STUDY ON HOW TO CONSIDER PILE FOUNDATION PERFORMANCE WHEN SETTING SEISMIC PERFORMANCE OF BUILDING

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Abstract

In this paper, I discuss how to consider the seismic performance of pile foundation when setting the seismic performance of building.

1. Look back on past earthquake damage of pile foundation in Japan and follow the revision process of related regulations

2. Outline the current state of seismic design of piles.against large Earthquake
   * Building Low not require. for pile foundation.
   * Government /Local Administrative Agency :require it with the target seismic performance of Important bldgs.: without repairing or not requiring major repair

3. From the lessen of recent Large earthquake. once the pile is damaged, there are many difficulties in restoring it, so we recognize that there are many cases where buildings are disassembled even if the superstructure is not damaged.

4. My personal opinion; Based on the perspective of property protection and function maintenance after large Eathq. , it is necessary to set the target seismic performance of the building comprehensively by combining seismic performance of the superstructure and the pile foundation, and it is important to explain this setting result to the owner and to get his agreement.

5. Newly developed pile system is presented. this pile is strengthened seismic performance and can be continuously used also after large earthquake.

The author expects specially a comment about the current situation of your country to this subject.
How is the Seismic design of pile foundation performed??

Supplement:
Structural design system in japan under the Building Standard Law :
Buildings of a certain size or larger more must be designed by the 1st class Kenchiku-shi (mean registered architect or building engineer).
in addition ,If the structural engineer has not passed the Structural Design Examination for the 1st class Structural design engineer(Kouzou-sekkei 1st class Kenchiku-shi),it is necessary to undergo design review by them.
So, We don't have Geotechnical Engineer license system to design building foundations.
How about in your country? SE or GE ,who design foundation?

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Introduction

In the Japanese seismic codes, the design for the superstructure is specified against two stages of seismic forces. Taking the design route such as the most general allowable stress design as an example, we design by allowable stress method in the 1st phase design for the medium earthquake, and in the 2nd phase design for the large earthquake, make the horizontal holding capacity of the building more than the necessary holding horizontal strength. On the other hand, the 1st phase seismic design of foundation introduced as a legal requirement in 2000

1. Past Seismic Damage of Pile in Japan and Changes in Related Regulations and Guideline

1.1 Legalization of Seismic Design (1st Phase) of Pile Foundation.

Table 1 Major earthquakes caused pile damage in JAPAN and its effect to design practice

Earthquake	*Major events*	*Affect to design practice*
1964 Nigata (M7.5)	Liquefaction damage enormous. Settlement/inclination; buildings,	1974 (AIJ std. revised), Simplified liquefaction assessment 1981(Bldg-Law) New seismic design code introduced
1968 tokachi-oki (M7.9)	Serious damage / collapse of RC buildings, Pile damages reported	1984(Bldg-Recm) Pile aseismic design (1^{st} phase) recommended
1978 miyagikenn -oki (M7.4)	RC Buildings Damage, PC Pile damages ,focused	1988(AIJ std.revised) liquefaction assessment (FL-method), Pile aseismic design (2^{nd})
1995Hyogokenn -nannbu(M7.2)	Building collapsed serious , damage to various piles reported	2001(Bldg-Law revised) Seismic design(1^{st}) for pile required (AIJ std. revised) liquefaction assessment modified, Pile aseismic design (2^{nd})
2011 Higashi-nihon (M9.0)	Tsunami damage was enormous PC,PHC piles damages reported	
Notes: AIJ std.; Architectural Institute of JAPAN design standard / recommendation, Bldg-Law; Building Law, Bldg-Recm; Recommendation		

◇Seismic design against the large earthquake (so called "Shin-taishin:New seismic design regulation⇒2^{nd}phase seismic design") for superstructure introduced in 1982.
On the other hand, Seismic design for pile foundations, (only the 1^{st} phase, against medium earthquake) was introduced in The Bldg-Law in 2000

◇It is considered that requiring the seismic design of 2^{nd} phase for the pile foundation deviates from a policy of minimum legislation aiming at human life protection.

1964 Niigata（M7.5）⇒Lliquefaction damage enormous,

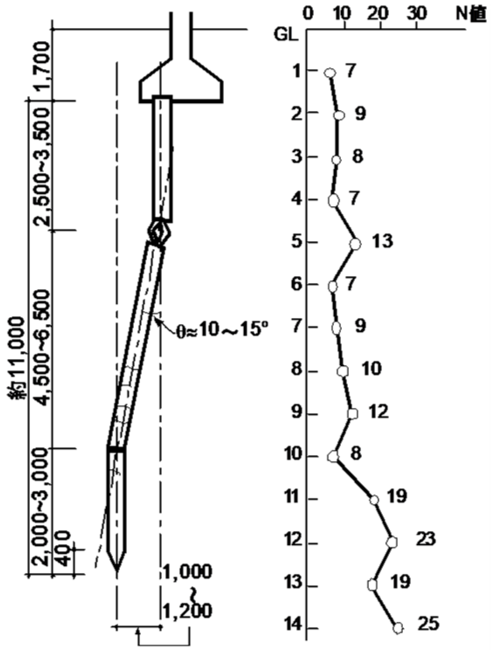


Fig 1 Earthquake Damage Case of Pile Foundation Building
(a) Niigata1964 Source :(a); Kawamura.et al. (1985),

◇More than 300 buildings were settled and incline damaged due to liquefaction.

◇Some of damaged pile foundation building used for more than 20 years after restoring settlement and inclination without noticing

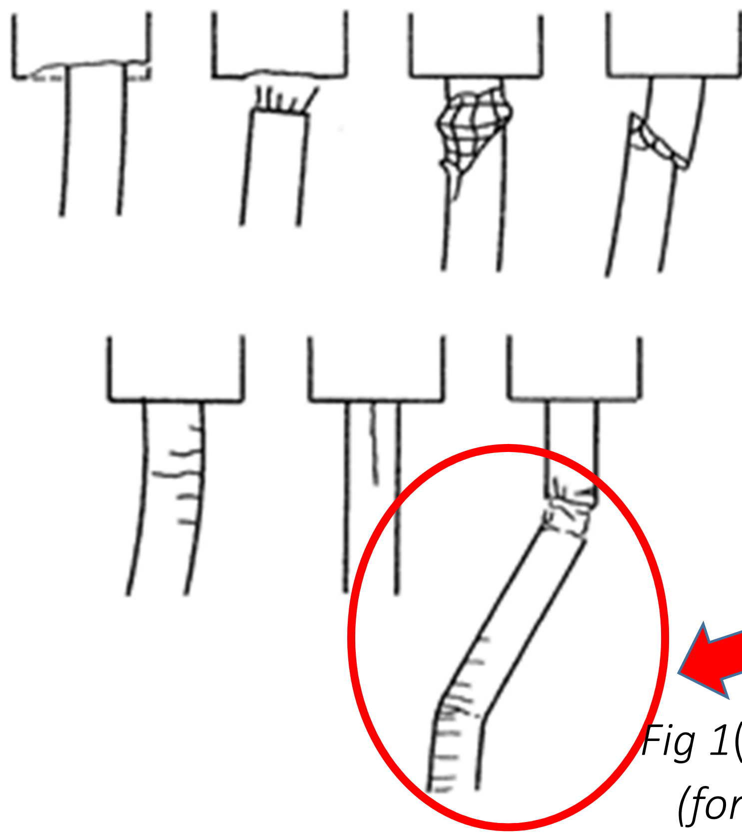
◇RC 5F apartment with spread foundation layered sideways, **but gradually tilted after the shake finished.** no human life has been lost.

1.2 Summary of Foundation Damage in the Hyogo ken Yanbu *earthquake1995*

◇Regional distribution of damage caused by piles spreads widely: reclaimed land areas, soft ground areas along coast-line, hilly areas and alluvial topography areas.

