(a) When verifying the performance of a structure as a whole, the unevenly distributed load may be converted to a uniform load in an area of an apron, transit shed or warehouse. However, where a large concentrated load acts on the structure, it should be considered as the concentrated load.

(b) It is not usually the case where materials such as cargo are evenly loaded over the entire area. However, as an example, when steel is placed on timber pillows, it can be assumed that its weight acts as a line load. In this case it is preferable to assume the weight is a concentrated load such as line load or point load.

(c) When considering a given area, even though the mean value of unevenly distributed load may fall within the value of the replaced uniform load, it is necessary to take account of the case where uneven load acts as a concentrated load. For example, in the case of a sheet pile quaywall, it may be dangerous if a large concentrated load acts on the back of the quaywall. Similarly, in the case of a piled pier, if a concentrated load acts in the center, the pier may break. Such possibilities should be considered when setting the static load.

④ Snow Load

(a) After heavy snowfall, the snow piled up on an apron is compacted and hardened by automobiles, and then it may be a static load. Therefore it is preferable to set an appropriate snow load in line with the actual conditions.

(b) For quaywalls where snow removal operations will be carried out, it is often sufficient to determine the snow load with the accumulated weight of snow over one night. In this case the snow load may be determined by the engineer taking into consideration the past snowfall records, general climatic conditions during snowfall, snow quality and snow removal

(c) In most cases the snow load is set as 1 kN/m^2. This is equivalent to, for example, approximately 70 - 100 cm thickness of dry and new powder snow.

(d) The relationship between normal snow conditions and snow unit weight, described in the **Railway Structure Design Standards and Commentary**,[3)] is shown in **Table 3.1.2**.

Table 3.1.2 Normal Snow Conditions and Characteristic Value of Unit Weight of Snow [3)]

General Snow Condition	Characteristic Value of Unit Weight（kN/m^3）
Dry powder snow compressed under own weight	1.2
Dry powered snow subject to wind pressure	1.7
Fairly wet snow compressed under own weight	4.5
Very wet snow compressed under own weight	8.5

3.2 Live Load

(1) Train Load

Train load shall be applied in such a way to induce the maximum effect on the structures or their members, by taking into consideration the net weight, loaded weight, and axle arrangement of the train or cars which are generally used for the objective section of track. In doing so, train load shall be applied as a full set of multiple loads in succession without dividing it into two or more separate sets.

(2) Vehicle Load

① The vehicle load specified here corresponds to that (T load and L load) specified in the **Highway Bridge Specifications and Commentary**.[5)]

② The international regulations concerning the dimensions and maximum gross mass of containers are set out by the **International Organization for Standardization (ISO)** as listed in **Table 3.2.1.**

Table 3.2.1 Standard Dimension of Containers [6)]

<table>
<tr><th rowspan="2">Type</th><th colspan="4">Length (L)</th><th colspan="4">Width (W)</th><th colspan="4">Height (H)</th><th colspan="2">Rating
(gross mass)</th></tr>
<tr><th>mm</th><th>Allowance
mm</th><th>ft in</th><th>Allowance
i in</th><th>mm</th><th>Allowance
mm</th><th>ft</th><th>Allowance
i in</th><th>mm</th><th>Allowance
s mm</th><th>ft in</th><th>Allowance
s in</th><th>kg</th><th>lb</th></tr>
<tr><td>1AAA</td><td rowspan="4">12,192</td><td rowspan="4">0
-10</td><td rowspan="4">40</td><td rowspan="4">0
-3/8</td><td rowspan="4">2,438</td><td rowspan="4">0
-5</td><td rowspan="4">8</td><td rowspan="4">0
-3/16</td><td>2,896*</td><td>0
-5</td><td>9 6*</td><td>0
-3/16</td><td rowspan="4">30,480*</td><td rowspan="4">67,200*</td></tr>
<tr><td>1AA</td><td>2,591*</td><td>0
-5</td><td>8 6*</td><td>0
-3/16</td></tr>
<tr><td>1A</td><td>2,438</td><td>0
-5</td><td>8</td><td>0
-3/16</td></tr>
<tr><td>1AX</td><td><2,438</td><td></td><td><8</td><td></td></tr>
<tr><td>1BBB</td><td rowspan="4">9,125</td><td rowspan="4">0
-10</td><td rowspan="4">29 11 1/4</td><td rowspan="4">0
-3/16</td><td rowspan="4">2,438</td><td rowspan="4">0
-5</td><td rowspan="4">8</td><td rowspan="4">0
-3/16</td><td>2,896*</td><td>0
-5</td><td>9 6*</td><td>0
-3/16</td><td rowspan="4">30,480*</td><td rowspan="4">67,200*</td></tr>
<tr><td>1BB</td><td>2,591*</td><td>0
-5</td><td>8 6*</td><td>0
-3/16</td></tr>
<tr><td>1B</td><td>2,438</td><td>0
-5</td><td>8</td><td>0
-3/16</td></tr>
<tr><td>1BX</td><td><2,438</td><td></td><td><8</td><td></td></tr>
<tr><td>1CC</td><td rowspan="3">6,058</td><td rowspan="3">0
-6</td><td rowspan="3">19 10 1/2</td><td rowspan="3">0
-1/4</td><td rowspan="3">2,438</td><td rowspan="3">0
-5</td><td rowspan="3">8</td><td rowspan="3">0
-3/16</td><td>2,591*</td><td>0
-5</td><td>8 6*</td><td>0
-3/16</td><td rowspan="3">30,480*</td><td rowspan="3">67,200*</td></tr>
<tr><td>1C</td><td>2,438</td><td>0
-5</td><td>8</td><td>0
-3/16</td></tr>
<tr><td>1CX</td><td><2,438</td><td></td><td><8</td><td></td></tr>
<tr><td>1D</td><td rowspan="2">2,991</td><td rowspan="2">0
-5</td><td rowspan="2">9 9 3/4</td><td rowspan="2">0
-3/16</td><td rowspan="2">2,438</td><td rowspan="2">0
-5</td><td rowspan="2">8</td><td rowspan="2">0
-3/16</td><td>2,438</td><td>0
-5</td><td>8</td><td>0
-3/16</td><td rowspan="2">10,160*</td><td rowspan="2">22,400*</td></tr>
<tr><td>1DX</td><td><2,438</td><td></td><td><8</td><td></td></tr>
</table>

* Some countries regulate the total height of the vehicle and container.

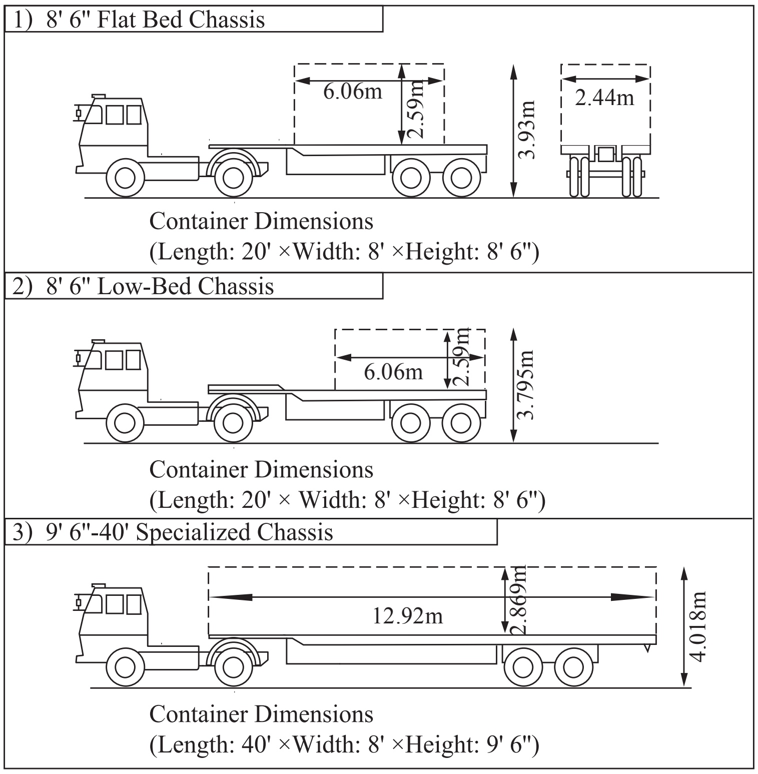

Fig 3.2.1 Tractor-Trailer Height, etc., when Loading a Container

(3) Cargo Handling Equipment Load

① General

(a) Cargo handling equipment load is classified into three types: mobile, rail mounted and fixed equipment, and the respective actions can generally be considered as follows:

1) As the characteristic values of mobile cargo handling equipment load, the total self weight, the maximum wheel load, the maximum load of the outrigger operation, or the maximum ground contact pressure load of crawler of the mobile cargo handling equipment may be used.

2) As the characteristic values of rail mounted cargo handling equipment load, the total self weight or the maximum wheel load considering the wheel interval and number of wheels may be used.

3) As the characteristic values of fixed cargo handling equipment load, the maximum hoisting load may be used.

(b) Cargo handling equipment continues to grow in size, and it is preferable to appropriately set the design conditions after fully studying the size of cargo handling equipment that is expected to be used in the objective facilities.

② Mobile Cargo Handling Equipment Load

(a) Mobile cargo handling equipment includes tire-mounted multi-purpose jib cranes, rough-terrain cranes, all-terrain cranes, tractor cranes, crawler cranes, container cargo handling equipment (including straddle carriers, transfer cranes, front fork lifts, and side rollers), fork lifts, and log loaders. Machines such as tire-mounted multi-purpose jib cranes and tractor cranes that use an outrigger give a relatively large concentrated load, so it is preferable to assume the most dangerous loading arrangement for the performance verification. **Table 3.2.2** shows examples of the dimensions of multi-purpose tire-mounted jib cranes.

(b) Examples of the mobile cargo handling equipment are shown in **Fig. 3.2.2** to **3.2.8** and **Tables 3.2.2** to **3.2.7**.

Table 3.2.2 Examples of Dimensions of Tire-mounted Multi-Purpose Jib Cranes

Type	Rated Load (t)	Total Weight Equipped (t)	Main Chassis Dimensions (m)					Maximum Wheel Load When Moving (kN/wheel)	Maximum Ground Contact Pressure During Operation (*3) (kPa)
			Maximum Operating Radius	Total Width (*1)	Wheel Base	Tread	Total Height (*2)		
Jib Crane	34.0	289	24.0	8.8	8.0	4.0	37.5	217	527
	34.1	395	30.0	11.0	25.2	3.5	48.0	255	174
	38.0	349	32.0	11.5	8.5	3.4	51.4	147	882
	40.0	370	34.0	12.0	9.7	4.3	59.5	320 (axle load)	280
Double Link Drawing Crane	34.0	406	30.0	13.0	15.0	5.0	42.5	142	358
	34.1	402	30.0	12.8	15.0	5.0	45.0	139	301
	34.5	425	28.0	11.7	10.0	4.5	39.0	294	314
	37.5	417	32.6	12.0	8.0	5.5	52.0	139	293

Notes : (*1)“Total width” is the total width of the moving portion.
(*2)“Total height” is the height of the highest portion of the jib at the smallest operating radius.
(*3)“Maximum ground contact pressure during operation” is the contact pressure of the outrigger during operation.

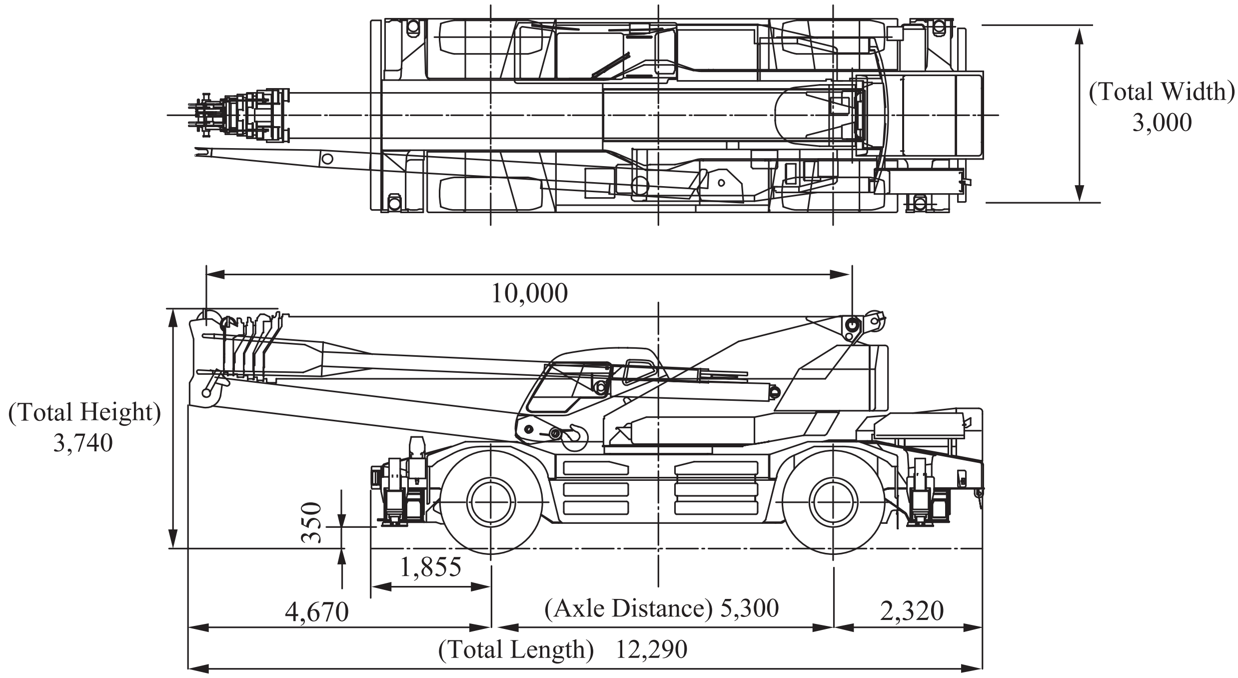

Fig. 3.2.2 Example of a Rough-Terrain Crane

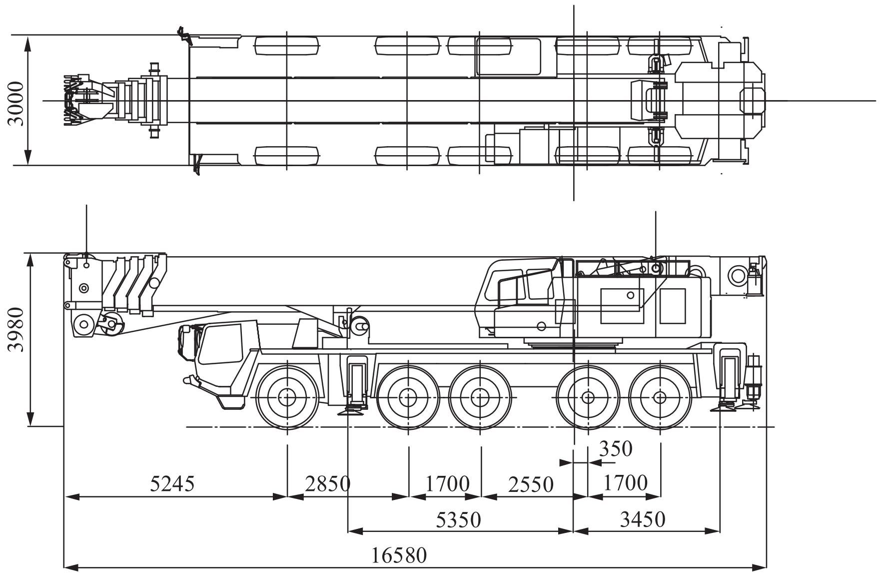

Fig. 3.2.3 Example of an All-Terrain Crane

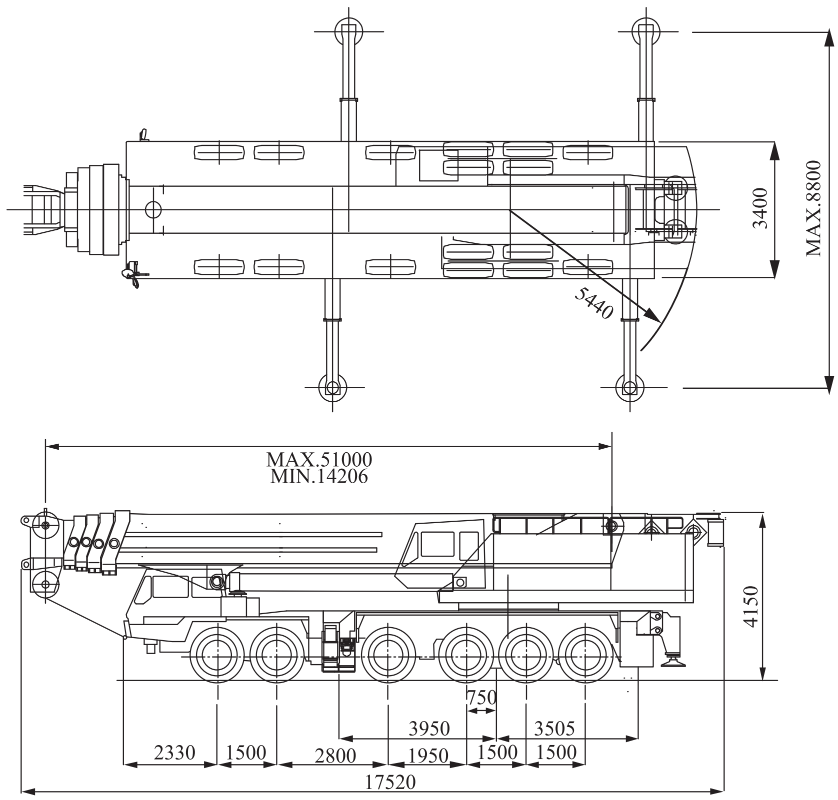

Fig. 3.2.4 Example of a Tractor Crane

Table 3.2.3 Examples of Dimensions of Rough-Terrain Cranes, All-Terrain Cranes, and Tractor Cranes

