Geosynthetic Reinforced Segmental Retaining Walls (SRWs)

1.0 Background and Aesthetics

2.0 Retaining Wall Costs

3.0 Design Issues and Example Problem

4.0 Cases of Inadequate Performance

5.0 Concerns

6.0 Summary and Conclusions

1.0 Background and Aesthetics

Historic progression of wall types:

- rigid and/or gravity walls
- bin and crib walls
- MSE – metallic reinforcement
- MSE – polymeric reinforcement

This paper focuses on the last category.

Various types of wall facing:

- wrap-around
- timber
- welded-wire mesh
- gabion (metal or polymer)
- precast full-height concrete
- precast panel units (various shapes)
- modular concrete blocks, or segmental retaining walls (SRWs)

Types of polymeric* reinforcement:

Geogrids (mainly)

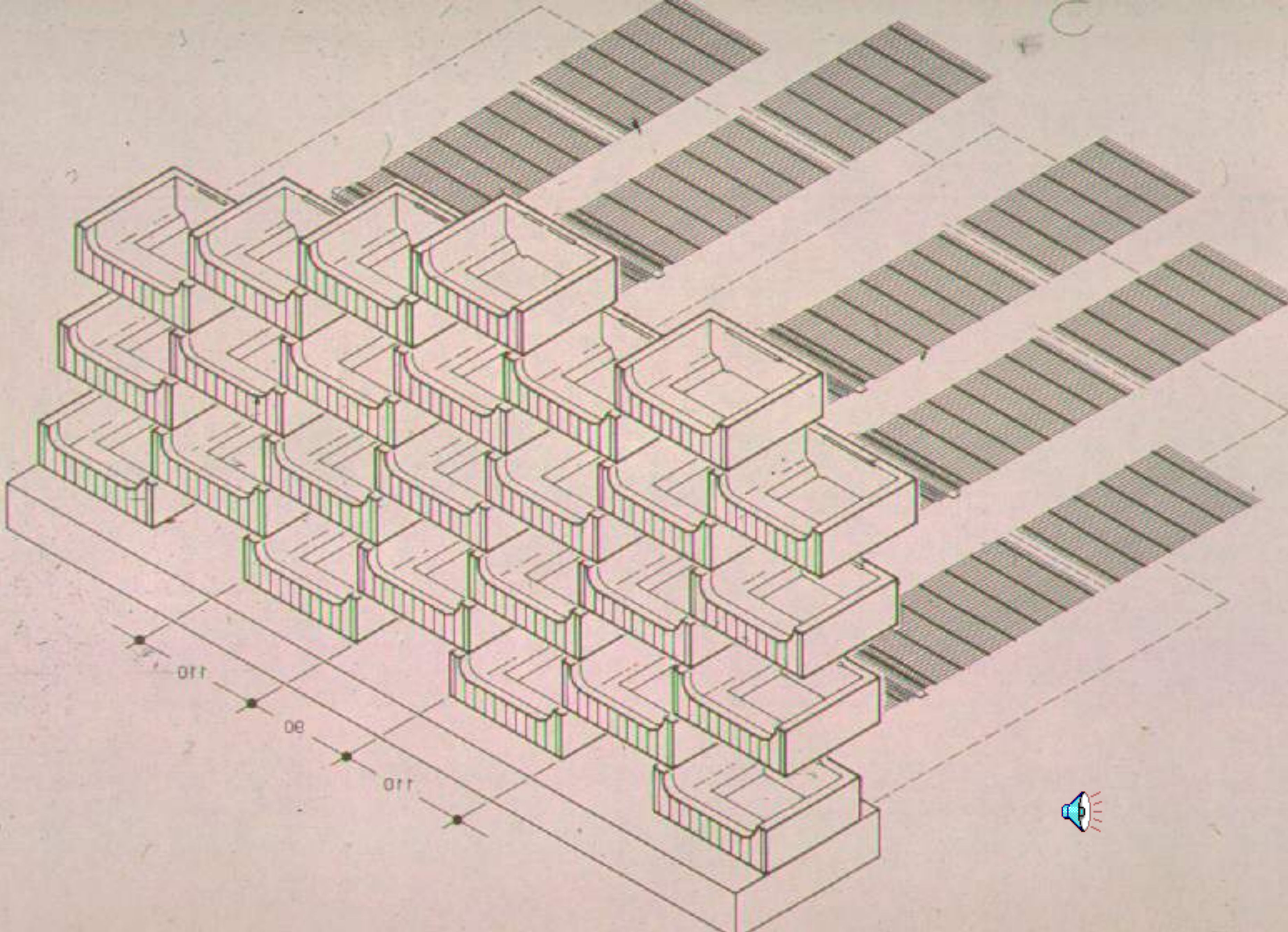
Geotextiles (sometimes)

Geostraps/Geoanchors (rarely)

*HDPE, PET & PP mainly; PA, FG occasionally

“SRWs are Hot”!

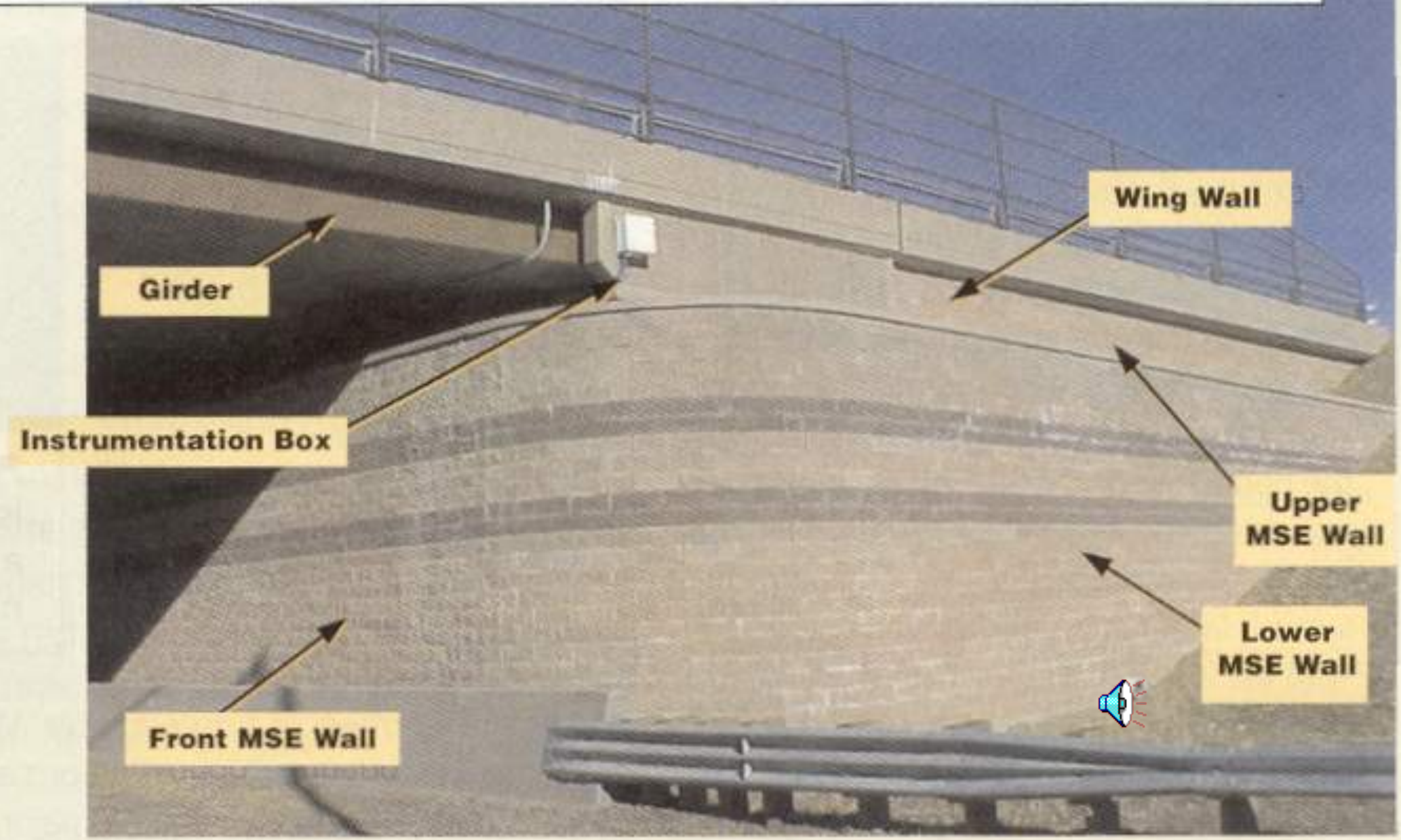
- factory fabrication of blocks
- good quality control at a low cost
- modular construction in field
- eliminates large equipment
- no need for carpenters, rod-setters, etc.
- conforms to any line and grade
- good tolerance for irregularities
- can accommodate reasonable settlement
- outstanding aesthetics

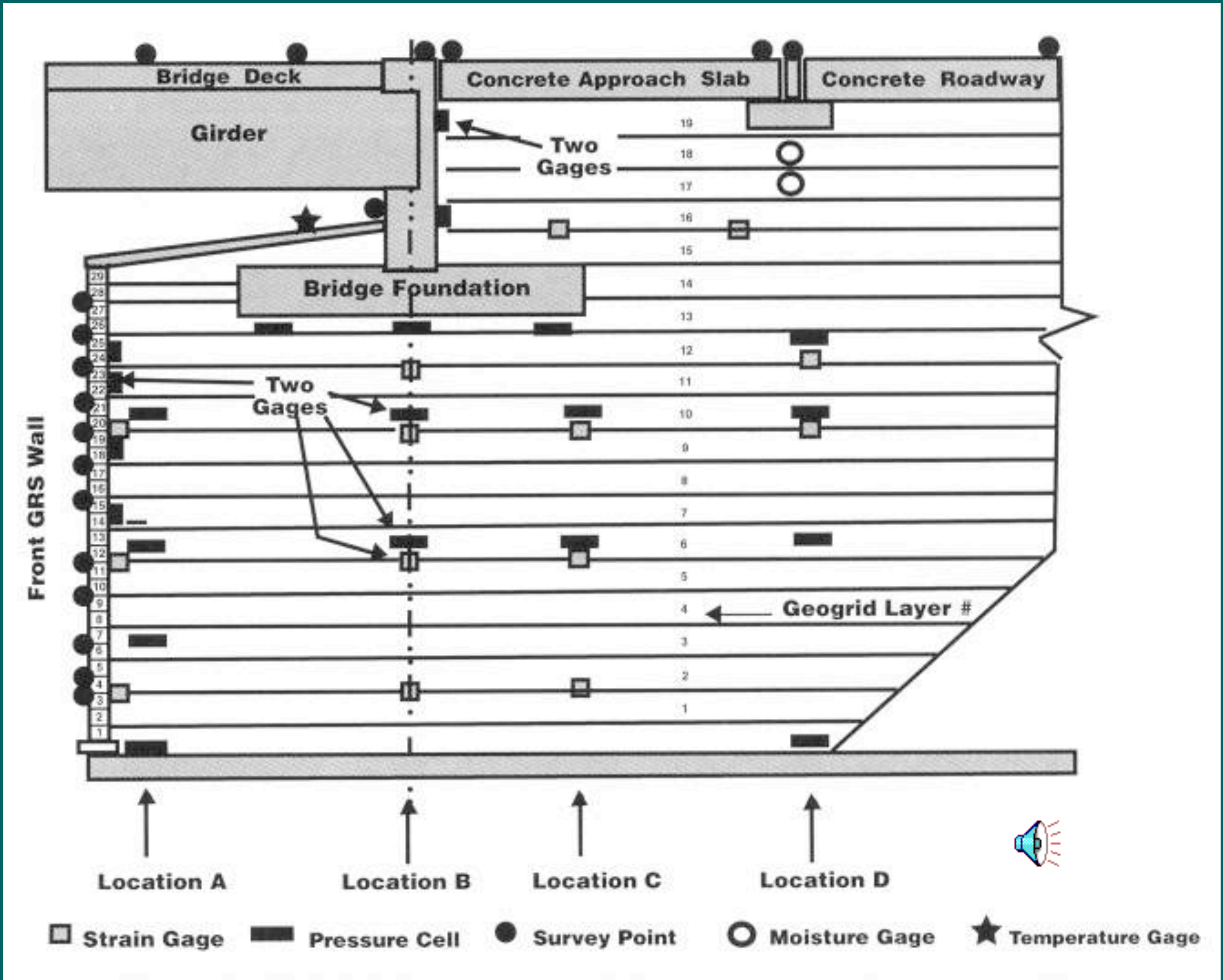

110
80
110

Eine Hangsicherung aus RemuTex-Elementen; kleines Bild: unmittelbar nach Fertigstellung – großes Bild: nach bereits erfolgter Bepflanzung. Die Abbildungen veranschaulichen gut den großen Raum, der für die Begrünung zur Verfügung steht und der auch für Sträucher oder größere Pflanzen Platz bietet.


DANGER
PROHIBIDO

Photo 1. Segmental retaining wall (SRW) components of a completed bridge abutment.