◇Many damage cases of cast-in-place concrete piles which had not been reported so far have also **collected.** *Bored pile(precast pile):d46+b75=121(72%),Cast-in-place pile;35(20%)

◇Survey by the Kinki branch of AIJ: 168 cases of pile foundation damage were collected.
the damage status (Figure 1 (d)) : pile head, over 40%,pile body under the ground ;10%.
⇒Study on pile design considering the influence of the ground displacement



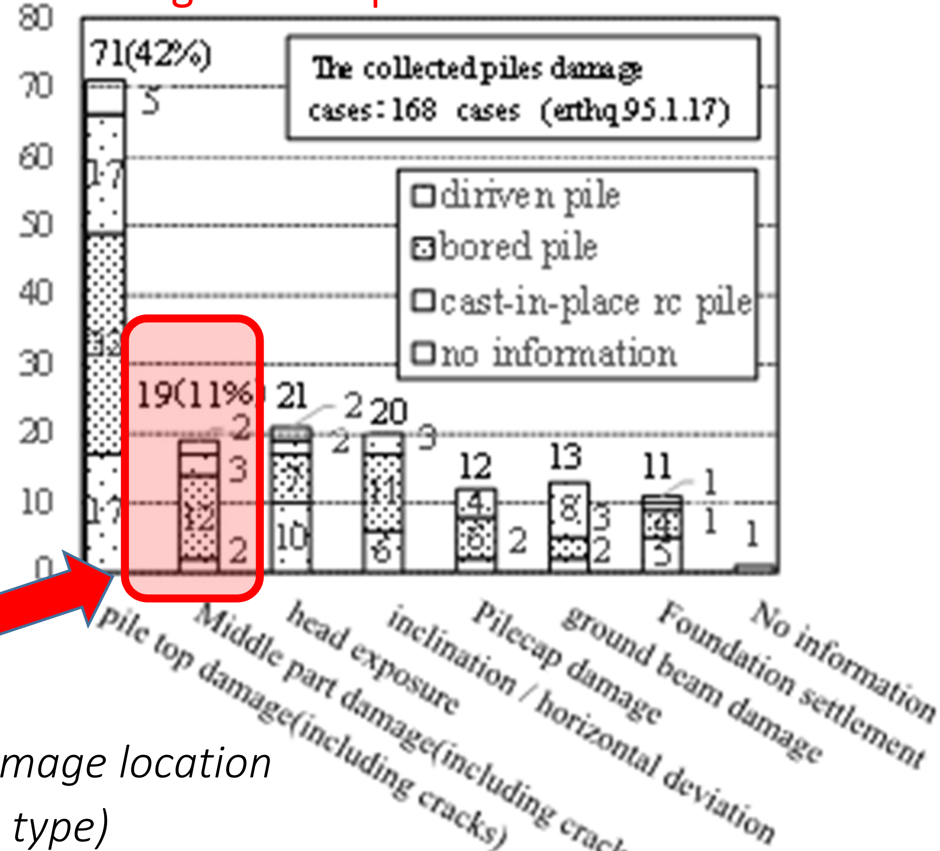
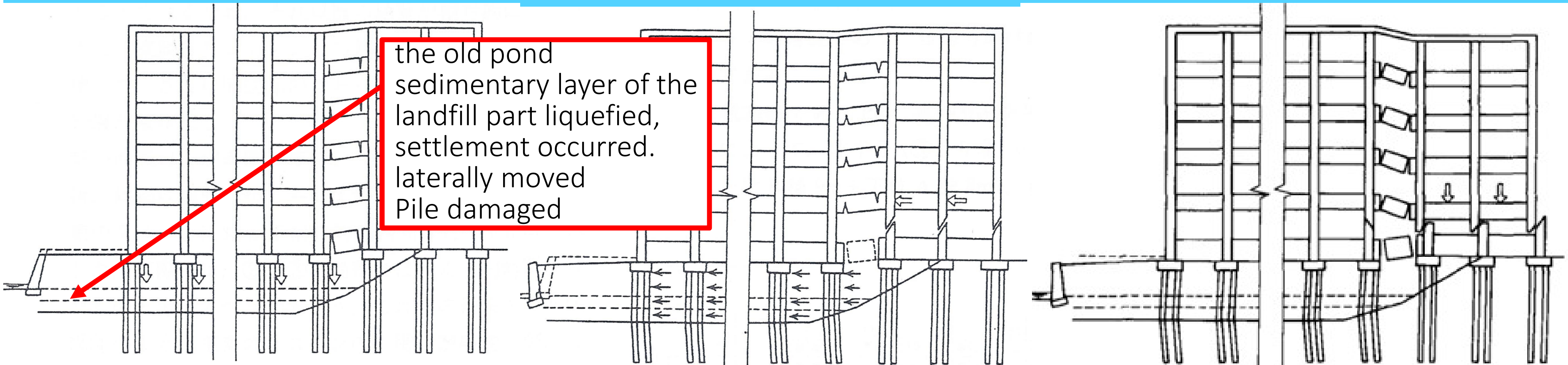


Fig 1(d) Pile damage location (for each pile type)

Fig 1 Earthquake Damage Case of Pile Foundation Building ((c) Pile damage pattern observed

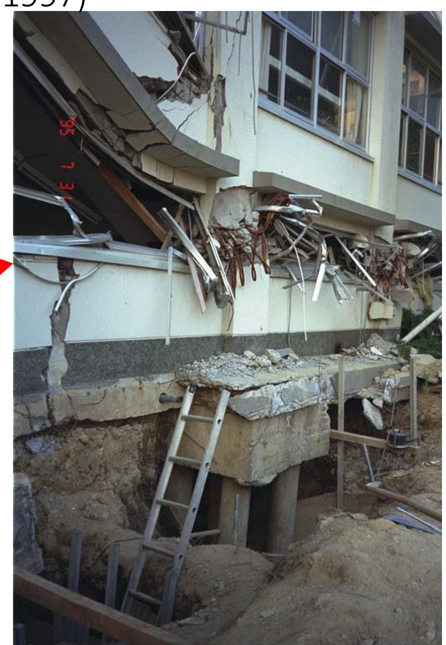
1.3 Remarkable damage of pile foundation building.



School building built across the landfill part created by pond reclaiming and natural ground.

Source :(a); Kawamura.et al. (1985), (b); Nishida. et al. (1997)

Fig 1 Earthquake Damage Case of Pile Foundation Building (b) Hyogo-ken-nanbu1995),



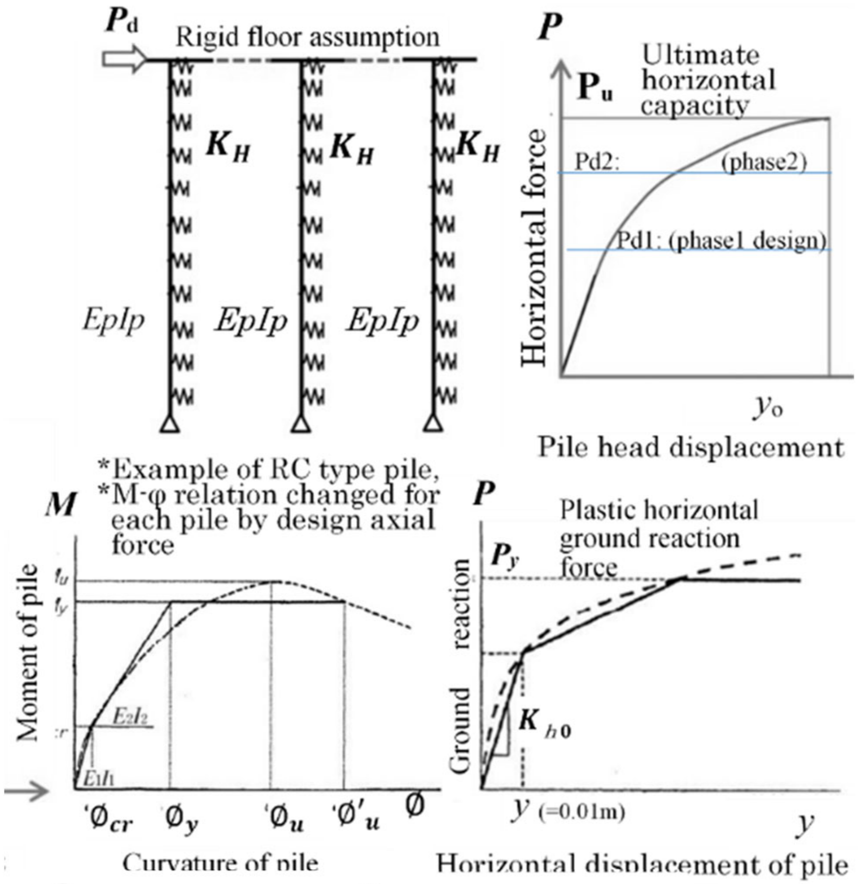
1st floor columns on the natural ground side were collapsed and 2nd floor fallen down.
Researchers point out that the possibility of damaging the pile foundation can cause damage to buildings related to human lives.⇒In 1985 Mexico, Building collapsed due to pile destroyed , the human life was spoiled.

