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 that the facilities concerned will encounter during the design working life:

(1), (2) (omitted)

(3) Selection of materials and appropriate setting of their physical properties in consideration of their characteristics and environmental influences on them.

1 General

(1) The materials to be used for port facilities shall be appropriately selected with consideration of actions, deterioration, designed working life, shapes, workability, economic efficiency, and impact on surrounding environments.

(2) The materials to be used for buildings and railroad facilities are, respectively, subjected to the **Building Standards Act** (Act No. 201 of 1950), the **Technical Regulatory Standards on Japanese Railways** (Ordinance of the Ministry of Land, Infrastructure, Transport and Tourism No. 151 of 2001), the **Railway Construction Regulations** (Ordinance of the Ministry of Interior and Railways No. 1 of 1923), and orders related to these Acts and Ordinances.

(3) Selection of Materials

When selecting materials, give proper consideration to their quality and durability. The main materials for facilities subject to the Technical Standards include steel, concrete, bituminous materials, stone materials, wood materials, metal materials other than steel, plastic, rubber, paint materials, injection materials, landfill materials (including waste), and recyclable resource materials (for example, slag, coal ash, concrete mass, dredged soil, asphalt concrete mass). Also, those materials complying with Japanese Industrial Standards have the quality necessary to satisfy required performance of the facilities subject to the Technical Standards. The quality of those materials which do not comply with Japanese Industrial Standards, and those materials for which no Japanese Industrial Standards have been established, shall be verified through appropriate means such as material tests.

(4) Physical Properties of Materials

The physical properties of materials mean strength, unit weight, friction coefficient and others and shall be appropriately set on the basis of the standard values of Japanese Industrial Standards or quality data obtained through reliable tests. Also, the physical properties and cross-sectional specifications of materials shall be appropriately set considering the degradation of materials due to environmental actions.

2 Steel

2.1 General

(1) Steel to be used for facilities subjected to the Technical Standards shall have the quality necessary to achieve the required performance for facilities. One example of materials satisfying such requirements is steel complying with Japanese Industrial Standard (JIS). In these Technical Standards and Commentaries, steel means carbon steel and, when referring to metal materials other than steel, respective individual names, such as stainless steel, titanium and aluminum, are used (Refer to **Part II, Chapter 11**, **8.1 Metal Materials other than Steel**).

Tables 2.1.1 and **2.1.2** list steel which complies with JIS and has been used for port facilities relatively frequently.[1)] In addition to the types of steel listed in the tables, JIS has standardized many more steel materials.

(2) In general, high-strength steel means structural steel with a tensile strength of 490 N/mm^2 or more. One of the important characteristics of high-strength steel is that a yield ratio (a ratio of yield strength to tensile strength) gets larger as the strength of steel is enhanced. Some types of high-strength steel, such as SM570, have had a problem with increased workload for preheating when used for welded members. The type of high-strength steel developed to solve this problem is the higher yield strength steel plates for bridges (SBHS steel), which has been used for Tokyo Gate Bridge.[2)]

(3) The atmospheric corrosion-resisting steel is classified into Type W for use without painting and Type P for use with painting. In order to exhibit predetermined corrosion-resistant performance, the atmospheric corrosion-resisting steel needs to be used under proper environments. For example, when using Type W SMA without painting, pay attention to the applicable range in terms of the allowable amount of air-borne salt.[3)] There have been cases of developing nickel-based and tin-based high atmospheric corrosion-resisting steel usable under a more severe splashed salt environment than SMA. Such types of steel have already been used for actual bridges.[4)]

(4) Hat-shaped steel sheet piles, which have wider widths than conventional steel sheet piles, have been developed.[5)] Because of the expanded widths per sheet, they are characterized by improved economic efficiency, workability, and structural reliability.

Table 2.1.1 Quality Standards of Steel (JIS)[1)]

Type of steel	Standard		Symbol[*1]	Application
Structural steel	JIS G 3101	Rolled steels for general structure	SS400	Steel bar, shaped steel, steel plate, flat steel, steel strip
	JIS G 3106	Rolled steels for welded structure	SM400, SM490, SM490Y, SM520, SM570	Shaped steel, steel plate, flat steel, steel strip
	JIS G 3114	Hot-rolled atmospheric corrosion-resisting steels for welded structure	SMA400, SMA490, SMA570	Shaped steel, steel plate
	JIS G 3140	Higher yield strength steel plates for bridges	SBHS400, SBHS400W SBHS500, SBHS500W, SBHS700, SBHS700W	Steel plate
	JIS G 3136	Rolled steels for building structure	SN400A, SN400B, SN400C SN490B, SN490C	Steel plate, steel strip, shaped steel, flat steel
Steel pipe	JIS G 3444	Carbon steel tubes for general structure	STK400, STK490	
Steel pile	JIS A 5525	Steel pipe piles	SKK400, SKK490	
	JIS A 5526	Steel H piles	SHK400, SHK400M, SHK490M	
Steel sheet pile	JIS A 5528	Hot-rolled steel sheet piles	SY295, SY390	
	JIS A 5523	Weldable hot-rolled steel sheet piles[*2]	SYW295, SYW390, SYW430	
	JIS A 5530	Steel pipe sheet piles	SKY400, SKY490	
Cast and forged steel product	JIS G 3201	Carbon steel forgings for general use	SF490A, SF540A	Mooring post, chain, etc.
	JIS G 5101	Carbon steel castings	SC450	
	JIS G 4051	Carbon steels for machine structural use	S30CN,[*3] S35CN[*3]	
	JIS G 5501	Gray iron castings	FC150, FC250	

Type of steel	Standard		Symbol*1	Application
Welding material	JIS Z 3211	Covered electrodes for mild steel, high tensile strength steel and low temperature service steel		Steel in general
	JIS Z 3214	Covered electrodes for atmospheric corrosion-resisting steel		Atmospheric corrosion-resisting steel
	JIS Z 3312	Solid wires for MAG and MIG welding of mild steel, high-strength steel and low temperature service steel		Steel in general
	JIS Z 3315	Solid wires for MAG and MIG welding of atmospheric corrosion-resisting steel		Atmospheric corrosion-resisting steel
	JIS Z 3313	Flux cored wires for gas shielded and self-shielded metal arc welding of mild steel, high-strength steel, and low temperature service steel		Steel in general
	JIS Z 3320	Flux cored wires for gas shielded and self-shielded metal arc welding of atmospheric corrosion resisting steel		Atmospheric corrosion-resisting steel
	JIS Z 3183	Classification for deposited metal of submerged arc welding for carbon steel and low alloy steel		Steel in general, atmospheric corrosion-resisting steel
	JIS Z 3351	Solid wires for submerged arc welding of carbon steel and low alloy steel		Steel in general, atmospheric corrosion-resisting steel
	JIS Z 3352	Fluxes for submerged arc welding		Steel in general, atmospheric corrosion-resisting steel
Joint material	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	
Wire	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 hard steel wire, wire rope
	JIS G 3532	Low carbon steel wires	SWM	
	JIS G 3536	Steel wires and strands for prestressed concrete	SWPR1, SWPD1, SWPR2, SWPD3, SWPR7, SWPR19	
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, SDR295, SDR345	
	JIS G 3109	Steel bars for prestressed concrete	Class A, Type 2; SBPR 785/1030 Class B, Type 1; SBPR 930/1080 Class B, Type 2; SBPR 930/1180 Class C, Type 1; SBPR 1080/1230	

Note:

*1: The symbols used for steel in JIS have suffixes. For example, JIS uses SM400A, SM400B, and SM400C for the classification of SM400 series. However, in the table above, these suffixes are omitted.

*2: There was a necessity of standardizing steel sheet piles having proper weldability to cope with the cases of breakage of welded sections on steel sheet piles caused by earthquakes. Thus, considering the importance of continued operation of the existing standards for steel sheet piles for the use which does not involve welding, particularly for temporary use, JIS A 5523 Weldable hot-rolled steel sheet piles was standardized separately from conventional JIS A 5528 Hot-rolled steel sheet piles.

*3: The materials standardized as S30C and S35C in JIS G 4051 are considered to be processed into the materials standardized as S30CN and S35CN respectively through normalizing so as to satisfy the mechanical properties specified in the explanatory attachment to JIS G 4051.

Table 2.1.2 Standardized Shapes of Steel (JIS)[1)]

Type of steel		Standard	Material 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 strip	JIS G 3193	SS400, SM400, SM490, SM490Y, SM520, SM570, SMA400, SMA490, SBHS400, SBHS500, SBHS700, SBHS400W, SBHS500W, SBHS700W
	Flat steel	JIS G 3194	SS400, SM400, SM490, SM490Y, SM520
Pile	Steel pipe piles	JIS A 5525	SKK400, SKK490
	H-shaped steel piles	JIS A 5526	SHK400, SHK400M, SHK490M
Sheet pile	Hot-rolled steel sheet piles	JIS A 5528	SY295, SY390
	Weldable hot-rolled steel sheet piles	JIS A 5523	SYW295, SYW390, SYW430
	Steel pile sheet piles	JIS A 5530	SKY400, SKY490
Joint material	Hexagon head bolts and hexagon head screws	JIS B 1180	
	Hexagon nuts and hexagon thin nuts	JIS B 1181	
	Sets of high-strength hexagon bolt, hexagon nut for friction grip joints	JIS B 1186	F8T, F10T
Reinforced concrete	Steel bars for concrete reinforcement	JIS G 3112	SR235, SR295, SD295, SD345
	Rerolled steel bars for concrete reinforcement	JIS G 3117	SRR235, SRR295, SDR235
Prestressed concrete	Steel wires and strands for prestressed concrete	JIS G 3536	SWPR, SWPD
	Steel bars for prestressed concrete	JIS G 3109	SBPR, SBPD
Mooring material	Wire ropes	JIS G 3525	SWRS, SWRH
	Flash butt welded anchor chain	JIS F 3303	
Wire mesh	Welded steel wire	JIS G 3551	WFP, WFR, WFI

(5) When using rolled steel for general structures, rolled steel for welded structures, and hot-rolled atmospheric corrosion-resisting steels for welded structure, thicknesses can be selected with reference to **Fig. 2.1.1**.[6)] When using steel with thicknesses less than 8 mm, it shall comply with the **Specifications and Commentary for Highway Bridges**.[7)] The upper limits of thicknesses have been specified for respective steel grades in accordance with JIS standards because the steel to be used for members having large thicknesses requires a large additive amount of carbon to achieve the prescribed strength and increased carbon addition causes insufficient miniaturization of crystal grains during rolling and thereby aggravating notch brittleness.

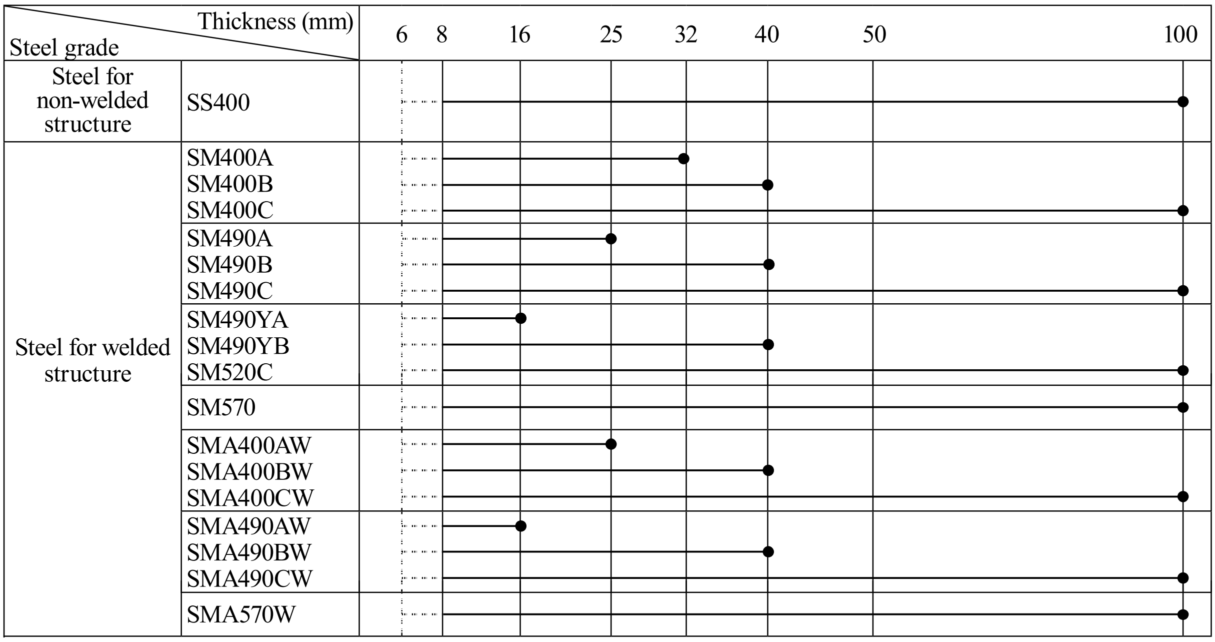

Fig. 2.1.1 Standards for Selecting Thicknesses by Steel Grades[6)]

(6) The strength standards for PC steel wires and stranded steel wires are specified in **JIS G 3536** and the chemical compositions of steel are specified in **JIS G 3502 Piano wire rods**.

(7) If the facilities have many welded sections (for example facilities with panel point structures), it is necessary to pay attention to chemical compositions and steel weldability. The steel grades generally used for welded members are: **JIS G 3106 Rolled steels for welded structure**; **JIS G 3114 Hot-rolled atmospheric corrosion-resisting steels for welded structure**; and **JIS G 3140 Higher yield strength steel plates for bridges**. In contrast, using SS400 specified in **JIS G 3101 Rolled steels for general structure** shall be limited to non-welded members.

2.2 Characteristic Values of Steel

(1) The characteristic values of steel and cast steel required in the performance verification shall be appropriately set in consideration of strength characteristics.

(2) Characteristic Values of the Constants of Steel

In general, the values in **Table 2.2.1** can be used for the Young's modulus, the shear modulus, Poisson's ratio, and the linear expansion coefficient of steel and cast steel.[8) and 9)] For the constants of steel used for reinforced concrete and prestressed concrete, refer to the values in the **Standard Specification for Concrete Structures**.[10)]

Table 2.2.1 Constants of Steel[8) and 9)]

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

(3) Characteristic Values of Yield Stress

The characteristic values of yield stress of steel and cast steel shall be appropriately set on the basis of test results.

① **Structural steel**

(a) In general, the values in **Table 2.2.2** can be used for characteristic values of yield stress of structural steel depending on the steel grades and thicknesses.[11)]

Table 2.2.2 Characteristic Values of Yield Stress of Structural Steel[11)]

Steel grade	Thickness mm	Tensile yield stress N/mm²	Compressive yield stress N/mm²	Shear yield stress*1 N/mm²	Bearing yield stress (between steel plates) N/mm²	Tensile strength N/mm²
SS400	< 16	245 or more	245 or more	141	368	400 to 510
	16 to 40	235 or more	235 or more	136	353	
	40 to 100	215 or more	215 or more	124	323	
	100 <	205 or more	205 or more	118	308	
SM400 SMA400	< 16	245 or more	245 or more	141	368	400 to 510 (< 540)*2
	16 to 40	235 or more	235 or more	136	353	
	40 to 75	215 or more	215 or more	124	323	
	75 to 100	215 or more	215 or more	124	323	
	100 to 160	205 or more	205 or more	118	308	
	160 to 200	195 or more	195 or more	113	293	
SM490	< 16	325 or more	325 or more	188	488	490 to 610
	16 to 40	315 or more	315 or more	182	473	
	40 to 75	295 or more	295 or more	170	443	
	75 to 100	295 or more	295 or more	170	443	
	100 to 160	285 or more	285 or more	165	428	
	160 to 200	275 or more	275 or more	159	413	
SM490Y SMA490	< 16	365 or more	365 or more	211	548	490 to 610
	16 to 40	355 or more	355 or more	205	533	
	40 to 75	335 or more	335 or more	193	503	
	75 to 100	325 or more	325 or more	188	488	
	100 to 160	305 or more	305 or more	176	458	
	160 to 200	295 or more	295 or more	170	443	
SM 520	< 16	365 or more	365 or more	211	548	520 to 640
	16 to 40	355 or more	355 or more	205	533	
	40 to 75	335 or more	335 or more	193	503	
	75 to 100	325 or more	325 or more	188	488	
SM570 SMA570	< 16	460 or more	460 or more	266	690	570 to 720
	16 to 40	450 or more	450 or more	260	675	
	40 to 75	430 or more	430 or more	248	645	
	75 to 100	420 or more	420 or more	242	630	
SBHS400 SBHS400W	6 to 100	400 or more	400 or more	231	600	490 to 610
SBHS500 SBS500W	6 to 100	500 or more	500 or more	289	750	570 to 720
SBHS700 SBHS700W	6 to 75	700 or more	700 or more	404	1050	780 to 930

*1: The von Mises yield criteria are applied to the calculation of shear yield stress.
*2: The figure within parentheses shows the value for SMA400.

(b) When the contact mechanism between two steel surfaces is a flat surface against a flat surface (including cylindrical and curved surfaces close to plane ones), the bearing yield stress can be set at 50% more than the tensile yield stress. In the case of contact between a spherical (or cylindrical) steel surface and a plane steel surface on a very small area, the bearing yield stress can be calculated by the Hertz formula in the **Specifications and Commentary for Highway Bridges**[12)] as needed.

② **Characteristic values of steel piles and steel sheet piles**

(a) In general, the values in **Table 2.2.3** can be used for the characteristic values of the yield stress of steel piles and steel pipe sheet piles depending on the steel grades and the types of stress (for the reduction coefficients of axial compressive yield stress of steel piles, reference can be made to **Part III, Chapter 5,**

5.2.4 Performance Verification of Open-type Wharves on Vertical Piles).[13] There are cases of using high-strength steel equivalent to the grades of SM490Y, SM520, and SM570 for steel piles although the steel of these grades is not standardized by JIS.[14]

Table 2.2.3 Characteristic Values of Yield Stress of Steel Piles and Steel Pipe Sheet Piles[13] (N/mm^2)

Type of stress \ Steel grade	SKK400 SHK400 SHK400M SKY400	SKK490 SHK490M SKY490
Axial tensile stress (per net cross sectional area*1)	235	315
Bending tensile stress (per net cross sectional area*1)	235	315
Bending compressive stress (per total cross sectional area*2)	235	315
Shear stress (per total cross sectional area*2)	136	182

*1: A cross sectional area considering partial loss of areas such as bolt holes.
*2: A total cross sectional area without considering partial loss of areas.

(b) The von Mises yield criteria are applied to the shear yield stress calculation.

(c) When it is necessary to combine axial and shear stress, yield stress can be set with reference to the **Specifications and Commentary for Highway Bridges**.[15]

(d) Buckling strength varies, depending on the conditions of members subject to buckling and, therefore, shall be appropriately set in the verification of respective facilities.

③ **Steel sheet piles**

(a) In general, the values in **Table 2.2.4** can be used for the characteristic values of the yield stress of steel sheet piles depending on the steel grades and the types of stress.[16]

Table 2.2.4 Characteristic Values of Yield Stress of Steel Sheet Piles[16] (N/mm^2)

Type of stress \ Steel grade	SY295 SYW295	SY390 SYW390	SYW430
Bending tensile stress (per net cross sectional area)	295	390	430
Bending compressive stress (per total cross sectional area)	295	390	430
Shear stress (per total cross sectional area)	170	225	248

(b) The von Mises yield criteria are applied to the calculation of shear yield stress.

④ **Cast and forged steel products**

(a) In general, the values in **Table 2.2.5** can be used for the characteristic values of the yield stress of cast and forged sheet products depending on the steel grades and the types of stress.[17]

Table 2.2.5 Yield Stress of Cast and Forged Steel Products[17] (N/mm^2)

Type of stress \ Type of steel	Forged steel		Cast steel	Steel for machine structure		Cast iron	
	SF490A	SF540A	SC450	S30CN	S35CN	FC150	FC250
Axial tensile stress (per net cross sectional area)	245	275	225	275	305	70	105
Axial compressive stress (per total cross sectional area)	245	275	225	275	305	140	210
Bending tensile stress (per net cross sectional area)	245	275	225	275	305	70	105
Bending compressive stress (per total cross sectional area)	245	275	225	275	305	140	210
Shear stress (per total cross sectional area)	141	159	130	159	178	54	88

(b) The calculation method of bearing yield stress using the Hertz formula shall conform to the **Specifications and Commentary for Highway Bridges**[18) as needed.