Bridge Deck
Girder
Concrete Approach Slab
Concrete Roadway
Two Gages
Bridge Foundation
Two Gages
Front GRS Wall
Geogrid Layer #
Location A
Location B
Location C
Location D
Strain Gage
Pressure Cell
Survey Point
Moisture Gage
Temperature Gage


ONE WAY
NO OUTLET

2.0 Retaining Wall Costs

- wall categories:

  gravity; crib/bin; MSE (metal); MSE (geosynthetics)

- wall heights:

  low (< 4.5 m); medium; high (> 9.0 m)

- Previous surveys:

  Lee (1973); VSL (1981); Yako & Christopher (1988)

The GRI Survey (1998)

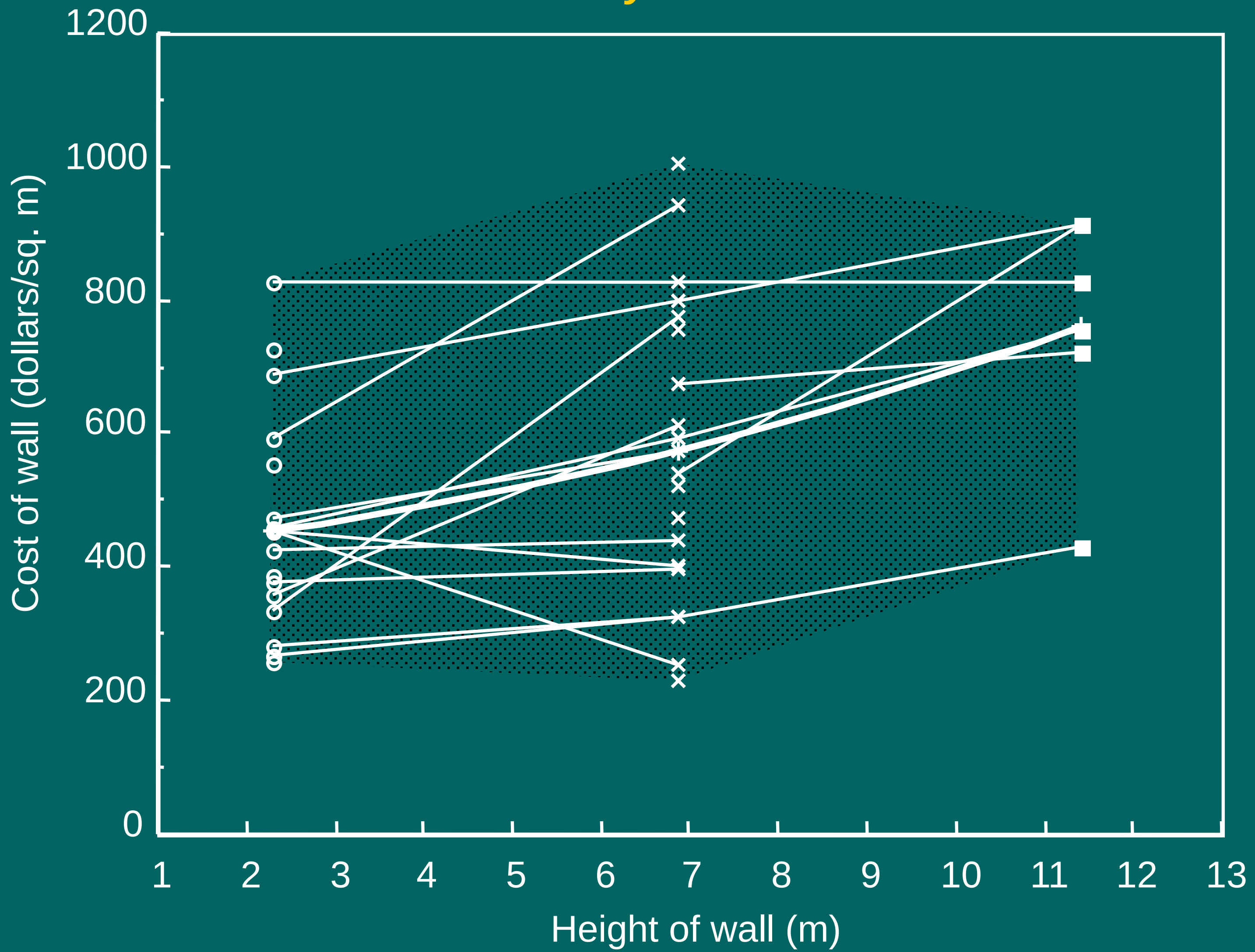
- contacted all 50-DOTs
- obtained responses from 40 states
- includes thousands of walls
- these are bid prices of public financed walls
- prices are in $\$/m^2$ of wall facing

Comparison of Retaining Wall Costs

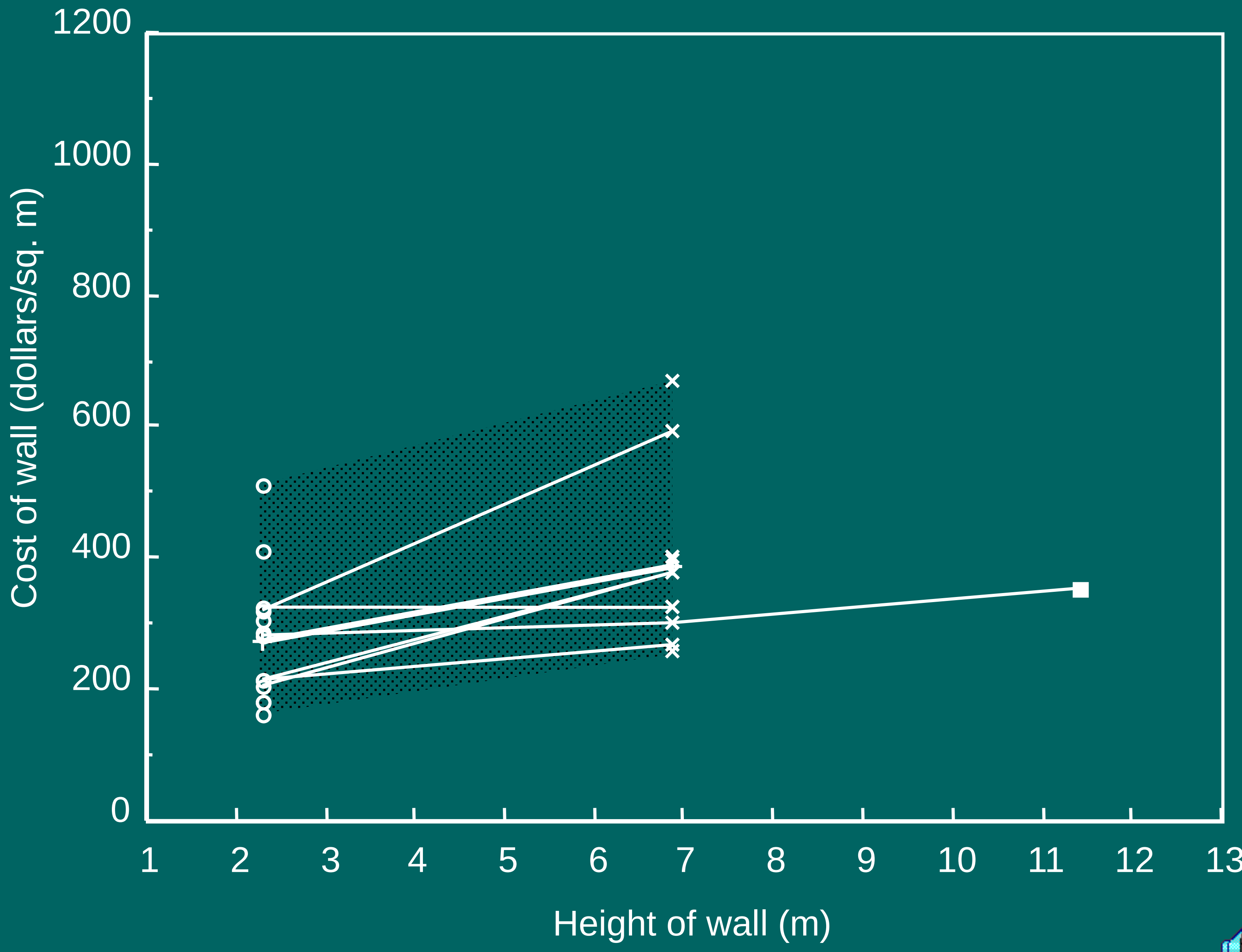
Wall Category	Wall Height	Lee, et. al (1973)	VSL Corp. (1981)	Yako & Christopher (1988)	J. Koerner, et. al. (1998)
Gravity	high	300	570	570	760
	medium	190	344	344	573
	low	190	344	344	455
Crib/Bin	high	245	377	377	I/D
	medium	230	280	280	390
	low	225	183	183	272
MSE Walls (metal)	high	140	300	300	358
	medium	100	280	280	381
	low	70	172	172	341
MSE Walls (geosynthetic)	high	N/A	N/A	250	357
	medium	N/A	N/A	180	279
	low	N/A	N/A	130	223

