

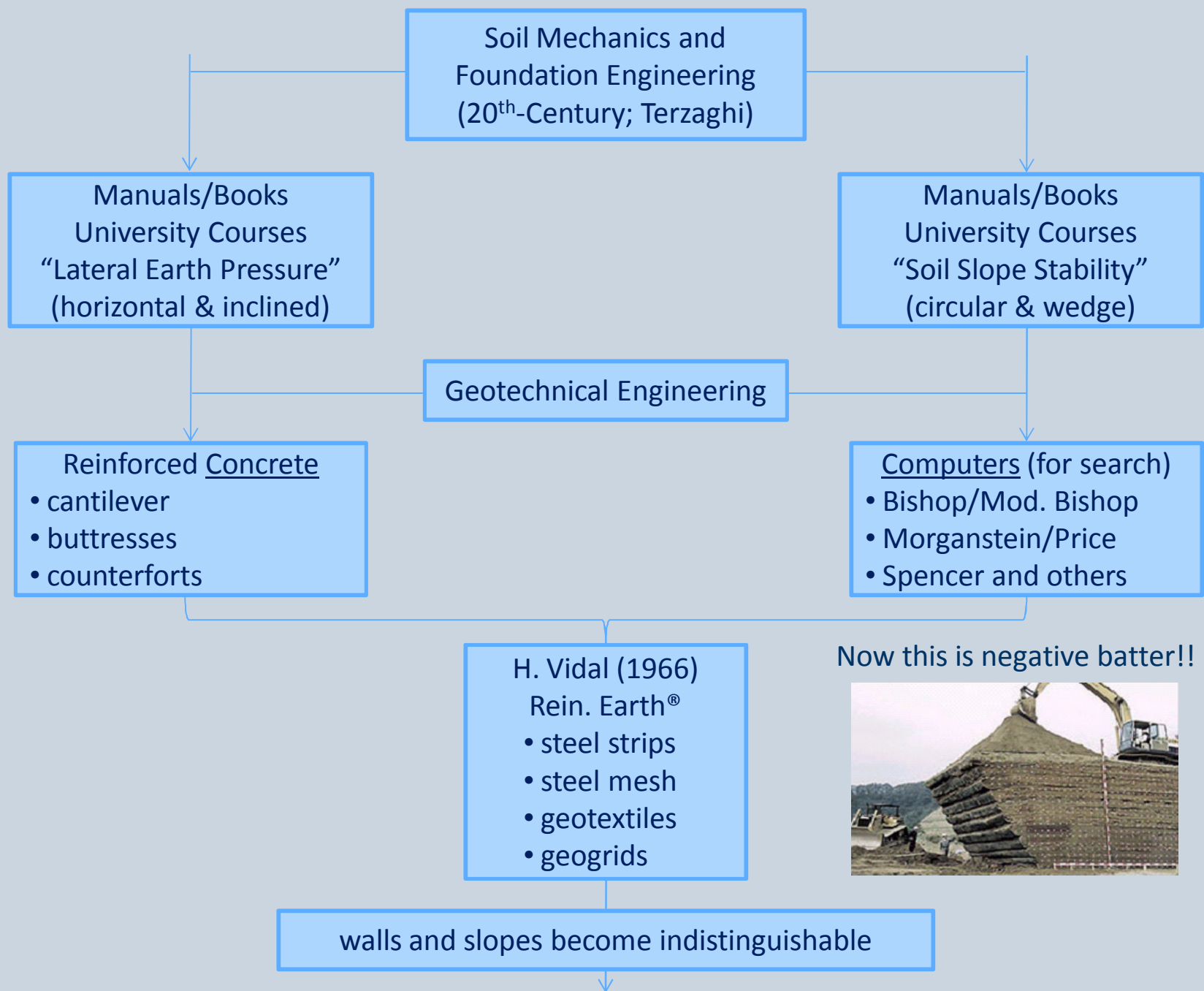
# **Geosynthetic Reinforced MSE Wall Failures and Their Remediation**

**by**

**Bob and George Koerner  
Geosynthetic Institute**

0. A Few Historical Musings
1. Introduction and Background
2. The Two Failure Classifications
3. Main Statistical Findings
4. Design & Construction Issues
5. Remediation Case Histories
6. The Cost of Remediation
7. Summary and Conclusions





Now this is negative batter!!



walls and slopes become indistinguishable

Since  $\approx$  1980

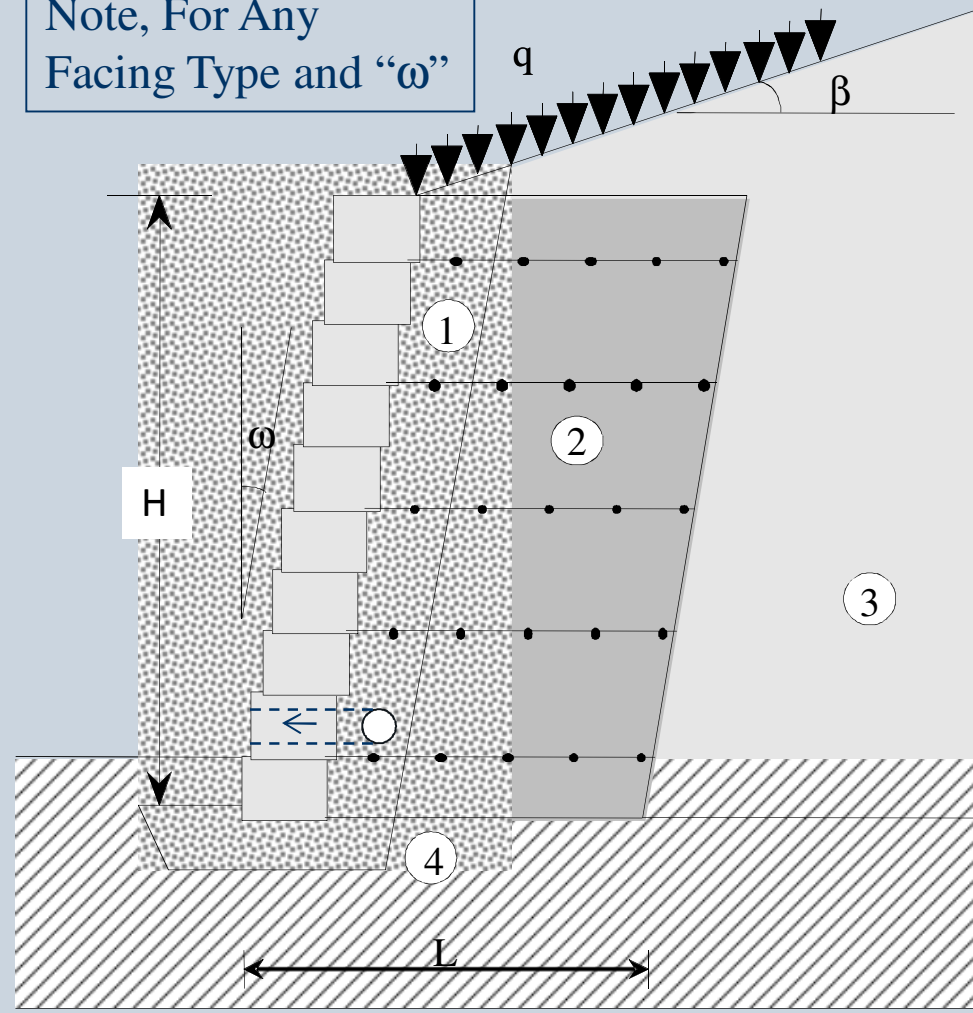
Always Computer  
Design or Analysis  
(FHWA, NCMA, ReSSA)

Internal  
Piecewise Linear  
Compound  
(Spencer Method)

External  
Circular Arc  
Behind & Beneath  
(Mod. Bishop Method)

Present Status of MSE Walls  
(many courses on design; just one  
on failure and remediation)

