URBAN HIGHWAYS

CHANNEL LINING DESIGN GUIDELINES

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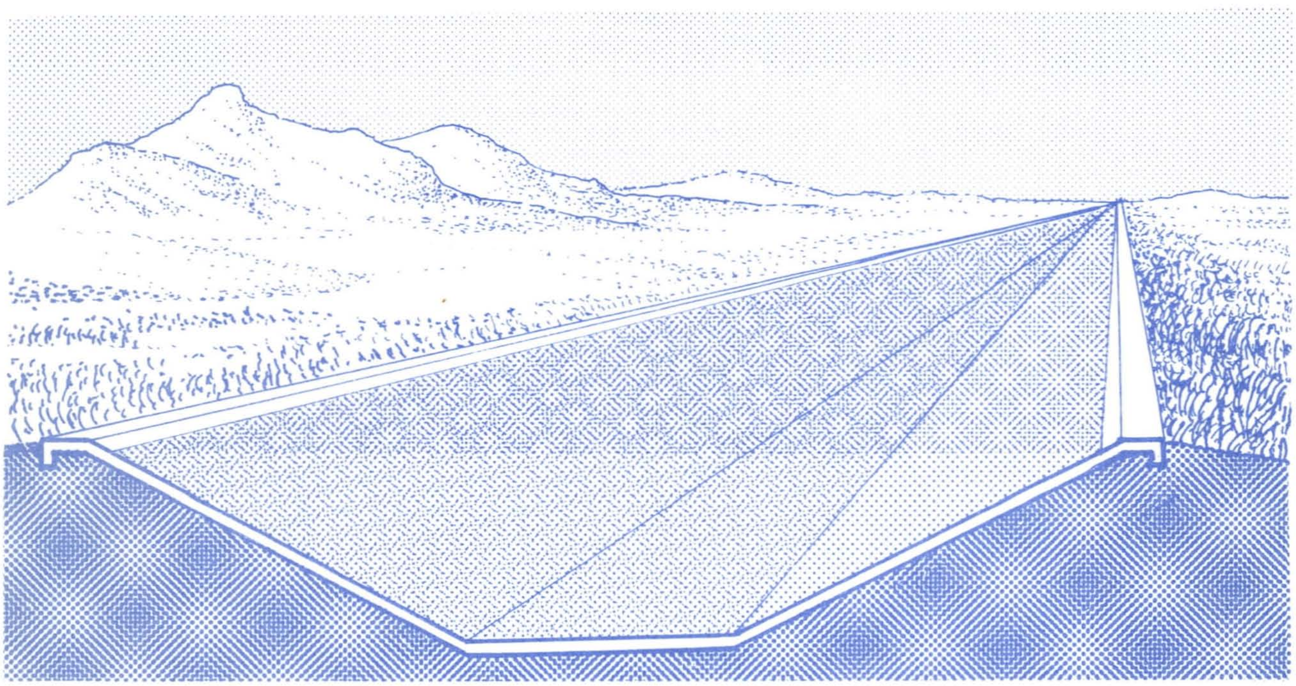


ARIZONA DEPARTMENT OF TRANSPORTATION

URBAN HIGHWAYS
CHANNEL LINING DESIGN GUIDELINES

Introduction:

This publication is intended as an Executive Summary for channel lining designs. It was prepared to establish design criteria for concrete channel linings for the East Papago/ Hohokam Freeway project. This criteria can also be adopted for similar channel lining designs on other Arizona Department of Transportation (ADOT) projects. The study was conducted by gathering, reviewing and analyzing various published documents from Federal, State, and local agencies which are involved in the design and construction of concrete channel linings. These documents are included in a separate publication titled "Report on Concrete Lined Drainage Channels" dated February, 1989, which also contains this Executive Summary.

Design Criteria:

There are three distinct approaches to the design of channel lining reinforcement for canals and hydraulic drainage structures. Two of these approaches utilize expansion and/or contraction joints with the reinforcement varying from 0.0 to 0.5 percent depending on joint spacing. The third approach utilizes no joints with continuous reinforcing varying from 0.3 to 0.4 percent depending on climatic conditions. The design criteria of most agencies reviewed fall within one or more of these approaches and the resulting linings have performed satisfactorily for the most part.