⑤ **Yield stress of welding sections and joint materials**

(a) In general, the values in **Table 2.2.6** can be used for the characteristic values of the yield stress of welding sections, depending on the steel grades and the types of stress. When joining steel members with different strengths, the values corresponding to the steel member with lower strength shall be used in general.

Table 2.2.6 Characteristic Values of Yield Stress of Welding Sections[19)] (N/mm²)

Type of welding		Type of stress \ Steel grade	SM400 SMA400	SM490	SM490Y SM520 SMA490	SM570 SMA570	SBHS400 SBHS400W	SBHS500 SBHS500W	SBHS700 SBHS700W
Shop welding	Full penetration groove welding	Compressive stress	235	315	355	450	400	500	700
		Tensile stress	235	315	355	450	400	500	700
		Shear stress	136	182	205	260	231	289	404
	Fillet welding, partial penetration groove welding	Shear stress	136	182	205	260	231	289	404
On-site welding		The same values as shop welding in principle.							

(b) Considering the advancement of welding technologies and enhanced on-site construction management, as well as quality control, the same characteristic values of yield stress for shop welding can be applied to on-site welding, provided that on-site welding is executed by welders with appropriate skills under appropriate work environments, as stipulated in the **Specifications and Commentary for Highway Bridges**[20)] and the quality of on-site welding is controlled in the same level as that of shop welding through nondestructive tests and recording of work progresses. Basically, it is advisable to avoid underwater welding. Still, if underwater welding is to be executed by necessity, the characteristic yield stress values of the sections subjected to underwater welding shall be appropriately set, considering the possibility that welding quality largely fluctuates depending on work environments. When on-site construction management and quality control can be sufficiently implemented, the characteristic values for underwater welding can generally be 80% of those for shop welding.[21)]

(c) For the characteristic values of yield stress of anchor bolts and pins, **Table 2.2.7** can be used as a reference. There have been many cases of using stainless steel for anchor bolts and pins (Refer to **Part II, Chapter 11, 8.1 Metal Materials other than Steel**).

Table 2.2.7 Characteristic Values of Yield Stress of Anchor Bolts and Pins (N/mm²)

Type	Type of stress \ Steel grade	SS400	S35CN
Anchor bolt	Shear stress	100	133
Pin	Bending stress	320	438
	Shear stress	168	235
	Bearing stress	353	470

(d) The anchor bolts specifications in this section are based on the assumption that they are being embedded in concrete. Considering the anchor bolt installation is likely to be problematic, and the strength of anchor bolts needs to be balanced with that of the supporting concrete, the design values of anchor bolts shall be calculated to have sufficient safety margins. Also, reference can be made to the **Recommendations for Design and Construction of Post-installed Anchors in Concrete**.[22)]

(e) Pins have no risk of being subjected to stress concentration because they do not require bolt holes, unlike steel plates and shaped steel, or do not normally require notches. Also, the verification items of pins are generally their resistance to shear and bearing stress, with no reduction in the limit values with respect to shear stress even if shear is accompanied by sliding. In consideration of these points, the values of shear yield stress for pins are larger than the values in **Tables 2.2.2** and **2.2.5**.

(f) The yield stress characteristic values of finished bolts can be set with reference to the values in **Table 2.2.8**. The reference values of tensile stress in **Table 2.2.8** are the yield stress of hexagon head bolts specified in **JIS B 1180**. The mechanical properties of hexagon head bolts are specified for respective strength classifications in **JIS B 1051 Mechanical properties of fasteners made of carbon steel and alloy steel**. The values in the table below are those for the strength classifications of 4.6, 8.8 and 10.9.[23)]

Table 2.2.8 Yield Stress of Finished Bolts[23)] (N/mm^2)

Type of stress \ Strength classification according to JIS B 1051	4.6	8.8	10.9
Tensile stress	240	660	940
Shear stress	140	380	540
Bearing stress	360	990	1410

(g) Studs reliably transfer cross sectional force from steel members (such as steel pipe piles and steel sheet piles) to reinforced concrete. The yield stress characteristic values of headed studs can be set with reference to the values in **Table 2.2.9**.[24)]

Table 2.2.9 Shapes, Dimensions, and Mechanical Properties of Headed Studs[24)]

Nominal designation	Nominal length	Shaft diameter	Head diameter	Head thickness (Minimum)	Yield point or 0.2% yield strength (N/mm^2)	Tensile strength (N/mm^2)	Elongation (%)
13	80, 100, 120	13	22	10	235	400 to 550	20% or more
16		16	29				
19	80, 100, 130, 150	19	32				
22		22	35				

2.3 Corrosion of Steel

2.3.1 General

The steel used for port facilities are generally under severe corrosive environments. Steel members are subjected to particularly severe local corrosion at the portions immediately below mean low water levels.

2.3.2 Corrosion of Steel

(1) Steel undergoes corrosion due to the influences of surrounding environments. The corrosive environments for steel vary a great deal. In the port facility environments, where the pH values of seawater, fresh water, and soil are considered almost neutral, water and oxygen play important roles in steel corrosion. When steel is immersed in neutral water solution, there are numerous corrosion cells, comprising anodes and cathodes, formed on the steel surface.[25)] Generally, the chemical reactions, represented by **equations (2.3.1)** and **(2.3.2)**, progress at anodes and cathodes of corrosion cells in equivalent weight.

$$Fe \rightarrow Fe^{2+} + 2e^- \quad \textbf{(2.3.1)}$$

$$1/2O_2 + H_2O + 2e^- \rightarrow 2OH^- \quad \textbf{(2.3.2)}$$

The dissolution of steel, represented by **equation (2.3.1)**, is called the anodic reaction of corrosion, and the reduction of oxygen, represented by **equation (2.3.2)**, is called cathodic reaction of corrosion. Then, the corrosion reaction of steel can be expressed by **equation (2.3.3)**.

$$Fe+1/2O_2+H_2O \rightarrow Fe(OH)_2 \tag{2.3.3}$$

$Fe(OH)_2$ in **equation (2.3.3)** deposits on steel surface, undergoes further oxidation and dehydration syntheses, and finally turns into complex hydrated iron oxide which is called rust.

(2) **Figure 2.3.1** shows typical corrosion distribution in the depth direction of a steel member installed in seawater.[26) As can be seen in the figure, the portion of the steel positioned in a splash zone, with an ample supply of splashed seawater and oxygen, undergoes particularly severe corrosion. In the splash zone, the point immediately above the H.W.L. has the fastest corrosion rate.

In contrast, in the submerged portion of the steel, the point immediately below a tidal zone has the fastest corrosion rate. However, the corrosion rates in this portion vary significantly, depending on the environmental conditions and cross sectional shapes of long steel members. For steel sheet pile and steel pipe pile structures, the corrosion rates immediately below the M.L.W.L. are larger than those at other submerged portions and, in extreme cases, larger than those in splash zones. Such intensified local corrosion is called concentrated corrosion.

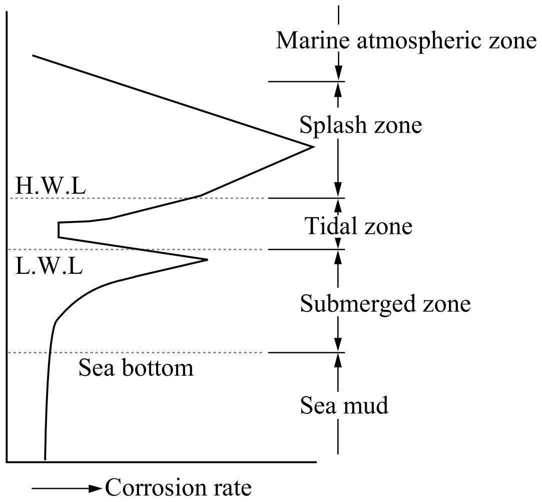

Fig. 2.3.1 Example of the Profile of the Reduction in Thickness of Steel Pipe Pile without Corrosion Protection[26)]

2.3.3 Corrosion Rates of Steel

(1) Steel corrosion rates vary depending on corrosion environment conditions. The corrosion rates of steel used for port facilities are largely affected by meteorological conditions in water areas, the salinity and pollution degrees of seawater, the presence or absence of the inflow of river water, and other aquatic environmental conditions.

(2) **Table 2.3.1** shows the standard values of steel corrosion rates. These values are the averages obtained by summarizing the survey results of existing steel structures. Here, it shall be noted that the corrosion rates of concentrated corrosion may be significantly larger than those in **Table 2.3.1**.

(3) The corrosion rates of steel in the ground are generally small. However, there may be cases where steel in the ground has large corrosion rates depending on the physical properties (grain sizes, moisture contents and soil resistivity) and chemical properties (pH, dissolved oxygen and the activity of microorganisms).

(4) In closed spaces, such as inside steel pipe piles, steel is not considered to undergo corrosion because there is no oxygen supply.

(5) Sand erosion is a phenomenon in which the movement of sand exposes bare steel surfaces by removing superficial rust layers, increasing the corrosion rates.[27)] There are cases of sand erosion on steel sheet piles constructed as sediment control groins, which caused the average corrosion rates of the portion of the steel sheet piles immediately above sand surfaces to increase to 1.25 to 2.39 mm per year.[28)] It is said that corrosion rates can be higher than the cases above when the sand surface level fluctuations are small and sand erosion is concentrated on the areas

immediately above sand surfaces. The application of cathodic protection to steel can control sand erosion progress.[27)]

Table 2.3.1 Standard Values of Corrosion Rates of Steel[25)]

Corrosive environment		Corrosion rate (mm/year)
Sea side	Above H.W.L.	0.3
	H.W.L. to 1 m below L.W.L.	0.1 to 0.3
	In seawater	0.1 to 0.2
	Sea mud	0. 03
Land side	Above ground in the air	0.1
	Underground*1	
	a) Above residual water level	0. 03
	b) Below residual water level	0. 02

*1: Including the backside of steel sheet piles

2.4 Corrosion Protection of Steel

2.4.1 General

(1) The corrosion protection countermeasures for steel shall be appropriately taken in a manner that implements either cathodic protection methods, protective coating methods or other corrosion protection methods. To design corrosion protection for steel, refer to **Part III, Chapter 2, 1.3.5 Corrosion Protection Design for Steel**.

(2) For overall corrosion protection, refer to the **Manual for Corrosion Protection and Maintenance Work for Port Steel Facilities (2009 Edition)**.[21)]

2.4.2 Cathodic Protection Methods

(1) Cathodic protection can be classified into a galvanic anode method and an impressed current method depending on energization systems.

In the galvanic anode method, anodes made of metal having negative potential with respect to steel, such as aluminum (Al), magnesium (Mg), or zinc (Zn), are connected to steel structures. The electric current generated due to the potential difference between the two types of metal is used as protective current. Almost all cathodic protection used for the port steel structures in Japan is the galvanic anode method, mainly because of easy maintenance. The performance of galvanic anode materials is summarized in **Table 2.4.1**. Aluminum alloy anodes are: the largest in electricity generation capacity per unit mass; excellent in economic efficiency; and suitable for the environments in seawater as well as sea bottom mud. Thus, aluminum alloy anodes are generally used for port steel structures.

In the impressed current method, protective current flows from external DC power sources to steel structures, with negative electrodes and counter electrodes connected to the steel structures and the positive terminals of power sources, respectively. Platinum based electrodes or oxide coating electrodes are typically used in seawater. Because the impressed current method enables output potential to be flexibly controlled, it can be applied to rapidly changing environments due to strong tides or inflow of river water and places requiring fine potential control.

Table 2.4.1 Comparison of Performance of Galvanic Anode Materials[29)]

Characteristics		Al-Zn-In	Pure Zn, Zn alloy	Pure Mg-Mn	Mg-6Al-3Zn
Specific gravity		2.6 to 2.8	7.14	1.74	1.77
Closed circuit anode potential (V) (vs. S.C.E.)		-1.05	-1.00	-1.55	-1.45
Effective potential difference with respect to iron (V)		0.25	0.20	0.75	0.65
Theoretical effective electric quantity (A·h/kg)		2,700 to 2,900	820	2,200	2,210
In seawater with 1 mA/cm^2 *1	Effective electric quantity (A·h/kg)	2,600	780	1,100	1,220
	Consumption (kg/A/year)	3.4	11.8	8.0	7.2
In soil with 0.03 mA/cm^2 *1	Effective electric quantity (A·h/kg)	1,860*2	530	880	1,110
	Consumption (kg/A/year)	4.7	16.5	10.0	7.9
Applicable environment*3		In seawater and marine soil	In seawater	In land soil and fresh water	In land soil and fresh water

*1: The current density applied to test pieces of anode materials as specified in the **Laboratory test method of Galvanic Anodes for Cathodic Protection (JSCE S-9301)**, the standards of the Japan Society of Corrosion Engineering.

*2: The design value of 1,860 A·h/kg has been used as the electric power generation capacity (effective electric quantity) of aluminum alloy anodes for use in marine soil. Considering the possible fluctuation of the effective electric quantity and effective potential depending on the environment where aluminum alloy anodes are installed, verification tests to confirm the performance of these anodes have been conducted by authorities concerned. The test results will be available for use in the design of the aluminum alloy anodes to be installed in marine soil.

*3: It is preferable to select appropriate anodes through surveys and tests in the case of implementing the galvanic anode method in brackish water regions, and the regions with varying resistant ratios as well as strong tidal flows.

(2) In the galvanic anode method, anodes are normally fixed to steel on-site with underwater welding. In some cases, for example, when jacket-type steel structures are assembled on shore, anodes are fixed to steel with shop welding.

(3) There have been reports on the brittle fractures of galvanic anodes at the places where they were fixed to steel sheet pile wharves, using the steel sheet piles manufactured before relevant JIS was revised in 2000, by underwater welding when the steel sheet piles were subjected to excessive earth pressure with the ground at their back liquefied during earthquake ground motions.[30)] Based on these reports, the chemical compositions of steel sheet piles have been revised to ensure reliable underwater welding. When fixing anodes to steel sheet piles manufactured before the revised relevant JIS by underwater welding, the reliability of underwater welding performance can be improved by paying attention to the following points:[31)]

① To avoid the degradation effect of abrupt heating and cooling in welding operation on steel sheet pile materials, welding shall be started and stopped at the positions not on steel sheet piles but on core bars of anodes.

② To avoid material degradation due to temporary welding of anodes, the positions of temporary welding shall be limited to the areas for final welding.

2.4.3 Protective Coating Methods

(1) General

① Cathodic protection cannot be applied to the sections of port steel structures which are submerged in seawater only for a short period of time. Thus, it is preferable to apply coating methods to these sections.

② The following five types of protective coating methods are generally applied to port steel structures.

(a) Painting
(b) Organic coating
(c) Petrolatum coating
(d) Inorganic coating
(e) Metal coating

③ The coating methods protect objects from corrosion by isolating them from corrosive environmental factors. The scope of application of protective coating methods varies depending on the coating method. Some types are applied mainly to corrosion protection in tidal and splash zones, as well as marine atmospheres, and other types can be applied to corrosion protection, not only in tidal and splash zones, but also in seawater. The protective coating methods applicable to corrosion protection in seawater are classified into those with or without the combined implementation with cathodic protection methods. Also, some protective coating methods are applicable only to new facilities and others are applicable to both new and existing facilities.

④ The corrosion protection performance of coating materials is affected by workmanship (particularly that of surface preparation). The purposes of surface preparation are: to remove substances on steel surfaces, such as rust, grease, and pollution harmful to adhesive and corrosion prevention properties of coating materials; and to provide surface roughness effective for insuring the initial adhesive strength of coating materials. Different coating materials require different types of surface preparation to ensure their corrosion prevention properties and service life.

Because steel surfaces after surface preparation are chemically active and undergo rapid oxidation, coating materials shall be applied to the steel surfaces immediately after surface preparation. Also, it is necessary to pay attention not to damage coated surfaces while applying coating materials.

(2) Painting

The painting is to apply paint to steel surfaces so as to form paint film on them when the paint is dried. The painting can prevent steel from corroding through its effect to isolate steel from corrosive environments and the effect of rust-proof colorants. Paint comprises resin, which is a main component of colorants and paint film, additive agents, and solvent. The painting has many advantages compared to other corrosion protection methods. For example, it can be implemented through simple application. Painting has long been used as the corrosion protection method of steel structures. Also, because the corrosion protection performance of paint has been improved, owing to the development of paint and painting technologies, many port steel structures have also used painting as corrosion protection methods.

The types of paint generally used for the painting are as follows.

• Marine painting (marine thick epoxy painting, marine epoxy glass flake painting, etc.)

• Other painting (fluorine resin painting, polyurethane resin painting, polyester resin painting, etc.)

(3) Organic coating

The organic coating is not advantageous in terms of workability, reparability, and construction costs because it requires larger film thicknesses than painting, which makes the organic coating highly durable. The organic coating has been used in particularly severe cases, such as corrosion protection in seawater, and tidal as well as splash zones, for which a high environmental isolation effect or extended service period of corrosion prevention is required.

The types of widely used organic coating are as follows.

① **Heavy-duty corrosion protection coating (urethane elastomer coating, polyethylene coating)**

Heavy-duty corrosion protection coating is applicable to steel pipe piles, steel sheet piles and steel pipe sheet piles in the factories having dedicated machines. The materials available for the heavy-duty corrosion protection coating are urethane elastomer and polyethylene. Applying the coating materials to steel products can be implemented through mass production systems under thorough quality control. The coating thicknesses are around 2 to 3 mm.

② **Super high build coating**

As is the case with the painting, the super thick film coating applies liquid materials to steel. The super thick film coating enables durable film having thickness of 1 to 3 mm which cannot be achieved by painting to be formed in a small number of applications. The super thick film coating can be applied to steel structures with complex shapes or large scale structures and is generally implemented in factories.

③ **Underwater-cured resin coating**

The underwater-cured resin coating is a method for coating steel, positioned in tidal and splash zones, using the materials capable of being applied to steel underwater. The major component of the material is hydraulic epoxy resin. The underwater-cured resin coating is classified into two types: one is a putty type which forms super thick film coating by manually applying putty like coating material to steel in the same as putty work; and the other is a paint type which applies liquid materials to steel with rubber pallets.

(4) Petrolatum Coating

The petrolatum coating coats steel surfaces with corrosion protection material using petrolatum, which is a type of petroleum wax separated from crude oil through reduced-pressure distillation. Coated steel surfaces are provided with protection covers to ensure long-term durability of corrosion protection film on the steel surfaces by protecting them from external forces, such as waves and impacts of floating objects. Depending on the types of materials used for protection covers, the petrolatum coating is largely classified into a resin protection cover method and an anticorrosion metal protection cover method.

Petrolatum corrosion protection materials are available in the forms of: nonwoven fabric tapes or sheets impregnated with petrolatum and corrosion inhibitor as an additive agent; paste of petrolatum as a primer; and tapes containing petrolatum paste. The petrolatum corrosion protection materials can control the progress of rust because: they have adherence and ductility, so as to attach firmly to steel surfaces; they can adhere a long period of time without being subjected to hardening or evaporation; their water-repellent property can isolate steel surfaces from moisture and air; and the corrosion inhibitor included in petrolatum paste forms an anticorrosive film on steel surfaces.

(5) Inorganic Coating

The inorganic coating, which has been used for port steel structures includes mortar, concrete, and electrodeposition coating. The inorganic coating has also been known as the corrosion protection methods implemented on-site.

① **Mortar coating**

The mortar coating is a corrosion protection method which coats the surfaces of steel structures with mortar to enable strong alkalinity of cement mortar to prevent seawater from corroding steel surfaces. There were cases where cement mortar had cracks, or was partially removed or washed off by severe waves and the impact of driftwood. Thus, in order to prevent cement mortar from significantly decreasing the corrosion protection function even in such cases, the mortar coating is basically provided with protection covers.

② **Concrete coating**

The concrete coating is a method to coat steel surfaces with reinforced concrete. The concrete coating is more resistant to external forces than the mortar coating and, therefore, advantageous in environments with risks of severe waves and impact from driftwood. Basically, the concrete coating does not require protection covers, which can enhance durability of the concrete coating.

