PERFORMANCE BASED DESIGN FOR PORT STRUCTURES

by

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ABSTRACT

This paper presents a performance based design approach for port structures. The performance based design is an emerging art, which was born from the lessons learned from the recent earthquakes in 1990's. This is to overcome the limitation in the conventional seismic design, which was based on the force balance against a design seismic force. The performance based design is a user friendly approach to take into account the requirements of the seismic performance of a structure against the probabilistic occurrence of earthquake motions. This paper is an initial proposal of the seismic performance based design for port structures.

Key Words : Performance, Design, Earthquake, Quaywall

1. INTRODUCTION

The performance based design is an emerging art, which was born from the lessons learned from the recent earthquakes in 1990's. This is to overcome the limitation in the conventional seismic design. In the conventional seismic design, the design is accomplished based on the force balance against a design seismic force but the design does not provide the information on the performance of a structure when exceeding the limit of the force balance. In the performance based design, design earthquake motions are defined in two levels and the required performance of a structure specified in terms of displacements and stress levels is defined for varying levels of the earthquake motions. The performance based design, thus, should be the key to accomplishing higher reliability of a structure against earthquake without appreciable increase in construction cost.

2. Definition of Performance Grades

In the seismic design considering structural performance, it is necessary to clearly define the required performance of a structure against design earthquake motions in terms of allowable displacements and stress levels. The defined performance is used as a criteria to evaluate an initial structural design. If the initial design does not satisfy the required performance, then the design should be modified until it meets the requirements. The required performance thus defined is called seismic performance criteria.

The seismic design considering structural performance, called performance based seismic design, is accomplished according to the flowchart shown in Fig. 1. Relevant issues in this flowchart will be discussed below.

(1) Design Earthquake Motions

The levels of design earthquake motions for port structures are specified, in the two level approach, as follows.

Level 1 : Earthquake motion having a return period of 75 years

Level 2 : Earthquake motion having a return period of 475 years.
Level 2 earth quake motion includes a near field motion of a very rare event from an active seismic fault, if the fault is located nearby.

The earthquake motions having a return period of 75 and 475 years have a probability of 50 and 10% occurrence, respectively.

(2) Damage Criteria

The seismic performance criteria are defined by specifying acceptable extent of damage to a structure against the two levels of design earthquake motions. The performance criteria are specified as a function of earthquake motion levels as shown in Fig. 2.

The extent of damage, defining the longitudinal coordinate in Fig. 2, is determined by both serviceability and structural damage. The serviceability is defined in a broad sense. In addition to the original definition for sea transport, the definition of serviceability includes such effects of damage as threats to human lives and properties, loss of function as a emergency base for transportation, threats from hazardous materials, depend-

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ing on the functions of port structures. The structural damage depends on a structural type; i.e. the extent of structural damage to a gravity quaywall is mainly specified by displacements and tilting while that to a sheet pile quaywall is mainly specified by stress states in the structure. The acceptable extent of damage thus depends on both function and type of a structure.

The extent of damage shown in Fig.2 is specified in the most general qualitative terms into three degrees. More specific descriptions for the extent of damage is defined in Table 1 with respect to the serviceability and the structural damage. The most specific and quantitative damage criteria will be described in **3** and **4** for each type of structures.

(3) Performance Grades

The damage criteria defined by three degrees described above permits to define the performance criteria as shown in Fig. 2. As shown in this figure, the performance grades are specified in four grades, XS, XA, XB and XC, as follows.

Grade XS : The extent of damage remains degree I for Level 2 motion.
Grade XA : The extent of damage remains degree I for Level 1 motion and degree II for Level 2 motion.
Grade XB : The extent of damage remains degree I for Level 1 motion and degree III for Level 2 motion.
Grade XC : The extent of damage remains degree II for Level 1 motion. Collapse of structure, if occurs at Level 2 motion, does not have threats to the surrounding.

(4) Importance of Structure and Performance Grades

The performance grades defined above closely relate to the importance of structures. A structure with higher importance requires a higher performance grade. The importance of port structures is generally measured by the seismic effects on serviceability (in a broad sense) and structural damage. For example, the importance of port structures specified in the current Japanese design code[1] are categorized into four classes as shown in Table 2. These classes of importance approximately corresponds to the required performance grades as shown in Table 3.

3. Damage Criteria for Gravity Quaywall

In the performance based design, the acceptable extent of damage, i.e. the damage criteria, should be clearly specified based on the function and seismic response of a structure. The damage criteria should be generally established by a group of design engineers with assistance and advice from the user and owner of the structure/facility.

The guidelines for establishing the damage criteria for typical port structures will be shown in **3** and **4**. These guidelines are for the most general case, considering a general purpose quay wall where the seismic damage poses no threats to human lives, no hazardous material is handled, without a movable crane, and the sea space in front of the quay wall is unlimited. Additional guidelines are offered in **5** for the quay walls having container and other movable cranes.

(1) Seismic response of gravity quaywall

A gravity quaywall is made of a caisson or other gravity wall put on seabed, and maintains its stability by the friction at the bottom of the wall against the earth pressures from the backfill soil behind the wall. Typical failure modes during earthquakes are seaward displacements and tilting as shown in Fig. 3(a) for a firm foundation. For a loosely deposited sandy foundation, the failure modes involve overall deformation of the foundation beneath the wall, resulting in large seaward displacement, tilting and settlements. A wall with a smaller width to height ratio exhibits tilting mode rather than horizontal displacements. A wall designed with a seismic coefficient of 0.15 in the pseudo static approach is on the border line for exhibiting tilting mode and horizontal displacements.

Large horizontal displacements and settlements of a gravity quaywall do not significantly reduce the residual state of stability, and are considered generally acceptable for structural damage. Tilting of the wall, however, significantly reduce the residual stability, thus providing restrictive conditions for structural damage criteria. The past case histories[2] show overturning/collapse of cellular block and cantilever types. These types of gravity walls need a careful consideration in specifying damage criteria regarding overturning/collapse.