Notes: I/D = inadequate data
N/A = not available at time of survey

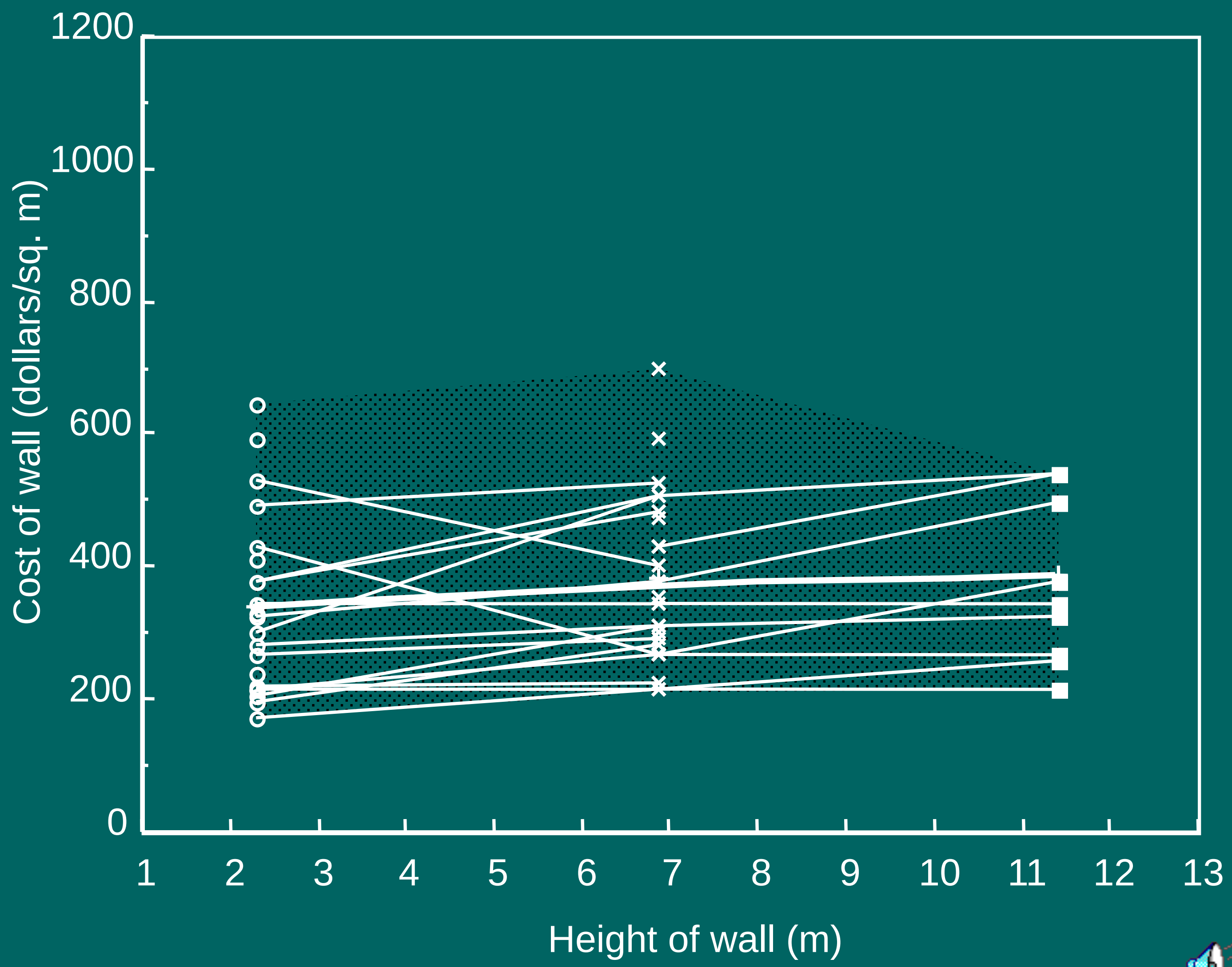
Gravity Walls



Crib/bin walls

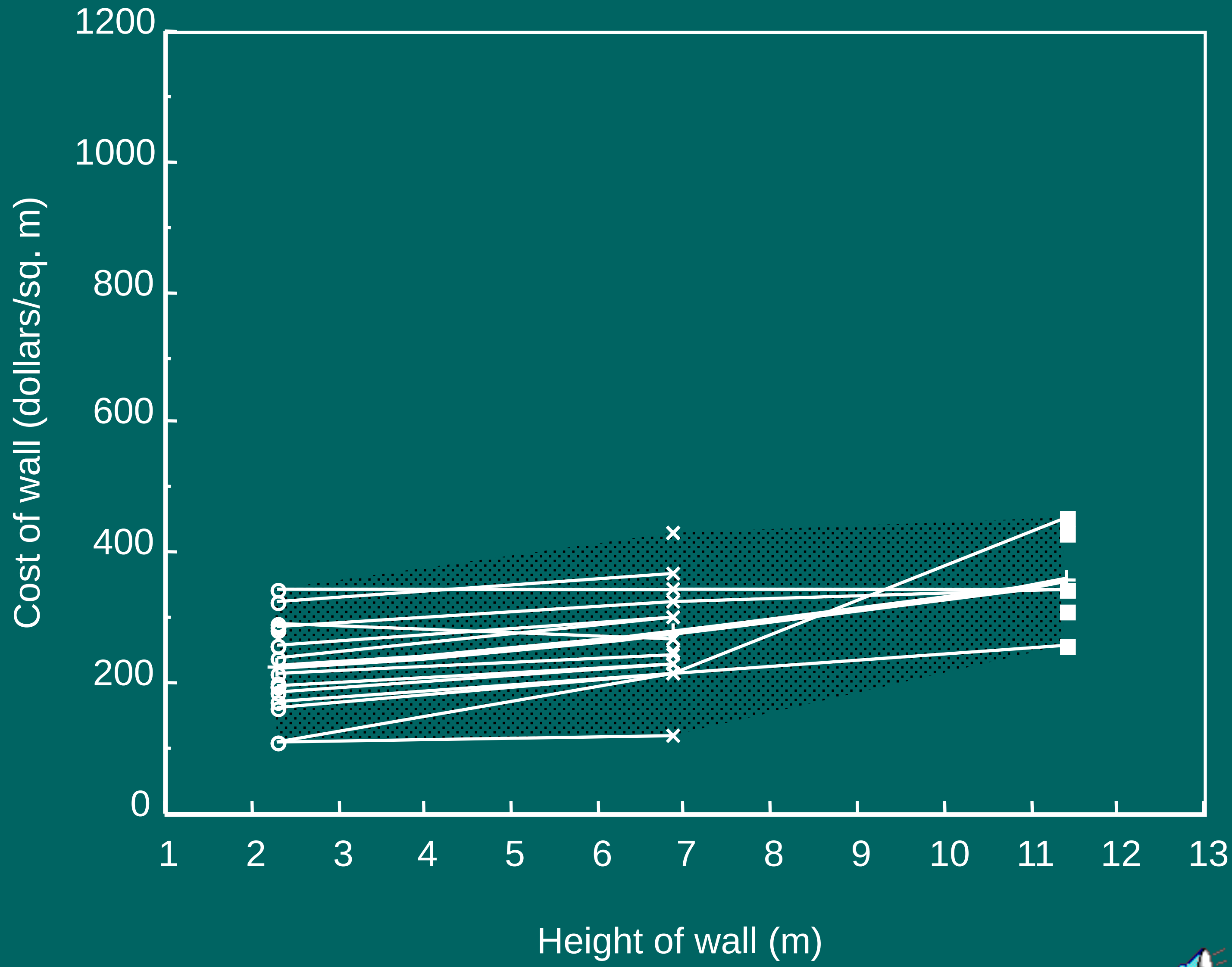


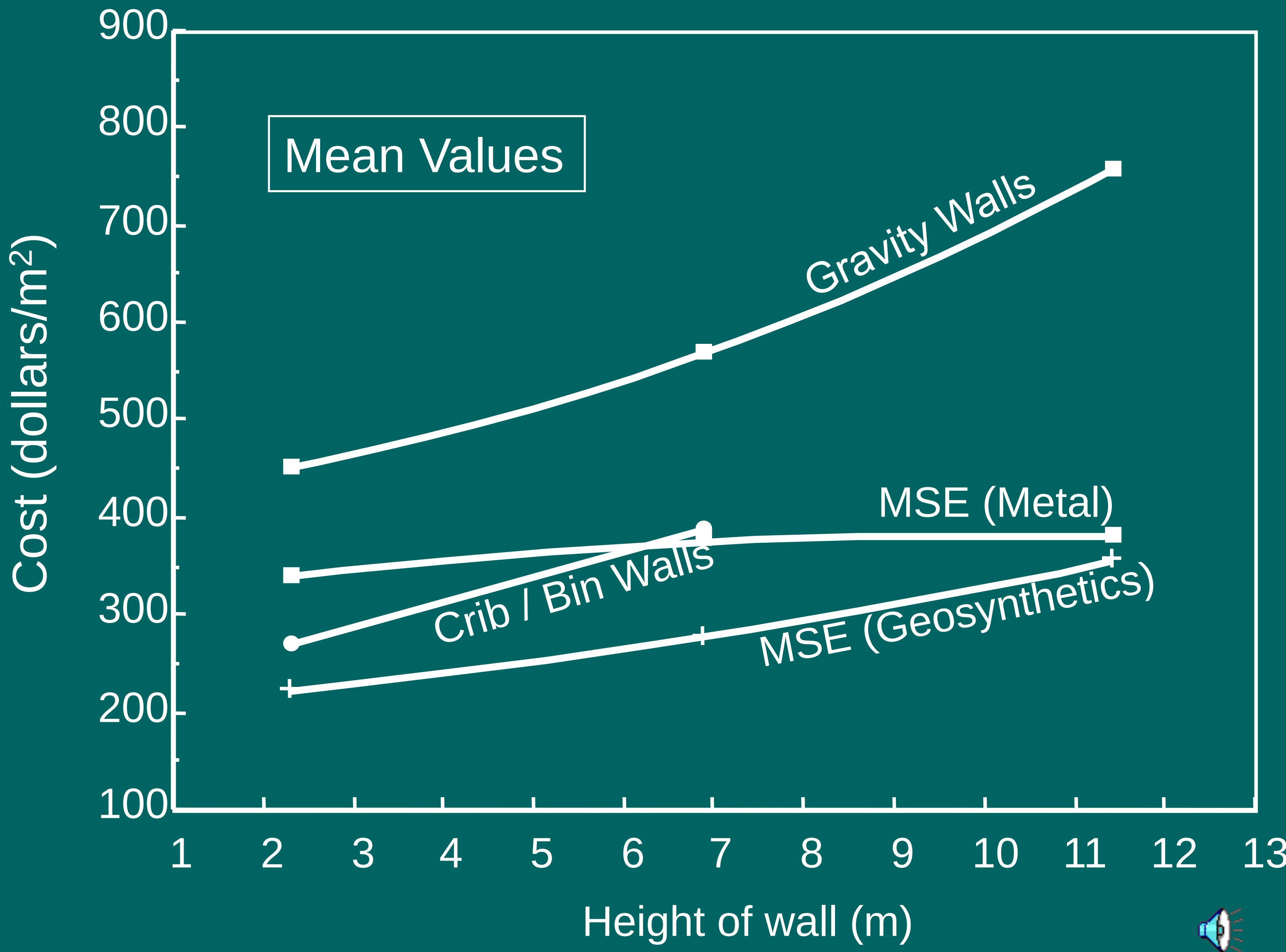
MSE (metal)



1200
1000
800
600
400
200
0
Cost of wall (dollars/sq. m)
1
2
3
4
5
6
7
8
9
10
11
12
13
Height of wall (m)

MSE (Geosynthetics)





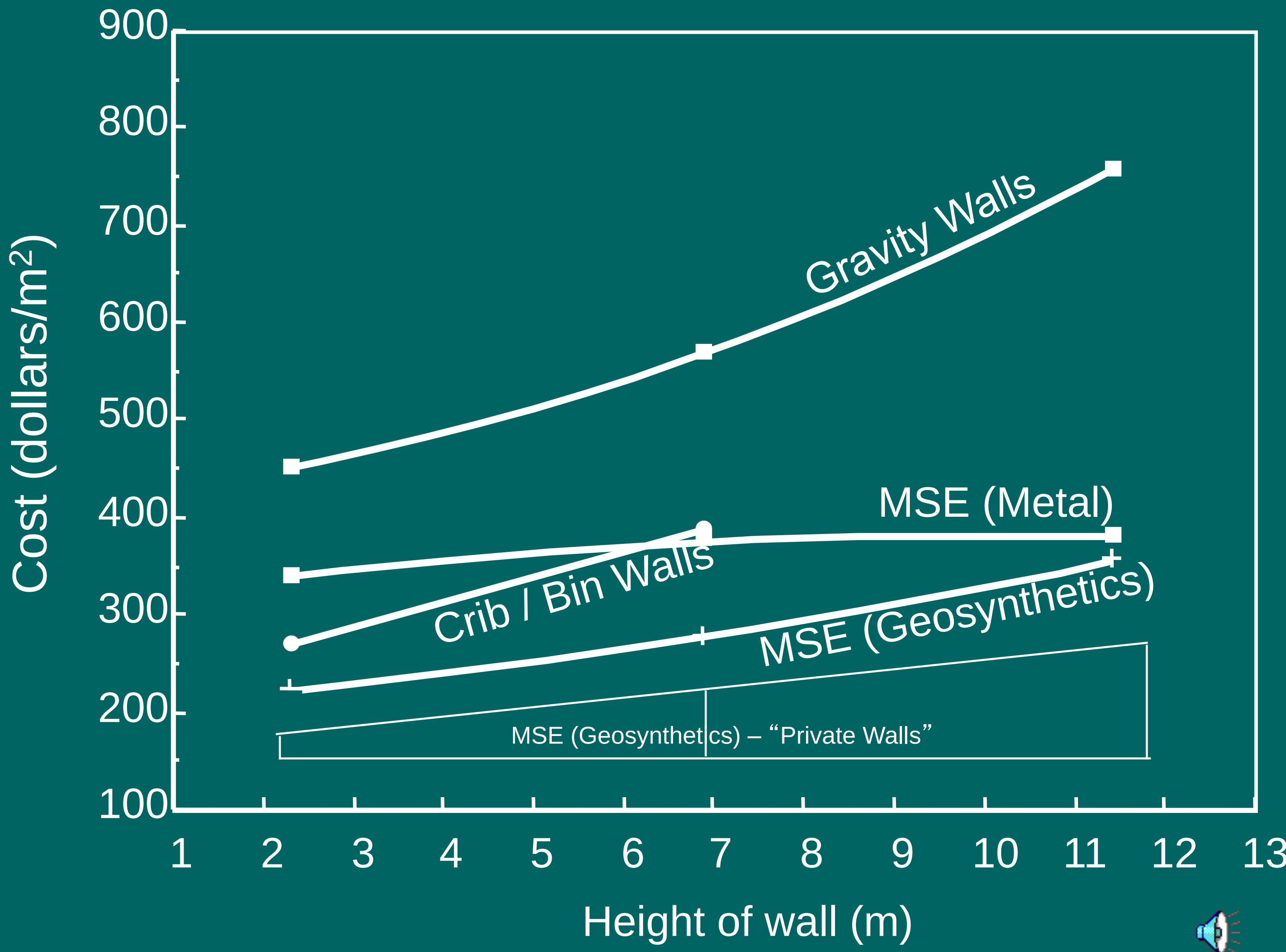
Mean Values
Cost (dollars/m²)
900
800
700
600
500
400
300
200
100
1
2
3
4
5
6
7
8
9
10
11
12
13
Height of wall (m)
Gravity Walls
MSE (Metal)
Crib / Bin Walls
MSE (Geosynthetics)

Statistical Data for Retaining Wall Costs from J. Koerner, et al. (1998) Survey

Wall Category	Wall Height (m)	Wall Costs in dollars/sq. m		Variance (%)
		Mean	Std. Dev.	
Gravity walls	>9.0	760	180	24
	4.5 to 9.0	573	224	39
	< 4.5	455	166	37
Crib/bin walls	>9.0	I/D	I/D	I/D
	4.5 to 9.0	390	129	33
	< 4.5	272	98	35
MSE (metal)	>9.0	385	122	32
	4.5 to 9.0	381	126	33
	< 4.5	341	135	40
MSE (geosynthetic)	>9.0	357	73	20
	4.5 to 9.0	279	81	29
	< 4.5	223	67	30

Thus:

- MSE (GS) walls are lowest cost over all height categories
- with continued strong growth costs may be driven lower
- prices for privately financed walls are lower – some (sparse) data follows


Cost (dollars/m2)
900
800
700
600
500
400
300
200
100
1 2 3 4 5 6 7 8 9 10 11 12 13
Height of wall (m)
Gravity Walls
MSE (Metal)
Crib / Bin Walls
MSE (Geosynthetics)
MSE (Geosynthetics) – "Private Walls"