Type	Maximum Lift Load (t)	Total Weight Equipped (t)	Main Chassis Dimensions (*1) (m)					Maximum Axle Load (*2) (kN)
			Total Length	Total Width	Total Height	Wheel Base	Tread	
Rough-Terrain Crane	16	19.7	8.23	2.20	3.14	3.20	1.82	97.5
	25	26.5	11.21	2.62	3.45	3.65	2.17	131.2
	35	32.6	11.57	2.75	3.55	3.90	2.24	163.9
	50	37.8	11.85	2.96	3.71	4.85	2.38	185.3
	60	39.6	12.29	3.00	3.74	5.30	2.42	194.4
All-Terrain Crane	100	60.0	13.53	2.78	3.95	6.00	2.32	147.1
	160	87.5	16.58	3.00	3.98	8.80	2.56	171.6
	360	90.0	17.62	3.00	4.00	10.24	2.55	154.9
	400	126.0	18.29	3.00	4.10	11.30	2.56	179.5
	550	132.0	18.00	3.00	4.25	11.30	2.56	198.1
Tractor Crane	120	94.7	15.38	3.40	4.00	7.38	2.76/2.52	392.8
	160	131.4	16.72	3.40	4.05	7.30	2.83/2.54	543.8
	360	114.0	17.52	3.40	4.34	9.25	2.83/2.54	297.7

Notes : (*1) "Main chassis dimensions" are the dimensions when moving inside the yard.
(*2) "Maximum axle load" is the maximum value of the axle loads when moving inside the yard

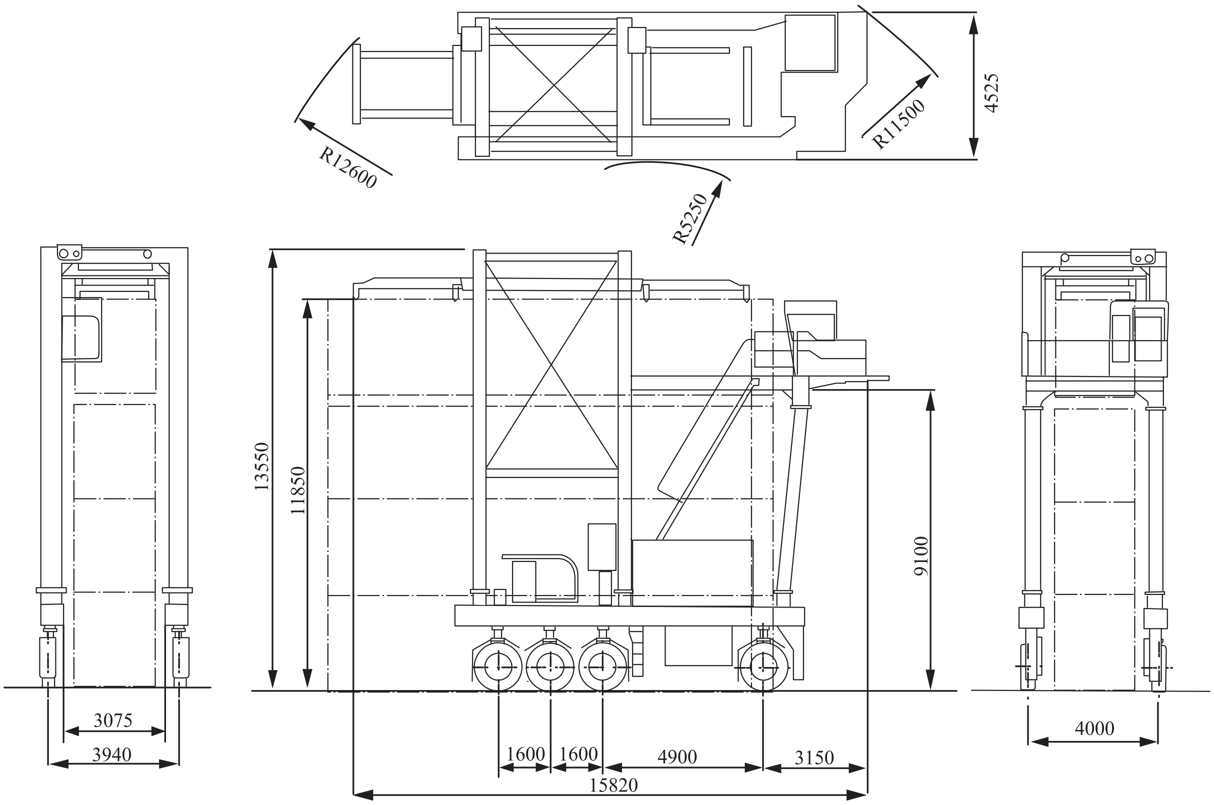

Fig. 3.2.5 Example of a Straddle Carrier

Table 3.2.4 Examples of Dimensions of Straddle Carriers

Machine Name	Handled Containers (ft)	Rated Load (t)	Total Weight Equipped (t)	Main Chassis Dimensions (m)				Maximum Operating Wheel Load (kN/wheel)
				Total Length (*1)	Total Width	Total Height	Wheel Base	
A	20, 40	35	60	15.8	4.5	13.6	8.1	117
B	20, 40	40	59	12.2	5.3	12.6	7.4	122
C	20, 40, 45	35	59	17.4	4.5	13.7	8.0	124

Notes : (*1) "Total length" is the total length when handling a 40-foot container.

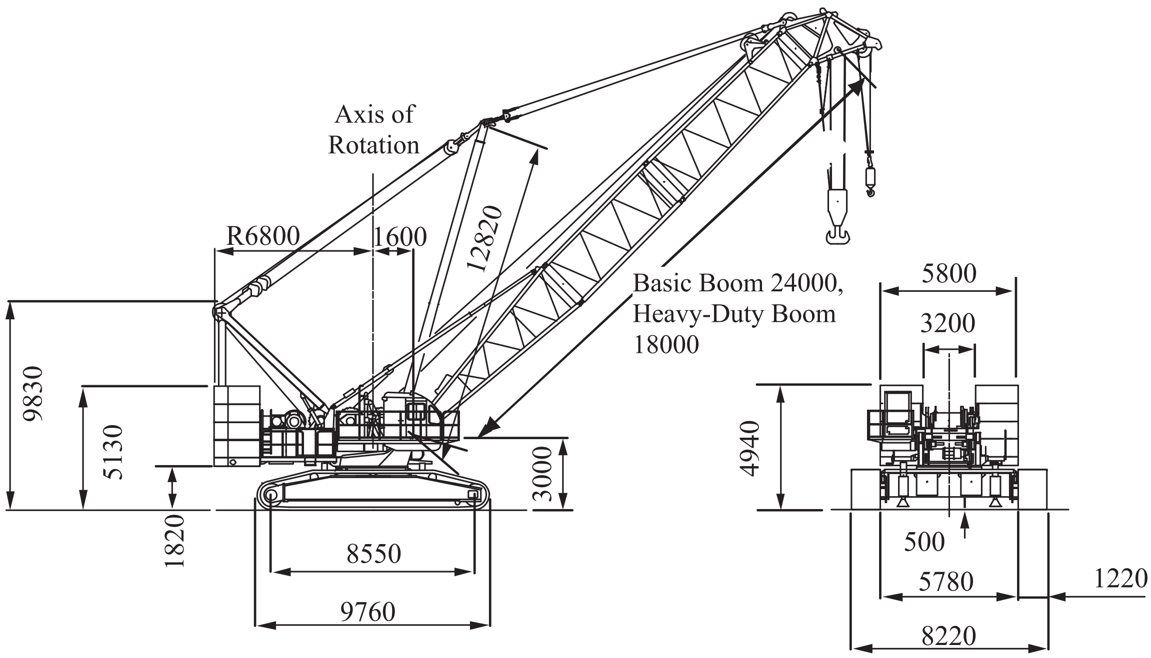

Fig. 3.2.6 Example of a Crawler Crane

Table 3.2.5 Examples of Dimensions of Crawler Cranes

Lift Load (t)	Total Weight Equipped (t)	Main Chassis Dimensions (m)				Crawler Ground Contact Pressure (kPa)
		Total Height	Crawler Total Length	Crawler Total Width	Crawler Shoe Width	
30	33	4.72	4.49	3.30	0.76	54
45	45	5.12	5.40	4.30	0.76	60
50	49	5.25	5.57	4.35	0.76	61
70	71	6.18	5.99	4.83	0.80	80
80	85	6.56	6.32	4.90	0.90	86
90	89	6.64	6.40	4.90	0.85	91
100	122	7.92	7.88	6.17	0.92	90
150	161	8.49	8.49	7.07	1.07	89
200	193	8.49	9.18	7.07	1.07	103
300	284	9.83	9.76	8.22	1.22	127
350	294	7.82	10.14	8.79	1.29	120
450	390	10.12	11.51	9.50	1.50	122
800	1,190	–	14.68	12.80	2.00	127

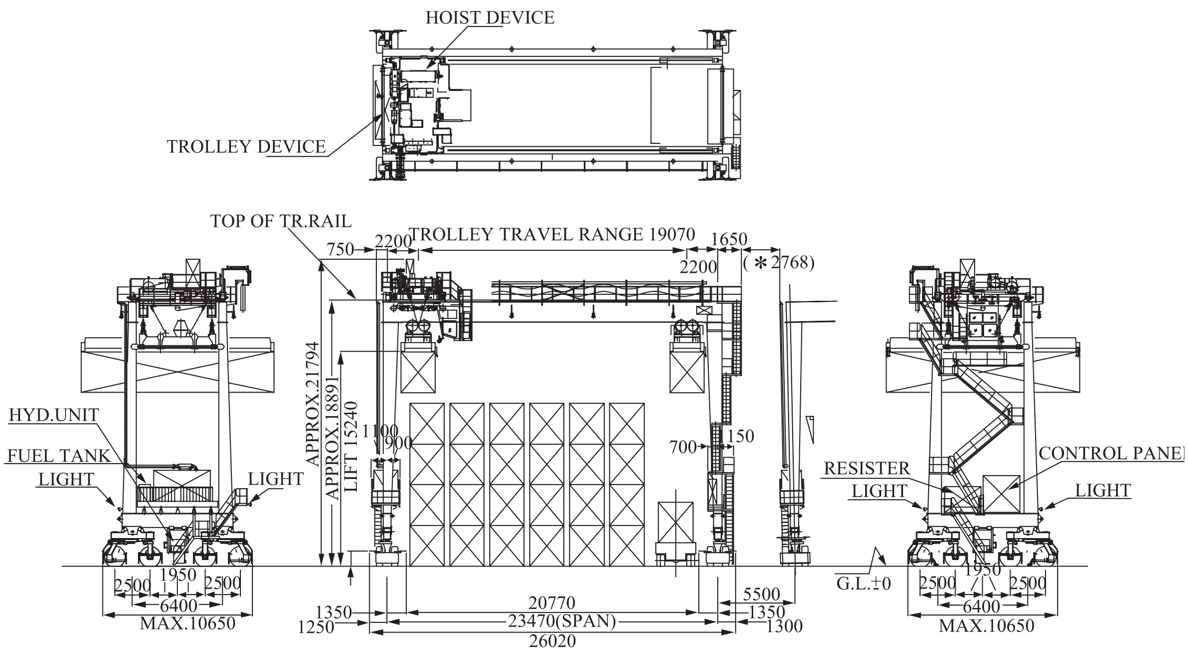

Fig. 3.2.7 Example of a Transfer Crane

Table 3.2.6 Examples of Dimensions of Transfer Cranes

Machine Name	Handled Containers (ft)	Rated Load (t)	Total Weight Equipped (t)	Main Chassis Dimensions (m)				Maximum Operating Wheel Load (kN/ wheel)	Number of Wheels (Wheels/ Corner)
				Total Length	Total Width	Total Height	Wheel Base		
A	20, 40	36.0	133	26.1	12.0	21.5	6.4	281	2
B	20, 40, 45	40.6	119	26.0	11.3	21.1	6.4	275	2
C	20, 40, 45	40.6	129	26.3	12.2	21.8	6.4	293	2
D	20, 40, 45	40.6	140	25.8	11.7	24.4	6.4	295	2
E	20, 40, 45	51.0	150	25.8	12.7	28.3	8.0	327	2
F	20, 40, 45	40.6	129	26.0	11.3	21.1	6.4	142	4
G	20, 40, 45	50.0	150	26.0	10.7	21.8	6.4	167	4

③ Rail-Mounted Cargo Handling Equipment Load

(a) Rail-mounted cargo handling equipment includes container cranes, pneumatic unloaders, double link luffing cranes, and double link unloaders. In the case of large cargo handling equipment such as gantry cranes and ore unloaders, it is necessary to appropriately consider items such as the actions of seismic movement, wind load, and impact loads during cargo handling.

(b) **Fig. 3.2.8** and **Table 3.2.7** show examples of rail-mounted cargo handling equipment. **Fig. 3.2.8** and **Table 3.2.7,** which are based on studies of the Japan Association of Cargo-Handling Machinery Systems, show examples of the dimensions of types of rail-mounted cargo handling equipment that are actually in use.

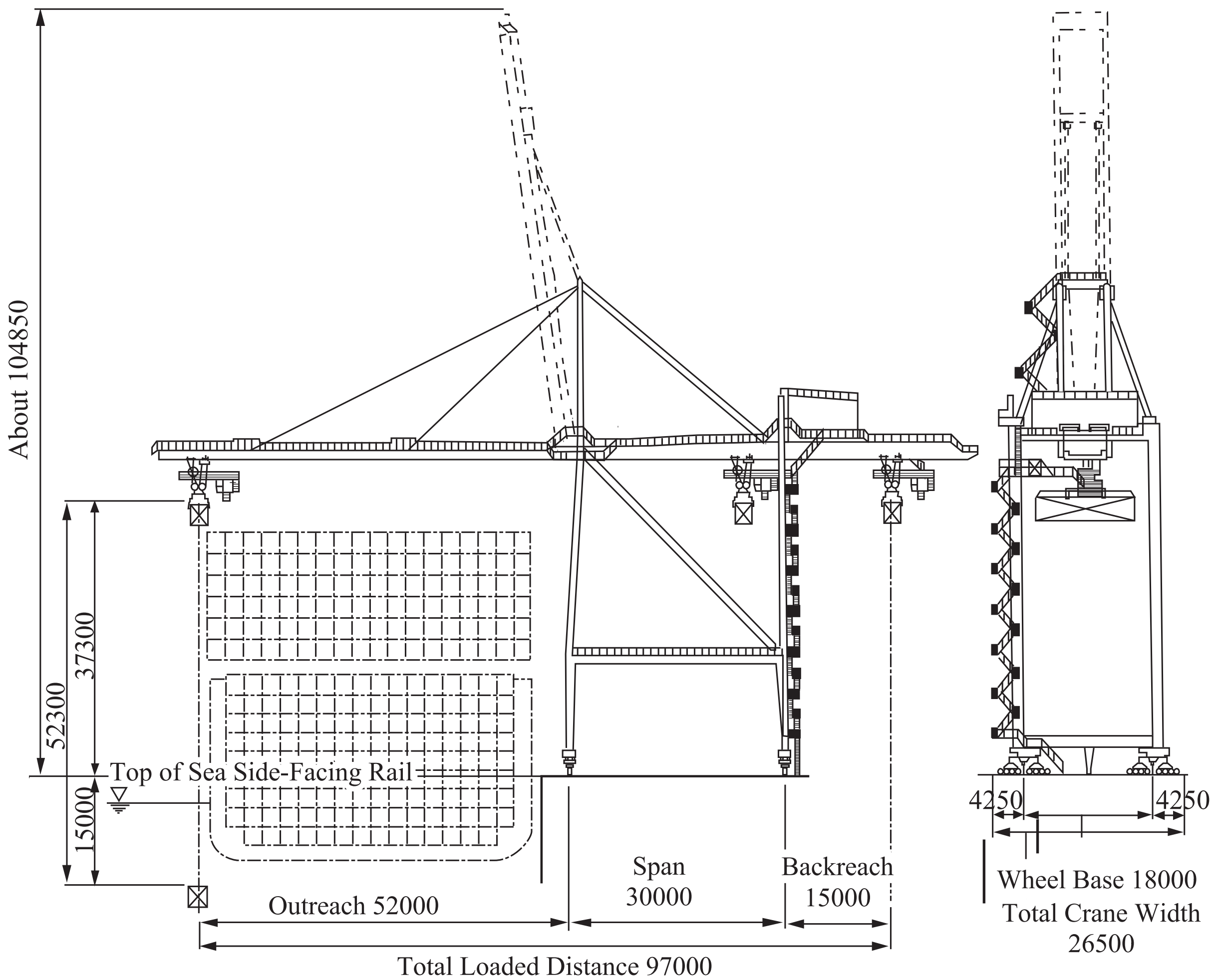

Fig. 3.2.8 Example of a Container Crane

Table 3.2.7 Examples of Dimensions of Container Cranes

Machine Name	Handled Containers (ft)	Rated Load (t)	Total Weight Equipped (t)	Main Chassis Dimensions (m)						Maximum Operating Wheel Load (kN/wheel)	Number of Wheels (Wheels/ Corner)
				Out-reach	Span	Back-reach	Total Width	Total Height	Wheel Base		
A	20, 40	30.5	580	31.0	16.0	10.0	27.0	68.0	18.0	406	8
B	20, 40	30.5	627	31.0	16.0	9.0	28.0	72.0	18.0	314	8
C	20, 40	30.5	668	31.0	16.0	9.5	27.0	46.0	18.0	314	8
D	20, 40	30.5	635	40.0	16.0	11.0	27.0	80.5	18.0	343	8
E	20, 40	40.6	1,127	50.0	30.0	15.0	27.0	73.1	18.0	577	8
F	20, 40, 45	40.5	890	47.1	30.0	15.0	28.0	100.0	18.0	558	8
G	20, 40, 45	40.6	965	50.0	30.5	15.0	28.0	102.3	18.0	394	10
H	20, 40, 45	40.6	1,030	50.5	30.0	14.0	26.5	65.0	18.0	720	8
I	20, 40, 45	50.0	993	52.0	30.0	15.0	26.5	105.0	18.0	744	8
J	20, 40, 45	65.0	1,360	63.0	30.0	16.0	26.5	127.2	16.5	711	8

④ Stationary Cargo Handling Equipment Load

Stationary cargo handling equipment includes stationary jib cranes and stationary pneumatic unloaders.