③ **Electrodeposition coating**

The electrodeposition coating is to coat steel surfaces to be corrosion protection objects in a manner that: applies DC electricity from the electrodes installed in seawater to the steel surfaces to be negative electrodes; and deposits Ca^{2+} and Mg^{2+} in seawater on the steel surfaces as $CaCO_3$ and $Mg(OH)_2$.

(6) Metal Coating

The metal coating is classified into a method which coats steel surfaces with molten metal through metal spraying or plating and a method which puts covering metal plates on steel surfaces. The latter method has excellent impact and abrasion resistance in that it can provide coated surfaces with larger mechanical strength than other coating methods. When using corrosion resistance metal for covering plates, the latter method is expected to improve long-term durability.

① **Corrosion resistant metal covering**

The corrosion resistant metal, which can be used for marine steel structures, includes titanium and seawater-resistant stainless. The corrosion resistant metal covering is implemented either by locally fixing thin corrosion resistant metal plates to steel surfaces by welding or covering steel surfaces with layers of corrosion resistant metal through hot rolling (called cladded steel).

Titanium is highly resistant to pitting and crevice corrosion and is completely corrosion-free under a normal marine environment. However, because titanium produces brittle intermetallic compound when welded to steel, it cannot be directly welded to steel in a practical sense. Thus, thin-plate titanium cladded steel has been used as corrosion protection coating in a manner that uses the titanium surfaces of the cladded steel as corrosion protection coating with the steel members of the cladded steel connected to steel structures.

The seawater-resistant stainless has larger contents of corrosion-resistant alloy elements, such as Cr, Ni, and Mo, than general stainless steel and, thereby, significantly improves corrosion resistance. Because the seawater-resistant stainless can be directly welded to steel, the seawater-resistant stainless covering has been widely used for jacket structures with thin plates of seawater-resistant stainless steel locally welded to the structures.[32] Recently, seawater-resistant stainless cladded steel has been developed.

② **Metal spraying and plating**

The metal spraying and plating methods coat steel surfaces with molten metal. The types of corrosion resistance metal used in these methods are zinc, aluminum, and zinc-aluminum alloy.

In the metal spraying, metal sprayed film, with a sealing treatment, has been applied to the portion of steel surfaces exposed to the marine atmosphere with a primer coat preliminarily applied to them; in many cases, there has been no case of independently applying the metal spraying film with sealing treatment to steel surfaces.[33]

The metal plating has high corrosion resistance in the atmosphere but, as is the case with galvanization in particular, significantly poor durability under marine enviornments.[34] Thus, it is necessary to select appropriate types of plates in consideration of use environments. The hot dip galvanized coating and hot dip aluminized coating have been specified in JIS (**JIS H 8641** and **JIS H 8642** respectively).

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3 Concrete

3.1 Concrete Materials

(1) The concrete materials to be used for port facilities shall have the quality necessary for achieving the required performance of the facilities. In principle, these concrete materials shall satisfy the quality specified in **JIS A 5308 Ready-mixed concrete**.

(2) Cement

The cement to be used for concrete shall comply with **JIS R 5210 Portland cement**, **JIS R 5211 Portland blast-furnace slag cement**, **JIS R 5212 Portland pozzolan cement**, and **JIS R 5213 Portland fly-ash cement**. The performance of the cement other than the above shall be confirmed through tests and past performance records.

Among the several types of cement, moderate-heat Portland cement, Portland blast-furnace cement, and Portland fly-ash cement are considered to have higher durability under marine environment than ordinary Portland cement. The concrete created using these types of cement has advantages of a large increment in long-term strength and reduced heat of hydration but has a disadvantage of low initial strength. Based on the viewpoint that the concrete created using type B Portland blast-furnace cement is more robust against corrosion of steel bars than the ordinary Portland cement,[1) and 2)] it is preferable to use type B Portland blast-furnace cement. Therefore, it is necessary to pay special attention to initial curing when using these cements.

(3) Water

Mixing water shall be tap water or water complying with **JSCE-B 101 Qualities of Water for Concrete**.[3)] For the reinforced concrete using ordinary steel bars, seawater cannot be used as mixing water. For plain concrete, seawater can be used only when clean fresh water is not easily available. There have been many studies on the use of seawater as mixing water for plain concrete[1) and 4)] and cases of construction of plain concrete using seawater as mixing water.

It shall be noted that seawater tends to shorten the setting time of cement and causes the consistency of concrete to be lost in an early stage. Thus, when using seawater as mixing water, a retarder can be utilized as needed.

Also, the use of seawater as mixing water results in the increase of alkali ion concentration and pH values of fine pore solution in concrete, thereby enhancing the alkali-silica reaction (ASR). Thus, when using aggregate with a reactive property, it is necessary to take countermeasures to suppress the ASR.

(4) Admixtures

Fly-ash and ground granulated blast-furnace slag to be used for concrete as admixtures shall comply with **JIS A 6201 Fly ash for use in concrete** and **JIS A 6206 Ground granulated blast-furnace slag for concrete**, respectively. Both admixtures can improve the performance of concrete. When using fly-ash and ground granulated blast-furnace slag, reference can be made to the **Guide for Construction of Concrete Using Fly-ash**[5)] and the **Guide for Design and Construction of Concrete Using Ground Granulated Blast-furnace Slag**, respectively.[6)]

Expansive additives to be used for concrete shall comply with **JIS A 6202 Expansive additive for concrete**. Expansive additives are used to control cracks due to the shrinkage of concrete. When using expansive additives, reference can be made to the **Guide for Design and Construction of Expansive Concrete**.[7)]

The performance of admixtures other than those mentioned above shall be confirmed through tests and past performance records.

(5) Chemical Admixture Agents

Those chemical admixture agents, such as AE agents, water-reducing agents, and high-performance AE water-reducing agents, shall comply with **JIS A 6204 Chemical admixtures for concrete**. When using the chemical admixture agents other than the above, their performance shall be confirmed through tests and past performance records to determine their availability.

In the case of the necessity to use cold-resistant agents when placing cold-weather concrete, reference can be made to the **Guide for Construction of Cold-Weather Concrete Using Cold-Resistant Agents**.[8)]

(6) Aggregate

Basically, the aggregate to be used for concrete shall meet the quality requirements specified in **Annex A of JIS A 5308 Ready-mixed concrete**. It is necessary to use aggregate which is clean, rigid, permanent, properly graded, and free from harmful substances, such as organic impurities and chloride in amounts exceeding the predetermined limits. It is also necessary to avoid the use of aggregate containing waste, mud, flakes of stone, and long and thin stones or having water-absorbing and swelling properties. When using aggregate which does not comply with JIS (such as aggregate originated from coral), a preliminary examination is required to determine its availability.[9)]

(7) Reinforcing Materials

Steel bars to be used for concrete shall comply with **JIS G 3112 Steel bars for concrete reinforcement**.

The following types of steel bars are made of corrosion-resistant steel for the purpose of improving the durability of concrete members: a) epoxy-coated steel bars; b) stainless steel bars; and c) continuous fiber reinforcing materials. When using a), b), and c), reference can be made respectively to the **Guide for Design and Construction of Reinforced Concrete Using Epoxy-Coated Steel Bars [Revised Edition]**[10)]; the **Guide for Design and Construction of Concrete Structures Using Stainless Steel Bars**[11)]; and the **Guide for Design and Construction of Concrete Structures Using Continuous Fiber Reinforcing Materials**.[12)] The stainless steel bars to be used for concrete shall comply with **JIS G 4322 Stainless steel bars for concrete reinforcement**.

The steel materials to be used for prestressed concrete shall comply with **JIS G 3536 Steel wires and strands for prestressed concrete** and **JIS G 3109 Steel bars for prestressed concrete**. As is the case with steel bars for reinforced concrete, the types of steel materials for prestressed concrete include a) epoxy-coated steel materials and b) continuous fiber reinforcing materials. When using a) and b), reference can be made respectively to the **Guide for Design and Construction of Prestressed Concrete Using Epoxy-Coated Highly Functional PC Steel Materials**[13)] and the **Guide for Design and Construction of Concrete Structures Using Continuous Fiber Reinforcing Materials**.[12)]

(8) Surface Protection Materials

There may be cases of application of surface protection materials to concrete surface for the purpose of protecting concrete from the infiltration of degrading factors, such as chloride ions. In such cases, reference can be made to the **Guide for Design and Construction of Surface Protection Work**[14)] and the **Manual for Repairing Port Concrete Structures**.[15)]

(9) Cross-sectional Repair Materials

There are cases of repairing existing concrete structures (called cross-sectional repair method) in a manner that chips off deteriorated sections of concrete and restores exposed cross sections with new materials (cross-sectional repair materials). The main cross-sectional repair materials include polymer cement mortar. When applying the cross-sectional repair method to port concrete structures, reference can be made to the **Manual for Repairing Port Concrete Structures**.[15)]

(10) Chloride Ion Contents

To reduce the risk of corrosion of steel inside the concrete, the chloride ion contents in fresh concrete shall be no more than 0.30 kg/m^3.

(11) Alkali -Silica Reaction Preventive Countermeasures

One of the following three countermeasures shall be appropriately selected as alkali -silica reaction preventive countermeasure:

① **A countermeasure to control total alkali in concrete**

The use of the types of cement in which total alkali contents are known, such as Portland cement, so as to ensure that total alkali contents are equal to or less than 3.0 kg/m^3

② **A countermeasure to use mixed cement effective in controlling the alkali–silica reaction**

The use of the types of cement effective in controlling the alkali aggregate reaction, such as blast-furnace cement (Type B or C) or fly-ash cement (Type B or C)

③ **A countermeasure to use aggregate confirmed safe for avoiding alkali –silica reaction**

The use of aggregate confirmed to be harmless through the tests specified in **JIS A 1145 Method of test for alkali–silica reactivity of aggregates by chemical method** and **JIS A 1146 Method of test for alkali–silica reactivity of aggregates by mortar-bar method.**

3.2 Quality and Performance of Concrete

(1) Concrete shall have uniform quality, workability suitable for concrete work, and properties to satisfy the required strength, durability, water tightness, crack resistance, and steel bar protection performance.

(2) Concrete shall be resistant to deterioration caused by environmental actions, waves, and mechanical actions, such as impacts and abrasion due to drifting objects. The types of deterioration of concrete subjected to environmental actions are as follows:

① **Freezing and thawing action**

The progress of deterioration on concrete surface in the form of scaling and cracks when concrete is subjected to the repeated freezing and thawing actions involving the volume expansion with moisture inside concrete frozen and the water supply with frozen moisture inside concrete thawed.

② **Deterioration due to the actions of salts in seawater**

The sulfate ions in seawater react with calcium hydroxides and alumina (Al_2O_3) which are cement hydrates to form ettringite ($3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot mH_2O$). The pressure generated through volume expansion along with the above reaction causes crack on concrete. However, on the basis that the rate of sulfate ion penetration into concrete is lower than chloride ions and general seawater has a moderately low concentration of sulfate ions of about 2.6 g/L, it has become clear that the effect of the salts in seawater on the deterioration of concrete is not so high and the progress of deterioration of concrete is limited to superficial areas unless the quality of concrete is significantly low.[16)]

③ **Leaching of calcium hydroxide**

Because the calcium hydroxides in cement hydrates are soluble in seawater, the leaching of calcium hydroxides causes porosity and brittleness on concrete.

④ **Deterioration due to the corrosion of steel bars**

The existence of chloride ions on the surfaces of steel bars in concrete with ample supply of oxygen causes rust on the steel bars, and rusty steel bars, in turn, causes the deterioration of concrete in a manner that generates expansive pressure which develops cracks in concrete covering and allows cracked concrete to spall off. Such chloride ions are supplied to steel bars either: from external environments in the form of seawater or antifreezing agents; or along with the materials used when manufacturing fresh concrete.

⑤ **Deterioration due to harmful aggregate reaction**

In the case of concrete using reactive aggregate or cement with high alkalinity, harmful reaction between aggregate and cement may worsen abnormal cracks, cleavage, or swelling to a level that can result in partial or total destruction of concrete structures.

⑥ **Deterioration due to the actions of waves and drifting objects**

The impacts of waves and drifting objects aggravate the deterioration of concrete surfaces due to any of the above actions. Even sound concrete inevitably undergoes progressive abrasion due to continued actions of littoral drift.

(3) Characteristic values of concrete strength

① The characteristic values of concrete strength necessary for the performance verification shall be appropriately set through pertinent test results or by taking into consideration the types of concrete and natural and construction conditions of performance verification object facilities.

② For the characteristic values of concrete strength of ordinary concrete to be used in the performance verification of the main structural members of port facilities, it is usually preferable 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
Plain concrete	Compressive 18 (N/mm^2)
Reinforced concrete	Compressive 24 (N/mm^2)
Concrete for apron pavement	Bending 4.5 (N/mm^2)

In the case of reinforced concrete with the maximum water-cement ratio set at 50% or less as the mix proportion condition of ordinary concrete in consideration of durability, 30 N/mm^2 can be used as the characteristic value of the compressive strength. In the case of plain concrete lids: having a risk of being subjected to wave impacts or floods in an early post-placement material ages; or to be constructed during cold months, 24 N/mm^2 can be used as the characteristic value of compressive strength. In the case of large-scale deformed plain concrete blocks with nominal weight in the range of 35 to 50 tons, the characteristic values of compressive strength can be set at 21 N/mm^2 or other values depending on individual situations.

③ The characteristic values of bond strength of ordinary concrete to be used in the performance verification of port facilities can be calculated using **equation (3.2.1)**.[17)]

$$f_{bok} = 0.28 f'^{2/3}_{ck} \quad \textbf{(3.2.1)}$$

where:

f_{bok} : characteristic value of bond strength of ordinary concrete (N/mm^2)

f'_{ck} : characteristic value of compressive strength of ordinary concrete (N/mm^2)

Equation (3.2.1) is applicable to deformed steel bars complying with **JIS G 3112 Steel bars for concrete reinforcement**. The characteristic values of plain bars can be 40% of the values calculated by **equation (3.2.1)** on the condition that the plain bars are provided with semicircular hooks at both ends.

④ The characteristic values of other types of concrete can follow the **Standard Specifications for Concrete Structures "Design."**[17)]

(4) The conditions for concrete mix proportion shall be appropriately set considering durability. Also, when setting the conditions, reference can be made to **Table 3.2.2**, which shows the standard conditions for concrete mix proportion by the type of structural members on the basis of the survey results of existing concrete structures in ports and the study outcomes and knowledge on the durability of concrete subjected to the actions of seawater. However, for the types of structural members, such as the superstructures of piled piers, having many cases of deterioration of the required performance due to chloride-induced corrosion in the past, proper conditions for mix proportion shall be set so as to achieve the required performance of facilities through examination on durability (the changes in performance over time). Such examination can be made with reference to **Part III, Chapter 2, 1.2.4 Examination on Change in Performance Over Time**.

Table 3.2.2 Reference Table of Conditions for Concrete Mix Proportion by the Type of Structural Members

Type	Example of the type of structural member	Condition for mix proportion		
		Maximum water-cement ratio (%)		Maximum dimension of coarse aggregate (mm)
		Region with frequent freezing and thawing actions	Region with temperatures rarely dropping below zero	
Plain concrete	Superstructure of breakwater, concrete lid, main block, deformed block (for wave dissipation or covering), foot protection block, packed concrete	65	65	40
	Superstructure of wharf, parapet, mooring post foundation (gravity type)	60		
Reinforced concrete	Mooring post foundation (pile type), parapet, superstructure of wharf*1)	60	65	20, 25, 40
	Superstructure of open-type piled pier *2)	–	–	–
	Caisson, well, cellular block, L-shaped block	50	50	20, 25, 40
	Wave-dissipating block	55	55	20, 25, 40
	Buttress, superstructure of anchor piles	60	60	20, 25, 40
Apron pavement		–	–	25 (20),*3) 40

*1) Excluding superstructure of open-type piled pier

*2) Structural member with a risk of performance deterioration during design working life with steel bar corrosion due to chloride-induced corrosion
*3) 25 mm for gravel and 20 mm for crushed stone

(5) Concrete shall have consistency most suitable for individual work conditions. Also, AE concrete with air content normally set at 4.5% shall be used in principle unless otherwise required. The air contents shall be carefully set in cold areas and those areas with a risk of frost damage.

(6) Recently, high-fluidity and medium-fluidity concrete has been developed, which has high fluidity and excellent material segregation resistance to achieve self-compaction performance by the combined use of appropriate admixtures.[18) and 19)] The concrete with improved fluidity has facilitated concrete placement in the work items to which general concrete compaction methods cannot be applied, for example, concrete placement for members with dense arrangement of steel bars and spaces enclosed by steel shells. Also, it is preferable to apply the concrete with improved fluidity to wider scope in terms of structural types and construction conditions so as to take advantage of its beneficial effects to facilitate laborsaving and streamlining in concrete work and enhance the durability of concrete as a result of improved reliability of concrete placement.

(7) Construction Joints

There have been many cases of port facilities having concrete damage rising from construction joints.[20)] Thus, it is preferable to avoid construction joints to the extent possible. However, if construction joints are determined to be inevitable to alleviate the influence of the shrinkage of concrete or the reduction in workability, proper measures shall be taken. The use of epoxy resin to ensure concrete strength at construction joints is considered to be one of the measures; however, it shall be noted that epoxy resin is effective in enhancing the strength but not durability of construction joints.[21)]

(8) Curing

Concrete needs to be cured in a manner that maintains the temperature and humidity, for a certain period after placement, necessary for it to harden and to ensure the required quality.[22)] Generally, clean fresh water, such as tap water, is used for curing concrete, but the use of seawater for curing concrete, particularly the plain one, is proposed in literature 23).

Also, to prevent moisture from dissipating while curing, concrete may be covered with sheets or coated with film, or membrane curing agents may be applied to concrete.

(9) Surface Protection against Physical Actions

Those facilities subjected to severe physical actions, such as abrasion and impacts due to water flows with suspended sand particles and wave carrying gravel, shall be provided with surface protections in the form of shields made of appropriate materials or the increases in material cross sections or concrete cover of steel bars. The materials which can be used for shields include timber, high-quality stone, steel, or polymer materials, polymer-impregnated concrete, and ultra high strength fiberreinforced concrete. Some types of concrete formwork are left on concrete surfaces permanently as surface protections.

(10) Structural Types

It is known that there is a close relationship between structural types of facilities and susceptibility to chloride-induced corrosion. In terms of the types of structural members, beams and slabs are more susceptible to chloride-induced corrosion than columns and walls. Considering that the substances responsible for chloride-induced corrosion, such as chloride ions, oxygen, and water, infiltrate through concrete surfaces, the surface areas of members are preferably minimized to the extent possible. Or, it is also effective to select structural types which can be easily repaired, reinforced, or replaced on the assumption of inevitable degradation.

3.3 Underwater Concrete

The types of concrete to be placed underwater, for example, in marine construction are general underwater concrete and anti-washout underwater concrete. The characteristics of these types of concrete are described below.

3.3.1 General Underwater Concrete

(1) General underwater concrete shall be placed and subjected to the performance verification in accordance with the **Standard Specifications for Concrete Structures**[22)] and the **Standard Specifications for Port and Harbor**

Works.[24] For the underwater concrete work using casings, reference can be made to the **Maritime Underwater Concreting Method (Casing Method)**.[25]

(2) The points of caution when selecting mix proportion are as follows[22]: ① the strength of underwater concrete is basically set at 0.6 to 0.8 times that of the standard test pieces prepared on land; ② the standard water-cement ratio is 50% or less; ③ the standard unit cement content is 370 kg/m^3 or more with the exception of 340 kg/m^3 for the casing method mentioned in (1); and ④ the selection of mix proportion is based on past performance records in actual work environments (fluidity, strength, pumping capacity, etc.). Also, reference can be made to **References 26)** to **29)** which summarize the past performance records.