The following items were considered in reaching the conclusion that a continuously reinforced lining without joints will provide the most cost-effective and serviceable channel lining:

- Review of lining performance relative to minimal cracking in continuously reinforced channels;
- Reported and observed maintenance problems of weeds growing in unsealed joints;
- High maintenance cost of replacing damaged joints;
- Moderate difference in construction cost between continuous versus discontinuous reinforcement;
- Potential local compressive buckling of lining due to open joints being filled with incompressible material;
- Potential infiltration of water through open expansion or contraction joints into moisture sensitive soils.

A 0.3 percent longitudinal reinforcement for a moderate climate was found reasonable for adoption to the Phoenix area, (it is performing well on the U.S. Army Corps of Engineers (Corps) Arizona Canal Diversion Channel). A minimum 0.2 percent transverse reinforcement for moderate climates is also considered reasonable for narrow to medium width channels up to 70 feet wide. For wider channels, it is considered realistic to increase the percentage based on the subgrade drag method to a maximum of 0.3 percent.

The criteria for the channel invert lining thickness follows two basic approaches and relates either to velocity or the presence of corrosive materials in the channel bed. Review of collected data indicates that the current general practice for establishing base slab thickness for channels without corrosive material follows closely the U.S. Soil Conservation Service (SCS) nomograph for thickness versus water velocity and it is concluded that bottom lining thickness should be based on this criteria. The minimum thickness, however, is dictated by two considerations--reinforcing clearance, and access for maintenance vehicles. Based on the support capacity of the stabilized moisture sensitive soils, a minimum thickness of 6 inches is required for maintenance vehicle access. A minimum 3-inch clearance for corrosion protection limits the minimum lining thickness to 6 inches for tied reinforcement and 5 inches for flat mesh.

Special consideration of thickness needs on a site specific basis will be required for unusual hydraulic and soil conditions. Energy dispators and extreme breaks in grade will require special design to ensure that lining thickness can resist potential negative pressures. Areas of collapsing or expansive soils require evaluation of thickness in conjunction with subgrade treatment to ensure a serviceable lining.

Slope paving thickness criteria (excluding SCS) generally approximates 80 percent of bottom thickness and is considered a reasonable approach. The limitations on minimum thickness for reinforcement and vehicle access applies to slope paving as well as bottom thickness. It was found that slope paving has even been placed vertically in transition areas, but it is the general consensus that a 1.5:1 maximum slope is more reasonable for maintenance of a quality product. In no circumstance should the slope exceed the soils angle of repose without being formed and designed as a retaining wall. In keeping with a continuously reinforced lining, it is concluded that transitions from trapezoidal channels to rectangular cross-sections should be accomplished without warped slope paving which the Corps is using on the ACDC (Figure 1).

A review of concrete qualities in the various standards indicates a wide range of values but with a general need for shrinkage and crack control. Concrete mix designs will be required which achieve a low drying shrinkage, while also maintaining strength requirements and constructibility.

A review of soil conditions in the Phoenix area indicates the area is well suited for construction of concrete lined channels. Most areas will require only a scarification and recompaction of surface soils without pressure relief. Minor areas of moisture sensitive collapsing or expansive soils will require partial or total removal and replacement with compacted fill based upon a site specific evaluation. Pressure relief and seepage barrier requirements in these moisture sensitive areas will also require special consideration.

The method of pressure relief on channel lining has generally been gravel pockets with weep holes. Problems with silting have been identified which create a maintenance requirement. Use of pressure relief flap valves in conjunction with geocomposite drainage strips is considered a better solution than weep holes. The need for pressure relief will require evaluation on a site specific basis not only for soil condition but for potential groundwater infiltration from heavy irrigation and special conditions such as parallel or crossing utilities.

The use of transverse cutoff walls has generally been eliminated from most design criteria (except at the start and end of a lining), and are not considered to be needed for elimination of seepage or progressive failure. A need does exist for transverse stiffening or stabilizing walls in continuously reinforced linings at movement sensitive structures and where unbalanced compressive forces may occur.

General details were reviewed to reduce construction and maintenance problems. Top of slope paving cutoff walls are a general practice and are needed to eliminate erosion and ground water seepage. A vertical wall set back from the top of slope sufficiently to allow machine trenching provides easier construction. A 2 percent cross slope to one side of the channel bottom (a minimum slope of 6 inches is recommended) provides a means to transport sediment during low flows. Access ramps should be located on the high side of the channel and slope downstream where possible to reduce hydraulic disturbance and sediment buildup. O-Gee control structures should be constructed with sufficient open area at the channel floor to allow flushing of sediment during low flows.

