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COTTONWOOD MINE
BLASTING PLAN

INCORPORATED
EFFECTIVE:

JUN 05 1995

WOOD DIVISION OIL, GAS AND MINING
Cottonwood Mine
Surface Blasting Plan

LOCATION: Cottonwood Mine, approximately Eight (8) miles northwest of Orangeville Utah.

TYPE OF OPERATION: Underground Coal Mine.

TYPE OF BLASTING ACTIVITIES: Road grading, Rock removal, Trenching Footings, etc.

BLASTER CERTIFICATION: Blasters will have a valid Utah Blaster Certification. This Certification will be carried by the blaster or kept on file during blasting operations. At least one other person will be present during a blast. Proper training will be given to crews associated with the blast or explosives.

BLAST DESIGN: When applicable, a blast design will be prepared by a Certified Blaster. This design will be submitted to the Division at a time before the blast.

PRE-BLAST SURVEY: No blasts will utilize more than five (5) pounds of blasting agent or explosives detonated in any eight-millisecond period.

BLASTING SCHEDULE: All blasting will be done between sunrise and sunset.

BLASTING SIGNS AND WARNINGS: Blasting signs will meet R645-301-521.200 and be conspicuously placed along the edge of the blasting area or road entrance. Signs will be placed at all accessible entrances to the blasting area that are within the permit area from public roads stating "Warning! Explosives in Use." Access control will be exercised preventing anyone from entering the blasting area.

ADVERSE BLASTING EFFECTS: No structures exist within a distance that would present concerns from Airblast or Ground Vibration.

BLASTING RECORDS: Blasting records will be kept on file for review by the Division. Blasting records will comply with R645-301-524.700.
Energy West Mining Co.
Blasting Design & Record
(R645-301-524.700)

(R645-301-524.711) Name of Operator Conducting Blast.

(Company Name)

(Address)

(City - State)

(Telephone Number)

(R645-301-524.712) Location, Date and Time of Blast.

(Mine)

(Location)

(Date)  (Time of Blast)

(R645-301-524.713) Name, Signature, and Certification Number of Blaster in Charge.

(Name)

(Signature)  (Certification Number)

[Stamp: INCORPORATED EFFECTIVE: JUN 05 1995]
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<th>Description</th>
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<td>(R645-301-524.720)</td>
<td>Direction and Distance, in feet from the nearest blast hole to the nearest dwelling, public building, school, church, community or institutional building outside the permit area.</td>
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<td>(Distance in Feet)</td>
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<tr>
<td>(R645-301-524.730)</td>
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<td>(Wind Direction &amp; Approximate Velocity)</td>
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<td>(R645-301-524.741)</td>
<td>Type of Material Blasted</td>
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<td>(R645-301-524.742)</td>
<td>Sketchs of the blast pattern including number of holes, burden, spacing, decks, and delay pattern.</td>
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(R645-301-524.743) Diameter and Depth of Holes.

(R645-301-524.744) Types of Explosives Used.

(R645-301-524.745) Total Weight of Explosives Used.

(R645-301-524.746) Maximum Weight of Explosives Detonated in an Eight (8) Millisecond Period.

(R645-301-524.747) Initiation System.

(R645-301-524.748) Type and Length of Stemming.

(R645-301-524.749) Mats or Other Protection Used.

(R645-301-524.750) Seismographic Records and Airblast Information.

(Reading)

(Location & Distance)

(Name of Person Taking Reading) 1995

(Name of Person & Firm Analyzing Reading)

(R645-301-524.760) Reason for Unscheduled Blast.
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Culvert Design

Inlet Detail

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Cottonwood Fan Portal

Sedimentation Ponds Cross-Sections

South Sediment Basin Details and Cross-Sections

North Sediment Basin Details and Cross-Sections

Sedimentation Ponds No's 1 & 2

Outlet Structure Pond #1

Outlet Structure Pond #2

Haul Road Culvert

Map 1

Figure 1

Figure 2

Map 2

CM-10552-WR

CM-10351-CP

CM-10353-CP

7704-C121

7704-C125

7704-C126

7704-C45

Revised 11/14/89
HYDROLOGIC ANALYSIS OF DISTURBED AREA RUNOFF CONTROL CULVERTS, SEDIMENT PONDS, AND SMALL AREA EXEMPTION AT THE COTTONWOOD/WILBERG MINE PORTAL SITE

AND

HYDROLOGIC ANALYSIS OF UNDISTURBED AND DISTURBED AREA RUNOFF CONTROL DITCHES, CULVERTS, AND SEDIMENT BASINS AT THE COTTONWOOD/WILBERG MINE COTTONWOOD CANYON FAN PORTAL SITE.

Prepared For

UTAH POWER & LIGHT MINING DIVISION

Prepared By

HANSEN, ALLEN & LUCE, INC.
6771 South 900 East
P.O. Box 21146
Salt Lake City, Utah

MAY, 1989
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INTRODUCTION

This report and accompanying analyses have been prepared in accordance with HA&L letter proposal and scope of work dated May 9, 1989. This report summarizes the hydrology of the disturbed area runoff control facilities at the Cottonwood/Wilberg Mine Portal Site and hydrology of the disturbed and undisturbed area runoff control facilities at the Cottonwood/Wilberg Mine Cottonwood Canyon Fan Portal Site. It is our understanding that, the analysis of the undisturbed area runoff control facilities for the Cottonwood/Wilberg Mine Portal Site was requested by DOGM (Utah Department of Oil Gas And Mining) during the present analysis and thus will be included in a separate report at a later time.

The remainder of this report is divided into three sections 1) Hydrologic Methodology, 2) Cottonwood/Wilberg Mine Portal Disturbed Area Runoff Control Culverts and Sediment Ponds, and 3) Cottonwood Fan Portal Undisturbed and Disturbed Area Runoff Control Facilities.

HYDROLOGIC METHODOLOGY

This section details the methods used to estimate storm runoff volume, peak storm runoff rates, and mean sediment yield.

STORM RUNOFF VOLUME

Sediment ponds and other sediment treatment facilities are required to treat the runoff from a 10-year 24-hour storm event.

The runoff depth resulting from a given rainfall depth was determined using the runoff curve number technique, as defined by the USDA Soil Conservation Service (1972). According to the curve number methodology, the relationship between storm rainfall, soil moisture storage, and runoff can be expressed by the equations:

\[ Q = \frac{(P - 0.2S)^2}{P + 0.8S} \quad (1) \]

\[ CN = \frac{1000}{10 + S} \quad (2) \]

where:

- \( Q \) = direct runoff depth, inches;
- \( P \) = storm rainfall depth, inches;
- \( S \) = maximum infiltration depth (defined as the maximum possible difference between \( P \) and \( Q \)), inches; and

\( CN \) = curve number, dimensionless.
Use of Equations 1 and 2 requires the selection of a curve number, which is a function of vegetative cover and the hydrologic soil groups. Curve numbers for the study area were selected from information provided by the USDA Soil Conservation Service (1972), by U.S. Bureau of Reclamation (1977), and from personal hydrologic judgment following field observation. Volume weighted curve numbers were used for heterogeneous areas. More detail on Curve Number selection is given in subsequent sections of this report and in the appendix.

Values of precipitation (P) were selected for the design return periods from Volume VI-Utah of the NOAA ATLAS 2 Precipitation-Frequency Atlas of the Western United States (Miller et. al., 1973).

Equation 1 is based on the assumption that \( I_a = 0.2S \), where \( I_a \) is the initial abstraction from storm rainfall, defined as the rainfall which must fall before runoff begins (i.e., to satisfy interception, evaporation, and soil-water storage). Therefore, determination of runoff from Equation 1 is valid only when \( P \geq 0.2S \). Below this point, no runoff can occur. Once \( Q \) was determined from the above equation, the runoff volume was calculated by multiplying the runoff depth by the drainage area.

FLOW HYDROGRAPHS AND PEAK DISCHARGE

The regulations require that temporary facilities such as culverts and ditches which will be removed at final reclamation be sized to pass at least the peak runoff from a 10-year 6-hour storm event. Sediment pond spillways are to be designed such as to pass at least the 25-year 6-hour storm event with at least 1-foot of freeboard. The US Army Corps of Engineers' (COE) computer program "HEC-1 Flood Hydrograph Package" (COE, 1985) was used to model the 10-year and 25-year design storm events to produce hydrographs at selected locations at the Cottonwood/Wilberg Mine Portal and the Cottonwood Canyon Fan Portal sites. The model was prepared using the SCS Curve Number and dimensionless unit hydrograph technique (SCS, 1972) to compute hydrographs for each sub-basin and the kinematic wave routing routine (COE, 1985) to route hydrographs to places of confluence. The SCS 6-hour storm distribution was used in the analysis (SCS Tech. Release No. 60, revised 1985).

Input required for the SCS Curve Number and dimensionless unit hydrograph subroutine includes sub-basin area, sub-basin representative curve number, and lag time (TLAG). Sub-basin areas were determined using a polar planimeter. Curve numbers were selected for each cover type and a volume weighted curve number was computed to represent the sub-basin.

The lag time (TLAG) is defined as the time from the center of mass of rainfall excess to the peak of the runoff hydrograph. Two methods were utilized in the analysis to find TLAG. For undisturbed areas an empirical relationship for TLAG developed by the SCS was used (SCS, 1972):
\[ TLAG = \frac{(h)(S + 1)}{1900 Y} \]  

where:

- \( TLAG \) = watershed lag, in hours;
- \( h \) = hydraulic length, or the length of the mainstream to the farthest divide, in feet;
- \( S \) = is as previously defined; and
- \( Y \) = average watershed slope, in percent.

Values of \( Y \) were obtained from methods outlined by Craig and Rankl (1977). The hydraulic length was taken from an appropriate topographic map, and \( S \) was determined from Equation 2 once the runoff curve number was estimated.

\( TLAG \) for disturbed areas was computed using the following relationship for time of concentration taken from the Denver "Urban Drainage and Flood Control Criteria Manual" (WME, 1972 revised 1984).

\[ t_c = t_i + t_r \]  

where:

- \( t_c \) = time of concentration defined as the time required for flow from the hydraulically most remote point in a basin to reach the basin outlet, \( t_i \) is \( \geq 5 \) minutes.
- \( t_i \) = initial time or overland flow time

\[ t_i = \frac{1.8 (1.1 - C_s l)^2}{(l)^{0.5}} \]

\( s = \text{slope in percent} \)
\( C_s = \text{rational equation runoff coefficient for 5-year return period, } C_s = 0.87 \text{ for pavement, see table in appendix.} \)
\( l = \text{overland flow length or length of initial flow.} \)

\( t_r = \text{travel time in gutter, ditch, or culvert from end of initial length to sub-basin outlet.} \)

According to the USDA Soil Conservation Service (1972), the watershed lag is equal to 0.6 \( t_c \).

The model input and output for the studied areas is presented in the \( \chi \) appendix.
MEAN ANNUAL SEDIMENT YIELD

The amount of sediment to be yielded to the sediment ponds was determined from the Universal Soil Loss Equation (Israelsen et al., 1984). In accordance with this equation, soil erosion caused by water is determined from:

\[ A = R \cdot K \cdot LS \cdot VM \]  \hspace{1cm} (5)

where:

\[ A = \text{computed amount of soil loss, in tons/acre/year;} \]
\[ R = \text{rainfall factor, in foot-tons/acre-hour;} \]
\[ K = \text{soil erodibility factor, in tons/acre/year/unit of R;} \]
\[ LS = \text{topographic factor (length and steepness of slope), dimensionless; and} \]
\[ VM = \text{erosion control factor, dimensionless.} \]

Values for R and K were determined from Israelsen et al. (1984). The topographic factor (LS) was determined from:

\[ LS = \frac{65.41 \cdot S^2 + 4.56 \cdot S + 0.065}{S^2 + 10,000} \times (L/72.6)^m \]  \hspace{1cm} (6)

where:

\[ L = \text{average overland flow length, in feet;} \]
\[ S = \text{average steepness of slope, in percent; and} \]
\[ m = \text{an exponent dependent upon the steepness of slope (0.3 for slopes less than 0.5%,} \]
\[ 0.5 \text{ for slopes 0.51% to 10%, and 0.6 for slopes greater than 10%).} \]

Values for VM were determined from the Israelsen et al. (1984) and from the Barfield et al. (1985).
The Cottonwood/Wilberg Mine Portal Site is located at the head of Grimes Wash Canyon 8 miles northwest of Orangeville. The mine portal site disturbed area runoff control facilities are shown on Map 1. The undisturbed runoff control facilities will be addressed in a separate report at a later date. The tributary sub-basins associated with runoff control facilities are delineated on Map 1. The sub-basin boundaries were defined based on topographic mapping and data provided by UP&L and field inspection. During this study, it was decided by UP&L to intercept the majority of the undisturbed area tributary to Sub-basin DA-1 by constructing an inlet and storm drain to the undisturbed bypass system. The following detail assumes that the new inlet is constructed.

SUB-BASIN HYDROLOGIC CHARACTERISTICS

Sub-basin hydrologic characteristics are summarized in Table 1.

**TABLE 1**

COTTONWOOD/WILBERG MINE PORTAL SITE DISTURBED AREA SUB-BASIN CHARACTERISTICS

<table>
<thead>
<tr>
<th>SUB-BASIN</th>
<th>AREA (acres)</th>
<th>VOL. WEIGHTED CURVE NUMBER</th>
<th>TLAG (hrs)</th>
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TOTAL 26.27 ACRES
The volume weighted curve number for each sub-basin was defined using curve numbers based on soil type and cover density for areas of different cover within the sub-basin. See the appendix for sub-basin specific details. The following different types of cover were identified in the sub-basins tributary to the sediment ponds at the Cottonwood/Wilberg Mine Portal Site.

Juniper-Pine Grass Complex: In undisturbed areas which are tributary to the sediment ponds, the south facing slopes are estimated to have a cover density of 20% with a curve number of 85 while west facing slopes are estimated to have a cover density of 40% and a curve number of 76 (see Figure 9.6 in the appendix taken from SCS, 1972).

Rock Outcrop: Horizontal areas of rock outcrop were found with the aid of an aerial map. The rock outcrops tend to be highly fractured with well developed talus slopes. A curve number of 88 is believed representative of the rock outcrop areas.

Disturbed Areas: All of the disturbed areas which are actively used within the mine portal site have been treated with either asphalt or concrete paving or are covered with gravel. Areas which have been disturbed during construction operations in the past and are not in active use have tended to naturally revegetate. Paved areas are assigned a curve number of 98 (SCS, 1972), graveled areas are assigned a curve number of 93 (SCS, 1972), and disturbed areas which are not actively used are estimated to have a curve number of 86 based on a cover density of about 10% Juniper-Grass with a Type C soil (see Figure 9.6 in the appendix taken from SCS, 1972).

DISTURBED AREA RUNOFF CONTROL CULVERTS

The disturbed area runoff control culverts are classified as temporary structures and are to have capacity for the 10-year 6-hour storm event. The storm runoff peak flow for the 10-year 6-hour storm event was found using the above referenced model (COE HEC-1, see input and output in Appendix) with a precipitation depth of 1.51 inches (Miller et al., 1973). The peak flowrate from the 10-year 6-hour precipitation event at each of the selected culverts is summarized in Table 2 along with the required minimum inlet depth and the required minimum pipe slope to convey the design flow. The required inlet depth to pass the design flow was found using "Hydraulic Charts for the Selection of Highway Culverts" H.E.C. 5 (US DOT, 1965). The required minimum pipe slope for inlet flow conditions was found using the Manning's Equation (see calculations in Appendix).