2. Current Status of Seismic Design of Pile Foundation in Japan

Table 2 Outline of Pile Foundation design Standards (Seismic design) in Japan

Name of Text	*(1)Building Standard Law* *Including relevant enforcement orders & notification*	*(2)General seismic planning standard for government facility* *(By Government Buildings Department, Ministry of LIT)*	*(3)Recommendation for design of building foundation* *(By Architectural institute of Japan: AIJ)*
Characteristic	Laws and regulations	Specification for design ordering	Recommended guidelines of academic organizations
Target building	All buildings requiring application for building confirmation	Public facility	General building
Seismic design 1st phase (Moderate earthquake) It may be described as a shake of about 80 gal in surface acceleration Required performance: No damage	1)Design method: Allowable stress design 2)Design horizontal force: $P_{hp}=P_h*(1-α)$ (T1) α: embedding effect (Max.0.7) $P_h=P_{h0}+k*Wg$ (T2) P_{h0}:horizontal shear force of the lowest story k:seiseimic coefficient of basement (0.1 to 0.05 depending on the basement depth H) Wg:Weight ofbasement $P_{ho}=Z*Co*Ws$ (T3) Z:zoning factor Co: Standard shear coefficient (=0.2) Ws:weight of superstructure	1) : same as the left 2)Design horizontal force: P_{hp} '= P_{hp}*I (T1a) *consider the importance factor(I) in the expression on the left category1:I=1.5 category2:I=1.25 category3:I=1.0 category1: Disaster Command Center& Disaster base medical / Firefighting facility etc. * Required performance: Secure functionality without repairing after severe earthquake	1)Design method: resembling the limit state design(LRFD) the damage limit design of this Recommendation corresponds to the seismic phase-1 2)Design horizontal force: design load of seismic phase-1 is applicable 3) Details of design: Explanation on evaluation method of ground resistance and elasto-plastic properties of pile body
Seismic design2nd phase (severe earthquake) described as a shake of about 250gal in surface acceleration Required performance: life safety/ Collapse prevention of superstructure	Not required * except for the the slender building which tower ratio would be H/B>4, (required to verify the bearing capacity of pile) * building height exceeding 60m & isolated structure: requested by the Design Review Committee	Required by the following condition a) Category1&2 b) Height over 31m c) Soft surface ground 1) Design method: Capacity design (Horizontal holding capacity) 2) Design horizontal force Horizontal capacity of piles foundation ≧Required capacity of superstructure 3)General analysis method: Push over analysis	Required 1) Design method: Capacity design 2) Design horizontal- force Not clear Designer should set by himself 3)Design method: Elasto-Plastic Stress Analysis (Push over analysis,etc.)

Can be achieved in this way?



$(0.0 \le y \le 0.1)$	$K_H = 3.16 \cdot k_{h0} \cdot B \cdot H$	(1)
$(0.0 \le y \le 0.1)$	$K_H = k_{h0} \cdot B \cdot H$	(1a)
$(0.1 \le y)$	$K_H = k_{h0} \cdot y^{-1/2} \cdot B \cdot H$	(2)
	$K_{h0} = \alpha \cdot \xi \cdot E_0 \cdot B^{-3/4}$	(3)

Remark: In practice, the expression (1a) is often used instead of the expression (1)

K_H : horizontal springs (kN/m), y : horizontal displacement (m)

k_{h0} : coefficient of lateral subgrade reaction (kN/m^3)

$k_{h0} \cdot y \le P_y$, P_y : Plastic horizontal ground reaction force (see *Fig.2*)

B : pile diameter(m) , H : spring interval(m), E_pI_p: Flexural rigidity of pile

α : constant according to the evaluation method of E_0 (m^{-1})

ξ : pile group coefficient (simple pile foundation to $\xi = 1.0$)

E_0 : modulus of deformation of the ground (kN/m^2)

1) borehole horizontal loading test (pressuremeter test etc.) : $\alpha = 80$

2) unconfined or triaxial compression test : $\alpha = 80$

3) $E_0 = 700N$, (N value of SPT) sand; $\alpha = 80$,clay; $\alpha = 60$

Fig 2 Seismic design model of pile foundation common in practice (leftmost above).the top next; right figure analysis result of P - Y relationship of whole pile, leftmost down; model example of flexural stiffness and subgrade reaction of each pile

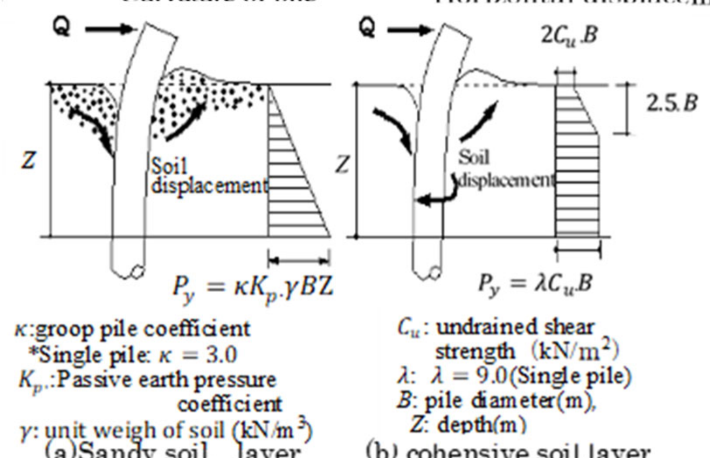


Fig 3. Plastic horizontal subgrade reaction force; Py.

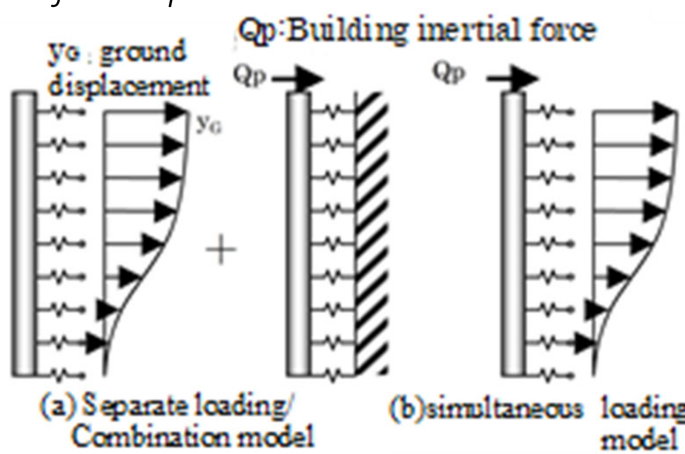


Fig 4 Pile-ground model for evaluating the influence of ground displacement in addition to the inertial force of the superstructure. (AIJ (2001)

3. Concept of Target Performance of Pile Foundation

3.1 Difficulty of Restoration of Damaged Pile Foundation

◇As far as looking back on our past experiences of earthquake damage, it is very unlikely that damage to the pile would cause the building to collapse and endanger human life.