Recommendations:

We recommend the following "Design Guidelines for Concrete Lined Drainage Channels":

1. Channel lining shall be continuously reinforced without expansion or tooled joints except as follows. Construction joints shall be located at the end of a day's pour or when concrete placement stops for more than 45 minutes and between longitudinal paving strips. Longitudinal construction joints shall be located 1-foot up the side slope and in the bottom slab as dictated by channel width but not within the low flow section. Reinforcing steel shall be continuous through lining construction joints and through joints with box culverts and other hydraulic structures.

2. Reinforcing steel shall be Grade 60 or flat sheet welded wire fabric and have the following percentage ratios (p) of reinforcement to cross section area of concrete.

Longitudinal Reinforcement: p = 0.30%

Transverse Reinforcement:

Channel Width*	p
less than 70 feet	0.20%
70 to 90 feet	0.25%
more than 90 feet	0.30%

*Total width including side slopes

Reinforcing steel shall have a minimum 3-inch clearance to grade and a maximum size of #4 for 6 inch lining thickness.

3. Minimum lining thickness for trapezoidal channels shall be:

Bottom Slab

Mean Water Velocity (fps)	Thickness (inches)
less than 10	5*
10 to 15	6
15 to 20	7
more than 20	8

Side Slopes

Mean Water Velocity (fps)	Thickness (inches)
less than 15	5*
15 to 20	5 1/2
more than 20	6

*Minimum slab thickness of 6 inches is required for use of tied reinforcement and in channels wide enough to accommodate maintenance vehicles.

Lining thickness and channel profile shall be investigated on a site specific basis where negative pressures might occur such as a change from a light to a steeper slope per Corps manual EM 1110-2-1602 and 1603.

Lining thickness and reinforcement shall be investigated on a site specific basis in conjunction with subsoil treatment where collapsing or expansive soils occur.

4. Side slopes on main channels should not exceed 1.5 horizontal to 1.0 vertical or the recommended maximum safe cut slope (Table 2) and preferably should not exceed 2.0 to 1.0.

   If side slopes which are steeper than the recommended safe cut slope are used for warped transitions, lining shall be designed as retaining walls for lateral earth pressures listed in Table 2.

5. Sealed vertical expansion joints shall be provided at bridge piers and abutments.

6. Transverse cutoff or stiffening walls which are rigidly attached to the paving shall be installed in the following locations:

   a. At the beginning and end of concrete lining unless terminating in a movement stable structure.

   b. Where new lining abuts an existing concrete lining that is not designed with continuous reinforcement. A transverse sealed expansion joint should be provided between new and existing linings.

   c. At the upstream or start of a transition section to widen the channel.

   d. At breaks in channel profile where the increase in slope exceeds 0.5 degree or 0.009 ft./ft.

   e. Immediately upstream and downstream of movement sensitive structures such as intersecting drainage channels. This shall be evaluated on a project specific basis.

7. Continuous 12-inch deep vertical cutoff walls with a top elevation 6-inches below natural grade shall be provided at the top of side slopes 2 foot back of the top of slope. The 2 foot horizontal section shall have a 2 percent slope toward the channel. Cutoff walls shall be increased to 24-inches deep where substantial flows occur.

8. Bottom lining shall have a cross slope to one side of 2 percent with a minimum of 6 inches of slope.

9. Access ramps shall be located upstream and downstream of box culverts and other hydraulic structures that will not allow vehicular access. Ramps should be located on the high side of the channel invert and slope in a downstream direction where possible.

10. Transitions from a trapezoidal cross section to a rectangular cross section should be made with a varying height vertical retaining wall (Figure 1) instead of warped side slopes. The retaining walls are to be designed for earth pressures listed in Table 2.

11. O-Gee control structures should be constructed with a 30 to 50 percent opening at the base slab for flushing.

12. Subgrade treatment shall be on a site specific basis in accordance with recommendations for the five typical subsurface profile cases in Table 1 and shall result in a minimum Modulus of Subgrade Reaction of 200 pci. Detailed discussions of subsurface profile cases and recommendations are found in Appendix A of the East Papago/Hohokam Freeway "Design Guidelines for Concrete Lined Drainage Channels."

13. Pressure relief of channel linings shall be accomplished with geotextile or geocomposite drainage strips and 4" diameter PVC weepholes through the lining in accordance with recommendations for the five subsurface profile cases in Table 1. Weepholes should be located 1-foot vertically above channel bottom and slope down 3" from back to face of lining. Plastic flap type relief valves should be considered if available and a workable detail can be developed.

