3. Earthquake Engineering

3.1. Evaluation of Ground Damage

Basic Terminology:

Damage: Collapse, slip, crack, subsidence, undulation and inclination of ground, which includes retaining wall, caused by an earthquake.

Damage grade: Grade of damage by ground conditions after an earthquake.

Restoration: Repair the crack and the subsidence, etc. of ground due to an earthquake and recover the ground to the condition before an earthquake.

Retrofit: Secure necessary ground strength by reinforcing the ground where the strength decreased due to an earthquake, and enable to reuse.

Safety: The ground conditions which ensure the safety of human life and building conditions even at a possible severe earthquake.

Purpose:

Methodology of an evaluation of safety on ground condition after earthquake or tsunami

Important Points:

Timing:

Timing	Evaluation Methodology	Example
Immediate	・First announcement of damage of ground ・Damage overview in damaged area	・Reports of eye witness & Feelings by local habitants ・Broadcast
Within few days	・Quick inspection ・Damage survey in a typical area	・Judgment of off-limits or emergency retrofit
Within few weeks	・Damage Classification	・Judgment of need to retrofit or not
After several months	・Investigation for retrofit	・Retrofit method and design

Grade:

Grade	Methodology	Measures
Minimum Necessary	Reports of eye witness & Feelings by local habitants	Information to habitants
Better	Instant evaluation	Restoration of damage area Retrofit of damage area
Best	Evaluation on ground safety	Retrofit of damage area

3.1.1. Damage investigation flow chart

The flow chart of ground damage investigation is presented in Figure 3.1.1-1. The ground damage investigation may be classified into two types: one that concerns the ground in a broad area and the other that is limited in scope to the ground in each building site.

"Quick Inspection" of the ground is made within two or three days after an earthquake, with emphasis placed on the more seriously damaged ground. The purposes are to a) judge whether it is necessary to take measures such as preventing people from entering or evacuating the residents, b) determine if emergency repair and reinforcement is needed, c) determine whether the current ground should be maintained, and d) when the current ground is maintained, the necessity of repair or reinforcement is judged according to "Damage Grade Classification" that is conducted within several weeks.

In cases where repair or reinforcement is needed to restore the ground, either the restoration method is selected or the restoration design is investigated. The method is decided several weeks to several months after the earthquake. But when the ground is judged impossible to restore, the use of the area in question has to be reconsidered.

When such measures as forbidding people from entering or evacuating residents from the ground are taken, either the restoration of the ground is investigated with a view to reusing it for the same purpose as before, or its restoration is abandoned and the category of usage, including new application, of the area in question is considered anew.

For the details of the liquefaction map, refer to materials listed under the heading of "Zoning for Soil Liquefaction" in the reference section.