⇒ When the required performance of the building would be "protection of human life" against large earthquake , There may be no necessity of taking into consideration the seismic performance of pile foundation to the seismic performance of building.

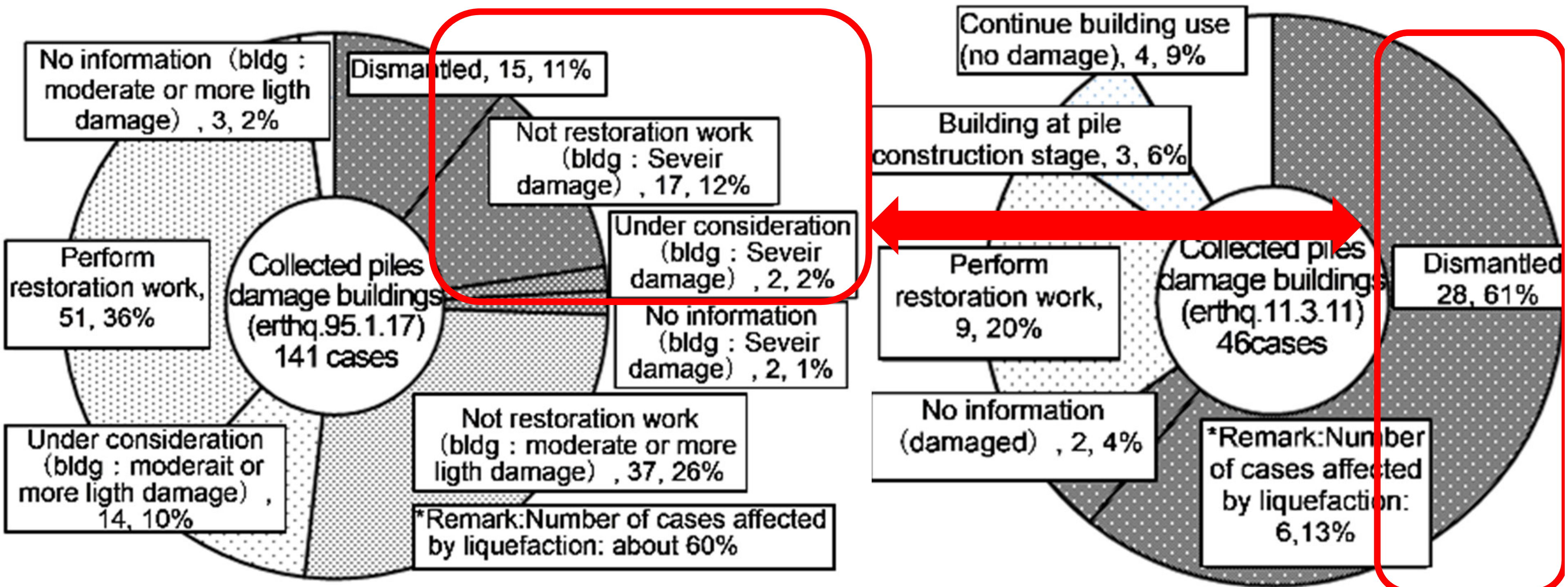
→ We are only having been blessed with the fortune until now?

◇On the other hand, from the viewpoint of conservation of property, prompt restart of use after the earthquake, and ensuring continuous usability, the seismic design of pile aimed at reducing or preventing damage of pile foundation is significant. And we should always think together with the target performance of the superstructure and foundation.

◇ The important point is that **the degree of difficulty of the reinforcement and repair technique of the pile foundation** and the cost associated with it are far more enormous than the superstructure.

◇ there is a technical limit to the detection of damage in the underground, even if reinforcement or repair is done, the risk of being damaged again remains. Even though the damage of the superstructure is minor, it is estimated that there are many cases where the building is dismantled due to the damage of the foundation.

◇ the construction method and related data is not sufficient to select whether to repair the foundation of the damaged pile or to dismantle the building, The further research and development are expected very much



(a)Hyougo ken nanbu Erthq.(1995.1.17) (b)Higashi nihon Erthq.(2011.3.11)

Fig 5 Dismantled / restoration investigation of pile foundation damaged building

- In the year after the earthquake1995.1.17 occurred, 141 cases of pile foundation damage were collected and 65 cases (46%) answered that restoration work would be carried out, including during on study.⇒dismantled is 34 cases(24%), *
- Erthq.2010. recovery ;9 cases(20%) vs. disassembly ;28(**60%**)
- From the lesson of Erthq.1995, the engineers recognized: the reinforcement of the pile foundation is expensive, it is difficult to reinforce the underground part of pile body and also the risk of damage again after the reinforcement will be not solved .
- **Is it possible to guess that the above-mentioned recognition affected the increase in the ratio of demolition?.**

3.3 Accountability of Target Performance of Pile Foundation

- It is dangerous to repair and reuse damaged piles unless it is clear that there is no possibility of damage other than the pile head and the underground soundness is guaranteed.

In other words, it is difficult to respond to the request of the builder as maintaining function and resumption of use at an early stage on the conditions which permitted some degree of damage (shear failure and bending crush) to the pile foundation.

Considering that the selection method of seismic performance of pile foundation against large earthquake is not sufficiently clarified, I think that it is important to explain to the builder and form consensus with the builder is very important about the setting of the target performance of the pile foundation which must be performed by the structural designer's own judgment.

- Fig. 6 is an attempt to classify the damage pattern of the pile foundation at the time of the earthquake according to the degree of damage and apply it to the required performance of the assumed building and use it for grading the target performance. (KOBAYASHI (1997))
- A viewpoint to evaluate comprehensive performance by combining the superstructure and the foundation will be further necessary.
- In addition, a research and technical development for **reparability (maintain a repairable damage condition)** of pile foundation related to damage B (**limit of property preservation)** shown in the figure is necessary

Author added ⇒

More research and technical development for **reparability (maintain a repairable damage condition)** of pile foundation is necessary

