WELCOME

WORKSHOP ON

Collaborative Research and Development Project for Disaster Mitigation in Earthquake Prone Areas in Asia

STUDY ON SEISMIC PERFORMANCE AND STRUCTURAL INSPECTION OF RETAINING WALL

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27 September, 2007

Table of Contents

Objectives

- Comparison of seismic performance of concrete block type retaining wall by shaking table test and Finite Element Method.
- To disseminate and generate awareness for earthquake disaster mitigation about the existing retaining walls to residents to encourage for regular environmental inspection
- To analyze the preliminary inspection sample survey data of retaining walls by using guideline of Japan
- Preparing an inspection manual for different types of retaining walls

Retaining walls

Stone masonry Retaining wall with clogged weep holes due to weeds

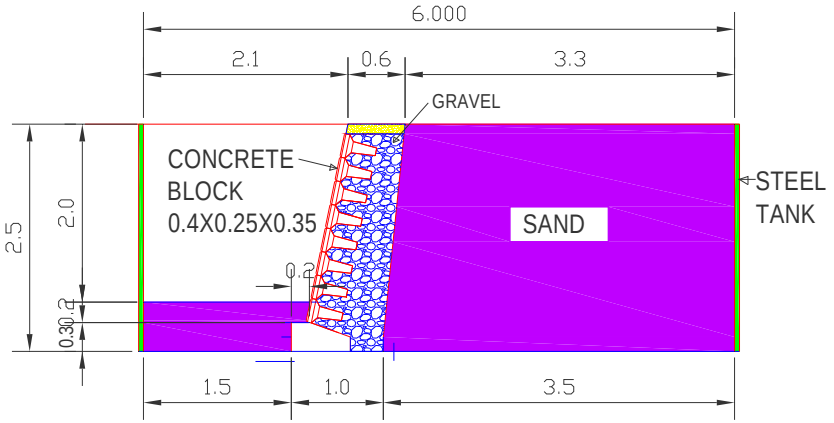
No provision of proper catch drain in the upstream side of Retaining wall and water flowing over the wall

Stone masonry Retaining wall constructed outer face vertically to protect building from damage

Noto Japan

3 Shaking table test for Retaining walls

- The length, breadth and height of the specimen were 6m, 3m and 2.5m respectively was set inside a steel tank.
- The size of each concrete block was 400mm x 250mm x 350mm



SECTIONAL ELEVATION OF DRY BLOCK
RETAINING WALL WITHOUT CONCRETE BACKING

- Two specimens tests on retaining wall without concrete backing and with concrete backing.
- The inclination of retaining wall was 77 degree with horizontal.

818gal.mpg

1000gal.mpg

Applied Accelerations Kobe Earthquake 1995
NS component:

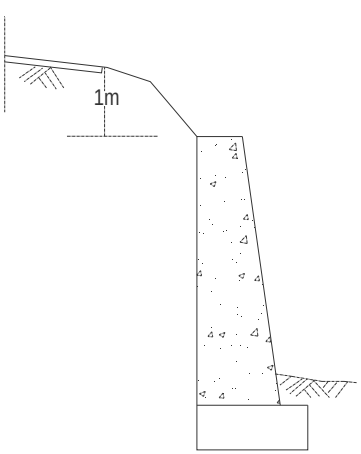
100gal, 200gal, 400gal, 818gal and 1000gal

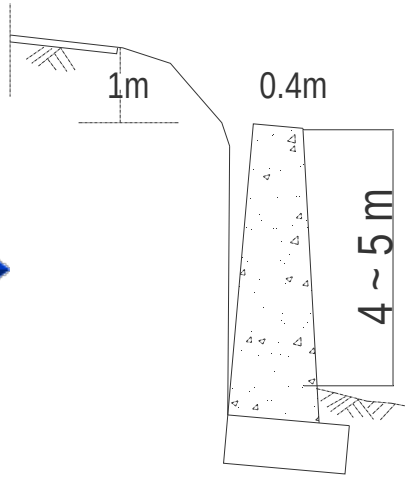
Concrete block retaining wall with concrete backing case

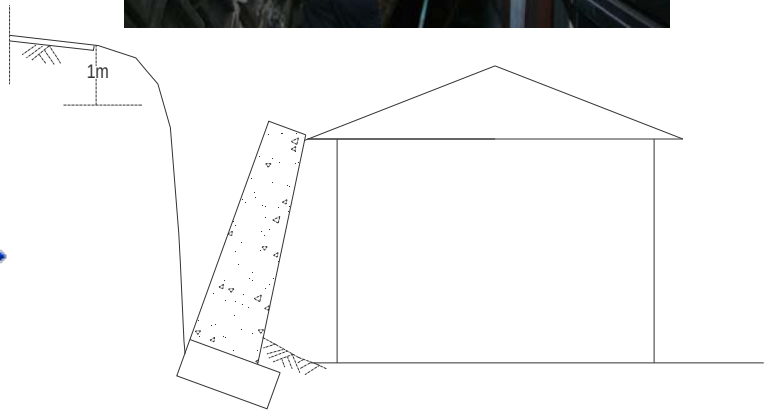
Slope of the wall 77°

Applied Acceleration Kobe 1995 NS component (1.2*818)