(4) Sidewalk Live Load

Characteristic values for sidewalk live load may usually be 5 kN/m^2. However, it is preferable to appropriately set the characteristic values for special kinds of facilities by considering the usage conditions of the facilities.

References

1) Japan Port Association: Handbook of Construction of port facilities, p,140, 1959
1) Japan Port Association: Handbook of Construction of port facilities, pp,303-304,1959
2) Moriya Y. and T. Nagao: Earthquake loads of reliability design of mooring facilities, Proceedings of Offshore Development Vol.19, pp.713-718, 2003
3) Railway Technical Research Institute: Standard and commentary of design of railway structures- Concrete structures, Maruzen Publishing, pp58-59,2004
4) Railway Technical Research Institute: Standard and commentary of design of railway structures- Concrete structures, Maruzen Publishing, pp.31-36, 2004
5) Japan Road Association,: Specifications and commentary for Highway Bridges Part. I, General, p.p. 11-20, pp. 82, 2004
6) Japan Container Association: Containerization, No.291,p.15,1996

Chapter 11 Materials

Public Notice

Fundamentals of Performance Verification

Article 3 (excerpts)

2 The performance verification of the facilities subject to the Technical Standards shall be made in principle by executing the subsequent items taking into consideration the situations in which the facilities concerned will encounter during the design working life:

(1), (2) (omitted)

(3) Select the materials of the facilities concerned in consideration of their characteristics and the environmental influences on them, and appropriately specify their physical properties.

[Commentary]

Corrosion of Steel:
In the performance verification of facilities subject to the Technical Standards, appropriately consider the corrosion of steel depending on conditions such as the natural environment. In general, steel that is used in facilities that are subject to the Technical Standards are placed under severe corrosive environmental conditions, and appropriate corrosion protection must be performed, using methods such as cathodic protection and covering/coating.

[Technical Note]

1 General

Steel used in port facilities shall be selected from appropriate materials taking into account effects on actions, deterioration, working life time, shape, constructability, economy and environment.

2 Steel

2.1 General

(1) Steel used in port facilities must have the necessary qualities to satisfy the required functionality of the facilities. Steel that comply with the Japanese Industrial Standard (JIS) may be given as examples that satisfy such requirements.

Table 2.1.1 and **Table 2.1.2** list the steel complying with the Japanese Industrial Standard that are most often used in port facilities.[1] For each of them, JIS specifies many types of steel.

(2) In general, structural steel with a tensile strength of 490 N/mm^2 or more is called high-strength steel. High-strength steel has an important characteristic that the higher the strength it has the larger is its yield ratio, namely the ratio of the yield strength to the tensile strength.

(3) Corrosion resistant steel has excellent resistance to particles of seawater salt above the sea level, and they may be either W type for uncoated use or P type for coated use.

Table 2.1.1 Quality Standards for Steel Materials (JIS) 1)

Type of steel material	Standard		Symbols	Applications
Structural steel	JIS G 3101	Rolled steel for general structures	SS400	Steel bar, shaped steel, steel plate, flat steel, steel strips
	JIS G 3106	Rolled steel for welded structures	SM400, SM490, SM490Y, SM520, SM570	Shaped steel, steel plate, flat steel, steel strips
	JIS G 3114	Hot-rolled atmospheric corrosion resisting steels for welded structure	SMA400, SMA490, SMA570	Shaped steel, steel plate
Steel pipe	JIS G3444	Carbon steel tubes for general structural purposes	STK400, STK490	–
Steel pile	JIS A 5525	Steel pipe piles	SKK400, SKK490	–
	JIS A 5526	Steel H piles	SHK400, SHK400M, SHK490M	–
Sheet pile	JIS A 5528	Hot rolled steel sheet piles	SY295, SY390	U-shaped, Z-shaped, H-shaped, flat
	JIS A 5530	Steel pipe sheet piles	SKY400, SKY490	
Cast or forged items	JIS G 3201 JIS G 5101 JIS G 4051 JIS G 5501	Carbon steel forgings for general use Carbon steel castings Carbon steel for machine structural use Gray iron castings	SF490A, SF540A SC450 S30CN, S35CN FC150, FC250	Mooring posts, chains, etc
Welding rods	JIS Z 3211	Covered electrodes for mild steel	–	SS400, SM400, SMA400
	JIS Z 3212	Covered electrodes for high tensile strength steel	–	SM490, SM490Y, SM520, SMA490
	JIS Z 3351	Submerged arc welding solid wires for carbon steel and low alloy steel	–	–
	JIS Z 3352	Submerged arc welding fluxes for carbon steel and low alloy steel	–	–
	JIS Z 3312	MAG welding solid wires for mild steel and high strength steel	–	–
Steel materials used for joining	JIS B 1180	Hexagon head bolts and hexagon head screws	–	–
	JIS B 1181	Hexagon nuts and hexagon thin nuts	–	–
	JIS B 1186	Sets of high strength hexagon bolt, hexagon nut, and plain washers for friction grip joints	F8T, F10T	–
Wires	JIS G 3502	Piano wire rods	SWRS	Piano wire, oil tempered wire, PC steel and stranded steel wire, wire rope
	JIS G 3506	High carbon steel wire rods	SWRH	Hard steel wire, oil tempered wire, PC high carbon steel wire, wire rope
	JIS G 3532	Low carbon steel wires	SWM	–
	JIS G 3536	PC steel wire and strands	SWPR1, SWPD1, SWPR2, SWPD3. SWPR7, SWPR19	–
Steel bar	JIS G 3112	Steel bars for concrete reinforcement	SR235, SR295, SD295A, SD295B, SD345	–
	JIS G 3117	Rerolled steel bars for concrete reinforcement	SRR235, SRR295, SDR235	–
	JIS G 3109	PC Steel bars	Type A2: SBPR 785/1030 Type B1: SBPR 930/1080 Type B2: SBPR 930/1180 Type C1: SBPR 1080/1230	–

Notes : A symbol for steel may come in varieties in JIS, for example, for SM400 there are three varieties SM400A, SM400B, and SM400C, but in this table these symbol suffixes that follow the number are omitted.
The carbon steel for machine structures, S30CN and S35CN, are obtained from the materials S30C and S35C specified in **JIS G 4051** by a normalizing heat treatment to satisfy the mechanical properties specified in the explanatory attachment to that standard.

Table 2.1.2 Shape Specifications for Steel (JIS) 1)

Type of steel		Standard	Materials used
Structural steel	Steel bar	JIS G 3191	SS400
	Shaped steel	JIS G 3192	SS400, SM400, SM490, SM490Y, SM520, SM570, SMA400, SMA490, SMA570
	Steel Plate and Steel Strips	JIS G 3193	SS400, SM400, SM490, SM490Y, SM520, SM570, SMA400, SMA490
	Flat steel	JIS G 3194	SS400, SM400, SM490, SM490Y, SM520
Steel pile	Steel pipe pile	JIS A 5525	SKK400, SKK490
	H-shaped steel pile	JIS A 5526	SHK400, SHK400M, SHK490M
Sheet pile	Hot rolled steel sheet pile	JIS A 5528	SY295, SY390
	Steel pipe sheet pile	JIS A 5530	SKY400, SKY490
Steel materials used for joining	Hexagonal head bolts	JIS B 1180	
	Hexagonal shape nuts	JIS B 1181	
	Sets of high strength hexagonal head bolts for friction grip joints	JIS B 1186	F8T, F10T
Steel bar	Steel bar for reinforced concrete	JIS G 3112	SR235, SR295, SD295, SD345
	Recycled steel bar for reinforced concrete	JIS G 3117	SRR235, SRR295, SDR235
Prestressed concrete	PC steel wire and strands	JIS G 3536	SWPR, SWPD
	PC steel bars	JIS G 3109	SBPR, SBPD
Materials for mooring	Wire rope	JIS G 3525	SWRS, SWRH
	Electrically welded anchor chains	JIS F 3303	
Wire mesh	Welded wire mesh	JIS G 3551	WFP, WFR, WFI

(4) When rolled steel for general structures, rolled steel for welded structures, or corrosion resistant hot rolled steel for welded structures is used, thickness may be chosen from **Fig. 2.1.1**.[2] When steel with thicknesses less than 8 mm are used, follow the standards in **Specifications for Highway Bridges**.[3] In general, for reasons such that steel with large thicknesses require a large amount of carbon for a specific strength, and during rolling fine crystallization may be insufficient and the notch brittleness may become greater, a usable upper bound for the thickness is specified in JIS for each steel.

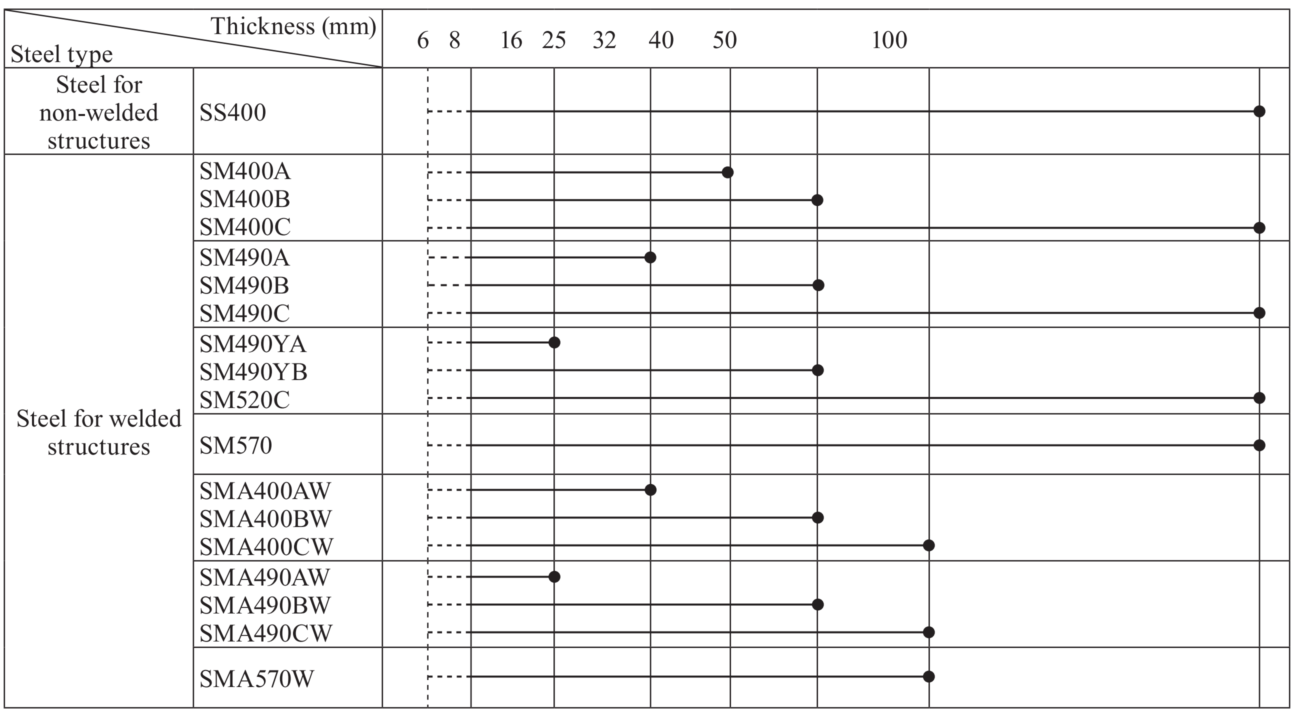

Fig. 2.1.1 Standards for Selecting Thickness Based on the Steel Grade 2)

(5) Strength standards for PC steel wire and stranded PC steel wire are specified in **JIS G 3536**, and the standards for the chemical compositions of steel are presented in **JIS G 3502, Piano Wire**.

(6) In facilities that have many welded portions for example, facilities with joint construction, it is necessary to pay attention to the chemical composition and weldability of the steel. In general, welded steel materials use **JIS G 3106, Rolled Steel for Welded Structures**, or **JIS G 3114, Corrosion Resistant Hot Rolled Steel for Welded Structures**. On the other hand, SS400, which belongs to **JIS G 3101, Rolled Steel for General Structures**, should be limited to non-welded portions.

2.2 Characteristic Values of Steel

(1) Characteristic values for various constants of the steel and cast steel required for performance verification are appropriately specified by considering factors such as strength characteristics.

(2) In general, characteristic values for the Young's modulus, the shear modulus, Poisson's ratio, and the linear expansion coefficient of steel and cast steel can use the values given by **Table 2.2.1**.[4] Also, the constants for steel used in reinforced concrete and prestressed concrete can refer to the values given in the **Standard Specification for Concrete Structures**.[5]

Table 2.2.1 Mechanical Characteristics for Steel [4]

Young's modulus E	2.0×10^5 N / mm^2
Shear modulus G	7.7×10^4 N / mm^2
Poisson's ratio v	0.30
Linear expansion coefficient α	12×10^{-6} 1 / °C

(3) Characteristic Values of Yield Strength
Characteristic values of yield strength for steel and cast steel are appropriately specified based on test results.

① Structural steel

(a) Generally, the values listed in **Table 2.2.2** can be used as characteristic values of yield strength for structural steel based on the grade of steel and the thickness.[6]

Table 2.2.2 Characteristic Values of Yield Strength for Structural Steel (JIS) 6)

Type of steel	Thickness mm	Tensile yield strength N/mm2	Compressive on yield strength N/mm2	Shear yield strength N/mm2	Bearing yield strength between steel plate and steel plate N/mm2	Tensile strength N/mm2
SS400	≤ 16	≥ 245	≥ 245	141	368	400 to 510
	16 to 40	≥ 235	≥ 235	136	353	
	40 to 100	≥ 215	≥ 215	124	323	
	≥ 100	≥ 205	≥ 205	118	308	
SM400 SMA400	≤ 16	≥ 245	≥ 245	141	368	400 to 510 (to 540) *1
	16 to 40	≥ 235	≥ 235	136	353	
	40 to 75	≥ 215	≥ 215	124	323	
	75 to 100	≥ 215	≥ 215	124	323	
	100 to 160	≥ 205	≥ 205	118	308	
	160 to 200	≥ 195	≥ 195	113	293	
SM490	≤ 16	≥ 325	≥ 325	188	488	490 to 610
	16 to 40	≥ 315	≥ 315	182	473	
	40 to 75	≥ 295	≥ 295	170	443	
	75 to 100	≥ 295	≥ 295	170	443	
	100 to 160	≥ 285	≥ 285	165	428	
	160 to 200	≥ 275	≥ 275	159	413	
SM490Y SMA490	≤ 16	≥ 365	≥ 365	211	548	490 to 610
	16 to 40	≥ 355	≥ 355	205	533	
	40 to 75	≥ 335	≥ 335	193	503	
	75 to 100	≥ 325	≥ 325	188	488	
	100 to 160	≥ 305	≥ 305	176	458	
	160 to 200	≥ 295	≥ 295	170	443	
SM520	≤ 16	≥ 365	≥ 365	211	548	520 to 720
	16 to 40	≥ 355	≥ 355	205	533	
	40 to 75	≥ 335	≥ 335	193	503	
	75 to 100	≥ 325	≥ 325	188	488	

*1:The figure within parentheses ( ) shows the value for SMA400.

(b) The von Mises yield criteria are used to calculate the shear yield strength.