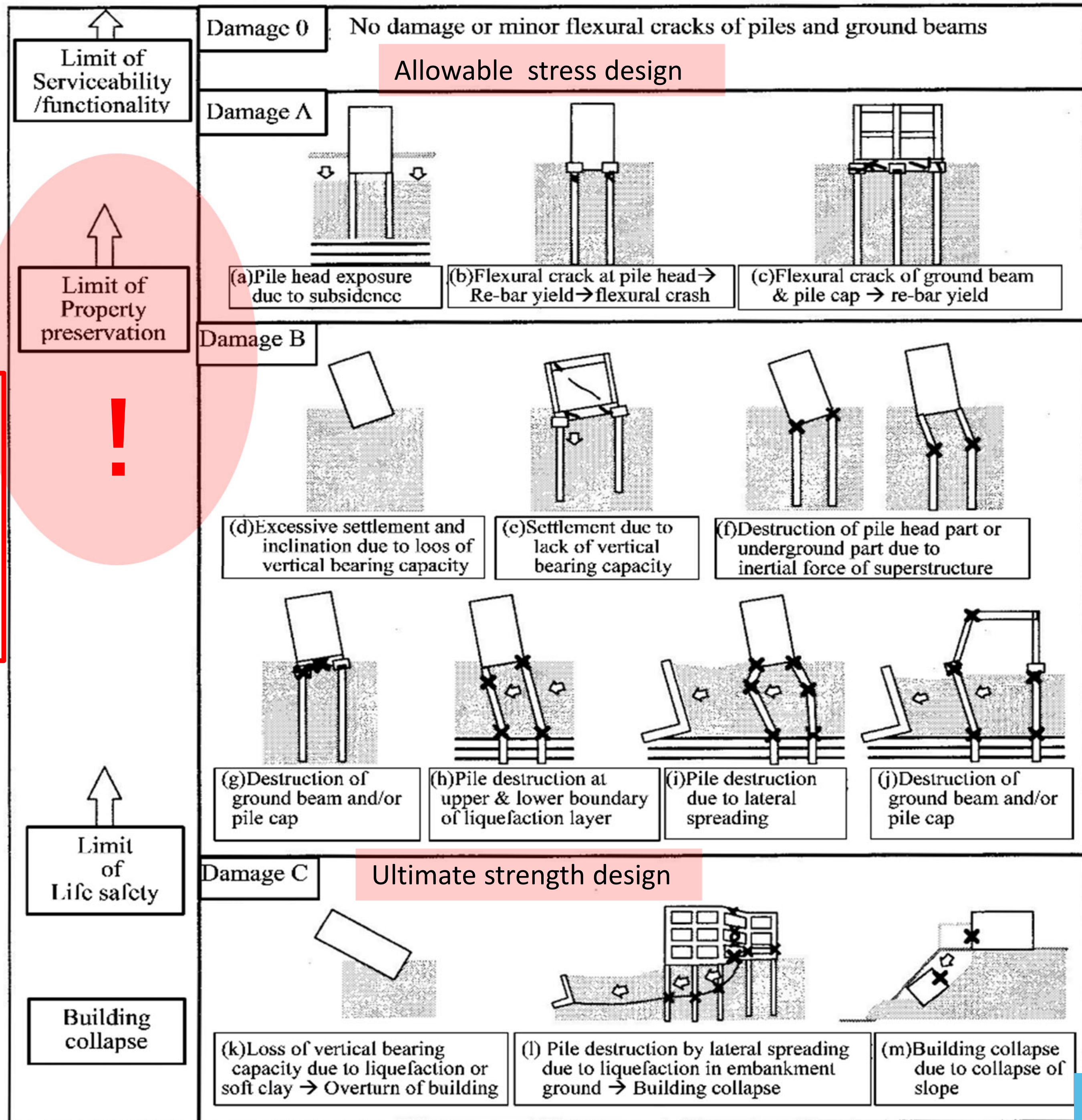


Fig 6 Relationship between damage statuses of pile foundation (EQ 95.1.17) and required performance of building (Translation of Kobayashi (2001) in Japanese at the author's responsibility)

4. Example of Pile with Enhanced Seismic Performance

4.1 Out line of SPHC Pile

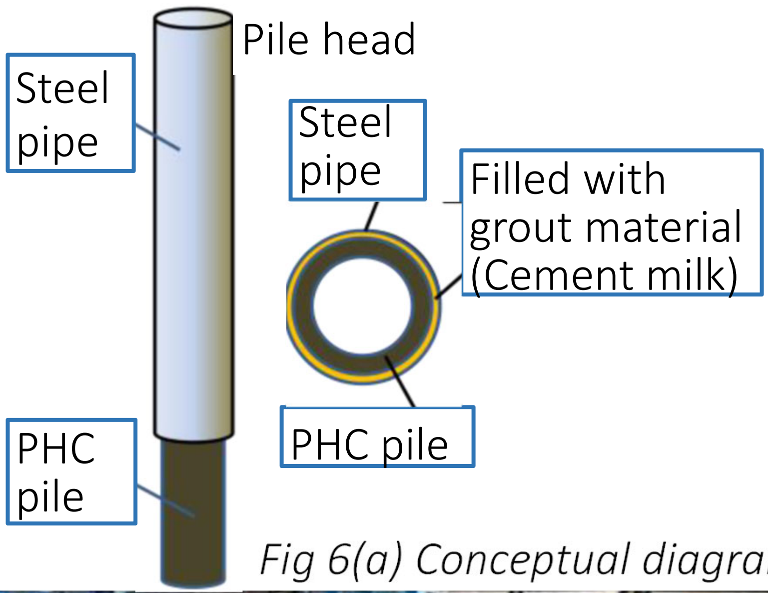
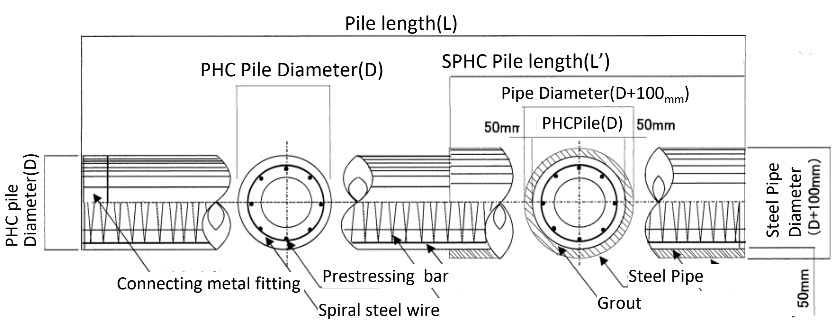
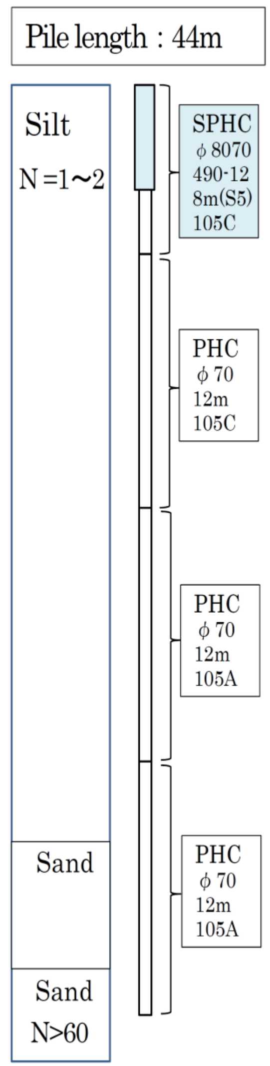


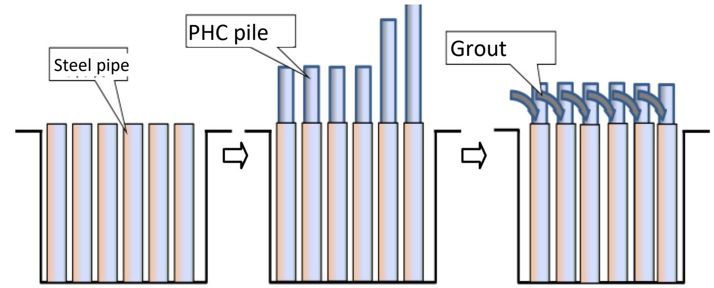
Fig 6(a) Conceptual diagram

Fig 6(b) Full view





Fig(a)- 1 Example of pile foundation



fig(a)-2 Manufacture method

SPHC pile Specification:

Type of pile: Prestressed High-Strength Pile(PHC) Covered by Steel Pipe to use as Top Pile as the left

Diameter(D) : ϕ400〜ϕ1300mm

Length (L): 4 〜15m (L':3.5-14.5m)

Steel pile: SKK & STK 400,490,ts=4.5-22_{mm}

σy;235,325 N/mm^2

Adapted PHC Pile: ϕ300〜ϕ1200mm

(D-100mm)