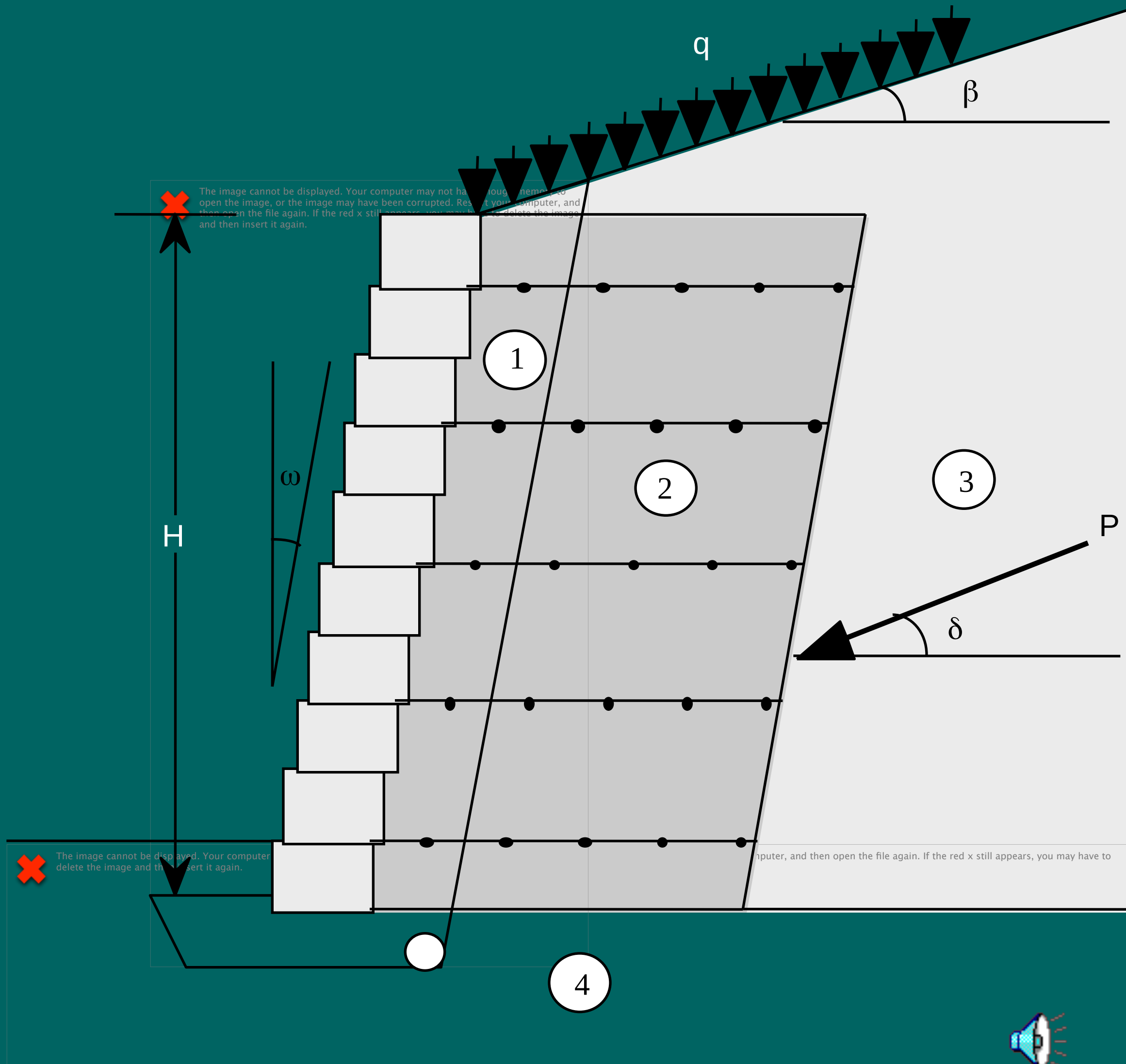
3.0 Design Issues

External Stability	Internal Stability
• mass sliding*	• tensile overstress (spacing)*
• bearing capacity*	• soil pullout*
• overturning	• facing connection overstress

*dependent upon lateral earth pressure assumptions

Soil Zones in SRWs

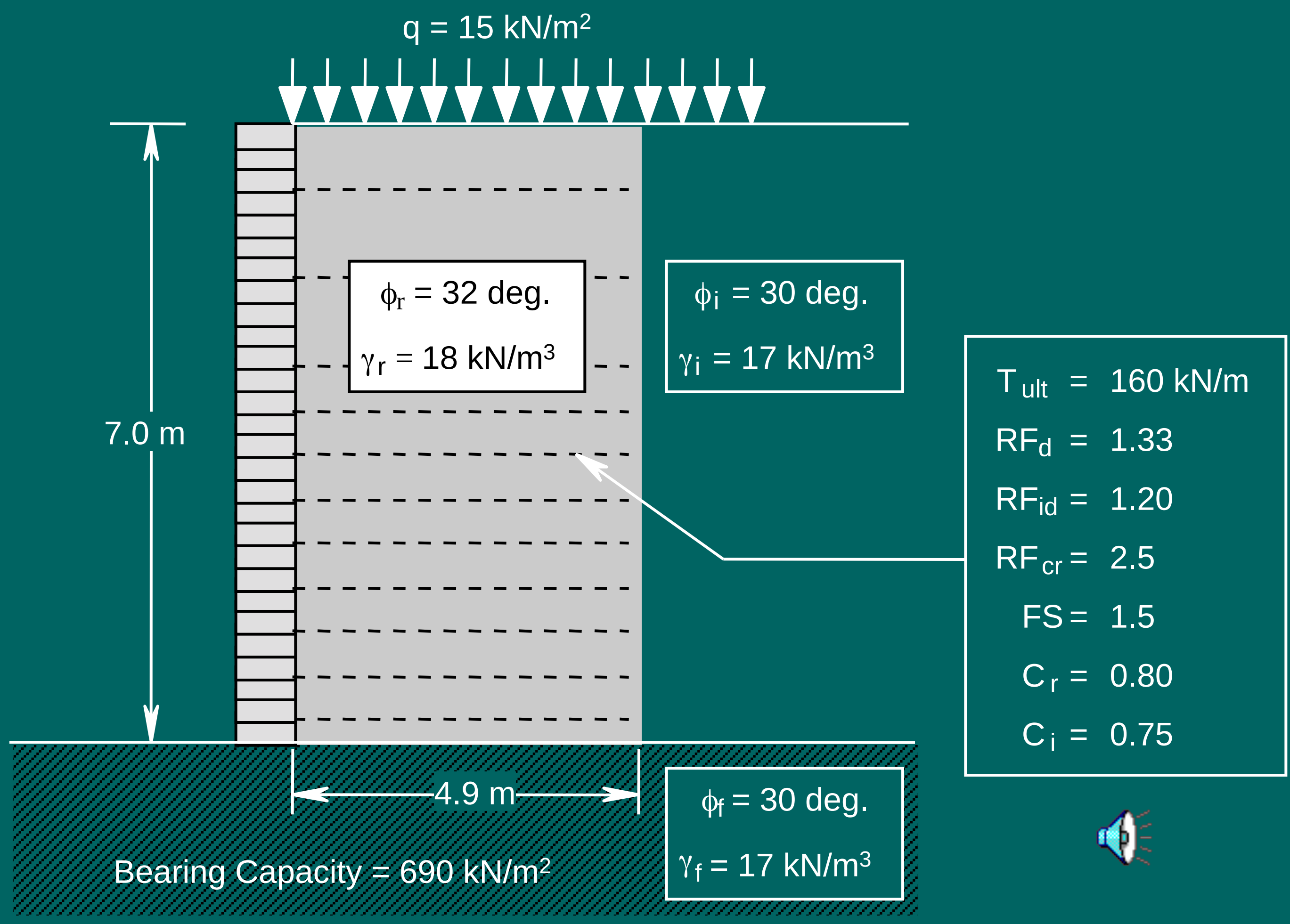
1. drainage soil (same as block infill):
   (gravel, typ. #57 stone)
2. reinforced soil:
   (varies greatly, more later)
3. retained soil
   (in-situ soil or local borrow)
4. foundation soil or rock:
   (in-situ condition or compacted fill)


q
β
1
2
3
ω
H
P
δ
4

Design Methods in Common Use

Item	mod.-Rankine	FHWA	NCMA
K_a – basis	Rankine	Coulomb	Coulomb
K_p – basis	neglect	neglect	neglect
earth pressure angle	horizontal	inclined	inclined
surcharge	applicable	applicable	applicable
wall batter	not applicable	applicable	applicable
inclined backslope	not applicable	applicable	applicable

Example Problem (blocks are 0.25-m high)



Results of Example Problem Illustrating Three Design Methods

(a) External Stability Consideration

Item	Modified Rankine	FHWA	NCMA
FS (Foundation Sliding)	2.07	2.30	2.87
FS (Bearing Capacity)	3.59	3.59	5.35
FS (Overturning)	3.43	*	4.93

* = generally not a concern

Results of Example Problem (cont.)

(b) Internal Stability Considerations

Note: Reinforcement layer at El. -3.75 m is used for illustration

Item	Modified Rankine	FHWA	NCMA
FS (tensile overstress)	2.88	2.84	2.91
FS (soil pullout)	10.90	13.80	15.40
Str. (facing connection)	n/a	14.40	12.00

n/a = not applicable

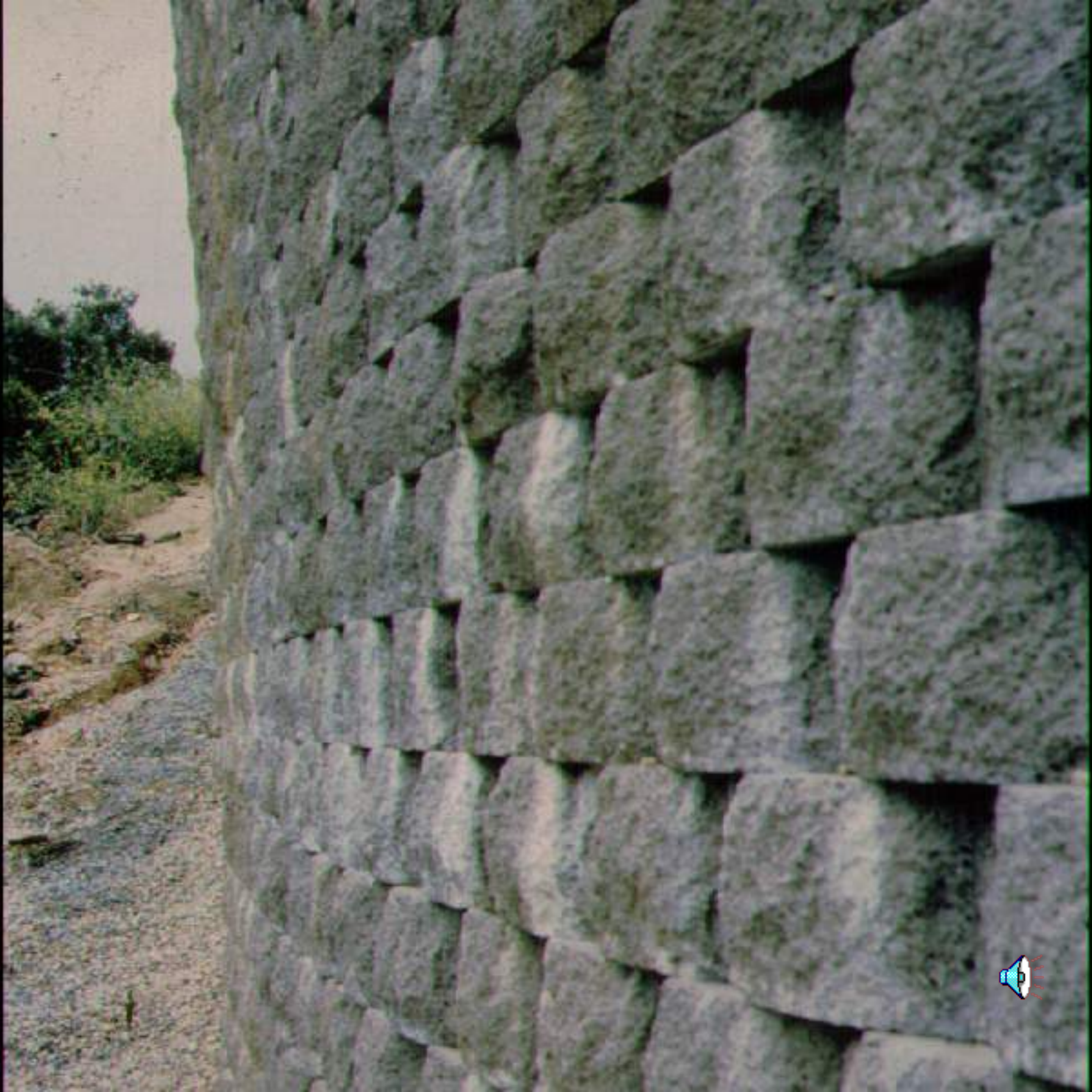
Comparison of Example Problem Results "Assuming that FHWA has it right"!

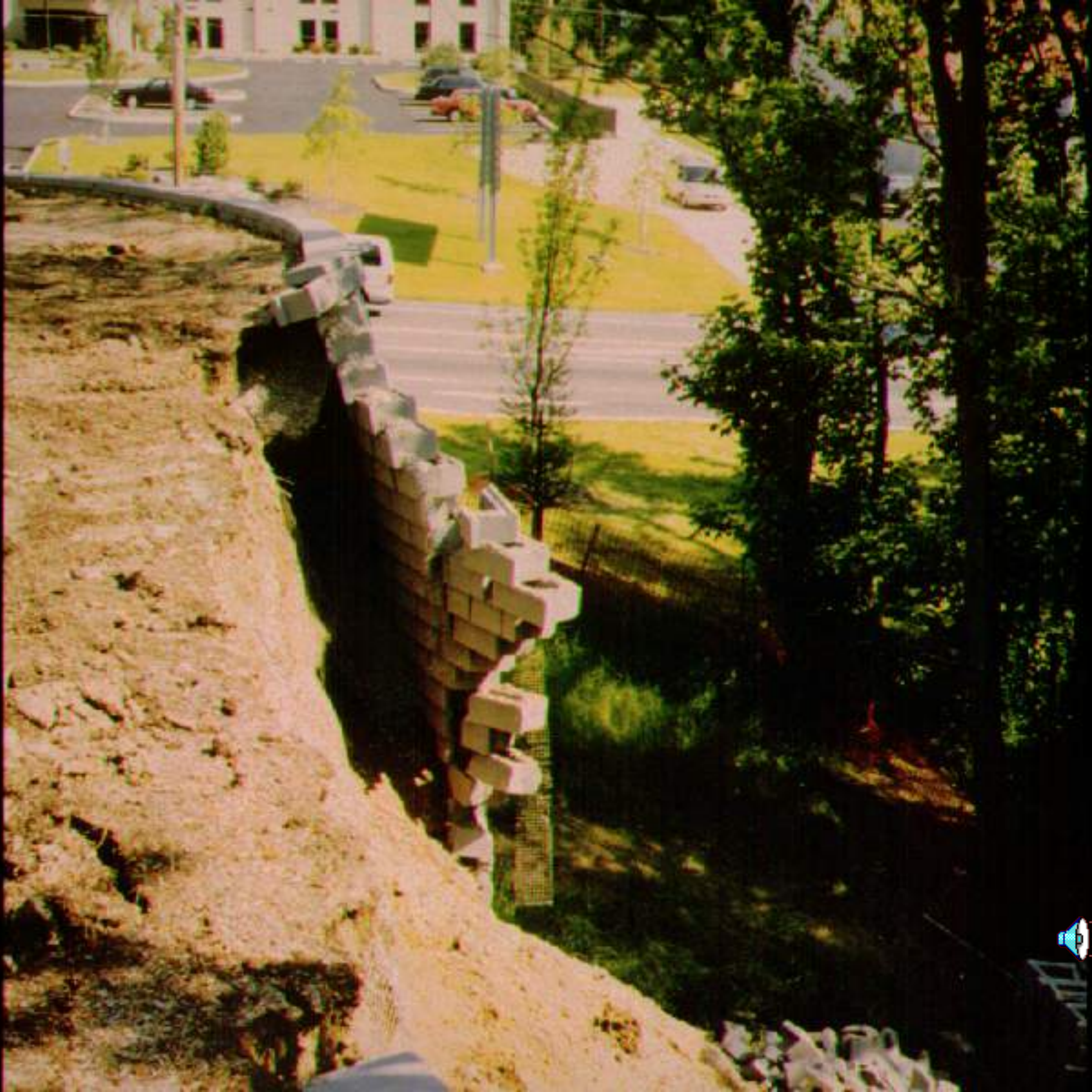
Design Issue	Mod. Rankine	FHWA	NCMA
"external stability"			
• mass sliding	111%	100%	80%
• bearing capacity	100	100	67
• overturning	100	n/a	70
"internal stability"			
• tensile overstress	99%	100%	98%
• soil pullout	123	100	85
• facing connection	n/a	100	83