Earth quake as per Kashiwazaki K-net 667 gal





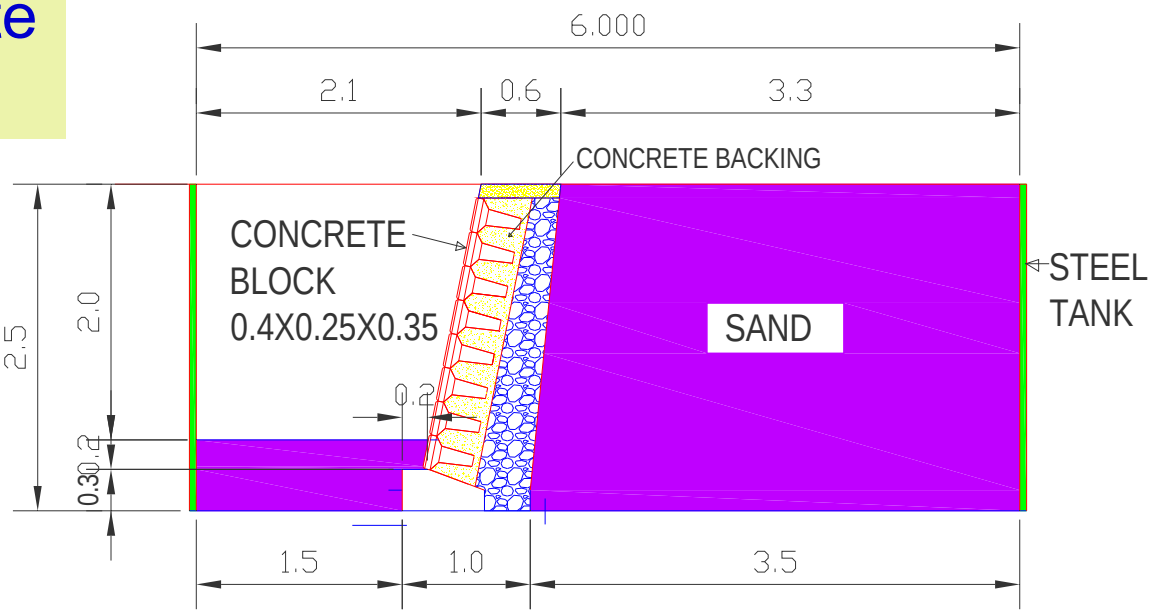


Slope of wall 78°

Nearly vertical after Earthquake

Overturning after 2 or 3 days

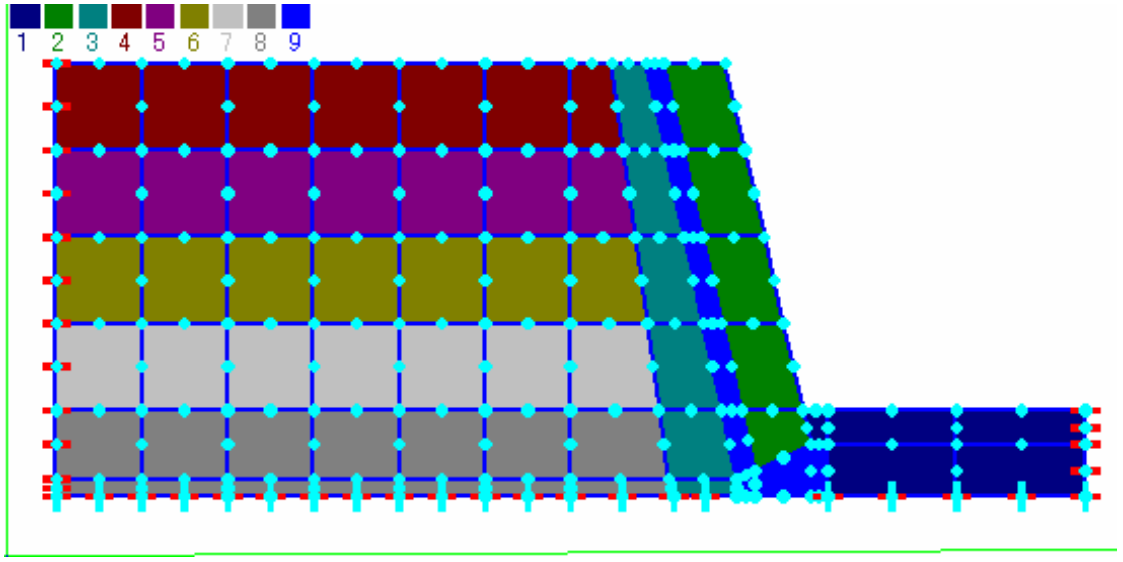
4. Calculation by Finite Element Method



SECTIONAL ELEVATION OF BLOCK RETAINING WALL WITH CONCRETE BACKING

- Elasto-Plastic two dimensional FEM dynamic analysis was performed in order to compare the shaking table test results for retaining wall with concrete backing

Material properties and support conditions



S.No	Young's modulus, Es(KPa)	Poisson's ratio n	Cohesion c (KPa)	Frictional angle Ø(Degree)	Dilatancy angle y	Unit wt.(KN/ m3)	Ko
1	3100	0.35	1	35	5	16	0
2	2.0E+5	0.15	1.0E+20	0	0	20	0
3	10000	0.3	1	45	15	19	0
4	3100	0.35	1	35	5	16	0
5	4300	0.35	1	35	5	16	0
6	5300	0.35	1	35	5	16	0
7	6100	0.35	1	35	5	16	0
8	6900	0.35	1	35	5	16	0
9	2.5E+7	0.15	1.0E+20	0	0	20	0

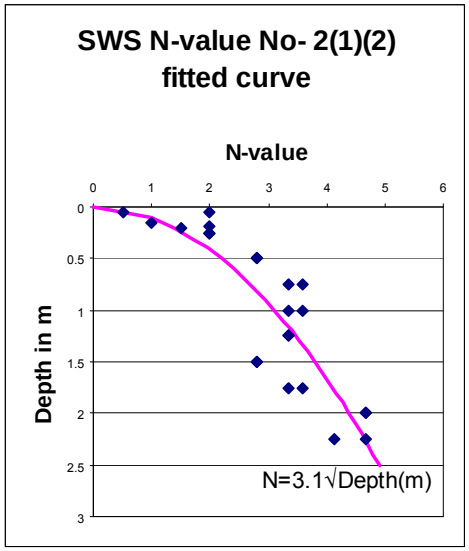
Young's modulus (in MN/m^2) of soil is calculated by: $Es=1.4N$

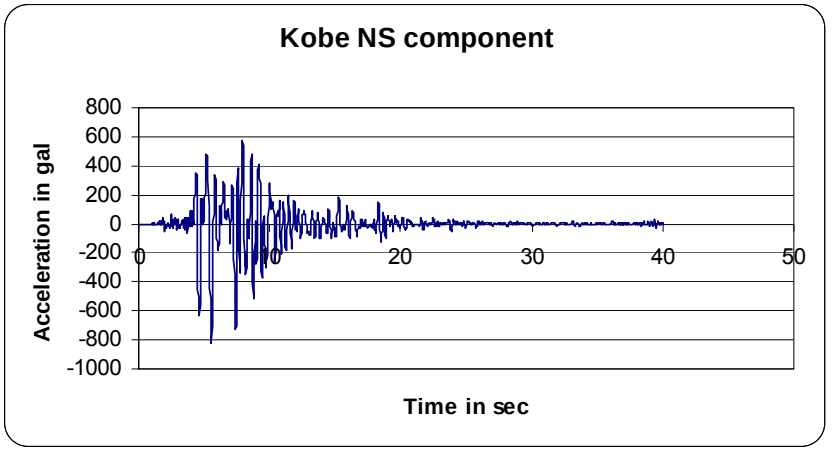
N-is calculated value from Swedish Weight Sounding test

(Recommendation for the Design of Building Foundations 2001(Japan)

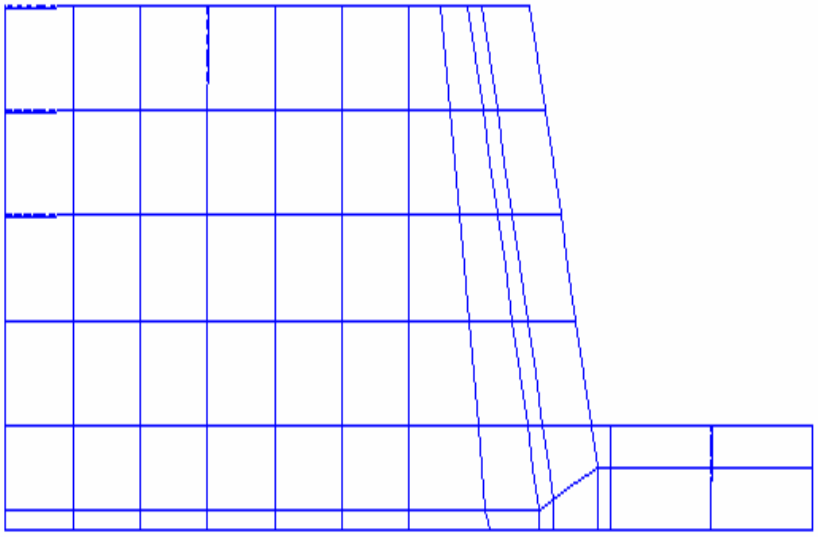
$Y=Ø - 30^\circ$

(Introduction to soil strength & ground failure published by Japan Geotechnical Society, 1995)