    Project and site specific evaluation will be required based on subsurface investigations, potential future changes in ground water levels, where structural back fill occurs adjacent to channel, and at parallel or crossing utilities.

14. Concrete strengths, mix design and drying shrinkage evaluation shall be in accordance with recommendations in Table 3. Detailed recommendations for concrete design mix and shrinkage criteria are found in Appendix A of the East Papago/Hohokam Freeway "Design Guidelines for Concrete Lined Drainage Channels."

TABLE 1

RECOMMENDED SUBGRADE TREATMENT, DRAINAGE & PRESSURE RELIEF PROCEDURES FOR THE FIVE TYPICAL SUBSURFACE PROFILES IN THE GREATER PHOENIX AREA

Subsurface Profile Case	Description	Subgrade Treatment	Drainage & Pressure Relief
1	Clean sands or sands & gravels	• No special treatment required	
		• Scarification & recompaction of surface soils	• Pressure relief not required unless potential exists for groundwater to rise above canal bottom
2	Cemented desert alluvium	• No special treatment required	
		• Scarification & recompaction of surface soils	• Low risk of water accumulation: Pressure relief not required
			• High risk of water accumulation: ex: Extended flow periods adjacent water/sewer lines, heavy landscaping, potential groundwater rise
			Geocomposite drainage strips with pressure relief weepholes
3	Moisture sensitive soils over poorly drained cemented desert alluvium	• **Collapsing soils**	• Low risk of water accumulation: Pressure relief not required
		• 4-feet thick: partial over-excavation, wetting, vibratory compaction & replacement with compacted fill	• High risk of water accumulation: ex: Extended flow periods adjacent water/sewer lines, heavy landscaping, potential groundwater rise
		• Full removal & replacement with compacted fill	• Geocomposite drainage strips with pressure relief weepholes

TABLE 1 (Continued)

RECOMMENDED SUBGRADE TREATMENT, DRAINAGE & PRESSURE RELIEF PROCEDURES FOR THE FIVE TYPICAL SUBSURFACE PROFILES IN THE GREATER PHOENIX AREA

Subsurface Profile Case	Description	Subgrade Treatment	Drainage & Pressure Relief
3 (continued)		• **Expansive Soils**	• Low risk of water accumulation: Pressure relief not required
		• Partial or total removal & replacement with compacted fill	• High risk of water accumulation: ex: Extended flow periods adjacent water/sewer lines, heavy landscaping, potential groundwater rise
		• Geomembrane underliner as seepage barrier	• Geocomposite drainage strips with pressure relief weepholes
4	Moisture sensitive soils over free draining granular stata	• **Collapsing soils**	• Pressure relief not required unless potential exists for groundwater to rise above canal bottom
		• 4-feet thick: partial over-excavation, wetting, vibratory compaction & replacement with compacted fill	
		• Full removal & replacement with compacted fill	
		• **Expansive soils**	
		• Partial or total removal & replacement with compacted fill	
		• Geomembrane underliner as seepage barrier	

TABLE 1 (Continued)

RECOMMENDED SUBGRADE TREATMENT, DRAINAGE & PRESSURE RELIEF PROCEDURES FOR THE FIVE TYPICAL SUBSURFACE PROFILES IN THE GREATER PHOENIX AREA

Subsurface Profile Case	Description	Subgrade Treatment	Drainage & Pressure Relief
5	Expansive clays throughout profile	• Overexcavate & replace with nonexpansive compacted fill; depth of overexcavation as required to limit potential expansion to tolerable limits	• Low risk of water accumulation: Pressure relief not required
			• High risk of water accumulation: ex: Extended flow periods adjacent water/sewer lines, heavy landscaping, potential groundwater rise
		• Geomembrane underliner as seepage barrier	• Geocomposite drainage strips with pressure relief weepholes

Note: Methodology for design of geocomposite drainage systems can be found in "Designing for Flow:", R.M. Koerner, Civil Engineering, Volume 56, No. 10, October 1986, and "Designing with Geosynthetics", R.M. Koerner, Prentice Hall International, New Jersey, 1986