3.3.2 Anti-washout Underwater Concrete

(1) Anti-washout underwater concrete shall be placed and subjected to the performance verification in accordance with the **Standard Specifications for Concrete Structures**[22] and the **Standard Specifications for Port and Harbor Works**.[24] Also, reference can be made to the **Manual for Anti-washout Underwater Concrete (Design and Construction)**[30] and the **Guideline for Design and Construction of Anti-washout Concrete in Underwater (Draft)**.[31]

(2) The admixture agents used for anti-washout underwater concrete include anti-washout underwater admixture consisting primarily of cellulose or acrylic water-soluble polymer. In principle, the admixture agents shall comply with **JSCE-D104 Quality standards for anti-washout underwater admixture for concrete**.[3]

(3) The points of caution when selecting mix proportion are as follows[22]: ① the strength shall be set on the basis of the compressive strength of test pieces, prepared underwater in accordance with **JSCE-F 504 Method for underwater preparation of test pieces for compression tests for anti-washout underwater concrete**,[3] at the material age of 28 days; ② underwater segregation resistance shall be set on the basis of the degrees of underwater segregation or ratios of underwater strength to atmospheric strength; and ③ the selection of mix proportion is based on past performance records in actual work environments (fluidity, strength, pumping capacity, etc.).

3.4 Mass Concrete

The types of concrete for which cracks, generated by the increase in the temperature of concrete due to hydration heat of cement and succeeding decrease in the temperature, pose a major problem are required to be treated as mass concrete and provided with countermeasures accordingly.[22] In the cases of port facilities, the footing sections of caissons, superstructures of breakwaters, and bridge piers may need to be treated as mass concrete depending on their cross-sectional dimensions.

When placing mass concrete, it is necessary to examine the countermeasures to suppress temperature cracks due to hydration heat of cement with due consideration to actual construction conditions. (For examination method, **Part III, Chapter 2, 1.2.5 Examination of Initial Cracks**, can be used as a reference, and the examples of examination are shown in **Reference 32)**.)

It is particularly important to use appropriate cement selected by fully examining the characteristics of the available types of cements. Generally, it is preferable to use low-heat-generating cement, such as moderate-heat Portland cement, low-heat Portland cement, and Portland blast-furnace cement (low-heat type). Depending on the shapes and dimensions of structures, there may be cases where the use of expanding materials is effective in curbing temperature cracks.

3.5 Other Special Concrete

(1) Infilled concrete can be used when placing concrete in closed spaces as is the case with immersed tunnel elements having composite structures. For the performance verification and construction of infilled concrete, reference can be made to the **Manual for Grout Concrete Construction with Vibrator**.[33]

(2) For the performance verification and construction of prestressed concrete sheet piles (PC sheet piles), reference can be made to the **Technical Manual for PC Sheet Pile for Port Construction Work**.[34]

(3) Other special types of concrete include high-strength concrete, lightweight concrete,[35) to 37)] heavyweight concrete,[38) and 39)] high-fluidity concrete, moderate-fluidity concrete, expansive concrete, fiber-reinforced concrete,[40) to 44)] continuous fiber-reinforced concrete, prepacked concrete, and spray concrete. For the performance verification and

construction of these special types of concrete, reference can be made to the **Standard Specifications for Concrete Structures, "Materials and Construction."**[22)]

3.6 Concrete Pile Materials

(1) The physical values of concrete pile materials used in port facilities shall be appropriately set with due consideration to their characteristics. Generally, concrete piles are inferior to steel pile in terms of maintenance. It is particularly difficult to repair and reinforce concrete piles in comparison with steel piles if these concrete piles are installed in seawater or on the sea with the steel bars inside them subjected to aggravated corrosion.

(2) Precast Concrete Piles Molded by Centrifugal Force

Precast concrete piles molded by centrifugal force include RC piles which are reinforced concrete piles fabricated in factories; PC piles which are concrete piles with their tensile and bending capacity improved by applying tensile force to PC tendons (and they are classified into Types, A, B, and C, depending on the amount of effective prestress); and PHC piles which are PC piles made of high-strength concrete with standard design strength of 80 N/mm^2 or more. Recently, PHC piles have been the mainstream of precast concrete piles. In addition to the above, precast concrete piles include PRC piles which are PHC piles with the reinforcement of steel bars used to increase ductility and SC piles which are steel piles with high-strength concrete used as lining to achieve large bending and shear capacity. JIS standards corresponding to precast concrete piles are **JIS A 5372 Precast reinforced concrete products** for RC and SC piles and **JIS A 5373 Precast prestressed concrete products** for PC, PHC, and PRC piles.

When setting the characteristic values of concrete strength and yield strength of steel materials for precast concrete piles in the performance verification of port facilities, reference can be made to **JIS A 5372** and **JIS A 5373**. For PC steel bars, steels bars for PRC piles, and steel pipes for SC piles, reference can also be made to **JIS G 3137 Small diameter steel bars for prestressed concrete**, **JIS G 3112 Steel bars for concrete reinforcement**, and **JIS A 5525 Steel pipe piles**, respectively.

(3) Cast-in-Place Concrete Piles

Cast-in-place concrete piles are classified into two types, those with and those without outer shells. The feature of cast-in-place concrete piles is that they are constructed at the exact places underground where they are finally installed. Thus, unlike in the case of PRC piles, it is not necessary to pay attention to the influence of the impacts when piles are driven into the ground. However, different from the case of piles fabricated under a fully controlled condition on land, cast-in-place piles need to be constructed underground while being subjected to the influence of the neighboring piles under construction. Thus, it shall be noted that cast-in-place piles, particularly those without shells, have uncertainties about construction quality. For the details of cast-in-place piles, reference can be made to the **Specifications and Commentary for Highway Bridges Vol. IV, Substructures**.[45)]

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4 Bituminous Materials

4.1 General

(1) The bituminous materials to be used in port facilities shall have the following quality and properties necessary to achieve the required performance of the facilities: elasticity, viscosity, waterproof property, water resistance, durability, weather resistance, and others in accordance with the intended use. The bituminous materials include asphalt and asphalt emulsion.

(2) The types of asphalt mainly used in port facilities are straight asphalt manufactured by distilling crude oil, blown asphalt manufactured through oxidative polymerization of straight asphalt, and polymer-modified asphalt manufactured by adding thermoplastic elastomer to straight asphalt so as to improve properties, such as antiflow resistance. In this section, asphalt means straight and blown asphalt as well as polymer-modified asphalt as the secondary product of straight asphalt unless otherwise noted.

(3) Asphalt has rarely been used alone but is normally mixed with aggregate as asphalt mixtures for the use of asphalt concrete for pavement, asphalt mats, sand mastic, and asphalt stabilized material. The types and mix proportion of asphalt vary depending on the intended purposes. Thus, it is necessary to appropriately select materials satisfying predetermined purposes.

(4) The performance of asphalt mixtures has been specified on the basis of appropriate material tests taking into consideration the intended purposes and construction methods. Generally, the standards of material tests have been specified so as to enable asphalt mixtures to have sufficient stability and durability to achieve predetermined purposes.

(5) Asphalt emulsion is liquid manufactured by dispersing particulate asphalt in water containing an emulsifying agent. Asphalt emulsion enhances bonding strength through it breaks to water and asphalt. It is also used as a tack coat to improve adherence between the layers of asphalt mixtures for pavement and prime coat to protect the base course.

(6) The Japanese Industrial Standards with respect to bituminous materials are **JIS K 2207 Petroleum Asphalts** and **JIS K 2208 Asphalt Emulsion**. In addition to JIS, **the Japan Emulsified Asphalt Association Standard (JEAAS-2011)**[1] specifies the requirements for asphalt emulsion having high adherence.

(7) **Tables 4.1.1** to **4.1.3** show the standard values of the quality of asphalt generally used in port facilities.

Table 4.1.1 Quality of Straight Asphalt (JIS K 2207)

Item		Unit \ Type	40 to 60	60 to 80	80 to 100
Penetration (25°C)		(1 for 0.1 mm)	More than 40 and less than 60	More than 60 and less than 80	More than 80 and less than 100
Softening point		°C	47.0 to 55.0	44.0 to 52.0	42.0 to 50.0
Elongation (15°C)		cm	10 or more		100 or more
Toluene soluble		mass%	99.0 or more		
Flash point		°C	260 or more		
Thin film heating	Mass change rate	mass%	0.6 or less		
	Residual penetration rate	%	58 or more	55 or more	50 or more
Penetration ratio after vaporization		%	110 or less		
Density (15°C)		g/cm^3	1.000 or more		

Note: The kinetic viscosity at 120°C, 150°C, and 180°C shall be indicated in test reports.

Table 4.1.2 Quality of Blown Asphalt (JIS K 2207)

Item	Type / Unit	10 to 20	20 to 30	30 to 40
Penetration (25°C)	(1 for 0.1 mm)	More than 10 and less than 20	More than 20 and less than 30	More than 30 and less than 40
Softening point	°C	90.0 or more	80.0 or more	65.0 or more
Elongation (25°C)	cm	1 or more	2 or more	3 or more
Toluene soluble	mass%	98.5 or more		
Flash–point	°C	210 or more		
Change rate of vaporized mass	mass%	0.5 or less		
Penetration-index		2.5 or more		1.0 or more

Table 4.1.3 Quality Standards of Polymer-Modified Asphalt (JMAAS-01)[2)]

Item	Type / Added symbol	Type I	Type II	Type III			Type H	
					Type III-W	Type III-WF		Type H-F
Softening point	°C	50.0 or more	56.0 or more	70.0 or more			80.0 or more	
Elongation (7°C)	cm	30 or more	-	-			-	-
Elongation (15°C)	cm	-	30 or more	50 or more			50 or more	-
Toughness (25°C)	N·m	5.0 or more	8.0 or more	16 or more			20 or more	-
Tenacity (25°C)	N·m	2.5 or more	4.0 or more	-			-	-
Stripping area ratio of coarse aggregate	%	-	-	-	5 or less		-	-
Frath breaking point	°C	-	-	-	-	−12 or less	-	−12 or less
Bending work (− 20°C)	kPa	-	-	-	-	-	-	400 or more
Bending stiffness (−20°C)	MPa	-	-	-	-	-	-	100 or less
Penetration rate (25°C)	1/10 mm	40 or more						
Mass change rate through thin film heating	%	0.6 or less						
Residual penetration after thin film heating	%	65 or more						
Flash point	°C	260 or more						
Density (15°C)	g/cm^3	to be added in test reports						
Optimum mixing temperature	°C	to be added in test reports						
Optimum compaction temperature	°C	to be added in test reports						

Definitions of added symbols: W for water resistance and F for flexibility

4.2 Asphalt Mats

4.2.1 General

(1) Asphalt mats shall have appropriate structures satisfying the required strength, durability, and workability according to the intended use, the locations of use, and the hydrographic conditions of construction sites.

(2) Asphalt mats are manufactured in a manner that embeds reinforcement materials and wire ropes for suspension in asphalt mixtures made by mixing asphalt, fillers (limestone powder), sand, and crushed stone and molding them into the form of mats (see **Fig. 4.2.1**).

(3) There are several types of asphalt mats, including friction enhancement mats to increase sliding resistance of gravity-type structure bodies, scouring prevention mats to prevent structural foundations from scouring, and sand washing-out prevention mats to prevent foundation sand mounds and backfill sand from being washed out. When using asphalt mats, it is preferable to give due consideration to their quality, long-term durability, and workability

according to the intended use, the locations of use, and the hydrographic conditions of construction sites. Particularly in the special hydrographic conditions, such as cold and subtropical regions, as well as tidal zones, which are considered to be severe environmental conditions for asphalt mats in terms of long-term durability[3),4)], it is preferable to carefully examine the use of asphalt mats, including their applicability.

(4) The strength and workability of asphalt mats vary depending on the mix proportion of asphalt mixtures and thickness as well as the sizes of reinforcement materials and mats. The mix proportion of asphalt mats can be determined with reference to **Part II, Chapter 11, 4.2.3 Mix Proportion**. Also, reinforcement materials are preferably determined on the basis of the results of the push-out test specified also in **4.2.3**.

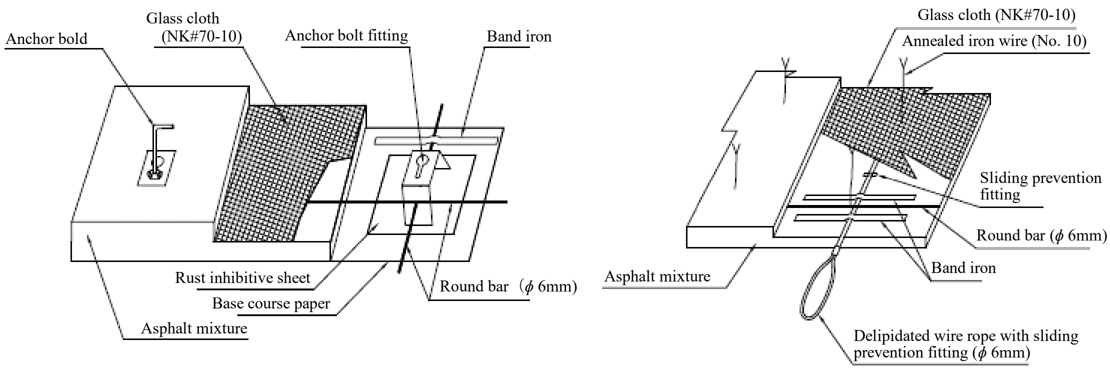

Fig. 4.2.1 Example of Structure of Friction Enhancement Mats
(Left: Anchor Bolt Method, Right: Annealed Iron Wire Method)

(5) The thicknesses of asphalt mats can be determined in consideration of the intended use and the required strength and flexibility, provided, however, that the thicknesses of friction enhancement mats shall be determined, as a standard, by additionally taking into consideration residual thicknesses, strain amounts, and the amounts sinking into rubble mounds.

(6) For the friction coefficients of friction enhancement mats, reference can be made to **Part II, Chapter 11, 9 Friction Coefficients**.

4.2.2 Materials

(1) The materials for asphalt mats shall be appropriately selected so as to ensure the required strength and durability.

(2) The following materials can be used for asphalt mats.

① **Asphalt**

Straight asphalt or blown asphalt which complies with **JIS K 2207 Petroleum Asphalts** or the mixture of straight and blown asphalt

② **Sand**

Clean sand with the maximum grain size of 2.5 mm with no inclusion of waste, mud, and organic matters

③ **Fillers**

Those fillers which comply with **JIS A 5008 Limestone Filler for Bituminous Paving Mixtures**

④ **Crushed stone**

Crushed stone which has grain sizes from 2.5 to 20 mm and complies with **JIS A 5001 Crushed Stone for Road Construction**

(3) The straight or blown asphalt which complies with **JIS K 2207 Petroleum Asphalts** can be used for asphalt mats. However, because there are large differences in plastic fluidity and other properties between straight and blown asphalt and single use of either of the two types of asphalt cannot develop the required strength and poses a problem with workability, they are normally mixed so as to ensure the required properties of asphalt mats. In this case, the

needle penetration rates of 40 to 100 and 10 to 40 are generally used as standards to evaluate the availability of straight asphalt and blown asphalt, respectively.

(4) Crushed stone is a coarse aggregate of asphalt mats and has an important influence on the strength of asphalt mats. Thus, crushed stone shall be of sufficiently high quality. Generally, the maximum grain size of crushed stone is preferably not more than 1/6 of the thicknesses of asphalt mats for the purpose of facilitating construction work; however, larger grain sizes are preferable when asphalt mats are subjected to large pressure as is the case with friction enhancement mats.

(5) In addition to the materials described above, asphalt mats require reinforcement materials and wire ropes for suspension. Generally, glass cloth and glass fiber mesh tape are used as reinforcement materials.

4.2.3 Mix Proportion

(1) The mix proportion of asphalt mats is generally determined through mix proportion tests to ensure the required strength and flexibility. Considering that friction enhancement mats and scouring/sand washing-out prevention mats have been used for a relatively long period and that extensive performance records exist[5), 6)], the values in **Table 4.2.1** can be used as the mix proportion of asphalt mats except in the case of special use conditions.

Table 4.2.1 Standard Mix Proportion of Asphalt Mats

Material	Ratio by weight (%)	
	Friction enhancement mat	Scouring/sand washing-out prevention mat
Asphalt	10 - 14	10 - 14
Dust	14 - 25	14 - 25
Fine aggregate	20 - 50	30 - 50
Coarse aggregate	30 - 50	25 - 40

Note: Dust means sand and fillers with grain sizes of 0.075 mm or less
Fine aggregate means crushed stone, sand and fillers with grain sizes of 0.075 to 2.5 mm.
Coarse aggregate means crushed stone with grain size of 2.5 mm or more.

(2) The deformation property of asphalt mats is susceptible to temperature. Thus, it is preferable to use those unlikely to fluidize when constructed in summer and those capable of maintaining flexibility when constructed in winter.

(3) Performance Verification

① For friction enhancement mats and scouring/sand washing-out prevention mats, it is preferable to determine mix proportion through specific gravity tests of asphalt mixtures and bending as well as compression tests so as to ensure the required performance. In the case of sand washing-out prevention mats subjected to relative large local actions due to armor stones, mix proportion shall be determined, as a standard, through push-out tests of the mats in order to confirm the strength of the entire mats, including reinforcement materials.

② The performance verification of asphalt mats can be carried out in accordance with the **Reference 7)**. Generally, bending and compression tests shall be conducted at the temperature of 20°C and the loading rate of 20 mm/min, and push-out tests shall be conducted in a manner that uses loading test equipment, as shown in **Fig. 4.2.2**, where 30-cm-square test pieces of asphalt mixtures with reinforcement materials are subjected to the test at the temperature of 20°C and the loading rate of 50 mm/min.

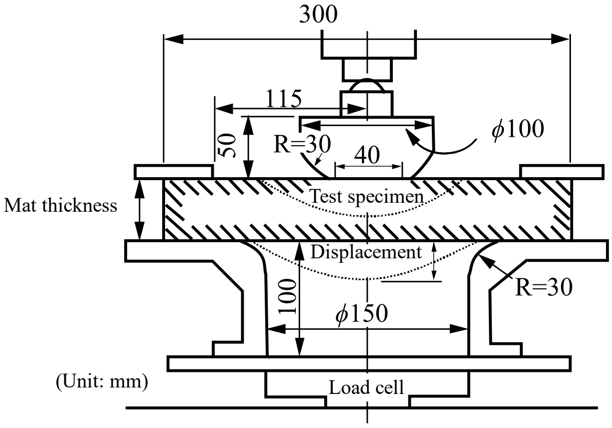

Fig. 4.2.2 Example of Push-Out Test Set-up

③ The required performance of asphalt mats is preferably set depending on the respective conditions. **Table 4.2.2** shows the standard limit values for the respective test results.

Table 4.2.2 Determination Reference Values of the Test Results

Test item		Friction enhancement mat	Scouring/sand washing-out prevention mat	
			Normal mat	Reinforced mat
Tests for asphalt mixture	Specific gravity test	2.2 or more	2.2 or more	
	Bending test Strength Displacement	 $2.0\ N/mm^2$ or more 3 mm or more	 $1.0\ N/mm^2$ or more 3 mm or more	
	Compression test Strength	 $2.0\ N/mm^2$ or more	 $1.0\ N/mm^2$ or more	
Push-out test Maximum load Displacement		 — —	 8 kN or more 10 mm or more	 15 kN or more 30 mm or more

The types and applicability of scouring/sand washing-out prevention mats shall be determined on the basis of past performance records and meteorological as well as hydrographic conditions; however, there are cases of using normal mats and reinforced mats for armor blocks of less than 3 tons/unit and not less than 3 tons/unit, respectively.

4.3 Paving Materials

(1) Paving materials can comply with **the Guideline for Pavement Design and Construction**[8], **the Handbook for Pavement Design**[9], and **the Handbook for Pavement Construction**[10] except in the areas subjected to special actions.

(2) Aprons are examples of areas subjected to special actions. Slightly different from general roads, the type of traffic on the paved areas of cargo handling facilities, particularly aprons, is mostly large vehicles with a large proportion of heavy equipment having large ground contact pressure. Also, the actions of large vehicles are rarely in a fast-moving state but mostly in a stationary or slow-moving state. Moreover, there are cases where the paved areas are partially used as yards to store cargoes to be loaded or unloaded. Thus, it is necessary to select paving materials for such paved areas with appropriate consideration to the characteristics of materials with reference to **Part III, Chapter 5, 9.18 Aprons**.

(3) Guss asphalt has impervious and high deflection tracking properties and is, therefore, frequently used for steel floor and bridge deck pavement.