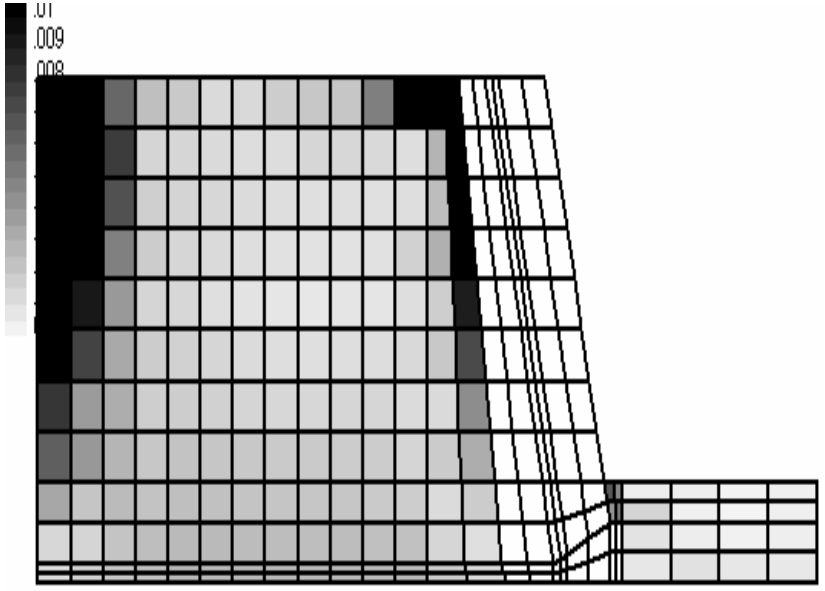




Recorded Kobe NS Component

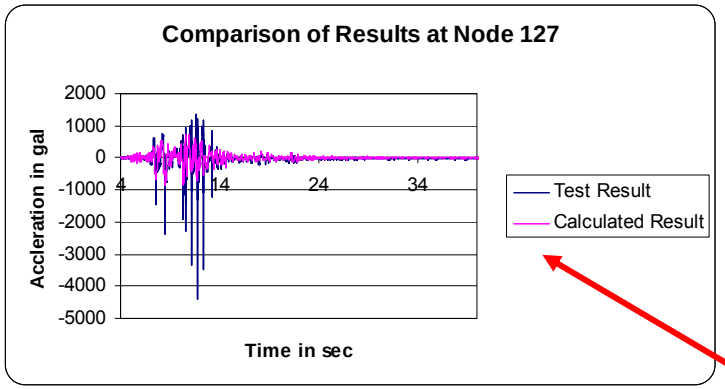


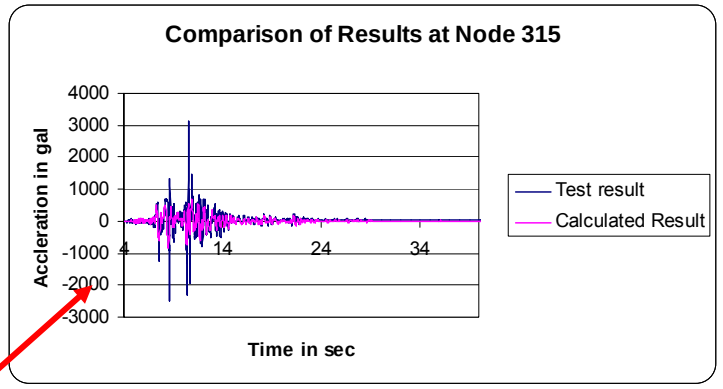
Displaced shape of specimen

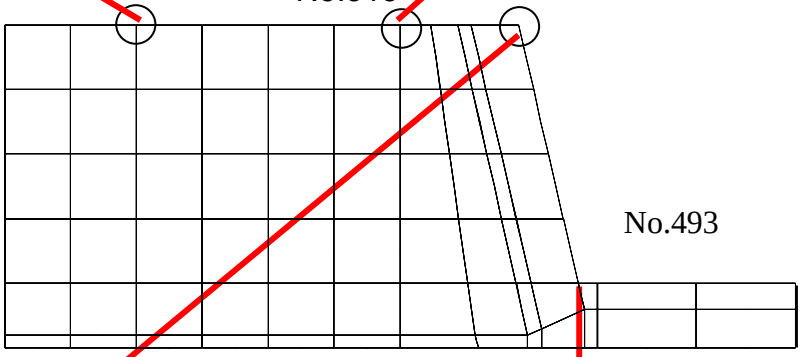


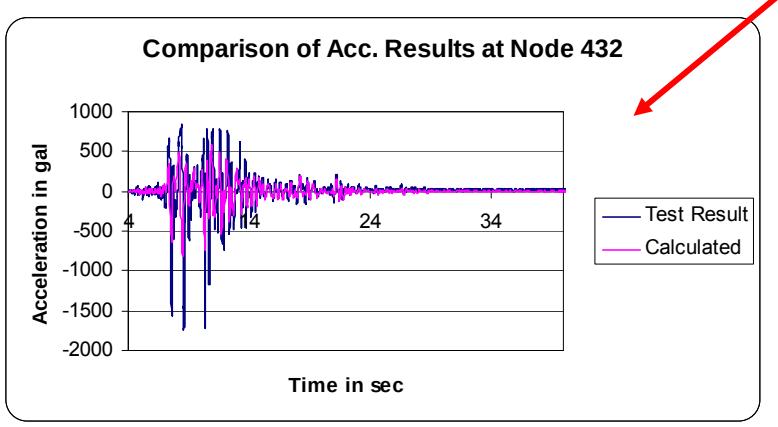
Strain in specimen

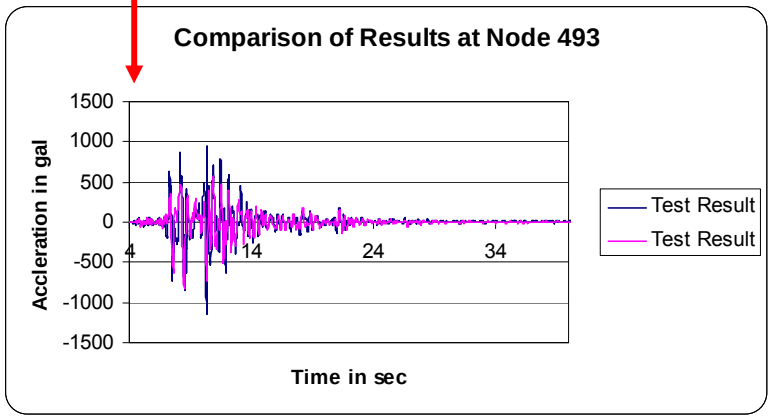
Comparison of acceleration at different nodes with applied Kobe NS component (818 gal)