All of the culverts analyzed have head water depth requirements less than one pipe diameter and required minimum slopes less than .01 feet/feet. Based on the provided mapping and field inspection, all of the analyzed culverts have the required head water depth and all appear to have slopes in excess of the minimum required. Therefore we conclude that all of the analyzed culverts can convey the required peak flowrate from the design 10-year 6-hour storm event.
<table>
<thead>
<tr>
<th>CULVERT</th>
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<th>PIPE DIAMETER (IN)</th>
<th>REQUIRED HEAD WATER DEPTH (FT)</th>
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<td>12</td>
<td>0.1</td>
<td>0.001</td>
</tr>
<tr>
<td>CD-16</td>
<td>0.2</td>
<td>12</td>
<td>0.1</td>
<td>0.001</td>
</tr>
</tbody>
</table>
10-YEAR 24-HOUR RUNOFF VOLUMES AND MEAN ANNUAL SEDIMENT YIELD

The 10-year 24-hour rainfall depth was found in the NOAA ATLAS 2 Volume VI-Utah (Miller et. al.,1973) to be 2.40 inches for the Cottonwood/Wilberg Mine Portal Site. Based on the sub-basin characteristics (Table 1) and a precipitation of 2.40 inches the estimated runoff from the 10-year 24-hour rainstorm event from the areas tributary to the sedimentation ponds is 1.42 inches or 3.1 acre-feet. The calculated mean annual sediment yield is 0.81 acre-feet. The required sediment pond volume to contain the 10-year 24-hour storm event and the mean annual sediment yield is 3.9 acre-feet.

NORTH AND SOUTH SEDIMENT PONDS

The runoff from the disturbed areas (except for the Small Area Exemption) of the Cottonwood/Wilberg Mine Portal site is conveyed via culverts and ditches to two sediment ponds which are connected in series. Both sediment ponds utilize a 36-inch diameter corrugated metal pipe riser type spillway. The spillway from the North Sediment Pond discharges into the South Sediment Pond. The South Sediment Pond discharges into the undisturbed area bypass system and thence to the natural stream channel. Only about 5% of the total disturbed area is directly tributary to the South Sediment Pond, the rest of the tributary area is tributary through the North Sediment Pond. Figures 1 and 2 present the stage capacity curves for the North and South Sediment Ponds respectively. The curves are based on data and cross sections provided by UP&L (UP&L, 1984). The capacity of the North and South Sediment Ponds is summarized in Table 3. The combined runoff storage volume of 3.1 acre-feet is equivalent to the required runoff storage volume.

TABLE 3
COTTONWOOD/WILBERG MINE PORTAL SITE CAPACITY OF THE NORTH AND SOUTH SEDIMENT PONDS ACRE-FEET

<table>
<thead>
<tr>
<th></th>
<th>NORTH POND</th>
<th>SOUTH POND</th>
<th>COMBINED</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEDIMENT STORAGE</td>
<td>0.65</td>
<td>0.29</td>
<td>0.94</td>
</tr>
<tr>
<td>RUNOFF STORAGE</td>
<td>1.50</td>
<td>1.60</td>
<td>3.10</td>
</tr>
<tr>
<td>TOTAL CAPACITY</td>
<td>2.15</td>
<td>1.89</td>
<td>4.04</td>
</tr>
</tbody>
</table>

The existing 36-inch riser type spillways in the North and South Sediment Ponds are both set 2 feet below the top of the embankment and provide a discharge capacity with one foot of freeboard of 81 cfs (see calculations and stage discharge curve in Appendix). The peak flow rate tributary to the ponds from a
FIGURE 1.

STAGE-CAPACITY CURVE FOR NORTH SEDIMENT POND COTTONWOOD/WILBERG MINE PORTAL SITE.
FIGURE 2.

STAGE CAPACITY CURVE FOR SOUTH SEDIMENT POND
COTTONWOOD/WILBERG MINE PORTAL SITE.
25-year 6-hour storm event was modeled using the model described above with a rainfall depth of 1.81 inches (Miller et. al., 1973). The predicted peak flow into the sediment ponds is 23 cfs, therefore the existing spillways have adequate capacity for the 25-year 6-hour storm event.

SMALL AREA EXEMPTION

UP&L requests a Small Area Exemption (SAE) for the small disturbed area associated with the Deer Creek Ventilation Portals (see Map 1). It is our understanding that there are three criteria that must be met in order for an area to qualify as a SAE. These criteria include:

1. The area cannot be tributary to a sediment pond.
2. The area must have some form of a treatment structure to treat runoff from the area.
3. The summation of the areas of the SAE's must be less than ten to fifteen percent of the total disturbed area.

It is believed that the SAE proposed by UP&L meets these criteria. The runoff from the disturbed area associated with the Deer Creek Ventilation Portals is not tributary to the sediment ponds. Runoff from the SAE is tributary to the undisturbed area bypass culvert inlet above sub-basin DA-7. Runoff from the SAE is presently treated with a depression in the access road which acts as a sediment trap. UP&L is also investigating the feasibility of the use of straw bales and/or silt fence to further treat the area. The total disturbed area of the SAE is 1.3 acres which is about 6% of the total disturbed area associated with the Cottonwood/Wilber Mine Portal Site, which is less than the 10% criteria.

CONCLUSIONS AND RECOMMENDATIONS

Based on the above presented analysis and upon the addition of a new inlet to intercept undisturbed area drainage above sub-basin DA-1, the following conclusions are reached. The major components of the disturbed area runoff system are adequate to convey the 10-year 6-hour storm runoff event to the North and South sediment ponds. The existing sediment ponds are adequate to contain the runoff from the 10-year 24-hour storm event plus the mean annual sediment yield. The existing 36-inch pipe riser type spillways for the North and South sediment ponds have adequate capacity to discharge the peak flowrate of the 25-year 6-hour storm event.
COTTONWOOD/WILBERG MINE COTTONWOOD CANYON FAN PORTAL
UNDISTURBED AND DISTURBED AREA RUNOFF CONTROL
FACILITIES

The Cottonwood/Wilberg Mine Cottonwood Canyon Fan Portal is located in Section 25, Township 17 South, Range 6 East near the Old Johnson Mine. The disturbed and undisturbed runoff control facilities are shown on Map 2.

The undisturbed runoff control facilities consist of ditches (labeled UD - for undisturbed ditch) and culvert C-1. Ditches UD-1 and UD-2 convey runoff to culvert C-1. Ditch UD-3 intercepts runoff above the Fan Portal Site and conveys runoff to the existing drainage to the south which is tributary to the existing 48" County Road culvert.

The disturbed area runoff control facilities consist of ditches which convey runoff from all disturbed areas (except DA-4) to the sediment basins. Treatment for runoff from sub-basin DA-4 is provided with sediment traps formed by gabions in ditch DD-5.

SUB-BASIN HYDROLOGIC CHARACTERISTICS

Sub-basin hydrologic characteristics are summarized in Table 4.

| TABLE 4 |
| COTTONWOOD/WILBERG MINE COTTONWOOD CANYON FAN PORTAL SITE
 SUB-BASIN CHARACTERISTICS |

<table>
<thead>
<tr>
<th>SUB-BASIN</th>
<th>AREA (acres)</th>
<th>VOL. WEIGHTED CURVE NUMBER (hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UA-1</td>
<td>16.9</td>
<td>76</td>
</tr>
<tr>
<td>UA-2</td>
<td>74.7</td>
<td>74</td>
</tr>
<tr>
<td>UA-3</td>
<td>15.3</td>
<td>75</td>
</tr>
<tr>
<td>TOTAL</td>
<td>107.9</td>
<td></td>
</tr>
<tr>
<td>DA-1</td>
<td>1.2</td>
<td>81.8</td>
</tr>
<tr>
<td>DA-2</td>
<td>2.3</td>
<td>80.3</td>
</tr>
<tr>
<td>DA-3</td>
<td>1.5</td>
<td>85.5</td>
</tr>
<tr>
<td>DA-4</td>
<td>1.8</td>
<td>69.5</td>
</tr>
<tr>
<td>TOTAL</td>
<td>6.8</td>
<td></td>
</tr>
</tbody>
</table>

Volume weighted curve number for each sub-basin was derived using curve numbers based on soil type and cover density for areas of different cover within the sub-basin. See the appendix for sub-basin specific details. The following
different types of cover were identified in the sub-basins associated with the Cottonwood/Wilber Mine Cottonwood Canyon Fan Portal Site.

Juniper-Pine Grass Complex: The slopes above the Fan Portal Site are estimated to have an effective cover of 51% with a Curve Number of 72 (see Figure 9.6 in the appendix taken from SCS, 1972).

Sage-Grass complex: The sage-grass areas are estimated to have an effective cover of 54% with a Curve Number of 62 (see Figure 9.6 in the appendix taken from SCS, 1972).

Temporarily reclaimed: Areas which have been temporarily reclaimed are estimated to have 50% cover of herbs with a Curve Number of 80 (see Figure 9.5 in the appendix taken from SCS, 1972).

Disturbed areas: Areas which have been disturbed during the construction activities are assumed to have a Curve Number of 90.

RUNOFF CONTROL CULVERTS AND DITCHES

The runoff control culverts and ditches are classified as temporary structures and are to have capacity for the 10-year 6-hour storm event. The storm runoff peak for the 10-year 6-hour storm event was found using the above referenced model (COE HEC-1, see input and output in Appendix) with a precipitation depth of 1.55 inches (Miller et. al., 1973). The 10-year 6-hour peak runoff at each of the selected culverts is summarized in Table 5 along with the required minimum inlet depth and the required minimum pipe slope to convey the design flow. The required inlet depth to pass the design flow was found using "Hydraulic Charts for the Selection of Highway Culverts" H.E.C. 5 (US DOT, 1965). The required minimum pipe slope for inlet flow conditions was found using the Manning's Equation (see calculations in Appendix).

Table 6 presents the design criteria for the runoff control ditches at the Fan Portal Site. The channel depth shown on Table 6 includes 0.5 feet of freeboard. Ditch hydraulics were analyzed with the Manning's flow equation. A Manning's n of 0.03 was assumed for unlined ditches. Riprap was sized with a minimum safety factor of 1.5 in accordance with the methods presented in the Barfield et. al. (1981). Ditch hydraulics are summarized on Map 2, see appendix for further detail. The ditch configurations presented in Table 6 and in the Ditch Hydraulics Table on Map 2 represent required design configurations, not existing conditions. Riprap is assumed to be needed where velocities exceed 5 feet per second. Ditch UD-2 and the south end section of ditch UD-3 require riprap lining.
### TABLE 5
**CULVERT DESIGN CRITERIA**
**COTTONWOOD/WILBERG MINE COTTONWOOD CANYON**
**FAN PORTAL SITE**

<table>
<thead>
<tr>
<th>CULVERT</th>
<th>DESIGN FLOW (CFS)</th>
<th>PIPE DIAMETER (IN)</th>
<th>REQUIRED HEAD WATER DEPTH (FT)</th>
<th>REQUIRED MINIMUM SLOPE (FT/FT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-1</td>
<td>14.0</td>
<td>36</td>
<td>2</td>
<td>.002</td>
</tr>
<tr>
<td>C-2</td>
<td>1.7</td>
<td>24</td>
<td>1</td>
<td>.001</td>
</tr>
<tr>
<td>C-3</td>
<td>.6</td>
<td>24</td>
<td>1</td>
<td>.001</td>
</tr>
<tr>
<td>C-4</td>
<td>.6</td>
<td>18</td>
<td>1</td>
<td>.001</td>
</tr>
</tbody>
</table>

### TABLE 6
**DITCH DESIGN CRITERIA**
**COTTONWOOD CANYON FAN PORTAL**

<table>
<thead>
<tr>
<th>CHANNEL</th>
<th>DESIGN FLOW (cfs)</th>
<th>MAXIMUM SLOPE (h/v)</th>
<th>BOTTOM WIDTH (ft)</th>
<th>SIDE SLOPE (H/V)</th>
<th>CHANNEL DEPTH (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UD-1</td>
<td>3.1</td>
<td>0.13</td>
<td>4</td>
<td>2.0</td>
<td>1.0</td>
</tr>
<tr>
<td>UD-2</td>
<td>11.0</td>
<td>0.09</td>
<td>3</td>
<td>2.5</td>
<td>1.0</td>
</tr>
<tr>
<td>UD-3</td>
<td>2.8</td>
<td>0.20</td>
<td>3</td>
<td>2.5</td>
<td>1.0</td>
</tr>
<tr>
<td>DD-1</td>
<td>0.4</td>
<td>0.10</td>
<td>1</td>
<td>2.0</td>
<td>1.0</td>
</tr>
<tr>
<td>DD-2</td>
<td>0.6</td>
<td>0.18</td>
<td>1</td>
<td>2.0</td>
<td>1.0</td>
</tr>
<tr>
<td>DD-3</td>
<td>0.6</td>
<td>0.18</td>
<td>1</td>
<td>2.0</td>
<td>1.0</td>
</tr>
<tr>
<td>DD-4</td>
<td>0.7</td>
<td>0.12</td>
<td>1</td>
<td>2.0</td>
<td>1.0</td>
</tr>
<tr>
<td>DD-5</td>
<td>0.6</td>
<td>0.11</td>
<td>1</td>
<td>2.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>
10-YEAR 24-HOUR STORM RUNOFF VOLUMES AND MEAN ANNUAL SEDIMENT YIELD TO SEDIMENT BASINS

Storm runoff from Sub-basin DA-1 is treated by the north sediment basin and runoff from Sub-basins DA-2 and DA-3 is treated by the south sediment basin. Table 7 presents a summary of the tributary drainage to the north and south sediment basins. The existing sediment basins have capacity for the runoff from the 10-year 24-hour rainfall event and the mean annual sediment yield.

TABLE 7

SEDIMENT BASIN CAPACITY, 10-YEAR 24-HOUR RUNOFF VOLUMES, AND MEAN ANNUAL SEDIMENT YIELD
COTTONWOOD/WILBERG MINE
COTTONWOOD CANYON FAN PORTAL SITE

<table>
<thead>
<tr>
<th>SEDIMENT BASIN</th>
<th>TRIBUTARY AREA (acres)</th>
<th>10-YR 24-HR RUNOFF (acre-feet)</th>
<th>MEAN ANNUAL SEDIMENT YIELD (acre-feet)</th>
<th>BASIN CAPACITY (acre-feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NORTH</td>
<td>1.2</td>
<td>0.09</td>
<td>.01</td>
<td>0.11</td>
</tr>
<tr>
<td>SOUTH</td>
<td>3.8</td>
<td>0.30</td>
<td>0.16</td>
<td>0.52</td>
</tr>
</tbody>
</table>

CONCLUSIONS AND RECOMMENDATIONS

The existing culvert system is adequate to pass the peak flowrate of the 10-year 6-hour storm event. Ditches should be constructed or modified to reflect configuration presented in Ditch Design Criteria Table 6, with riprap in sections that exceed 5 feet per second. Riprap is required in ditch UD-3 south of the proposed fan portal site and in ditch UD-2. The existing disturbed area runoff treatment system consists of two sediment basins with adequate capacity to contain the runoff from the 10-year 24-hour storm event and the mean annual sediment yield, and road-side sediment traps formed by gabions in ditch DD-5.
REFERENCES


Grimes Wash Left Fork Inlet (Rock-Lined Basin)

~350' of 12" STL Pipe

12"

18"

Reducer

Inlet (See Fig. 2 for detail)

Top of Rock Ledge

72" Cu-1

MINE WATER TANK

(See Map 1 Appendix XIII)
APPENDIX XIII
FIGURE 2
INLET DETAILS
DISCHARGE DETAIL
NO SCALE

REFER TO DWG. NO. CM-10501-CP FOR LOCATION

COTTONWOOD/WILBERG MINE
COTTONWOOD FAN PORTAL
SOUTH SEDIMENT BASIN
DETAILS & CROSS SECTIONS

SCALE: 1/2" = 30'
DRAWN BY: E M C
DRAWING NUMBER: CM-10351-CP

DATE: NOV 19, 1980
CHECKED BY: CM-10351-CP
REFER TO DWG. NO. CM-10501-CP FOR LOCATION

COTTONWOOD/WILBERG MINE
COTTONWOOD FAN PORTAL
NORTH SEDIMENT BASIN
DETAILS & CROSS SECTIONS

UTAH POWER & LIGHT COMPANY
DEPARTMENT OF MINING & EXPLORATION

SECTION 25 T.17 S., R.6 E., S.L.B.M.
No. 5214
COTTONWOOD FAN PORTAL

DRAWN BY:
SMC
DATE: NOV 20, 1980
CHECKED BY:
CM-10353-CP

SCALE: 1" = 30'
Addendum to the Subsidence Control Plan entitled:

“UTAH POWER AND LIGHT COMPANY”
“DEER CREEK AND COTTONWOOD/WILBERG MINES”

“Subsidence Monitoring Plan”
“Revised 1/20/89”

Pages 4 and 5 of this document committed the permittee to indefinite yearly subsidence surveys and reports.