TABLE 2

RECOMMENDED ENGINEERING DESIGN PARAMETERS FOR SUBSURFACE CONDITIONS 1 THROUGH 5

		*Slopes		Modules of Subgrade Reaction, pci		Lateral Earth Pressures Against Retaining Walls: "Active" β, deg.				"At Rest" β, deg.			
Case	Subsurface Conditions	Cut	Fill	Dry	Wet	0	10	20	30	0	10	20	30
1	Clean sand or sand & gravel	2:1	2:1	600	600	30	31	37	56	50	52	61	93
2	Moderately to strongly cemented alluvial soils	1:1	1:1	750	600	30	31	37	56	50	52	61	93
3	Moisture sensitive (collapsing or expansive soils over cemented alluvium)	1:1	1:1	200	100	30	31	37	56	50	52	61	93
4	Moisture sensitive (collapsing or expansive) soils over granular free-draining soils	2:1	2:1	200	100	30	31	37	56	50	52	61	93
5	Medium to highly expansive clays throughout entire profile	1:1	1:1	600	400	30	31	37	56	50	52	61	93

*Notes:

1. Recommended slope ratios are horizontal to vertical. Slopes are maxiumum safe slopes. In most cases, slopes will be controlled by construction considerations and will be no steeper than 1.5:1.

2. Moduli of subgrade reaction for Cases 3, 4 and 5 for wet conditions are based on the moisture sensitive soils not being stabilized or replaced with structural fill. Values for dry conditions for these cases apply to stabilized moisture sensitive soils or structural fills.

3. "Active" case for lateral earth pressures applied to conditions in which the retaining wall is free to move at the top. The "at rest" case applies where walls are restrained from movement at the top. The angle β refers to the slope angle of the backfill from the horizontal.

TABLE 3

RECOMMENDED GUIDELINES FOR CONCRETE DESIGN MIX & EVALUATION OF DRYING SHRINKAGE

DESIGN MIX

- Design mix should meet the general specification requirements of ADOT 1006-3.

Strength

- Compressive strength should be 3,000 psi at 28 days.

Aggregates

- Aggregates should meet minimum requirements of ADOT Standard Specification 1006-3. Coarse aggregate should be size 57. Coarse aggregate should have a minimum of 75 percent crushed faces.

Mineral Filler

- Ninety (90) pounds of fly ash Class F (ASTM C618) shall be used as a mineral filler. Loss on ignition should be a maximum of 3.0 percent. Fly ash should not be considered as a replacement for cement. Fly ash should have an R factor less than 2.5. The R factor is defined as (C-5%)/F, where C is the calcium oxide content expressed as a percentage and F is the ferric oxide content expressed as a percentage. The R factor requirement may be waived if the contractor furnishes documented test results that the soil in contact with the Portland Cement concrete contains less than 0.10 percent water soluble sulfate, (as SO4) and/or the water in contact with the Portland Cement concrete contains less than 150 milligrams per liter sulfate (as SO4). The tests for sulfates should be performed in accordance with the requirements of California Department of Transportation Test Method No. 417. Calcium and ferric oxide content should be determined in accordance with the requirements of ASTM C311

Chemical Admixtures

- Should meet the requirements of ADOT 1006-2.04.

Water

- Should meet the requirements of ADOT 1006-2.02.

Cement

- Should be Portland Cement Type II, meeting the requirements of ASTM C150.

Slump

- Maximum 4 inches (AASHTO T119).

Air Content

- 5 plus or minus 2 percent by volume (AASHTO T-152).

TABLE 3 (Continued)

RECOMMENDED GUIDELINES FOR CONCRETE DESIGN
MIX & EVALUATION OF DRYING SHRINKAGE

Curing

- Should meet the requirements of ADOT 1006-6 A.
- Subgrade shall be moistened and free of excess standing water prior to placement of concrete.

Hot Weather Concreting

- Should meet the requirements of ADOT 1006-5.02.

Minimum Cement Content

- Not applicable.

DRYING SHRINKAGE EVALUATION

Mortar Shrinkage Tests

- ASTM C157, "Length Change of Hardened Cement Mortar and Concrete," testing should be performed on the cement proposed for the project design concrete mix. If other than previously approved Type II cement is proposed, the shrinkage of the cement should be equal to or less than the value obtained in the control specimens made from previously approved cements which result in the lowest practicable shrinkage.