(c) When the contact mechanism between two steel is a flat surface against a flat surface including cylindrical surfaces and curved surfaces that are nearly flat, the bearing yield strength may be taken as 50% more than the tensile yield stress. If necessary, when there is a very small contact surface between a spherical surface or a cylindrical surface, and a flat surface, it is possible to use the Hertz formula in the **Specification for Highway Bridges**.7)

② Characteristic values for steel pile and steel pipe sheet pile

(a) As characteristic values of yield stress for steel pile and steel pipe sheet pile, generally the values of **Table 2.2.3** can be used, based on the types of steels and stresses.8)

Table 2.2.3 Characteristic Values of Yield Strength for Steel Pile and Steel Pipe Sheet Pile (JIS) 8)

(N/mm2)

Type of stress \ Steel grade	SKK400 SHK400 SHK400M SKY400	SKK490 SHK490M SKY490
Axial tensile stress (per net cross-sectional area)	235	315
Bending tensile stress (per net cross-sectional area)	235	315
Bending compression stress (per total cross-sectional area)	235	315
Shear stress (per total cross-sectional area)	136	182

(b) When it is necessary to combine the axial stress and shear stress, yield strength may be determined by referencing the to **Specifications for Highway Bridges**.9)

(c) Buckling strength depends on the condition of the member and is specified appropriately during the verification of facility.

③ Steel sheet pile

(a) As characteristic values of yield strength for steel sheet pile, generally the values of **Table 2.2.4** can be used, based on the types of steels and stresses.[10)]

Table 2.2.4 Characteristic Values of Yield Strength for Steel Sheet Pile (JIS) [10)]

(N/mm²)

Type of stress \ Steel	SY295	SY390
Bending tensile stress (per net cross-sectional area)	295	390
Bending compression stress (per total cross-sectional area)	295	390
Shearing stress (per total cross-sectional area)	170	225

④ Cast and forged items

(a) As characteristic values of yield strength for cast and forged structures, generally the values of **Table 2.2.5** can be used, based on the types of steels and stresses.[11)]

Table 2.2.5 Yield Strength for Cast and Forged Structures (JIS) [11)]

(N/mm²)

Type of strength \ Type of iron steel material	Forged steel		Cast steel	Steel materials for machine structures		Cast iron	
	SF490A	SF540A	SC450	S30CN	S35CN	FC150	FC250
Axial tensile strength (per net cross-sectional area)	245	275	225	275	305	70	105
Axial compression strength (per total cross-sectional area)	245	275	225	275	305	140	210
Bending tensile strength (per net cross-sectional area)	245	275	225	275	305	70	105
Bending compression strength (per total cross-sectional area)	245	275	225	275	305	140	210
Shearing strength (per total cross-sectional area)	141	159	130	159	178	54	88

(b) When calculations are performed with the Hertz formula, the method of calculating the bearing yield strength follows the **Highway Bridge Specifications and Commentary**.[12)]

⑤ Yield strength for welded portions and steel materials used for joining

(a) As characteristic values of yield strength for welded portions, the values in **Table 2.2.6** can be referred, based on the types of steels and strength. When joining steel of different strengths generally the value for the steel with lower strength shall be used.

Table 2.2.6 Characteristic Values of Yield Strength for Welded Portions (JIS)

(N/mm²)

Type of welding		Type of strength \ Steel	SM400 SMA400	SM490	SM490Y SM520 SMA490	SM570 SMA570
Shop welding	Full penetration groove welding	Compression strength	235	315	355	450
		Tensile strength	235	315	355	450
		Shearing strength	136	182	205	260
	Fillet welding, partial penetration groove welding	Shearing strength	136	182	205	260
On-site welding		1) As a rule, use the same values as for factory welding. 2) For steel pipe pile and steel pipe sheet pile, use 90% of the factory value.				

(b) Technologies for on-site welding have improved, and adequate execution management and quality control have been achieved on-site, so that on-site welding has attained the same management level as factory welding, and therefore for yield strength it has been decided that one can take the same values for on-site welding as for factory welding can be taken, as specified in Specification for Highway Bridges [13]. In locations where it is difficult to verify that the environmental conditions are good for the welding of materials such as steel pipe pile and steel pipe sheet pile, the yield strength for on-site welding can be taken to be 90% of the value for factory welding.

(c) **Table 2.2.7** lists the characteristic yield strength for anchor bolts and pins.

Table 2.2.7 Yield Strength for Anchor Bolts and Pins

(N/mm^2)

Type	Type of steel / Type of stress	SS400	S35CN
Anchor bolts	Shearing	100	133
Pins	Bending	320	438
	Shearing	168	235
	Bearing	353	470

(d) It is assumed that the specified anchor bolts are used as embedded in concrete. Since construction using anchor bolts can often be insecure, and it is necessary to maintain a strength balance with the concrete that they support, the calculation of design values should sufficiently include an extra margin of safety.

(e) Since pins do not use bolt holes as in sheet or shaped steel, and usually do not use notches, there is no concern that they will concentrate stress. Also, although pins are often verified for shear and bearing, their limit values are not lowered for shear accompanied by sliding. With these considerations in mind, values for shear yield strength are specified larger than the values listed in **Table 2.2.2** and **Table 2.2.5**.

(f) **Table 2.2.8** lists the characteristic yield strength for finished bolts.

Table 2.2.8 Yield Strength for Finished Bolts

(N/mm^2)

Strength categories according to JIS B 1051 / Type of stress	4.6	8.8	10.9
Tensile	240	660	940
Shearing	140	380	540
Bearing	360	990	1410

2.3 Corrosion Protection

2.3.1 Overview

(1) Corrosion protection should be taken into consideration when using steel because of the harsh corrosive environmental conditions. Severe localized corrosion occurs particularly in sections immediately below the mean low water level and, therefore, appropriate measures should be taken.

(2) The distribution of corrosion rate with respect to the depth of steel driven into the sea generally is shown in **Fig. 2.3.1**. [16] The corrosion is particularly heavy in the splash zone, where the structure is exposed to sea water splashes and there is an adequate supply of oxygen. In particular, the rate of corrosion is the highest in the section immediately above the high water level.

Among the submerged sections in **Fig. 2.3.1**, the corrosion rate is the highest in the section immediately below the intertidal zone. However, the corrosion rate in this section differs greatly depending on the environmental conditions and the cross-sectional shape of the structure. In steel sheet piles and steel pipe pile structures submerged in clean sea water, the corrosion rate in the section immediately below the mean low water level, MLWL, is often not much different from that in submerged zone. Depending on the environmental conditions of the structure, however, the corrosion rate in the section immediately below MLWL may be much larger than that in the submerged zone, and in some cases may even exceed the value in the splash zone. This remarkable local corrosion is called the concentrated corrosion.

(3) For all aspects of corrosion control, reference may be made to **"Manual on Corrosion Prevention and Repair for Port and Harbor Steel Structures (revised edition)"** [15] published by the Coastal Development Institute of Technology in Japan.

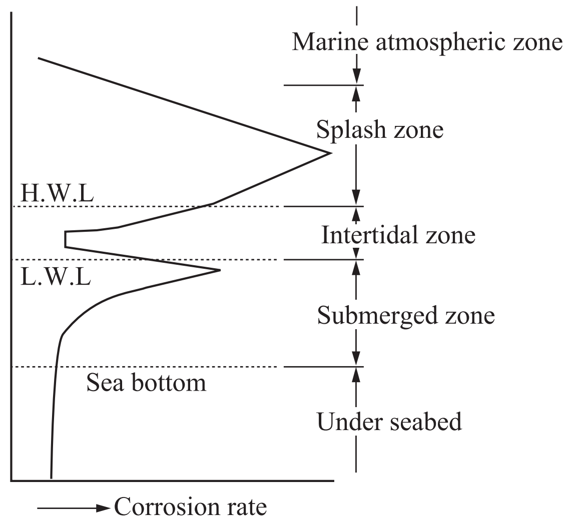

Fig. 2.3.1 Distribution of Corrosion Rates of Steel Structures 15)

2.3.2 Corrosion Rates of Steel

(1) The corrosion rate of steel shall be determined as appropriate in view of the environmental conditions of the site where structures are placed because the corrosion rate depends on the corrosive environmental conditions.

(2) The corrosion rate of steel used in port and harbor structures is influenced by the environmental conditions including the weather conditions, the salinity and pollution level of the sea water, the existence of river water inflow, etc. Therefore, the corrosion rate should be determined by referring to past cases in the vicinity and survey results under similar conditions.

(3) The corrosion rate of steel should generally be determined by referring to the standard values listed in **Table 2.3.1**, which has been compiled on the basis of survey results on the existing steel structures. However, the values in **Table 2.3.1** are the average ones, and the actual corrosion rate may exceed them depending on the environmental conditions of the steel material. Therefore, when determining the corrosion rate of steel, the results of corrosion surveys under similar conditions should be referred to. It should also be noted that the values in **Table 2.3.1** refer to the corrosion rate for only one side of the steel section. Thus, when the both sides of steel section are subject to corrosion, the sum of the corrosion rates of the both sides estimated on the basis of the values in **Table 2.3.1** should be employed.

(4) The values for “HWL or higher” in **Table 2.3.1** refer to the corrosion rate immediately above HWL. The corrosion rate between the HWL and the seawater sections should be determined by referring to actual corrosion rates in the properties of sea water around the structures. This is because past corrosion surveys have shown that the corrosion rate varies depending on the properties of sea water and the depth of water. The values in **Table 2.3.1** are listed as references with a range of variation. In general, the corrosion in the intertidal zone should be dealt with separately from that in the submerged zone because of the differences in the environmental conditions. The appropriate boundary between them is around 1.0 m below LWL.

In cases of the concentrated corrosion, the corrosion rate greatly exceeds the values listed in **Table 2.3.1**, and thus these values are not applicable to such cases.

(5) In oxygen-isolated spaces such as the inside of steel pipe piles, it may be assumed that corrosion cannot occur because there is no supply of oxygen.

Table 2.3.1 Standard Values of Corrosion Rates for Steel [15]

Corrosive environment		Corrosion rate (mm/year)
Seaside	HWL or higher	0.3
	HWL – LWL -1 m	0.1–0.3
	LWL -1 m – seabed	0.1–0.2
	Under seabed	0.03
Land side	Above ground and exposed to air	0.1
	Underground (residual water level and above)	0.03
	Underground (residual water level and below)	0.02

(6) Sand abrasion is a phenomenon in which the rust layer on the steel surface is removed by the movement of sand to expose the bare steel and to result in increasing the corrosion rate.[17] There are examples where steel sheet pile was used as a sediment control groin and the mean corrosion rate due to sand corrosion directly above the sand surface was from 1.25 to 2.39 mm/year.[18] When the vertical motion of the sand surface is small, the sections of abrasion are limited to areas immediately above the sand surface and so it is said that the corrosion rates become larger in these sections.

2.3.3 Corrosion Protection Methods

(1) Corrosion protection methods for steel shall be undertaken as appropriate by employing the cathodic protection method, the covering/coating method, or other corrosion prevention method, depending on the environmental conditions in which the steel material exists. For the sections below the mean low water level, the cathodic protection shall be employed. For the sections above the depth of 1.0 m below L.W.L., the covering/coating method shall be employed.

(2) In the intertidal zone and submerged zone, there is a risk of concentrated corrosion, depending on the corrosive environmental conditions. Therefore, in principle, corrosion protection by means of the thickness allowance should not be undertaken as a corrosion protection method for steel structures in Japan. However, in the case of temporary structures, it is acceptable to employ the corrosion allowance method as corrosion prevention.

(3) The backfilling side of steel sheet pile has a slower corrosion rate than that of the seaward side, and thus no corrosion protection is required in particular. In cases where a strongly corrosive environment is conjectured due to the influence of waste material in the backfill, however, surveys should be conducted in advance and appropriate measures should be taken.

(4) For the most effective actual corrosion protection, the covering/coating method is used for sections above 1 m below L.W.L., while cathodic protection is used for submerged sections below M.L.W.L and for sections in the sea bottom soil, and their reliability has been verified. When the covering/coating method is used underwater it is necessary to pay attention to durability when selecting the covering/coating material and to watch for damage, such as during construction or from collisions with driftwood. In cases where the covering/coating is used both in the air over the sea and in sections within the water, while the cathodic protection is used in the sea bottom soil, if a margin to estimate the degradation and damage of the covering/coating material is specified for the performance verification of the cathodic protection and then cathodic protection can compensate the degraded and damaged parts of the portions that use covering/coating protection.

2.3.4 Cathodic Protection Method

(1) Range of Application

① The range of application of the cathodic protection shall in principle be at or below M.L.W.L.

② Above the MLWL, corrosion control must be carried out by covering/coating. The zone between M.L.W.L and the L.W.L. is submerged for a shorter time than that below L.W.L., and thus the corrosion rate is slightly lower. Also, because the sections immediately below L.W.L. are susceptible to corrosion, the covering/coating should extend to a certain depth below L.W.L. and should be combined with the cathodic protection.

③ During port construction there may be a period with no corrosion protection after steel pipe pile and steel sheet pile have been driven in and before the superstructure has been constructed, and there may be periods of no corrosion protection when the anodes used for cathodic protection are replaced. During such periods of no corrosion protection the steel may have been exposed to concentrated corrosion, so sufficient care should be taken.

④ As listed in **Table 2.3.2**, the effect of the cathodic protection, the corrosion rate increases when the period of immersion of the steel subject to corrosion in sea water is longer and decreases when it is shorter. The seawater immersion ratio and the corrosion rate are expressed in equation (**2.3.4**) and (**2.4.5**), respectively.

$$\text{Sea water immersion ratio} = \frac{\text{Total immersion time of test piece}}{\text{Total test time}} \times 100\,(\%) \tag{2.3.4}$$

$$\text{Corrosion Control Ratio} = \frac{\text{Mass reduction of unelectrified test piece - Mass reduction of electrified test piece}}{\text{Mass reduction of unelectrified test piece}} \times 100\,(\%) \tag{2.3.5}$$

Table 2.3.2 Corrosion Control Ratio of the Cathodic Protection Method

Seawater immersion ratio(%)	Corrosion control rate
below 40 %	below 40 %
equal to or greater than 40 % but below 80 %	equal to or greater than 40 % but below 60 %
equal to or greater than 80 % but below 100 %	equal to or greater than 60 % but below 90 %
100%	equal to 90 % or over

⑤ In general, 90% is used for the standard corrosion efficiency rate for the area below M.L.W.L.

⑥ The cathodic protection is divided into a galvanic anode method and a impressed current method. Under the galvanic anodes method, aluminum (Al), magnesium (Mg), zinc (Zn) and other alloy are electrically connected to the steel structure and the electric current generated by the difference in potential between the two metals is used as a corrosion protection current. This method is applied almost universally in cathodic protection of port steel structures in Japan, mainly because of ease of maintenance. The characteristics of the galvanic anode materials are listed in **Table 2.3.3**. Aluminum alloy anodes offer the highest flux of current generated per unit of mass, are outstandingly economical, and are suited to both the seawater zone and seabed environments. Therefore, aluminum alloy anodes are most commonly used for port steel structures.

Under the impressed current method, an electrode is connected to the positive pole of an external DC power source and the steel structure is connected to the negative pole. Then a protective current is applied towards the steel structure from the current electrode. In sea water, a platinum or oxide coating electrode is often used as the working electrode. Since the output voltage can be arbitrary adjusted with the impressed current method, it can be applied to the environments featuring pronounced fluctuations such as strong currents or the inflow of river water, and the places where a fine potential control is required.

Table 2.3.3 Characteristics of Galvanic Anode Materials [15)]

Characteristics		Al-Zn-In		Pure Zn, Zn alloy	Mg-Mn	Mg-6Al-3Zn
Specific gravity		2.6–2.8		7.14	1.74	1.77
Open circuit anode voltage (V) (SCE)		1.08		1.03	1.56	1.48
Effective voltage to iron (V)		0.25		0.20	0.75	0.65
Theoretical generated electricity flux (A·h/g)		2.87		0.82	2.20	2.21
In seawater with 1mA/cm²	Generated electricity flux (A·h/g)	2.30	2.60	0.78	1.10	1.22
	Consumed amount (kg/A)/year	3.8	3.4	11.8	8.0	7.2
In soil with 0.03mA/cm²	Generated electricity flux (A·h/g)	1.86*		0.53	0.88	1.11
	Consumed amount (kg/A)/year	4.71		16.5	10.0	7.9

Note)*Fluctuates depending on material composition.

⑦ In the galvanic anode method, the attachment of the anode to the steel material is usually accomplished by underwater welding. There have been reports on the steel sheet pile quaywalls where the underlying soil became liquefied during an earthquake so that an excessive amount of soil pressure acted upon the steel sheet pile and the portion that had been welded underwater suffered brittle fracture.[15)] Therefore, preventative measures should be applied, such as (1) modifying the chemical composition of steel sheet pile to adapt it to underwater welding, or (2) before driving in the sheet pile, while still on land, welding a cover plate of steel appropriate for welding to the portion where the anode will be attached, and then welding the anode to the cover plate underwater.

(2) Protective Potential

① In general, the protective potential of port steel structures shall be -780 mV vs. $Ag/AgCl_{(seaw)}$ electrode.

② When applying a protective current through a steel structure by the cathodic protection technique, the potential of the steel structure gradually shifts to a low level. When it reaches a certain potential, corrosion is to be protected. This potential is known as the protective potential.