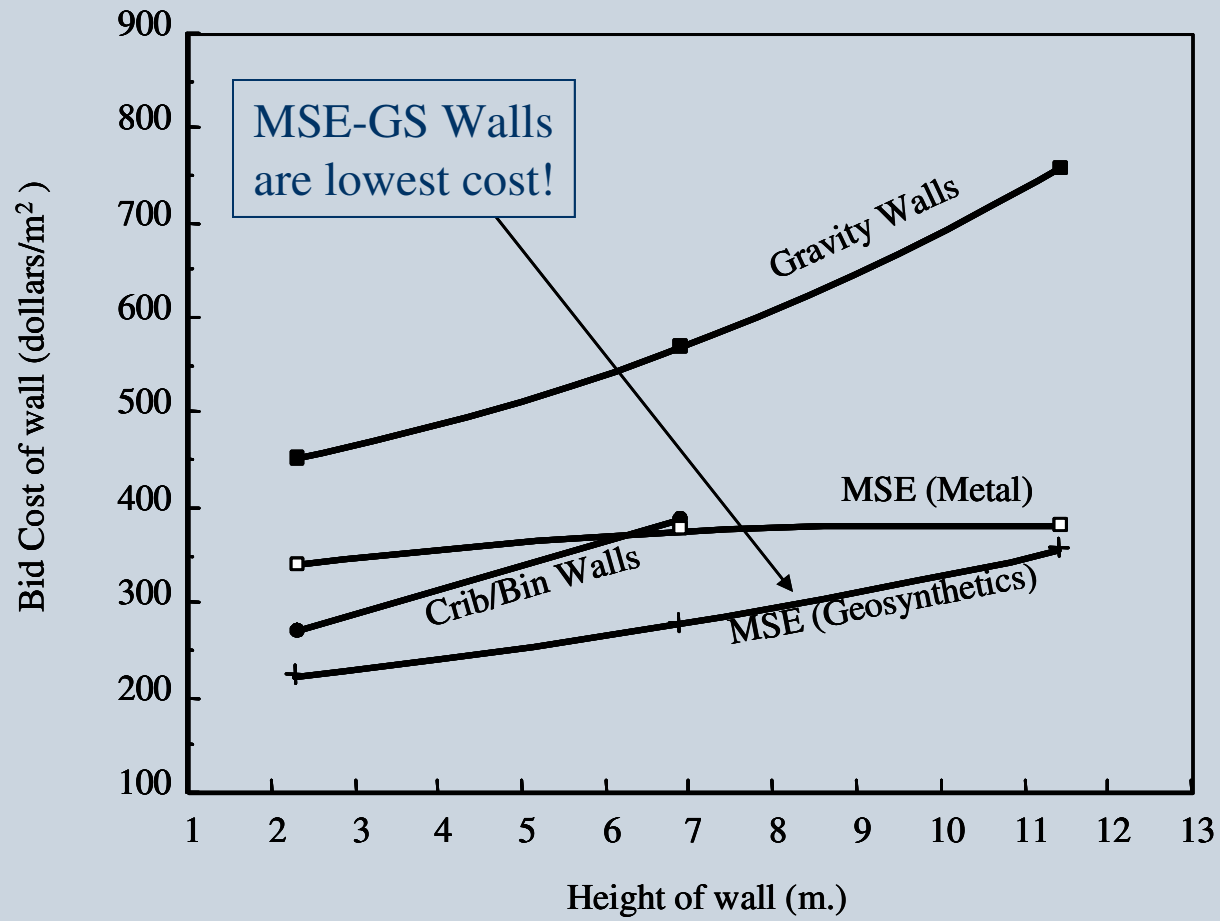
The Topic Under Discussion.....  
Note, For Any Facing Type and “ $\omega$ ”



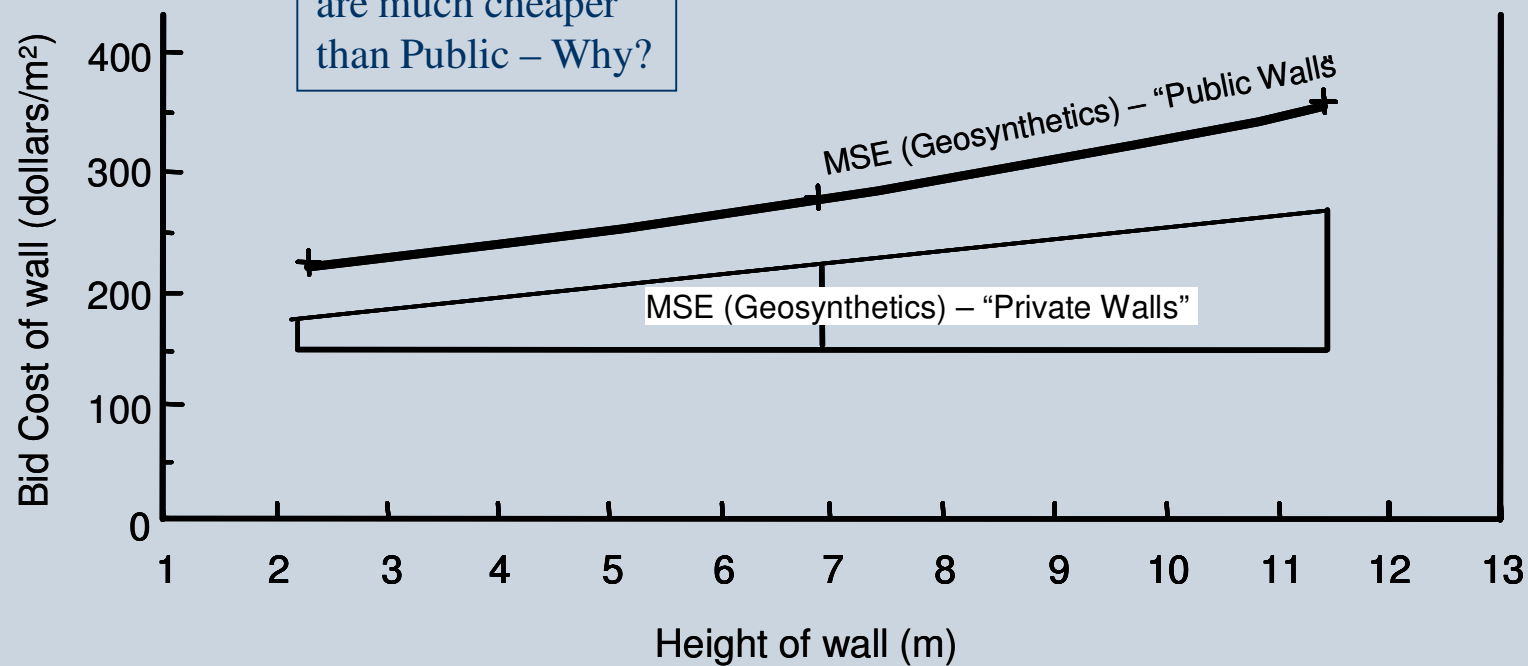
- Legend
- 1 – front drainage
  - 2 – rein. soil
  - 3 – ret. soil
  - 4 – fdtn. soil

# 1. Introduction and Background

- Koerner/Soong paper in 2001; 26 failures
- considered failure as being both excessive deformation and/or collapse
- 20 of 26 cases had silt and/or clay backfills
- most cases had no CQA inspection
- only one global geotechnical soil failure
- included an earlier cost survey of public and private walls (Koerner, et al., 2001)



But Private Walls  
are much cheaper  
than Public – Why?





# Possible Reasons for Lower Cost

(in no particular order)

- less conservative computer design code
- poor control of backfill soil and compaction
- less (or no) construction inspection
- vendor design without related project reports
- lack of peer review of plans and specifications

# GRI Report #38 (12/16/2009)

- contains 82-case history failures; 23 excessive deformation and 59 collapses (3 were both)
- information obtained from following sources:
  - Published literature = 27 cases
  - GSI files = 13 cases
  - Colleagues' files = 36 cases
  - Other (e.g., internet, etc.) = 6 cases
- report kept internal to GSI members

# Present Status (4/1/2012)

- report stimulated additional case histories
- presently 141-cases with 34 excessive deformation and 107 collapses (3 were both)
- information obtained from following sources
  - published = 53
  - GSI files = 15
  - colleagues files = 67
  - other (internet, etc.) = 6
- let's see what we have in this regard...

# Items Under Investigation

1. Wall ownership (public or private)
2. Location of case history (by continent!)
3. Type of wall facing
4. Maximum (or collapse) wall height
5. Type of geosynthetic reinforcement
6. Service lifetime of wall
7. Primary responsibility
8. Soil backfill type
9. Compaction of soil backfill
10. Basic failure mechanism

# 2.0 The Two Failure Classifications

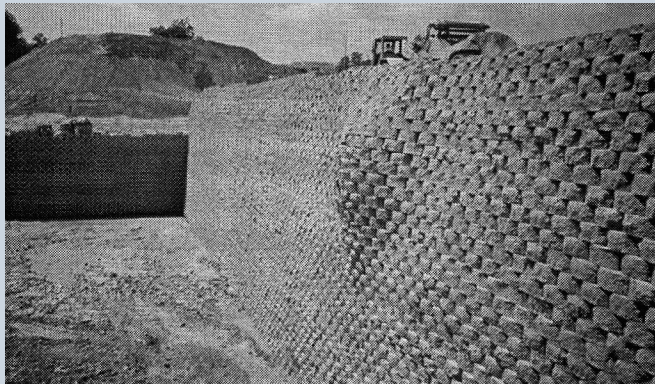
## (a) Excessive Deformation

- what is excessive?
- owner's answer differs from contractor's
- design engineer is probably in the middle
- masonry block most noticeable
- vegetated face least noticeable
- let's see some of them...

# Cases of Excessive Wall Deformations



Photos by GSI  
and others



## (b) Wall Collapse

- visually observable
- some are very extensive in length
- some are narrow, but full height
- some are at top only
- some are at bottom only
- let's see some of them...