Thus: mod. Rankine = most conservative
FHWA = intermediate
NCMA = least conservative

4.0 Cases of Inadequate Performance

- there are ~ 35,000 MSE walls with GS reinforcement
- perhaps 30% (~ 10,000) are SRWs
- percentage of problem walls is not known but probably very low
- from literature and GRI files
  - 12-serviceability cases, e.g., deformation
  - 14-failure cases, i.e., collapse





Root Causes in Inadequate Wall Performance

Category	Construction	Design/Spec
Serviceability (12)	5	7
Failure (14)	3	11

- 3 of the construction cases and 17 of the design/spec cases (20 of 26) had silt and/or clay backfill soils in reinforced zone
- 5 of the construction cases were due to lack of CQC and/or CQA
- 1 case was a deep shear failure, thus….
- 25 of 26 were poor backfill soil or poor quality construction and/or lack of inspection

5.0 Concerns

5.1 low permeability backfill

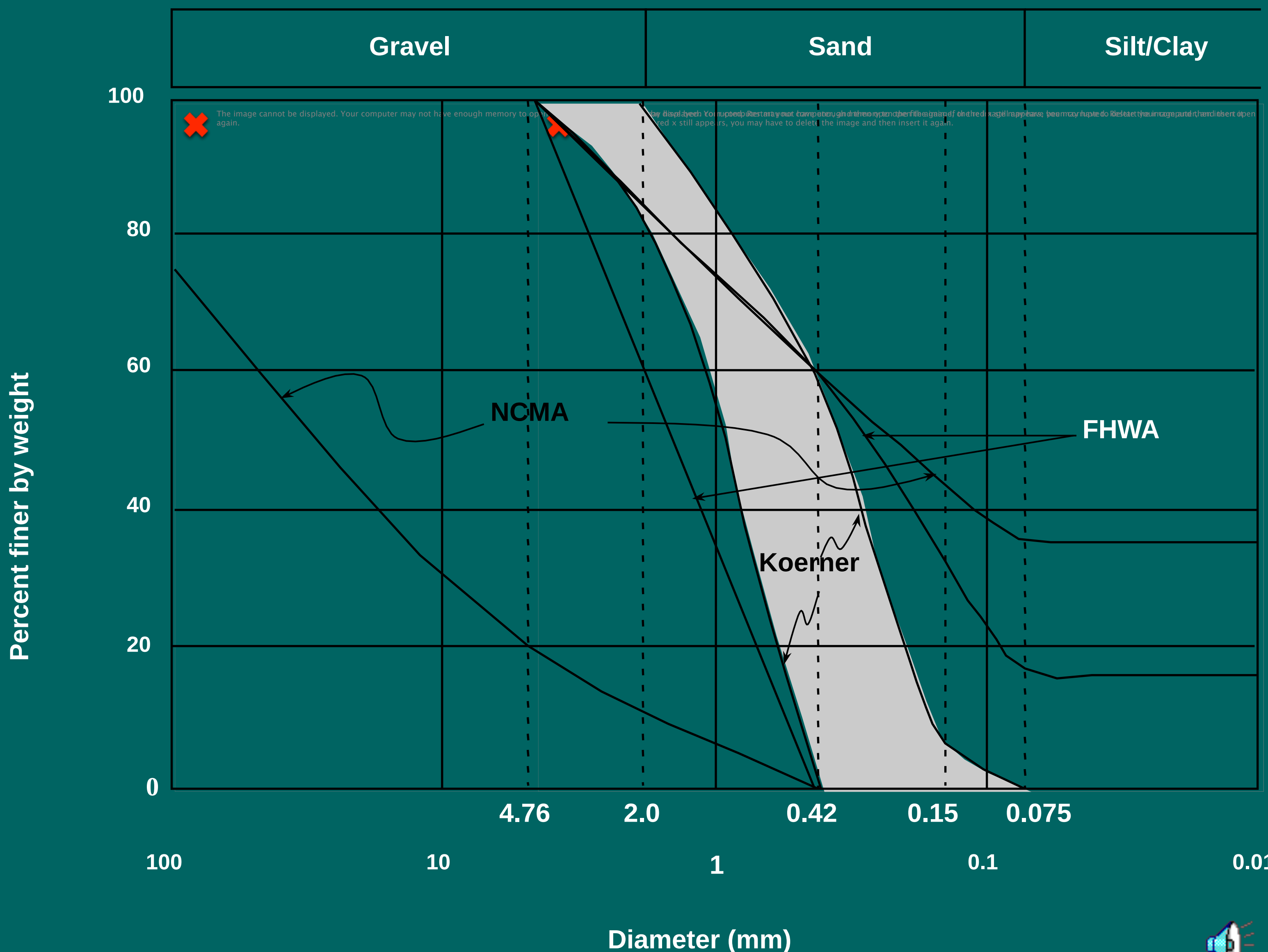
5.2 QC and QA

5.3 additional design issues

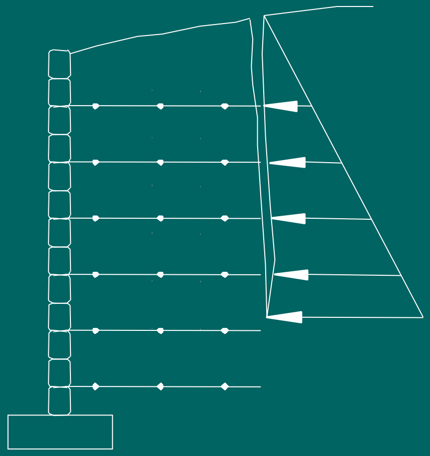
5.4 maintenance

5.1 – Low Permeability Backfill Soil

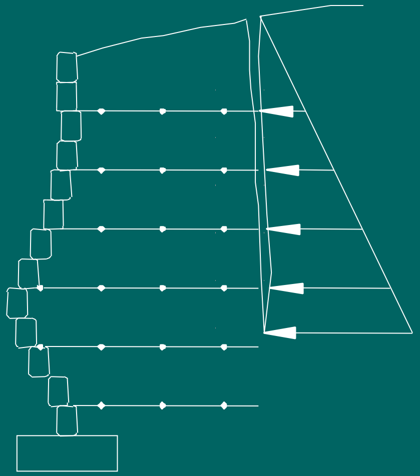
Sieve Size	Particle Size (mm)	Percent Passing Given Sieve		
		Koerner (1994)	FHWA (1998)	NCMA (1997)
-	100	-	-	75-100
No. 4	4.76	100	100	20-100
No. 10	2.0	90-100	-	-
No. 40	0.42	0-60	0-60	0-60
No. 100	0.15	0-5	-	-
No. 200	0.075	0	0-15	0-35


Gravel
Sand
Silt/Clay
100
80
60
40
20
0
NCMA
FHWA
Koerner
4.76
2.0
0.42
0.15
0.075
100
10
1
0.1
0.01
Percent finer by weight
Diameter (mm)

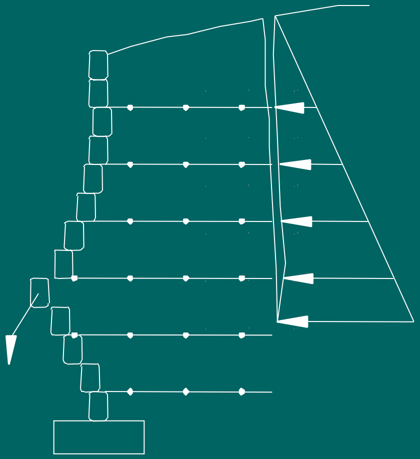
SRW Collapse Progression Due to Hydrostatic Pressure



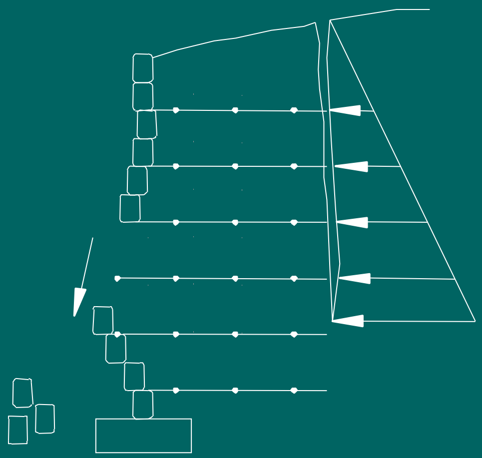
(a) crack forms; water enters
and pressure mobilized



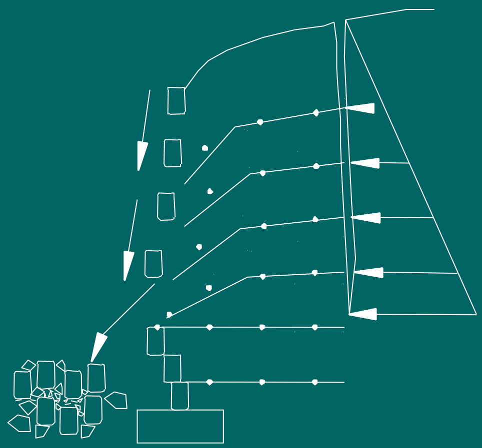
(b) wall deforms;
pressure continues



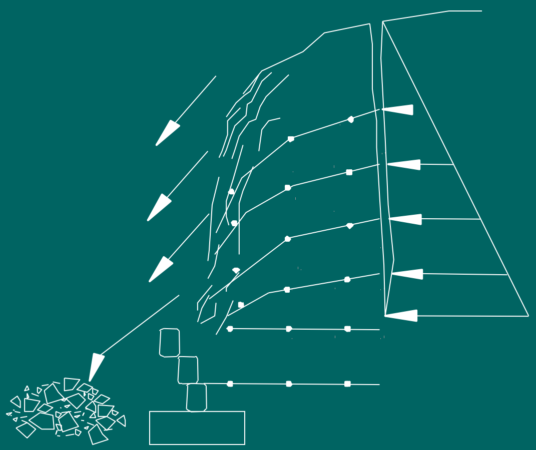
(c) deformation continues;
single block dislodges
and drop to toe of wall