Prestressed Glade -A,B,C

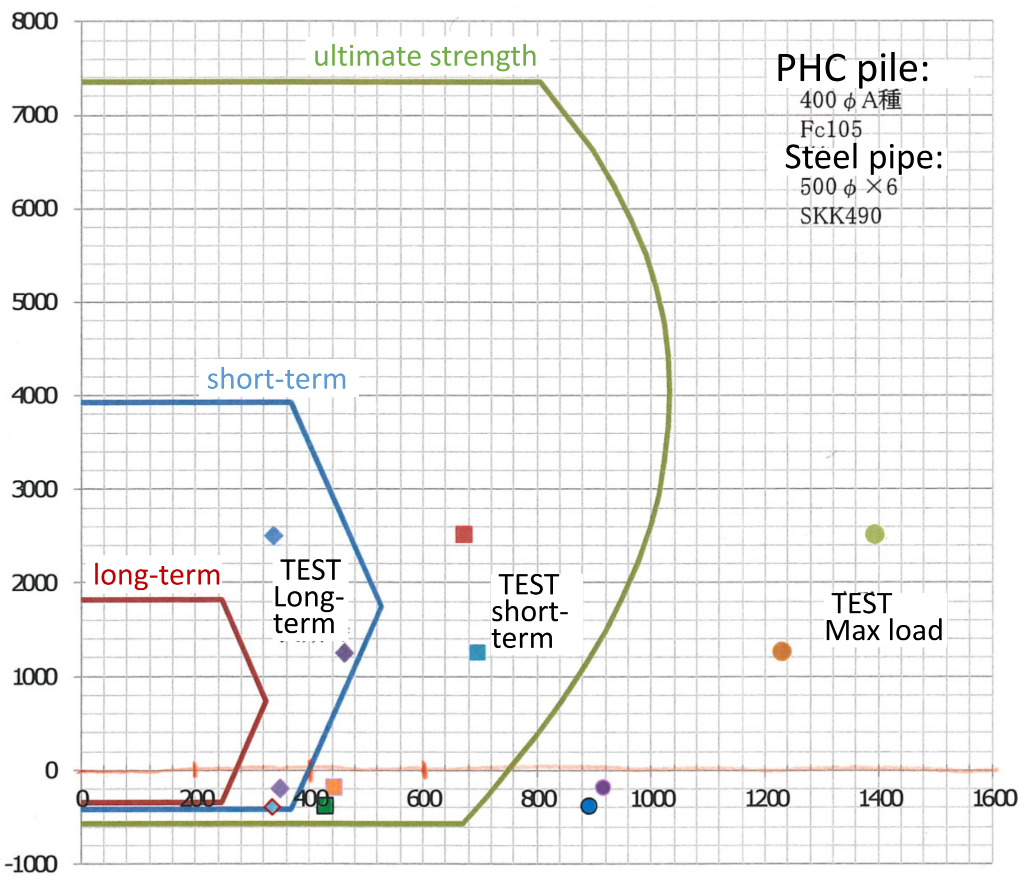
(σPc:4、8、10N/mm^2)

Concrete Strength Fc:85,105,123N/mm^2

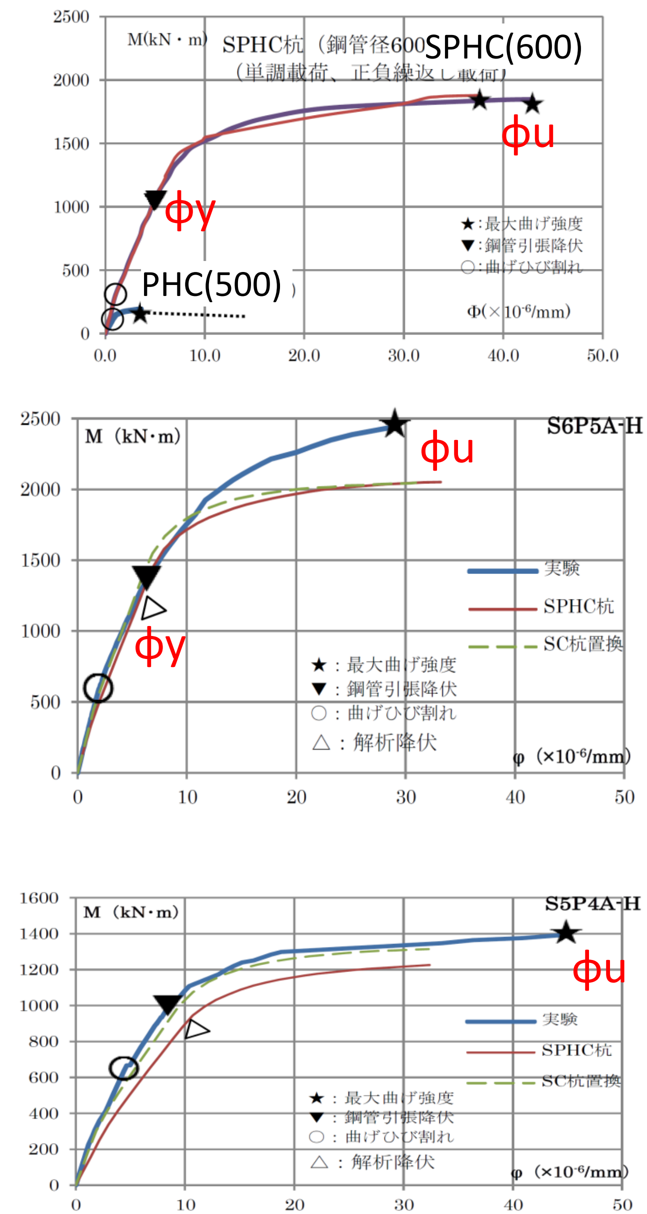
Grout material : Cement milk water cement ration W/C 60%,σc : 27N/mm^2

4.2 Seismic performance data-1:

- Structural performance of this pile has been certified by a third party judgment agency
  - (1) Calculation method of allowable Ma , Qa
    Ultimate Strength Mu , Qu
  - (2) Plastic deformation ability; 4 × ϕy
    ϕy: Curvature to which a steel pipe reaches yield stress.



Design M-N correlation diagram with The test load



M-ϕ diagram (design & Test)

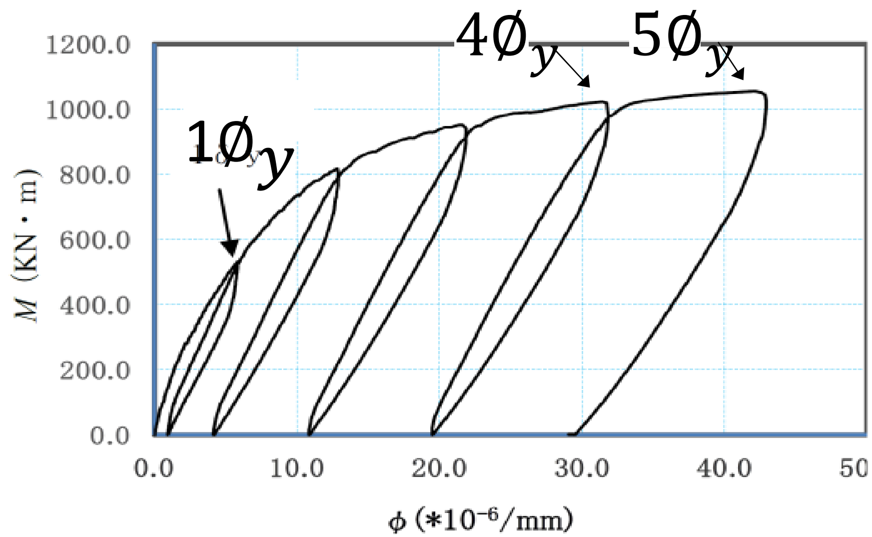
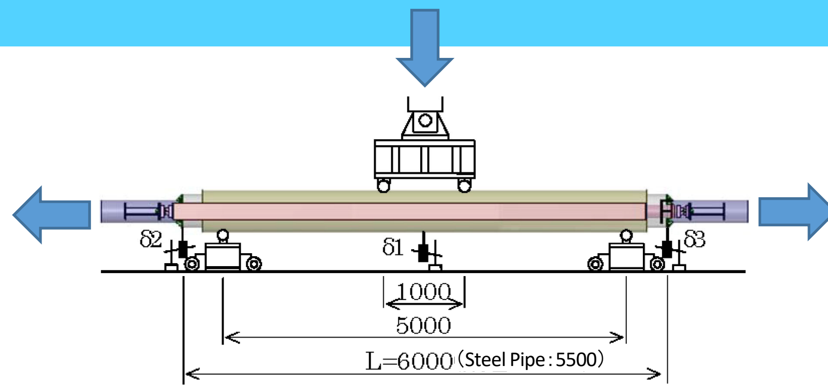