# Cases of Wall Collapse



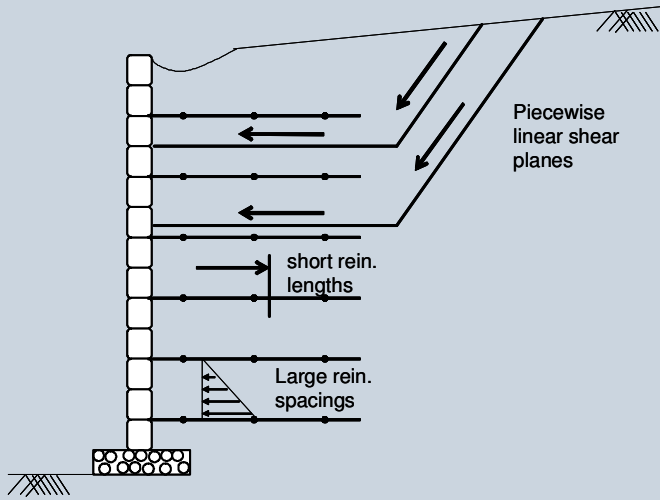
Photos by GSI  
and others



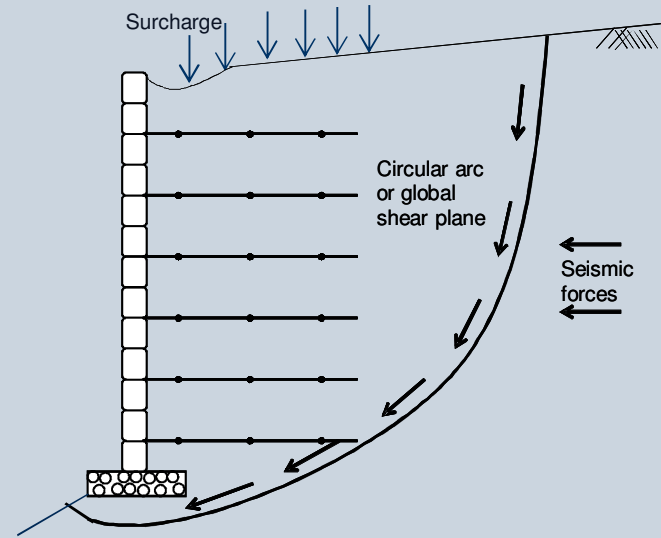


## 3.0 Main Statistical Findings

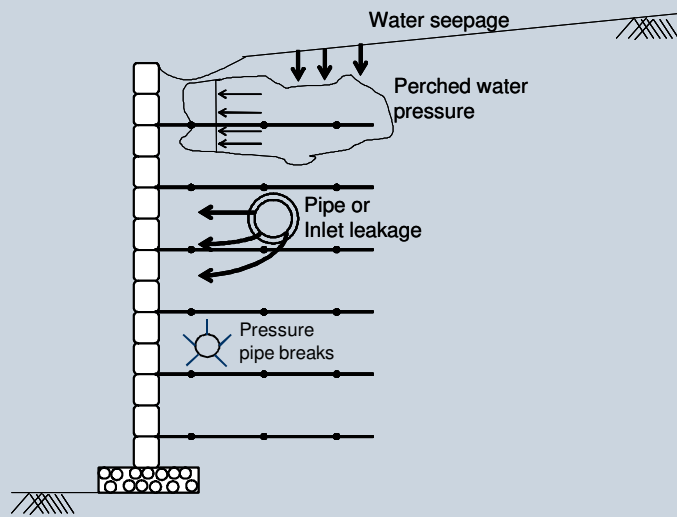
1. all but one were private walls
2. 72% were North American
3. 68% were masonry block faced (i.e., SRWs)
4. 49% were 4 to 8 m high
5. 90% were geogrid reinforced (others GT)
6. 81% failed in less than four years
7. 98% caused by improper design or construction;  
none (0%) were GG or GT manufacturing failures
8. 62% used silt and clay backfill soils
9. 75% had poor or moderate compaction
10. 58% caused by internal or external water  
(i.e., remaining 42% caused by soil related issues)



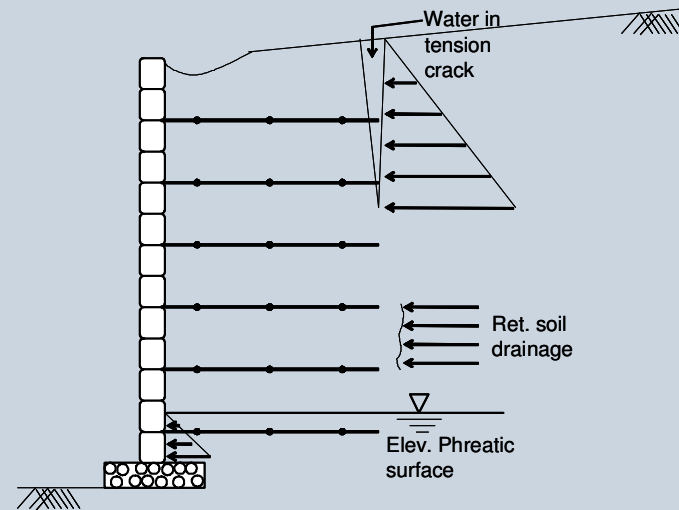
(a) Internal instability (26%)



(b) External instability (16%)



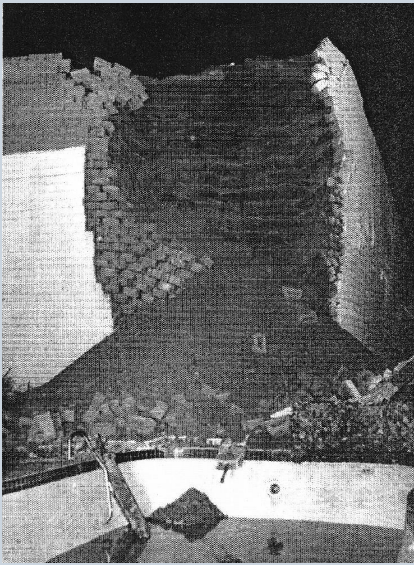
(c) Internal water (46%)



(d) External water (22%)

**Basic failure mechanisms  
(Examples Follow)**

# (a) Internal Instability Failures – 37 Cases (26%)



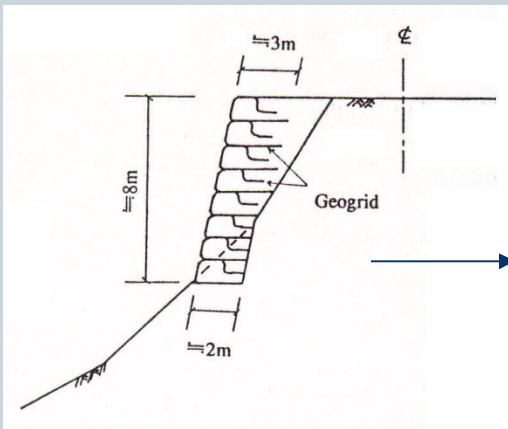
Rt. Angle Corner



Wide Spacing (0.76 m)



Wider Spacing ( $\approx 1.0$  m)



$L/H = 0.25(!)$



$L/H = 0.20 (!)$

Photos by GSI  
and others

# (b) External Instability Failures – 23 Cases (16%)



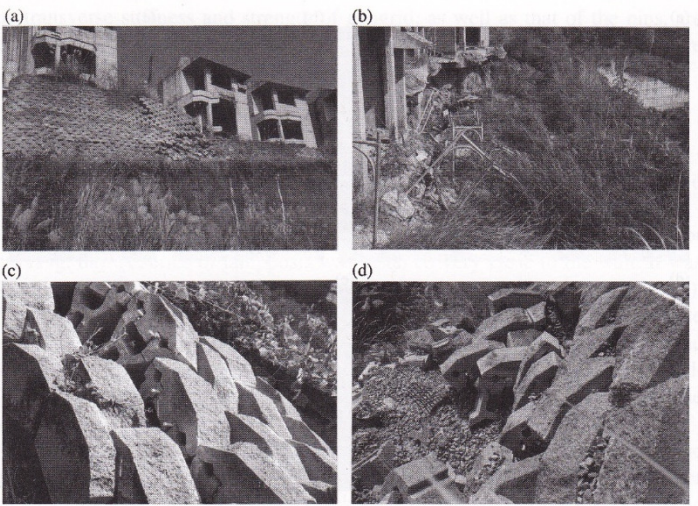
Sloping Toe



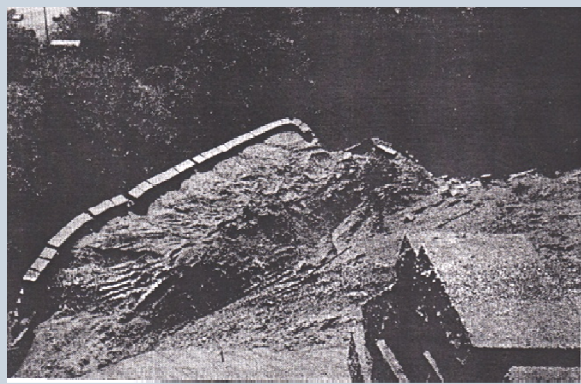
Seismic - Nisqually



Global - Front of Wall



Seismic – “Chi-Chi”