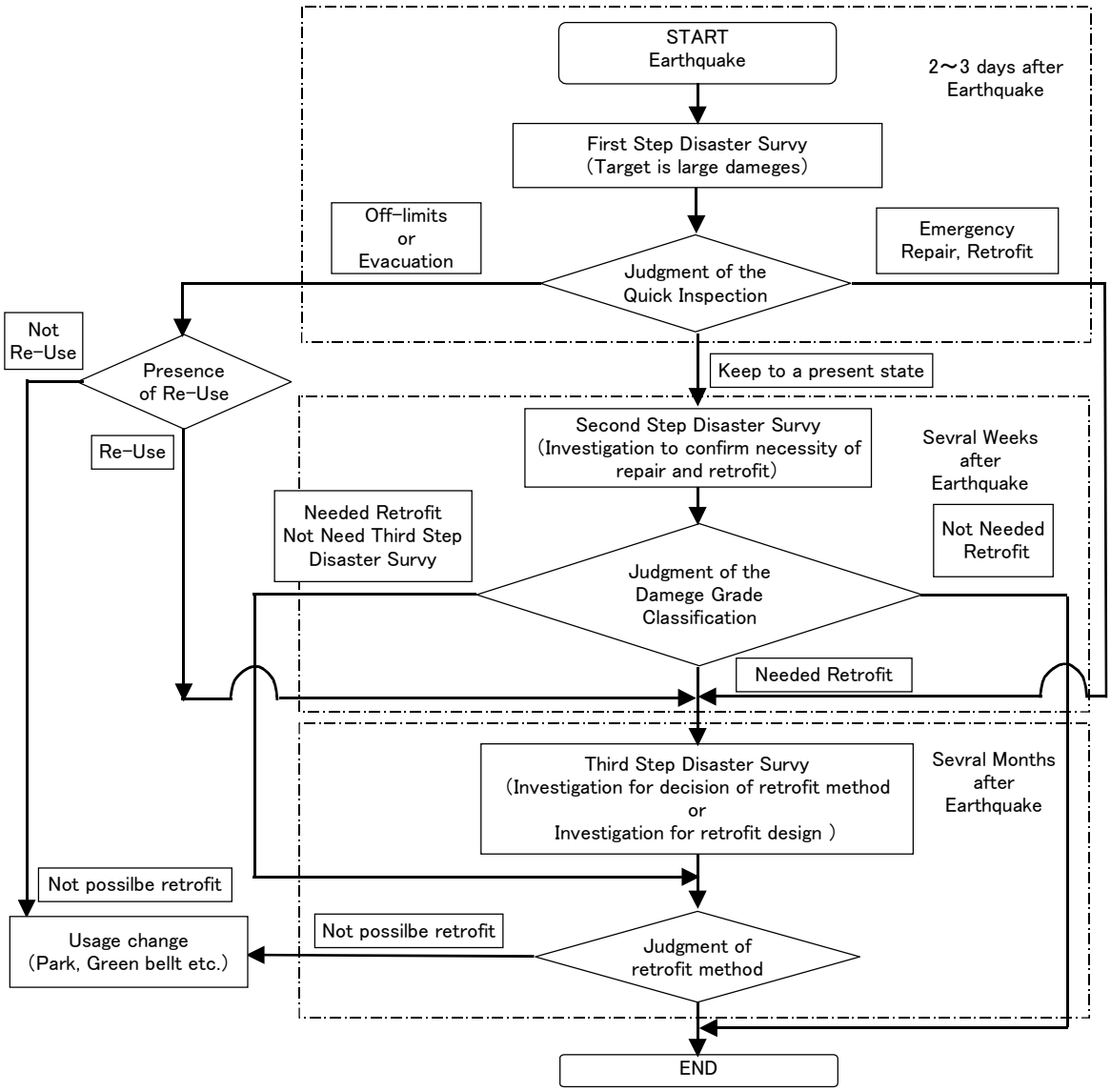

Fig. 3.1.1-1 Damage Investigation Flow of Ground[1]

3.1.2. Quick inspection

The quick inspection of the ground is done to prevent any secondary damages from occurring. The purpose of this inspection is to determine a) whether it is necessary to take such measures as prohibiting people from entering or evacuating residents and b) whether the area is in need of emergency repair and reinforcement.

Example 1(Table 3.1.2-1) shows a quick inspection sheet for the ground in a broad area. Example 2(Table 3.1.2-2) shows such a sheet for the ground in each building site. The inspection should be made on the site as a rule; however, aerial photographs, videos, and similar methods may be used when various factors do not allow inspectors direct access to the site.

3.1.3. Damage classification

When the judgment made by the quick inspection of the ground in 3.1.1 c) is that the ground should be maintained, the area's damage grade classification is determined to reflect the amount of damage. It is also determined whether repair and reinforcement is needed. Example 3(Table 3.1.3-1) shows a judgment of damage grade classification sheet for the ground in a broad area. Example 4(Table 3.1.3-2) shows such a sheet for the ground in each building site. For the ground in a broad area, attention should be paid also to the post inspection development of its damage.

Reference

1. Quick inspection & Damage Classification of Ground

[1] "Criterion on damage classification and guideline to restoration of buildings damaged by earthquake." Post earthquake damage inspection sheet for building area, The Japan Building Disaster Prevention Association, 1991 February. (in Japanese)

2. Zoning for Soil Liquefaction

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Example 1 **Sheet 1/3**

Table 3.1.2-1 Quick Inspection Sheet for Ground[1]

Sheet No.