(2) Items specifying damage criteria for gravity quaywall

Seismic performance of a gravity quaywall is specified based on the serviceability in safe mooring, safe operation of wheeled vehicles and cargo handling, flooding, and the structural damage exhibiting displacements and tilting (including relative displacements between the blocks of a cellular block type quaywall.).

Items specifying damage criteria are the deformation of wall including displacements, settlements, tilting, and differential displacements (winding of a face line), and the deformation at apron including settlement, differential settlement at and behind apron, and tilting as shown in Fig. 4.

Damage criteria should be established by choosing and specifying appropriate items from the items mentioned above considering performance requirements mentioned above. More specifics are given in the next subsection.

(3) Damage criteria for gravity quaywall

The damage criteria are established, as mentioned earlier, considering both serviceability and structural damage. The criteria for a gravity quaywall regarding structural damage should be established by referring to Table 4 with additions and modification for the specific conditions of a structure designed. The criteria shown in Table 4 show minimum requirements. Thus, in evaluating seismic performance by referring to the damage criteria, if different damage degree results from different items evaluated, the highest damage degree should be the final results of the evaluation.

The criteria for a gravity quaywall regarding serviceability should be established by referring to Table 5 with additions and modification for the specific conditions of a structure designed. In particular, Table 5 is a reference for upper limit of damage degree I.

As mentioned earlier, the overall damage criteria should be established based on both serviceability and structural damage criteria established above.

4. Damage Criteria for Trestle Pier

(1) Seismic response of trestle pier

A trestle pier is composed of a pier and a retaining wall. The pier is a system composed of a deck supported by pile, embankment below the deck and a bridge between the pier and the retaining wall. Typical failure modes during earthquakes depends on the relative magnitude of inertia force and ground displacements as shown in Fig. 5.

Structural damage to a trestle pier is governed by stress states rather than displacements. It is important to determine the sequence and degrees of ultimate states to occur in the composite system of a trestle pier. The 1995 Kobe earthquake caused various modes of damage, including displacements and tilting toward the sea or the land and collapse at the most serious case[3].

(2) Items specifying damage criteria for trestle pier

Seismic performance of a trestle pier is specified based on those of a retaining wall and a deck supported by piles. The seismic performance of the retaining wall is specified referring to those for a gravity or sheet pile wall. The effects of ground displacements, including the movement of the retaining wall and the embankment below the deck, should be carefully evaluated for the performance of the deck supported by piles. The seismic performance of the deck supported by piles is specified based on the serviceability and structural damage similar to those for a sheet pile quaywall.

Items specifying damage criteria are as follows (refer to Fig. 6).

■ Displacements
- deck and piles : settlement, tilting, differential displacements
- apron : differential settlement between deck and retaining wall, tilting, fall/fracture of bridge

■ Stresses
- piles (pile top and below mudline)
- deck (deck body, pile cap)
- bridge

Damage criteria should be established by choosing and specifying appropriate items from the items mentioned above considering performance requirements mentioned above.

The sequence to reach the ultimate states with increasing level of seismic load should be appropriately specified for a trestle pier as follows (refer to Fig. 7).

1) Pile cap
2) Pile top
3) Deck or Pile below mudline (within allowable ductility factor)

Structural details for a bridge such as fail-safe device to prevent fall down or easily repairable structure should be also important, and, if applicable, a structure to absorb the displacements from the retaining wall should be introduced. This could lead to a further development of energy absorption device for a trestle pier.

(3) Damage criteria for sheet pile quaywall

The criteria for the retaining wall of a trestle pier should be established by referring to those for a gravity or sheet pile quaywall.
The criteria for a trestle pier regarding structural damage should be established by referring to Tables 4 and 6. The most restrictive conditions among displacements and stresses should be the damage criteria. The displacements in Table 4 is applied for residual displacements while the stresses in Table 6 is for peak stresses during an earthquake.

Structural damage to the embedded portion of a pile is generally difficult to restore and has a potential to trigger collapse of a trestle pier, and thus needs more restrictive ductility factor used for design. No case histories are reported on brittle fracture of steel piles during earthquakes. The case histories on brittle fracture of thick steel columns during the 1995 Kobe earthquake reminded, however, that it is still necessary to study this aspect of the steel piles.

The criteria for a trestle pier regarding serviceability should be similarly established as for the gravity quaywall by referring to Table 5.

As mentioned earlier, the overall damage criteria should be established based on both serviceability and structural damage criteria established above.

5. Damage Criteria for Quaywall having Wheeled Cranes

In order to be serviceable after an earthquake, the quaywalls equipped with such facilities as wheeled cranes or ferry facilities need to maintain the serviceability of these facilities in addition to the basic serviceability required for the general purpose quaywalls. Safety for human lives should also be secured. Consequently, the damage criteria for the quaywalls equipped with wheeled cranes, etc. should be specified based on additional consideration to those shown in **3.** and **4.** For example, the serviceability of the quaywalls having a conveyor belt is strongly affected by differential displacements and settlements. The effects of earthquakes on ferry wharves needs additional consideration on displacements of quaywalls, fail safe devices for passenger bridges, etc. to secure the safety of passengers and the passenger transport operation.

In this section, the additional criteria to those discussed in **3.** And **4.** are discussed, which are needed for quaywalls having wheeled cranes such as container cranes.

(1) Seismic response of wheeled cranes

A wheeled crane consists of an upper structure, handling cargoes, and a foundation structure, supporting and transporting the upper structure as shown in Fig. 8. It is generally made of a steel framework. The foundation structure is either a rigid frame type (as shown in Fig. 8) or a hinged leg type, which have one hinge at the level A in Fig. 8). The foundation structure is supported by rails through the wheels. The rails are often directly supported by a portion of a retaining wall or the deck of a trestle pier for a gravity quaywall or a trestle pier. When the width of the gravity wall is small, or the quaywall is a sheet pile or cellular type, a separate set of foundations, often a pile foundation, is provided to support the rails.