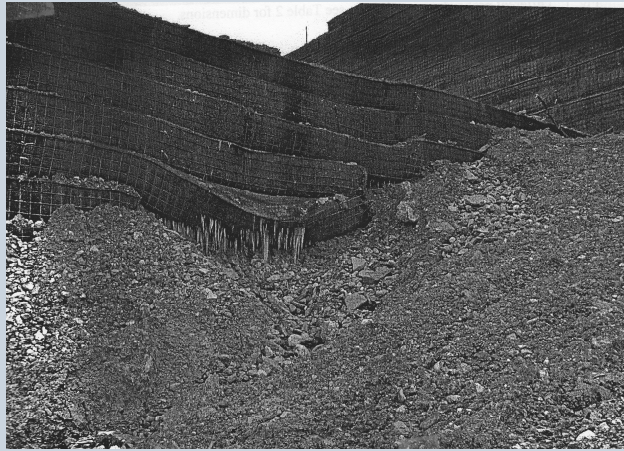
Global - Behind Wall

Photos by GSI  
and others

## (c) Internal Water Failures – 51 Cases (36%)



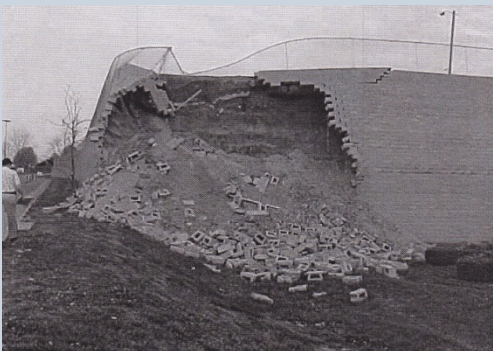
Saturated Backfill



Easy to Guess This One!



Internal Plumbing



Saturated Backfill



Internal Plumbing



Internal Plumbing

Photos by GSI  
and others

## (d) External Water Failures – 30 Cases (22%)



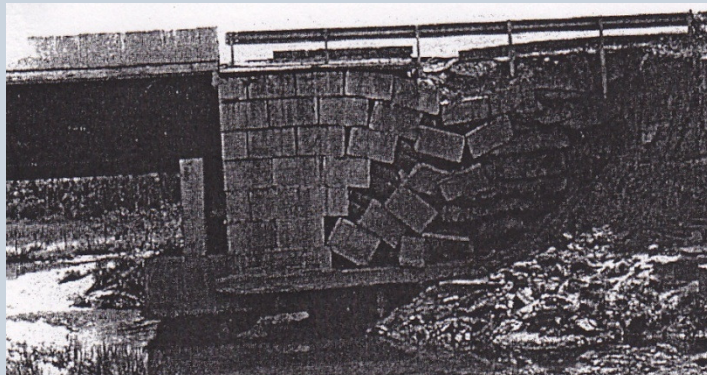
Tension Crack



Ret. Zone Water



Tension Crack



Adjacent Stream Washout



Tension Crack Behind



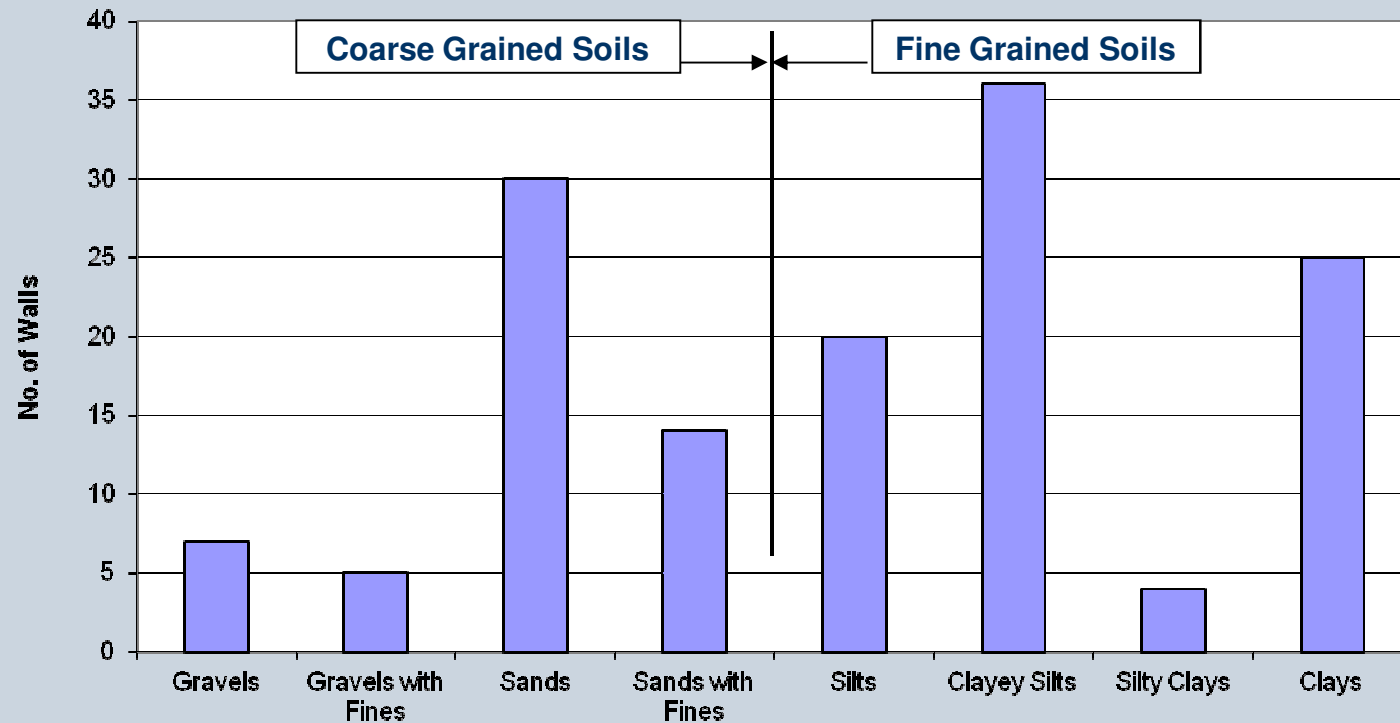
Adjacent River Flood

Photos by GSI and others

## **4.0 Design and Construction Issues**

- 4.1 Fine grained soils in backfill
- 4.2 Compaction of fine grained soils
- 4.3 Routing of internal drainage systems
- 4.4 Surface water control
- 4.5 Sensitive design details

# 4.1 Fine Grained Soils in Backfill



Type of soil used in the reinforced soil zones of the cases reported herein.



# Various Criteria for Backfill Soils

Sieve Size	Particle Size (mm)	Percent Passing Given Size		
		NCMA (2009)***	FHWA (1998)	Koerner (1994)
-	100	75-100	-	-
No. 4	4.76	20-100	100	100
No. 10	2.0	-	-	90-100
No. 40	0.42	0-60	0-60	0-60
No. 100	0.15	-	-	0-5
No. 200	0.075	0-35**	15*	0