4.4 Sand Mastic

4.4.1 General

(1) Sand mastic is an asphalt mixture manufactured by mixing and heating the mixture of asphalt, mineral fillers or additives, and sand. Sand mastic has almost no voids and does not necessitate compaction after injection.

(2) When sand mastic kept in a certain high temperature state is poured over a rubble mound, it flows into the voids among rubble stones without undergoing material separation underwater. Because sand mastic can integrate a rubble mound as a whole by covering individual rubble stones, it prevents rubble stones from being dissipated or washed out. Thus, sand mastic can be effective when general rubble mounds cannot be constructed with rubble stones of predetermined sizes or such rubble stones are not economically available. Also, sand mastic can be injected into the joints between caissons so as to ensure water tightness or to prevent sand from being washed out and used as impervious materials for the revetments of waste disposal sites.

(3) The performance verification of sand mastic shall be carried out with consideration to plastic flow due to the material characteristics of asphalt so as to ensure the stability.

(4) Regarding the durability of sand mastic, in the case where it is used underwater with less influences of ultraviolet rays and oxygen, it is considered that sand mastic does not undergo the changes in physical properties as is the case with asphalt mats. As a reference for the use of sand mastic above water, there is a test report on sand mastic used for solidifying rubble mound for a breakwater, stating that specimens taken out from the tidal zone of the rubble mound showed sufficient durability with respect to strength and deflection following property even after the service period of 36 years[11].

4.4.2 Materials

(1) The materials for sand mastic shall be appropriately selected so as to ensure the required strength and durability.

(2) The examples of the materials for sand mastic are as follows:

① **Asphalt**

The asphalt for sand mastic to be used underwater can be the straight asphalt with the needle penetration rates of either 40 to 60, 60 to 80, or 80 to 100 as specified in **JIS K 2207 Petroleum Asphalts**.

② **Sand**

Clean sand with the maximum grain size of 2.5 mm with no inclusion of waste, mud, and organic matters.

③ **Fillers**

Those fillers which comply with **JIS A 5008 Limestone Filler for Bituminous Paving Mixtures**.

(3) The asphalt for sand mastic to be used underwater[12),13] shall have sufficient fluidity because sand mastic is required to reliably flow into the voids among rubble stones when poured underwater over rubble mounds.

(4) Generally, the fluidity of asphalt mixture becomes greater with the increase in the sizes of sand grains, thereby allowing a small quantity of asphalt to achieve the required fluidity at the increased risk of material separation. In contrast, although the fluidity is low, denser sand mastic becomes available with the decrease in the size of sand grains. Thus, in order to prevent material separation of asphalt mixtures, sand preferably has continuous grain size distribution and gentle grading curves.

(5) When mixed with asphalt mixtures, fillers fill the voids among aggregate together with asphalt and function as binding materials which reduce the fluidity and increase viscosity and stability of asphalt mixtures. Asphalt generally adheres well to alkaline fillers. Thus, it is possible to use fillers made of limestone powder which shows mild alkalinity.

4.4.3 Mix Proportion

(1) The mix proportion of sand mastic shall generally be determined through mix proportion tests suitable for confirming the required fluidity and strength taking into consideration construction and natural conditions.

(2) The properties of sand mastic vary depending on mix proportion and the properties of materials. Also, the requirements for workability, strength, and flexibility of sand mastic vary depending on the locations of the construction sites and natural conditions.

(3) General

The values in **Table 4.4.1** are frequently used as the mix proportion of sand mastic to solidify rubble stones underwater.

Table 4.4.1 Standard Mix Proportion of Sand Mastic

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

Note: Dust refers to sand and fillers passing through a 0.075 mm sieve.
Fine aggregate refers to sand and fillers remaining on a 0.075 mm sieve.

(4) Performance Verification

The mix proportion of sand mastic for solidifying rubble stones is preferably determined so as to ensure the required performance through the following tests:

(a) Fluidity test

1) The time of flow of sand mastic used underwater shall be in the range of 10 to 60 s.
2) No visually identifiable material separation while flowing.

(b) Specific gravity test: 1.95 or more

(c) Bending test: strength of 1.0 N/mm^2 or more and deflection amount of 5.0 mm or more

(d) Compression test: 1.0 N/mm^2 or more

The tests of (c) and (d) above shall be conducted at the temperature of 10°C and the loading rate of 20 mm/min.

(5) Method for Calculating the Required Amount of Sand Mastic

The required amount of sand mastic used for a rubble layer can be calculated by **equation (4.4.1)**.

$$V = \alpha A(hv + d) \quad \textbf{(4.4.1)}$$

where:

V : required amount of sand mastic (m^3)

A : area of a rubble layer into which sand mastic is injected (m^2)

h : thickness of a rubble layer into which sand mastic is injected (m)

v : porosity of a rubble layer into which sand mastic is injected

d : thickness of a sand mastic cover on a rubble layer (m)

α : additional rate in consideration of the injection into a lower rubble layer (which varies depending on the size of the lower rubble layer and the fluidity of sand mastic but is generally set at 1.0 to 1.3)

(6) Points of caution in the performance verification

The points of caution when designing sand mastic are as follows:

① Careful attention is required when applying sand mastic to the locations with the risks of powerful impulsive wave pressure or damage due to drifting objects.

② Sand mastic shall not be used in locations where expected deflection is too large for sand mastic to follow as is the case with rapid or large-scale sedimentation.

③ The gradients of rubble surfaces to which sand mastic is applied are preferably 1:1.3 or less.

④ The sand mastic used at the tops and foots of slopes as well as edges of structures shall be provided with proper reinforcement.

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

[References]

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5 Stones

5.1 General

(1) Stone materials shall be selected taking into consideration the required quality and performance suitable for the intended use and economic efficiency.

(2) Generally, stone materials are used in large quantities for the construction of port facilities, such as breakwaters and wharves. Careful consideration shall be given to the selection of stone materials because they have large influences on the stability of facilities and construction period as well as costs.

(3) **Table 5.1.1** summarizes the results of the research conducted by the Okinawa General Bureau of the Cabinet Office on the types and physical properties of major stone materials related to port development. It shall be noted that even stone materials of identical types may have large differences in physical properties depending on production areas and quarrying positions.

It is also necessary to pay attention to the possible difference between actual and designed unit weight of stone materials because unit weight fluctuates in accordance with the porosities which vary depending on the shapes and sizes of stone materials.

Table 5.1.1 Physical Properties of Stones

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

Note: (true) means true specific gravity. The values not in the form of ranges are averages.

5.2 Rubble for Foundation

(1) The stones used as rubble for foundation shall be in proper shapes, not flat or slender and should be hard, dense, durable, and free from the risks of weathering and freezing damage.

(2) Stone materials to be used shall be determined on the basis of the material quality confirmed through tests, availability, transportability, and costs.

(3) The type of rocks classified as igneous rock is generally used for rubble foundations. However, aside from the portions of rubble foundations to which large loads are directly applied, such as the areas immediately below caissons, another type of rocks classified as sedimentary rock, such as tight sands, or artificial stone materials, such as hydration-hardened steel slag, can be used as rubble provided that they satisfy the required performance.

(4) Shoji[1)] studied the shear characteristics of rubble for foundations by conducting large-scale triaxial compression tests on the basis of the actual use conditions of rubble stones in port construction works.

(5) As a guide to determine strength constants without conducting large-scale triaxial tests, Minakami and Kobayashi[2)] reported that rubble stones with unconfined compression strength of 30 N/mm^2 or more are expected to have apparent cohesion of 0.02 N/mm^2 and an angle of shear resistance of 35°.

5.3 Backfill Materials

(1) Backfill materials shall be selected taking into consideration their properties, such as angles of shear resistance and unit weight.

(2) Generally, the stone materials used for backfilling are rubble, unscreened gravel, cobblestone, and steel slag.

(3) The values in **Table 5.3.1** can be used as the characteristic values for backfill materials.

(4) In this section, rubble means the stone materials which are used in port-related works and comply with **JIS A 5006 Rubbles**.

(5) The unscreened gravel means the mixtures of equal parts of sand and gravel.

(6) Slope gradients are standard values of gradients of slopes of the backfill materials when they are naturally stabilized underwater during construction.

Generally, smaller values of gradients are used for the backfill areas with small influence of waves and larger values of gradients for the backfill areas with large influence of waves.

(7) When using steel slag, careful examination is required because its quality varies depending on the production factories. For the details of steel slag, **Part II, Chapter 11, 7.2.2 Steel Slag**, can be used as a reference.

(8) There are cases in which lightweight aggregates are used as backfill materials in order to reduce earth pressure.

Table 5.3.1 Characteristic Values of Backfill Materials

		Angle of shear resistance (°)	Unit weight		Slope gradient
			Above residual water level (kN/m^3)	Below residual water level Underwater effective weight (kN/m^3)	
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 Armor Stones

(1) Armor stones are subjected to severe meteorological actions and the abrasive action of sand carried by waves. Thus, as is the case with rubble for foundations, stone materials used for armor stones shall be hard, dense, large in specific gravity, durable, and free from weathering and freezing damage.

(2) Stone materials to be used shall be determined on the basis of the material quality confirmed through tests, availability, transportability, and costs.

(3) In addition to natural stone materials, artificial stone materials, such as hydration-hardened steel slag, have been used for armor stones.

5.5 Base Course Materials

(1) Base course materials shall be selected taking into consideration the required bearing capacity, the ease of compaction, and durability.

(2) Normally, granular materials, cement stabilized soil, or bituminous stabilized soil are used as base course materials. Granular materials include crushed stone, steel slag, unscreened gravel, pit gravel, unscreened crushed stone, crushed stone dust, and sand. These granular materials may be used independently or as mixtures with other types of granular materials.

(3) Base courses disperse loaded weight applied on them and transfer dispersed load to subgrades. Generally, base courses are separated into lower and upper base courses. The lower base courses have relatively low bearing capacity and are constructed by inexpensive materials. In contrast, the upper base courses are constructed by high-quality materials with large bearing capacity. The specifications for the required bearing capacity and use materials

of base courses differ between concrete and asphalt pavement. For these requirements, Cement Concrete Pavement[3)] and Essential Points of Asphalt Pavement[4)] in **Part III, Chapter 5, 9.18 Aprons**, can be used as references.

[References]

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6 Timber

6.1 General

Timber installed below groundwater levels can maintain its long-term durability and was widely used for foundations of concrete structures in ports such as quaywalls and breakwaters until the 1960s. Some timber piles constructed at that time are still in use, even now. Also, recently, a log placing method was developed for using logs as ground improvement materials for underground storage of carbon dioxide as a countermeasure against global warming, and there have been increasing cases of using the method.[1) and 2)]

The government, municipalities, business operators, and people are encouraged to promote the use of timber in the **Act on Promotion of Use of Wood in Public Buildings, etc.** (Act No. 36 of 2010) which was promulgated and put into effect on May 26, 2010. Owing to advanced wood fireproofing technologies, and the development of large cross sectional wooden structural members such as cross laminated timber (CLT), there has been widespread use of timber in public facilities, such as stadiums and school buildings. Timber has also been used for passenger terminal buildings, decks, and boardwalks in ports and airports, and the use of timber is expected to be further promoted in the future.

In contrast, it is difficult to apply timber to the undersea structural members, such as a pile of piled piers because, in such an environment, timber is subjected to feeding damage of marine borers, such as shipworms. Conventional conservation treatment through chemical injection has had problems because the chemical leaches into the environment and there is an unsustainable conservation effect. Recently however, conservation treatment technologies (thermal treatment, low-molecular phenol injection treatment, etc.) have been developed which can solve these problems[3) and 4)] and enable the use of timber as undersea structural members in the future.

Compared with steel, concrete, and plastic materials, timber has the following characteristics. When using timber in port facilities, it is necessary to pay attention to these characteristics.

(1) Strength Performance

Timber density differs depending on species. Because timber species with high density have few voids in timber textures, they are likely to have high strength and Young's modulus. Also, timber has anisotropic strength performance, where the strength and Young's moduli, with respect to loads in the direction perpendicular to fibers (woodgrains), are significantly smaller than those with respect to loads in the direction parallel to fibers. In addition, in timber, the tensile strength is higher than the compressive strength; bending failure is started with compressive buckling; and moisture contents and loading duration have measurable influences on strength.

(2) Durability

Timber undergoes degradation such as discoloration, surface contamination, morphology changes, and strength reductions due to the actions of organisms (such as bacteria, insects, and marine borers) and meteorological factors (such as ultraviolet rays, rain, and temperature). The main degradation factors of timber vary greatly depending on usage environments and moisture contents.

(3) Environmental Characteristics

Trees grow in a manner that fixes carbon dioxide in the atmosphere using solar energy. Thus, timber is a material which releases little carbon dioxide into the atmosphere through its production. Also, using thinned wood can help preserve artificial forests. It shall be noted that using timber from natural forests has a risk of causing forest destruction.

(4) Others

Timber has: flammable nature; esthetic values of the woodgrain patterns with moderate irregularity and shading; fragrance with favorable physical and mental effects on people; moderate elasticity to reduce the chance of people getting injured when falling on timber members; low thermal conductivity, which produces warmth texture; and moderately large friction coefficients with almost no difference between static and kinetic friction coefficients, which makes walking easier.[5)]

6.2 Strength Performance

Setting the characteristic values of timber strength and verification of the bearing capacity of timber as structural members can be made based on the **Standard for Structural Design of Timber Structures**[6)] (hereinafter referred to as the "**Standard**") or the **Recommendation for Limit State Design of Timber Structures (Draft)**[7)] (hereinafter referred to as the "**Recommendation (Draft)**") of the Architectural Institute of Japan. The following items are of particular concern when timber is used for port facilities.

(1) Moisture Content

The dry base moisture content, calculated by (mass of water in timber) ⁄ (total dry mass of timber) × 100(%), is normally used as the value expressing timber moisture content. The moisture in timber is separated into bound moisture and free moisture. The bound moisture is bound to cellulose in timber cell walls. In contrast, free moisture exists in intracellular spaces in the form of liquid. When timber has a moisture content of about 30% or less, it has no free moisture.

The strength of timber (compressive, tensile, bending, and shear strength) is affected, not by free moisture, but by bound moisture. As schematically illustrated in **Fig. 6.2.1**, timber shows a continuous decrease in its strength when moisture content is increased from totally dry to about 30% (fiber saturation point) as a result of the increase in bound moisture. In contrast, the strength is almost stabilized even when the moisture content is increased beyond the fiber saturation point as a result of the increase in free moisture. Under the meteorological conditions in Japan, the moisture content of timber reaches equilibrium at around 15%. Therefore, in the **Standard** and the **Recommendation (Draft)**, the standard strength characteristic values of timber are specified based on test results at the moisture content of 15%. Also, the **Standard** and the **Recommendation (Draft)** categorizes a constantly wet state as Usage Environment I, an intermittently wet state as Usage Environment II, and other states as Usage Environment III and requires the standard strength characteristic values of timber in the Usage Environments I and II to be reduced in a manner that multiplies them by the reduction coefficients of 0.7 and 0.8 respectively. Thus, when the wet states of timber structural members in port facilities fall under the categories of Usage Environments I and II, their standard strength characteristic values shall be reduced by using the reduction coefficients.

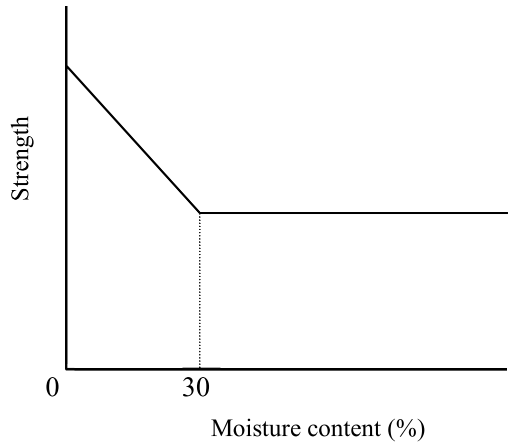

Fig. 6.2.1 Influence of Moisture Content on Timber Strength (Schematic Drawing)

Timber also undergoes dimensional changes (expansion or contraction) depending not on free moisture but on bound moisture. The timber dimensions are increased when the moisture content is increased from totally dry to about 30% (fiber saturation point) as a result of the increase in bound moisture. In contrast, the dimensions are almost stabilized even when the moisture content is increased beyond the fiber saturation point as a result of the increase in free moisture. The dimensional changes of timber are anisotropic in that the change rates are decreased in the order of tangential direction with respect to annual rings, radial direction with respect to annual rings and fiber direction with the approximate relative ratio of 1.0:0.5:0.1. In the case of Japanese cedar, the total expansion ratio from a totally dry point to a fiber saturation point reaches about 6% in the tangential direction with respect to annual rings. When timber is used in environments with possible fluctuations in moisture contents below fiber saturation points, it is necessary to design timber considering these dimensional changes.

The unit weight of timber largely varies depending on species and moisture contents. For example, the unit weight of Japanese cedar, Japanese red pine, and Japanese oak is about 0.38, 0.52, and 0.68 g/cm^3, respectively, in an air-dried state (moisture content of 15%).[8] With a large amount of moisture in intracellular spaces, the unit weight of the undried logs immediately after logging and timber which has been used underwater may be more than twice the unit weight in an air-dried state. Although the unit weight of 0.8 g/cm^3 (7.8 kN/m^3) has been used conventionally for timber in the design of port facilities, it is necessary to ensure that the design of port facilities is still on the safe side even after possible large fluctuations in actual unit weight of timber depending on the species and moisture contents.

(2) Loading Duration

According to the **Recommendation (Draft)**, loading duration has a relationship with loading duration influence coefficients, as shown in **Fig. 6.2.2**. The loading duration influence coefficients are: the coefficients to be multiplied by standard strength characteristic values when loading is expected to continue beyond 10 minutes, which is the standard material testing period; and introduced for the purpose of incorporating the influence of loading duration on material strength. It is also necessary for port facilities to reduce the standard strength characteristic values using the loading duration influence coefficients based on the assumption of the loading duration of respective temporary loads during construction and long-term loads after completion.

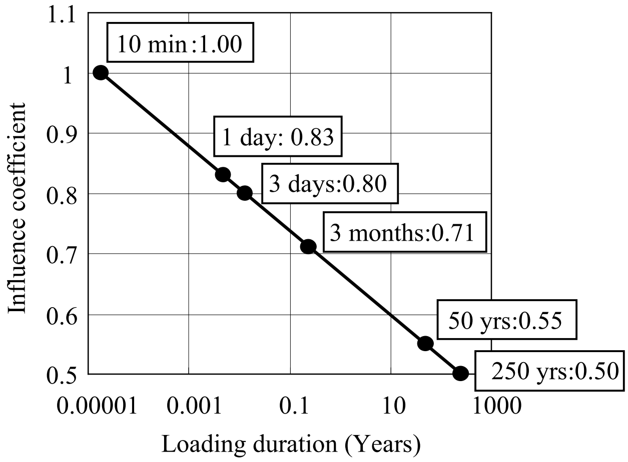

Fig. 6.2.2 Loading Duration Influence Coefficient[7)]

(3) Standard Strength Characteristic Values of Logs

With no fibers cut, logs are mechanically superior to lumber and suitable for use in port facilities in terms of economic efficiency and environmental friendliness. The **Standard** and the **Recommendation (Draft)** allow the standard strength characteristic values of general structural timber, or mechanically graded lumber, to be used as the standard strength characteristic values of logs.

6.3 Durability

The problems inherent in the use of timber are discoloration, surface contamination, morphology changes, and strength reductions. The degrees of importance of respective problems vary depending on the intended use of timber (required performance such as aesthetic property and strength).

(1) Degradation Factors

The main factors causing timber degradation are: living organisms (fungi, insects, marine borers, etc.), meteorological factors (ultraviolet rays, rain, temperature, etc.), and continuous loading. The main degradation factors of timber differ depending on the usage environments and moisture contents of timber as shown in **Table 6.3.1**. The three types of moisture states in the table are defined as follows: “Dry” means moisture contents, equal to or less than the fiber saturation point (about 30%), with no moisture in intracellular spaces; “Wet” means moisture contents, equal to or more than the fiber saturation point (about 30%), with moisture and oxygen in intracellular spaces; and “Saturated” means a state where intracellular spaces are almost filled with moisture and nearly empty of oxygen.