③ To measure the potential of steel structures, an electrode that indicates stable reference values even in the different environmental conditions should be used as the reference. The electrode that provides the standard value is known as the reference electrode. In seawater, in addition to the Ag/AgCl electrode, the saturated mercurous chloride electrode and the saturated copper sulfate electrode are sometimes used. The value of the protective potential differs depending on the reference electrode used for measurement, as in the following:

Seawater-silver/silver-chloride electrode;	-780 mV
Saturated mercurous chloride electrode;	-770 mV
Saturated copper sulfate electrode;	-850 mV

④ When combining the covering/coating and cathodic protection methods, particularly with the impressed current method, care should be taken not to let the coating film deteriorate due to excessive current. The potential in this case should ideally be -800 to -1,100 mV vs. Ag/AgCl electrode.

(3) Protective Current Density

① Protective current density shall be set to an appropriate value because it varies greatly depending on the marine environment.

② When applying the cathodic protection, a certain current density per unit surface area of the steel is needed in order to polarize the potential of the steel to a more base value than the protective potential. This density is known as the protective current density. The value of this protective current density decreases with the elapse of time from the initial value at the start of cathodic protection, and finally reaches a constant value. The constant value is around 40% to 50% of the initial value.

③ The protective current density varies with temperature, currents, waves, and water quality. Where there is an inflow of river water or various discharges, or where there is a high concentration of sulfides, the required protective current generally increases. Also, where the water current is fast, the required protective current increases. When verifying performance, the performance of the existing facilities in the area should be referred to for characteristic value settings.

④ The protective current density at the start of cathodic protection should be based on the standard values listed in **Table 2.3.4** for the bare steel surface in normal sea conditions.

⑤ As the duration of protection goes on, the generated current weakens. Therefore, the average generated current density for calculating the life time of the anode is often taken as the following, depending on the duration of protection:

When protected for 5 years;	0.55 x initial generated current density
When protected for 10 years;	0.52 x initial generated current density
When protected for 15 years;	0.50 x initial generated current density

If the protection is intended to last for more than 15 years, the value for 15 years should be applied.

⑥ If a portion covered with protective material exists within the range of application of cathodic protection, the value of the protective current density should be set by assuming a certain rate of damage to the covering/coating material. In seawater the following values may be set:

Paint;	$20 + 100\,S$ (mA/m^2)
Concrete;	$10 + 100\,S$ (mA/m^2)
Organic coating;	$100\,S$ (mA/m^2)

where S is the rate of damage defined as the ratio of assumed damaged covered area to the total covered area.

However, if the protective current density obtained from the above equation exceeds the values indicated in ⑤ values in **Table 2.3.4** may be employed.

Table 2.3.4 Protective Current Density at Start of Cathodic Protection (mA/m^2) [15]

	Clean sea area	Polluted sea areas
In seawater	100	130-150
In rubble mound	50	65-75
In soil (below seabed)	20	26-30
In soil (above seabed)	10	10

2.3.5 Covering/Coating Method

(1) Range of Application

① It is better to apply the covering/coating method to the sections in port steel structures, where the duration of seawater immersion is short because the cathodic protection cannot be applied to them.

As described in **2.3.4 Cathodic Protection Method**, the range of application of the cathodic protection method is designated as below M.L.W.L. However, concentrated corrosion is liable to occur in the vicinity of M.L.W.L., while the duration of immersion in seawater is shortened by the effects of waves and seasonal fluctuations in tide levels. Therefore, the covering/coating method should be applied in combination with the cathodic protection to the sections above the depth of 1 m below L.W.L.

② In steel sheet pile revetments in shallow sea areas, the covering/coating method is sometimes applied to the whole length of the structure depthwise. By combining the cathodic protection and covering/coating methods in sea water sections, the life of the galvanic anode may be extended.[15]

(2) Applicable Methods

① The covering/coating method applied to port steel structures shall be one of the following four methods:

(a) Painting

(b) Organic covering/coating

(c) Petrolatum covering/coating

(d) Inorganic covering/coating

② The covering/coating protection method basically controls corrosion by blocking the covered/coated material from corrosive environmental factors. The applicable range for the covering/coating protection method depends on the type, so that there are some methods that apply mainly to the intertidal zone, the splash zone, and the atmospheric zone, and there are other methods that apply in the seawater. In the seawater, the covering/coating method may be used together with the cathodic corrosion protection, or coating corrosion protection may be used alone. Moreover, some methods are only applicable to new facilities and other methods are applicable to not only new facilities but also existing facilities.

(3) Selection of Methods

When selecting the covering/coating protection method and determining the specification it is necessary to investigate each of the following items:

(a) Environmental conditions

(b) Range of corrosion protection

(c) Design working life

(d) Maintenance plan

(e) Construction conditions

(f) Construction duration

(g) Corrosion state and degradation of existing covering/coating material

(h) Initial design conditions

(i) Others

The above g) and h) are only applicable to existing structures.

References

1) Japan Standard Association: JIS Handbook, Iron and Steel I, II, Japan Industrial Standards, 2002
2) Japan Road Association: Specifications and Commentary for Highway Bridges Vol. II, Steel Bridge, p. 111, 2004
3) Japan Road Association: Specifications and Commentary for Highway Bridges Vol. II, Steel Bridge, p. 153, 2004
4) Japan Road Association: Specifications and Commentary for Highway Bridges Vol. I, General, p.p. 59, pp. 82, 2004
5) JSCE: Standard Specifications for Concrete Structures, Structural performance verification, pp.38-44, 2002
6) Japan Road Association: Specifications and Commentary for Highway Bridges Vol. II, Steel Bridge, p. 116, 2004
7) Japan Road Association: Specifications and Commentary for Highway Bridges Vol. II, Steel Bridge, p.136-141, 2004
8) Japan Road Association: Specifications and Commentary for Highway Bridges Vol. I, General, p.p. 71, 2004
9) Japan Road Association: Specifications and Commentary for Highway Bridges Vol. II, Steel Bridge, p. 151-180, 2004
10) Japan Standard Association : JIS Handbook, Iron and Steel Part I and II, Japan Standard, 2002
11) Japan Road Association: Specifications and Commentary for Highway Bridges Vol. I, General, p. 73, 2007
12) Japan Road Association: Specifications and Commentary for Highway Bridges Vol. II, Steel Bridge, p.136-141, 2004
13) Japan Road Association: Specifications and Commentary for Highway Bridges Vol. I, General, 2004
14) Japan Standard Association : JIS Handbook, Screw Part I, Japan Standard, 2002
15) Coastal Development Institute of Technology: Manual for corrosion protection and maintenance work for port steel facilities, iron slug hydration hardener (revised Edition), 200,
16) H.A. Humble: The cathodic protection of steel piling in seawater, Corrosion, Vol.5 No.9, p.292, 1949
17) Abe, M., T. Fukute, K. Shimizu and I. Yamamoto: Effect of cathodic corrosion protection against sand erosion in wavy sea area., Proceeding of 42nd open forum on corrosion and corrosion protection, C-203,pp.371-374,1995
18) C. W. Ross: Deterioration of steel sheet pile groins at Palm Beach, Florida, Corrosion, Vol.5 No.10, pp.339-342,1949

3 Concrete

3.1 Materials of Concrete

The constituent materials of concrete and their special care taken for port facilities are as follows;

(1) Cement

(2) Water

(3) Additive agent

(4) Admixture

(5) Aggregate

(6) Initial Chloride Ion Content
To reduce the risk of corrosion of steel inside the concrete, the amount of chloride ion contained in fresh concrete should be no more than 0.30 kg/m^3.

(7) Alkali Aggregate Reaction Prevention Measures
To prevent alkali aggregate reactions it is necessary to make appropriate choices among the following three preventative measures:

① Controlling the total amount of alkali within the concrete
Use a material such as Portland cement for which the total amount of alkali is known and verify that the total amount of alkali within the concrete is no more than 3.0 kg/m^3.

② Using materials such as blended cement
Use a cement that controls alkali aggregate reactions, such as type B or type C blast furnace slag cement or type B or type C fly ash cement.

③ Methods that use aggregates known to be safe against alkali aggregate reaction

(8) Of the various types of cement, those having good seawater resistance characteristics are said to be the moderate heat portland cement, blast-furnace slag cement, and fly ash cement. The advantages of these types of cement are that they have excellent performance in durability against seawater, greatly promote long-term strength, and have low hydration heat. However, they also have the disadvantage as relatively low initial strength. Therefore, when using these types of cement, all due care needs to be given to initial curing.
The anti-corrosion properties of steel reinforcement in concrete produced with type B blast furnace slag cement is better than concrete made with ordinary Portland cement [1).
In this case, it is important to perform a sufficient initial care of concrete.

(9) Seawater must not be used as mixing water for reinforced concrete. It may be used for non-reinforced concrete only when it is difficult to obtain clean freshwater.
One must note that, when seawater is used, the setting time of the cement becomes short, so the concrete tends to lose its consistency at an early stage. In such cases a retarder may be used as necessary.

3.2 Concrete Quality and Performance Characteristics

(1) Concrete should be of uniform quality with good workability and have the properties for meeting the strength requirements, durability, impermeability, crack resistance and protection of steel reinforcement.

(2) Concrete should be resistant against deterioration caused by environmental actions, waves and mechanical actions such as impact and friction caused by drifting solids.

(3) Characteristic Values for Concrete Strength

① For the characteristic values of concrete strength of an ordinary concrete to be used in the performance verification of the main structural members of port facilities, it is usually possible to use the values given in **Table 3.2.1** as standard values.

Table 3.2.1 Standard Characteristic Values of Concrete Strength of Ordinary Concrete

Concrete type	Characteristic value of concrete strength
Non-reinforced concrete	Compressive 18 (N/mm^2)
Reinforced concrete	Compressive 24 (N/mm^2)
Concrete for apron pavement	Bending 4.5 (N/mm^2)

For reinforced concrete, in cases when the maximum water-to-cement ratio is specified as 50% or lower in consideration of durability, 30 N/mm^2 may be used as the characteristic value for the compression strength. For concrete lids of non-reinforced concrete, in cases where there is a risk of wave impact or submerging in the early stage after concrete placement, or when construction is done in a cold climate, a characteristic value of 24 N/mm^2 may be used for the compression strength. For large, deformed blocks of non-reinforced concrete it is possible to specify the characteristic value based on the conditions, such as using 21 N/mm^2 as the characteristic value for compression strength for types from 35t to 50t of their nominal weights.

② Characteristic values for the bond strength of ordinary concrete in the performance verification can be calculated from equation **(3.2.1)**.[2)]

$$f_{bo_k} = 0.28 f'^{2/3}_{c_k} \tag{3.2.1}$$

where

f_{bo_k} = characteristic value of the bond strength of ordinary concrete (N/mm^2)

f_{c_k} = characteristic value of the compressive strength of ordinary concrete (N/mm^2)

Equation **(3.2.1)** applies to the use of deformed reinforcing bar conformed to **JIS G 3112, Steel Bar for Reinforced Concrete**. When ordinary round steel bars are used, values that are 40% of the values calculated from equation **(3.2.1)** may be used under the condition of providing semicircular hooks on the edges of the reinforcement.

(4) Mixture conditions for concrete must be specified appropriately in consideration of durability. **Table 3.2.2**, which provides standard mixture conditions for each type of structural member, is based upon verification results of the existing concrete structures in ports and upon research results and technical knowledge on the durability of concrete that is affected by seawater, and may be used as a reference. For the structural members for which there have been loss in performance by chloride attack, such as the superstructures of piers, it is necessary to examine durability, changes in performance over time, and appropriately specify the mixture conditions in order to achieve the desired performance for the facility. Such examinations may refer to **Part III, Chapter 2, 1.1.5, Examination on Change in Performance Over Time**, and **Part III, Chapter 5, 5.2, Open-type Wharf on Vertical Piles**.

Table 3.2.2 Reference for Concrete Mixture Conditions based on the Type of Structural Member

Type	Examples of types of structural members	Mixture conditions		
		Maximum water-to-cement ratio (%)		Maximum size of coarse aggregate
		Regions where freezing and thawing repeatedly occurs	Regions where the temperature rarely goes below the freezing point of water	
Non-reinforced concrete	Superstructure of breakwater, concrete lid, main block, deformed block (for wave dissipation or shielding), foot protection block, packed concrete	65	65	40
	Superstructure of quaywall, parapet, mooring vertical foundation (gravity type)	60		
Reinforced concrete	Mooring post foundations (pile-type), chest walls, superstructure of quaywalls*1)	60	65	20, 25, 40
	Superstructure of open-type wharf	–	–	–
	Caisson, well, cellular block, L-shaped block	50	50	20, 25, 40
	Wave-dissipating block	55	55	20, 25 40
	Anchor wall, superstructure of anchor piles	60	60	20, 25, 40
Concrete for apron pavement		–	–	25 (20)*2), 40

*1) Excludes superstructure of piers.

*2) Use 25 mm for gravel and 20 mm for crushed stone.

(5) Concrete must have the best consistency sufficient for its working conditions. As a rule, AE concrete shall be used when there are no special requirements, usually with an air content of 4.5%. In cold areas where there is a risk of frost damage the air content must be appropriately specified.

(6) Recently, a high performance concrete with self-compacting characteristics has been developed.[3), 4)] Its characteristics have been materialized through its high fluidity and outstanding resistance to material segregation by the combined use of appropriate admixtures. The use of this high-performance concrete makes it possible to place concrete into sections such as in congested reinforced sections or in spaces enclosed by steel shells in which

concrete placing have been difficult by using ordinary concrete .

(7) Construction Joints
In case of port facilities, damage often arises from joints in the concrete.[5)] Therefore, construction joints should be avoided as much as possible. When joints are inevitable in view of shrinkage of the concrete or the conditions of construction, necessary measures should be taken on the joints. [6)]

(8) Surface Protection
For facilities that experience harsh conditions such as abrasion or impact, such as from flowing water that contains sand particles or from waves that contain pebbles, it is necessary to protect the surfaces with appropriate materials, or to increase the material's cross-section or the concrete cover to reinforcement. Surface protection materials include surface coatings that use timber, high quality stone, steel materials, or polymer materials, and also include polymer-impregnated concrete.

(9) Structural Types
It is known that there is a close connection between the structural type of a facility and the occurrence of chloride-induced deterioration. As far as the type of member is concerned, beams and slabs are more sensitive to chloride-induced deterioration than are columns and walls. Chloride ions, oxygen, and water cause deterioration when they penetrate through the concrete surface, so it is preferable to make the area of the concrete surface of a member as small as possible. For example, it is easier to decrease the concrete surface area by using box-shaped beams and slabs than by using T-shaped beams and I-shaped beams, and this is desired from the viewpoint of durability. Assuming that there will be degradation, an additional consideration is to select structural types that permit easy repair, strengthening, or replacement.

3.3 Underwater Concrete

(1) Performance verification of underwater concrete shall be verified its performance and be executed according to **Standard Specifications for Concrete Structures** [7)] or **Port and Harbor Construction Work Common Specifications**. [8)]

(2) In addition to the underwater concrete that has generally been used in the past, today it is also possible to use anti-segregation underwater concrete, which uses anti-segregation underwater admixtures whose main components are cellulose or acrylic water-soluble polymers.

(3) It is preferable to avoid concrete construction joints, and when they are not avoidable appropriate processing must be performed.

(4) The concrete cover used in underwater construction should be 10 cm or more. This value is determined by referring to sources such as standards for underwater concrete used for cast-in-place pile and continuous underground walls.

3.4 Concrete Pile Materials

(1) The physical values of concrete pile materials used in port facilities shall be appropriately specified based on their characteristics.

(2) Precast Concrete Pile Molded by Centrifugal Force
Precast concrete pile molded by centrifugal force includes RC pile, which is a reinforced concrete pile that is made in the factory, PC pile, to which a tensile force is applied to reinforcement or PC tendon, thereby increasing its tensile strength and bending strength (and this is divided into three types, A, B, and C, based on the amount of effective pre-stress), and PHC pile, which uses high-strength concrete with a standard design strength of 80 N/mm^2 or more. Recently, the main trend has been to use PHC pile. Beside these, there are PRC piles, which is a pile that adds reinforcement to PHC pile in order to increase its toughness, and SC pile, which has high-strength concrete inside of a steel pipe to provide large bending strength and shear strength. For these types of precast concrete pile the Japanese Industrial Standard has **JIS A 5372, Prestressed Reinforced Concrete Products**, for RC pile and SC pile, and **JIS A 5373, Precast Prestressed Concrete Products**, for PHC pile and PRC pile.

In the performance verification, when specifying characteristic values for the concrete strength and yield strength of steel of precast concrete pile it is possible to refer to **JIS A 5372** and **JIS A 5373**, while for PC steel bars one can refer to **JIS G 3137, Small Diameter Deformed PC Steel Bars,** for the reinforcement of PRC pile one can reference **JIS G 3112, Steel Bars for Reinforced Concrete**, and for the steel pipes of SC pile one can reference **JIS A 5525, Steel Pipe Pile**.