\*PI ≤ 6.0

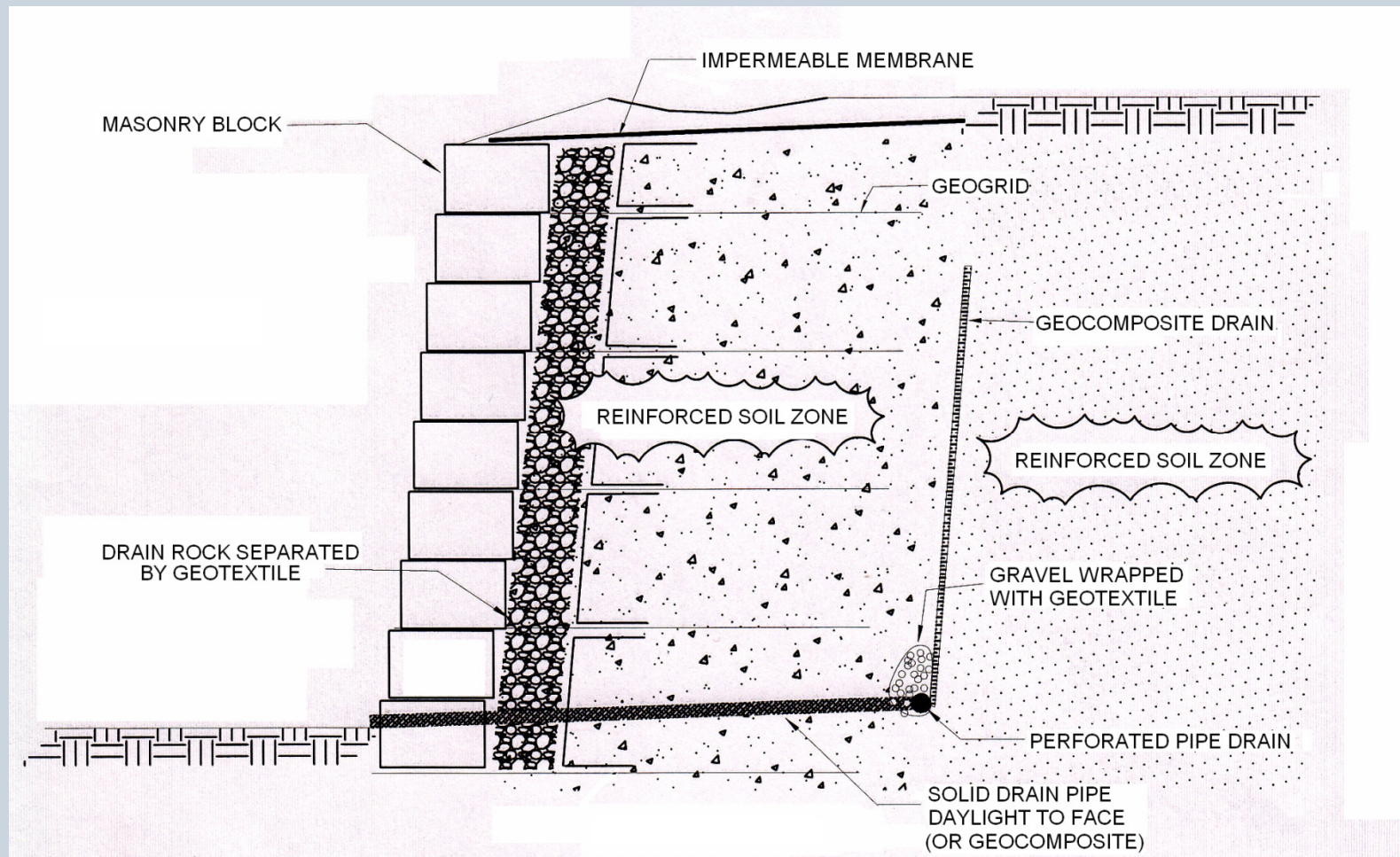
\*\*PI ≤ 20.0

\*\*\*2009 Design Manual cautions against use of fine-grained soils!

# Regarding Fine Grained Soil Backfill

- use of on-site soil is compelling
- cost savings (vs. imported) is 40-70%
- appears incapable of being stopped
- so, use it, but circumvent the poor drainage by external routing as follows...

# The Geocomposite Drain Alternative (compl., TenCate Geosynthetics, Inc.)

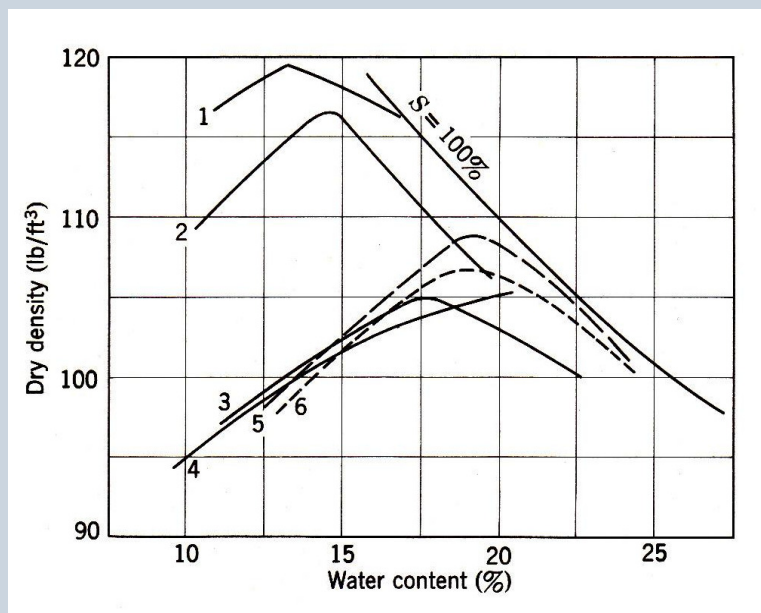




Use of continuous and intermittent geocomposite back drains when using fine grained soils in the reinforced soil zone (compl., TenCate Geosynthetics, Inc.)

## 4.2 Compaction of Fine-Grained Soils

- Use 95% standard Proctor (95% modified Proctor is too much for walls and slopes)
- This reference is from Turnbull in 1950!



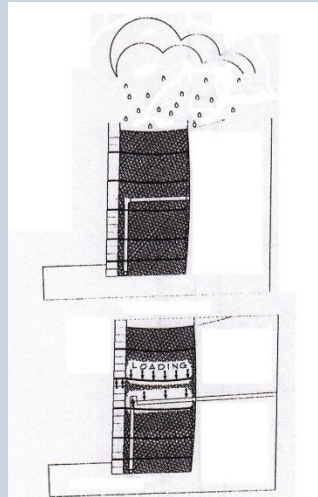
Legend  
1,2 = modified  
3-6 = standard



If no one watches, this is what you get; Photos by A. Filshill

## 4.3 Routing of Internal Drainage Systems

- 16 of 51 (31%) of internal water failures
- catch basins and manholes simply don't belong in the reinforced soil zone!
- nor does the associated transmission piping!!
- backfill soil settles and these walls deform
- this causes leakage or breakage of these heavy, hard and brittle drainage systems!!!



Drainage inlet for surface water

Face of collapsed wall



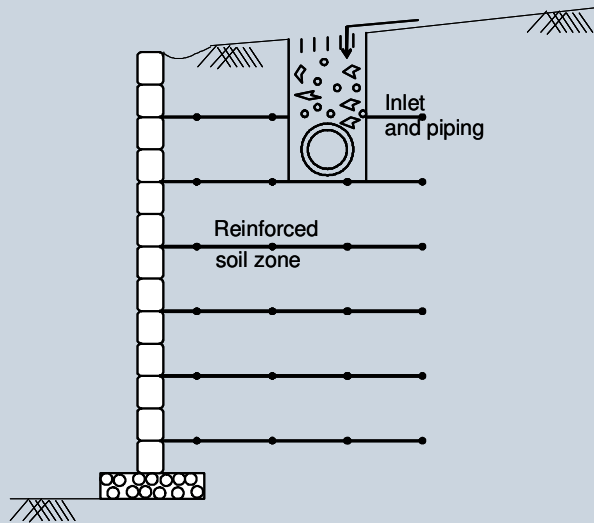
Surface water drainage inlet



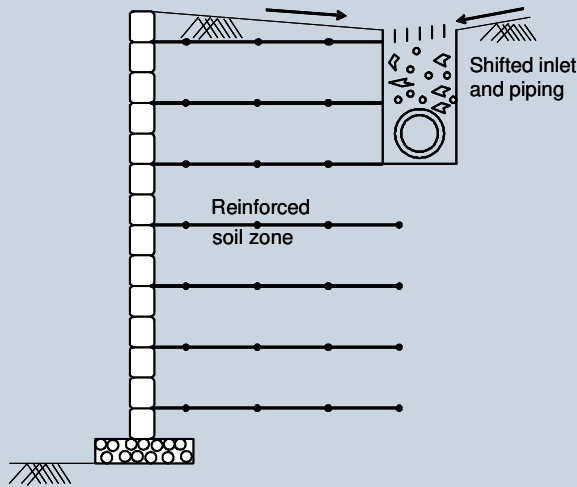
## Various Internal Drainage Failures



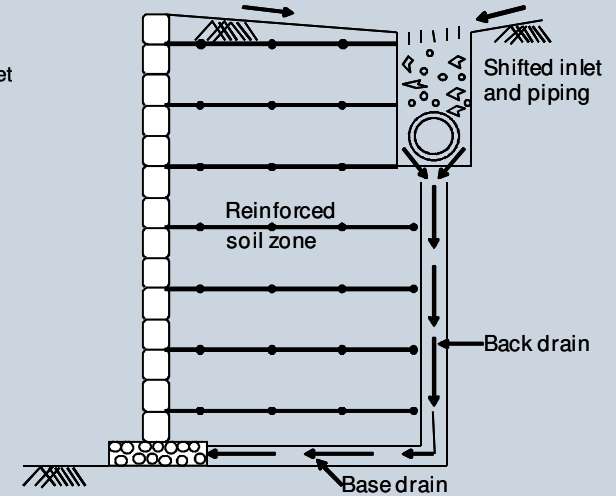
# A (Not-So) “Radical” Answer



(a) Customary internal drainage for surface water within reinforced soil zone



(b) Recommended external drainage for surface water behind reinforced soil zone



(c) Recommended external drainage for surface water coupled with back/base drain

**Shifting of internal drainage systems from within to behind the reinforced soil zone.**

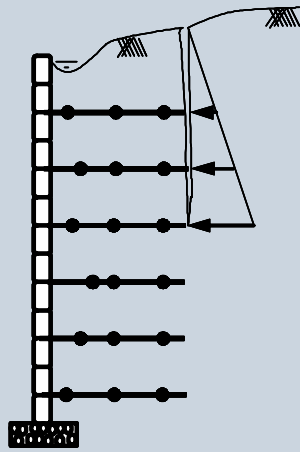


This redirection of surface water flow also avoids this from occurring.....  
(compl. A. Filshill)