Mining operations of Utah Power and Light Company (now Interwest Mining Company), a subsidiary of PacifiCorp, ceased all mining activities in January, 2015. Yearly subsidence surveys and reports continued for 3 years after the date of final mining, through 2017, as required by the Memorandum of Understanding originated by UDOGM, BLM, and the U.S. Forest Service in 1996. The 2017 report showed and stated that the subsidence in all mining areas was stable and complete. The BLM and UDOGM concur that the subsidence above the PacifiCorp mines is stable and complete. Yearly subsidence surveys and reports have ended with the report of 2017.
APPENDIX XVI
SUBSIDENCE MONITORING PLAN

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A. Deer Creek & Wilberg Mine Subsidence Monitoring Plan Attachment
   Classification, Standards of Accuracy, and General Specifications of Geodetic
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B. 11-16-78 Memo from Bureau of Mines with
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C. 10-25-79 Memo and Document Extending
   Agreement No. 09-0070-780 to 9-30-80
D. 10-30-79 Memo and Summary of Progress of
   Subsidence Study
E. 7-3-80 Bureau of Mines Memo and Subsidence
   Monitoring Program for First Longwall
F. 11-17-80 Memo and Document, with Additions,
   Extending Agreement No. 14-09-0070-780
to 9-30-81
G. 2-13-81 Memo and Map and Elevations as of
   9-17-80
H. Golden Eagle Nesting/Cliff Subsidence
   Monitoring Plan, May, 1986 Revised
   9-22-87
I. Maps Referred to in 9-22-87 Revised
   Eagle/Subsidence Plan:
   CM-10587-WB
   CM-10651-CW (2 each)
   CM-10752-CW
   CM-10680-EM

Revised 1/20/89
Enactment of coal mining operating regulations, Title 30 CFR 211, effective May 17, 1976, requires each coal mining operator controlling federal coal leases to submit detailed mining plans with provisions for subsidence and hydrology monitoring systems, if directed by the mining supervisor.

On May 17, 1977 the mining plans for the Deer Creek - Wilberg Mines were submitted excluding the subsidence and hydrology monitoring requirements as the federal guidelines were, at that time, not finalized.

Correspondence from the Area Mining Supervisor issued instructions that all operators of underground coal mines shall submit plans for monitoring subsidence and hydrology including a baseline report of existing conditions of the lands covered by the mining plan, an engineering assessment of potential subsidence and written agreements with the surface owners for monitoring access and rehabilitation of disturbed property. Operators were requested to submit their proposed monitoring plans before January 1, 1978.

The following subsidence narrative applies to both the Deer Creek and Cottonwood/Wilberg Mines which are, in part, superimposed or multiple seam mining operations.
In evaluating the different methods described in the federal guidelines, cost was a weighted factor.

The photogrammetric method appears, initially, to be the more costly but the cost difference diminishes as the mined area increases.

The pros and cons of conventional surveying versus photogrammetry will not be discussed in this text. It is sufficient to say that the latter serves not only as a visual record but can be recalled for additional information at a later time.

The principle objective of the survey is, of course, the proof of surface movement or the absence of it.

As stated in the guidelines, "The purpose of subsidence monitoring system is to identify the surface disturbances such as surface subsidence depressions, tension fractures in overburden, subsidence pits or potholes, and compression bulges."

Based on the required criteria and documentation as set forth in the federal regulations the following is Utah Power & Lights Company's subsidence monitoring system proposal.

Method of survey shall be precision photogrammetry with a relative vertical accuracy of 1.0 foot.

Permanent monuments shall be set outside of the leased and mined area with sufficient distance to compensate for the draw angle through the overburden. Permanent monuments shall also be set within the leased area for
determining horizontal and vertical displacement.

The initial survey shall include the surface of all lands above assigned federal coal leases excluding the areas mined prior to May 17, 1976.

With surface elevations averaging 2,000 to 10,000 feet and with surface access being available only six or seven months per year, it would be not only difficult but of little value to monitor twice in such a short period of time. Surveys will be conducted once each year during the summer or early fall months.

Photogrammetrical elevations on secondary points are determined by a person operating a stereo-plotting machine and are subject to certain limitations. Most obvious is the fact that to read the ground elevation, the operator must see the ground on the photograph and, secondly, when working with tolerances of less than one foot vertically, ground cover will surely have an effect on the results.

Within the Cottonwood/Wilberg and Deer Creek Mines limits, there are several areas covered by heavy timber but after viewing current photography, it appears there are sufficient clearings to adequately read within the dense cover for monitoring purposes.

Maintaining vertical accuracies in steep terrain by photogrammetrical methods poses yet another problem. As stated before, vertical resolution is a function of the flight altitude; more specifically, it is one ten-thousandth
of the altitude. For example, assume the mean flight altitude on East Mountain as 15,000 feet and the tops of the ridges average 10,000 feet, vertical resolution would then be .5 feet but in canyon bottoms or depressions, the flight altitude could increase by as much as 2,000 additional feet resulting in a vertical resolution of .70 feet.

However, after reviewing these problems and the alternatives, we feel by selective point setting, supplementation of conventional elevations and modification of the mean flight altitude desired accuracies can be obtained for purposes of surface monitoring.

A photogrammetrical survey will be superimposed on the mine plan to coincide entries, panels and barriers as shown on the survey location map. Vertical accuracies of the photogrammetric points or secondary points shall strive to maintain the 1.0 feet relative elevation with provisions to augment conventional control if suspect areas occur.

Monitoring will be repeated once each year with on the ground visual inspections conducted twice each year, in the spring and late fall.

Subsequent to the initial survey in the spring of 1978, an annual map will be submitted showing any irregularities measured above the mined areas at a contour interval of one foot.

All measurements will include that area in advance of mining equivalent to the depth of the overburden times a factor of 1.4 for compensation of formation shear or draw.
In 1978, Utah Power & Light Company and the Bureau of Mines entered into an agreement to study the effects of coal mining subsidence. In 1980, a longwall mining system was installed in the Wilberg Mine and the agreement was extended to include the monitoring of the Wilberg longwall panel also. The last conventional survey of these areas was done in 1988. No conventional survey was done in 1987. Results of these surveys have been submitted in the East Mountain Annual Subsidence Reports.

Monuments consisting of steel rods five feet long and 5/8 inch in diameter were driven at 200 foot intervals along the center line of the longwall panels. These monuments were first surveyed in the fall of 1980. All surveys are based on the Utah State Plane Coordinate System modified to coincide the underground surveys.

In addition to the longwall panel monitoring, Utah Power & Light Company, during the summer of 1980, initiated an aerial survey covering the entire permit area of the Wilberg Mine. Design parameters are based on final vertical elevation accuracies of 1.0 relative. Photography was flown with black and white film on August 20, 1980 at a scale of 1:7200 (1" = 600').

Aerial surveying is currently being conducted over the Cottonwood/Wilberg, Deer Creek and Des Bee Dove permit areas. This will continue on an annual basis with results being submitted in the Annual Subsidence Reports.
It is planned to superimpose the photography and mining plan during the stereo plotting operation. In effect, this places the underground workings and proposed mining panels on the surface where the stereo plotter operator can easily select monitoring lines to bisect panels, read spot shots on barriers and main entries. Each point selected will be assigned a coordinate (horizontal) and an elevation and digitized on computer cards for duplication and comparison to subsequent year surveys.

Attached are copies of the original survey subsidence monitoring plan together with the U.S. Bureau of Mines agreement and extension to include monitoring above the Wilberg Mine longwall panel. As information is available, it, along with conclusions, will be incorporated into the Annual Subsidence Reports.
Classification,
Standards of Accuracy,
and General Specifications of Geodetic Control Surveys

Prepared By:
Federal Geodetic Control Committee

U.S. DEPARTMENT OF COMMERCE
Frederick B. Dent, Secretary

National Oceanic and Atmospheric Administration
Robert M. White, Administrator

Federal Coordinator for Geodetic Control and Related Surveys
David H. Wallace

National Ocean Survey
Allen L. Powell, Director

Rockville, Md.
February 1974
Reprint February 1977
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Classification, Standards of Accuracy, and General Specifications of Geodetic Control Surveys

Introduction

The Government of the United States makes nationwide surveys, maps, and charts of various kinds which must be referenced to national datums. These are necessary to provide basic information for the conduct of public business at all levels of government, for planning and carrying out national and local projects, for programs relating to the development and utilization of natural resources, for National defense, and for development of the country. Requirements for geodetic control surveys are most critical where intense development is taking place; included are offshore areas, where the surveys are used in the development and exploitation of the marine resources and in the delineation of state and international seaward boundaries.

State and local governments and industry regularly cooperate in various parts of the total surveying and mapping program. In making surveys and maps of large areas, it is first necessary to establish frameworks of horizontal and vertical control surveys. These provide a common basis for all surveying and mapping operations, and so ensure a coherent product.

Geodetic surveys of large areas are affected by and must take into account the curvature of the earth, astronomical observations, and gravity determinations. Geodetic surveys, executed with high precision, are used to control mapping and charting operations as well as engineering projects. "Geodetic survey" and "control survey" are terms used almost interchangeably.

Control surveys are of two types: horizontal and vertical. Horizontal control surveys determine latitudes and longitudes referenced to a national datum and provide the basis for rectangular coordinate systems. Horizontal geodetic surveys are adjusted to the mathematical figure of the earth applicable to the national datum. Vertical control surveys determine elevations referred to a national datum that has been referenced to tidal measurements. Vertical geodetic surveys are adjusted with respect to the geoid, an equipotential surface of the earth approximated by mean sea level. These surveys provide permanently marked and properly described stations.

Horizontal control is established by triangulation, trilateration, and traverse procedures. Triangulation is a system of joined or overlapping triangles in which the length of an occasional side, known as a base line, is measured and the other sides are computed from angles measured at the triangle vertices. Trilateration is a method of surveying in which the lengths of the triangle sides are measured. Traverse is a method of surveying in which a sequence of lengths and directions of lines between points on the earth are measured and used in determining positions of the points.

Vertical control is established by leveling of a high order of accuracy. It provides elevations of marked points along lines that form closed circuits and is accomplished by measuring differences in elevation between consecutive bench marks.

These classifications and standards have been prepared by the Federal Geodetic Control Committee (FGCC) and have been reviewed by the American Society of Civil Engineers, the American Congress on Surveying and Mapping, and the American Geophysical Union. The opinions of other organizations and individuals were also requested and received.

After consideration of all comments, the original draft was revised in this, the present form.

These new classifications and standards replace those approved March 1, 1957 (and referred to in Exhibit C to the Office of Management and Budget Circular A-16 dated October 10, 1958). The classic First-, Second-, and Third-Order nomenclatures have been retained. However, classes within the orders have been revised to reflect a requirement for greater flexibility in designing surveys and in recognition of rapidly changing requirements for higher accuracy surveys. Improvements in the technology in recent years make these changes desirable and practical.
The specifications in the attached tables show the permissible tolerances on the indicated quantities as a function of order and class; these must be very closely followed to insure that the overall standards are achieved. Detailed specifications have been prepared by the Federal Geodetic Control Committee to supplement this publication. Some important although seemingly minor factors which do not fit into the tables could cause a survey to fail to attain the required closures even though the specified requirements were met. It is emphasized that closure is not the sole criterion for classifying a survey into a particular order, as the closure is only part of the requirements and must be considered together with the other specifications in classification.

These classifications and standards are a directive for surveys which are to be considered a part of the National Geodetic Control Networks. Densification and extension of control is also provided by analytic photogrammetric triangulation and satellite systems (e.g., Doppler). It is highly desirable that these and all other geodetic or precise engineering surveys be properly referenced to the National Networks and adhere to these standards whenever possible.

**Horizontal Control**

*First-Order (Primary Horizontal Control)*

The primary framework for National Horizontal Control Network consists of arcs of triangulation as well as trilateration and traverse, spaced about 100 kilometers apart in each direction. To maintain satisfactory mathematical consistency within the contained area networks between these arcs, this primary framework should have an accuracy of at least 1 part in 100,000. The study of gradual and secular ground creep movements in the earth’s crust in areas subject to seismic or tectonic activity, the testing of defense and scientific equipment, and use in high-precision engineering projects require control of this same accuracy. These surveys that develop the National Network, prepare for metropolitan expansion, and serve these scientific and engineering purposes are designated First-Order.

*Second-Order, Class I (Secondary Horizontal Control)*

This class includes the area networks between the First-Order arcs and detailed surveys in very high value land areas. Surveys of this class strengthen the National Network and are adjusted as part of the network. Thus, this class also includes the basic framework for further densification. The internal closures of this class of survey should indicate an accuracy of at least 1 part in 50,000.

*Second-Order, Class II (Supplemental Horizontal Control)*

The demands for reliable horizontal control surveys in areas which are not in a high state of development or where no such development is anticipated in the near future justify the need for this classification. This class is used to establish control along the coastline, inland waterways, and interstate highways and is recommended for controlling extensive land subdivision and construction. The control contributes to the National Network and is published as part of the network. The minimum accuracy allowable in Class II of Second-Order is 1 part in 20,000.

*Third-Order Class I and Class II (Local Horizontal Control)*

Surveys of this order are used to establish control for local improvements and developments, topographic and hydrographic surveys, or for such other projects for which they provide sufficient accuracy. This order of survey is based on higher order control, carefully connected to the National Network, and also should be permanently marked and adequately described. Spires, stacks, standpipes, flag poles, and other identifiable objects located to this accuracy also have significant value for many surveying and engineering projects. The work should be performed with sufficient accuracy to satisfy the standards listed in the tables.

Although the specifications for the triangle closure and side checks are better than the minimum required for the standards, the specifications are logical and obtainable with judicious procedures; adherence to the standards is recommended.