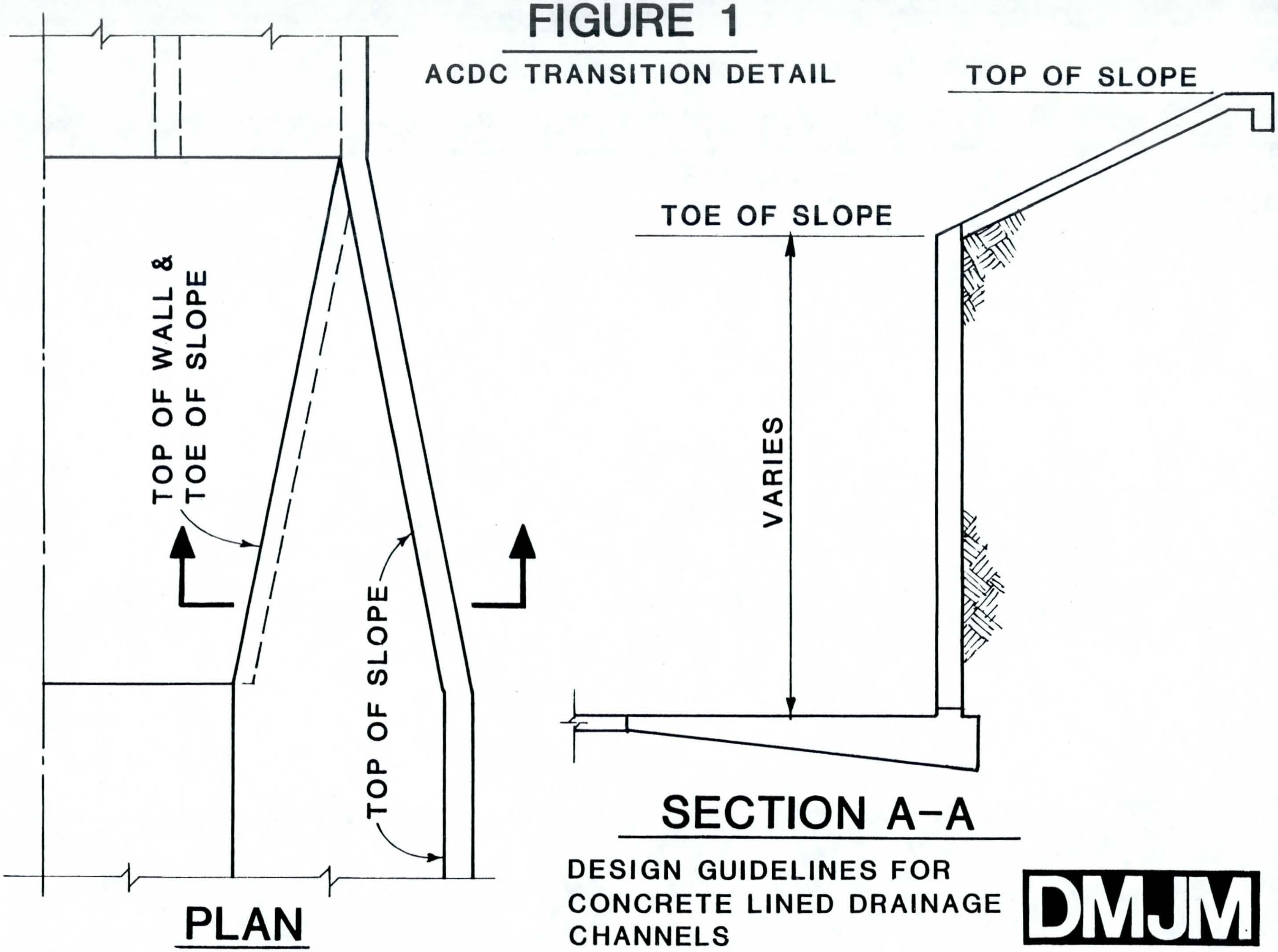
Field Shrinkage Tests

- Test panels should be prepared with the proposed concrete design mix for the purpose of evaluating drying shrinkage properties. Test panels should be made in accordance with the Kraai Method outlined in Concrete Construction, Volume 30, No. 9, September, 1985, 9 pp. 775-788. Test panels shall be 2 by 3 feet in plan dimension and 2 inches in thickness.
- The Control Test Panel should be made from an established reference mix design. Locally produced Salt River aggregate should be used. Minimum compressive strength should be 3,000 psi at 28 days. Fly ash, as a pozzolanic material, should be utilized as a mineral filler at a maximum of 90 pounds per cubic yard of concrete. A water reducing admixture should be used meeting the requirements of ADOT 1006-2.04.

  The project design mix acceptance should have an equal or reduced number and size of shrinkage cracking as compared to the Control Mix Test Panel.

FIGURE 1

ACDC TRANSITION DETAIL



SECTION A-A

DESIGN GUIDELINES FOR CONCRETE LINED DRAINAGE CHANNELS

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