Time&Date

Recoder

Site adress

Damage patern	
☐ [A]: Collapse of fill-up ground	
kind of fill-up ground terraced others	
Collapsing width:	(m)
Collapsing length:	(m)
Collapsing azimuth:	
Is there a housing lot in the vicinity of collapse ground	
☐ [Yes] ☐ [No]	
Investigation method	
☐ by watching ☐ by video ☐ by scaling ☐ others	
Soil type	
☐ Sand, ☐ Loam, ☐ Viscous soil , ☐ Gravel, ☐ Others	
☐ [B]: Collapse of hillback slope	
kind of hillback slope natural slope cutting slope	
Collapsing width:	(m)
Collapsing length:	(m)
Collapsing azimuth:	
Inclination of slope:	(deg)
Surface condition of slope:	
☐Weed ☐Turf	☐Mortar ☐Tree
Is there a building area in the vicinity of collapse ground?	
☐ [Yes] ☐ [No]	
Investigation method	
☐ by watching ☐ by video ☐ by scaling ☐ others	
Soil type	
☐ Sand, ☐ Loam, ☐ Viscous soil , ☐ Gravel, ☐ Others	

Example 1 (Cont.) **Sheet 2/3**

☐ [C]: Collapse or Fall of Retaining Wall
Hight of Retaining Wall Type of Retaining Wall Collapsing width: Collapsing length: Collapsing azimuth:
Is there a housing lot in the vicinity of damage retaining wall
☐ [Yes] ☐ [No]
Investigation method
☐ by watching ☐ by video ☐ by scaling ☐ others
Soil type
☐ Sand, ☐ Loam, ☐ Viscous soil , ☐ Gravel, ☐ Others
☐ [D]: Crack and Step
The generation points are filled in on figure.
Width of Crack or Step (m)
Length of Crack or Step (m)
Depth of Crack or Step (m)
Range of Crack (m^2)
Is there a building area in damage region?
☐ [Yes] ☐ [No]
Investigation method
☐ by watching ☐ by video ☐ by scaling ☐ others
Soil type
☐ Sand, ☐ Loam, ☐ Viscous soil , ☐ Gravel, ☐ Others
☐ [E]: Settlement , Inclination, Undulation and movement of retaining wall
The generation points are filled in on figure.
Damage hight (m)
Damage length (m)
Damage width (m)
Is there a building area in damage region?
☐ [Yes] ☐ [No]
Investigation method
☐ by watching ☐ by video ☐ by scaling ☐ others
Soil type
☐ Sand, ☐ Loam, ☐ Viscous soil , ☐ Gravel, ☐ Others

☐ [F]: Watter
The generation points are filled in on figure. Volume of water: ☐ Disorder, ☐ Usual Past situation: ☐ [Yes], ☐ [No] Liquifaction: ☐ [Yes], ☐ [No] Outflow of gas: ☐ [Yes], ☐ [No]
Investigation method
☐ by watching ☐ by video ☐ by scaling ☐ others
Soil type
☐ Sand, ☐ Loam, ☐ Viscous soil , ☐ Gravel, ☐ Others

Damage patern
Sketch of damage situation
 Failure  Settlement  Upheaval  Spring water  Displacement  Step  Crack  House  Retaining wall  Slope  S Emergency action is necessary

Filling in recoder's opinion
Is there a house thought that shelter is necessary in the surrounding? or Is there a house thought that off-limits is necessary in the surrounding? ☐ [Yes], ☐ [No], ☐[Not possible to judge]
Is there a place where the emergency repair (or retrofit) are necessary? ☐ [Yes], ☐ [No], ☐[Not possible to judge]
Maintenance of current state
Others

Example 2 **Sheet 1/3**

Table 3.1.2-2 Quick Inspection Sheet for Building Area Ground [1]

Sheet No.