Fig6(c) Bending test (M-∅)SPHC-pile(500φ)

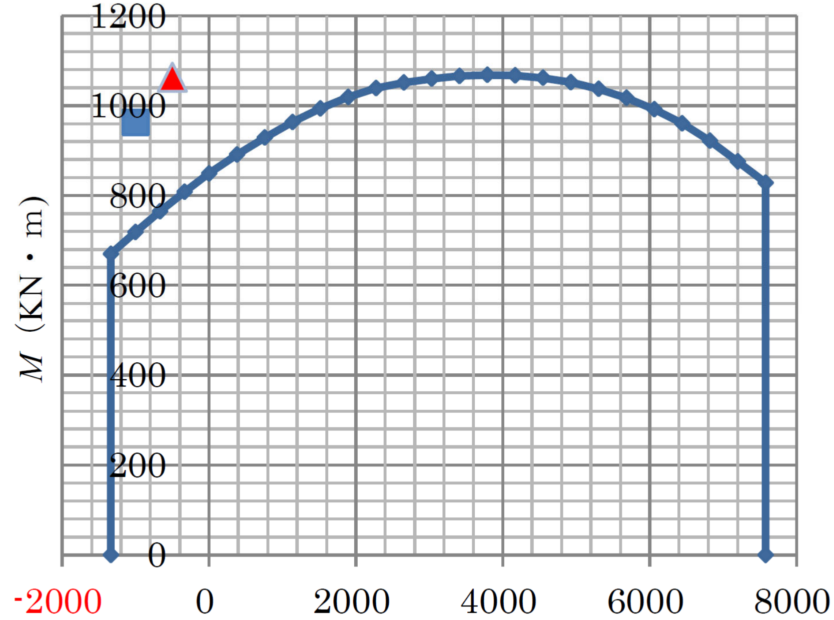
Tensile load N=-500kN┴=1/2of ┤

※┤:N=-1000kN ; 2/3Tu of PHC400ϕ(**grade** C)



Test pile :SPHC pile,SteelPipe 500ϕ,SKK490,ts=6mm
PHC pile 400ϕ(grade C)

Fig6(d) Status of internal PHC pile after test



Design N-M correlation diagram with The **test** load

After the force test, the steel pipe was peeled off and the damaged state of the inner PHC pile body was confirmed, but only a minute hair crack was observed, and almost no damage occurred.

- It is said that it can be used continuously after a major earthquake.
- Although the target performance of damage prevention has been replaced by verification of the short-term allowable stress degree so far, the damage avoidance limit, (damage limit)can be set for this SPHC pile
- it becomes possible to execute the design based on the new performance limit.

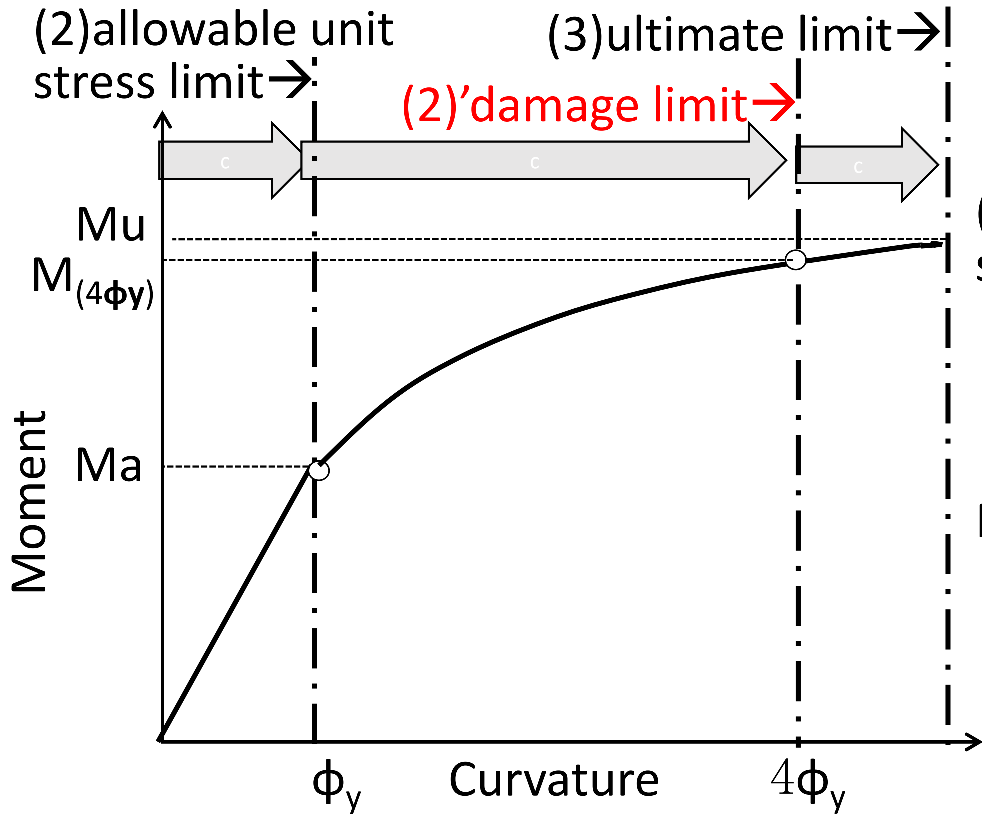


Fig7.(e) SPHC pile Assumed seismic performance

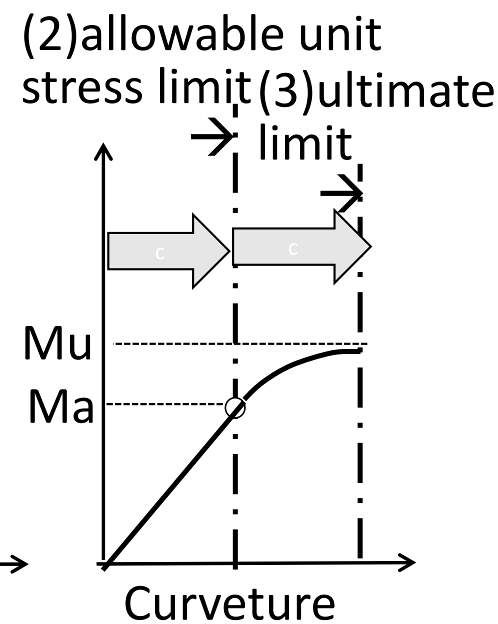


Fig7.(f) PHC pile(connecting below) Assumed seismic performance

5. Conclusion

My personal opinion on the target performance of pile foundation against a major earthquake is presented. As follows.

- When the target performance of a building is protection of " human life", there may be no necessity of taking the performance of the pile foundation into consideration. It could be negligible to take into count of performance of Pile foundation, Although it is a limitation based on the past experience.

- When the target performance of a building would be "maintain function or resume to use at an early stage ", the performance of the pile foundation against large earthquake should be considered.

- More research and technical development for reparability (maintain a repairable damage condition)of pile foundation is necessary

- Structural engineers should enforce the explanation to the builder about how to set the target performance of the pile foundation so as to satisfy the required seismic performance of the building as with the superstructure.