A wheeled crane at rest is fixed to rails or a quaywall with clamps or anchors, whose strength provides the upper limit for the resistance of the crane against external forces. A wheeled crane in operation, however, is not supported with clamps or anchors, so that the resistance of the crane against external forces is only due to those from the friction and the flanges of the wheels.

Typical failure modes during earthquakes are derailment, detachment or pull-out of wheels, rupture of clamps and anchors, buckling, and overturning[4]. As shown in Fig. 9(a), widening of a span between the legs due to the deformation of the quaywall results in derailment or buckling of legs. Conversely, as shown in Fig. 9(b), narrowing of a leg span can also occur due to rocking response of a crane. This is due to alternating action of horizontal component of resisting forces from the quaywall during rocking type response involving uplifting of one side of legs. Derailment and detachment of the wheel can also occur due to the rocking. As shown in Fig. 9(c), when a dent or differential settlement occur on a quaywall below the crane, the derailed leg can put into it, resulting in tilting and overturning of the crane. If the crane has one hinge type legs, the derailment can result in tilting and overturning of the crane as shown in Fig. 9(d).

Though the clamp or anchor provides more resistance for the motion against the external force, the internal stresses induced in the framework of a crane becomes larger with clamp or anchor than allowing rocking response.

The quaywall having wheeled cranes needs a special consideration on the foundation of the crane such as for providing a monolithic upper structure to support the rails.

(2) Items specifying damage criteria for the quaywall having wheeled cranes

Seismic performance of the quaywall having wheeled cranes is specified based on the serviceability of and the structural damage to the crane. The serviceability of the crane is specified regarding the function of upper structure (i.e. cargo handling) and that of foundation structure (i.e. transportation and support for the upper structure). The structural damage regarding the crane is specified not only by displacements, derailment, tilting, and stress of the crane but also the displacements and stresses of the rails and the foundation. With regard to the serviceability of the crane, maintaining the power supply should also be considered.

Items specifying damage criteria are as follows (refer to Fig. 10). For rails and foundation, the items include rail span, rail winding (including discontinuity), differential settlement (differential levels between the rails, differential levels, inclination and vertical discontinuity along a rail), displacements and stresses of rail foundation. For a wheeled crane, the items include wheels (derailment), vehicles (detachment), clamps and anchors (rupture), and displacements of the crane (derailment, tilting, and overturning) and stresses in the framework (stress levels, location of buckling, possibility of collapse).
Damage criteria should be established by choosing and specifying appropriate items from the items mentioned above considering performance requirements mentioned above. More specifics are given in the next subsection.

(3) Damage criteria for the quaywall having wheeled cranes

The damage criteria are established, as mentioned earlier, considering both serviceability and structural damage to not only the quaywall but also the crane and its foundation. The damage criteria for the quaywall required with respect to the crane are discussed below. The criteria for the quaywall with respect to the crane foundation should be separately established by referring to the damage criteria for both the crane and the quaywall.

a) Damage criteria regarding structural damage
The criteria for a wheeled crane regarding structural damage should be established by referring to Table 7. The most restrictive conditions among displacements and stresses should be the damage criteria. The displacements in Table 7 is applied for residual value while the stresses is defined for peak stresses during an earthquake.

The damage criteria for the quaywall having wheeled cranes should be established by referring to the following discussions.

The damage degree I of the quaywall should be the displacements less than that to keep the foundation structure of the crane within a elastic limit. For example, this limit corresponds to the widening of the leg span of one meter for a rigid frame crane having a rail span of 30 m. There is no limit for the damage degree I for a one hinged leg type.

The damage degree II of the quaywall should be the level difference between the rails within overturning limit for the crane as well as the differential settlements and tilting of the apron within the same limit. In addition, a measure to increase the surface friction of the apron can increase the overturning limit of a derailed one hinged leg crane or a crane having a plastic hinge at a leg. The required friction coefficient is given by

$$\mu \geqq \delta h / H \qquad (1)$$

where μ : coefficient of friction
δh : expansion of leg span (m)
H : height of the hinge from the apron (m) (refer to Fig. 11)

b) Damage criteria regarding serviceability
The damage criteria for serviceability of a wheeled crane should be specified by referring to Table 8.

The upper limit for assuring the original serviceability of a wheeled crane is given by Table 9, which is used as guidelines for daily maintenance[5]. This limit can be used as the criteria for a very important quaywall or a quaywall having a monolithic upper structure to support the crane rails. In this case, this limit can be introduced as the damage degree 0. The performance grades should be newly classified in accordance with this new damage degree.

As mentioned earlier, the overall damage criteria should be established based on both serviceability and structural damage criteria established above.

6. Evaluation of Seismic Performance

As mentioned earlier, the seismic design considering structural performance is acoomplished following the flowchart shown in Fig. 1. Thus, after establishing the performance criteria referring to the previous sections, the seismic performance of a designed cross section should be evaluated and compared with the performance criteria.

(1) Outline

Seismic performance is evaluated through seismic analyses and/or model tests of a designed structure for varying levels of earthquake motions. The analyses and/or tests results in an extent of damage defined as a function of an earthquake motion level. This curve will be called a seismic performance curve. Evaluation of seismic performance is accomplished by determining whether the seismic performance curve is included in the area of the performance grade required in Fig. 2.

For example, if a designed structure has the seismic performance curve "a" in Fig. 12, the curve is included in the area of performance grade XA through Levels 1 and 2 earthquake motions. Thus, this structural design assures the performance grade XA. If a designed structure has the seismic performance curve "b" in Fig. 12, however, the curve includes the portion to go through the area of performance grade XB. Thus this structural design assures only the performance grade XB.