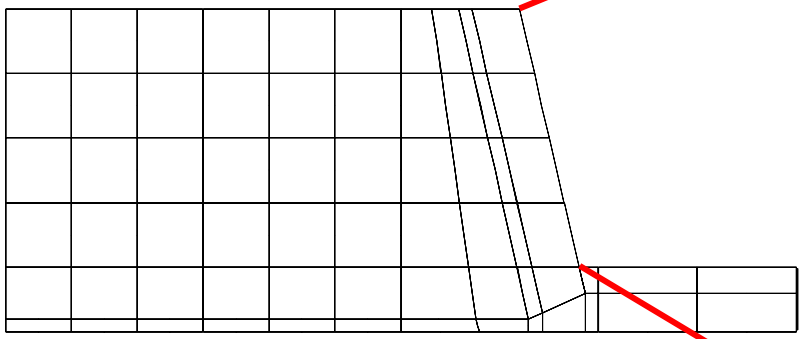


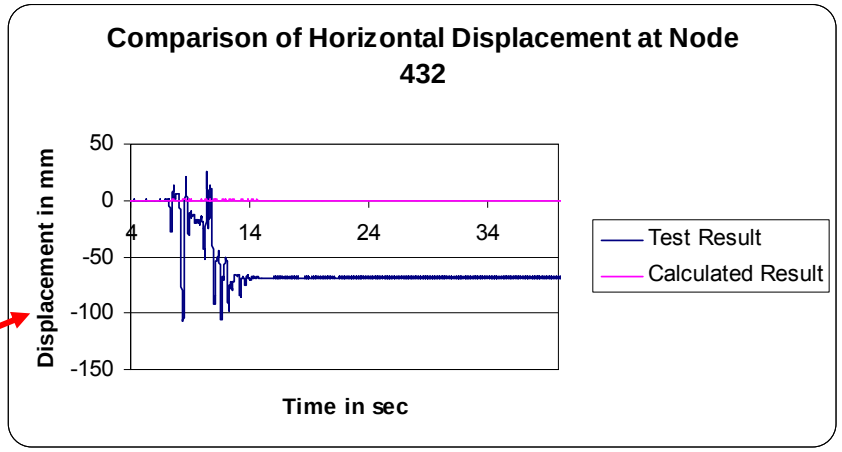


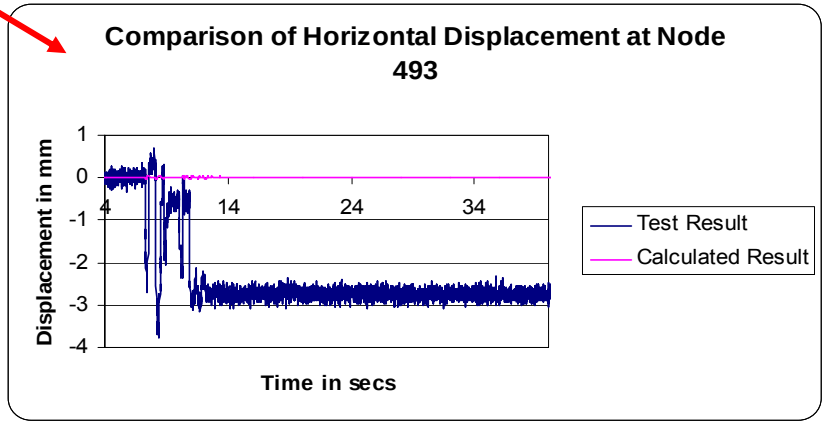
Wave forms are consistent

Displacements

Displacements are not consistent

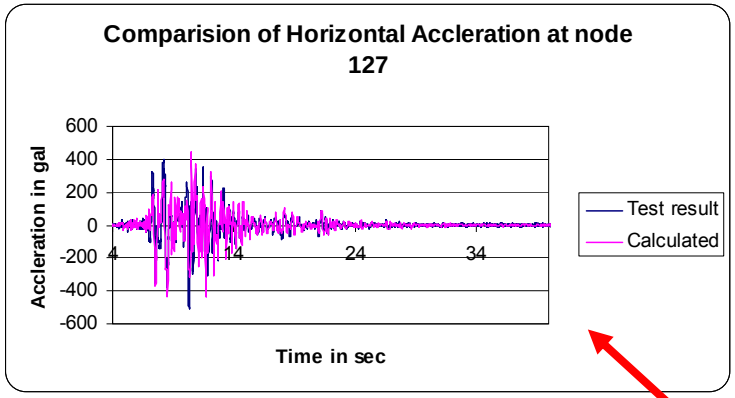


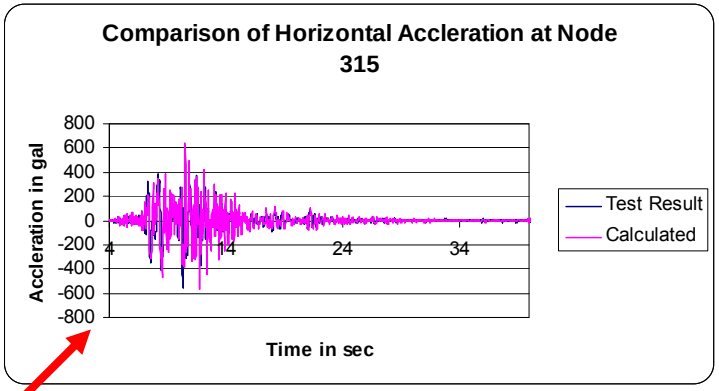




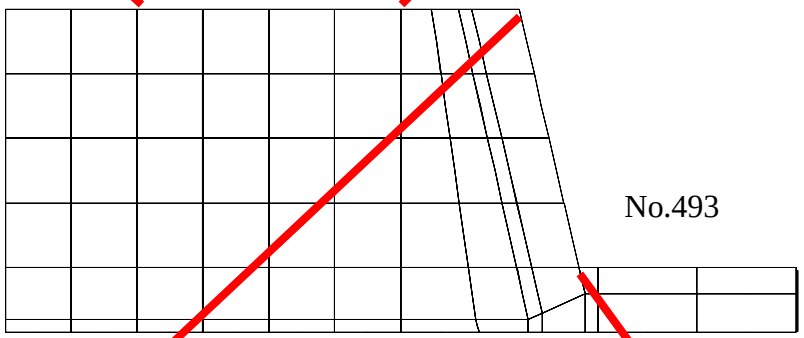
-Again I performed analysis by decreasing angle of internal friction for soil from 35° to 30° and same acceleration (818 gal) but the displacements were not matching with shaking table test

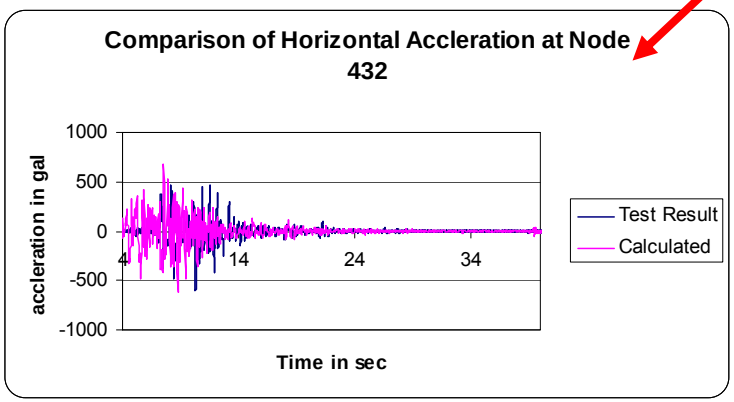
Comparison of Test Result and Calculated Result for 400 gal acceleration

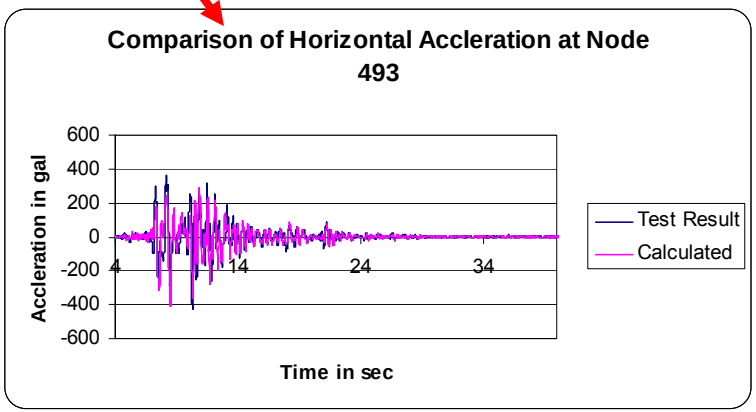




Wave forms are found consistent

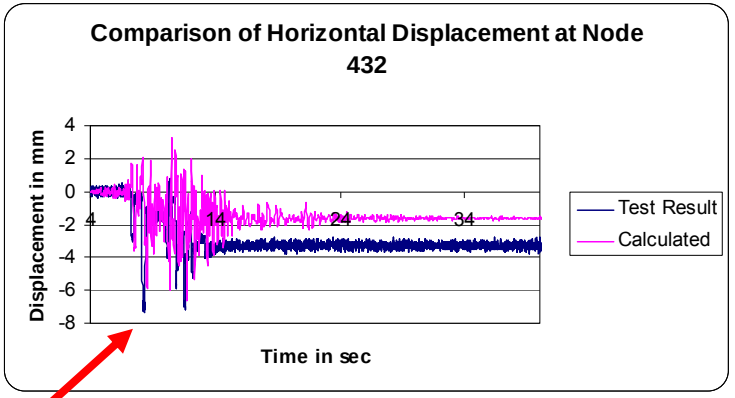


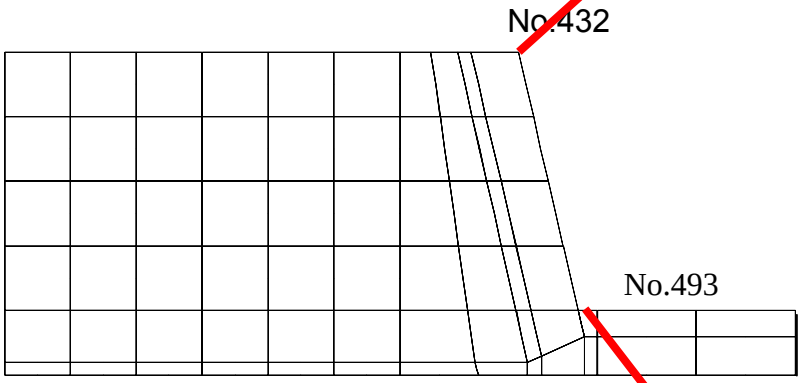




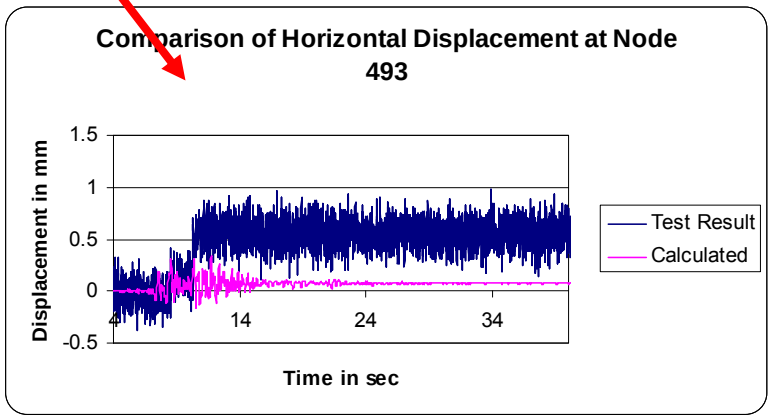
Comparison of Results for Displacement in 400 gal acceleration