Table 6.3.1 Usage Environments and Degradation Factors

Usage environment		Example of application	Moisture state	Main degradation factor
Indoor		Residence	Dry	Insects harmful to dried wood
			Wet	Fungi and termites
Outdoor	In the air	Outdoor construction material	Dry	Meteorological factors and insects harmful to dried wood
			Wet	Fungi, termites, meteorological factors
	Underground	Pile	Wet	Fungi and termites
			Saturated	Bacteria, continuous loading
	In fresh water	River facility	Wet	Fungi
			Saturated	Bacteria, continuous loading
	Splash zone of seawater	Port facility	Wet	Meteorological factors
	Tidal zone and in the seawater	Port facility	Wet	Marine borers
			Saturated	Marine borers

① **Fungi**[9)]

Generally, the types of fungi that are timber degradation factors can be classified into mold and wood rotting fungi. Mold causes the discoloration and contamination of timber surfaces, thereby posing problems when aesthetic properties are important. In contrast, wood rotting fungi degrade cellulose and lignin, which are the main compositions of wood, thereby causing morphology changes and strength reductions.

Wood rotting fungi are classified into brown-rot fungi, white-rot fungi, and soft decay fungi. Wood rotting fungi do not develop in timber in a dry state with too little free moisture, or in a saturated state with too little oxygen, because they require intracellular moisture (free moisture) and oxygen to grow. Thus, timber piles installed underground below groundwater levels are not subjected to degradation due to wood rotting fungi, thereby maintaining long-term durability.[10) and 11)]

② **Bacteria**

Bacteria and continuous loading can be timber degradation factors in a saturated state. Timber degradation due to bacteria progresses from the timber surfaces to the interiors at rates of 0.1 to 0.5 mm/year. There is a report saying that degradation is significantly slowed when bacteria reach heartwood (to be described later).[12)]

③ **Insects**[9)]

Termites (Japanese subterranean termites and formosan subterranean termites) and the insects harmful to dried wood (coleopteran such as Lyctus brunneus) can be degradation factors of timber.

④ **Marine borers**[3), 13), 14), 15), 16), and 17)]

Those marine borers causing timber degradation are shipworms, which are mollusks, and Limnoria species, which are crustaceans.

Shipworms are bivalves. Once their larvae with diameters of around 0.3 mm attach to timber in seawater, they penetrate the timber by grinding it with their shells. They leave only small holes, with diameters of about 0.3 mm on the timber surfaces, but their nests inside timber have diameters about 7 mm and lengths of about 10 cm or more. Thus, shipworms may significantly reduce sectional areas and strength of timber within a couple of months. The larvae of shipworms in an adhesion period are considered mobile in the entire vertical range from sea surfaces to sea bottoms but stop activities when salinity becomes 0.6% or less. Broad-leaf trees, such as oaks, are more susceptible to damage from shipworms than needle-leaf trees, such as cedars and cypress, but pines, one of the needle-leaf trees, are susceptible and camphor trees, one of the broad-leaf trees, are not susceptible to damage from shipworms.

Limnoria are a species of crustaceans, about 3 mm long and 1 mm wide, which create nest holes close to the surface of timber in seawater. Once porous pile surface sections due to the nest holes are removed by waves, they create nest holes close to the newly exposed pile surfaces, thereby reducing timber volumes. Their activities are slower when the salinity is reduced to 1.6%, and they are mostly dead when the salinity is 0.6%.

The types of timber having low density with soft surfaces are susceptible to the damage due to Limnoria and needle-leaf trees are likely to be more susceptible than broad-leaf trees.

In brackish-water regions, such as river mouths, timber is susceptible to the damage due to Sphaeromidae[18] which is a species of crustaceans like Limnoria and has a length of about 5 to 15 mm.[13]

⑤ **Meteorological factors**[9]

The meteorological factors causing timber degradation are sunlight (mainly ultraviolet rays), temperature, precipitation, fallen snow, and winds. Timber undergoes ashy white discoloration and grain depression (reductions in cross sectional areas and mass) through the degradation of lignin, which is one of the main composition elements of timber due to ultraviolet rays and the eluviation of degraded lignin due to the action of precipitation. Also, timber is susceptible to minute cracks, due to alternative wetting and drying, and abrasion, due to earth and sand blown by winds. The degradation caused by these meteorological factors is called weathering. In the case of the fast-growing sections (sections of annual rings with lighter colors) of needle-leaf trees, the degradation rates due to weathering are considered to be about 5 to 6 mm in 100 years but are largely affected by regional and local meteorological conditions of the places where timber is used. The fast-growing sections are softer and more susceptible to the grain depression than slow-growing sections (sections of annular rings with darker colors) and, therefore, weathering causes timber surface to aggravate concavity and convexity along annular rings.

(2) Degradation Countermeasures

Degradation countermeasures include: the use of inherently highly durable timber, conservation treatments, coating and maintenance.

① **Use of inherently highly durable timber**

In most tree species, the peripheral sections close to the bark have lighter colors than the interior sections. The peripheral sections, with lighter colors, and the interior sections, with darker colors, are called sapwood and heartwood, respectively. The heartwood contains larger substances called extractives than sapwood. The extractives include phenols, terpenes, tannins, and other substances which are active in preventing enzyme actions of decay fungi, fill gaps inside timber, and protect cell walls. For example, Ipe (South America), teak (Southeast Asia), Lophira alata (Africa), and cypress pine (Australia) are the species considered unsusceptible to biological degradation because of the effects of special extractives. The use of these exotic species of inherently highly durable timber shall be contingent on avoiding deforestation and disruption of the ecosystem. For ensuring the avoidance of deforestation and disruption of the ecosystem, it is preferable to use the certification system supported by the international organizations, such as the Forest Stewardship Council or illegal logging information, provided by environmental NGOs. Also, it is dangerous to easily introduce exotic species with favorable performance records of durability because they may be vulnerable to the indigenous fungi in Japan.

② **Conservation treatments**

Timber impregnated with antiseptic insect repellent chemicals has been widely used as foundation material for housing and outdoor facilities. The detailed specifications of these chemicals can be found in **JIS K 1570 Wood Preservatives**. Conventionally, creosote oil and copper chromated arsenate (CCA) have been widely used; however, because they have posed health problems for workers and increased environmental loads in the drainage and waste management, they have been substituted with low toxic chemicals. These alternative chemicals are generally less effective than CCA, and their effects on marine borers have not been elucidated. The other conservation treatments besides chemicals include low-molecular phenol resin infusion treatment and thermal treatment.[3) and 4)] When examining conservation treatments, it is necessary to evaluate the influences of treatments on environments through the life cycle, including production, use, and disposal based on precautionary principles.

③ **Coating**

Degradation countermeasures by coating have been experimentally implemented using FRP sheets, urethane resin, and polymer cement as coating materials.[19] Coating timber with screens having mesh sizes smaller than those of larvae of shipworms (about 0.3 mm) is confirmed effective against shipworms in on-site experiments in the sea.[3) and 20)]

④ **Maintenance**[21), 22) and 23)]

Maintenance is another degradation countermeasure for timber. For proper maintenance, inspections and diagnoses of timber degradation are important; therefore, it is necessary to examine inspection items and methods depending on the degrees of degradation.

The primary diagnoses of timber degradation shall include: visual identification of whether or not timber has discoloration, cracks, fruit bodies (mushrooms), and traces of insect damage with particular focus on the joint sections between timber and the ground or concrete members, as well as the portions of timber prone to rainwater accumulation; examination of whether timber surfaces slightly yield under pressure of a finger; examination of whether or not a sharp point, such as that of a screw driver, sinks into timber surfaces; identification of voids by tapping with a mallet; and photographing surface conditions with a digital camera and storage of image data.

The secondary diagnoses of timber degradation shall include quantitative evaluation of the degrees of degradation using the following on-site measuring devices: a Pilodyn (a device to measure a penetration depth of a pin shot into timber with given energy); a Resistograph (a device to measure torque required to screw a drill into timber at a constant rotation rate); an ultrasonic propagation velocity meter; a moisture content meter; and a driver with a force gauge.[24)]

The tertiary diagnoses of timber degradation include determining degradation causes through: the inspection of the presence or absence of hyphae and degradation of cell walls by observing specimen collected in the field through a microscope; and separation and cultivation of the hyphae.

On the basis of these diagnoses, it is necessary to implement proper maintenance such as the replacement of members as needed.

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7 Recyclable Materials

7.1 General

(1) Recyclable materials shall be used with due consideration of the characteristics of materials and facilities.[1)]

(2) The use of recyclable materials described in this section is subjected to: the **Act on the Promotion of Effective Utilization of Resources** (Act No. 48 of 1991) (hereinafter referred to as the "**Recycle Act**"); the **Waste Management and Public Cleansing Act** (Act No. 137 of 1970) (hereinafter referred to as the "Waste Management Act"); the **Act on Prevention of Marine Pollution and Maritime Disaster** (Act No. 136 of 1970) (hereinafter referred to as the "Marine Pollution Prevention Act"); and the **Soil Contamination Countermeasures Act** (Act No. 53 of 2002).

(3) The **Recycle Act** requires the government, municipalities, and ordering parties of construction works to promote respective countermeasures contributing to the effective use of limited resources and reduced waste generation.

(4) Recyclable materials used in port construction include slag, coal ash, crushed concrete, dredged soil, and asphalt concrete mass. Most of these can be recycled as earth and stone materials, such as landfill materials, base course materials, soil improvement materials, and concrete aggregate.

(5) When using slag, coal ash, crushed concrete, and asphalt concrete mass as recyclable materials, it is necessary to examine the applicability of the **Waste Management Act**, the **Marine Pollution Prevention Act**, and the **Soil Contamination Countermeasure Act**. Whether recyclable materials fall in the waste category cannot be objectively and essentially determined by their physical properties. Generally, when materials are useful and can be sold to others for value, they are not categorized as waste.

(6) Effective use of recyclable materials is extremely important for developing a sustainable society. Because of the characteristics of using large quantities of materials, port and harbor construction works must contribute to environmental preservation and develop a sustainable society by reducing the use of natural resources through effectively using recyclable materials. Also, in compliance with the **Recycle Act**, which strongly recommends effective use of recyclable materials, it is necessary to proactively use materials generated through construction activities by taking advantage of their characteristics.

In contrast, recyclable materials shall be used with due consideration for ensuring environmental safety based on applicable laws and regulations.[1)] For the basic concept of environmentally conscious use of recyclable materials, the **Recycling Technology Guidelines for Harbor and Airport Construction and Maintenance (Revision)**[1)] can be used as a reference.

Disposing of construction and industrial by-products into the sea as waste (including the areas to be landfilled) shall be subjected to the standards for harmful substances, stipulated in the **Marine Pollution Prevention Act** and the **Waste Management Act**. Although the disposal of such by-products into the sea for their effective use shall not be subjected to the **Marine Pollution Prevention Act** and the **Waste Management Act**, the provisions in the **Reference 2)** can be used as references.

Also, the **References 3) to 6)** can be used as references on the required quality for recyclable materials described in this section to ensure environmental safety. As the precautions to ensure the environmental safety in terms of setting monitoring target values, such as pH during construction, the **References 7) and 8)** can also be used as references although they are not standards established exclusively for recyclable materials.

(7) Some recyclable materials have relatively large fluctuations in their properties. Thus, it is necessary to examine whether such recyclable materials can fulfill their intended purposes by fully investigating, in advance, their physical and mechanical properties as well as availability (generation amounts).

(8) When constructing facilities using recyclable materials, they shall be appropriately transported, stored, managed, and inspected depending on the material characteristics that are different from natural resources.

(9) The facilities constructed using recyclable materials shall be appropriately maintained based on their material characteristics. Unlike natural resources, recyclable materials' properties change over time. Thus, it is preferable to state the points of caution in maintenance plans to ensure proper implementation of maintenance. Also, when implementing repair, reinforcement, and improvement of these facilities, the types, quality, and quantities of recyclable materials used in these facilities shall be stated in the maintenance programs, considering the possible conditions to which recyclable materials may be exposed during the use of these facilities and recycled again as construction by-products.

(10) When using recyclable materials exerts equivalent or superior marine environment improvement effects than using natural resources, these recyclable materials can be used to develop seaweed beds, shallow bottoms, mud flats, seabed cover, and artificial beaches.[1] Examples of effective use of recyclable materials for marine environment improvement can be found in the verification tests on using recyclable materials for the foundations of marine organism habitats.[9 to 13] (**Reference Part I, Chapter 3, 3 Conservation and Restoration of Natural Environment**)

7.2 Slag

7.2.1 General

There are several types of slag, including iron and steel slag (blast furnace slag and steel slag), nonferrous slag (copper slag, ferronickel slag, zinc slag), and eco slag. The characteristics of respective types of slag are described below. Among them, blast furnace, electric furnace oxidized, ferronickel, copper, and eco slag have been standardized as concrete aggregate in JIS.[1 and 14]

7.2.2 Iron and Steel Slag

(1) Iron and steel slag[15] are industrial by-products generated in large quantities from the steel industry and largely classified into blast furnace slag and steel slag. Blast furnace slag is generated from the pig iron manufacturing process (about 300 kg of slag from 1 ton of pig iron) and further classified into air-cooled blast furnace slag, produced through slow cooling by ambient air and spray of water, and granulated blast furnace slag, produced through quenching treatment with jets of pressurized water. Steel slag is generated from the process of manufacturing steel from pig iron and further classified into converter slag and electric furnace slag, depending on the types of steel furnaces (about 130 kg of slag from 1 ton of crude steel). For chemical compositions, physical properties, and use methods of iron and steel slag, the **Recycling Technology Guidelines for Harbor and Airport Construction and Maintenance (Revision)**[1] can be used as a reference.

(2) Air-cooled blast furnace slag is a granular material and has been used as road construction material.

(3) Granulated blast furnace slag is a lightweight sandy material and has been used as a raw material of Portland blast furnace cement, a backfill material of port facilities and infill of sand compaction piles, taking advantage of its lightweight property. When using granulated blast furnace slag in port development works, the **Technical Manual for Granulated Blast Furnace Slag Utilization in Harbor and Airport Construction and Maintenance**[16] can be used as a reference. Also, when using granular blast furnace slag as a backfill material, reference shall be made to **Part III, Chapter 2, 5.7 Granulated Blast Furnace Slag Replacement Method**.

(4) Steel slag is a granular material with larger particle density than sand and favorable grain size distribution. Steel slag undergoes swelling and disintegration when one of its components, free lime, reacts with water. Therefore, steel slag is normally used after being stabilized through an aging treatment with steam. In addition to the usage examples of steel slag as material for road construction and ground improvement, there are cases of using steel slag as material for sand compaction piles, taking advantage of the properties of steel slag with large shear resistance angles.[17] It has been known that, aside from the aging treatment, mixing steel slag with coal ash can be an efficient stabilization method to prevent steel slag from undergoing swelling and disintegration, and such steel slag has been used as concrete aggregate in the construction at Kashima Port.[15 and 18] In recent years, a method for using steel slag by mixing it with dredged soil (see **Part II, Chapter 11, 7.6 Dredged Soil**) has been developed. When using steel slag in port construction, the **Technical Manual for Steel Slag Utilization in Harbor and Airport Construction and Maintenance**[2] can be used as a reference.

(5) There have been recent cases of using solidified steel slag through hydration as a civil engineering material of port structures, such as deformed blocks and foot protection blocks. For the details of such cases, the **Technical Manual for Utilizing Solidified Steel Slag through Hydration**[19] can be used as a reference.

7.2.3 Nonferrous Slag

Nonferrous slag is a material produced by solidifying molten slag, produced as by-products from the smelting process of metal materials other than iron (copper, ferronickel, and zinc in this section), through slow cooling or quenching with air or water. For nonferrous slag details, the **Recycling Technology Guidelines for Harbor and Airport Construction and Maintenance (Revision)**[1] and the **Technical Manual for Nonferrous Slag Utilization in Harbor and Airport Construction**[4] can be used as references.

(1) Copper Slag

Copper slag is a sandy material produced by quenching molten slag with water, as is the case of granular blast furnace slag in a copper smelting process. Copper slag has larger grain density than sand and no hydraulic-setting properties. Although copper slag is likely to undergo grain crushing, it has a shear strength angle and permeability equivalent to sea sand. There have been the performance records of using copper slag as concrete aggregate, infill of caissons, and ground improvement material (such as sand compaction pile method).

(2) Ferronickel slag

Ferronickel slag is a material produced when manufacturing ferronickel, which is a raw material of stainless steel. Ferronickel slag has larger grain density than sand with no hydraulic-setting properties. Performance records exist on the use of ferronickel slag as concrete aggregate, infill of caissons, ground improvement material (such as sand compaction pile method), landfill material, and road paving material.

(3) Zinc slag

Zinc slag is a sandy material produced by quenching molten slag, in which iron and silica contents in a raw material are bound together with high pressure water in a zinc smelting process. Zinc slag has large density and almost no hydraulic-setting properties. There have been performance records of using zinc slag as infill of caissons.

7.2.4 Eco Slag

Eco slag is produced by solidifying molten slag into glassy or crystalline substances in a manner that cools molten inorganic substances and ash that remained after incinerating organic substances contained mainly in general waste (municipal solid waste) and sewage sludge at temperatures of 1200°C or higher. For the chemical compositions, physical properties and use methods of eco slag, the **Recycling Technology Guidelines for Harbor and Airport Construction and Maintenance (Revision)**[1] can be used as a reference.

The use of solidified eco slag in port construction has been examined.[20] Eco slag has undergone proper quality control and storage throughout its production process and, therefore, satisfies the standards for elution and contained amounts of harmful substances, specified by related notifications, when it is actually used. The type of eco slag produced by quenching molten slag with water is sandy grains and can be used as materials for concrete, ground improvement (sand compaction pile method), backfilling, infilling, and paving.[1]

7.3 Coal ash

(1) Coal ash is generated when burning pulverized coal at coal-fired power plants. The properties of coal ash vary depending on the types of coal and combustion methods of boilers.

(2) Coal ash is largely classified into fly ash and clinker ash, depending on the generation sites. Fly ash is collected from combustion gas of boilers through dust collectors. Clinker ash is produced by crushing coal ash welded at the bottoms of boilers.

(3) Fly ash has grain size distribution similar to silt and pozzolanic activity, which is a hydraulic-setting property. Clinker ash has grain size distribution similar to sand, and its permeability also equivalent to sand. Both fly ash and clinker ash are characterized by their grain density, which is lower than sand.

(4) Fly ash has been widely used as a raw material of cement and a mixture material of concrete. Also, it has been used as backfill, earth fill, and base course materials to take advantage of its lightweight and hydraulic-setting properties. In addition, there are cases of using fly ash as a ground improvement material in the deep mixing soil stabilization and surface stabilization of soft ground. In these cases, fly ash is normally used as a constituent material mixed with cement, water, and soil to produce solidified and crushed materials, solidified and granulated materials, slurry materials, coal ash plastic materials. For the properties of fly ash and respective coal ash mixing materials and their use methods, the **Recycling Technology Guidelines for Harbor and Airport Construction and Maintenance (Revision)**[1] and the **Guidelines for Utilizing Coal Ash Mixing Materials in Harbor Construction**.[3] can be used as references.

(5) Clinker ash, which is lightweight and permeable, has been used as materials for backfill and earth fill. It can also be used as a lower base course material for which performance equivalent to sand is required in road pavement work. For the properties and use methods of clinker ash, the **Recycling Technology Guidelines for Harbor and Airport Construction and Maintenance (Revision)**[1] can be used as a reference.

7.4 Concrete Mass

(1) Concrete mass is generated through concrete structure demolition. The iron materials, such as steel bars, are generally removed from concrete mass. **Table 7.4.1** summarizes main use forms of concrete mass. In the table, the utilization forms listed closer to the top require less energy for demolishing and recycling concrete mass.

Table 7.4.1 Utilization Forms of Concrete Mass

Utilization form		Typical application
As it is		Fish bed, paving stone
Block form of 20 to 40 cm		Stone material such as rubble
Crushed form	Coarse rubble	Stone material such as base course and backfill
	Coarse aggregate	Recycled coarse aggregate and base course material
	Fine aggregate	Recycled fine aggregate
Powder generated through demolition process		Ground improvement material, fillers

(2) Concrete mass has been used mainly as a base course material for paving.[21)] In addition, concrete mass has started to be used as a concrete aggregate substitute because of the increasing difficulty in getting good quality concrete aggregate.