(2) Initial design of a structure

The initial design of a structure to be evaluated for its seismic performance can be accomplished by any means, including the conventional pseudo static approach and other innovative design approaches. An efficient procedure to arrive at the final design to satisfy the required performance criteria need the initial design which closely approximates the final design. The candidate for this may be given by the conventional pseudo static approach with appropriate measures against soil liquefaction.

In the conventional pseudo static design, the importance factor of a structure is used to scale the design seismic force. In the performance based design, the importance of a structure is not reflected in the levels of design earthquake motions but is used in terms of a required performance grade of the structure. A fundamental difference seems to exist between the conventional and performance based approaches. The apparent difference in these approaches is resolved by referring to Fig. 13. In this figure, the levels of earthquake motions which corresponds to the same extent of damage correspond to the required performance grades, suggesting the two approaches are basically consistent with each other.

7. Introducing Performance Based Design

The performance based approach discussed in the preceding sections specifies a comprehensive seismic resistance against earthquakes. This approach will be very useful for establishing enough seismic resistance with a minimum cost. This approach, however, is an emerging art based on the recent earthquakes in 1990's. It is not practical to introduce this approach to the seismic design of all types of port structures. This approach should be introduced step by step by beginning from the structures of the highest importance such as those with the special class in Table 2 This approach is particularly useful for designing the structures with the following conditions.

- When a structure is located at the near field of an active seismic fault
- When a standard remediation measures against liquefaction is difficult to apply.
- When a structure is too complex to be designed by the conventional design approach.
- When a structure is a new (i.e. unconventional) type.

If the performance based approach can not be applied to, it is yet desirable to evaluate the seismic performance in an approximate way based on the past case histories and the existing results of the seismic response analysis. The following remarks can be useful.

- Structures with the importance factor higher than the Class B

By referring to the past case histories, it is desirable to avoid the types of structures which tended to collapse.

- Structures with the importance factor of the Class C

  Effects on the surrounding of the structure should be evaluated in the event of the collapse of the structure.

In evaluating the seismic performance curve of a structure, appropriate methods or methodologies whose applicability were confirmed with respect to the past case histories and/or model test results. These methods and methodologies will be described in the next chapter. They include simplified and sophisticated methods. The structures with higher importance should be evaluated with sophisticated methods. For example, the structures of the special class should be evaluated by effective stress analyses and/or model tests, and those of the class A can be evaluated simplified methods as well as effective stress analyses and model tests. If the simplified methods are used, however, the applicability of the methods should be confirmed by using a representative design of structures based on the results of the effective stress analyses an model tests.

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Table 1 Damage Criteria for Performance Based Design

Extent of Damage	Serviceability (Amount of work needed for temporary restoration)	Structural Damage (Amount of work needed for full restoration)
Degree I	Full serviceability is maintained without temporary restoration, or with minor temporary restoration.	No damage, or minor damage
Degree II	Full or partial serviceability is recoverable with temporary restoration.	Intermediate damage
Degree III	Service is difficult to recover until full restoration.	Extensive damage without collapse

Table 2 Importance of structure defined in the current Japanese design code

Importance of Structure	Definition (Seismic effects on structures)
Special Class	Structures having more serious effects for ①~③than Class A structures.
Class A	① Structures resulting in extensive loss of human lives and properties upon seismic damage ② Key structures designed serviceable for recovery from earthquake disaster ③ Structures handling hazardous materials ④ Structures, if disrupted, devastating the economic and social activities of the earthquake damage area ⑤ Structures, if damaged, being difficult to restore.
Class B	Structures other than those of Special Class and Classes A & C.
Class C	Small easily restorable structures other than those of Special Class and Class A.

Table 3 Importance of structures and Performance Grades

Importance of Structure defined in the current Japanese design code	Performance Grade for the PIANC seismic design guidelines
Special Class	XA(or XS)
Class A	XB
Class B	XC

Table 4 Damage Criteria for Gravity Quaywall regarding Structural Damage

Extent of Damage	Deformation Rate (δ/H) δ: Horizontal displacement H: Height of Gravity Wall	Tilting towards the sea
Degree I	less than 3 %	less than 3 deg
Degree II	3 ~ 10 %	3 ~ 5 deg
Degree III	larger than 10 %	5 ~ 8 deg (or less than 90 % of critical angle)

Table 5 Damage Criteria for Upper Limit of Degree I regarding Quaywall Serviceability

Main Body of Quaywall	Settlement	20 ~ 30 cm
	Tilting towards the sea	2 ~ 3 deg
	Differential Horizontal Displacements	20 ~ 30 cm
Apron	Differential Settlement on Apron	3 ~ 10 cm
	Differential Settlement behind Apron	30 ~ 70 cm
	Tilting towards the sea	2 ~ 3 deg

Table 6 Damage Criteria for Pile Supported Pier regarding Structural Damage
(Criteria with respect to Stresses)
(When pile cap should be the first to yield.)

Extent of Damage	Stresses in pile supported pier			
	Deck		Piles	
	pile cap	main body	pile top	below mudline
Degree I	elastic	elastic	elastic	elastic
Degree II	Plastic (less than allowable ductility factor)	elastic	elastic	elastic
Degree III	Plastic (less than allowable ductility factor)	Plastic (less than allowable ductility factor)	plastic (less than allowable ductility factor)	plastic (less than allowable ductility factor)

Table 7 Damage Criteria for Movable Crane regarding Structural Damage

Extent of Damage	Displacement	Stresses in Crane	
	gross displacement of crane	upper structure	supporting structure
Degree I	without derailment	elastic	elastic
Degree II	with derailment	elastic	Plastic (less than allowable ductility factor) for main framework. Damage to toe (including pull-out of vehicle, fracture of anchor/brakes)
Degree III	without overturning	plastic (less than allowable ductility factor)	without collapse

Table 8 Damage criteria for crane regarding serviceability

Extent of Damage	Serviceability Level
Degree I	Full serviceability is maintained with or without minor temporary restoration.
Degree II	Limited serviceability is restored with temporary restoration. (Limited serviceability does not include the ability to move.)