Displacements are found to be nearer to each other from the both cases





It is found that this software shows displacement in small quake as the quake increases the attached surfaces separated out and it does not show the displacement



6. Structural inspection for retaining walls

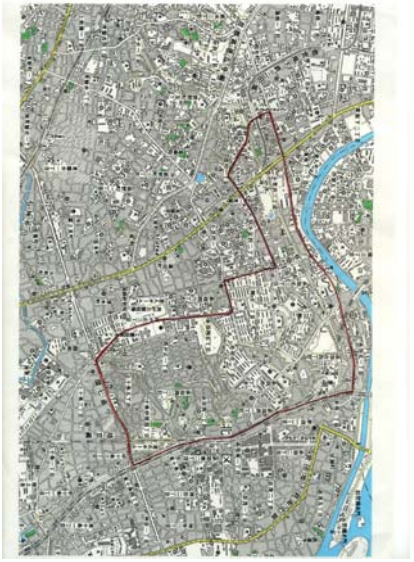
-To avoid secondary disasters right after an earthquake.

-Data of 229 retaining walls

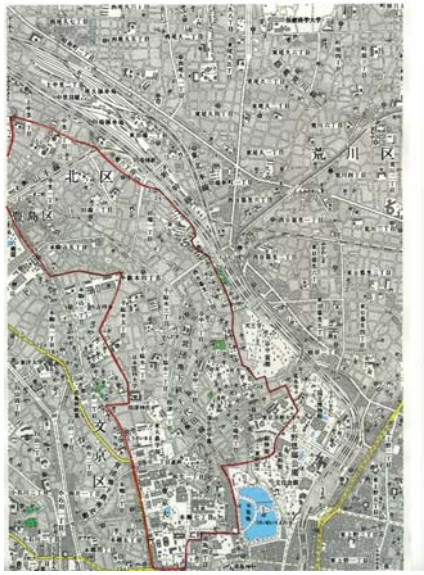
- Evaluation is performed based on guidelines of Yokohama city

- Evaluation is based on score system

Score <5,Almost safe:
>5 to less than or equal to 9, Relatively unsafe and > than 9 are High risk



Akabane area



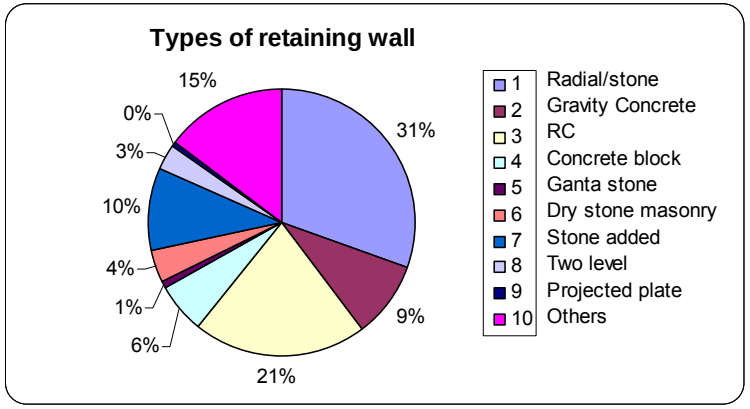
Ueno area

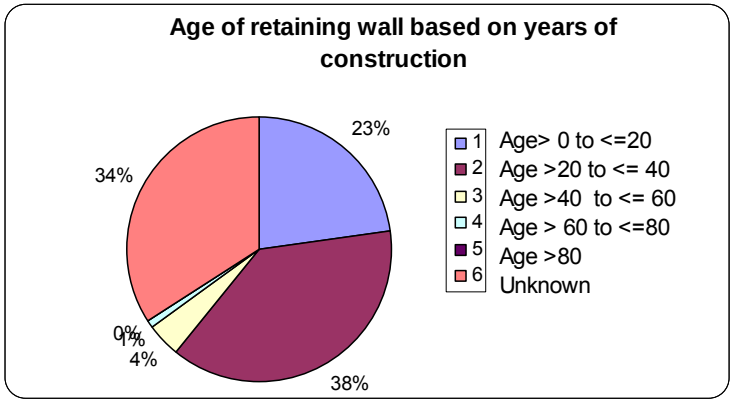
Map source: From Digital 25000 (Map image by Geographical Survey Institute, Japan)

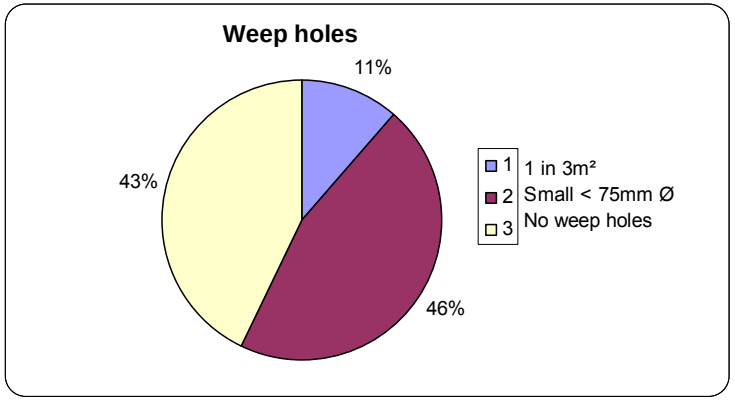
Evaluation criteria for retaining wall inspection

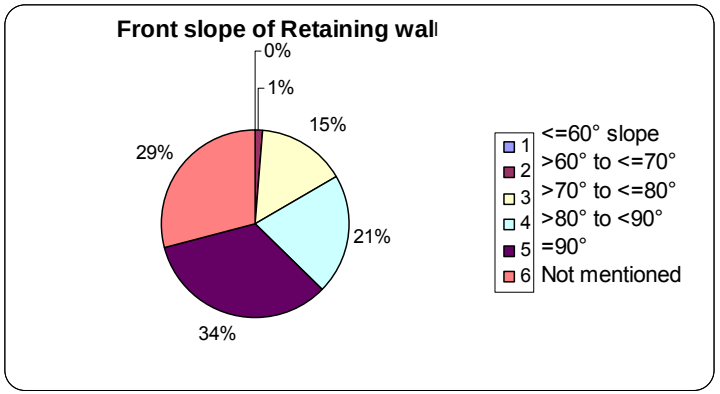
1	1 in 3m²	Small weep hole	No weep hole
Weep holes			
2	<75°	75° ~80°	>80°
Front slope of retaining wall			
3	No cracks	Width of 1~20(5)mm	Width >20(5)mm
Horizontal cracks			