Appendix: Outline of Two Major Piling Construction Method in Japan

The two major construction methods of pile foundation in Japan:

Pre-bored with enlarged base method for precast concrete piles.(Fig8(a))

the earth drill bottom-enlarged method for cast-in-place concrete pile (Fig8(b))

In both methods, to obtain a large vertical bearing capacity,

*the number of constructions/year(roughly); Cast-in-place:1,500 /Bored precast pile:4000

(a)Pre-bored with enlarged base method (precast concrete pile)

Using precast pile: PHC(Prestressed High Strength concrete pile), SC (Steel Composite Concrete Pile),etc.

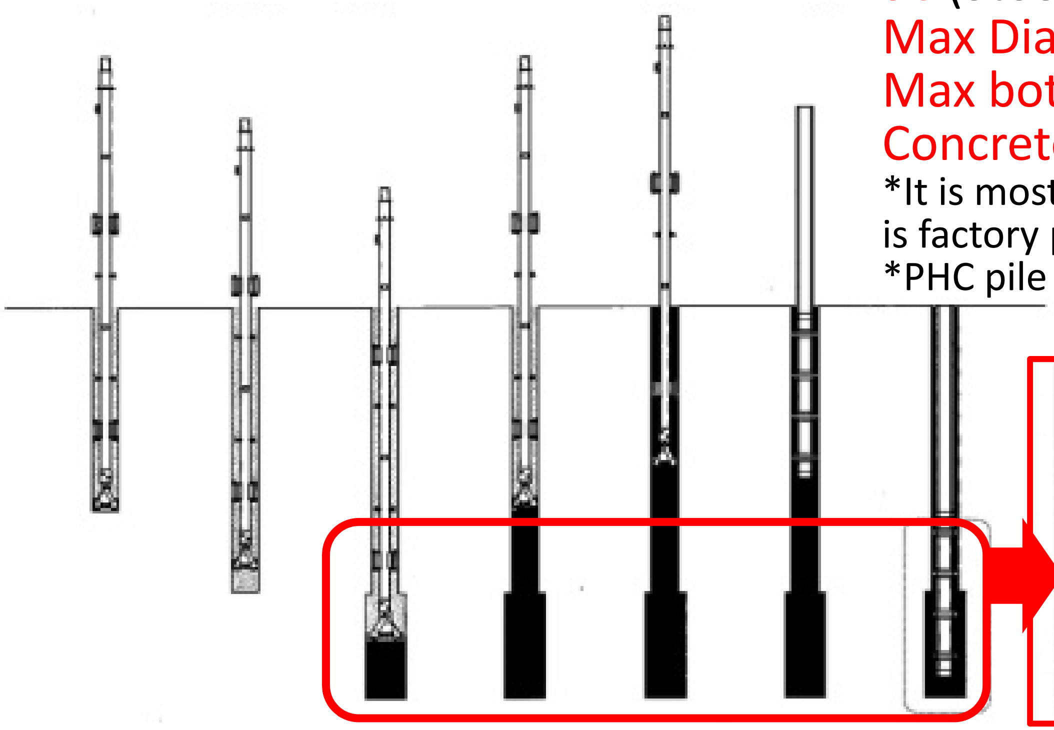
Max Diameter 1300mm

Max bottom bearing Capacity:Ra:19MPa

Concrete strength:Fc105,123 N/mm^2

*It is mostly adopted in a middle-scale buildings. Since it is factory production, the quality of concrete is stable.

*PHC pile is deficient in ductility by pre-stressing



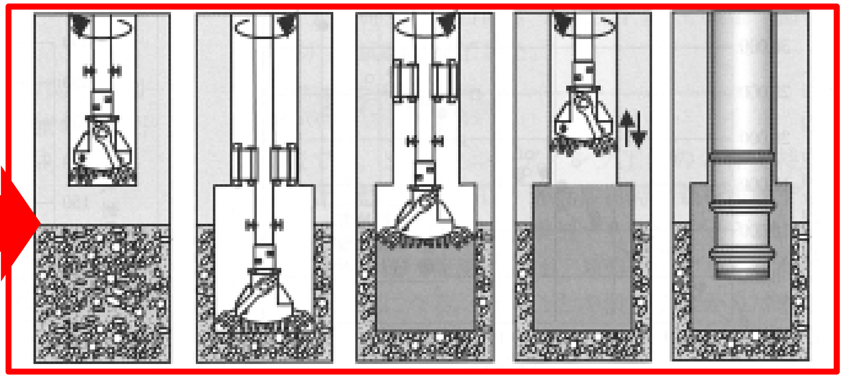


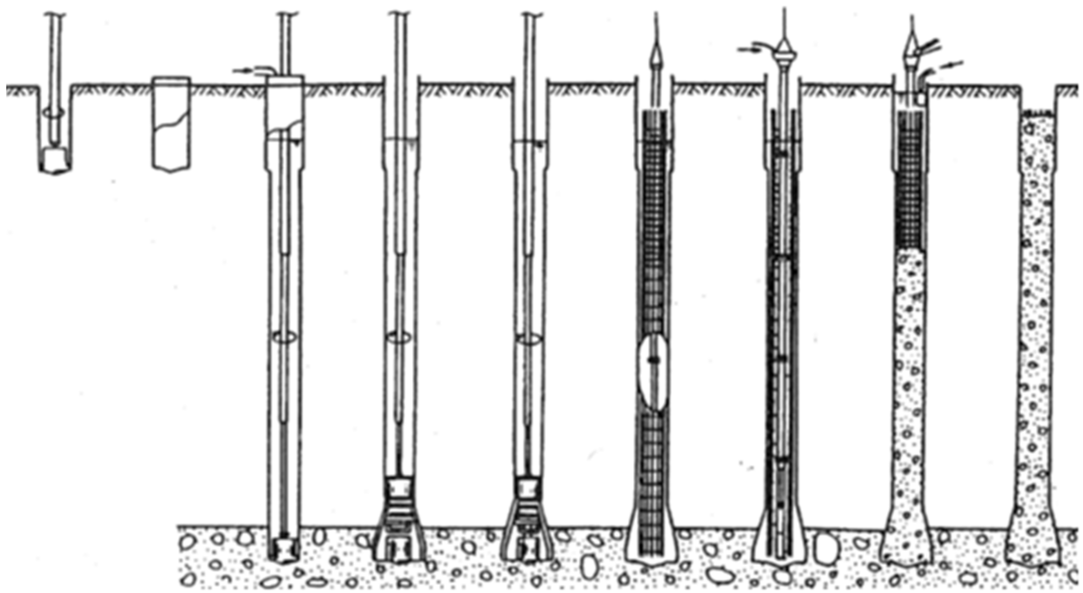
Fig 8. Construction procedure of two major piling method, part of pile specification (Pre-bored with enlarged base method for precast concrete piles.)

(b) the earth drill bottom-enlarged method

(cast-in-place concrete pile (Fig8(b))

Max Diameter 4400mm
Max bottom bearing Capacity:Ra:43MPa
Concrete strength:Fc60 N/mm^2

*Since large bearing capacity is expectable, it is adopted mostly in high rise buildings.
*In many cases, the digging ground is industrial waste and reservation of the disposal ground poses a problem.



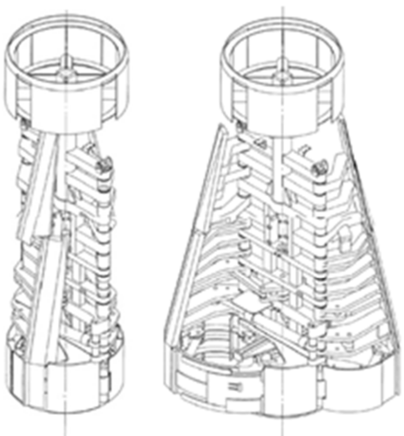


Fig 8. Construction procedure of two major piling method, part of pile specification (Cast-in-place RC pile (the earth drill bottom-enlarged method)

Thank you very much for your attention