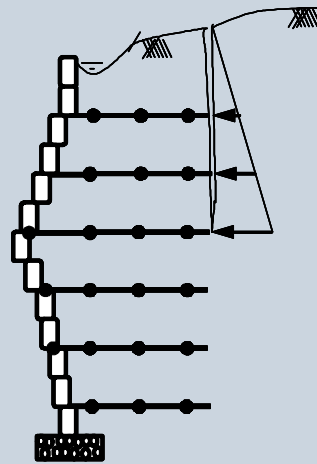


## 4.4 Surface Water Control

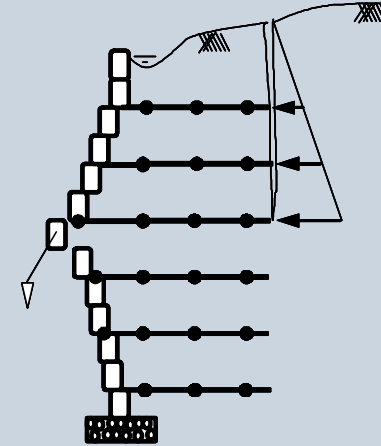
- 10 of 30 (33%) of internal water failures
- upper surface must be sealed (GM or GCL); but the water must be properly intercepted and transmitted
- this includes sealing the curb/asphalt intersections
- tension cracks are notorious; if they form, fill and seal them immediately
- following mechanism is well understood



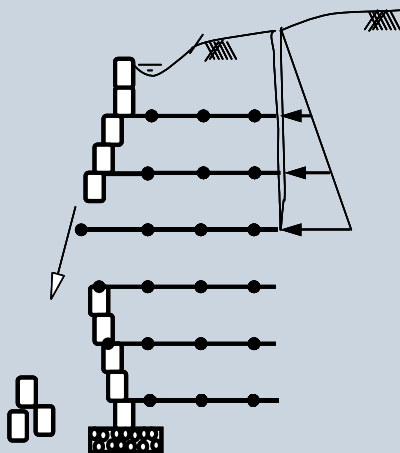
(a) crack forms, water enters and pressure is mobilized



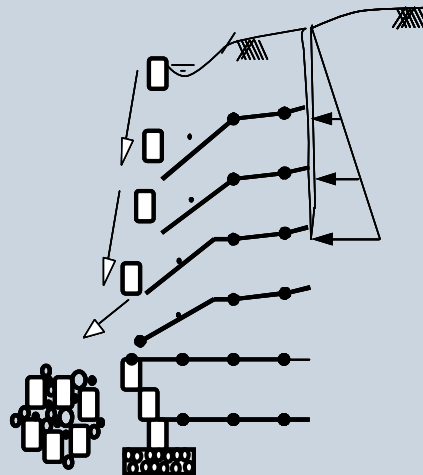
(b) wall deforms; pressure continues



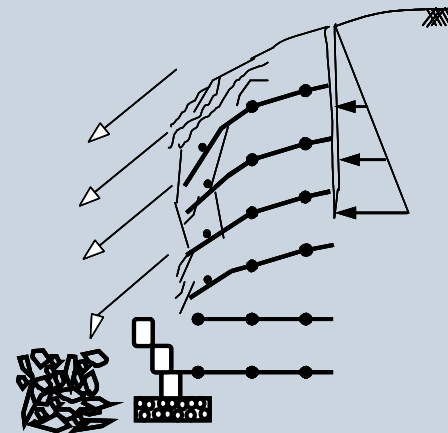
(c) deformations continues; single block dislodges and drops to toe of wall



(d) overlying blocks drop accordingly



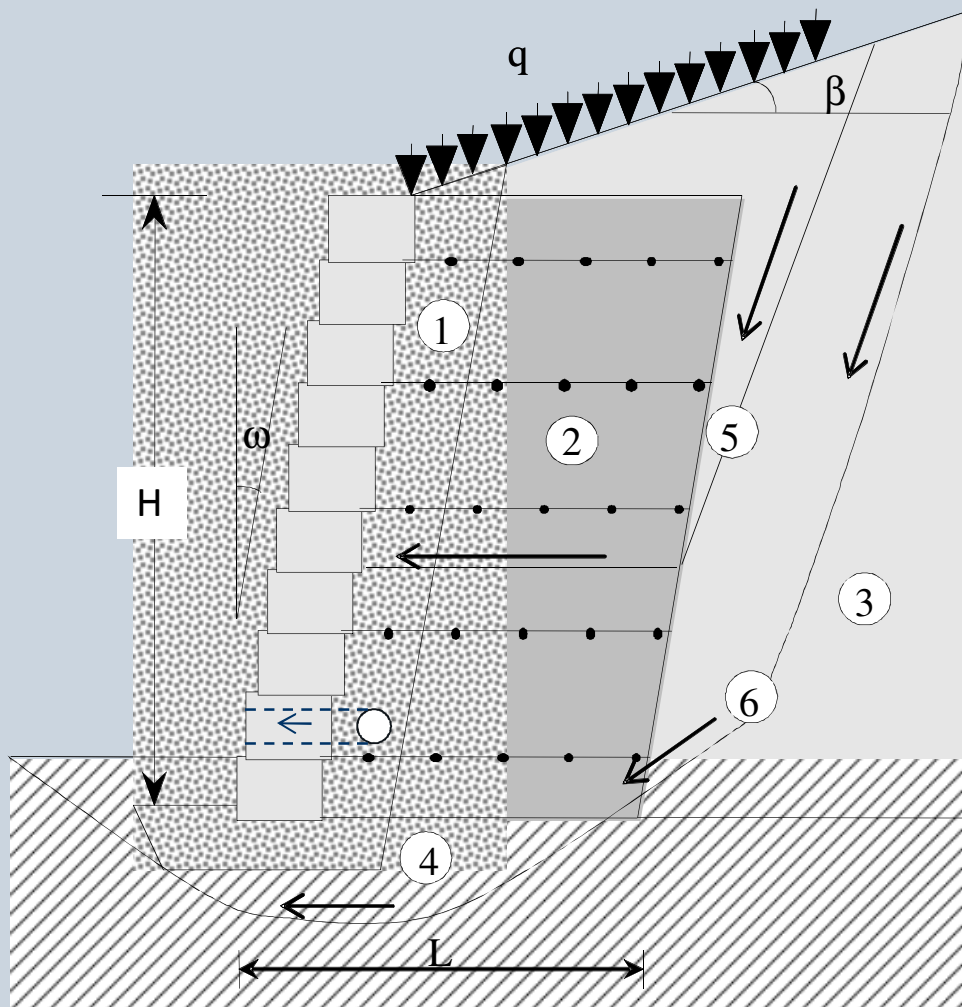
(e) blocks progressively drop along with gravel and some backfill soil



(f) after the wall facing collapses; majority of the MSE mass remains behind

**Modular block wall collapse progression due to hydrostatic pressure in tension cracks.**

## 4.5 Sensitivity of Design Details to FS-Values



### Typical Failure Surfaces

- ⑤ – internal (compound) failure via Spencer Analysis
- ⑥ – external (circular) failure via Bishop Analysis

Analyses to follow used the ReSSA (3.0) computer code

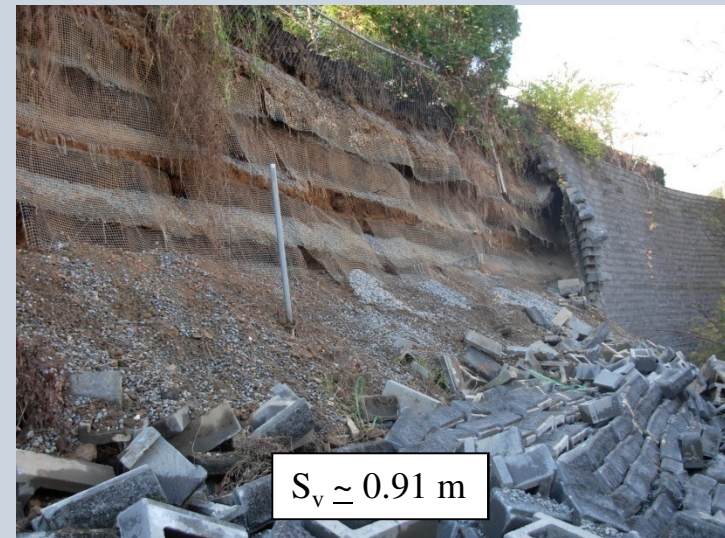
### 4.5.1- Effect of Reinforcement Length-to-Wall Height (L/H) Ratio

L/H Ratio	Spencer Analysis	Bishop Analysis
0.7	1.50	2.21
0.6	1.41	2.16
0.5	1.31	2.07
0.4	1.21	2.01
0.3	1.09	1.88
0.2	0.98	1.86