Standards for surveys below Third-Order are not included in these specifications.
<table>
<thead>
<tr>
<th>Classification</th>
<th>First-Order</th>
<th>Second-Order</th>
<th>Class I</th>
<th>Class II</th>
<th>Third-Order</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative accuracy</td>
<td>1 part in 100,000</td>
<td>1 part in 50,000</td>
<td>1 part in 10,000</td>
<td>1 part in 5,000</td>
<td></td>
</tr>
<tr>
<td>between directly</td>
<td>Primary National Network</td>
<td>Area control which strengthens the National Network</td>
<td>General control surveys referenced to the National Network</td>
<td></td>
<td></td>
</tr>
<tr>
<td>connected points</td>
<td>Metropolitan Area Surveys</td>
<td>Subsidiary metropolitan control.</td>
<td>Local control surveys.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(at least)</td>
<td>Scientific Studies</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recommended uses</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Classification</th>
<th>First-Order</th>
<th>Second-Order</th>
<th>Class I</th>
<th>Class II</th>
<th>Third-Order</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative accuracy</td>
<td>0.5 mm $\sqrt{K}$, 0.7 mm $\sqrt{K}$</td>
<td>1.0 mm $\sqrt{K}$</td>
<td>1.3 mm $\sqrt{K}$</td>
<td>2.0 mm $\sqrt{K}$</td>
<td></td>
</tr>
<tr>
<td>between directly</td>
<td>Basic framework of the National Network and metropolitan area control.</td>
<td>Secondary framework of the National Network and metropolitan area control.</td>
<td>Densification within the National Network.</td>
<td>Small-scale topographic mapping.</td>
<td></td>
</tr>
<tr>
<td>connected points</td>
<td>Regional crustal movement studies.</td>
<td>Local crustal movement studies.</td>
<td>Rapid subsistence studies.</td>
<td>Establishing gradients in mountainous areas.</td>
<td></td>
</tr>
<tr>
<td>or benchmark</td>
<td>Extensive engineering projects.</td>
<td>Large engineering projects.</td>
<td>Local engineering projects.</td>
<td>Small engineering projects.</td>
<td></td>
</tr>
<tr>
<td>marks (standard error)</td>
<td>Support for subsidiary surveys.</td>
<td>Tidal boundary reference.</td>
<td>Topographic mapping.</td>
<td>May or may not be adjusted to the National Network.</td>
<td></td>
</tr>
<tr>
<td>Recommended uses</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Classification</td>
<td>First-Order</td>
<td>Second-Order</td>
<td>Third-Order</td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------</td>
<td>------------</td>
<td>--------------</td>
<td>-------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Recommended spacing of principal stations</strong></td>
<td>Network stations seldom less than 15 km. Metropolitan surveys 3 km to 8 km and others as required.</td>
<td>Principal stations seldom less than 10 km. Other surveys 1 km to 3 km or as required.</td>
<td>As required</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Class I</td>
<td>Class II</td>
<td>As required</td>
<td></td>
</tr>
<tr>
<td><strong>Strength of figure</strong></td>
<td></td>
<td>Class I</td>
<td>Class II</td>
<td>As required</td>
<td></td>
</tr>
<tr>
<td>R, between bases</td>
<td></td>
<td>Class I</td>
<td>Class II</td>
<td>As required</td>
<td></td>
</tr>
<tr>
<td>Desirable limit</td>
<td>20</td>
<td>60</td>
<td>80</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Maximum limit</td>
<td>25</td>
<td>80</td>
<td>120</td>
<td>130</td>
<td></td>
</tr>
<tr>
<td>Single figure</td>
<td></td>
<td>Class I</td>
<td>Class II</td>
<td>As required</td>
<td></td>
</tr>
<tr>
<td>R, between bases</td>
<td></td>
<td>Class I</td>
<td>Class II</td>
<td>As required</td>
<td></td>
</tr>
<tr>
<td>Desirable limit</td>
<td>5</td>
<td>10</td>
<td>15</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Maximum limit</td>
<td>10</td>
<td>30</td>
<td>70</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Base measurement</td>
<td></td>
<td>Class I</td>
<td>Class II</td>
<td>As required</td>
<td></td>
</tr>
<tr>
<td>Standard error</td>
<td>1 part in 1,000,000</td>
<td>1 part in 900,000</td>
<td>1 part in 800,000</td>
<td>1 part in 500,000</td>
<td></td>
</tr>
<tr>
<td><strong>Horizontal directions</strong></td>
<td></td>
<td>Class I</td>
<td>Class II</td>
<td>As required</td>
<td></td>
</tr>
<tr>
<td>Instrument</td>
<td>0.2°</td>
<td>0.2°</td>
<td>1°</td>
<td>1°</td>
<td></td>
</tr>
<tr>
<td>Number of positions</td>
<td>16</td>
<td>16</td>
<td>8</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Rejection limit from mean</td>
<td>4°</td>
<td></td>
<td>5°</td>
<td>5°</td>
<td></td>
</tr>
<tr>
<td>Triangle closure</td>
<td></td>
<td>Class I</td>
<td>Class II</td>
<td>As required</td>
<td></td>
</tr>
<tr>
<td>Average not to exceed</td>
<td>1°.0</td>
<td>1°.2</td>
<td>2°.0</td>
<td>3°.0</td>
<td></td>
</tr>
<tr>
<td>Maximum seldom to exceed</td>
<td>3°.0</td>
<td>5°.0</td>
<td>5°.0</td>
<td>10°.0</td>
<td></td>
</tr>
<tr>
<td><strong>Side checks</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In side equation test, average correction to direction not to exceed</td>
<td>0°.3</td>
<td>0°.4</td>
<td>0°.6</td>
<td>0°.8</td>
<td></td>
</tr>
<tr>
<td><strong>Astro observations</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spacing-figures</td>
<td>6-8</td>
<td>6-10</td>
<td>8-10</td>
<td>10-12</td>
<td></td>
</tr>
<tr>
<td>No. of obs./night</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>No. of nights</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Standard error</td>
<td>0°.45</td>
<td>0°.45</td>
<td>0°.6</td>
<td>0°.8</td>
<td></td>
</tr>
<tr>
<td><strong>Vertical angle observations</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of and spread between observations</td>
<td>3 D/R—10°</td>
<td>3 D/R—10°</td>
<td>2 D/R—10°</td>
<td>2 D/R—20°</td>
<td></td>
</tr>
</tbody>
</table>
### TRILATERATION

<table>
<thead>
<tr>
<th>Number of figures between known elevations</th>
<th>Network stations seldom less than 10 km. Other surveys seldom less than 3 km.</th>
<th>Principal stations seldom less than 10 km. Other surveys seldom less than 1 km.</th>
<th>Principal stations seldom less than 5 km for some surveys a spacing of 0.5 km between stations may be satisfactory.</th>
<th>Principal stations seldom less than 0.5 km.</th>
<th>Principal stations seldom less than 0.25 km.</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-6</td>
<td>6-8</td>
<td>8-10</td>
<td>10-15</td>
<td>15-20</td>
<td>20-25</td>
</tr>
<tr>
<td>1 part in</td>
<td>1 part in</td>
<td>1 part in</td>
<td>1 part in</td>
<td>1 part in</td>
<td>1 part in</td>
</tr>
<tr>
<td>100,000</td>
<td>50,000</td>
<td>20,000</td>
<td>10,000</td>
<td>5,000</td>
<td>2,000</td>
</tr>
</tbody>
</table>

#### Geometric configuration *
- Minimum angle contained within, not less than 25°

#### Length measurement
- 1 part in 1,000,000

#### Vertical angle observations *
- Number of and spread between observations 3 D/R — 10°
- Number of figures between known elevations 4-6

#### Astro azimuths *
- Spacing-figures 6-8
- No. of obs./night 16
- No. of nights 2
- Standard error 0°.45

#### Closure in position *
- 1 part in 100,000

---

**NOTE:**

Position is ONE MEASURE on BOTH DIRECT AND INDIRECT POSITION.

*See notes (1)-(8), p. 7.*
Table 2—Continued

<table>
<thead>
<tr>
<th>Classification</th>
<th>First-Order</th>
<th>Second-Order</th>
<th>Third-Order</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Recommended spacing of principal stations</strong></td>
<td>Network stations 10-15 km</td>
<td>Principal stations seldom less than 4 km except in metropolitan area surveys where the limitation is 0.3 km.</td>
<td>Principal stations seldom less than 2 km except in metropolitan area surveys where the limitation is 0.2 km.</td>
</tr>
<tr>
<td><strong>Horizontal directions or angles</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Instrument</td>
<td>0°.2</td>
<td>0°.2</td>
<td>1°.0</td>
</tr>
<tr>
<td>Number of observations</td>
<td>16</td>
<td>8 or {12}</td>
<td>6 or {10}</td>
</tr>
<tr>
<td>Rejection limit from mean</td>
<td>4°</td>
<td>4°</td>
<td>5°</td>
</tr>
<tr>
<td><strong>Length measurements</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard error</td>
<td>1 part in</td>
<td>1 part in</td>
<td>1 part in</td>
</tr>
<tr>
<td></td>
<td>600,000</td>
<td>300,000</td>
<td>120,000</td>
</tr>
<tr>
<td><strong>Reciprocal vertical angle observations</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of and spread between observations</td>
<td>3 D/R—10°</td>
<td>3 D/R—10°</td>
<td>2 D/R—10°</td>
</tr>
<tr>
<td>Number of stations between known elevations</td>
<td>4-6</td>
<td>6-8</td>
<td>8-10</td>
</tr>
<tr>
<td><strong>Astro azimuths</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of courses between azimuth checks</td>
<td>5-6</td>
<td>10-12</td>
<td>15-20</td>
</tr>
<tr>
<td>No. of obs./night</td>
<td>16</td>
<td>16</td>
<td>12</td>
</tr>
<tr>
<td>No. of nights</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Standard error</td>
<td>0°.45</td>
<td>0°.45</td>
<td>1°.5</td>
</tr>
<tr>
<td>Azimuth closure at azimuth check point not to exceed</td>
<td>1°.0 per station or 1°.5 per station or 3° √N</td>
<td>2°.0 per station or 6° √N</td>
<td>3°.0 per station or 10° √N</td>
</tr>
<tr>
<td></td>
<td>2&quot; √N</td>
<td>Metropolitan area surveys seldom to exceed 2°.0 per station or 3° √N</td>
<td>Metropolitan area surveys seldom to exceed 4°.0 per station or 8° √N</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Metropolitan area surveys seldom to exceed 6°.0 per station or 15° √N</td>
</tr>
<tr>
<td><strong>Position closure</strong></td>
<td>0.04m √N or 0.08m √N or 0.2m√N or 0.4m√N or 0.8m√N</td>
<td>0.08m √N or 0.15m√N or 0.2m√N or 0.4m√N or 0.8m√N</td>
<td></td>
</tr>
<tr>
<td>after azimuth adjustment</td>
<td>1:100,000</td>
<td>1:50,000</td>
<td>1:20,000</td>
</tr>
</tbody>
</table>

* May be reduced to 8 and 4, respectively, in metropolitan areas.
NOTE (1)
The standard error is to be estimated by
\[ \sigma = \sqrt{\frac{\sum v^2}{n(n-1)}} \]
where \( \sigma \) is the standard error of the mean, \( v \) is a residual (that is, the difference between a measured length and the mean of all measured lengths of a line), and \( n \) is the number of measurements.
The term "standard error" used here is computed under the assumption that all errors are strictly random in nature. The true or actual error is a quantity that cannot be obtained exactly. It is the difference between the true value and the measured value. By correcting each measurement for every known source of systematic error, however, one may approach the true error. It is mandatory for any practitioner using these tables to reduce to a minimum the effect of all systematic and constant errors so that real accuracy may be obtained. (See page 267 of Coast and Geodetic Survey Special Publication No. 247, "Manual of Geodetic Triangulation," Revised edition, 1959, for definition of "actual error.")

NOTE (2)
The figure for "Instrument" describes the theodolite recommended in terms of the smallest reading of the horizontal circle. A position is one measure, with the telescope both direct and reversed, of the horizontal direction from the initial station to each of the other stations. See FGCC "Detailed Specifications" for number of observations and rejection limits when using transits.

NOTE (3)
The standard error for astronomic azimuths is computed with all observations considered equal in weight (with 75 percent of the total number of observations required on a single night) after application of a 5-second rejection limit from the mean for First- and Second-Order observations.

NOTE (4)
See FGCC "Detailed Specifications" on "Elevation of Horizontal Control Points" for further details. These elevations are intended to suffice for computations, adjustments, and broad mapping and control projects, not necessarily for vertical network elevations.

NOTE (5)
Unless the survey is in the form of a loop closing on itself, the position closures would depend largely on the constraints or established control in the adjustment. The extent of constraints and the actual relationship of the surveys can be obtained through either a review of the computations, or a minimally constrained adjustment of all work involved. The proportional accuracy or closure (i.e. 1/100,000) can be obtained by computing the difference between the computed value and the fixed value, and dividing this quantity by the length of the loop connecting the two points.

NOTE (6)
See FGCC "Detailed Specifications" on "Trilateration" for further details.

NOTE (7)
The number of azimuth courses for First-Order traverses are between Laplace azimuths. For other survey accuracies, the number of courses may be between Laplace azimuths and/or adjusted azimuths.

NOTE (8)
The expressions for closing errors in traverses are given in two forms. The expression containing the square root is designed for longer lines where higher proportional accuracy is required.
The formula that gives the smallest permissible closure should be used.
\[ N \] is the number of stations for carrying azimuth.
\[ K \] is the distance in kilometers.
Vertical Control

First-Order

Leveling of this order is used in developing the basic framework of the national vertical net in the United States (Basic Nets A and B) so that few points in the country will be more than 50 km from an established First-Order bench mark. All lines close upon First-Order leveling to form circuits. The lines are divided into sections 1 to 2 km in length, and each section is leveled forward and backward. The difference in the two levellings must not exceed 3.0 mm (K)\(1/2\) for Class I (Basic Net A), or 4.0 mm (K)\(1/2\) for Class II (Basic Net B), where K is the distance in kilometers. The same criteria are recommended for use in establishing primary networks of leveling in metropolitan areas, except that the lines should be closely spaced.

Actual gravity values at the bench marks are needed to compute geopotential differences. If the gravity is not already available with the required accuracy, it shall be measured at sufficient number of bench marks so that the gravity uncertainty computed for any interval will not affect the accuracy of the geopotential difference by more than 0.2 x 10\(^{-2}\)gpv\(^2\).

Second-Order, Class I

Leveling of this class should be used in developing the secondary net of the national vertical network and in densifying precise control in metropolitan areas. The leveling should connect to leveling of equal or greater accuracy to form closed circuits. All lines should be divided into sections 1 to 2 km in length, and each section should be run forward and backward, the two runnings of a section not to differ more than 6 mm (K)\(1/2\), where K is the length of the section in kilometers.

Second-Order, Class II

This class should be used in subdivideing loops of First-Order and Second-Order, Class I leveling to establish general area coverage. The leveling should form closed circuits with leveling of equal or greater accuracy, and should rarely extend more than 50 km unsupported in this manner. Single-run leveling for short distances is acceptable, but for distances greater than 25 km double-run leveling is recommended. For double-run leveling, the line should be divided into sections of 1 to 3 km, and the forward and backward runnings of each section should differ by not more than 8 mm (K)\(1/2\), where K is the distance in kilometers.