Table 9 Damage criteria for upper limit of degree 0 (no restoration needed) for crane serviceability
(Allowable limit for ordinary maintenance)

Items to be evaluated	Allowable Limit
Rail Span L (L < 25 m) (25 m ≦L≦40m)	±10 mm ±15 mm
Level difference between sea and land side rails	L/1000
Curving in vertical direction Curving in horizontal direction	5 mm per 10 m 5 mm per 10 m
Inclination	1/500
Rail joint Differential Displacements (vertical and horizontal) Gap	 1mm 5mm

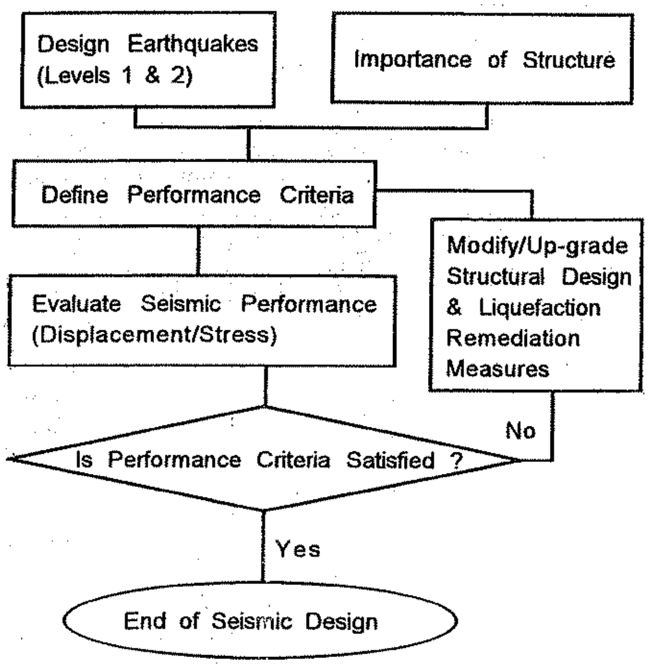


Fig. 1 Flowchart for Performance Based Seismic Design

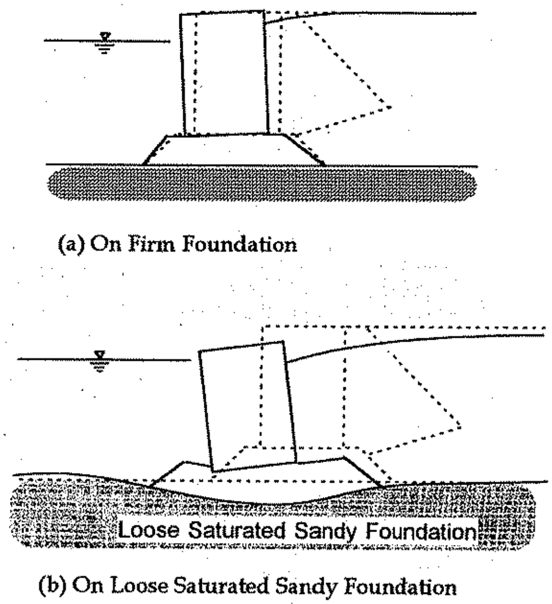


Fig. 3 Deformation/Failure Mode of Gravity Quaywall

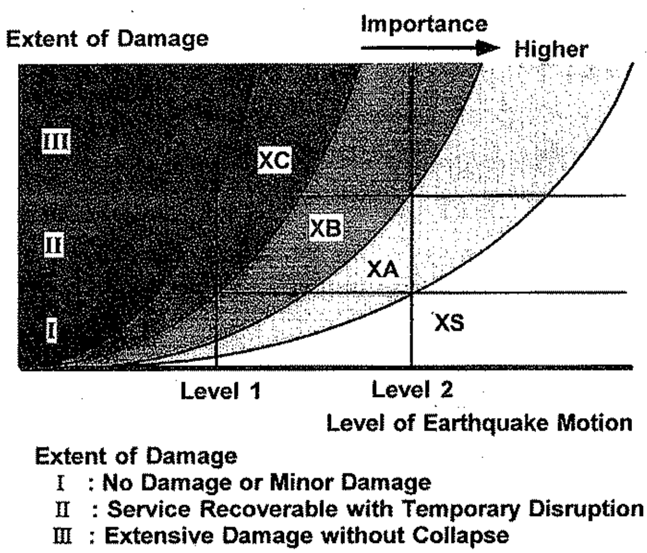


Fig. 2 Schematic Figure of Performance Grades XS through XC

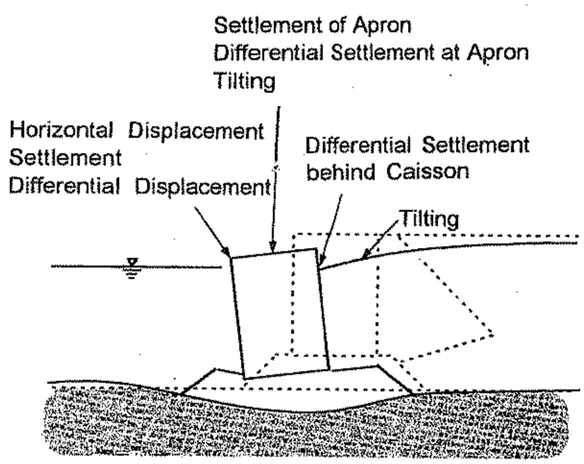
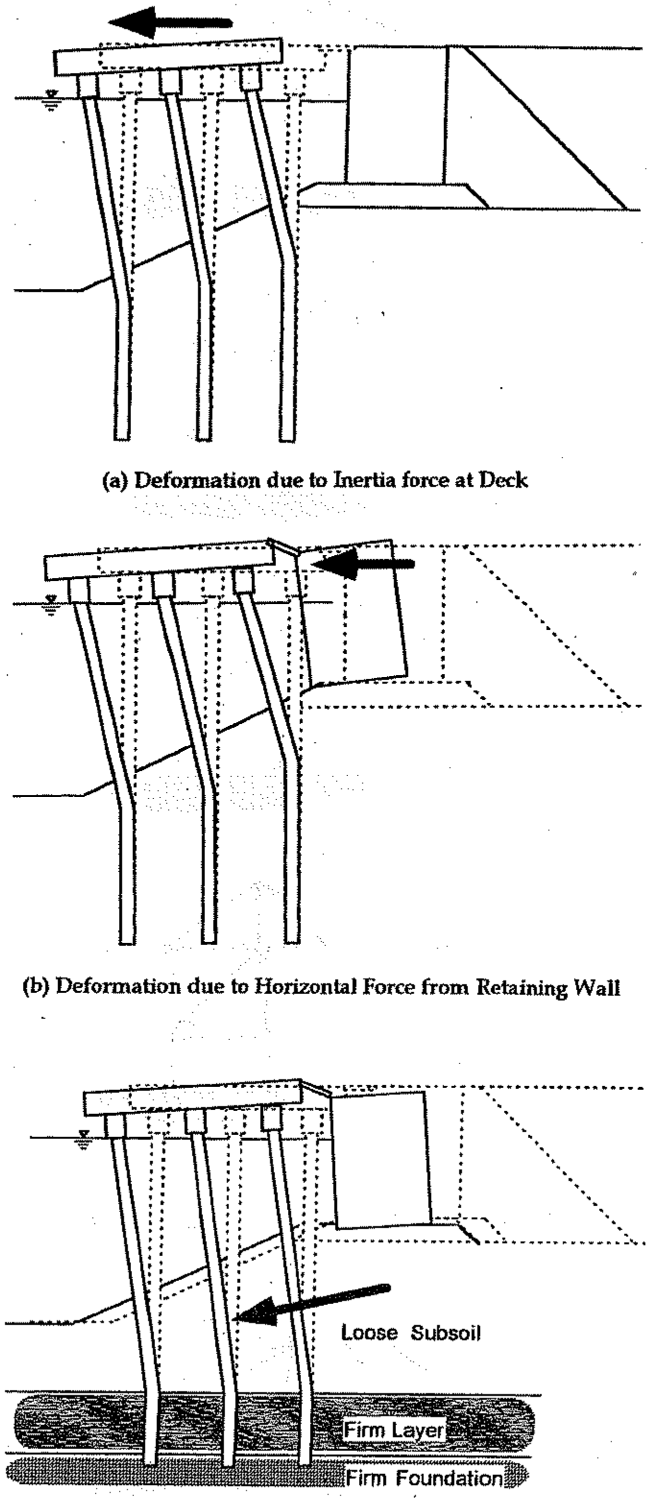