(3) Cast-In-Place Concrete Pile
Cast-in-place concrete pile is divided into types with and without an outer shell. The special feature of cast-in-place concrete pile is that the pile is constructed while it is situated in the ground. Therefore, the cast-in-place

concrete pile is different from the precast concrete pile in that it is not necessary to be concerned with influences such as impact when it is placed into the ground, but rather, different from the case when it is fabricated on land, there is the problem that during its construction it is influenced by pile constructed in the surrounding ground. For this reason, the cast-in-place concrete pile has some insecure characteristics during construction, and those without an outer shell have greater insecurity, so care must be taken. A reference for cast-in-place pile is the **Specification for Highway Bridges, Part 4, Substructures**.[13)]

References

1) Fukute, T., K. Yamamoto and H. Hamada: A study of the durability of offshore concrete mixed with sea water, Report of PHRI, Vol.29, No. 3, 1990
2) JSCE: Standard Specifications for Concrete Structures, Structural performance verification, 2002
3) Fukute T., H. Hamada, K. Miura, K. Sano, A. Moriwake and K. Hamazaki: Applicability of super-workable concrete using viscous agent to densely reinforced concrete members, Rept. of PHRI Vol. 33 No. 2, pp. 231-257, 1994
4) Coastal Development Institute of Technology (CDIT): High-fluidity Concrete Manual for Port Facilities, 1997
5) Seki, H., Y. Onodera and H. Maruyama: Deterioration of Plain Concrete for Coastal Structures Under Maritime Environments, Technical Note of PHRI, No. 142, 1972
6) Otsuki, N., M. Harashige and H. Hamada: Test on the Effects of Joints on the Durability of Concrete in Marine Environment (after 10 years' exposure), Technical Note of PHRI, No.606,1988
7) JSCE: Standard Specifications for Concrete Structures, Construction, 2002
8) Japan Port Association: Standard Specifications for Port Construction Work, Japan Port Association, 2005
9) Coastal Development Institute of Technology (CDIT)and Japanese Institute of Technology on Fishing Ports, Grounds and Communities: Manual for non-disjunction underwater concrete, (Design and construction), 1989
10) JSCE: Guideline for design and construction of unti-segregation concrete in underwater (Draft), JSCE Concrete Library, No.67, 1991
11) Coastal Development Institute of Technology (CDIT): Manual for sealing concrete construction with vibrator (for immersed tunnel element of steel and concrete sandwich structure), 2004
12) Coastal Development Institute of Technology (CDIT): Technical Manual for PC sheet pile for port construction work, 2000.
13) Japan Road Association: Specifications and commentary for Highway Bridges Vol. IV, Substructures, pp.418-424,2002

4 Bituminous Materials

4.1 General

(1) Bituminous materials used in port facilities shall satisfy the required quality and performance required to achieve the performance requirement of facilities. These shall include elasticity, cohesion, impermeability, waterproofness, durability, and weatherproofness.

(2) Bituminous materials are rarely used alone. Asphalt, for example, is usually mixed with aggregate and used as an asphalt mixture in asphalt concrete for pavement, asphalt mats, sand mastic asphalt, and asphalt stabilization. The type and mix proportion of asphalt depend on its use. Therefore, it is important to select a material that will meet the required objective.

4.2 Asphalt Mats

4.2.1 General

(1) Asphalt mats shall have an appropriate structure in consideration of the required strength, durability, and workability based on the purpose of their use, the location of their use, and the environmental conditions of the site.

(2) Asphalt mats are made by embedding reinforcement material and wire rope for suspension into a compound material mixed from asphalt, limestone filler, sand and crushed stone. They are then formed into a mat-shape (see **Fig. 4.2.1**).

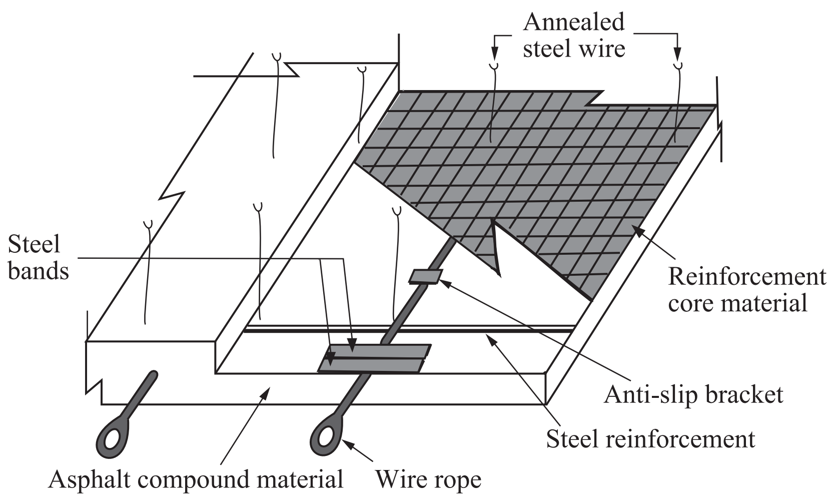

Fig. 4.2.1 Example of Structure of Friction Enhancement Asphalt Mat

(3) Types of asphalt mats include friction enhancement mats that increase the sliding resistance of gravity type structure walls, scouring prevention mats that prevent the scouring of structural foundations, and sand washing out prevention mats that prevent the washing out of foundation sand mound and backfilling sand from revetments. When asphalt mats are used sufficient care should be given to their quality, long-term durability, and constructability, based on the purpose of their use, the location of their use, and the environmental conditions of the site. In particular, when there are special environmental conditions such as cold regions, subtropical regions, or tidal zones, one must consider the harsh environmental conditions with regard to long-term durability, [1), 2)] and careful studies should be made, including the determination of appropriateness.

4.2.2 Materials

(1) Asphalt mat materials shall be selected as appropriate to yield the required strength and durability.

(2) The following materials can be used in asphalt mats:

① Asphalt

② Sand

③ Filler

④ Crushed Stone

4.2.3 Mix Proportion

(1) The mix proportion used for asphalt mixture is determined by mix proportion test to get the desired strength and flexibility. Friction enhancement mats and scouring prevention mats have a relatively long history and a considerably long record of use. They have caused no particular problem to date.[3] Therefore, the values given in **Table 4.2.1** may be used, except for special use conditions.

Table 4.2.1 Standard Proportion for Asphalt Mixture

Material	Ratio by mass(%)	
	Friction enhancement mat	Scouring prevention mat
Asphalt	10–14	10–14
Dust	14–25	14–25
Fine aggregate	20–50	30–50
Coarse aggregate	30–50	25–40

Notes: Dust is sand or filler with a grain size of 0.074 mm or less.
Fine aggregate is crushed stone, sand, or filler with a grain size from 0.074 to 2.5 mm.
Coarse aggregate is crushed stone with a grain size of 2.5 mm or larger.

4.3 Paving Materials

(1) Paving materials shall in principle comply with **Asphalt Paving Guidelines**, [5] except in the areas subject to special load conditions.

(2) Aprons are an example of the "areas subject to special load conditions". Traffic on pavements particularly apron paving in port areas, unlike that on roads in city areas, almost invariably involves heavy vehicles. This includes heavy machinery with large contact pressure. This type of load rarely travels at high speed and is almost always stationary or moving at low speeds. Parts of these paved areas are also used for cargo stacking. Thus, when considering the paving materials to be applied to such areas, care should be taken to the fact that bituminous materials are susceptible to static loading. **Part III, Chapter 5, 9.14. Aprons** can be used as a reference.

(3) Guss asphalt paving has the properties of being non-permeable and of following deflection well, so it is often used for steel floor slab paving and bridge surface paving.

4.4 Sand Mastic

4.4.1 General

(1) Sand mastic asphalt is made of asphalt heat-mixed with an ore-based filler or additive and sand. The sand mastic asphalt is an asphalt mixture virtually free of voids and does not require rolling compaction after grouting.

(2) Sand mastic asphalt at a certain high temperature is grouted into gaps between rubbles without segregation in water by pouring it onto the rubble mound. The grouted sand mastic asphalt wraps itself around the rubble to form a single unit, thus preventing the stone from breaking off or being washed away. It is sometimes used when it is not possible or uneconomical to obtain rubbles of the size required.

(3) When conducting the performance verification of sand mastic asphalt, due attention should be paid to the plastic flow due to the material properties of asphalt so that stability problem will not arise.

4.4.2 Materials

(1) Materials for sand mastic asphalt shall be selected as appropriate to meet the required strength and durability.

(2) For example, the following can be used as sand mastic materials:

① Asphalt

② Sand

③ Filler

(3) Asphalt that is used as sand mastic in underwater construction [6), 7)] should have sufficient fluidity so that, if it is flowed down, the rubble is completely filled in with no pores.

(4) With regard to the effect of sand on mixtures, the larger the sand grains the greater is the fluidity of the mixture, and although a certain amount of fluidity can be obtained with a small amount of asphalt the mixture readily segregates. The smaller the grain size the less fluidity there is, creating a dense sand mastic. Therefore, it is preferable that the sand grain sizes be continuous, where the grain-size curve changes smoothly, so that the mixture does not segregate.

(5) When filler is mixed into asphalt mixtures, it mixes with the asphalt to fill in the spaces among the aggregate while simultaneously working as a binding agent to decrease the fluidity of the mixture, thus increasing the viscosity and stability. Asphalt usually adheres well to filler that is slightly alkali, so it is possible to use filler made from slightly alkali lime powder.

4.4.3 Mix Proportion

(1) The mix proportion shall be determined through mixing tests to obtain the required fluidity and strength in view of the work and natural conditions.

(2) General
The values listed in **Table 4.4.1** are commonly used as the mix proportion for sand mastic asphalt applied underwater.

Table 4.4.1 Standard Proportion for Sand Mastic Asphalt Mix

Material	Proportion by mass(%)
Asphalt	16–20
Dust	18–25
Fine aggregate	55–66

Note: Dust refers to sand or filler passed through a 0.074 mm sieve.
Fine aggregate is crushed stone, sand, or filler remaining on a 0.074 mm sieve.

(3) Notes on the Performance Verification
Notes on the design of sand mastic asphalt is as follows:

① It should not be used in locations directly affected by powerful impulsive wave pressure or drifting objects.

② It should not be used in locations where rapid sedimentation is anticipated.

③ The gradient of the rubble surface where sand mastic is executed is preferably gentle than 1:1.3.

④ Suitable reinforcement should be used on the slope shoulder, slope toe, and the edges of the execution area.

⑤ The relationship between the design working life of port facilities and the durability of the sand mastic asphalt should be fully taken into account.

References

1) Imoto, T., Y. Mizuno and K. Yano: Research on durability of asphalt mats employed in the gravity type port facilities, Proceedings of Offshore Development, JSCE, to utilized to Survey Vo1.5,pp.119-124,1989
2) Mizuno Y., M. Tokunaga, Y. Sugimoto, K. Murase and O. Yasuda: Development and study of asphalt mats for friction increase of gravity type of offshore structures in cold sea area, Proceedings of Offs shore Development Vol. 8, pp. 171-176, 1992
3) Kataoka, S., K. Nishi, M. Yazima and O. Miura: Durability of asphalt mats placed under Caisson for friction increase, Proceedings of 30th Conference on Coastal Eng, pp,643-647,1983
4) Itakura, T. and T. Sugahara : Recent Development of Asphalt utilization, Journal of Japanese Petroleum Institute Vol. 7, No. 8, p.9, 1964
5) Japan Road Association: Essential points of asphalt pavement, 1998
6) Study group for asphalt mixture for hydraulic structures: Asphalt mixture for hydraulic structures- materials, design and construction for field engineers-, Kajima Publishing, 1976
7) Kagawa, M. and T. Kubo : Experimental study on stability of rubles poured sand mastic, Proceedings of 12th Conference on Coastal Eng,. JSCE, 1965

5 Stone

5.1 General

(1) Stone shall be selected in view of the required quality and performance to suit its purpose and its cost.

(2) Generally, stone is used in large quantities for port facilities such as breakwaters and quaywalls. Selection of stone materials has a major impact on the stability of the structure as well as the period and cost of construction.

(3) The types of stone mainly used in port construction and their physical properties are given in **Table 5.1.1**. It should be borne in mind that the physical properties of stone of the same classification may differ depending on the region and site of quarries.

Table 5.1.1 Physical Properties of Stones

Rock classification	Subclassification	Apparent density (t/m^3)	Water absorption ratio (%)	Compressive strength (N/mm^2)
Igneous rock	Granite	2.60 – 2.78	0.07 – 0.64	85 – 190
	Andesite	2.57 – 2.76	0.27 – 1.12	78 – 269
	Basalt	2.68 (absolute)	1.85	85
	Gabbro	2.91 (absolute)	0.21	177
	Peridotite	3.18	0.16	187
	Diabase	2.78 – 2.85	0.008 – 0.03	123 – 182
Sedimentary rock	Tuff	2.64	0.16	377
	Slate	2.65 – 2.74	0.08 – 1.37	59 – 185
	Sandstone	2.29 – 2.72	0.04 – 3.65	48 – 196
	Limestone	2.36 – 2.71	0.18 – 2.59	17 – 76
	Chert	2.64	0.14	119
Metamorphic rock	Hornfels	2.68	0.22	191

5.2 Rubble for Foundation Mound

(1) Rubble for foundation mounds shall be hard, dense and durable, and free from the possibility of breaking due to weathering and freezing. The shape of rubbles shall not be flat or oblong.

(2) When determining which type of stone to use, tests should first be conducted and the material properties be fully ascertained. The ease of procurement, transportability, and price should also be taken into account.

(3) The shear properties of rubble stones have been studied by Shoji [1)] using various large-scale triaxial compression tests. This study is based on the state of rubble actually used in port and harbor construction works.

(4) As a guideline proposed by Mizukami and Kobayashi [2)] for determining the strength constant without conducting large-scale triaxial compression tests, a shear strength of 0.02 N/mm^2 and a shearing resistance angle of 35º can be expected if the unconfined compressive strength is 30 N/mm^2 or more.

5.3 Backfilling Materials

(1) Backfilling materials shall be selected in view of their properties such as angle of shear resistance and specific weight.

(2) Rubble, unscreened gravel, cobblestone, and steel slag are generally used as backfilling materials. The material properties of mudstone, sandstone, and steel slag vary greatly, and therefore these should be examined carefully before use.

(3) The values listed in **Table 5.3.1** are often used as characteristic values for backfilling materials.

(4) “Rubble” used in ports and harbors has the equivalent performance to “riprap” prescribed by JIS A 5006.

(5) “Unscreened gravel” consists approximately half and half of sand and gravel.

(6) The slope gradient is the standard value of the natural gradient of backfilling materials executed in the sea. Generally, a larger value is adopted when the effect of waves are small at the time of backfilling execution, and a smaller value when the effect of waves are large.

(7) For steel slag, see **7.2 Slag**.

Table 5.3.1 Characteristic Values for Backfilling Materials

		Angle of shear resistance(°)	Unit weight		Slope gradient
			Above residual water level (kN/m3)	Below residual water level (kN/m3)	
Rubble	Ordinary type	40	18	10	1:1.2
	Brittle type	35	16	9	1:1.2
Unscreened gravel		30	18	10	1:2−1:3
Cobblestone		35	18	10	1:2−1:3

5.4 Base Course Materials of Pavement

(1) Base course materials of pavement shall be selected so as to have the required bearing capacity and high durability and to allow easy compaction.

(2) Normally, granular material, cement stabilized soil, or bituminous stabilized soil is used as a base course material. Granular materials include crushed stone, steel slag, unscreened gravel, pit gravel, unscreened crushed stone, crushed stone dust, and sand. These may be used on their own or mixed with other granular materials.

(3) The base course serves to disperse the surcharge transmitted from above and to transfer it to the course bed. Normally, it is divided into a lower base course and an upper base course. Materials used for the lower base course are cheaper and have relatively small bearing capacity. The upper base course requires materials of good quality with large bearing capacity.

References

1) Shoji, Y:. Study on shearing Properties of Rubbles with Large Scale Triaxial Compression Test, Rept. of PHRI Vol.22 No.4,1983
2) Mizukami, J. and M. Kobayashi Soil Strength Characteristics of Rubble by Large Scale Triaxial Compression Test, Technical Note of PHRI No.699,p.20, 1991
3) Japan Road Association: Cement concrete pavement, Maruzen Publishing, 1997
4) Japan Road Association: Essential points of asphalt pavement, 1998

6 Timber

6.1 General

Timber has the following characteristics in contrast to other construction materials. It is necessary to consider these characteristics when using timber in port facilities.

(1) Strength Performance
Timber's strength per unit mass is high. Strength along fiber direction is greater than that perpendicular to the fiber. Strength in tension is greater than in compression, and bending failure begins by buckling on the compressed side. The shear strength is small. The changes in strength, dimensions, and specific gravity due to water content cannot be ignored. There is large creep deformation under a continuous load.

(2) Durability
Degradation, such as discoloration, surface contamination, morphology change, and reduction in strength may occur due to organisms such as fungi, insects, and marine borers and meteorological factors such as ultraviolet light, rain, and temperature. The main degradation factors vary greatly depending on the usage environment and the water content.

(3) Environmental Character
Wood grows by using solar energy to fix carbon dioxide from the air, so it is a material that results in little carbon dioxide release as a result of its growth. The use of wood from routine thinning contributes to the conservation of artificial forests. One should be cautious about using timber from natural forests for reasons such as that it leads to the destruction of forests.

(4) Other
Timber is combustible. It is attractive if there is the proper amount of irregular grain patterns and color variation. The smell is pleasing to mind and body. It has moderate softness to prevent injuries when one falls to it. It is warm to the touch because it has low heat conductance. Its frictional coefficients are large, with almost no difference between the static friction coefficient and dynamic friction coefficient, so it is easy to walk on.