Third-Order

Third-Order leveling may be used in subdividing loops of First- and Second-Order leveling, where additional control is required for local development. Third-Order lines may be single-run, but must always be loops or circuits closed upon lines of equal or higher order with a check of 12 mm (K)\(1/2\), or better, where K is the length of the line in kilometers. It is recommended that single-run lines be limited to 10 km in length, and double-run, to 25 km. Exceptions would be control for topographic mapping at a scale of 1:24,000 or smaller, and leveling in mountainous areas, where accuracy requirements may permit Third-Order lines 50 km long.

Leveling of Lower Order

Trigonometric leveling, barometric leveling, and fly leveling may be considered as Fourth-Order, or less; standards for these surveys are not included in these classifications. Elevations are normally published as part of other data.

Instruments and Procedures

For First-Order leveling, an automatic or tilting level with parallel plate micrometer, or equivalent, should be used. It should have horizontal sensitivity of 0.25 second of arc, or better, and should have high-quality optics that will permit repeat reading of 0.2 mm on a geodetic rod at a distance of 50 m under normal atmospheric conditions. The instrument should remain stable in a moderate breeze (up to 20 km/h), and should be temperature compensated. The rod should be composed of an invar scale under tension on a wood or metal frame equipped with a bull’s-eye bubble. The scale should be accurate overall to 0.1 mm. The rods are used in pairs, each rod alternating as the forward and backward rod, and the same rod is always read first regardless of position. That is, one rod will be used for the back readings on odd-numbered instrument stations, and for the forward readings on even-numbered stations. The lengths of sights should not exceed the criteria given in table 3, and should be shortened if refraction or scintillation is troublesome. Balancing of forward and backward sights also shall conform to the limits given in table 3.
### Table 3—Classification, Standards of Accuracy, and General Specifications for Vertical Control

#### First-Order

<table>
<thead>
<tr>
<th>Classification</th>
<th>Class I, Class II</th>
<th>Class I</th>
<th>Class II</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Principal uses</strong></td>
<td>Basic framework of the National Network and of metropolitan area control</td>
<td>Secondary control of the National Network and of metropolitan area control</td>
<td>Control densification, usually adjusted to the National Net. Local engineering projects</td>
</tr>
<tr>
<td>Minimum standards; higher accuracies may be used for special purposes</td>
<td>Extensive engineering projects</td>
<td>Large engineering projects</td>
<td>Topographic mapping</td>
</tr>
<tr>
<td></td>
<td>Regional crustal movement investigations</td>
<td>Local crustal movement and subsidence investigations</td>
<td>Studies of rapid subsidence</td>
</tr>
<tr>
<td></td>
<td>Determining geopotential values</td>
<td>Support for lower-order control</td>
<td>Support for local surveys</td>
</tr>
</tbody>
</table>

#### Second-Order

<table>
<thead>
<tr>
<th>Recommended spacing of lines</th>
<th>National Network</th>
<th>Metropolitan control; other purposes</th>
<th>Spacing of marks along lines</th>
<th>Gravity requirement</th>
<th>Instrument standards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net A; 100 to 300 km Class I</td>
<td>Net B; 50 to 100 km Class II</td>
<td>2 to 8 km As needed</td>
<td>0.2 x 10^{-6}epu</td>
<td>Autonomic or tilting levels with parallel plate micrometers; lnvar scale rods</td>
<td>Double-run; forward and backward, each section 2 km</td>
</tr>
</tbody>
</table>

#### Field procedures

<table>
<thead>
<tr>
<th>Maximum length of sight</th>
<th>50 m Class I; 60 m Class II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section length, average</td>
<td>2 km</td>
</tr>
<tr>
<td>Maximum length of sight</td>
<td>60 m</td>
</tr>
</tbody>
</table>

#### Field procedures

<table>
<thead>
<tr>
<th>Max. difference in lengths</th>
<th>Forward &amp; backward sights per setup</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class I</td>
<td>2 m Class I; 5 m Class II</td>
</tr>
<tr>
<td>Class II</td>
<td>4 m Class I; 10 m Class II</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Max. length of line between connections</th>
<th>Net A; 100 km Class I; 300 km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net B; 100 km Class II</td>
<td>50 km</td>
</tr>
</tbody>
</table>

#### Maximum closures

<table>
<thead>
<tr>
<th>Section; fwd. and bkwd.</th>
<th>3 mm √K Class I; 4 mm √K Class II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loop or line</td>
<td>6 mm √K</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>6 mm √K Class I; 4 mm √K Class II</th>
<th>8 mm √K</th>
</tr>
</thead>
</table>

* See text for discussion of instruments.

† The maximum length of line between connections may be increased to 100 km for double run for Second-Order, Class II, and to 50 km for double run for Third-Order in those areas where the First-Order control has not been fully established.

‡ Check between forward and backward runnings where X is the distance in kilometers.
For Second-Order leveling, parallel plate or similar micrometers on the instruments are not required but are desirable. Otherwise, three-wire geodetic spirit or automatic levels with horizontal sensitivity 0.5 seconds of arc are recommended. Stadia should be read for keeping the sight lengths balanced and for adjustment purposes. The red scale should be accurate overall to 0.2 mm. For Third-Order leveling, it is necessary to read only the middle wire when using the three-wire geodetic spirit level.

National Networks of Geodetic Control

There is a continuing basic program for establishing, upgrading, and maintaining of the National Geodetic Control Networks described in these classifications to provide adequate spacing as well as sufficient strength and accuracy to meet the needs and satisfy the requirements of engineers and scientists engaged in the development and conservation of the resources of the United States. The accuracy and spacing of the National Network control must be based on the most stringent requirements to be placed upon it; this accuracy should be the best achievable considering economic advantage and the capabilities of instruments and technology.

Horizontal Control Network

National overall accuracy is derived through the establishment of a fundamental backbone of the high-precision traverses, with accuracies of 1:1,000,-000 integrated with satellite triangulation. Primary horizontal control (First-Order, accuracy of 1:100,-000) establishes the principal network with arcs or traverses at a spacing not in excess of 100 km. Secondary horizontal control (Second-Order, Class I, accuracy of 1:50,000), together with supplemental work (Second-Order, Class II, accuracy of 1:20,-000) breaks down the principal network and strengthens the whole. Local horizontal control (Third-Order, Class I, accuracy of 1:10,000, and Third-Order, Class II, accuracy of 1:5,000) is referenced to the network. To meet these accuracy criteria and for optimum utilization of the network, approximate station spacing, in general, along First-Order arcs is 15 km, with a breakdown to 10 km for Second-Order, Class I and 5 km for Second-Order, Class II. In areas of high land value, the station spacing for First-Order is a maximum of 8 km and Second-Order, Class I, 3 km. Second-Order, Class II and all Third-Order, Class I and Class II are as required for local usage.

In addition to the above spacing of stations, control shall be established at all airports, towns of 2,000 or more population, colleges, and at 6- to 8-km spacing along coastlines and interstate highways. Although wider spacing may suffice for federal topographic mapping, closer spacing is required for surveys of property, highways, transmission lines, reclamation projects, and numerous other engineering activities. Such stations should be situated so they are readily available to local engineers and surveyors. Frequency, stability, recoverability, and accessibility are factors to be considered when emplacing marks (including underground marks, reference marks, and witness posts when appropriate).

Nationwide High Precision Traverses

These traverses provide scale for the worldwide satellite triangulation network and upgrade the scale and orientation of the National Network of Horizontal Control. They consist of a series of high-precision length, angle, and astronomic azimuth determinations running approximately east-west and north-south through the conterminous states, forming somewhat rectangular loops. Smaller loops and spur traverses are added to connect satellite triangulation stations and areas of special interest.

Standards of accuracy for high-precision traverses are not given herein. Supporting specifications approved by the Federal Geodetic Control Committee outline procedures indicating the care required to obtain the approximate 1 part in 1,000,000 accuracy.

The high precision traverses provide a geodetic reference framework of continental extent which, when re-measured in the future, will provide data for studies of deformation of the earth's crust, including continental drift and spreading.

Triangulation, Trilateration, Traverse, and Bases

Methods of establishment of horizontal control are triangulation, trilateration, and traverses, either separately or in combination. This publication does not differentiate between the methods used. Appropriate instrumentation and procedures are to be selected to satisfy the standards in the tables and to obtain the precision required.

The general availability of electronic distance-measuring equipment has practically eliminated the use of taping procedures for the measurement of
base lines or traverse lengths. Accuracies are comparable or superior to those obtained with invar tapes.

**Vertical Control Network**

In leveling, inasmuch as survey errors propagate at least as the one-half power of the distance surveyed, and because of the great continental distances in the United States, the precision of the primary network measurements must be of high order.

The national vertical control network provides for this by a framework of high-precision basic control supporting a secondary network, which in turn supports area control of a density convenient for users.

The framework consists of two interrelated systems, designated as Basic Nets A and B, covering the country. Basic Net A is composed of lines of First-Order, Class I leveling, forming more or less rectangular circuits 100 to 300 km across, and is the fundamental reference system. Basic Net B is composed of lines of First-Order, Class II leveling, subdividing the circuits of Net A to provide an overall spacing of 50 to 100 km. The Secondary Network consisting of lines of Second-Order, Class I leveling spaced 25 to 50 km apart densifies the national network. The more closely spaced Second-Order, Class II area control is referenced to the network.

The surface of our continent is constantly changing because of tectonic and other physical forces. Large areas are undergoing subsidence owing to removal of ground water or petroleum resources, regions are still emerging from glacier recession, elevations are changing because of natural movement of the earth's crust, and seismic activity is continuous. Engineers and planners need up-to-date elevations to cope with new water levels and crustal changes.

One of the most important factors in the development of a control level net is to establish marks that will remain stable. In some areas, the causes of ground movement are so deep-seated that it is difficult to establish a mark that will remain stable indefinitely. The usual practice is to establish, at 1- to 3-km intervals along lines of First- or Second-Order leveling, bench mark disks set in concrete posts, stable structures, and outcropping bedrock, or secured to rods and pipes driven to refusal (or a stable stratum). At each intersection of lines of the basic framework, a cluster of three "super" marks is established; this cluster consists of deep isolated-pipe marks or marks in bedrock. Intersections of lines of the Secondary Network are marked by clusters of three driven-rod marks. In both cases, the next adjacent regular bench mark on each level line is the driven-rod or outcropping rock type. This pattern permits, to a degree, a check on the stability of marks for future extensions.

**Earth Movement Surveys**

Surveys for the measurement of horizontal and vertical movements of the earth's crust are undertaken in areas of known or suspected subsidence or seismic activity, where the safety of the inhabitants and the economy of the region are involved. These surveys consist of periodically repeated precise measurements to provide information relative to crustal distortions and strain buildup for use in geophysical studies and in engineering design and maintenance. Similar surveys, particularly vertical, are required in areas of subsidence caused by withdrawal of underground resources. These repeat surveys are necessary to maintain the quality of the networks and to correlate between changes in local mean sea level and crustal distortion. The economic and engineering impact, and the rate of movement, dictate the period between surveys.
### Table 4—National Geodetic Networks

#### Horizontal

<table>
<thead>
<tr>
<th>Classification</th>
<th>Nationwide high precision traverses—Satellite Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network component</td>
<td>Basic horizontal framework (control establishes the National Network)</td>
</tr>
<tr>
<td>Nominal accuracy or precision between adjacent points</td>
<td>1 part in 1,000,000</td>
</tr>
<tr>
<td>Recommended density of control</td>
<td>Traverses and satellite stations at 900-1200 km. Stations at 15 km. to limit of technical and geometric restraints</td>
</tr>
</tbody>
</table>

#### First-Order

- **Class I**: Primary horizontal network (control develops the National Network) 1 part in 100,000 Arcs not in excess of 100 km. Stations at 12-20 km. Urban control 3-8 km.

#### Second-Order

- **Class I**: Secondary horizontal control (control strengthens the National Network) 1 part in 50,000 Stations at 10-13 km. Urban control 1-3 km.
- **Class II**: Supplemental horizontal control (Control contributes to the National Network) 1 part in 20,000 As required

#### Third-Order

- **Class I**: Local horizontal control (control is referenced to the National Network) 1 part in 10,000 1 part in 5,000

#### Vertical

<table>
<thead>
<tr>
<th>Classification</th>
<th>First-Order</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class I</td>
<td>Basic Vertical Network A (control establishes the National Network)</td>
</tr>
<tr>
<td>Nominal accuracy between points*</td>
<td>1.5 mm√K</td>
</tr>
<tr>
<td>Recommended density of lines</td>
<td>100-300 km</td>
</tr>
</tbody>
</table>

| Class II | Basic Vertical Network B |
| Nominal accuracy between points* | 2 mm√K |
| Recommended density of lines | 50-100 km |

| Class I | Secondary Vertical Network (Control develops the National Network) |
| Nominal accuracy between points* | 3 mm√K |
| Recommended density of lines | 25-50 km |

| Class II | Supplemental Vertical Control (Control contributes to the National Network) |
| Nominal accuracy between points* | 4 mm√K |
| Recommended density of lines | 10-25 km |

| Third-Order | Local vertical control |
| Nominal accuracy between points* | 6 mm√K |
| Recommended density of lines | As needed |

*One-half of permissible closure
United States Department of the Interior
BUREAU OF MINES
BUILDING 20, DENVER FEDERAL CENTER
DENVER, COLORADO 80225
November 16, 1978

Certified Mail

Mr. Donald Dewey
UTAH POWER AND LIGHT COMPANY
Mining and Exploration Department
Box 899
Salt Lake City, UT 84110

Dear Mr. Dewey:

Enclosed is one fully executed copy of Cooperative Agreement No. 14-09-0070-780 between your Company and the Bureau.

Thank you for your interest and participation in this research.

Very truly yours,

[Signature]
Harry R. Nicholls
Acting Research Director
Denver Mining Research Center

Enclosure
COOPERATIVE AGREEMENT

BETWEEN

THE UNITED STATES OF AMERICA

AND

UTAH POWER AND LIGHT COMPANY

THIS AGREEMENT, made and entered into this __ day of ____, 1978, between Utah Power and Light Company (hereinafter referred to as the Company) and the United States of America, acting through the Department of The Interior, Bureau of Mines (hereinafter referred to as the Bureau), WITNESSETH that it is agreed and understood as follows:

1. Cooperation

The Bureau and the Company agree to cooperate and collaborate on a research project to determine the surface effects of room-and-pillar and longwall mining at the Deer Creek Mine near Huntington, Utah.

2. General

The Bureau of Mines is engaged in a research program designed to determine engineering and environmental effects of subsidence resulting from underground extraction of coal and similarly bedded deposits. The program objective is to develop knowledge and expertise in these subsidence areas which will be useful to mine planners and surface users in predicting surface effects of specific mining methods and extraction ratios.

Today's demands for improved production, recovery and safety are causing mine operators to adopt the longwall mining method. Because only 5% of the coal currently mined underground in the U.S. is by longwall, little is known of the effects of subsidence from longwall coal mining under U.S. conditions. Also few comparisons have been made of the character of subsidence over longwalls as opposed to subsidence over room-and-pillar sections. Therefore, this work is directed primarily toward subsidence and surface effects resulting from both room-and-pillar and longwall mining as done in single, multiple and thick seams of bedded deposits found in the western U.S.

3. Description of Work

This project involves the installation, and periodic monitoring by ground surveys, of a network of monuments to determine the magnitude, extent, and surface effects of subsidence caused by longwall and room-and-pillar mining in the Blind Canyon coal seam. The first two sections to be monitored under this study will be a room-and-pillar section, Fourth East, and the adjacent longwall panel. Monitoring of subsequently mined panels will be contingent upon extension of this Agreement.
Monitoring of subsidence will be done by periodic surveying of panel surface monuments from a number of established control points located on non-subsiding ground. Both vertical and horizontal displacement will be measured. Monthly surveys and data collection-analysis will be conducted, weather permitting.