Time&Date

Recoder

Site adress

Damage patern
☐ [A]: Collapse of slope
kind of slope natural slope cutting slope enbankment slope
Damage scale
☐Large, ☐Medium, ☐Small
Collapsing width: (m)
Collapsing length: (m)
Collapsing azimuth:
Inclination of slope: (deg)
Distance to Building: (m)
Investigation method
☐ by watching ☐ by video ☐ by scaling ☐ others
Soil type
☐ Sand, ☐ Loam, ☐ Viscous soil , ☐ Gravel, ☐ Others
☐ [B]: Collapse or Fall of Retaining Wall
Back ground material cutting ground material enbankment ground material
Damage scale
☐Large, ☐Medium, ☐Small
Collapsing width of Retaining Wall : Collapsing length of Retaining Wall: Collapsing azimuth:
Distance to Building: (m)
Investigation method
☐ by watching ☐ by video ☐ by scaling ☐ others
Soil type
☐ Sand, ☐ Loam, ☐ Viscous soil , ☐ Gravel, ☐ Others

Example 2 (Cont.) **Sheet 2/3**

☐ [C]: Crack and Step
Damage scale
☐Large, ☐Medium, ☐Small
Width of Crack (m)
Length of Crack (m)
Depth of Crack (m)
Generation Points
Sloop, Retaining Wall
Distance to Building: (m)
Investigation method
☐ by watching ☐ by video ☐ by scaling ☐ others
Soil type
☐ Sand, ☐ Loam, ☐ Viscous soil , ☐ Gravel, ☐ Others
☐ [D]: Inclination, Undulation and movement of retaining wall
The generation points are filled in on figure.
Damage scale
☐Large, ☐Medium, ☐Small
Damage length (m)
Damage width (m)
Damage hight (m)
Distance to Building: (m)
Investigation method
☐ by watching ☐ by video ☐ by scaling ☐ others
Soil type
☐ Sand, ☐ Loam, ☐ Viscous soil , ☐ Gravel, ☐ Others
☐ [E]: Settlement , Burying and Upheaval of Ground
The generation points are filled in on figure.
Damage scale
☐Large, ☐Medium, ☐Small
Damage hight (m)
Damage length (m)
Damage width (m)
Investigation method
☐ by watching ☐ by video ☐ by scaling ☐ others
Soil type
☐ Sand, ☐ Loam, ☐ Viscous soil , ☐ Gravel, ☐ Others

☐ [F]: Spring water
The generation points are filled in on figure. Volume of water: ☐ Disorder, ☐ Usual Liquifaction: ☐ [Yes], ☐ [No] Outflow of gas: ☐ [Yes], ☐ [No]
Investigation method
☐ by watching ☐ by video ☐ by scaling ☐ others
Soil type
☐ Sand, ☐ Loam, ☐ Viscous soil , ☐ Gravel, ☐ Others

Damage patern
Sketch of damage situation
 Failure  Settlement  Upheaval  Spring water  Displacement  Step  Crack  House  Retaining wall  Slope  Emergency action is necessary

Filling in recoder's opinion
Is there a place where the shelter (or off-limits) is necessary? ☐ [Need] ☐ [Not Need] ☐[Not possible to judge]
Is there a place where the emergency repair (or retrofit) is necessary? ☐ [Need] ☐ [Not Need] ☐[Not possible to judge]
Maintenance of current state
Others

Table 3.1.3-1 Judgment of Damage Grade Classification Sheet for Ground[1]

Sheet No.
Time&Date
Recoder
Site adress

Damage patern		
☐ [A]: Collapse of fill-up ground		
kind of fill−up ground terraced others		
Collapsing width:	(m)	
Collapsing length:	(m)	
Collapsing azimuth:		
Number of collapse housing lots		
Is there a building area in the vicinity of collapse ground?		
☐ [Yes] ☐ [No]	Numbers of housing lots	
Investigation method		
☐ by watching ☐ by video ☐ by scaling ☐ others		
Soil type		
☐ Sand, ☐ Loam, ☐ Viscous soil , ☐ Gravel, ☐ Others		
☐ [B]: Collapse of hillback slope		
kind of hillback slope natural slope cutting slope		
Collapsing width:	(m)	
Collapsing length:	(m)	
Collapsing azimuth:		
Inclination of slope:	(deg)	
Surface condition of slope:		
☐Weed ☐Turf	☐Mortar ☐Tree	☐Others
Number of outflow building area : Number of burying building area : Number of building area in surrounding :		
Investigation method		
☐ by watching ☐ by video ☐ by scaling ☐ others		
Soil type		
☐ Sand, ☐ Loam, ☐ Viscous soil , ☐ Gravel, ☐ Others		