6.2 Strength Performance

The specification of characteristic values for timber strength and the verification of its strength as a material can be based on the **Recommendation for Limit State Design of Timber Structures (Draft)** [1] of the Architectural Institute of Japan (hereafter, the **Recommendation (Draft)**). The following items are of particular concern when timber is used in port facilities.

(1) Water Content
The water content of wood is expressed as (weight of water) / (oven dry weight of the wood) x 100 (%). Water within wood is either bound water or free water. Bound water is bound to cellulose within the cell walls of the wood. Free water exists in cell cavities. If the water content is no more than about 28% then there is no free water.

Bound water affects timber strength, but free water doesn't. As shown in the conceptual drawing of **Fig. 6.2.1**, the strength goes down as the bound water content increases from the oven dry condition to a water content of 28%, the fiber saturation point, and the strength stays roughly the same when the water content increases beyond the fiber saturation point and the free water increases. Under the meteorological conditions of Japan the water content reaches equilibrium around 15%. Therefore, the standard strength characteristic values in the **Recommendation (Draft)** are specified based on tests with a water content of 15%. The **Recommendation (Draft)** defines constantly wet conditions to be usage environment I, intermittently wet conditions to be usage environment II, and other environments to be usage environment III, and in usage environment I the standard strength characteristic values are reduced by multiplication by a coefficient of 0.7, while for usage environment II they are reduced by a factor of 0.8. For port facilities all materials can be assumed to be in a wet condition, so it is necessary to reduce the standard strength characteristic values by the coefficient for usage environment I or II.

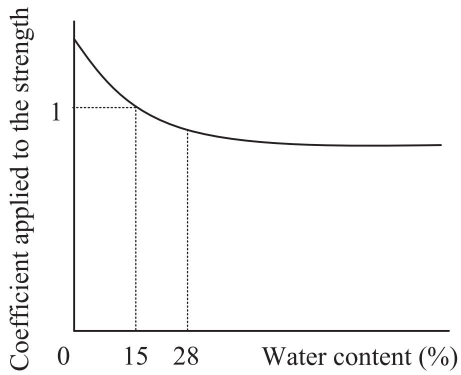

Fig. 6.2.1 Effect of Water Content on Wood Strength (Conceptual Drawing)

With regard to dimensional changes of wood, expansion, or shirinkage, it is true again that bound water has an effect but free water doesn't. The dimensions grow as the water content increases from the oven dry condition to a water content of 28%, fiber saturation point, and the dimensions stay roughly the same as the water content increases beyond the fiber saturation point and the free water increases. The dimensional change ratio varies with the direction, where "direction tangential to the rings" > "direction radial with respect to the rings" » "fiber direction", with a ratio of about 1 : 0.5 : 0.1. The total expansion ratio from the completely dry condition to the fiber saturation point can reach about 6% for the direction tangential to the rings in Japanese cedar. In applications where the water content below the fiber saturation point is expected to change it is necessary for the design to consider dimensional changes from the beginning.

The specific gravity of wood varies greatly with the species and water content. In the air-dried condition, water content 15%, the specific gravity is about 0.38 for Japanese cedar and about 0.53 for larch. For undried logs immediately after felling and timber that is used underwater the water content may range from 80% to 150%, so the apparent specific gravity including the water would be as much as twice that in air dry. In the design of port facilities it is customary to assume that the specific gravity of timber is 0.8, using a density of 7.8 kN/m^3, but it is necessary to remember that the apparent specific gravity can vary greatly with species and water content, and not to assume a specific gravity on the dangerous side.

(2) Continuous Loading Time

In the **Recommendation (Draft)**, the relationship between continuous loading time and its effect on the influence coefficients is given as in **Fig. 6.2.2**. When a load continues longer than 10 minutes, which is the standard loading test time for wood, the standard strength characteristic value is to be multiplied by an influence coefficient for the effect of the continuous loading time. Thus, for port facilities, it is necessary to specify continuous loading times for such factors as the temporary loading time during construction and the long-term continuous loading time after completion, and reduce the strength characteristic values by the influence coefficients for those effects.

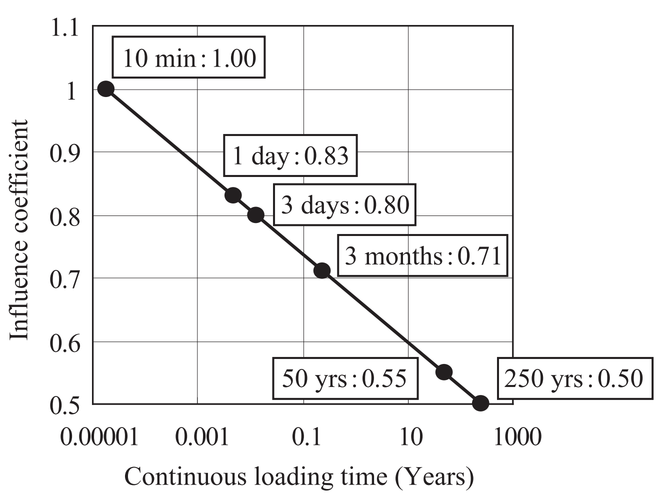

Fig. 6.2.2 Continuous Loading Time and Influence Coefficients 1)

(3) Standard Strength Characteristic Values for Logs

In logs, the fibers are not cut, so logs are mechanically better than manufactured wood, and they are suitable for port facilities both in terms of economics and environmental impact. The **Recommendation (Draft)** says that the standard strength characteristic values of logs may be taken from the standard strength characteristic values given for mechanical grade classifications of manufactured wood.

6.3 Durability

Examples of degradation phenomena that occur when timber is used include discoloration, surface contamination, morphology change, and reduction in strength. Whether these are considered as problems depends on the timber application. Discoloration, surface contamination, and morphology change are problems in applications where appearance is important, such as boardwalks and decks. While for construction materials that are out of sight, such as pile, reduction in strength would be a problem.

(1) Causes of Degradation [2)]

Examples of factors that cause degradation phenomena include organisms such as fungi, insects, and marine borers [3), 4), 5)], and meteorological factors such as ultraviolet light, rain, and temperature. The main degradation factors depend on the environment in which the timber is used and its water content, as shown in **Table 6.3.1**. The water content conditions in the table are: “dry”, meaning the condition where the water content is below the fiber saturation point, about 28% so that there is no free water, “wet”, meaning that the water content is at the fiber saturation point or higher but the cell cavities are not saturated with water, and “saturated”, meaning the condition where the cell cavities are saturated with water.

Table 6.3.1 Usage Environments and Degradation Factors

Usage environment		Examples of application	Water content condition	Main degradation factors
Indoor		Residence	Dry	Boring beetles
			Wet	Fungi, termites
Outdoor	In the air	Outdoor construction	Dry	Meteorological factors, boring beetles
			Wet	Fungi, termites, meteorological factors
	In the ground	Pile	Wet	Fungi, termites
			Saturated	None
	In fresh water	River facilities	Wet	Fungi
			Saturated	None
	In the seawater	Port facilities	Wet	Fungi, marine borer
			Saturated	Marine borer

(2) Preventative Measures for Degradation

Examples of preventative measures for degradation include the use of natural materials with high durability, protective processing, and maintenance. [6)]

References

1) Architectural Institute of Japan: Recommendation for Limit State Design of Timber Structures (Draft), 2003
2) Japan Wood Preserving Association: Introduction for the preservation of wood ‘Revised Edition'), 2001
3) Okada, K. Edition: Shipworm damage of wooden vessel and its countermeasures, Japan Society for the Promotion of science, 1958
4) Tsunoda, K. and Nishimoto, K.: Shipworm attack in the sea water log storage area and its prevention (3), Settlement season of shipworm, Wood Industry Vol. 35, pp. 166-168, 1980
5) Yamada, M.: Durability Test of Untreated Wood and Wood-powder/plastic Composite in Marine Environment, Technical Note of PARI No.1045, 2003
6) Japan Wood Preservation Association: Maintenance Manual of wooden exterior structural materials, 2004

7 Recyclable Materials

7.1 General

(1) Recyclable materials shall be used as appropriate in accordance with the characteristics of the materials and the facilities.

(2) Recyclable materials in port construction include slag, coal ash, crushed concrete, dredged soil, and asphalt concrete mass. Most of these can be used in landfill materials, sub-base course materials, soil improvement materials, and concrete aggregate.

(3) Effective use of recyclable materials is extremely important. Port and harbor construction works use large quantities of materials and it is, therefore, very important that they contribute to environmental conservation and sustainable development by recycling and using fewer natural materials. We also need to undertake exhaustive studies before using recycled materials to ensure that no environmental issues arise.

(4) The properties of recyclable materials are quite variable. Therefore, their physical and dynamic properties and the volume to be supplied should be fully examined in advance to ensure the purpose of use.

7.2 Slag

(1) Slag includes ferro-slag, water granulated copper-slag, and ferronickel granulated slag

(2) Ferro-slag [2)] is industrial waste generated in large quantities by the steel industry. It is broadly divided into blast furnace slag and steel- making slag.

(3) Air-cooled blast furnace slag is a granular material mainly used as road construction material and has been effectively utilized. Water granulated blast furnace slag is a lightweight sand-like material. As well as being used as a raw material for blast furnace cement, it is also increasingly used as a backfilling material for ports facilities and sand compaction material, in view of its lightness.[3), 4), 5)]

(4) Because steel- slag causes expansion and disintegration when free lime reacts with water, in order to avoid adverse effect, it is steam autoclaved and used as road and soil improvement materials.

Table 7.2.1 [2)] lists a comparison of chemical compositions of ferro-slag and ordinary earth materials. **Table 7.2.2** lists the physical and dynamic properties of steel- slag and air-cooled blast-furnace slag.

Water granulated copper-slag is a sandy material obtained through high-speed cooling with water in the copper refining process similar to the water granulated blast furnace slag. It has a higher particle density than sand. Although it is susceptible to particle crushing, its angle of shear resistance and hydraulic conductivity are about the same as those of beach sand. As well as being used for fine aggregate of concrete, sand mat and as a filling material, it has been experimentally used in the sand compaction pile method.[6), 7)]

Ferronickel granulated blast furnace slag is obtained during the manufacturing of ferronickel that is a raw material for stainless steel. Its specific weigh is larger than that of sand, and has been used as a caisson filling material.

Table 7.2.1 Chemical Compositions of Slag and Other Materials [2)]

(Units：%)

Component \ Item	Blast furnace slag	Converter slag	Electric furnace slag		Mountain soil	Andesite	Ordinary Portland cement
			Oxidizing slag	Reducing slag			
SiO_2	33.8	13.8	17.7	27.0	59.6	59.6	22.0
CaO	42.0	44.3	26.2	51.0	0.4	5.8	64.2
Al_2O_3	14.4	1.5	12.2	9.0	22.0	17.3	5.5
T-Fe	0.3*	17.5	21.2	1.5	–	3.1*	3.0**
MgO	6.7	6.4	5.3	7.0	0.8	2.8	1.5
S	0.84	0.07	0.09	0.50	0.01	–	2.0***
MnO	0.3	5.3	7.9	1.0	0.1	0.2	–
TiO_2	1.0	1.5	0.7	0.7	–	0.8	–

Note) *：FeO,、**：Fe_2O_2, ***：SO_3

Table 7.2.2 Physical and Dynamic Properties of Steel-Slag and Air-Cooled Blast Furnace Slag

	Steel- slag	Air-cooled blast furnace slag	
		MS–25	CS–40
Bone dryness density (BD) (g/cm^3)	3.19–3.40	–	–
Water absorption rate (%)	1.77–3.02	–	–
Unit weight (kN/m^3)	19.7–22.9	17.2–17.8	16.7–17.2
Optimum moisture content (%)	5.69–8.24	8.8–9.4	8.4–9.0
Maximum dry density (g/cm^3)	2.34–2.71	2.18–2.21	2.13–2.17
Modified CBR (%)	78–135	170–204	152–186
Coefficient of permeability (cm/s)	10^{-2}–10^{-3}	10^{-2}–10^{-3}	–
Angle of shear resistance (°)	40–50	–	–

(5) Recently, hydration-hardened steel- slag is used as a civil engineering material for port facilities, such as for deformed blocks, foot protection blocks, and dumping blocks. For details, one can refer to the **Hydration-Hardened Steel-Slag Technical Manual (Supplementary Edition)**.[9)]

7.3 Crushed Concrete

(1) Crushed concrete has mainly been used as a base course material for pavement so far, [15)] but recently it has become difficult to obtain good quality aggregate so there are attempts to also use concrete as an aggregate.

(2) When using crushed concrete as a material for aggregate, the properties such as the angle of shear resistance vary depending on mother concrete. Thus, under present circumstances it is difficult to give the standard values of their properties. If the properties of the concrete before crushing are similar to those presented in reference 18), the properties of crushed concrete can be determined by referring to it.

7.4 Dredged Soil

(1) Dredged soil has been used as a landfill material, and when no landfill area is under construction at the time of dredging it has been used to fill in land at waste disposal sites in port areas. In projects at ports and coastal airports, large amounts of soils are always used for purposes such as backfilling of quaywalls and seawalls, construction of reclamation land, and improvement of soft subsoil, so if dredged soil could be used for a larger percentage of such materials then that would be extremely effective in prolonging the life of waste disposal areas and reducing construction costs.

(2) When sandy dredged soil is used as reclamation or backfill it may be statically stable but a ground forms that liquefies extremely easily during ground motions, so some preventative measures are required against liquefaction. Also, cohesive dredged soil becomes a very soft ground with a high water content, so soil improvement is required after reclamation. In the past, one soil improvement method that has often been used is the installation of vertical drains to promote consolidation after the surface layer hardens. In recent years methods of soil improvement have been developed where dredged cohesive soil is first hardened and then used for reclamation or backfill. These include the method that use special hardening treatment ship to mix the soil hardening agents and then use it as reclamation, the method that mix the soil with hardening agents while it is being transported by barges and then use it as reclamation, and the method that mix it with hardening agents on-site.

(3) Pneumatic flow mixing methods are hardening methods that have been newly developed in order to use dredged soil more economically as a reclamation material. Such method add hardening agents while soil is being transported by air pressure within a tube, and use unique mixing equipment to enhance the kneading effect of the dredged soil's plug current generated under the pressurized flow, so as to simultaneously transport and harden the dredged soil. Proposed methods of mixing with hardening agents include the method that pass the soil through line mixers, the method that add and mix in powdered hardening agents, the method that first add in hardening agents and then pass the soil through multiple curved tubes to enhance the kneading effect, and the method that provide pipes at multiple places within the tubes to spray a hardening slurry so as to directly add the hardening agent into the cohesive soil as it passes through the tube.

(4) Lightweight treated soil methods make dredged soil into a slurry with a water content at the liquid limit or higher, then add in a cement hardener and a lightweight material such as foam or expanded beads. These methods have the following characteristics:

① The dredged soil is used effectively, even underwater, to create a stable ground.

② The density is from 10 to 12 kN/m^3, so this is effective in reducing the consolidation sedimentation of the foundation ground and in reducing the earth pressure.

③ The unconfined compressive strength is from 200 to 600 kN/m^2, with the same kind of mechanical characteristics as hard clay.

The cost of lightweight treated soil methods varies greatly depending on the scope of the project.

Besides these methods, there are also methods that perform dehydration at dredged soil dehydration plants to prepare reclamation material.

References

1) Takahashi, K.: Utilization of Fly Ash and Steel Slug, Technical Note of PHRI, Technical Note of PHRI
2) Nippon Slag Association: Characteristics and versatility of slag, 1996
3) Coastal Development Institute of Technology (CDIT) and Nippon Slag Association: Guideline for the utilization of granulated blast furnace slag for port construction, 1989
4) Port and Airport Recycling Promotion Forum: Technical guideline for recycling technology in development of port and airports, (http//:www.mlit.go.jp/kowan/recycle/),2004
5) Muraoka, T.: Report of test construction of Cellular type sea wall utilizing steel manufacture slag, Civil Engineering data, Vol. 51, No. 7, 1996
6) Kitazume, M S. Miyajima and Y. Nishida: Loading test of back fill of SCP improved soil by copper granulated slag, Proceeding the 50th Conference of JSCE, 1995
7) Kitazume, M. : Effect of SCP improvement of soil by copper granulated slag on sheet pile sea wall, Proceeding of 31st Conference on Earthquake Engineering, 1996
8) Coastal Development Institute of Technology: Handbook of utilization of Eco-Slug for port construction work, CDIT, 2006
9) Coastal Development Institute of Technology: Technical Manual for iron slug hydration hardener (enlarged Edition), 200,
10) Takahashi, K.: Geotechnical examination on improvement and replacement of port facilities, Soil and Foundation 43-2 (445), Society of Soil Mechanics and Engineering Science,1995
11) Ban, K., J. Asano and K. Takahashi: Mix proportion of coal ash in deep mixing method and engineering characteristics of improved soil, Proceeding of 50th Conference of JSCE, 1995
12) A. Watanabe, K. Takahashi and K. Azuma: Engineering Characteristics of Improved Soil by Deep Mixing Method Using Coal Ash, 12th International Symposium, American Coal AshAssosiation, 1997
13) Miura, M., K. Okuda, H. Kondo, K. Kawasaki and K. Suami: Field experiments of sand compaction utilizing hardened coal ash, Proceeding of 50th Conference of JSCE, 1995
14) K. Okuda, H, Kondo and M. Miura: Utilization of Solidified Coal Ash as a Substitute for Sand and Stone,121h International Symposium, American Coal Ash Assosiation,1997
15) Yokota, H. and S. Nakajima: Applicability of Recyclable Materials to Port and Harbour Construction, Technical Note of PHRI No.824,1996
16) Tanaka, j., T. Fukude., H. Hamada and A. Dozono: A Study on the Properties of Concrete mixed with Crushed Concrete as Aggregate, Rept. of PHRI Vol.36, No3,pp.37-60,1997
17) Itou, M., T. Fukude, T. Yamaji and J. Tanaka: A Study on Applicability of Recycled Concrete to Marine Structures Vol. 37, No. 4, 1998
18) Mizukami, J., Y. Kikuchi and H. Yoshino: Characteristics of concrete debris as rubble in marine construction, Technical Note of PHRI No.906, 1998

8 Other Materials

8.1 Plastic and Rubber

(1) When using plastics and rubbers, material shall be selected appropriately in view of the location and purpose of use, environmental conditions, durability, and cost.