Fig. 4 Item to be evaluated for Gravity Quaywall

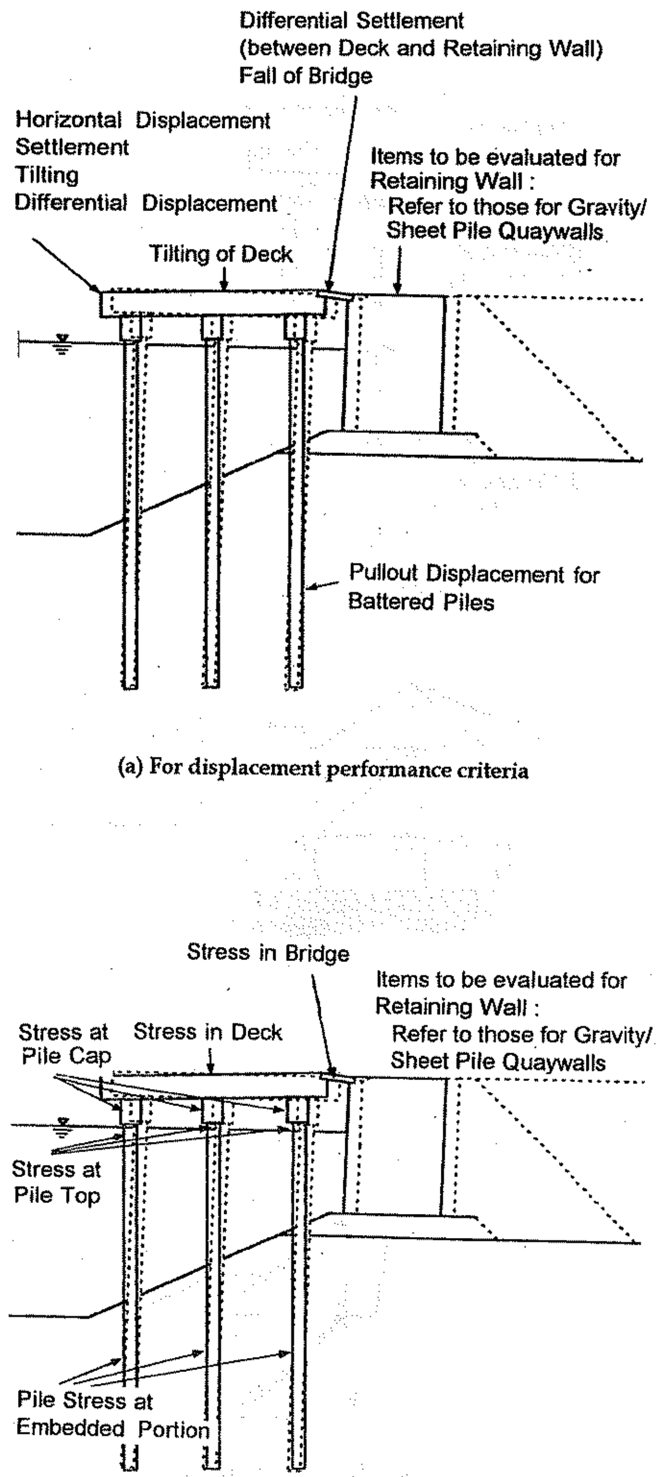


(a) Deformation due to Inertia force at Deck

(b) Deformation due to Horizontal Force from Retaining Wall

(c) Deformation due to displacement of loose subsoil

Fig. 5 Deformation/Failure Mode of Pile Supported Pier



(a) For displacement performance criteria

(b) For stress performance criteria

Fig. 6 Item to be evaluated for Pile Supported Pier

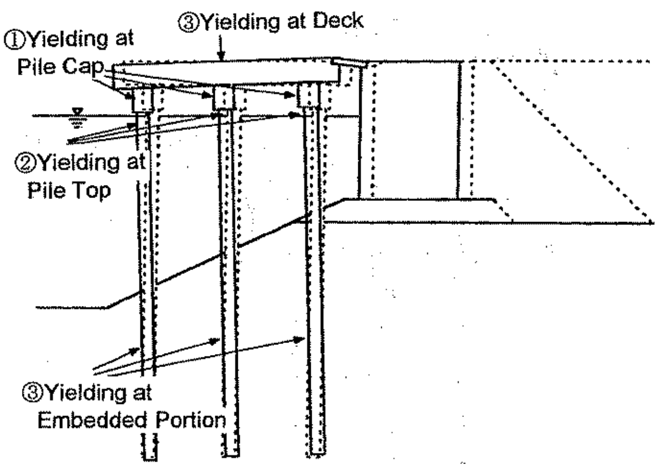


Fig. 7 Acceptable Order of Yielding for Pile Supported Pier

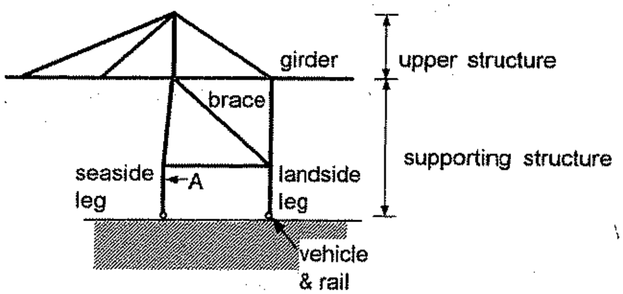
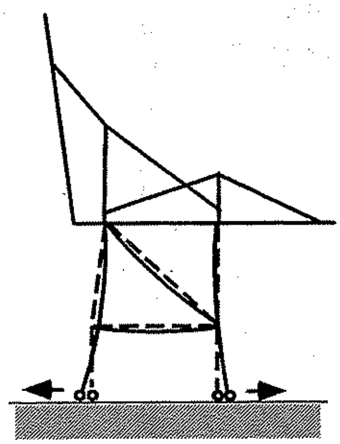
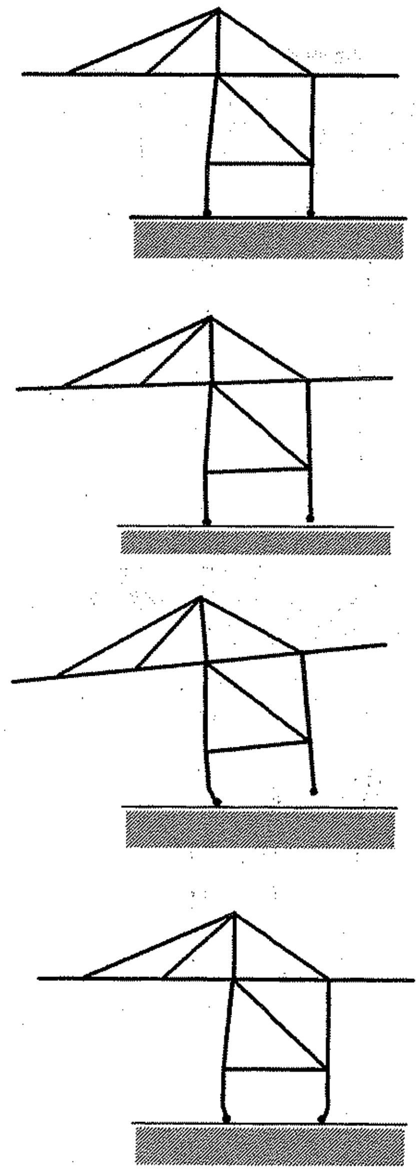