Observed subsidence will be correlated with mining progress and other factors which may be helpful in characterizing the subsidence.

4. Bureau's Contribution

The Bureau will design, install and periodically monitor the subsidence network(s) and shall provide all necessary materials, equipment and personnel to accomplish these tasks.

Quarterly progress reports of project results will be made by the Bureau. The Bureau will also prepare interim reports upon completion of each panel and will prepare a final report upon completion of the study.

The Bureau will forward to the Company on a quarterly basis any subsidence data obtained during the previous three (3) months and make available to the Company all reports prepared as part of the study.

The Bureau will give advance notice to the Company as to when its personnel will be at the site to perform field work in conjunction with the project. It is estimated that the monthly surveys will be performed by three (3) Bureau employees and will require a maximum of three (3) days to complete. Transportation of Bureau personnel to and from the test site will be by government-owned or rented vehicle unless other arrangements are required by the Company.

Upon completion of the study the Bureau will remove the above-ground portions of all surveying monuments and control points unless otherwise requested by the Company.

5. Cooperator's Contribution

The Company will provide Bureau research personnel access through Company property to the study site. The Company will furnish to the Bureau current surface and underground maps including those available of previous mine workings.

The Company will furnish to the Bureau survey control information sufficient to establish accurately the control points and locate the subsidence monuments over the panel.

The Company will make available to the Bureau on a monthly basis, as required, maps showing mining progress for the panel being monitored.
The Company will provide engineering consultation to the project relative to site selection and installation of the subsidence network.

The Company will provide consultation relative to the analysis of quality and validity of data.

Nothing contained herein shall be construed to permit any Bureau personnel to enter any underground mining operation of the Company without specific permission by the Company at time of entry.

6. Publication

It is understood that a major purpose of the work performed by the Bureau is to obtain information of value to the mining industry and public that may be made available by the Bureau through publications or otherwise. Other than reports to the USGS or other government agencies, the Company shall not announce, publish or otherwise disclose information or conclusions resulting from the work performed by the Bureau under this Agreement until after review for technical accuracy by the Bureau. Any announcement or publication of work under this Agreement by either party shall recognize and give credit in the text and on the title page to the cooperation of the other party unless required otherwise.

The Bureau will submit to the Company a draft of any proposed publication concerning the work under this Agreement for review and comment, but in no case will the Bureau abandon its right to publish information resulting from the expenditure of public funds or the use of public facilities.

7. Ownership of Data, Records and Property

Any and all property and equipment of whatever nature or kind furnished by either party in connection with work under this Agreement is and shall remain the property of the party furnishing such property and equipment. All original notebooks, data sheets, record charts, graphs, or other records maintained by the Bureau or Company which are kept during, or arise out of, the work done pursuant to the Agreement shall be the property of the originator and shall not be removed from the custody of the originator. Copies of such records as required will be forwarded to either the Bureau or Company by the originator.

8. Officials Not To Benefit

No Member or Delegate to Congress, or Resident Commissioner, shall be admitted to any share or part of this Agreement or to any benefit that may arise therefrom, but this provision shall not be construed to extend to this Agreement if made with a corporation for its general benefit.
9. Liability

The Company agrees to be responsible for its own acts and results thereof and will assume liability to itself, its agents or employees for injury to persons or property resulting in any manner from the negligent or intentional acts of itself, its agents or employees. The Bureau agrees, to the extent of and by authority set forth in Federal Tort Claims Act to be responsible for injury to any persons or property of the Company or others resulting in any manner from the negligent or intentional acts of itself, its agents or employees, for injury to persons or property resulting in any manner from the negligent or intentional acts of itself, its agents or employees.

10. Termination

This Agreement shall expire on the 30th day of September, 1979, but may be extended by written agreement between the Parties hereto, provided, however, that it may be terminated at any time by either party giving written notice of termination to the other party at least thirty (30) days prior to the date fixed in such notice.

Where the operation of this Agreement extends beyond the current fiscal year, this Agreement is expressly conditioned and contingent upon Congress making appropriation for necessary expenditures hereunder after such current year shall have expired. In case such appropriation as may be necessary to carry out this Agreement is not made, the Company hereby releases the Bureau from all liability for failure to perform due to the failure of Congress to make such appropriation.

IN WITNESS WHEREOF, the Parties hereto have made and executed this Agreement as of the day and year first above written.

Approved: Date NOV 7 1978

Director, Bureau of Mines
ROGER A. MARKLE

The United States of America
Department of the Interior
Bureau of Mines

By Paul H. Russell
Utah Power and Light Company

By John J. Dias
Title Vice President

Attest:
Mr. Donald A. Dewey  
Director of Mining  
Mining & Exploration  
UTAH POWER AND LIGHT COMPANY  
Box 899  
Salt Lake City, UT 84110

Dear Mr. Dewey:

Enclosed is a signed copy of Extension No. 1 to Memorandum of Agreement No. 14-09-0070-780.

The comments of Mr. Jerman on review for technical accuracy do apply to the technical data.

Thank you for your continued interest in Bureau research.

Very truly yours,

Harry R. Nicholls  
Research Center  
Denver Federal Center

Enclosure
EXTENSION OF
MEMORANDUM OF AGREEMENT
BETWEEN
THE UNITED STATES OF AMERICA
AND
UTAH POWER AND LIGHT COMPANY
The memorandum of agreement, previously described as cooperative agreement, between the United States of America, acting through the Department of the Interior, Bureau of Mines, and Utah Power and Light Company, dated November 7, 1978, for collaboration on a research project to determine the surface effects of room-and-pillar and longwall mining at the Deer Creek Mine near Huntington, Utah, is hereby extended for a period ending September 30, 1980, upon the same terms and conditions of the original agreement.

 Approved: OCT 1 9 1979

The United States of America
Department of the Interior
Bureau of Mines
By

Utah Power and Light Company
By Date 9/18/79

Attest: Title Vice President
Mr. Donald A. Dewey, Director of Mining  
Utah Power & Light Company  
Mining & Exploration Department  
Box 899  
Salt Lake City, Utah 84110

Dear Mr. Dewey:

Enclosed is a summary of the progress on the subsidence study over the Deer Creek Mine during the past year. Also included is a copy of the elevation data for the subsidence network through September 1979, an x-y plot of the network in relation to the longwall panel, profile plots of the monument lines and a number of photographs taken during monument installation and monitoring.

We believe this data shows that no surface movement has occurred and that it serves as a solid reference base with which to compare the results of subsequent surveys.

If you have any questions concerning this information, or would like to discuss any phase of the project, do not hesitate to contact us.

Enclosures

Very truly yours,

Frederick K. Allgaier  
Civil Engineer  
Denver Research Center  
Mine Environment Engineering Group
SUMMARY REPORT
Deer Creek Subsidence Study

In September 1978, an agreement was signed between the U.S. Bureau of Mines and Utah Power and Light Company, which provided for cooperation on a research project to study surface subsidence over the longwall panels in the Deer Creek Mine.

The major objectives of this study are to measure surface subsidence caused by longwall mining in the Blind Canyon coal seam, determine the timing, rate and areal extent of subsidence, establish the final subsidence profile, correlate mining and geologic variables with measured subsidence values, evaluate predictive capabilities with regards to actual, observed subsidence values versus theoretical values, document any observed effects of subsidence on the surface and supply the above information to the mining company.

Field work on the project began in September 1978 and continued into October. During this period, control stations were established, the first portion of the panel was monumented and an initial survey was performed. Field work resumed in early July 1979 with a resurvey of the monuments which were installed the previous October. At this time, the face had advanced approximately 800 feet. During the remainder of the summer, monument installation was completed and control stations were established to cover the remainder of the network. In September, the first survey of the completed network was performed.

The monuments used for this project consist of lengths of 1-1/2" pipe driven 3 to 5 feet into the ground. Instruments being used to survey the network are a Zeiss Th-2 one second theodolite and a K & E Autoranger EDM unit. A prism/target assembly which is fitted onto the monuments and then leveled, is used for distance and angle measurements to the monuments.
The surveying techniques being used are as follows. Coordinates for instrument station BM1 were established from section corner coordinates supplied by UP&L. Using vertical and horizontal angles and slope distances measured with the EDM unit, the other instrument stations, BM2, BM3, BM4, and BM5 are established from the BM1 coordinates. Each resurvey of the network begins by checking locations of all instrument stations. Each monument over the panel is then surveyed from one instrument station using another instrument station as a reference backsight. Elevations are determined by trigonometric leveling, using vertical angles and slope distance measurements. Horizontal angles and distances are used to calculate north and east coordinates. Measured angles and distances are input data for a computer program which calculates the north and east coordinates and elevations for the monuments.

Through October 1979, 95 monuments have been installed over the panel and surveyed. This has required a total of 431 man-hrs. of field work which includes control location and stakeout work, installation of the monuments and the surveys. Monument surveys were performed on four separate occasions on portions of the network. This data has been arranged into three sets which represent monument coordinates for the portions of the network in place in October 1978, July 1979 and September 1979. A comparison of the data from the September survey, which includes all 95 monuments, with the previous two surveys does not show any significant difference which would indicate subsidence has occurred. Subsequent surveys will be run on the entire network and continued at intervals until subsidence activity is no longer detected.

It is anticipated that additional monuments will be installed over and monitoring extended to the adjacent panel in 1980. The number and location of these monuments will depend on several factors including the face position of at the time installation and the results from continued surveys of the network over the first panel.
Mr. Donald A. Dewey  
Director of Mining  
Utah Power & Light Company  
Mining & Exploration Department  
Box 899  
Salt Lake City, Utah 84110

Dear Mr. Dewey:

Enclosed is a general description of the subsidence monitoring program to be initiated over the first longwall panel in the Wilberg Mine. The attached map shows the recommended monument layout in red. As discussed at our June 26 meeting, UP&L will locate and install the monuments and clear the lines. The Bureau will run the periodic surveys and reduce the data.

Additions are being made to the current Deer Creek agreement which will cover the work at the Wilberg site. The modified agreement will be forthcoming for your approval. Bureau work at the site will not be delayed while the agreement is being processed so that an initial survey can be completed before mining of the first longwall panel begins.

Sincerely,

Frederick K. Allgaier  
Civil Engineer  
Denver Research Center  
Mine Engineering Division
Wilberg Subsidence Monitoring Program

As an extension of the subsidence monitoring research project being conducted over the Deer Creek Mine, the Bureau of Mines in cooperation with Utah Power and Light Company will monitor surface subsidence over the first longwall panel in the Wilberg Mine.

The purpose of monitoring the Wilberg site is to provide additional subsidence data to be utilized by the Bureau in its research program to characterize surface subsidence resulting from longwall mining in the western United States. The subsidence data will be supplied to Utah Power and Light Company for their use.

MONITORING NETWORK

The subsidence monitoring network will consist of two lines of monuments located over the longwall panel as shown on the attached map. One line will run over the centerline of the panel in an east-west direction. The other line will run perpendicular to the long axis of the panel in a north-south direction. Both lines of monuments will extend beyond the edges of the panel to cover the effects of the chain pillars and the angle of draw. The spacing of the monuments will be 200 feet on both lines.

The monuments will consist of one-inch diameter steel rods driven into the ground to a depth of between three and five feet. The tops of the monuments will be protected so as not to present a hazard to livestock or vehicles. A minimum of four inches of horizontal clearance around the top five inches of the rods is required to accommodate the target mount.

MONITORING

Elevations of the monuments will be determined by trigonometric leveling procedures utilizing control points located outside of the subsidence area. These level surveys will be performed twice during each year until the Bureau determines that subsidence activity is complete or the project is terminated. The Bureau may elect to run a standard, direct level survey on a portion of the network either in addition to, or instead of the trigonometric level survey. In addition, selected monuments (not to exceed 5 in number) located over the panel will have horizontal positions determined in conjunction with the level surveys to detect horizontal movement.
United States Department of the Interior
BUREAU OF MINES
BUILDING 20, DENVER FEDERAL CENTER
DENVER, COLORADO 80225
November 17, 1980

CERTIFIED MAIL – Return Receipt Requested

Mr. Dean L. Bryner
Vice President, Systems
and Resource Planning
UTAH POWER AND LIGHT COMPANY
Mining and Exploration Department
Box 899
Salt Lake City, UT 84110

Dear Mr. Bryner:

Enclosed is one fully executed copy of Extension No. 1 to the Memorandum of Agreement No. 14-09-0070-780 between your company and the Bureau.

Your continued interest in Bureau research is appreciated.

Very truly yours,

Galen G. Waddell
Research Director
Denver Research Center

Enclosure
EXTENSION OF
MEMORANDUM OF AGREEMENT
BETWEEN
THE UNITED STATES OF AMERICA
AND
UTAH POWER AND LIGHT COMPANY

The memorandum of agreement, previously described as cooperative agreement, between the United States of America, acting through the Department of the Interior, Bureau of Mines, and Utah Power and Light Company, dated November 7, 1978, for collaboration on a research project to determine the surface effects of room-and-pillar and longwall mining at the Deer Creek Mine near Huntington, Utah, is hereby extended for a period ending September 30, 1981, upon the same terms and conditions of the original agreement, except as described on the attached sheet.

Approved:

The United States of America
Department of the Interior
Bureau of Mines

By ____________________________

Deputy Director, Bureau of Mines

Attest:

Utah Power and Light Company

By ____________________________

Assistant Secretary

Title: Vice President

Date: September 2, 1980
ADDITIONS TO THE MEMORANDUM OF AGREEMENT
BETWEEN
THE UNITED STATES OF AMERICA
AND
UTAH POWER AND LIGHT COMPANY

Additional Work

Surface subsidence monitoring currently being done by the Bureau of Mines over the Deer Creek mine under the existing agreement will be broadened to include the first longwall panel at the Wilberg mine. Surveys will be made at the Wilberg mine twice during each year for the duration of the study.

Bureau's Contribution

The Bureau's contribution at the Wilberg subsidence monitoring site will be the same as outlined in the current agreement for Deer Creek mine except that the Bureau will not install the monuments.

Company's Contribution

The Company's contribution at the Wilberg site will remain as outlined in the current agreement for Deer Creek mine except that the Company will be responsible for locating and installing the monuments and clearing the sight lines.
Mr. Chris Shingleton  
Utah Power & Light Company  
Mining & Exploration Department  
Box 899  
Salt Lake City, Utah 84110

Dear Mr. Shingleton:

Enclosed is a map of the subsidence monitoring network over the first long-wall panel in the Wilberg Mine and a copy of the initial monument elevations as of September 17, 1980.

Two additional level surveys will be run on the network during 1981 as per the approved subsidence monitoring program.

Sincerely yours,

Frederick K. Allgaier

Enclosure
<table>
<thead>
<tr>
<th>STATION</th>
<th>1ST</th>
<th>2ND</th>
<th>3RD</th>
<th>4TH</th>
<th>5TH</th>
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<tbody>
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ATTACHMENT A
SPECIAL CONDITION 5

In accordance with these instructions Company submits maps of sufficient scale and accuracy to depict both primary grid control (Control Diagram) and coordinate address overlay maps 1" - 400' showing individual photogrammetrical survey points. Also, in accordance with the special instructions, Company submits computer listings of subsidence control points for years 1980, 1981, 1982 and 1983.

This information is in addition to Company's subsidence monitoring report which is appropriately submitted annually.