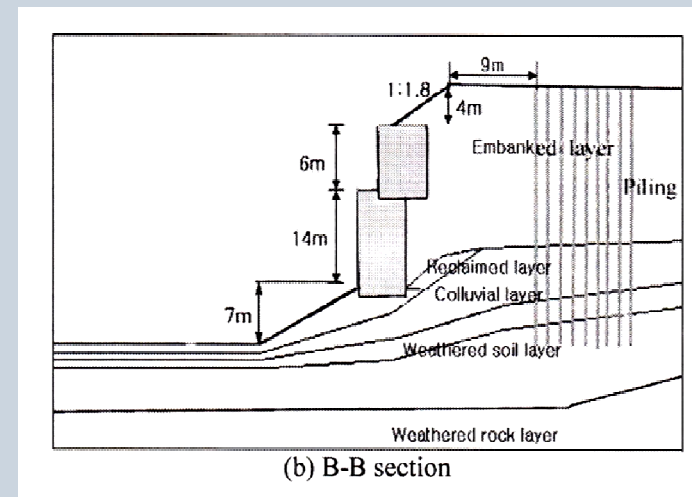
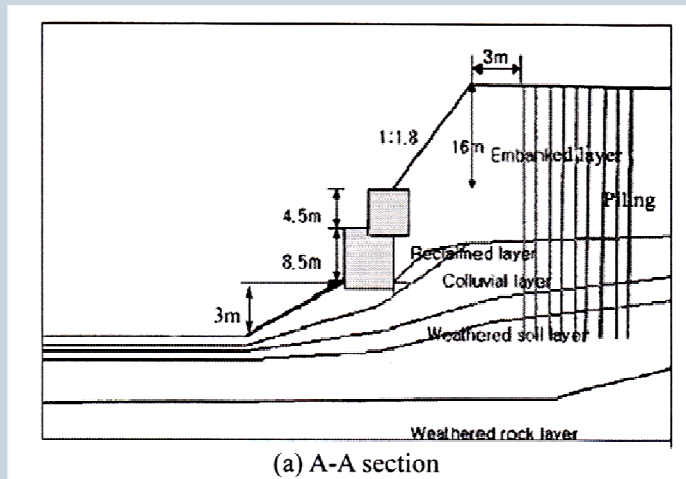
## 4.5.2- Effect of Reinforcement Layer Spacing

Spacing (m)	Spencer Analysis	Bishop Analysis
0.50	1.50	2.21
0.75	1.27	2.07
1.00	1.15	2.03
1.25	1.07	1.97
1.50	0.99	1.96
1.75	0.93	1.96



### 4.5.3- Effect of Front Soil Exit Angle at Toe of Wall

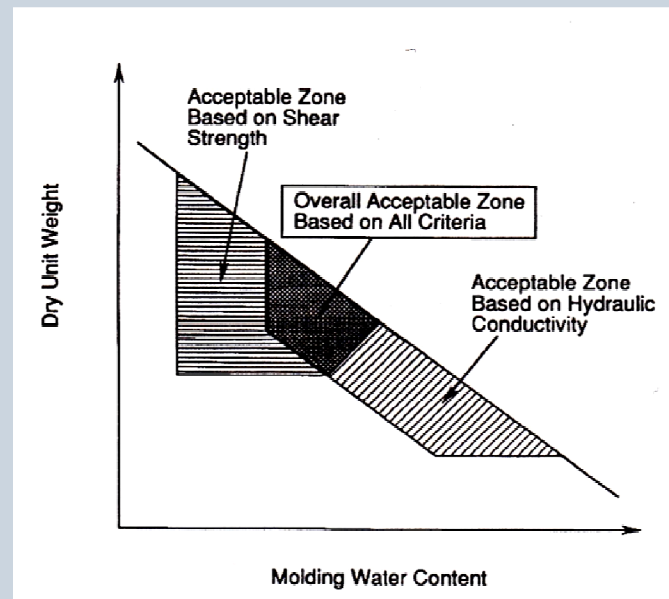
Exit Angle at Toe (deg)	Spencer Analysis	Bishop Analysis
0	1.50	2.21
10	1.50	1.91
20	1.50	1.63
30	1.50	1.34
40	1.50	1.08





#### 4.5.4- Effect of Backfill Soil Shear Strength (Cohesion is Assumed to be Zero)

Friction Angle (deg)	Spencer	Bishop
40	1.50	2.21
35	1.34	2.08
30	1.19	1.91
25	1.07	1.76
20	0.95	1.60



### 4.5.5- Effect of Water Filled Tension Crack Behind Reinforced Soil Zone

Depth (% H)	Spencer	Bishop
0	1.50	2.21
10	1.50	2.21
20	1.48	2.21
30	1.42	2.21
40	1.29	2.08
50	0.85	1.33



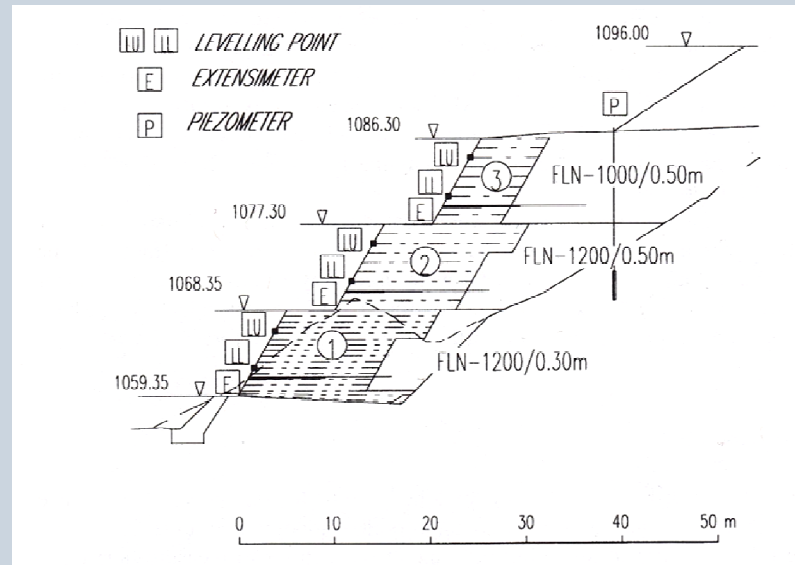
Wall



Wall is immediately in back of this fence

### 4.5.6- Effect of Elevated Phreatic Surface Within Reinforced Soil Zone

Toe Water Ht. (% H)	Internal Water (% H)	Spencer	Bishop
0	0	1.50	2.21
0	20	1.48	1.71
0	40	1.39	1.47
0	60	1.29	1.30
0	80	1.10	1.10



# Some Comments on Wall Failures

- the wall failure situation is of great concern
- it (mistakenly) looks bad for geosynthetics
- primary causes are poor design and construction
- design-wise it's lack of proper drainage design
- construction-wise it's poor placement and compaction of the fine grained soil
- new inspector certification program might help

## 5.0 Remediation Case Histories

- 34 of 141 failure cases involved excessive deformation of the facing or backfill zone
- 14 of 34 deforming ones were remediated
- this section describes several remediated cases
- note that none of them were dewatered???

## 5.1 Remediation Using Ground Anchors

### 5.1.1 Case History in Virginia (Authors)

- 9.1 m high masonry block wall
- bulged in lower and central sections within six months of construction
- ML-CL backfill soil, poorly compacted
- remediated by using ground anchor tendons attached to massive concrete pilasters

# Wall Remediation Using Ground Anchors and Reinforced Concrete Pilasters

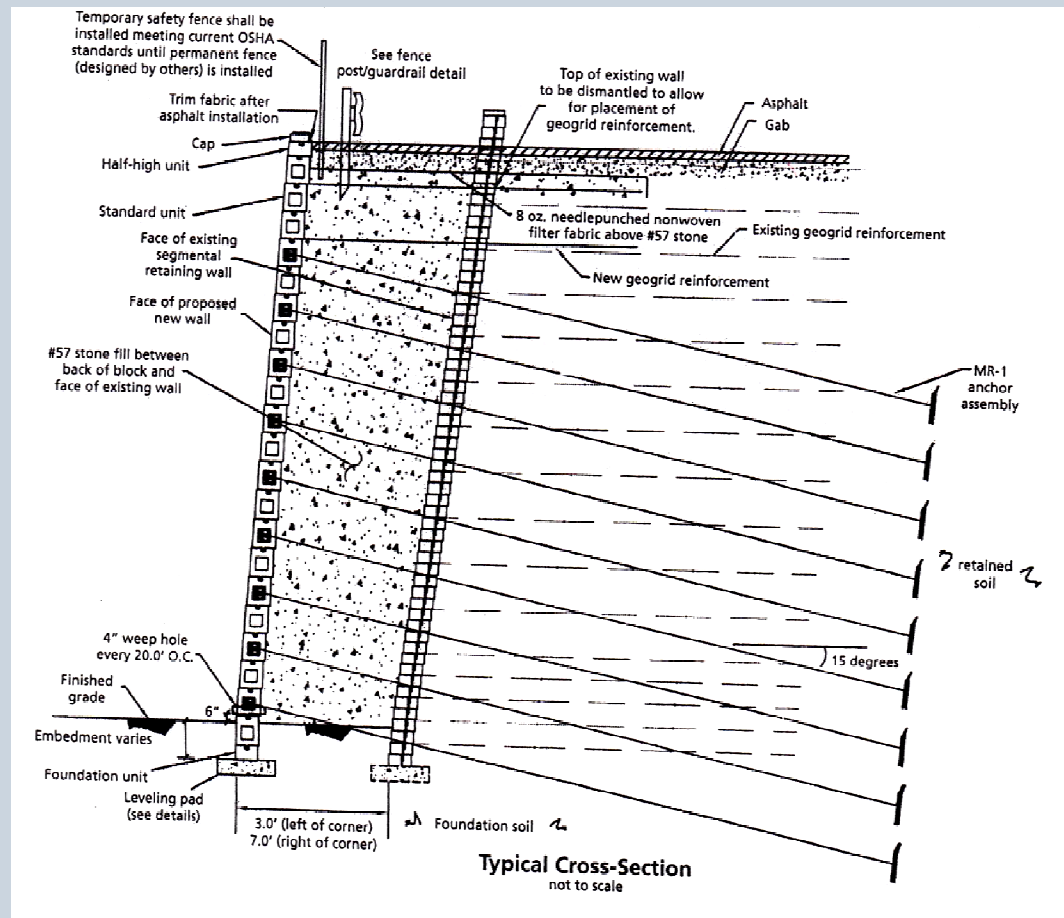


## 5.1.2 Case History in Georgia (J. Paulson)

- 9.1 m high masonry block wall
- small section collapsed after two years
- section rebuilt and entire wall stabilized
- ML-SP backfill soil, poorly compacted
- geogrids were laid out incorrectly
- rainfall triggered instability
- ground anchor (type?) tendons tied to H-beams within new facing