Example 3 (Cont.) **Sheet 2/3**

☐ [C]: Collapse or Fall of Retaining Wall
Hight of Retaining Wall Type of Retaining Wall Collapsing width: Collapsing hight: Collapsing length: Collapsing azimuth:
Number of outflow building area : Number of burying building area : Number of building area in surrounding :
Investigation method
☐ by watching ☐ by video ☐ by scaling ☐ others
Soil type
☐ Sand, ☐ Loam, ☐ Viscous soil , ☐ Gravel, ☐ Others
☐ [D]: Crack and Step
The generation points:
Width of Crack or Step (m)
Length of Crack or Step (m)
Depth of Crack or Step (m)
Range of Crack or Step (m^2)
Number of building area in damage region :
Investigation method
☐ by watching ☐ by video ☐ by scaling ☐ others
Soil type
☐ Sand, ☐ Loam, ☐ Viscous soil , ☐ Gravel, ☐ Others
☐ [E]: Settlement , Inclination, Undulation and movement of retaining wall
The generation points:
Damage hight (m)
Damage length (m)
Damage width (m)
Number of building area in damage region :
Investigation method
☐ by watching ☐ by video ☐ by scaling ☐ others
Soil type
☐ Sand, ☐ Loam, ☐ Viscous soil , ☐ Gravel, ☐ Others

☐ [F]: Watter
The generation points: Volume of water: ☐ Large amount, ☐ Midlle amount, ☐ Oozes out Past situation: ☐ [Yes], ☐ [No] Liquifaction: ☐ [Yes], ☐ [No] Outflow of gas: ☐ [Yes], ☐ [No]
Investigation method
☐ by watching ☐ by measurement ☐ others
Soil type
☐ Sand, ☐ Loam, ☐ Viscous soil , ☐ Gravel, ☐ Others

Damage patern
Sketch of damage situation
Failure Settlement Upheaval Spring water Displacement Step Crack House Retaining wall Slope S Emergency action is necessary

Filling in recoder's opinion
Is there a place where the repair (or the retrofit) are necessary? ☐ [Need] ☐ [Not Need] ☐[Not possible to judge]
Progress situation of damage ☐ [Change], ☐ [No change]
Necessity of movement observation ☐ [Need], ☐ [No need]
Others

Example 4 **Sheet 1/4**

Table 3.1.3-2 Judgment of Damage Grade Classification Sheet for Building Area Ground [1]

Sheet No.
Time&Date
Recoder
Site adress

Damage patern and content

☐ [A]: Slope failure

Kind of slope
- ☐ cutting slope
- ☐ enbankment slope
- ☐ natural slope

Hight of slope(H): (m)
Inclination of slope: (deg)
Azimuth of slope:
Collapsing slope width(B): (m)
Collapsing slope length(L): (m)
Distance to Building(S): (m)

Caluculation of damage grade index R1 or R3s

R1=(H x B x L)/(S + 1) ⋯(Eq. − 1) R1 =

or

R3s=(H x (B+1) x (L+1))/(S + 1) R3s=

Evaluation of damage grade index point P1 or P3s

R1 or R3s	P1	P3s
50=< R1 or R3s	9	6
25<R1orR32<50	6	4
R1 or R3s <= 25	3	2

P1 =
P3s=

Investigation method

☐ by watching ☐ by scaling
☐ by video ☐ others

Soil type

☐ Sand, ☐ Loam, ☐ Cohesive soil , ☐ Gravel, ☐ Others

☐ [B]: Collapsing or Over turnning of Retaining Wall

Type of Retaining Wall

Hight of Retaining Wall (H): (m)
Collapsing or Over turnning retaining wall width((m)
Collapsing or Over turnning retaining wall length (m)
Distance to Building(S): (m)