(3) The provisional concrete standards of recycled concrete mass to be used as aggregate for concrete, base course materials, and infill as well as backfill materials are specified in the **Provisional Quality Standards by Use for Recycling of Concrete By-products (Draft)** (Notification No. 88 of the Ministry of Construction on April 11, 1994). Recycled aggregate for concrete is subjected to the attachment of mortar, derived from concrete structures before demolition, and the quality of recycled aggregate, such as absorption and soundness , which varies depending on the degrees of such mortal adhesion and thereby largely affecting concrete properties. Recycled aggregate for concrete with high quality has been standardized in JIS (**JIS A 5021 Recycled aggregate for concrete-Class H**).[1)] In contrast, with respect to recycled aggregate for concrete with medium and low quality, JIS specifies the concrete quality using such aggregate (**JIS A 5022 Recycled aggregate concrete-Class M** and **JIS A 5023 Recycled concrete using recycled aggregate Class L**).[1)] Also, There have been studies on concrete performance using recycled aggregate under marine environments.[22) and 23)]

(4) It is difficult to show standard values of the material constants, such as angles of shear resistance, when the concrete mass is used as an earth and stone material because such values vary depending on the concrete mass to be generated. However, material constants can be set with reference to the **Reference 24)**, provided that the performance of concrete before demolition is equivalent to that shown in the reference.

7.5 Asphalt Concrete Mass

(1) Asphalt concrete mass is asphalt debris generated when removing or scraping pavement. Many technical guides[25) to 27)] have already been established for recycling asphalt concrete mass, promoting relatively wide use of recycled asphalt concrete mass. It has been used mainly in the field of pavement, and its use applications are roughly twofold: aggregate of asphalt pavement, such as surface base layers and stabilized base courses; and a granular base course material, such as recycled crusher-run and size controlled crush stone.

(2) The asphalt concrete mass properties vary because it is collected from different construction sites in many cases.[21)] Thus, variations of the quality of recycled asphalt mixtures are larger compared to new ones. It is necessary to prevent foreign matters from getting mixed in with recycled asphalt mixtures while being transported and stored.

(3) Because aging causes asphalt to get harder, new asphalt and admixtures for recycled asphalt are generally added so that recycled asphalt can satisfy required needle penetration rates.

(4) When using asphalt concrete mass for pavement, it is necessary to confirm that the asphalt concrete mass quality satisfies related standards which are listed in the **Recycling Technology Guidelines for Harbor and Airport Construction and Maintenance (Revision)**.[1)]

(5) When the recycled asphalt mixtures to be used as surface and base layers satisfy the requirements in related standards, they are considered to have the quality equivalent to the asphalt mixtures manufactured only with new raw materials. However, when problems associated with the use of facilities using recycle asphalt mixtures are identified in the past performance records and damage history, it is necessary to examine whether such recycled asphalt mixtures have equivalent quality to new ones through laboratory tests or test pavement. The wheel tracking test is one of the laboratory tests for examining fluidity and peeling resistance of asphalt.

(6) Recycled asphalt concrete mass is considered available for a subgrade earth fill material. However, because sufficient information on applicable technologies has not been accumulated, it is necessary to confirm whether recycled asphalt concrete mass satisfies required performance, through laboratory tests and test construction, as needed.

7.6 Dredged Soil

(1) Dredged soil has conventionally been used as a landfill material or disposed of at waste disposal sites in port areas in case no available landfill area is under construction at the time of dredging. In the port and offshore airport development, however, huge amounts of soil (ground materials) have been used constantly for backfilling quaywalls and revetments, filling reclamation land, improving soft ground, and developing shallow bottoms and mud flats (**Part III, Chapter 11, 3.6 Conservation of Natural Environment**), and sand covers (**Reference (Part I), Chapter 3, 3 Conservation and Restoration of Natural Environment**). Thus, increasing the percentage of dredged soil in the ground materials can be an extremely effective means of extending the service life of waste disposal sites and reducing construction costs.

(2) Using sandy dredged soil as a landfill or backfill material causes filled ground to be statically stable but to undergo liquefaction easily when earthquake ground motions are applied to it, thereby requiring some sort of liquefaction countermeasures to be taken. Also, using cohesive dredged soil as a landfill or backfill material causes filled ground to be extremely soft with a high water content, thereby requiring ground improvement after the filling operation. One ground improvement method which has been used frequently in such cases is surface layer solidification followed by the installation of vertical drains to enhance consolidation.

(3) In recent years, a method has been developed to solidify dredged cohesive soil and use it as a landfill or backfill material, and such a method has been implemented in a manner that uses a dedicated vessel where dredged soil is subjected to solidification before being used for landfill; solidifies dredged soil in a sand carrier, with a solidifier mixed with it, during the transport to a landfill site; and solidifies dredged soil in-situ with a solidifier mixed with it. In addition to cement-based solidified soil, converter steel slag-based solidified soil has been put into practical use. However, because the shear strength of solidified soil significantly varies depending on the additive amounts of solidifiers and the properties of dredged soil, it is necessary to solidify dredged soil appropriately, in accordance with intended use and use environments. For the details of converter steel slag-based solidified soil, reference can be made to the **Technical Manual for Calcia Modified Soil Utilization in Harbor, Airport and Coastal Construction**.[28)]

(4) The pneumatic flow mixing method is one of the solidification methods developed to implement a landfill economically and efficiently using dredged soil. The method enables transportation and kneading of dredged soil to be executed concurrently in a manner that injects solidifiers into pipes where dredged soil is pneumatically transported. It enhances the performance of a mixing device with the kneading effect of plug flows generated in the pipes when dredged soil is pneumatically transported in them. Many methods have been proposed for mixing dredged soil and solidifiers, including those which: make dredged soil and solidifiers pass through line mixers; add and mix powder solidifiers to and with dredged soil; make dredged soil with solidifiers preliminarily added to it pass through plural bent pipes to enhance a kneading effect; and directly inject slurry solidifier into the flows of cohesive dredged soil passing through transport pipes with plural solidifier slurry injection pipes arranged in them.

(5) The lightweight treated soil method produces a lightweight landfill material, using dredged soil in a manner that slurries dredged soil by adjusting the moisture content to a liquid limit or higher and mixes it with a cement-based solidifier and a weight saving material, such as bubbles or expanded beads. The lightweight treated soil method has the following characteristics.

① The method can effectively use dredged soil and develop stable ground, even undersea.

② The method can adjust unit weight of soil to 10 to 12 kN/m^3 to alleviate consolidation settlement of foundation ground, reduce earth pressure, and prevent soil from floating due to buoyancy.

③ The method can adjust unconfined compressive strength of soil to 200 to 600 kN/m^2 equivalent to hard cohesive soil.

Although the lightweight treated soil method's cost largely fluctuates depending on construction sizes, there has been a steady increase in the number of application cases since the first application to the earthquake disaster restoration works in Kobe Port. Other application cases include a large scale implementation at the upper sections of the shield tunnel under the apron of the international terminal and at the joint section of D runway in Haneda International Airport.

There is another method, which produces landfill material by dehydrating dredged soil with a dehydration plant, and has been applied, in a large scale, to the embankment material, raising the elevation of the offshore soil disposal site off Shin Moji Port.

7.7 Shells

7.7.1 General

Among shells, crushed oyster and scallop shells have been used as construction materials.

7.7.2 Oyster Shells

(1) Oyster harvesting areas inevitably produce oyster shells in large quantities. Conventionally, they have been used mainly as cattle feed and fertilizers but, recently, there have been studies on using oyster shells as ground improvement materials (sand compaction pile method), developing shallow bottoms and mud flats, as well as sand covers.[1)]

(2) The characteristics of crushed oyster shells generally include: the angles of shear resistance equivalent to sand; specific gravity and density larger than sand; permeability larger than sand; CBR equivalent to sand; compaction property larger than sand; and grain size distribution equivalent to sand.[29) to 31)]

7.7.3 Scallop Shells

(1) There have been studies on the use of scallop shells, which are produced after scallops are subjected to external cleaning, boiling and shelling, as fine aggregate for concrete provided that they are appropriately crushed,[32) to 34)] and ground improvement (sand compaction pile and sand drain methods) and road paving materials.

(2) The characteristics of crushed scallop shells generally include: the angles of shear resistance equivalent to sand; specific gravity and density larger than sand; permeability larger than sand; compaction property larger than sand; and grain size distribution equivalent to sand.

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8 Other Materials

8.1 Metal Materials other than Steel Product

(1) When using metal materials other than steel (carbon steel) products, most suitable materials shall be selected taking into consideration use locations, purposes, environmental conditions, durability, and economic efficiency.

(2) The metal materials other than steel (carbon steel) products used for the facilities subjected to the technical standards include stainless steel, aluminium, and titanium. The metal materials to be used for port facilities shall have quality necessary to achieve required performance of these facilities. The Japan Industrial Standards (JIS) are the typical examples of these metal materials satisfy such conditions.

① **Stainless steel**

Table 8.1.1 shows the types of stainless steel products, among those complying with JIS, generally used in civil engineering facilities.[1)] Stainless steel has been used mostly for corrosion prevention, but the corrosion resistance of stainless steel under marine environments significantly varies depending on the types of stainless steel. Thus, it is preferable to select appropriate types of stainless steel with reference to test results and past performance records. Additionally, when designing and constructing stainless steel structures, reference can be made to the **Guideline for the Design and Construction of Stainless Steel Civil Engineering Structures (Draft)**.[1)]

The examples of stainless steel used in large quantity for facilities under marine environments include SUS 312L with high corrosion resistance in seawater used as the coating material for the jacket section of D runway in Haneda International Airport;[2)] and SUS 304 N2, SUS 323L and SUS 821 L1 used for water gate facilities.

Recently, stainless steel has been used as concrete reinforcing bars (refer to **Part II, Chapter 11, 3.1 Concrete Materials**).

Table 8.1.1 Quality Standards for Stainless Steel Products[1)]

Standard		Symbol	Application
JIS G 4303	Stainless steel bars	SUS304 (L), SUS316 (L), SUS304N2	General steel members
JIS G 4304	Hot-rolled stainless steel plate, sheet and strip	SUS304 (L), SUS316 (L), SUS821L1, SUS323L	General steel members
		SUS312L	Anticorrosion coating of steel structures
JIS G 4305	Cold-rolled stainless steel plate, sheet and strip	SUS304 (L), SUS316 (L), SUS821L1, SUS323L	General steel members
		SUS312L	Anticorrosion coating of steel structures
JIS G 4309	Stainless steel wires	SUS304 (L), SUS316 (L)	Ropes
JIS G 4317	Hot-formed stainless steel sections	SUS304 (L), SUS316 (L)	General steel members
JIS G 4321	Stainless steel for building structure	SUS304A, SUS316A, SUS304N2A	General steel members
JIS G 4322	Stainless steel bars for concrete reinforcement	SUS410-SD, SUS304-SD	Concrete reinforcing bars
JIS B 1054	Mechanical properties of corrosion-resistant stainless steel fasteners	A2-50 (equivalent to SUS304), A4-50 (equivalent to SUS316)	Fastener components (bolts)

② **Aluminium**

Aluminium and aluminium alloys have advantages in that they are light, with density of 2.65 to 2.80 kg/m^3; high in corrosion and weather resistance; capable of being produced with strength and surface membranes depending on intended use; and excellent in workability. **Table 8.1.2** shows the types of aluminium materials, among those complying with JIS, generally used in civil engineering facilities. The examples of the facilities for which aluminium materials are used include water gates,[3) and 4)] land locks, tide gates, vehicle protection fences, intrusion prevention fences, lighting towers, inspection passages, guard rails, and bridge railings.

Also, aluminium alloys have been widely used as the anodes of the cathodic protection method by galvanic anodes (refer to **Part II, Chapter 11, 2 Steel Products**).

Table 8.1.2 Quality Standards for Aluminum Materials

Standard		Symbol	Application
JIS H 4000	Aluminum and aluminum alloy sheets, strips and plates	A5052P, A5083P, A3004P	Water gates, land locks, tide gates, lighting towers and roofs of facilities
JIS H 4100	Aluminum and aluminum alloy extruded shape	A5083S, A5052S, A6061S, A6063S, A6N01S	Water gates, land locks, tide gates, vehicle protection fences, bridge railings, intrusion protection fences, lighting towers, inspection passages and roofs of facilities
JIS H 8602	Combined coatings of anodic oxide and organic coatings on aluminum and aluminum alloys	A1, A2	Surface coating of aluminum and aluminum alloys

③ **Titanium**

Titanium has large strength-mass ratios. That is, titanium is strong (tensile strength of 350 to 520 N/mm^2) for its weight (density of about 4.5 kg/m^3). Titanium also has a high ability to bind oxygen and is easily passivated with an oxide layer (TiO_2) with a thickness of about a few dozen angstroms formed on its surface. Thus, titanium barely corrodes and shows extremely high resistance against pitting and crevice corrosion even undersea. Taking advantage of these properties, titanium has been used as material to prevent steel products from corrosion. **Table 8.1.3** shows the types of titanium materials, among those complying with JIS, used relatively frequently for port facilities. The examples of materials using titanium include titanium clad steel and protection covers for petrolatum coating.

Also, there are cases of using titanium meshes or grids as anode materials of the impressed current method as cathodic protection method to steel bars of reinforced concrete taking advantage of the fact that such anodes can stably function without undergoing material deterioration even after applying anode current to them for a long period of time.

Table 8.1.3 Quality Standards of Titanium Materials

Standard		Symbol	Application
JIS H 4600	Titanium and titanium alloys-sheets, plates and strips	TP270C	Titanium clad, protection covers for petrolatum coating
JIS H 4650	Titanium and titanium alloys-bars		

8.2 Fiber Reinforced Materials

The typical fiber reinforced materials are: 1) continuous-fiber reinforced materials using continuous fibers; and 2) short-fiber reinforced materials using short fibers mixed in cement-based materials. The raw materials frequently used for continuous-fiber reinforced materials are carbon, glass, and aramid fibers. The same raw materials are also used for producing for short-fiber reinforced materials but there are cases of using steel fibers instead of them.

(1) Continuous-fiber reinforced materials

Continuous-fiber reinforced materials have been used as steel bars and PC steel products for concrete taking advantage of their characteristics to be highly resistant against corrosion (refer to **Part II, Chapter 11, 3.1 Concrete Materials**).

Also, there are cases of using continuous-fiber reinforced materials as structural members. For example, FRP (Fiber Reinforced Plastic) is used for the scaffolds of inspecting facilities. When design and constructing structures using FRP, reference can be made to the **Standard Specifications for Hybrid Structures, Design**[5)] and the **Standard Specifications for Hybrid Structures, Construction**.[6)] There are cases of using FRP plates as embedded formwork for concrete and FRP sheets as reinforced materials of beam members and floor slabs.

(2) Short-fiber reinforced materials

Short-fiber reinforced materials are generally mixed in cement-based materials which are called fiber reinforced concrete. The characteristics of fiber reinforced concrete include high resistance against cracks and high ductility.[7) to 11)] When designing and constructing fiber reinforced concrete, reference can be made to the **Design Guidelines**

for Steel Fiber Reinforced Concrete Column Members (Draft)[12] and the **Design and Construction Guidelines for Ultrahigh Strength Steel Fiber Reinforced Concrete (Draft)**.[13]

8.3 Plastic and Rubber

(1) When using plastic and rubber, appropriate types shall be selected taking into consideration the sections where plastic and rubber are used, intended use, environmental conditions, durability, and economic efficiency.

(2) The followings are examples of the use of plastic and rubber products in port construction.[14 and 15]

① **Geo-synthetics**

The term geo-synthetics collectively denotes geo-textiles (permeable polymer sheet products) and geo-membranes which are the products having impermeable membrane-like structures. Geo-synthetics comprise geo-textiles, geo-membranes and geo-composites.

Geo-synthetics are largely separated into permeable and impermeable ones. The characteristic of respective geo-synthetics are as follows.[16]

(a) Permeable geo-synthetics

Geo-woven is a woven cloth made of polyester in general and has textures of warp and weft threads perpendicular to each other.

Geo-nonwoven has a textile structure manufactured not by weaving but by making fibers adhere to or interlock with each other or both through mechanical or chemical means or other means using solvent media.

1) Long fiber: a material, represented by spunbond, which is made of extremely long fibers. It has a relatively thin thickness of 10 mm or less in general and the thickness cannot be adjusted easily.
2) Short fiber: a material, represented by felt, which is made of short fibers with lengths of 3 to 5 cm. It has a thickness of 10 mm or more and the thickness can be adjusted easily.

(b) Impermeable geo-synthetics

Impermeable geo-synthetics are represented by impermeable plates having impermeable membrane structures with soft vinyl chloride applied to woven cloth.

Also, the followings are the examples of applications of geo-synthetics in port construction

(a) Earth fill reinforcement countermeasure

When spreading quality soil over the ground filled with dredged cohesive soil, geo-synthetic sheets or nets are directly laid on the surfaces of the ground so as to construct a quality soil layer necessary to allow heavy equipment to travel on it while preventing the quality soil from sinking.[17] In the recent construction of earth fill on soft landfill areas, there have been many cases of using geo-synthetic nets.[18]

(b) Sand washing-out and scouring prevention

When geo-synthetics are used as filter materials to prevent sand washing-out, sand invasion prevention geo-synthetic cloth is generally laid at the back of backfill stone or rubble mounds of quaywalls and on the entire bottom faces or a portion of the sections at the sea side of rubble mounds. Such sand invasion prevention geo-synthetic cloth is also used as a countermeasure to prevent scouring due to waves. For the details of sand washing-out and scouring prevention, reference can be made to **Part II, Chapter 2, 7.5 Sand Washing-out and Scouring**.

② **Joint materials**

The geo-synthetics used for construction joints of concrete structures include seal plates, joint plates, and joint-sealing materials. Seal plates are mostly made of vinyl chloride resin for which required quality has been standardized in **JIS K 6734 Plastics−Unplasticized poly (vinyl chloride) sheets**. Joint plates are mostly made of plastic foam such as vinyl chloride polyethylene, polyethylene. Joint-sealing materials are mostly elastic sealing compounds made of polysulfide, silicon, butyl rubber, or chloroprene rubber.

③ **Fenders**

The materials used for fenders are generally natural rubber or diene series synthetic rubber such as styrene-butadiene rubber. Rubber fenders shall be subjected to physical, static compression, and durability tests because they need to deliver such physical performance as aging and ozone resistance, compression performance with respect to energy absorption and reaction force, and durability performance with respect to cyclic loads.[19] For the methods of these tests, reference shall be made to **Reference (Part II), Chapter 1, 5.7 Fenders**. The fenders to be selected in the performance verification shall be those which have ability to absorb berthing energy of ships when they come alongside berths. In selecting fenders, it shall be noted that the energy absorption performance of fenders is largely affected by their constituent materials and shapes. For the performance verification of fenders, **Part III, Chapter 5, 9.2 Fender Systems** can be used as a reference. When determining whether or not to replace (renew) rubber fenders through the evaluation of the degrees of aging degradation and damage in the course of maintaining rubber fenders, reference can be made to the **Guidelines for the Maintenance of Rubber Fenders (Revision)**.[20]

④ **Seal Materials**

Seal materials are used for the joints of sand discharge pipes and seal rubber gaskets of immersed tunnel elements.

⑤ **Adhesives**

There are adhesives made of several types of synthetic resin which have been used for joining bridge members or precast concrete slabs and repairing cracks on concrete.

⑥ **Drain materials**

There are two types of drain materials: one has a composite of a core made of especially hard core and a nonwoven filter; and the other has a porous unitary structure made of specially-treated polyvinyl chloride.[21]

⑦ **Joints and bearings**

In bridges, rubber expansion joints, and single-layer or multi-layer rubber pad bearings have been used.

⑧ **Ancillary facilities**

FRP has also been used for floating facilities such as buoys and pontoons. FRP and rubber have been used for some types of ladders, handrails, and curb.