Special Condition 6

The Bureau of Mines entered into an agreement with Utah Power & Light Company in 1979, renewable on a yearly basis. This agreement is presently in force and field data is being generated. Utah Power states it plans to continue monitoring if, in the event the Government (Bureau) discontinues the subsidence monitoring surveys.
Methodology, frequency and accuracies will be compatible with past compiled data.

Owner will continue to publish reports on an annual basis summarizing the surface effects of undermining mining. Included will be comparisons between conventional and photogrammetrical surveys. Each annual subsidence monitoring report will identify appropriate mitigation measures to be taken if significant subsidence impacts occur.
## APPENDIX XVII

COTTONWOOD/WILBERG SAFETY FACTOR

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* Reference used for formulas and charts to calculate Safety Factors for Roads and Embankments.
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COTTONWOOD/WILBERG
SEDIMENT POND EMBANKMENT BETWEEN NORTH & SOUTH POND

(H) = Height of Slope = 25' (approximate outslope)
(C) = Cohesion* = 1872 psf
(φ) = Friction Angle* = 30°
(αf) = Slope Angle = 26.57° or 2:1
(y) = Unit Weight* = 108 pcf
(A) = Chart reading along arc from x to y axis
(a) = Chart reading along y axis
(b) = Chart reading along x axis
(F) = Factor of Safety

** FORMULAS

\[
\frac{C}{y\times H \times \tan \phi} = A
\]

(x to y axis Formula)

\[
\frac{\tan \phi}{F} = a, so, F = \frac{\tan \phi}{a}
\]

(y axis formula)

\[
\frac{C}{y \times H \times F} = b, so, F = \frac{b}{y \times H}
\]

(x axis formula)

** CALCULATIONS

\[
\frac{1872}{108 \times 25 \times \tan 30°} = 1.20
\]

(using chart No. 5, a = 0.09)

\[
A = 1.20
\]

\[
a = 0.09
\]

\[
\frac{\tan 30°}{F} = 0.09, so, F = \frac{\tan 30°}{0.09} = 6.42
\]

\[
F = 6.42 \text{ FACTOR OF SAFETY}
\]

* Values taken from Triaxial Shear Tests (see Appendix XVIII).

** Dike for the South Pond is incised, therefore no Safety factor information is provided.
COTTONWOOD/WILBERG
HAUL ROAD

(H)= Height of Slope = 30’ (maximum outslope)
(C)= Cohesion* = 1872 psf
(\phi)= Friction Angle* = 30°
(f)= Slope Angle = 33.69° or 1\frac{1}{4}:1
(y)= Unit Weight* = 108 pcf
(A)= Chart reading along arc from x to y axis
(a)= Chart reading along y axis
(b)= Chart reading along x axis
(F)= Factor of Safety

FORMULAS
\[ \frac{C}{y \times H \times \tan \phi} = A \]

(x to y axis Formula)
\[ \tan \phi = a, \text{so, } F = \frac{\tan \phi}{a} \]

(y axis formula)
\[ \frac{C}{y \times H \times F} = b, \text{so, } F = \frac{C}{b} \]

(x axis formula)

CALCULATIONS
\[ \frac{1872}{108 \times 30 \times \tan 30°} = 1.00 \]

(using chart No. 1, a = 0.11)
\[ A = 1.00 \]
\[ a = 0.11 \]
\[ \frac{\tan 30°}{F} = 0.11, \text{so, } F = \frac{\tan 30°}{0.11} = 5.25 \]

\[ F = 5.25 \text{ FACTOR OF SAFETY} \]

* Values taken from Triaxial Shear Tests (see Appendix XVIII).
COTTONWOOD/WILBERG
TRUCK TURN AROUND

(H) = Height of Slope = 35' (maximum outslope)
(C) = Cohesion* = 1872 psf
(\phi) = Friction Angle* = 30'
(\gamma) = Slope Angle = 33.69° or 1\frac{1}{3}:1
(y) = Unit Weight* = 108 pcf
(A) = Chart reading along arc from x to y axis
(a) = Chart reading along y axis
(b) = Chart reading along x axis
(F) = Factor of Safety

FORMULAS

\[ \frac{C}{y \times H \times \tan \Phi} = A \]  
(x to y axis Formula)

\[ \frac{\tan \Phi}{F} = a, \text{ so } F = \frac{\tan \Phi}{a} \]  
(y axis formula)

\[ \frac{C}{y \times H \times F} = b, \text{ so } F = \frac{C}{b \times y \times H} \]  
(x axis formula)

CALCULATIONS

\[ \frac{1872}{108 \times 35 \times \tan 30°} = 0.86 \]  
(using chart No. 1, a = 0.12)

\[ A = 0.86 \]
\[ a = 0.12 \]

\[ \frac{\tan 30°}{F} = 0.12, \text{ so } F = \frac{\tan 30°}{0.12} = 4.81 \]

\[ F = 4.81 \text{ FACTOR OF SAFETY} \]

* Values taken from Triaxial Shear Tests (see Appendix XVIII).
COTTONWOOD/WILBERG
SERVICE ROAD

(H) = Height of Slope = 100' (maximum outslope)
(C) = Cohesion* = 1872 psf
(\phi) = Friction Angle* = 30°
(\text{if}) = Slope Angle = 33.69° or 1\frac{1}{4}:1
(y) = Unit Weight* = 108 pcf
(A) = Chart reading along arc from x to y axis
(a) = Chart reading along y axis
(b) = Chart reading along x axis
(F) = Factor of Safety

FORMULAS

\[
\frac{C}{y \times H \times \tan \phi} = A
\]

(x to y axis Formula)

\[
\frac{\tan \phi}{F} = a, \text{so}, F = \frac{\tan \phi}{a}
\]

(y axis formula)

\[
\frac{C}{y \times H \times F} = b, \text{so}, F = \frac{C}{b \times y \times H}
\]

(x axis formula)

CALCULATIONS

\[
\frac{1872}{108 \times 100 \times \tan 30°} = 0.30
\]

(using chart No. 1, a = 0.22)

\[
A = 0.30 \\
a = 0.22
\]

\[
\frac{\tan 30°}{F} = 0.22, \text{so}, F = \frac{\tan 30°}{0.22} = 2.62
\]

\[F = 2.62 \text{ FACTOR OF SAFETY}\]

* Values taken from Triaxial Shear Tests (see Appendix XVIII).
COTTONWOOD/WILBERG
PORTAL ROAD

(H) = Height of Slope = 120' (maximum outslope)
(C) = Cohesion* = 1872 psf
(\(\phi\)) = Friction Angle* = 30°
(\(\beta\)) = Slope Angle = 33.69° or 1½:1
(y) = Unit Weight* = 108 pcf
(A) = Chart reading along arc from x to y axis
(a) = Chart reading along y axis
(b) = Chart reading along x axis
(F) = Factor of Safety

FORMULAS

\[ C = \frac{A}{y \times H \times \tan\Phi} \]

(x to y axis Formula)

\[ \frac{\tan\Phi}{F} = a, \text{ so } F = \frac{\tan\Phi}{a} \]

(y axis formula)

\[ C = \frac{b}{y \times H \times F}, \text{ so } F = \frac{C}{b} \]

(x axis formula)

CALCULATIONS

\[ \frac{1872}{108 \times 120 \times \tan 30°} = 0.25 \]

(using chart No. 1, \(a = 0.25\))

\[ A = 0.25 \]
\[ a = 0.25 \]

\[ \frac{\tan 30°}{F} = 0.25, \text{ so } F = \frac{\tan 30°}{0.25} = 2.31 \]

\[ F = 2.31 \text{ FACTOR OF SAFETY} \]

* Values taken from Triaxial Shear Tests (see Appendix XVIII).
COTTONWOOD/WILBERG
FAN ACCESS ROAD

(H) = Height of Slope = 180' (maximum outslope)
(C) = Cohesion* = 1872 psf
(\(\phi\)) = Friction Angle* = 30'
(I) = Slope Angle = 33.69' or 1½:1
(y) = Unit Weight* = 108 pcf
(a) = Chart reading along arc from x to y axis
(b) = Chart reading along x axis
(F) = Factor of Safety

FORMULAS

\[
\frac{C}{y\times H \times \tan \phi} = A
\]

(x to y axis Formula)

\[
\frac{\tan \phi}{F} = a, \text{so, } F = \frac{\tan \phi}{a}
\]

(y axis formula)

\[
\frac{C}{y\times H \times F} = b, \text{so, } F = \frac{b}{y\times H}
\]

(x axis formula)

CALCULATIONS

\[
\frac{1872}{108 \times 180 \times \tan 30^\circ} = 0.17
\]

(using chart No. 1, a = 0.29)

A = 0.17
a = 0.29

\[
\frac{\tan 30^\circ}{F} = 0.29, \text{so, } F = \frac{\tan 30^\circ}{0.29} = 1.99
\]

F = 1.99 FACTOR OF SAFETY

* Values taken from Triaxial Shear Tests (see Appendix XVIII).
Chapter 9: Circular failure

Introduction

Although this book is concerned primarily with the stability of rock slopes, the reader will occasionally be faced with a slope problem involving soft materials such as overburden soils or crushed waste. In such materials, failure occurs along a surface which approaches a circular shape and this chapter is devoted to a brief discussion on how stability problems involving these materials are dealt with.

In a review on the historical development of slope stability theories, Golden210 has traced the subject back almost 300 hundred years. During the past half century, a vast body of literature on this subject has accumulated and no attempt will be made to summarise this material in this chapter. Standard soil mechanics text books such as those by Taylor174, Tenzer231 and Terzaghi and Whitman32 all contain excellent chapters on the stability of soil slopes and it is suggested that at least one of these books should occupy a prominent place on the bookshelf of anyone who is concerned with slope stability. In addition to these books a number of important papers dealing with specific aspects of soil slope stability have been published and a selected list of these is given under references 213 to 233 at the end of this chapter.

The approach adopted in this chapter is to present a series of the slope stability charts for circular failure. These charts enable the user to carry out a very rapid check on the factor of safety of a slope or upon the sensitivity of the factor of safety to changes in groundwater conditions or slope profile. These charts should only be used for the analysis of circular failure in materials where the properties do not vary through the soil or waste rock mass and where the conditions assumed in deriving the charts, discussed in the next section, apply. A more elaborate form of analysis is presented at the end of this chapter for use in cases where the material properties vary within the slope or where part of the slide surface is at a soil/rock interface and the shape of the failure surface differs significantly from a simple circular arc.

Conditions for circular failure

In the previous chapters it has been assumed that the failure of rock slopes is controlled by geological features such as bedding planes and joints which divide the rock body up into a discontinuous mass. Under these conditions, the failure path is normally defined by one or more of the discontinuities. In the case of a soil, a strongly defined structural pattern no longer exists and the failure surface is free to find the line of least resistance through the slope. Observations of slope failures in soils suggests that this failure surface generally takes the form of a circle and most stability theories are based upon this observation.

The conditions under which circular failure will occur arise when the individual particles in a soil or rock mass are very small as compared with the size of the slope and when these particles are not interlocked as result of their shape. Hence, crushed rock in a large waste dump will tend to behave as a "soil" and large failures will occur in a circular mode. Alternatively, the finely ground waste
Figure 102: Shallow surface failure in large waste dumps are generally of a circular type.

Figure 103: Circular failure in the highly altered and weathered rock forming the upper benches of an open pit mine.
material which has to be disposed of after completion of a milling and metal recovery process will exhibit circular failure surfaces, even in slopes of only a few feet in height. Highly altered and weathered rocks will also tend to fail in this manner and it is appropriate to design the overburden slopes around an open pit mine on the assumption that failure would be by a circular failure process.

**Derivation of circular failure charts**

The following assumptions are made in deriving the stability charts presented in this chapter:

a. The material forming the slope is assumed to be homogeneous, i.e. its mechanical properties do not vary with direction of loading.

b. The shear strength of the material is characterised by a cohesion c and a friction angle φ which are related by the equation $t = c + o.\tan \phi$.

c. Failure is assumed to occur on a circular failure surface which passes through the toe of the slope.

d. A vertical tension crack is assumed to occur in the upper surface or in the face of the slope.

e. The locations of the tension crack and of the failure surface are such that the factor of safety of the slope is a minimum for the slope geometry and groundwater conditions considered.

f. A range of groundwater conditions, varying from a dry slope to a fully saturated slope under heavy recharge, are considered in the analysis. These conditions are defined later in this chapter.

**Defining the factor of safety of the slope as**

$$F = \frac{\text{Shear strength available to resist sliding}}{\text{Shear stress mobilised along failure surface}}$$

and rearranging this equation, we get

$$\phi_{ab} = \frac{c + o.\tan \phi}{\phi} \quad (97)$$

where $\phi_{ab}$ is the shear stress mobilised along the failure surface.

Since the shear strength available to resist sliding is dependent upon the distribution of the normal stress $\sigma$ along this surface and, since this normal stress distribution is unknown, the problem is statically indeterminate. In order to obtain a solution it is necessary to assume a specific normal stress distribution and then to check whether this distribution gives meaningful practical results.

*Terzaghi, page 170, shows that the toe failure assumed for this analysis gives the lowest factor of safety provided that $\phi > 50$. The $\phi = 0$ analysis, involving failure below the toe of the slope through the base material has been discussed by Skempton and Bishop and Bjerrum and is applicable to failures which occur during or after the rapid construction of a slope. Such conditions are unlikely to occur in typical mining operations.*
The influence of various normal stress distributions upon the factor of safety of soil slopes has been examined by Frohlich who found that a lower bound for all factors of safety which satisfy statics is given by the assumption that the normal stress is concentrated at a single point on the failure surface. Similarly, the upper bound is obtained by assuming that the normal load is concentrated at the two and points of the failure arc.

The unreal nature of these stress distributions is of no consequence since the object of the exercise, up to this point, is simply to determine the extremes between which the actual factor of safety of the slope must lie. In an example considered by Lamb and Whitman, the upper and lower bounds for the factor of safety of a particular slope correspond to 1.52 and 1.27 respectively. Analysis of the same problem by Bishop's simplified method of slices gives a factor of safety of 1.30 which suggests that the actual factor of safety may lie reasonably close to the lower bound solution.

Further evidence that the lower bound solution is also a meaningful practical solution is provided by an examination of the analysis which assumes that the failure surface has the form of a logarithmic spiral. In this case, the factor of safety is independent of the normal stress distribution and the upper and lower bounds coincide. Taylor compared the results from a number of logarithmic spiral analyses with results of lower bound solutions and found that the difference is negligible. On the basis of this comparison, Taylor concluded that the lower bound solution provides a value of the factor of safety which is sufficiently accurate for most practical problems involving simple circular failure of homogeneous slopes.

The authors have carried out similar checks to those carried out by Taylor and have reached the same conclusions. Hence, the charts presented in this chapter correspond to the lower bound solution for the factor of safety, obtained by assuming that the normal load is concentrated at a single point on the failure surface. These charts differ from those published by Taylor in 1948 in that they include the influence of a critical tension crack and of groundwater in the slope.

Groundwater flow assumptions

In order to calculate the uplift force due to water pressure acting on the failure surface and the force due to water in the tension crack, it is necessary to assume a set of groundwater flow patterns which coincide as closely as possible with those conditions which are believed to exist in the field.

In the analysis of rock slope failures, discussed in chapters 7 and 8, it was assumed that most of the water flow took place in discontinuities in the rock and that the rock itself was practically impermeable. In the case of slopes in soil or waste rock, the permeability of the mass of

---

The lower bound solution discussed in this chapter is usually known as the Friction Circle Method and was used by Taylor for the derivation of his stability charts.
material is generally several orders of magnitude higher than that of intact rock and, hence, a general flow pattern will develop in the material behind the slope.