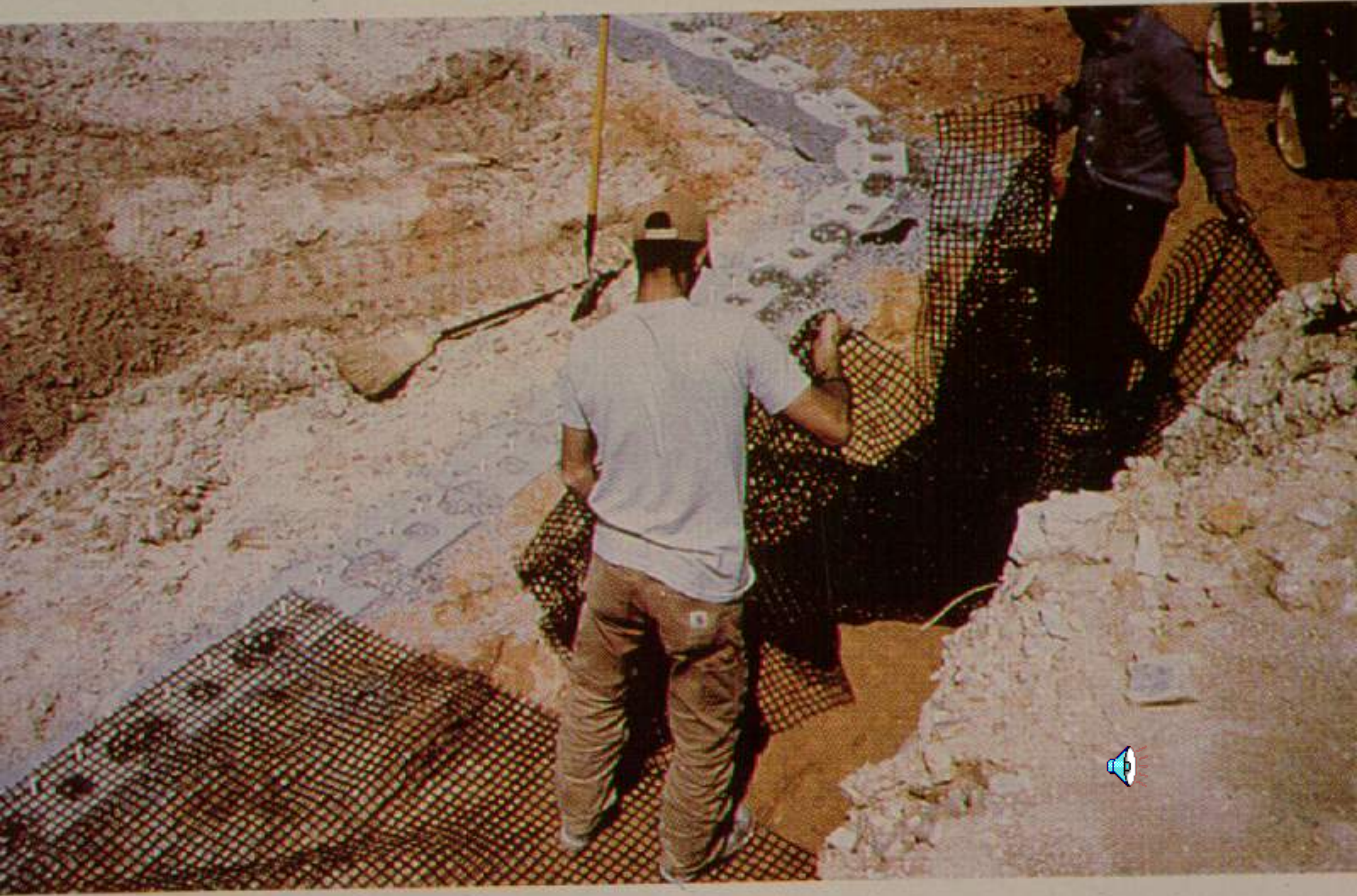
(d) overlying blocks
drop accordingly



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



(f) wall facing and gravel
gone; partial MSE mass
remains behind



Comments

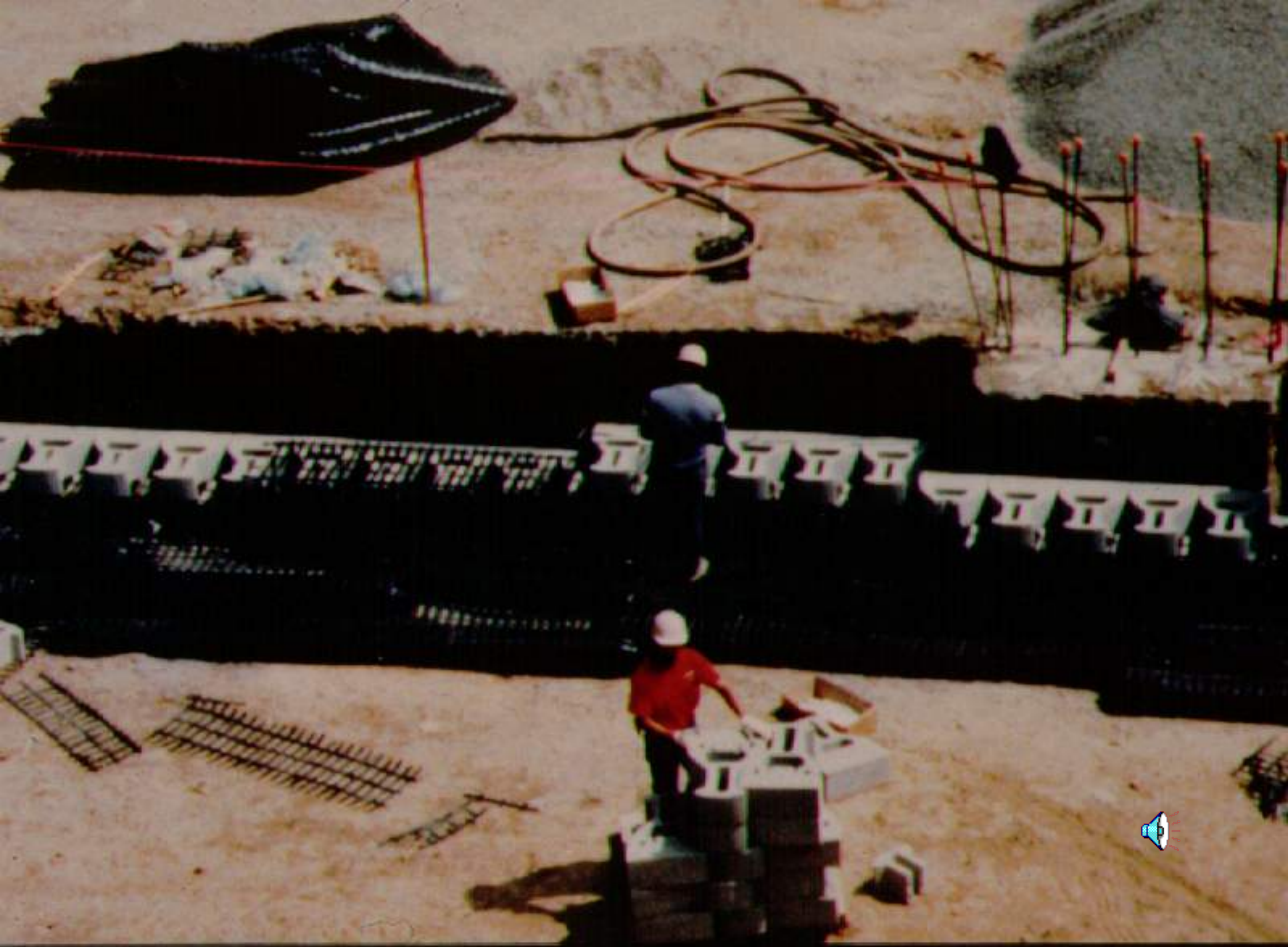
- sand backfill in reinforced zone is preferred
- gravel is acceptable, but cost may be high and RF_{ID} will also be high
- if silt and/or clay soils are used they must be drained externally and/or internally
- proper surface drainage is especially critical
- design must carefully consider the effects of hydrostatic pressures from all sources and directions

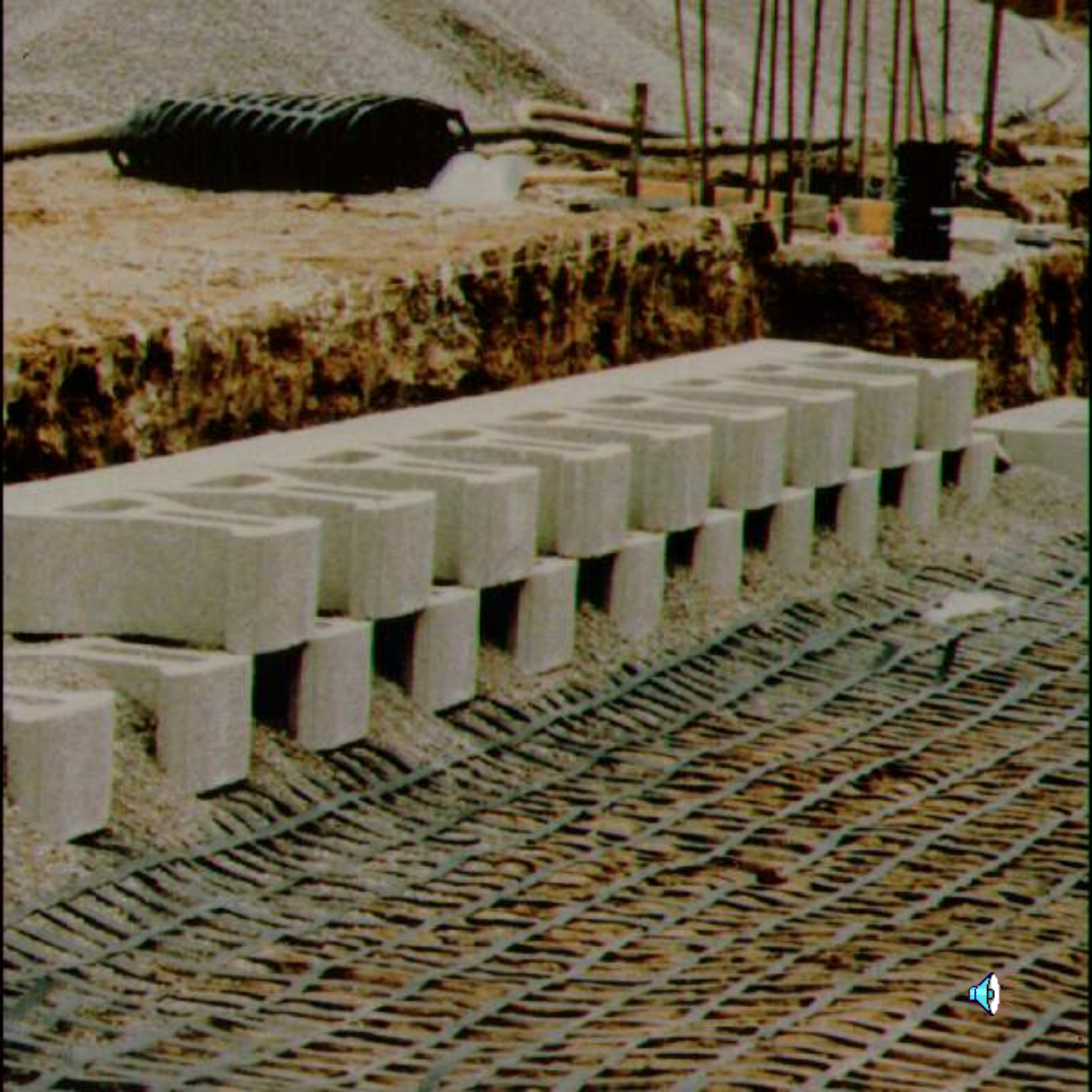
5.2 – Quality Control and Quality Assurance

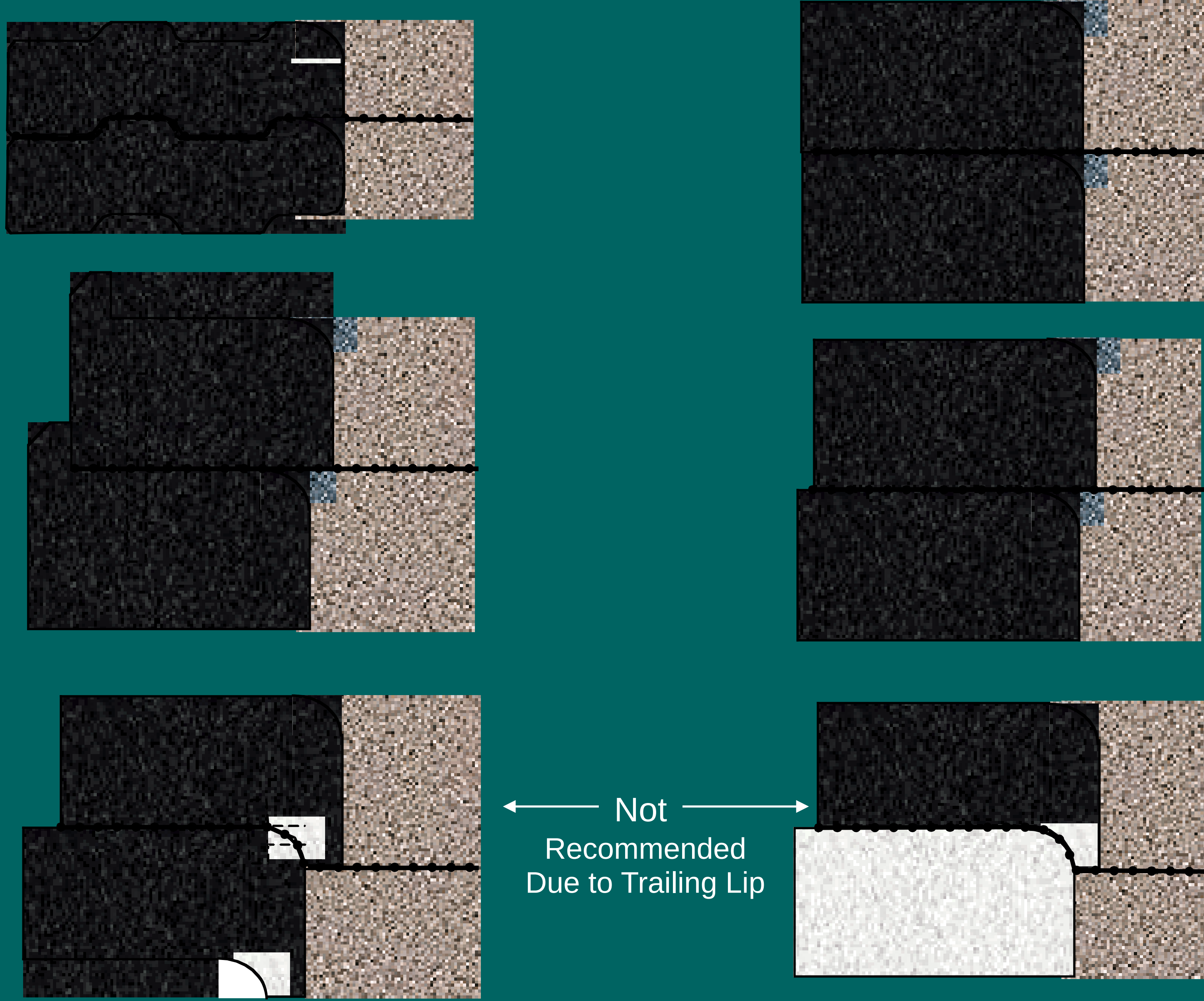
- MQC is responsibility of the manufacturer
- CQC is responsibility of the <u>contractor</u>!
- where are contractor's "quality manuals"?
- what about contractors ISO 9000 and ISO 14,000?