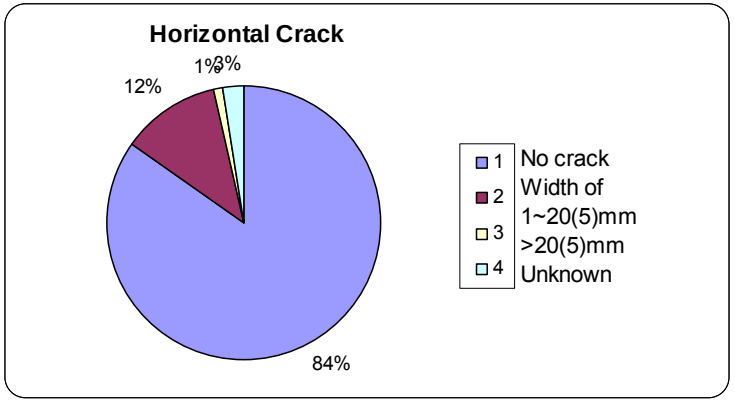
Results

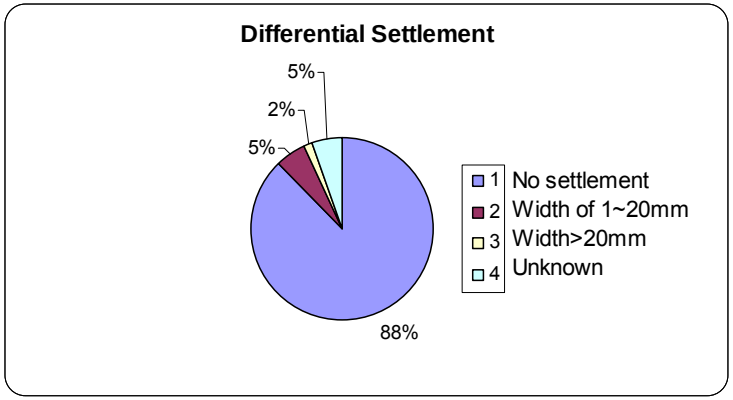

Types of retaining wall
15%
0%
3%
10%
4%
1%
6%
21%
9%
31%
1 Radial/stone
2 Gravity Concrete
3 RC
4 Concrete block
5 Ganta stone
6 Dry stone masonry
7 Stone added
8 Two level
9 Projected plate
10 Others

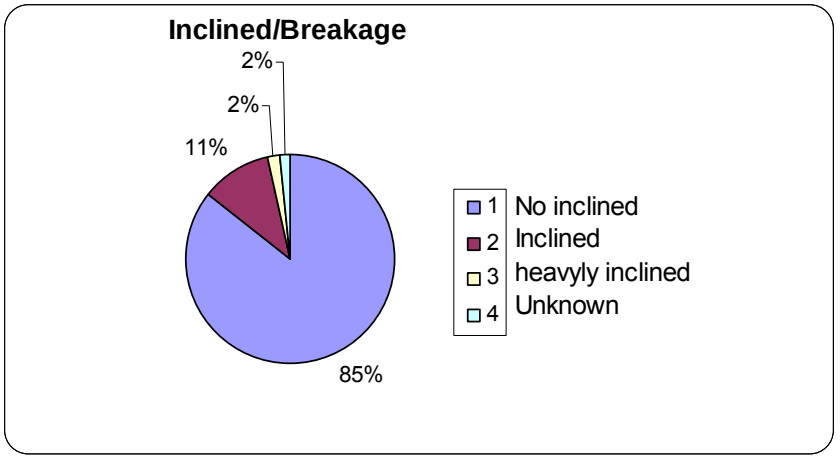

Age of retaining wall based on years of construction
23%
34%
0%
1%
4%
38%
1 Age> 0 to <=20
2 Age >20 to <= 40
3 Age >40 to <= 60
4 Age > 60 to <=80
5 Age >80
6 Unknown

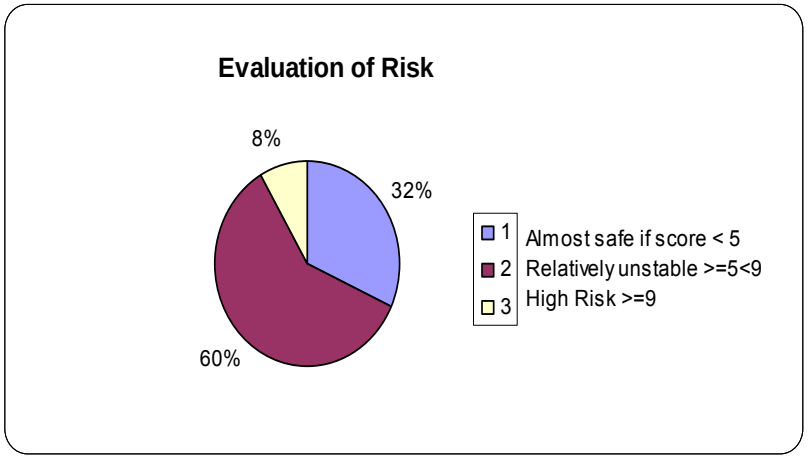

Weep holes
11%
43%
46%
1 1 in 3m²
2 Small < 75mm Ø
3 No weep holes


Front slope of Retaining wall
0%
1%
15%
29%
21%
34%
1 <=60° slope
2 >60° to <=70°
3 >70° to <=80°
4 >80° to <90°
5 =90°
6 Not mentioned


Horizontal Crack
1%
3%
12%
84%
1 No crack
2 Width of 1~20(5)mm
3 >20(5)mm
4 Unknown


Differential Settlement
5%
2%
5%
88%
1 No settlement
2 Width of 1~20mm
3 Width>20mm
4 Unknown





Findings:

- 32% of walls are found to be almost safe, 60% of walls are found to be relatively unstable and 8% of walls need to take due care.

- All the retaining walls have front slope more than 60˚

- 11% of retaining walls have only proper weep holes

Field investigation of retaining walls damaged by:

Noto Hanto Earthquake 2007

- Magnitude 6.9, 9:42 AM, On 25th March, 2007
- One person was killed, 170 people were injured

- Toge area has a steep slope more than 20° and retaining walls are found to be constructed for the construction of approach roads and houses to maintain the slope stability
- Lateral movement of retaining walls due to increased active earth pressure.

Lateral movement of retaining wall

Vertical crack near the corner for vertically extended wall

Niigata Chuetsu - Oki Earthquake 2007

•A couple of earthquakes 6^{+} on Japanese scale (JMA) in the interval of 14 hours in Niigata prefecture on 16th July,2007.

- •Death toll – 11 persons
- •Injured more than 1890

Completely collapsed wooden houses - 1024

Nearly 12,500 people are in evacuation center

Most of the casualties were from the collapsed of old wooden houses due to failure of earth retaining structures in Kashiwazaki city at Banzin area

Causes of failure of retaining walls

- Failure of foundation
- Slip or sliding of ground
- Inadequate thickness of wall with respect to height
- Overturning of walls
- Insufficient front slope

Overturning of retaining wall

Failure due to insufficient thickness of hollow block wall

Tilted pre-cast concrete block retaining wall

Sliding of retaining wall and crumbling of road side drain

Checking of ground water table from the existing wells

Corner splitting and tilted block compound wall

Sliding of RC retaining wall

Karihamura area

Failure of newly constructed house at the foot hill due to slip, upheaval of ground and liquefaction

Less or no clearance between slope toe and house

Cracking at corner of wall

Settlement of ground due to combined effects of sliding and liquefaction

Recommendation of manual for inspection of retaining walls

Checking algorithm

1) Checking the surrounding environmental conditions

a) Weep holes

b) Exuded water

c) Drainage facilities

The largest one is used out of scores in a) to c)

2) Checking retaining wall based on followings:

a) Cracks

b) Horizontal displacement

c) Differential settlement

d) Clearance at external corner

e) Bulge

f) Inclination/ Breakage

The largest one is used out of scores in a) to f)

3) Finally, evaluating the retaining wall based on the higher scores obtained in 1) and 2) items

- If the sum of the higher score of 1) and 2) is less than 5 points, the safety class of the retaining wall is Almost safe
- If the sum of the higher scores of 1) and 2) is equal or greater than 5 to less than 9 points safety class of the retaining wall is Relatively unsafe

•If the sum of the higher scores of 1) and 2) is more than 9 points safety class of the retaining wall is Relatively unsafe

1) Surrounding environmental condition

Weep hole (Excluding dry stone and Gabion walls)