Caluculation of damage grade index R2

R2 = B x L ⋯(Eq. − 2) R2 =
R3w=(B+1) x (L+1) R3w=

Evaluation of damage grade index point P2 or P3w

R2 or R3w	P2	P3w
20=< R2 or R3w	9	6
10<R2orR3w<20	6	4
R2 or R3w <= 10	3	2

P2 =
P3w=

Investigation method

☐ by watching ☐ by scaling
☐ by video ☐ others

Soil type

☐ Sand, ☐ Loam, ☐ Cohesive soil , ☐ Gravel, ☐ Others

Example 4 (Cont.) **Sheet 2/4**

Damage patern and content

☐ [C]: Occurrence of Crack

Place of Crack
- ☐ Slope
- ☐ Retaining Wall
- ☐ Building area

Width of Crack (B): (m)
Length of Crack (L): (m)
Depth of Crack: (m)
Distance to Building(S): (m)
Hight of slope(H): (m)

Caluculation of damage grade index and Evaluation of damage grade index point

Slope

R3s=(H x (B+1) x (L+1))/(S + 1) R3s=
P3s=

Retaining Wall

R3w=(B+1) x (L+1) R3w=
P3w=

Building Area

R3g=(B+1) x (L+1)= m^2 R3g=
P3g=

R3g	P3g
150 =< R3g	3
50<R3g<150	2
R3g <= 50	1

Investigation method

☐ by watching ☐ by scaling
☐ by video ☐ others

Soil type

☐ Sand, ☐ Loam, ☐ Cohesive soil , ☐ Gravel, ☐ Others

☐ [D]: Inclination, Moving, Undulation of Retaining Wall

Damage type
- ☐ Inclination
- ☐ Moving
- ☐ Undulation

Width of Damage(B) (m)
Length of Damage(L) (m)
Hight of Damage(H) (m)
Degree of Inclination (deg)
Amount of movement (mm)
Distance to Building(S): (m)

Damage grade index and Evaluation of damage grade point

R4	P4
Undulation	3
Inclination	2
Moving	1

P4 =

Investigation method

☐ by watching ☐ by scaling
☐ by video ☐ others

Soil type

☐ Sand, ☐ Loam, ☐ Cohesive soil , ☐ Gravel, ☐ Others

Example 4 (Cont.) **Sheet 3/4**

Damage patern and content

☐ [E]: Settlement , Burying and Upheaval of Ground

Damage type

☐ Settlement
☐ Burying
☐ Upheaval

Damage scale

Width of damage(B) (m)
Length of Damage(L) (m)
Settlement or Upheaval (H) (m)

Damage grade index and Evaluation of damage grade point

R5 = B x L x H = ____ m^2

R5	P5
100 =< R5	3
50 < R5 < 100	2
R5 =< 50	1

P5 =

Investigation method

☐ by watching ☐ by scaling
☐ by video ☐ others

Soil type

☐ Sand, ☐ Loam, ☐ Cohesive soil , ☐ Gravel, ☐ Others

☐ [F]: Spring water such as liquifaction

Liquifaction: ☐ [Yes], ☐ [No]
sand boil ☐ [Yes], ☐ [No]
Amount of spring water ☐Many, ☐few, ☐blots begin
Past spring water situation ☐ [Yes], ☐ [No]
Generation points

Damage grade index and Evaluation of damage grade point

R6	P6
Soft ground	2
Spring water	1

P6 =

Investigation method

☐ by watching ☐ by measurement
☐ others

Soil type

☐ Sand, ☐ Loam, ☐ Cohesive soil , ☐ Gravel, ☐ Others

☐ [G]: Others

Example 4 **Sheet 4/4**

Damage pattern and content

Sketch of damage situation


Failure


Settlement


Upheaval


Spring water


Displacement


Step


Crack


House


Retaining wall


Slope


Emergency action is necessary

Evaluation of damage

P = P1 + P2 + P3 + P4 + P5 + P6 P =

(P3 = P3s + P3w + P3g) Evaluation of damage

Total point P	Damage level
10 =< P	Large damage
6 < P < 9	Middle damage
P =< 5	Small damage