- QA is the responsibility of <u>owner</u>!
- should also be of concern to <u>designer</u>
- refers to both MQA and CQA (blocks & GSs)
- NICET has a QA certification program for geosynthetics inspectors…. let's use it !


SAND?






Not
Recommended
Due to Trailing Lip

Suggested Levels of CQA* as Percentage of Construction Time

Duration → Significance ↓	Temporary	Permanent
Noncritical	33%	67%
Critical	67%	100%

*MQA can be by testing or via certification

5.3 – Additional Design Issues

- seismic design
- friction connections
- details, e.g., penetrations
- durability of facing (or alternate)
- durability of GS reinforcement

Various Mechanical Connections

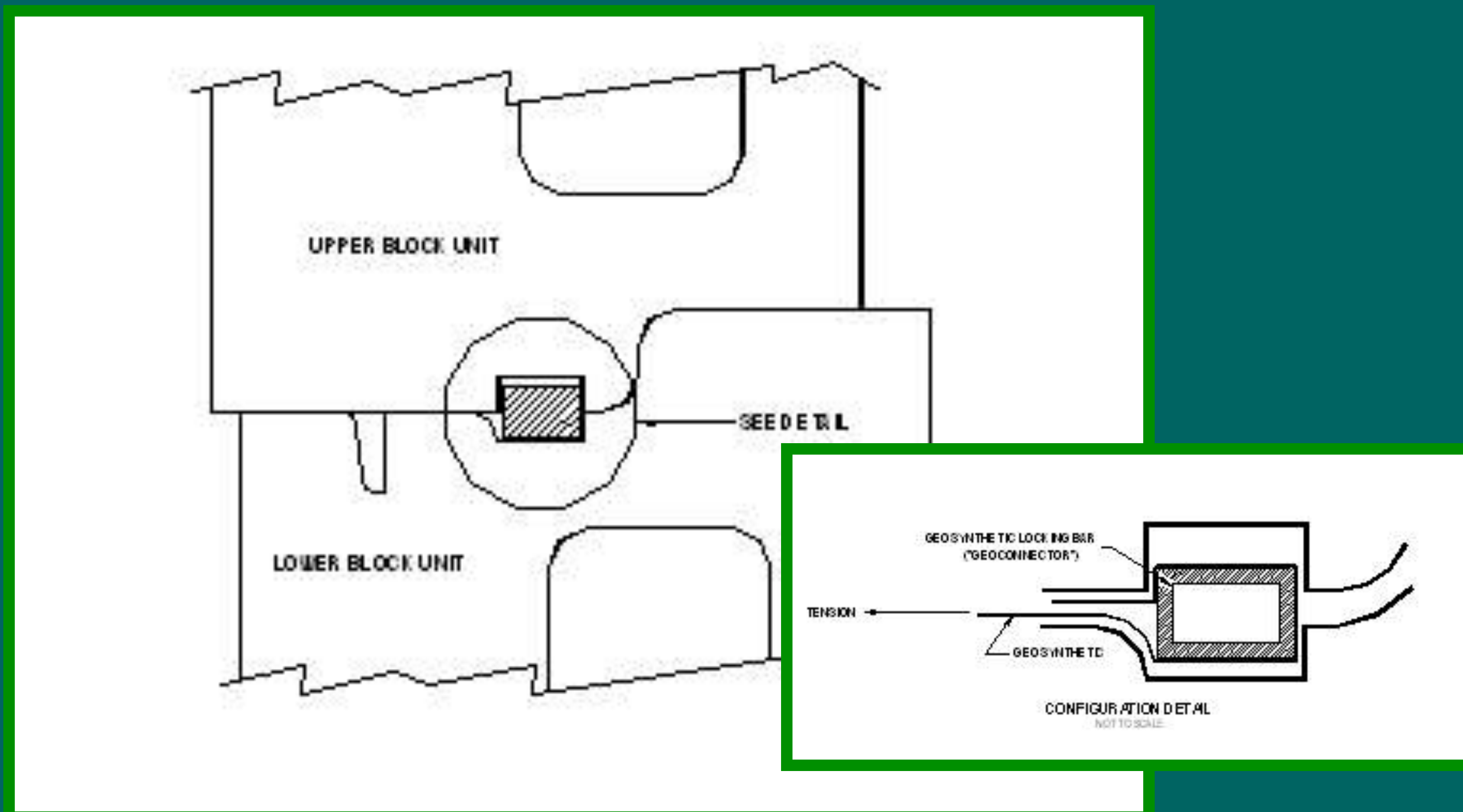
- pins or combs
- wrap-around bars
- keepers in grooves

Mesa Block and Connector System

Verdura Block and Connector System

Landmark Block and Keeper System

New Castle Wall System



On Durability of GS Reinforcement

Polymer	CEG	M_w	UV	OIT	Oven	ESCR
PET	√	√				
HDPE			√	?	?	?
PP			√	?	?	

√ = AASHTO has criteria

Recommended Specifications Items to Assure Long Lifetime

(a) Polyester (AASHTO)

- Carboxyl end group < 30 via GRI-GG7
- Molecular weight > 25,000 via GRI-GG8

(b) High Density Polyethylene

- UV exposure for 500 hrs. via D4355 with ≥ 70% str. ret. (AASHTO)
- OIT via D3895 ≥ 100 min.

  or

  OIT via D5855 ≥ 400 min.
- Oven aging at 85°C via D5721 with 55% OIT remaining via D3895 or 80% OIT remaining via D5885
- Stress crack resist. via D5397-A ≥ 200 hr.

optional

(c) Polypropylene

- UV exposure for 500 hrs. via D4355 with ≥ 70% str. ret. (AASHTO)
- OIT via D3895 ≥ ?

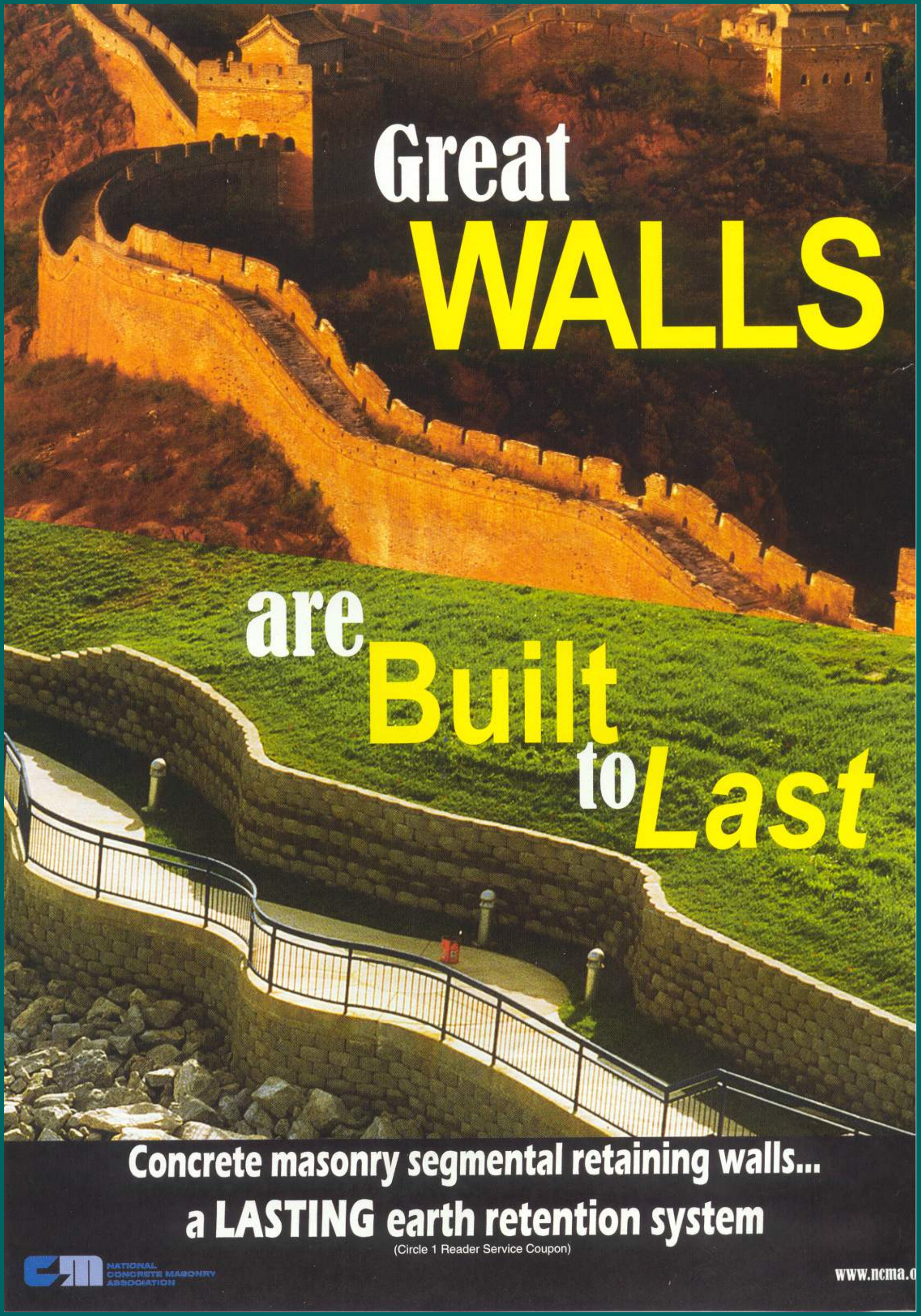
  or

  OIT via D5855 ?
- Oven aging at 85°C via D5721 with ?% OIT remaining via D3895 or ?% OIT remaining via D5885

optional

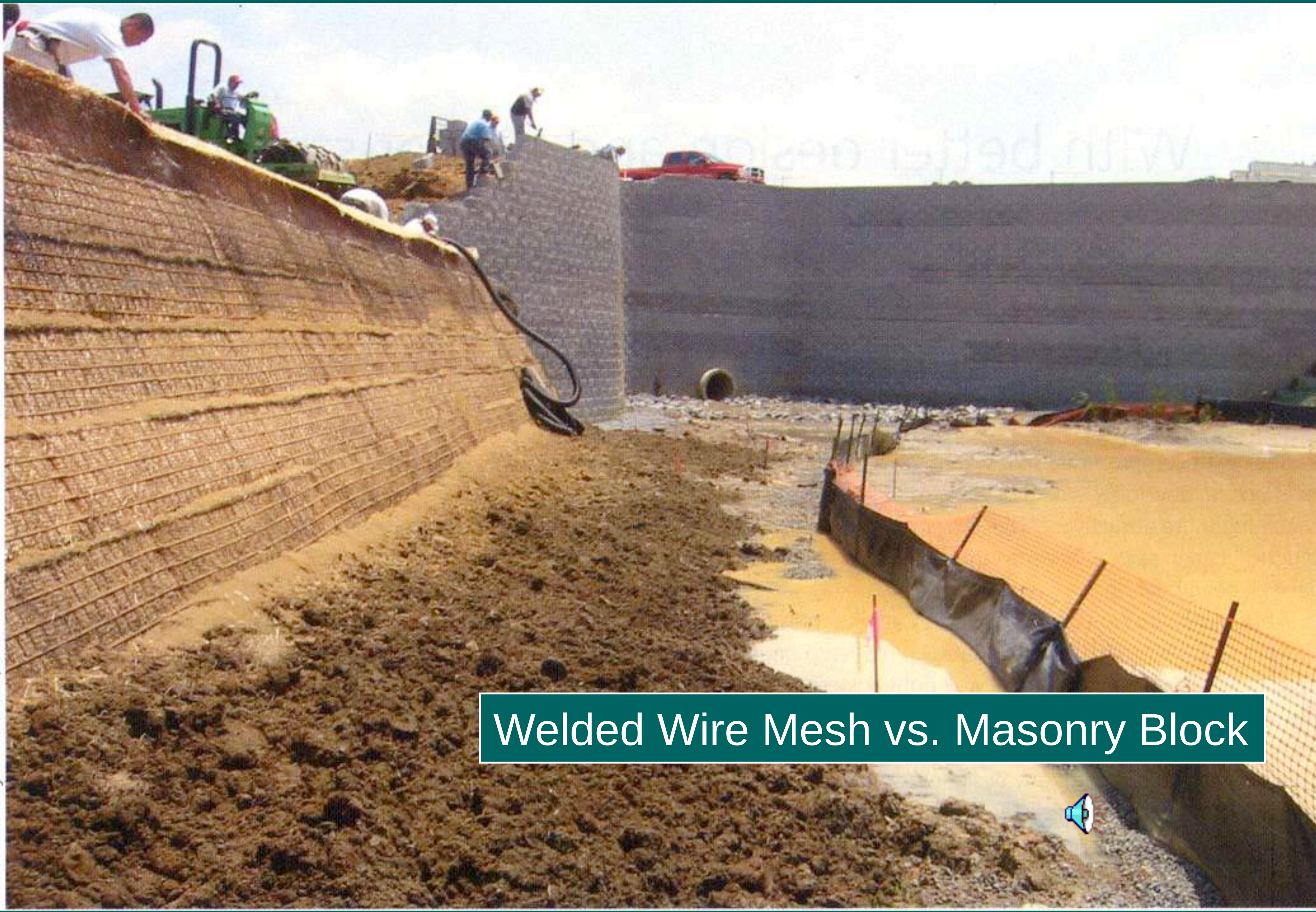
Regarding Durability
of the Masonry Block…

This advertisement
addresses the issue,
but leaves much to
be desired ???