Condition of retaining wall	Score
Drainage of upstream and proper numbers of weep holes exists (1 weep hole of 100Ø at 2.25 m² surface area of wall)	0.0
Weep holes are clogged or small weep hole exists	1.0
No weep holes	2.0

Water exudation

The surface of retaining wall is dry	0.0
The surface of wall is always wet	0.5
Water flows over the surface	1.0

Drainage facility

The drainage facility is good	0.0
Side drain and upstream drain is crumbled, sedimentation, depressions are formed on the upstream side	0.5
Water flows out from the cracks or joints of retaining wall	1.0

The largest score out of above 3 cases is used for evaluation

2) Cracks

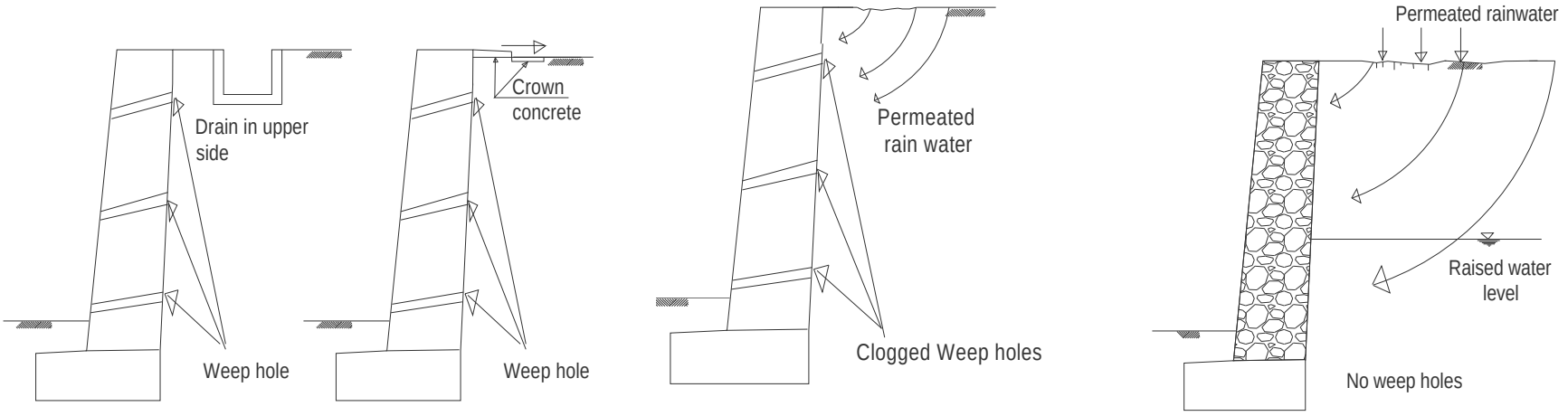
Horizontal crack for R.R. stone masonry/Brick masonry/ Concrete block

No cracks	0.0
Horizontal crack along the joint of masonry in the vicinity of center	3.5
Horizontal crack at the joint of masonry and material of wall itself	5.0
Horizontal large open crack	6.5

Inclination/ Breakage

No inclination	0.0
Slightly inclined forward or backward	5.0
Apparently inclined forward or backward	6.5
Breakage due to inclination	9.0

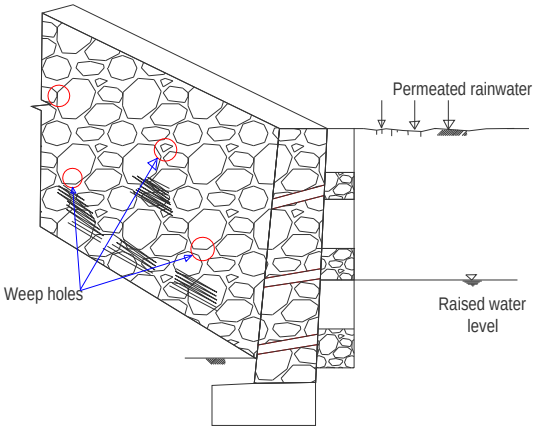
Surrounding environmental condition inspection



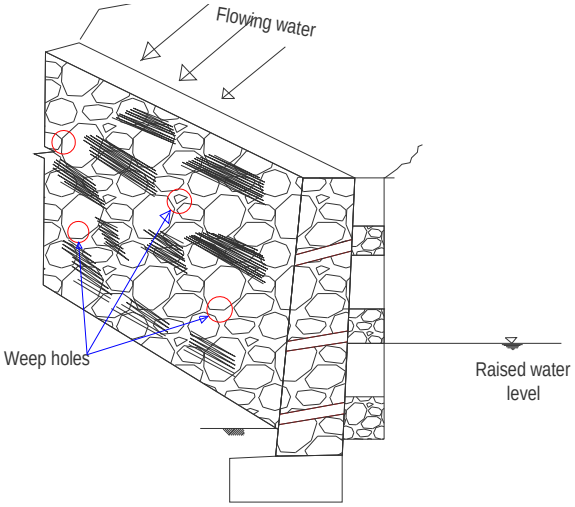
Weep holes, Exuded water and Drainage conditions

Reference drawings for manual

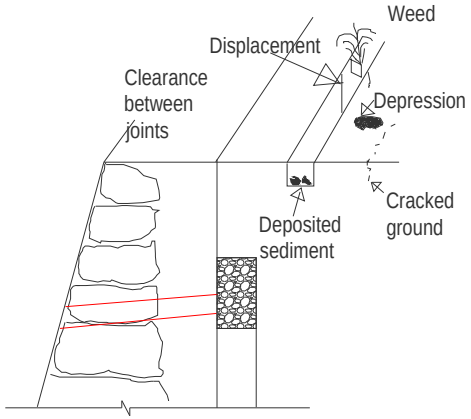
Surrounding environmental conditions



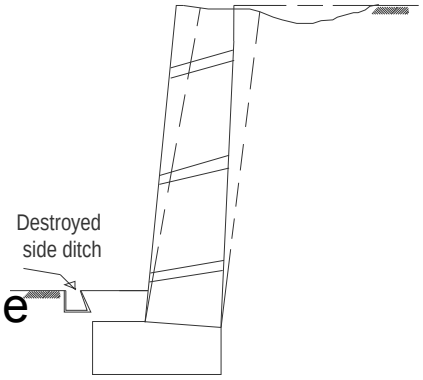
Wetted retaining wall



Flowing water over the retaining wall



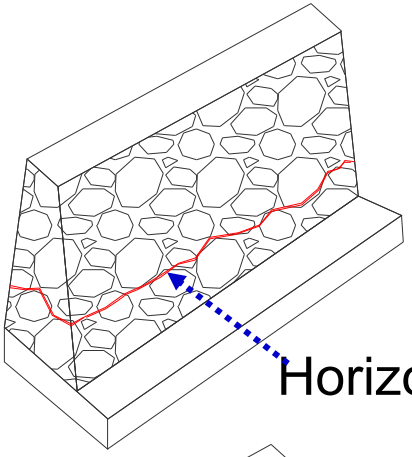
Lack of proper routine maintenance



Displacement due to settlement

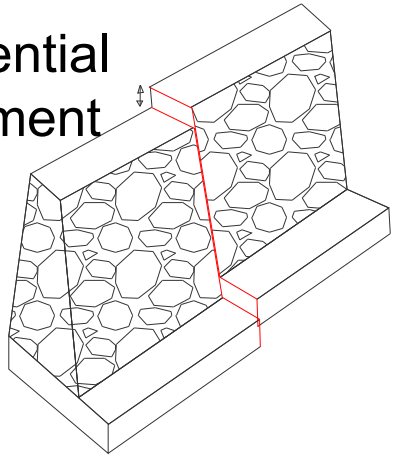
Crumbled side drain and tilted structure