⑨ **Expanded polystyrene**

Taking advantage of its lightweight property, expanded polystyrene has been used as floats of buoys and pontoons; a part of civil engineering structures; civil engineering materials such as EPS blocks and expanded plastic beads. EPS blocks have been used as the countermeasures to reduce earth pressure, prevent settlement of earth fill constructed on soft ground, prevent ground surface from producing level differences, and facilitate foundation construction of temporary roads. Expanded plastic beads have been used as a material to produce lightweight backfill materials in a manner that mixes local soil with a solidifier such as cement so as to reduce settlement and earth pressure.[22]

(3) The followings are the description of sand invasion prevention cloth and plates as well as rubber mats generally used in port facilities.

① **Sand invasion prevention cloth**

The types of cloth used for sand invasion prevention cloth preventing soil from mixing into backfill materials are plain-woven, multi-ply woven, high strength multi-ply woven, high elongation multi-ply woven, short fiber nonwoven, and long fiber nonwoven fabrics. When determining the types of cloth, it is preferable to give appropriate consideration to construction conditions including waves transmitting through mounds during construction, waves and winds in landfill areas, wearing due to the effect of ultraviolet rays, degradation, backfilling methods, residual water levels, the accuracy of the leveling work of backfill, and waves transmitting through mounds after construction. When laying sand invasion prevention cloth, it is necessary to ensure that neighboring sheets of cloth are arranged with enough allowance and sewn together with materials having strength and elasticity so as not to leave any gaps. The strength and elasticity of sewn sections between neighboring sheets of cloth shall be close to that of the cloth itself in both longitudinal and lateral directions. For the purpose of preventing sand invasion prevention cloth from floating and being worn by backfill stone, it is preferable to take preventive measures in a manner that puts sandbags, installs anchoring chains, and lays wire meshes over the cloth immediately after the laying of the cloth. In taking such preventive measures, it is also preferable to pay particular attention to ensure that the cloth is sufficiently covered without floatation at the edges of the preventivecounter measures where the cloth is vulnerable to wearing. For the pressure due to wave transmitting through mounds, **Part II, Chapter 2, 6 Wave Force** can be used as a reference.

The types of sand invasion prevention cloth laid under rubble mounds to prevent ground soil from being washed out shall be selected in consideration of such construction conditions as wave heights, tidal currents, and the sizes of rubbles.

Table 8.3.1 shows the minimum standards which have been applied to woven and nonwoven cloth so far. It is preferable to use the products in accordance with acting external force

Table 8.3.1 (a) Minimum Standards which have been Applied to Sand Invasion Prevention Cloth (Woven Cloth)

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 8.3.1 (b) Minimum Standards which have been Applied to Sand Invasion Prevention Cloth (Nonwoven Cloth)

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

② **Sand invasion prevention plates**

Sand invasion prevention plates to be used as scour prevention countermeasures and to be installed at vertical joints of caissons are made of flexible polyvinyl chloride or rubber. In order to prevent landfill soil from being washed out through the gaps between sand invasion prevention plates and joints, sand invasion prevention plates shall be provided with backfill so as to isolate landfill soil from the plates. Also, because the spaces inside joints are subjected to wave pressure, sand invasion prevention plates are preferably determined so as to prevent the plates from damage due to waves during their service period. For the wave pressure inside joints, **Part II, Chapter 2, 6 Wave Force** can be used as a reference.

Tables 8.3.2 and **8.3.3** show the minimum standards which have been applied to sand invasion prevention plates so far. It is preferable to use the products in accordance with acting external force.

Table 8.3.2 Minimum Standards which have been Applied to Sand Invasion Prevention Plates (Case of Flexible Vinyl Chloride Plates with a Thickness of 5 mm)

Test item	Contents of tests		Standard values
	Method	Tensile direction	
Tensile strength	Compliance with JIS K 6723 Test sample No. 1 type dumbbell	Lateral	740 N/cm or greater
Tear strength	Compliance with JIS K 6252 Test sample uncut angle shape	Longitudinal	250 N or greater
Elongation	Compliance with JIS K 6723 Test sample No. 1 type dumbbell	Lateral	180% or greater
Seawater resistance Tensile strength residual ratio	Compliance with JIS K 6773	Lateral	90% or greater
Seawater resistance Elongation residual ratio	Compliance with JIS K 6773	Lateral	90% or greater
Specific gravity	Compliance with JIS K 7112	—	1.2 – 1.5

Test item	Contents of tests		Standard values
	Method	Tensile direction	
Stripping strength	Compliance with JIS K 6256 Width 25×250 mm Strip-shaped sample	Longitudinal	30 N/cm or greater

Table 8.3.3 Minimum Standards which have been Applied to Sand Invasion Prevention Plates (Case Rubber Plates)

Test item	Contents of tests		Standard value
	Method	Tensile direction	
Tensile strength	JIS K 6404-2	—	4,400 N/3 cm or greater

③ **Rubber mats**

The rubber mats used for increasing friction are twofold: one made of recycled rubber, and the other made of brand-new rubber. The rubber mats having quality shown in **Tables 8.3.4** and **8.3.5** have been used in many cases.

Table 8.3.4 Quality of Recycled Rubber

Test item			Performance	Test conditions/method	
Physical tests	Before aging	Tensile strength	4.9 MPa or greater	JIS K 6251	
		Tear strength	18 N/mm or greater	JIS K 6252	
		Hardness	55−70 graduations	JIS K 6253	
		Elongation	160% or greater	JIS K 6251	
	After aging	Tensile strength	3.9 MPa or greater	JIS K 6251	
		Tear strength	—		Aging tests are according to JIS K 6257
		Hardness	Within ± 8 of pre-aging value	JIS K 6253	Aging temperature 70°± 1°
		Elongation	140% or greater	JIS K 6251	Aging time $96\,{}^{0}_{-2}$ hours

Table 8.3.5 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	
		Tear strength	—		Aging tests are according to JIS K 6257
		Hardness	Within ± 8 of pre-aging value	JIS K 6253	Aging temperature 70°± 1°
		Elongation	200% or greater	JIS K 6251	Aging time $96\,{}^{0}_{-2}$ hours
	Compressive permanent strain		45% or less	JIS K 6262	Aging temperature 70°± 1° Aging time $24\,{}^{0}_{-2}$ hours

8.4 Painting Materials

(1) Painting materials shall be selected taking into consideration the following items.

① The purposes of painting
② The properties and characteristics of painted surfaces
③ The performance and composition of painting materials
④ Economic efficiency
⑤ Maintenance

(2) Several types of painting materials are selectively used for the purposes of preventing rust and corrosion, protecting surfaces, resisting heat, enhancing aesthetic quality, and displaying information. Depending on the materials of the surfaces to be painted, the types of painting materials are classified into those for concrete, metal, and wood. It is necessary to select the painting materials most suitable for the purpose of the painting and the materials of the surfaces to be painted.

(3) Generally, two to three types of painting materials having different properties or performance are overlaid one above the other so as to allow them to collectively exert required performance. These roles of painting materials are classified into primer coat, base coat, middle coat, and top coat. It is necessary to select appropriate combinations of painting materials depending on the roles and purposes.

(4) When using painting materials for the purpose of preventing corrosion on port steel structures, reference can be made to **2.4.3 Coating Methods in this Chapter** and the **Manual for Corrosion Protection and Repair of Port Steel Structures**.[23] When using painting materials for the purpose of preventing corrosion on port concrete structures, reference can be made to the **Guidelines for the Design and Construction of Surface Protection Methods (Draft)**[24] and the **Manual for the Repair of Port Concrete Structuers**.[25]

(5) When selecting painting materials for the bridges categorized as port transportation facilities, reference can be made to the **Handbook for Steel Road Bridge Painting**[26] and the **Heavy-duty Coating**[27] for steel bridges and the **Guidelines for Chloride-induced Corrosion Countermeasures (Draft)**[28] for concrete bridges.

(6) When using painting materials for the purposes other than (4) and (5) above, the literatures introduced in these sections can be used as references.

(7) There are many variations in the colors of painting materials and the color is generally determined in consideration of intended use, aesthetic performance and economic efficiency.

(8) For traffic painting, there are following types of painting materials.

① **Normal temperature drying type painting materials**

They are the materials which are made of alkyd, vinyl, or acrylic resin and used for simple repairs because of low durability.

② **High-temperature drying type painting materials**

They are the materials which are made of special synthetic resin, heated before being sprayed over surfaces to be painted, excellent in workability due to quick-drying performance, high in abrasion resistance, and particularly suitable for cold regions.

③ **Deposit type painting materials**

They are the materials which are applied to surfaces to be painted in a hot and melted state and subjected to cooling and solidification after application, excellent in quick-drying performance, high in durability because of the availability of thick paint layers, and particularly suitable for urban districts.

④ **Adhesive sheets**

They are the painting sheets which are manufactured with vinyl resin as vehicle and pasted on surfaces to be painted.

8.5 Grout Materials

8.5.1 General

(1) Grouting methods shall be appropriately selected in accordance with construction conditions and implemented with due consideration to surrounding environments.

(2) The grouting methods are implemented for preventing groundwater flows, enhancing ground strength, and reinforcing the members such as caisson infill by filling gaps in bedrock, ground, in and around facilities, and coarse aggregate. Several types of grouting materials are available depending on the characteristics of grouting objects.

Grout materials are classified into following types in terms of raw materials as shown in **Fig. 8.5.1**.[29)]

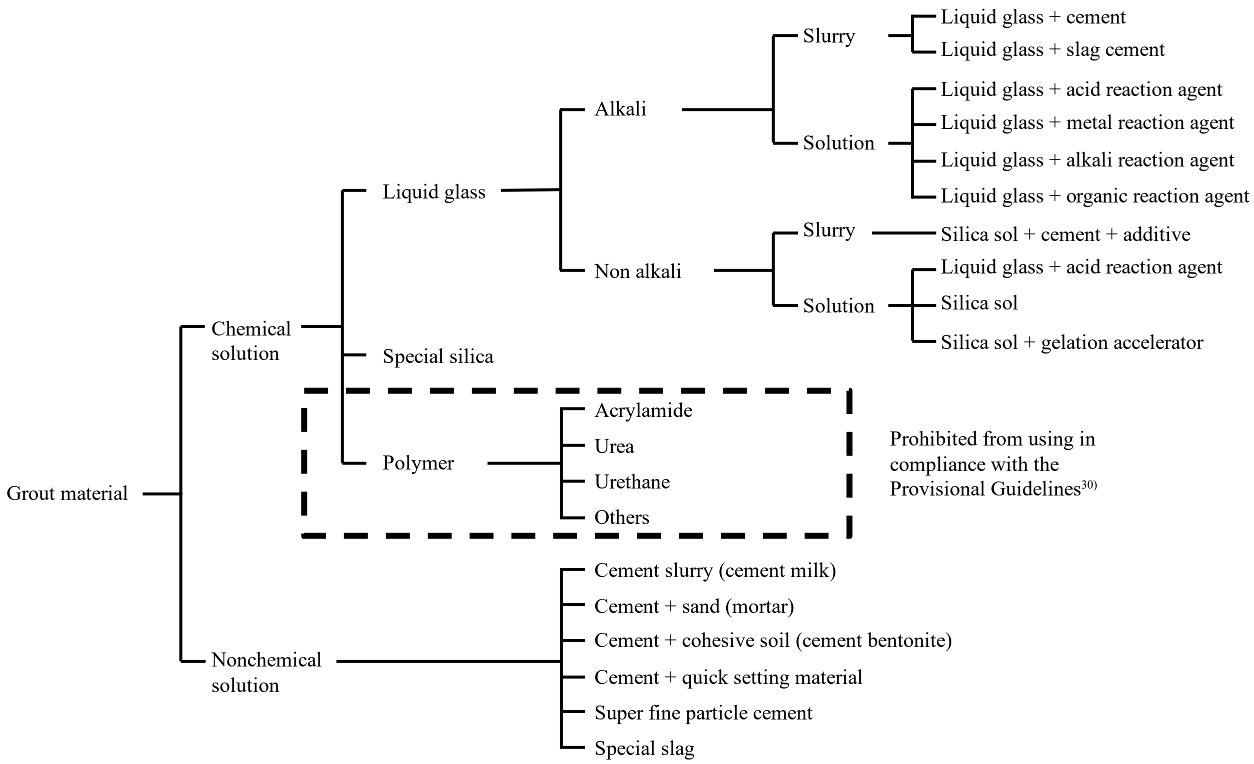

Fig. 8.5.1 Modification of Classification of Grout Materials [29)]

(3) Because some types of grout materials are slightly toxic, it is necessary to pay particular attention to the influence of grout materials on the contamination of groundwater quality and associated human health when implementing chemical grouting methods with reference to the **Provisional Guidelines for the Implementation of Construction Works through Grouting Methods**.[30)]

The essentials of the provisional guidelines are as follows.

① It is necessary to conduct preliminary soil, underground buried object and groundwater level surveys.

② The chemical solution shall be limited to liquid glass types (with silicate sodium as base resin) which do not contain deleterious substances or fluorine compounds except in the case of urgently cope with emergency during construction (the use of nonchemical solution is out of the scope of application of the provisional guidelines).

③ It is necessary to conduct on-site grouting tests.

④ It is necessary to prevent industrial accidents by paying particular attention to the safe execution of grouting operation and storage of chemicals and to take proper measures on the occurrence of abnormal situations

⑤ The drainage and sludge generated in drainage treatment facilities shall be treated in compliance with the standards and provisions in related laws and regulations. Also, surplus soil and remaining materials shall be disposed of in a manner that prevents the contamination of water quality and human health problems.

⑥ The quality of groundwater and public water shall be monitored so as to ensure that such quality is kept within the standards.

8.5.2 Properties of Grout Materials

(1) Grout materials to be selected shall satisfy predetermined performance with respect to target ground.

(2) The basic properties required for grout materials include permeability, filling and solidification performance, the strength of solidified materials, and water-imperviousness. Among them, the permeability largely affects the applicability of grout materials to grouting objects.

Grout materials can be classified into slurry types containing suspended components such as cement and slag and solution types containing no suspended components.[29), 31) and 32)] In terms of gel time, grout materials are also classified into flash setting types and slow setting types. **Table 8.5.1** roughly summarizes the compatibility of the different types of chemicals with different types of object soil.[31)]

When comparing slurry type grout materials to solution ones, stabilized bodies by the slurry types grouting materials tend to have larger strength than those by the solution ones in the case of permeation grouting into the gaps among soil particles. In contrast, solution type grout materials have wider permeation areas of uniform stabilized bodies than slurry ones.[31)] In recent years, however, there has been significant improvement in the permeability of slurry type grout materials through the advancement of atomization and the use of surface acting agents.[33) and 34)]

Table 8.5.1 Soil and Grout Chemicals [modification of 31)]

Soil type	Slurry type		Solution type	
Gel time	Fast setting	Slow setting	Fast setting	Slow setting
Cohesive silt	○ (Cleave injection)	×	△ (Cleave injection)	×
Fine sand	×	△	△	○
Coase sand	△	△	△	○
Gravel	△	○	○	△

○: Compatible, △: Compatible depending on conditions, ×: Not compatible

8.6 Waste as Landfill Materials

The disposal of waste as landfill materials is subjected to the provisions in the laws relevant to waste, i.e., the **Wastes Disposal and Public Cleansing Act** (Act No. 137 of 1970, hereinafter referred to as "**Waste Disposal Act**") and the **Act on Prevention of Marine Pollution and Maritime Disaster** (Act No. 136 of 1970, hereinafter referred to as the "**Marine Pollution Act**").

As summarized in **Table 8.6.1**, the applicability of the **Waste Disposal Act** and the **Marine Pollution Act** to the disposal of waste as landfill materials varies depending on the locations of waste generation, location of waste utilization and disposal methods.

Table 8.6.1 Applicability of the Laws Relevant to the Disposal of Waste

Location of disposal		Onshore	Sea area disposal		Ocean dumping
Disposal method		Ship or other facility than marine one	Ship or other facility than marine one	Ship or marine facility	Ship or marine facility
Location of generation	Onshore	Waste Disposal Act	Waste Disposal Act	Marine Pollution Act	Marine Pollution Act
	Offshore	Waste Disposal Act	Waste Disposal Act	Marine Pollution Act	Marine Pollution Act

Note) Marine facility means a structure constructed in the sea.

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9 Friction Coefficients

(1) Static friction coefficients can be used as the friction coefficients of materials used to calculate friction resistance against the sliding of facilities. In such a case, it is preferable to appropriately set the friction coefficients of materials in consideration of the characteristics of object facilities and materials.

(2) The values listed in **Table 9.1.1** can generally be used as the characteristic values of static friction coefficients to be used in the performance verification of port facilities. It should be noted that the measurements of friction coefficients show large variations even when measurements are obtained through repeated tests under identical conditions. The values in **Table 9.1.1** have been conventionally used as empirically appropriate friction coefficients. For those cases which are not in the table, it is preferable to conduct tests to determine the values of friction coefficients.

(3) The values in **Table 9.1.1** can be used only for the verification of stability of facilities with respect to sliding and cannot be used as friction coefficients in the examination of the bearing capacity of piles based on the skin friction between the outer peripheries of piles and soil; the verification of the stability of sloping breakwaters; the calculation of friction resistance when launching caissons through slip ways; and the calculation of earth pressure based on the angles of wall friction. In contrast, although the values in **Table 9.1.1** are static friction coefficients with respect to static actions, they can be used as the friction coefficients with respect to dynamic actions such as earthquake ground motions because no appropriate data on dynamic friction coefficient has been available.

Table 9.1.1 Characteristic Values of Static Friction Coefficients

Concrete and concrete	0.5
Concrete and bedrock	0.5
Underwater concrete and bedrock	0.7 to 0.8 note 1)
Concrete and rubbles	0.6
Rubbles and rubbles	0.8
Timber and timber	0.2 (wet) to 0.5 (dry)
Friction enhancement mat and rubbles	0.75

Note 1) In the case of friction between underwater concrete and bedrock, the friction coefficient can be 0.8 under standard conditions provided however that the value needs to be reduced to 0.7 depending on the severity of the brittleness or cracks of base rock or the movement of sand covering base rock.

Note 2) The friction coefficients in the performance verification of cellular blocks, reference can be made to **Part III, Chapter 5, 2.2 Gravity Type Wharves**.

(4) For sliding and friction resistance, the **References 1)** to **6)** can be used as references. Additionally, for the friction coefficients between the bottom faces of earth retaining walls (on land) and foundation ground, reference can be made to the **Guidelines for Road Earthwork, and Earth Retaining Walls**.[7)]

(5) Friction coefficients of friction enhancement mats

Generally, the materials for friction enhancement mats shall be selected with careful consideration to the test results of friction coefficients in addition to the durability of the materials to be used, the importance of facilities, hydrographic conditions and economic efficiency. As shown in **Table 9.1.1**, the friction coefficient of 0.75 can be used when bituminous or rubber materials are used for friction enhancement mats. In the case of cold regions, it is preferable to set friction coefficient through separate examinations. The above provisions shall not be applied to the cases of the friction coefficients to be individually verified for example through the tests on the basis of the design conditions and structural conditions of individual facilities.[8) and 9)] For reference, the maximum friction coefficient between friction enhancement mats and rubbles is 0.8 in the past design. When using friction enhancement mats for mooring facilities, reference can be made to **Part III, Chapter 5, Mooring Facilities, 2.2.3 Performance Verification (3) ① (a)**.

(6) Friction coefficients of cast-in-place concrete

Among the values of static friction coefficients in **Table 9.1.1**, those related to concrete are considered to vary depending on whether the concrete is cast-in-place or precast. It is necessary to appropriately set the friction coefficients of cast-in-place concrete taking into consideration material properties and natural conditions.

(7) Sliding resistance between bedrock and prepacked concrete

There are cases of constructing mooring facilities or protective facilities for harbors on the seafloor through the prepacked concreted method. The resistance of these massive facilities against sliding is established as a result of complex mechanisms involving adhesion and friction resistance between bedrock and prepacked concrete and shear resistance of the bedrock and prepacked concrete due to the surface irregularity of the bedrock. In contrast, the sliding resistance of facilities is affected by the properties of base rock and the bottom sediment covering it at construction sites, the quality of injected mortar, the level of elaborate workmanship and the hydrographic conditions during construction. For convenience, after careful consideration of various aspects including the performance records of existing facilities,[10)] the friction value for underwater concrete and bedrock in **Table 9.1.1** can be applied as the friction coefficient between bedrock and prepacked concrete. This provision can also be applied to other types of underwater concrete than prepacked concrete.

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