(2) The following are examples of applications of plastic and rubber in port construction.[1), 2)]

① Geosynthetics
Geosynthetics is a general term that includes the geotextiles, namely polymer material products in the form of permeable sheets, as well as geomembranes, which are nonpermeable films.

(a) Permeable materials
Permeable materials may be woven or non-woven. Woven types, geowovens, are woven into a matrix with perpendicularly crossing warps and woofs. Non-woven types, non-woven geotextiles, are textiles created by adhesion of fibers, interlocking adhesion, or both.

(b) Water sealing materials
The following are examples of applications of geosynthetics in port construction.

(c) Embankment reinforcing
When laying good-quality soils over a land reclaimed with dredged clay, a sheet or net of geosynthetics is spreaded directly over the surface. Its purpose is to ensure the passage of heavy machinery, while preventing subsidence of good-quality soils.[4)] The net method has often been used in recent reclamation works with soft ground.[5)]

(d) Preventing washing out and scouring
When used as a filter material with the aim of preventing sand washing out, a sand invasion prevention cloth is often laid out on the surface of backfill stone or on the back of rubble mound of the quaywall, and under the entire bottom of the rubble mound, or under the part of the sea side of the mound. It is also used as a measure to scouring prevention.

② Joint sealing materials
These include seal plates, joint boards, and grouting materials used in/on the joint sections of concrete structures.

③ Expanded polystyrene
This is used for buoys, pontoon floats, and other civil engineering structures, on account of its lightness. Expanded polystyrene (EPS) blocks and EPS beads are used as civil engineering materials. Generally, EPS blocks are used to reduce earth pressure, to counter settlement in embankments on soft ground, and to form the foundations of temporary roads. EPS beads are mixed with cement or another cementing material together with soils and used as a lightweight material in backfilling, in order to reduce settlement and earth pressure.[8)]

(3) The standards for sand invasion prevention cloth and plate, and rubber mats normally used to prevent scouring, piping or infiltation in port and harbor facilities are as follows:

① Sand invasion prevention cloth
Sand invasion prevention cloth used to prevent invasion of soil into the backfill will normally be determined in consideration of the constructions conditions such as the placing method of backfilling, the residual water level, and the leveling precision of backfilling.

The cloth that is laid under the bottom of rubble mounds to prevent washing out of the subsoil will normally be determined in consideration of the natural and construction conditions such as the wave height, tidal current, and rubble size.

Tables 8.1.1 (a) and **(b)** list the minimum standards for woven and nonwoven materials under favorable execution conditions.

Table 8.1.1 (a) Minimum Standards for Sand Invasion Prevention Sheets (Nonwoven)

Type	Thickness	Tensile strength	Elongation	Mass	Remarks
Nonwoven cloth	4.2 mm or greater	880 N/5cm or greater	60% or greater	500 g/m^2 or greater	JIS L 1908

Note: The thickness of 4.2 mm or greater is applied for the cloth under loading of 2 kN/m^2 according to JIS L 1908. With no loading, the thickness should be 5 mm or greater.

Table 8.1.1 (b) Minimum Standards for Sand Invasion Prevention Sheets (Woven)

Type	Thickness	Tensile strength	Elongation	Remarks
Woven cloth	0.47 mm or greater	4,080 N/5cm or greater	15% or greater	JIS L 1908

② Sand invasion prevention plates
The standard thickness of the plates used to prevent scouring and that used for the vertical joints of caisson 5 mm. The plates should meet the standards listed in **Table 8.1.2.** In cold regions, rubber plates are sometimes used. In this case, the values listed in **Table 8.1.3** be satisfied.

Table 8.1.2 Standards for Sand Invasion Prevention Plates (Soft Vinyl Chloride)

Test item	Particulars		Standard values
	Method	Tensile direction	
Tensile strength	JIS K 6723 Test sample No. 1 type dumbbell	Lateral	740N/cm or greater
Tear strength	JIS 6252 Test sample uncut angle shape	Longitudinal	250 N or greater
Elongation	JIS K 6723 Test sample No. 1 type dumbbell	Lateral	180% or greater
Seawater resistance Tensile strength residual ratio	JIS K 6773	Lateral	90% or greater
Seawater resistance Elongation residual ratio	JIS K 6773	Lateral	90% or greater
Specific gravity	JIS K 7112	–	1.2–1.5
Stripping strength	JIS K 6256 Width 25×250mm Strip-shaped sample	Longitudinal	30 N/cm or greater

Table 8.1.3 Standards for Sand Invasion Prevention Plates (Rubber)

Test item	Particulars		Standard value
	Method	Tensile direction	
Tensile strength	JIS K 6328	–	4,400 N/3cm or greater

③ Rubber mats
Rubber mats used for enhancing friction may be made of brand-new or recycled rubber. The quality is commonly as listed in **Tables 8.1.4** and **8.1.5**.

Table 8.1.4 Quality of Recycled Rubber

Test item			Performance	Test conditions/method
Physical tests	Before aging	Tensile strength Tear strength Hardness Elongation	4.9 MPa or greater 18 N/mm or greater 55–70 graduations 160% or greater	JIS K 6251 JIS K 6252 JIS K 6253 JIS K 6251
	After aging	Tensile strength Tear strength Hardness Elongation	3.9 MPa or greater Within ± 8 of pre-aging value 140% or greater	JIS K 6251 Aging tests are according to JIS K 6257 JIS K 6253 Aging temperature 70°± 1° JIS K 6251 Aging time 96- 20 hours

Table 8.1.5 Quality of Brand-New Rubber

Test item			Performance	Test conditions/method
Physical tests	Before aging	Tensile strength	9.8 MPa or greater	JIS K 6251
		Tear strength	25 N/mm or greater	JIS K 6252
		Hardness	70 ± 5 graduations	JIS K 6253
		Elongation	250% or greater	JIS K 6251
	After aging	Tensile strength	9.3 MPa and above	JIS K 6251 Aging tests are according to JIS K 6257
		Tear strength		
		Hardness	Within ± 8 of pre-aging value	JIS K 6253 Aging temperature 70°± 1°
		Elongation	200% or greater	JIS K 6251 Aging time 96- 20 hours
	Compressive permanent strain		45% or less	JIS K 6262 Aging temperature 70°± 1° Aging time 24-20 hours

8.2 Painting Materials

(1) The following items should be considered when selecting painting materials:

① The purpose of the painting

② The properties and characteristics of the painted surface

③ The performance and composition of the painting material

④ Cost

⑤ Maintenance

8.3 Grouting Materials

8.3.1 General

(1) The grouting methods shall be selected by examining the site conditions and performed in consideration of the influence on the surrounding environment.

(2) The grouting methods are employed to strengthen the ground or to cut off the ground water flow by filling crevices in rocks or subsoils, vacant spaces in or around structures, or voids of coarse aggregate with grouting materials. Various grouting materials are used according to the characteristics of the object to be grouted.

8.3.2 Properties of Grouting Materials

(1) Grouting materials shall be selected in view of the required performance for the subsoils to be grouted.

(2) The basic properties required of grouting materials are the efficiency of seepage, filling and coagulation, the strength and impermeability of the stabilized body. Suitability with the grouting object is particularly affected by the seepage efficiency of the material.

Fig. 8.3.1 shows the seepage limits of various grouting materials for subsoils in view of grain-size distribution.

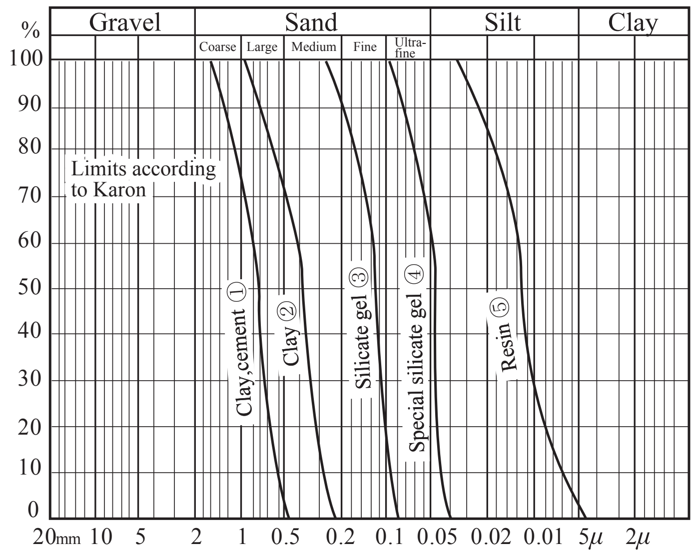

Fig. 8.3.1 Seepage Limits of Grouting Materials for Subsoils in View of Grain-size Distribution [15)]

8.4 Asphalt Concrete Mass

(1) Asphalt concrete mass is often collected from many different places, so it has various properties.[19)] The quality of recycled asphalt mixtures shows more variation than that of brand-new mixtures. Therefore, to have the desired needle penetration, one typically adds brand- new asphalt or additives when recycling.

(2) Recycled asphalt mixtures that are used for the foundation layer or surface layer can be handled the same way as asphalt mixtures that are purely brand-new material.

8.5 Oyster Shell

Crushed oyster shell with a size of at most 30 mm when mixed with sand in a ratio of 2 to 1 in volume can be used to improve ground materials. The strength of soil improvement pile with mixed-in oyster shell is evaluated as about the same as that of improvement pile composed of sand. However, characteristics such as water content ratio and compression index vary based on the particle sizes when the oyster shell is crushed and on the mixing ratio with sand, so the use of oyster shell requires sufficient investigation, such as by soil test.

References

1) JSCE, Civil Engineering Handbook (Forth Edition), ,pp.143-146,pp.150-151、1989
2) Okada, K., S. Akashi and Materials for Civil Engineering (Revised Edition)People’s Science, Kokumin-Kagaku Publishing, 1995l
3) Industrial Technology Service Center: Compendium of reinforcing methods for slope and embankment, ,p174,1995
4) Industrial Technology Service Center: Compendium of practical measures for soft ground, pp.619-631,1993
5) Society of Soil Mechanics and Engineering Science, Handbook of Soil Mechanics, pp.1041-1043,1982
6) Port and Harbour Bureau, Ministry of Transport Edition: Guideline for Port surveys (Revised Edition), Japan Port Association, pp.3-187-3-205,1987
7) Kamon, M.: Plastic Board Drain Method, Foundation, Vol. 19, No,6, pp. 19-24, 1991
8) Kuraku, M: Characteristics of light weight embankment method and its applications, Foundation, Vol. 18 No.12,pp.2-9,1990
9) Coastal Development Institute of Technology (CDIT): Manual of corrosion protection and repair for port and harbour facilities (Revised Edition), 1997
10) Japan Road Association: Handbook of Painting and corrosion protection of steel bridge, 2006
11) Japan Road Association: Guideline and commentary of countermeasures against to salt damages for highway bridges (Draft), 1984
12) Terauchi, K.: Study on Deterioration and painting Specification of Bridges located in Port Area, Technical Note of PHRI No.651,1989
13) Dodo, I Edition: Know-how of construction:. Kindai Tosho Publishing, p.32,1997
14) ‘ Tentative guidelines on constructions utilizing Chemical grouting method (Government Order),July 15, 1974 Safety Control Bureau, Ministry of Public Works, No.146, 1974

15) Shimada, S.: The most advanced technology of chemical grouting method, Riko Tosho Publishing, ,p.161,1995
16) Japan Road Association: Guideline for plant recycling of Pavement, 1992
17) Japan Road Association: Guideline for surface recycling method (Draft), 1988
18) Japan Road Association: Guideline for surface recycling method (Draft), 1987
19) Yokota, H. and S. Nakajima : Applicability of Recyclable Materials to Port and Harbour Construction, Technical Note of PHRI No.824,1996
20) Hashidate, Y., S. Fukuda, T. Okumura and M. Kobayashi: Engineering characteristics of sand containing oyster shells, Proceedings of the 28th Conference of Soil Mechanics, pp.869-872,1992
21) Hashidate, Y., S. Fukuda, T. Okumura and M. Kobayashi: Engineering characteristics of sand containing oyster shells and utilization for sand compaction piles, Proceedings of the 29th Conference of Soil Mechanics, pp.869-872,1994
22) Nishizuka, N.: Utilization of oyster shells for SCP method, Proceedings of 11th Conference of Port and Harbour technology, ,pp.149-164, 1994

9 Friction Coefficient

(1) For the friction coefficient of a material when the frictional resistance force against the sliding of a facility is calculated, the static friction coefficient can be used. In this case the friction coefficient of the material should be appropriately specified by considering factors such as the characteristics of the facility and the characteristics of the material.

(2) For the characteristic values of the static friction coefficient for the performance verification of port facilities it is generally possible to use the values given in **Table 9.1**. Consideration is needed as there usually is a large variation when the friction coefficient is repeatedly measured under the same conditions. The values shown in **Table 9.1** are kind of values used from the past experience, and if a value is not shown here then it is preferable to perform experiments to determine it.

(3) The values shown in **Table 9.1** are values used to verify the stability of facilities against sliding, and cannot be used for purposes such as for determining the friction coefficient between the surface of a pile and the soil when calculating the bearing capacity of a pile, or the friction coefficient for verifying the stability of a sloping breakwater, or the friction coefficient used to calculate the launching of a caisson on slope, or the friction angle of a wall to calculate earth pressure. The values shown in **Table 9.1** are the static friction coefficients when a static actions occur, but there are no appropriate references for when dynamic motions occur, such as through seismic forces, so in fact these values are also used in such cases.

Table 9.1 Characteristic Values for the Static Friction Coefficient

Concrete and concrete	0.5
Concrete and base rock	0.5
Underwater concrete and base rock	0.7 to 0.8
Concrete and rubble	0.6
Rubble and rubble	0.8
Timber and timber	0.2 (wet) to 0.5 (dry)
Friction enhancement mat and rubble	0.75

Note 1: Under standard conditions the value 0.8 may be used for the case of underwater concrete and base rock. However, in situations such as if the bedrock is brittle or has many cracks, or if there are places where the movement of the sand that covers the bedrock is significant, the coefficient can be lowered under such conditions to about 0.7.

Note 2: **Part III, Chapter 5, 2.2, Gravity-Type Quaywalls** can be referred to for the friction coefficient in the performance verification of cellular blocks.

(4) Friction Coefficient for Friction Enhancement Mats
In the performance verification of port facilities, if a material such as a bituminous material or rubber is used as a friction enhancement mat then the friction coefficient may be taken as 0.75, as shown in **Table 9.1**. In cold areas a separate investigation is recommended.

(5) Friction Coefficient for In-Situ Concrete
The friction coefficient for in-situ concrete must be appropriately specified by taking into account factors such as the characteristics of the material and the natural conditions.

(6) Sliding Resistance between Base Rock and Prepacked Concrete
As for friction coefficient between base rock and prepacked concrete, the values of **Table 9.1** can be used. It is also possible to similarly treat other types of underwater concrete other than prepacked concrete.

References

1) Morihira, M., T. Kihara and H. Horikawa: Friction coefficient of rubble mound of composite breakwater, Proceedings of 25th Conference on Coastal Eng., JSCE, pp,337-341,1978
2) Morihira, M. and K. Adachi: Friction coefficient of rubble mound of composite breakwater (Second report), Proceedings of 26th Conference on Coastal Eng., JSCE, pp.446-450,1979
3) Japan Society of Mechanical Engineers Edition: Handbook of mechanical Engineering
4) Ishii, Y. and T. Ishiguro : Steel pile method. Giho-do Publishing, 1959
5) Yokoyama, Y.: Design and construction of steel piles, Sankai-do Publishing, 1963
6) Japan Road Association: Earth work for roads- guideline for construction of retaining wall, ,pp.20-21,1999

7) Kagawa, M. : Increase of friction coefficient of gravity structures, Proceedings of the 11th Conference on Coastal Eng. JSCE, pp.217-221, 1964
8) Shinkai, E., O. Kiyomiya and Y. Kakizaki: friction coefficient of rubber mats for enlargement of friction, Proceedings of 52nd Conference of JSCE, pp.354-355,1997
9) Onodera, Y. and Y. Aoki: A Study on the Coefficient of Friction between Prepacked Concrete and Bedrock, Technical Note of PHRI No.135, p. 8, 1972