Fig. 8 Schematic figure of Movable Crane

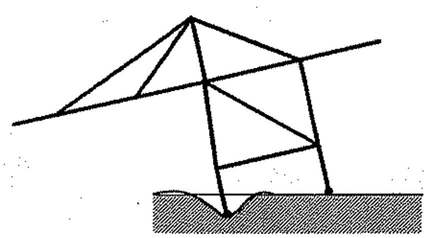


(a) Widening of Span between the Legs

Fig. 9 Deformation Mode of Movable Crane

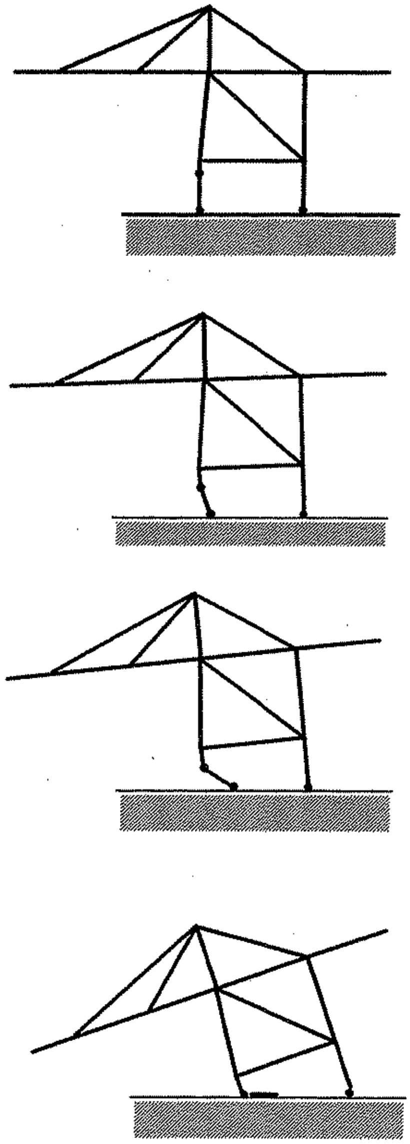


(b) Narrowing Span between the Legs due to Rocking Motion



(c) Tilting of Crane due to Differential Settlement of Foundation

Fig. 9 (Continued)



(d) Overturning of One Hinged Leg Crane due to Rocking/Sliding

Fig. 9 (Continued)

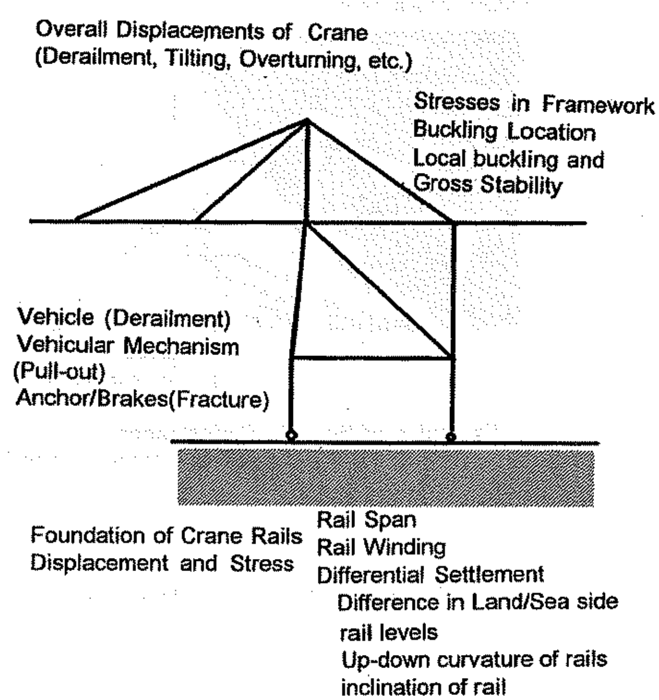


Fig. 10 Items to be evaluated for Crane

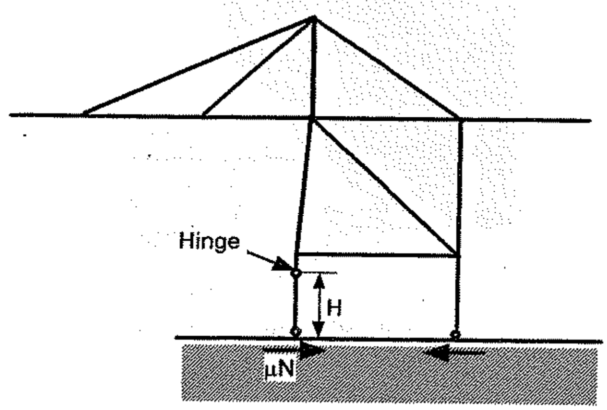


Fig. 11 Schematic figure for evaluating overturning of using Eq. (1)

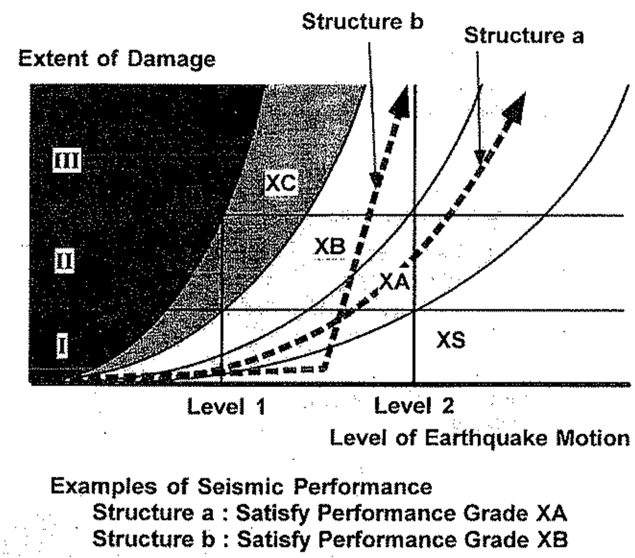


Fig. 12 Examples of Seismic Performance

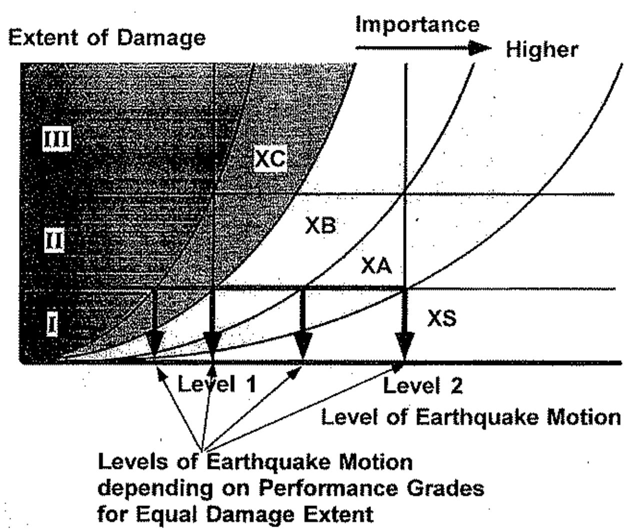


Fig. 13 Levels of Earthquake Motion depending on Performance Grades