Different possible cases of cracks for R.R stone masonry

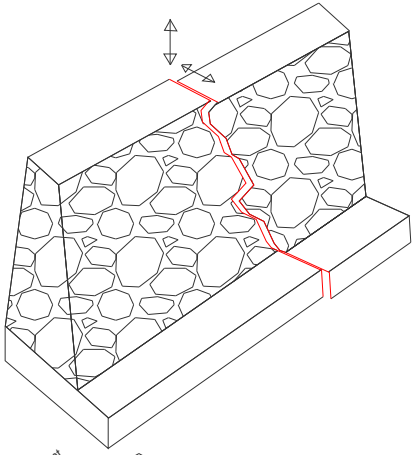


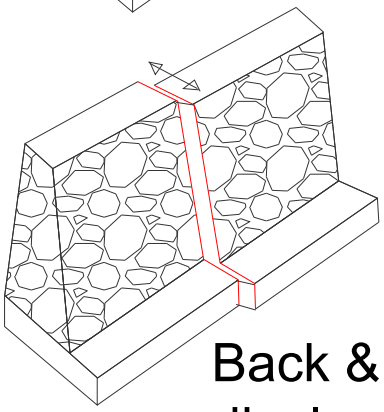
Horizontal

Differential settlement



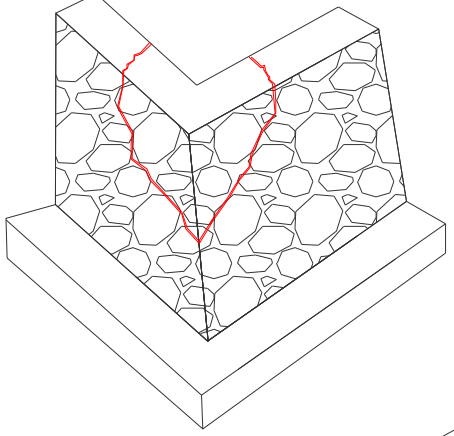
Vertical/ Oblique failure

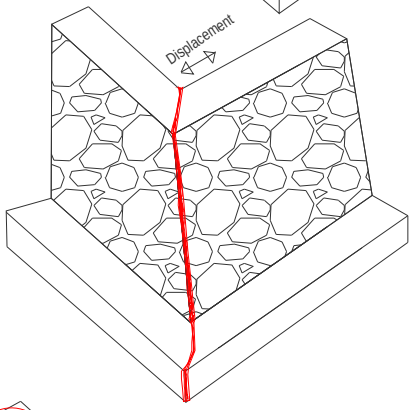




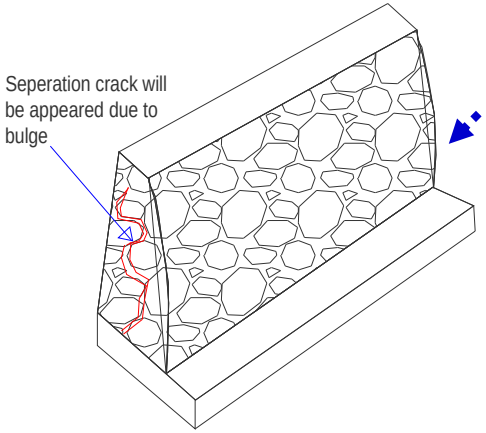
Back & Forth displacement

External corner cracking

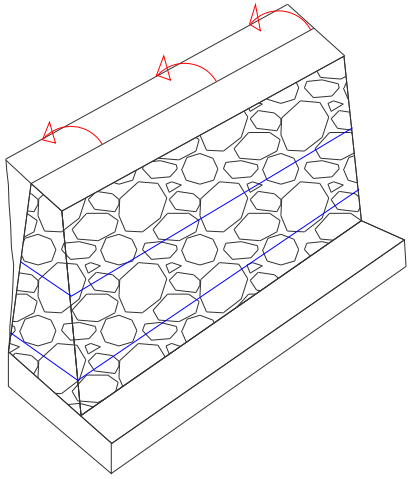




Corner splitting

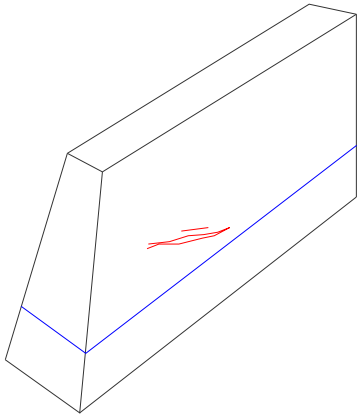


Bulging

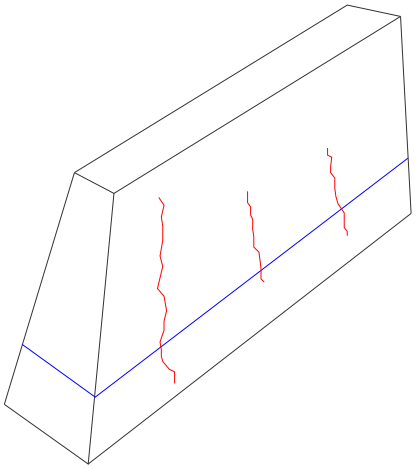


Inclination/ breakage

Possible cracks in gravity concrete retaining walls

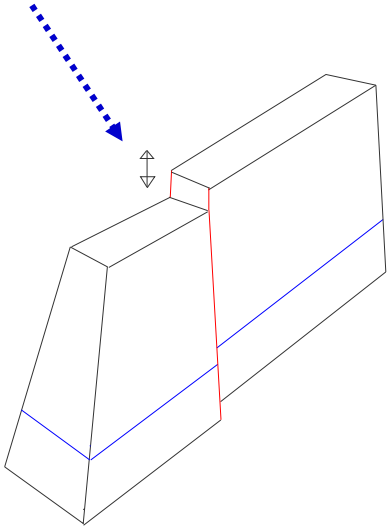


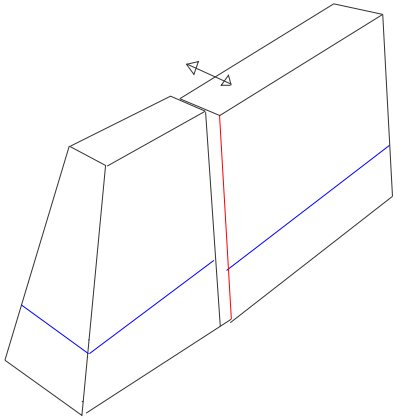
Horizontal crack



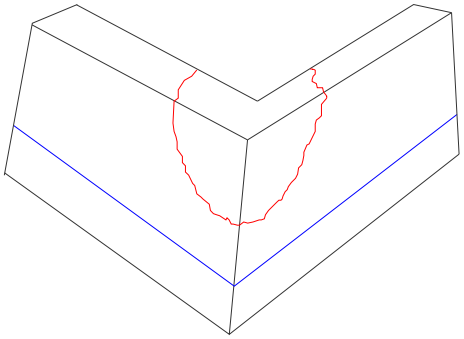
Vertical cracks

Differential settlement crack



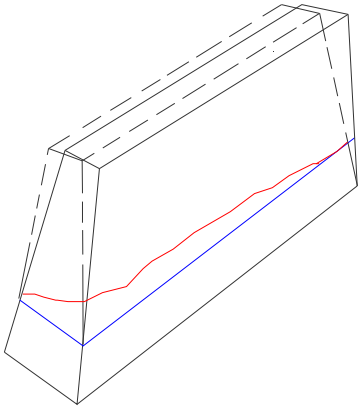


Back & forth movement crack



Cracking at external corner

Tilted/ Inclined wall



Conclusion

- The wave form of acceleration from the both shaking table test and finite element method for retaining wall are consistent at measured different nodes.
- The displacements obtained by the application of acceleration of 400gal are nearly consistent for both FEM and Shaking table test.
- The displacement obtained by the application of 400 gal acceleration and 818 gal were not found any change due to the slip of the surfaces at the crack point.
- Developed manual for the inspection of retaining wall will help to raise awareness among the concerns and will be a meaningful tool to evaluate the level of risk and to prevent the loss of life and properties from the secondary disaster right after a big quake.
- Field study right after an occurrence of earthquakes helped me to understand the key points to be taken in consideration while designing of earth retaining structures.


THANK YOU
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