# Typical Cross-Section of Original Wall and its Newly Constructed Support Wall (after, Paulson, GFR, 2002)



### 5.1.3 Case History in New Jersey (A. Filshill)

- 4.6 m high masonry block wall
- partial collapse after eight years
- ML-CL backfill soil; poorly compacted
- internal water from leaking catch basins
- remediated using gabions with duckbill anchors at end of driven tendons

# Drainage Inlet (Catch Basin) Located in the Reinforced Soil Zone of Collapsed Wall



# Remediation to the Collapsed Wall (A. Filshill)



## 5.2 Remediation Using Soil Nails

### 5.2.1 Case History in California (F. Jaecklin)

- 4.6 m high masonry block wall
- deformed after two years
- bulging first; then horizontal sliding
- cause attributed to rainfall events
- stabilized using grouted soil nails and reinforced shotcrete at face

# Evidence of Horizontal Sliding Wall Sections



# Remediation Using Soil Nails and Reinforced Shotcrete (F. Jaecklin)

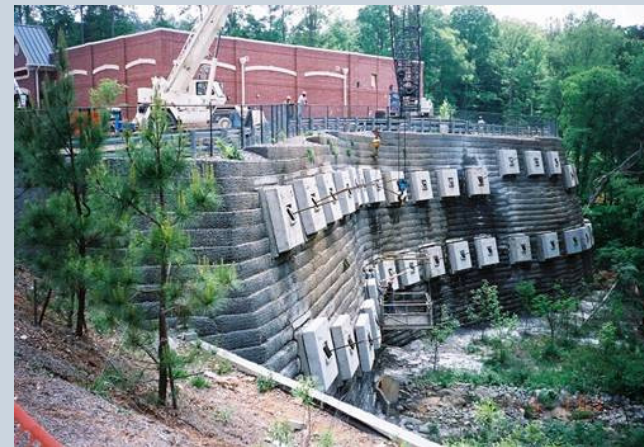


## 5.2.2 Case History in Virginia (D. Leshchinsky)

- 16.5 m high masonry block wall
- >>150 mm deformation after two years
- internal water pressure from drainage system located within reinforced zone
- deformations correlated to rainfall events
- grouted soil nails against concrete panels
- complex and costly wall stabilization

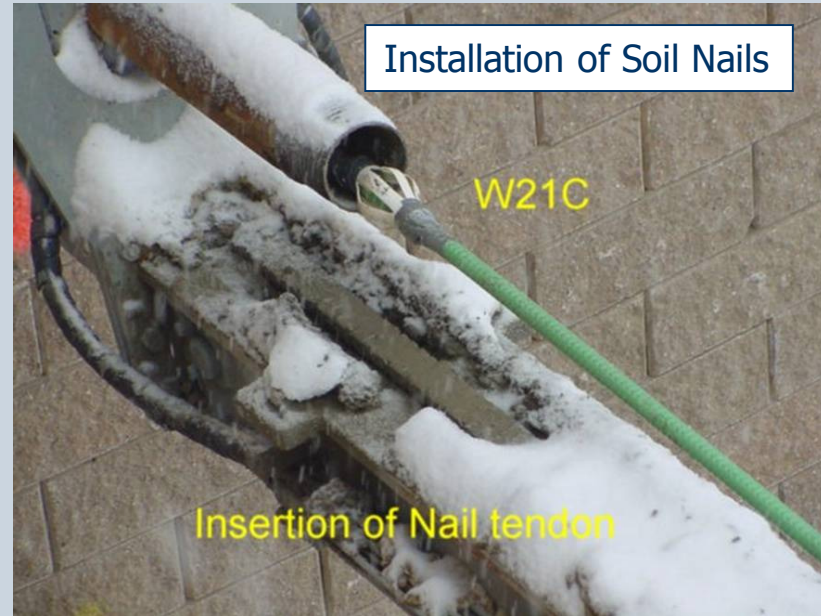


# Remediation Scheme Used to Stabilize Deforming WWM/GG Wall



### 5.2.3 Case History in New Jersey (M. Yako)

- 11.6 m high masonry block wall
- deformed after 18-months service
- blocks were constantly wet
- ML backfill soil; moderate compaction
- homogeneous HDPE geogrid reinforcement
- tension cracks behind reinforcement
- grouted soil nails attached to concrete pilasters



Photos compl.  
of GEI Inc.

# Stabilization Scheme Using for this Deforming Masonry Block Wall (M. Yako)



## **5.3 Rebuilding of Collapsed MSE Walls (authors)**

- rebuild is usually using sandy gravel backfill soils with good compaction
- concern is over steep backslope stability, i.e., workers' safety and OSHA
- this wall had internal drainage problems

# Common Problem of Capturing and Transmitting Roof Runoff and Paved Surface Water Flow Within Reinforced Soil Zone



Surface water  
drainage inlet



# Collapsed Wall Rebuild with Shotcreted Retained Soil Zone for Stability



shotcrete  
retained soil  
(see next photos)

# 6.0 The Cost of Remediation

- we suspect that most remediation projects are “time and materials” contracts
- with a contractor’s professional estimator we did a case-by-case analysis of initial and remediated costs of the ten case histories
- costs are based on 2010 prices for the site-specific location



## Approximate Costs of Remediation of Failed Walls (S. I. Units)

Case <sup>(1)</sup>	Type <sup>(2)</sup>	Max. Ht. (m)	Length (m)	Area <sup>(3)</sup> (sq. m)	Original Cost <sup>(4)</sup>		Remediation Method	Remediated Cost <sup>(4)</sup>		Remed./Original Cost Ratio
					(\$/m <sup>2</sup> ) <sup>(5)</sup>	(\$1000)		(\$/m <sup>2</sup> ) <sup>(5)</sup>	(\$1000)	
D4	MBW	9.1	270	1720	226	389	anchored pilasters	237	408	1.05
C24	MBW	9.1	180	1147	194	223	anchored blocks	904	1037	4.66 <sup>(6)</sup>
C38	MBW	5.2	120	437	323	141	anchored blocks	484	212	1.50
C39	MBW	4.6	75	241	301	73	anchored gabions	431	104	1.43
C40	MBW	3.7	90	233	301	70	anchored blocks	484	113	1.61
D6	MBW	4.6	150	483	301	145	soil nails and shotcrete	495	239	1.64
D15	WWM	16.8	110	1294	280	362	soil nails and conc. pads	980	1268	3.50
D18	MBW	11.6	120	974	301	293	soil nails and pilasters	441	430	1.46
D19	MBW	8.5	90	535	301	161	soil nails and pilasters	409	219	1.36
C15	MBW	8.5	30	179	312	56	rebuilt MBW completely	549	98	1.75

### Notes

- (1) refers to case history number in GRI Report #38 by Koerner and Koerner, 2009
- (2) MBW = modular block wall facing, and WWM = welded wire wall facing
- (3) calculated as 70% of maximum height (an average height) times the length
- (4) based on prevailing wages in state of wall location
- (5) material cost estimates were in force in 2010
- (6) failed wall was made redundant by constructing a new frontal wall



Case D4 remediation, i.e., the most cost effective



Case D15 remediation, i.e., the most costly method

Remediation of two excessively deforming walls  
(D4 at 1.05X original and D15 at 3.50X original)

# Commentary on Remediation

- as seen, the costs vary from 1.05 to 3.50 times the 2010 cost of building the wall
- the ratio would be much higher compared to the original cost of building the wall
- other than the embarrassment of being associated with a failure are the possibilities of insurance and legal claims
- of course, additional work for this client is questionable and perhaps not likely

# 7.0 Summary and Conclusion

- 141 failures were examined and classified; watch out for both internal and external water
- remediation of deforming walls is not cheap and it destroys the aesthetics
- ground anchors and soil nails were illustrated (also one collapsed wall that was rebuilt)
- dewatering was never used???

# Concluding Comments

- state-of-the-practice of MSE wall design and construction is very dicey (in our opinion).....
- designers often don't explore or visit sites and they often do not have civil, geotechnical, and site plans and details
- subsurface water collection and pipe transmission must be removed from the reinforced soil zone
- contractors seem to use "any" available soil backfill and are quite cavalier in its placement and compaction
- private sector MSE walls really need improvement
- full day course on failures is available as is a full day inspectors course with an associated certification program

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# Thanks for Listening Any Questions???

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