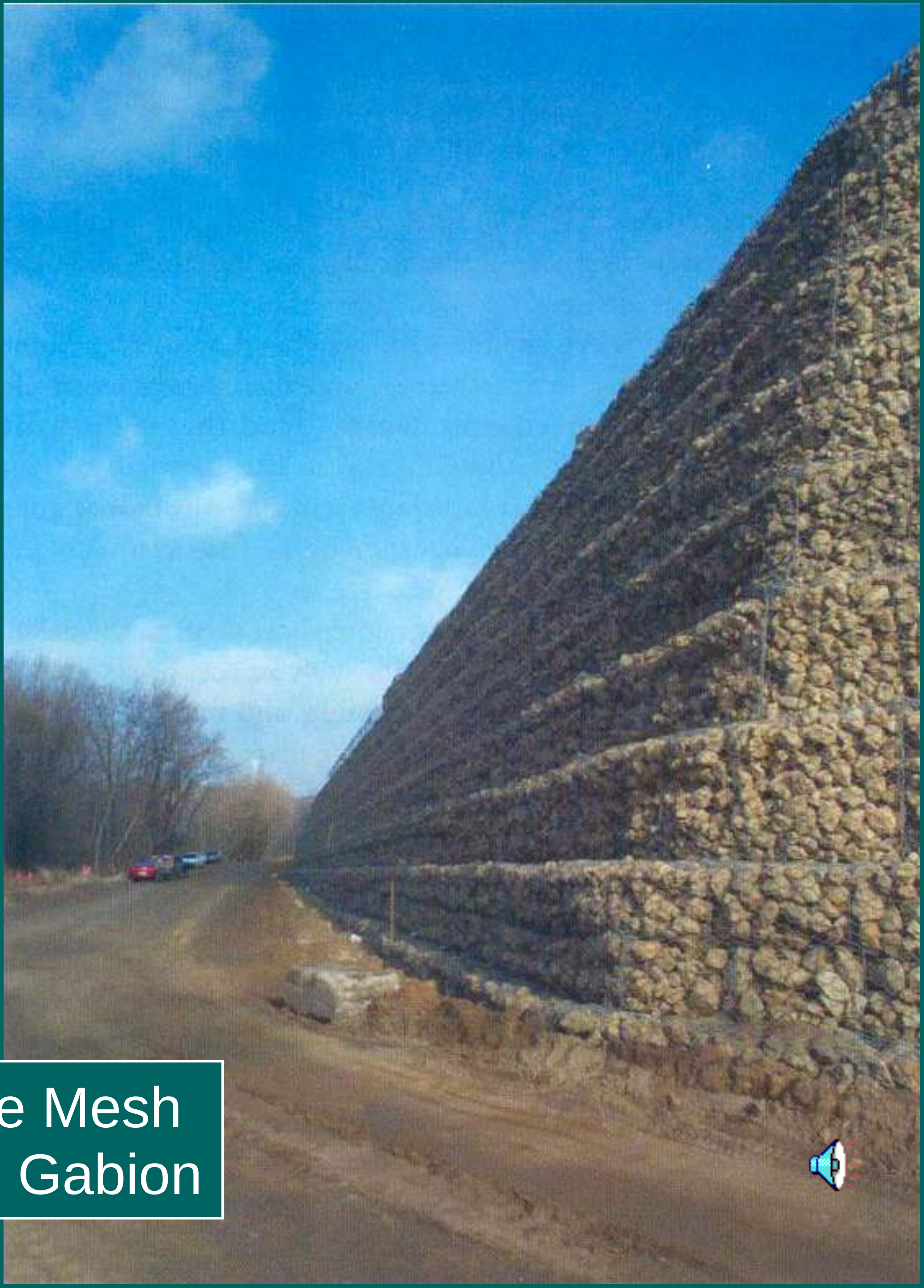
The New Paradigm

- omit masonry blocks entirely
- use welded wire mesh facing
- either braced L-shaped or gabions
- results in a green or live wall
- many new variations appearing……



Welded Wire Mesh vs. Masonry Block

Photo courtesy of Huesker, Inc.



Welded Wire Mesh
Stone Filled Gabion

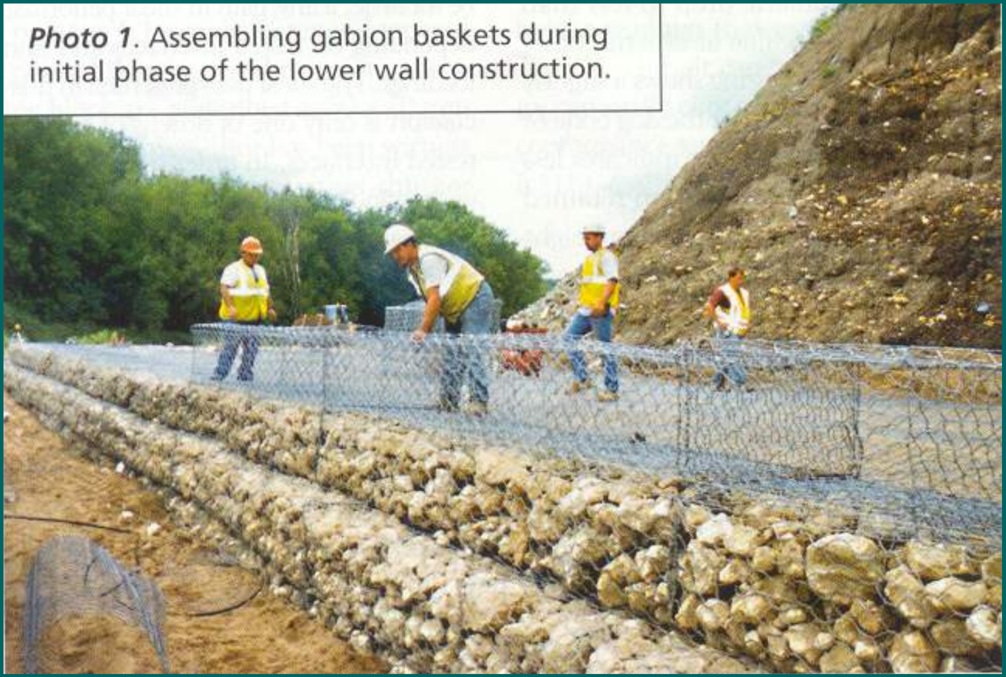


Photo 1. Assembling gabion baskets during initial phase of the lower wall construction.

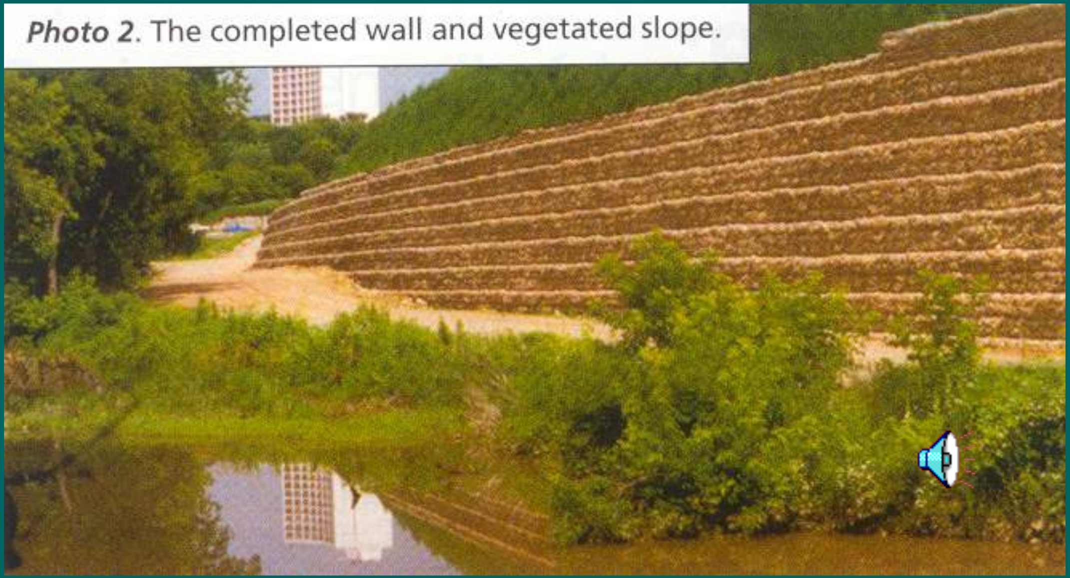
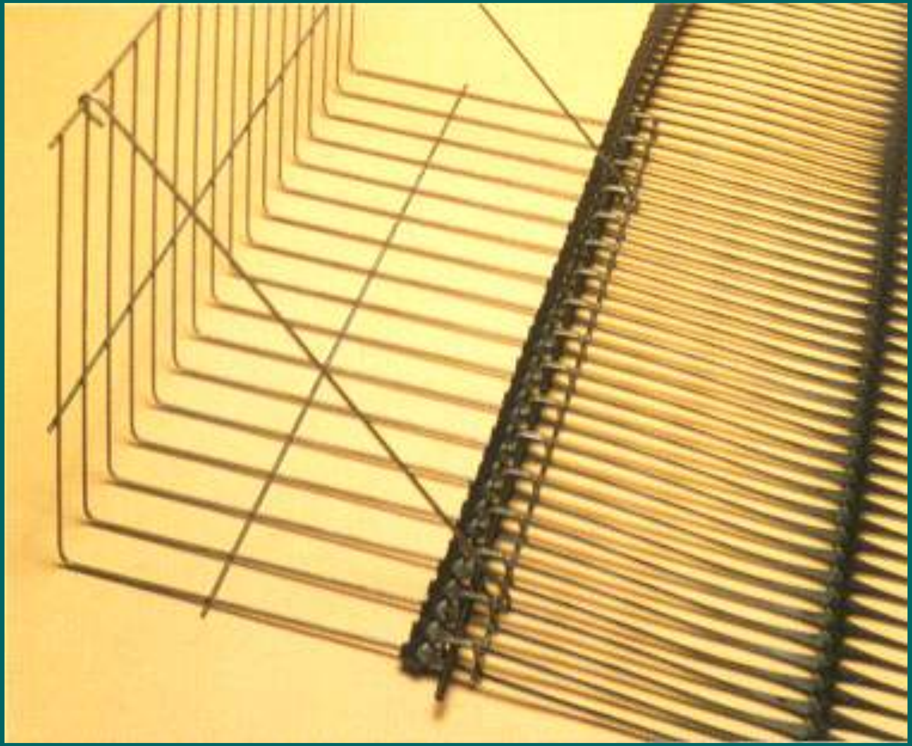
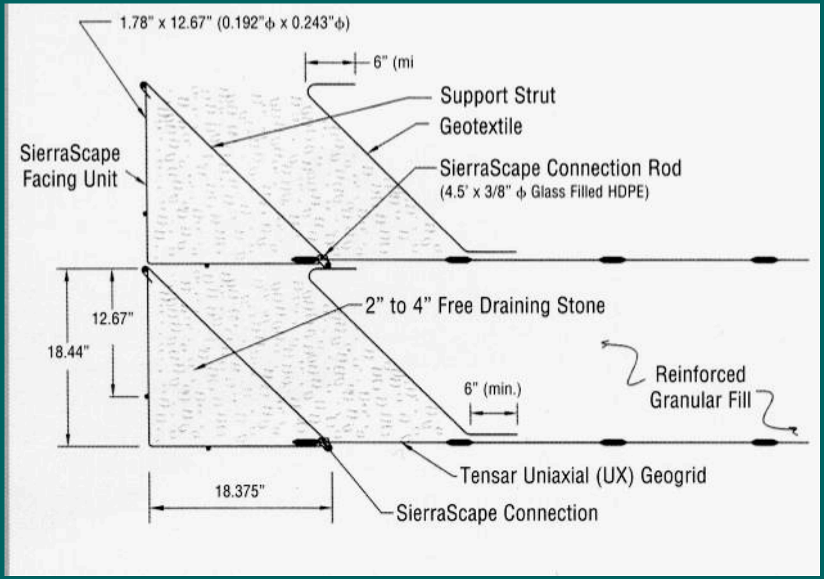


Photo 2. The completed wall and vegetated slope.

Polymer Grid
Stone Filled Gabion





Tensar's SierraScape™
Using
Welded Wire L-Bracket

Seeded Erosion Control Material/Bidirectional Geogrid/Welded Wire Mesh

Beginning of Vegetative Growth


Final Wall at GROWS Landfill

Mountain View Landfill Access Road Embankment

Comments on Welded Wire Mesh Facing

- less costly (by a lot) !
- no masonry degradation issue
- issue is now steel corrosion
- it must be evaluated – not trivial
- results in a green or live wall
- this seems to be the current direction

5.4 Maintenance by Owner and/or Designer

- site visits on 6 to 12 month basis
- drainage patterns are critical
- look for stained and/or cracked blocks
- look for vertical settlement of backfill
- look for horizontal wall movement
- also leaning lightposts and guardrails
- consider monitoring: surveying, inclinometers, crack gages, and other geotech instruments if concerned

6.0 Summary and Conclusions

Summary

- SRW-wall growth is awesome
- being driven on basis of superb aesthetics and low cost
- mod. Rankine is probably too conservative
- FHWA design is sound
- NCMA also, but less conservative
- poor performance is nominal in light of the number of existing walls
- watch out for low-k backfill soils and lack of QC/QA!!!

Conclusions

- growth in SRWs with GS reinforcement is justified; providing that failures are properly analyzed and action taken to avoid in the future
- current growth shows no sign of weakening
- as technology spreads worldwide, SRWs will probably be the wall-of-choice in the future

Thanks for Listening