Figure 55a on page 137 shows that, within the soil mass, the equipotentials are approximately perpendicular to the phreatic surface. Consequently, the flow lines will be approximately parallel to the phreatic surface for the condition of steady state drawdown. Figure 104a shows that this approximation has been used for the analysis of the water pressure distribution in a slope under conditions of normal drawdown. Note that the phreatic surface is assumed to coincide with ground surface at a distance z, measured in multiples of the slope height, behind the toe of the slope. This may correspond to the position of a surface water source such as a river or dam or it may simply be the point where the phreatic surface is judged to intersect the ground surface.

The phreatic surface itself has been obtained, for the range of slope angles and values of z considered, by a computer solution of the equations proposed by L. Casagrande, discussed in the textbook by Taylor.

For the case of a saturated slope subjected to heavy surface recharge, the equipotentials and the associated flow lines used in the stability analysis are based upon the work of Rankine who used an electrical resistance analogue method for the study of groundwater flow patterns in isotropic slopes.

Production of circular failure charts

The circular failure charts presented in this chapter were produced by means of a Hewlett-Packard 9100 B calculator with graph plotting facilities. This machine was programmed to seek out the most critical combination of failure surface and tension crack for each of a range of slope geometries and groundwater conditions. Provision was made for the tension crack to be located in either the upper surface of the slope or in the face of the slope. Detailed checks were carried out in the region surrounding the toe of the slope where the curvature of the equipotentials results in local flow which differs from that illustrated in Figure 104a.

The charts are numbered 1 to 5 to correspond with the groundwater conditions defined in the table presented on page 233.

Use of the circular failure charts

In order to use the charts to determine the factor of safety of a particular slope, the steps outlined below and shown in Figure 105 should be followed.

Step 1: Decide upon the groundwater conditions which are believed to exist in the slope and choose the chart which is closest to these conditions, using the table presented on page 233.

Step 2: Calculate the value of the dimensionless ratio

\[ \gamma \tan \theta \]
a. Groundwater flow pattern under steady state drawdown conditions where the phreatic surface coincides with the ground surface at a distance $z$ behind the toe of the slope. The distance $z$ is measured in multiples of the slope height $N$.

b. Groundwater flow pattern in a saturated slope subjected to heavy surface recharge by heavy rain.

Figure 10k: Definition of groundwater flow patterns used in circular failure analysis of soil and waste rock slopes.
Find this value on the outer circular scale of the chart.

Step 3: Follow the radial line from the value found in step 2 to its intersection with the curve which corresponds to the slope angle under consideration.

Step 4: Find the corresponding value of $\tan \phi / F$ or $c/\gamma H F$, depending upon which is more convenient, and calculate the factor of safety.

Consider the following example:

A 50 foot high slope with a face angle of $40^\circ$ is to be excavated in overburden soil with a density $\gamma = 100$ lb/ft$^3$, a cohesive strength of 800 lb/ft$^2$ and a friction angle of $30^\circ$. Find the factor of safety of the slope, assuming that there is a surface water source 200 feet behind the toe of the slope.

The groundwater conditions indicate the use of chart No. 3. The value of $c/\gamma H = 0.28$ and the corresponding value of $\tan \phi / F$, for a $40^\circ$ slope, is 0.32. Hence, the factor of safety of the slope is 1.80.

Because of the speed and simplicity of using these charts, they are ideal for checking the sensitivity of the factor of safety of a slope to a wide range of conditions and the authors suggest that this should be their main use.
<table>
<thead>
<tr>
<th>GROUNDWATER FLOW CONDITIONS</th>
<th>CHART NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td>FULLY DRAINED SLOPE</td>
<td>1</td>
</tr>
<tr>
<td>SURFACE WATER &amp; SLOPE HEIGH</td>
<td>2</td>
</tr>
<tr>
<td>T BEHIND TOE OF SLOPE</td>
<td>3</td>
</tr>
<tr>
<td>SURFACE WATER &amp; SLOPE HEIGH</td>
<td>4</td>
</tr>
<tr>
<td>T BEHIND TOE OF SLOPE</td>
<td>4</td>
</tr>
<tr>
<td>SATURATED SLOPE SUBJECTED</td>
<td>5</td>
</tr>
<tr>
<td>TO HEAVY SURFACE RECHARGE</td>
<td></td>
</tr>
</tbody>
</table>
CIRCULAR FAILURE CHART NUMBER 1
CIRCULAR FAILURE CHART NUMBER 2
CIRCULAR FAILURE CHART NUMBER 4
CIRCULAR FAILURE CHART NUMBER 5

Diagram showing various lines and grids for analysis.
Location of critical failure circle and tension crack

During the production of the circular failure charts, presented on the previous pages, the locations of both the critical failure circle and the critical tension crack for limiting equilibrium \( (F = 1) \) were determined for each slope analysed. These locations are presented, in the form of charts, in Figure 106.

It was found that, once groundwater is present in the slope, the locations of the critical circle and the tension crack are not particularly sensitive to the position of the phreatic surface and hence only one case, that for chart No. 9, has been plotted. It will be noted that the location of the critical circle centre given in Figure 106(b) differs significantly from that for the drained slope plotted in Figure 106(a).

These charts are useful for the construction of drawings of potential slides and also for estimating the friction angle when back-analysing existing circular slides. They also provide a start for a more sophisticated circular failure analysis in which the location of the circular failure surface having the lowest factor of safety is found by iterative methods.

As an example of the application of these charts, consider the case of a slope having a face angle of \( 30^\circ \) in a drained soil with a friction angle of \( 20^\circ \). Figure 106(a) shows that the critical failure circle centre is located at \( X = 0.2H \) and \( Y = 1.85H \) and that the critical tension crack is at a distance \( b = 0.1H \) behind the crest of the slope. These dimensions are shown in Figure 107 below.

![Figure 107: Location of critical failure surface and critical tension crack for a 30° slope in drained soil with a friction angle of 20°.](image-url)
figure 106(a) - Location of critical failure surface and critical tension crack for drained slopes.
Figure 106(b) : Location of critical failure surface and critical tension crack for slopes with groundwater present.
Practical example number 1

China clay pit slope

Lay193 has investigated the stability of a China clay pit slope which was considered to be potentially unstable. The slope profile is illustrated in Figure 108 below and the input data used for the analysis is included in this figure. The material, a heavily kaolinitised granite, was carefully tested by Lay and the friction angle and cohesive strength are considered reliable for this particular slope.

Two piezometers in the slope and a known water source some distance behind the slope enabled Lay to postulate the phreatic surface shown in Figure 108. The chart which corresponds most closely to these groundwater conditions is considered to be chart number 2.

From the information given in Figure 108, the value of the ratio $c/yH$ = 0.0056 and the corresponding value of $\tan \phi'$, from chart number 2, is 0.76. Hence, the factor of safety of the slope is 1.01.

Lay also carried out a number of trial calculations using Janbu's method238 and, for the critical slip circle shown in Figure 108, found a factor of safety of 1.03.

These factors of safety indicated that the stability of the slope was inadequate under the assumed conditions and steps were taken to deal with the problem.

---

**Figure 108**: Slope profile of China clay pit slope considered in example number 1.

Input data for analysis:
- Slope height $H = 252$ ft.
- Slope angle $\phi = 35^\circ$.
- Unit weight $\gamma = 132$ lb/ft$^3$.
- Friction angle $\phi' = 37^\circ$.
- Cohesion $c = 145$ lb/ft$^2$.

---

---
Practical example number 2

Projected open pit slope

An open pit mine plan calls for a slope on one side of the pit to have an angle of 42°. The total height of the slope will be 200 feet when completed and it is required to check whether the slope will be stable. A site visit enables the slope engineer to assess that the slope is in weathered and altered material and that failure, if it occurs, will be of a circular type. Insufficient time is available for groundwater levels to be accurately established or for shear tests to be carried out. The stability analysis is carried out as follows:

For the condition of limiting equilibrium, \( F = 1 \) and \( \tan \theta / F = \tan \phi \). For a range of friction angles, the values of \( \tan \phi \) are used to find the values of \( c/\gamma \tan \phi \), for 42°, by reversing the procedure outlined in Figure 10b. The resulting range of friction angles and cohesive strengths which would be mobilised at failure are plotted in Figure 10g.

The shaded circle included in Figure 10g indicates the range of shear strengths which are considered probable for the material under consideration, based upon the data presented in Figure 10 on page 152. It is clear from this figure that the available shear strength may not be adequate to maintain stability in this slope, particularly when the slope is saturated. Consequently, the slope engineer would have to recommend that, either the slope should be flattened or, that investigations into the groundwater conditions and material properties should be undertaken in order to establish whether the analysis presented in Figure 10g is too pessimistic.

The effect of flattening the slope can be checked very quickly by finding the value of \( c/\gamma \tan \phi \) for a flatter slope, say 30°, in the same way as it was found for the 42° slope. The dashed line in Figure 10g indicates the shear strength which would be mobilised in a dry slope with a face angle of 30°.

![Figure 10g](image-url)
Practical example number 3

Stability of waste dumps

As a result of the catastrophic slide in colliery waste material at Aberfan in Wales on October 22, 1966, attention was focused on the potential danger associated with large dumps of waste material from mining operations. Since 1966, a number of excellent papers and handbooks dealing with waste dump stability and with the disposal of finely ground waste have become available, and the authors do not feel that a detailed discussion on this subject would be justified in this book. The purpose of this example is to illustrate the application of the design charts for circular failure, presented earlier in this chapter, to waste dump stability problems.

McKechnie Thompson and Kolin have shown that the relationship between shear strength and normal stress for colliery waste material is usually non-linear as shown in Figure 110. In view of the discussion on shear strength presented in chapter 5, this finding is not particularly surprising and the authors suspect that most waste materials exhibit this non-linearity to a greater or lesser degree. Consequently, the methods used in this example, although applied specifically to colliery waste, are believed to be equally applicable to most rock waste dumps.

In order to apply the circular failure charts presented earlier in this chapter to the failure of a material which exhibits non-linear failure characteristics, it is necessary to determine a number of instantaneous friction angles and cohesive strengths for different effective normal stress levels. This is done by drawing a series of tangents to the Mohr envelope, each tangent touching the envelope at the normal stress level at which $c$ and $\phi$ are to be found.

In the case of the failure curve for colliery waste, shown in Figure 110, the instantaneous cohesion and the friction angles given by the three tangents are as follows:

<table>
<thead>
<tr>
<th>Tangent number</th>
<th>Cohesion $K_N$/$m^2$</th>
<th>Friction angle $\phi$ degrees</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>30</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
<td>26</td>
</tr>
<tr>
<td>3</td>
<td>40</td>
<td>22</td>
</tr>
</tbody>
</table>

The relationship between slope height and slope angle for the condition of limiting equilibrium, $F = 1$, will be investigated for a dry dump (using chart No.1) and for a dump with some ground-water flow (using chart No.3).

Tangent number 1

Since the cohesion intercept is zero for this tangent, the value of the dimensionless ratio $c_n/H$.Tan$\phi = 0$ and hence, the slope angle at which the face would repose is given by the slope angle corresponding to the value of $Tan$ 30° = 0.78 on the $Tan$/NP axis (noting that $F = 1$). From chart No. 1, this intercept is 30° and for chart No.3 it is approximately 25°.

Note that, for zero cohesion, the dump face angle would be...
Figure 110: Shear strength of typical colliery waste material.

Figure 111: Relationship between slope height and slope angle for a typical colliery waste dump with different water conditions.
Independent of the slope height. It is normally assumed that the angle of repose of a waste dump is independent of the height of the dump and is equal to the angle of friction of the material. Figure III shows that this assumption is only correct for a dry slope of limited height. Any build-up of water pressure within the dump causes a serious reduction in the stable face angle and, once the normal stress across the potential failure surface becomes high enough for the next tangent to become operative, the high initial friction angle no longer applies and the dump face assumes a flatter angle.

Tangent number 2

For \( c = 20 \text{ kN/m}^2 \), \( \gamma = 18 \text{ kN/m}^3 \) and \( \phi = 26^\circ \),

\[
\frac{c}{\gamma H \tan \phi} = \frac{20}{18 \tan 26^\circ} = 2.28
\]

and \( \tan \phi / F = \tan 26^\circ = 0.49 \)

Hence

\[
\begin{array}{ccc}
\text{N meters} & \frac{c}{\gamma H \tan \phi} & \text{Slope angle}^\circ \\
20 & 0.114 & 50 & 39 \\
40 & 0.057 & 39 & 25 \\
60 & 0.038 & 34 & 20 \\
80 & 0.029 & 32 & 18 \\
100 & 0.023 & 31 & 17 \\
\end{array}
\]

Plotting these values on Figure III gives the curves numbered 2 for the drained and the wet dumps.

Tangent number 3

\( c = 60 \text{ kN/m}^2 \), \( \gamma = 18 \text{ kN/m}^3 \) and \( \phi = 22^\circ \), hence

\[
\frac{c}{\gamma H \tan \phi} = \frac{60}{18 \tan 22^\circ} = 5.55 \text{ N}
\]

and \( \tan \phi / F = 0.4 \)

Hence

\[
\begin{array}{ccc}
\text{N meters} & \frac{c}{\gamma H \tan \phi} & \text{Slope angle}^\circ \\
20 & 0.275 & 61 & 56 \\
40 & 0.136 & 63 & 31 \\
60 & 0.092 & 34 & 22 \\
80 & 0.059 & 31 & 18 \\
100 & 0.035 & 30 & 16 \\
\end{array}
\]

The relationships between dump face angle and dump height, for both drained and wet dumps, are given by the envelopes to the curves derived from tangents 1, 2, and 3. These envelopes, shown in Figure III, illustrate the danger in continuing to increase the height of a dump on the assumption that it will remain stable at an angle of repose equal to the friction angle. The dangers associated with poor dump drainage are also evident in this figure.

The reader who attempts this type of analysis for himself, and it is strongly recommended that he should, will find that the slope height versus slope angle relationship is extremely sensitive to the shape of the shear failure curve. This emphasizes the need for reliable in situ shear test methods such as those described by McKenna, Thompson and Rodin,12 and Schultz and Horn,13 to be further developed for application to waste dump problems.
May 12, 1980

Utah Power & Light Company
Mining and Exploration Division
1407 West North Temple
Salt Lake City, UT 84110

ATTENTION: Willie J. Whitney Jr., Project Engineer

Gentlemen:

In accordance with your request, we have investigated the waste dumps associated with the proposed Cottonwood Mine in Cottonwood Canyon west of Orangeville, Utah. The purpose of this investigation was to obtain an indication of the stability of the waste dumps and to provide recommendations for maintaining the stability of these facilities during the interim period before beginning mining operations.

The work has been completed in a manner to accomplish the basic objective, and the results of the investigation are outlined in the following sections of this report. Specifically, the report includes: (1) location and existing conditions throughout the dump area, (2) physical characteristics of the material existing within the waste dumps, (3) stability considerations, (4) conclusions and recommendations.

1. Location and Existing Conditions Throughout the Dump Area

The proposed Cottonwood Mine is located several miles west of Orangeville, Utah, in Section 25 of Township 17 South, Range 6 East, Salt Lake Base and Meridian.

The material within the waste dumps throughout the area consist of materials stripped from the coal seams upslope from the dumps. Three waste dumps exist throughout the area as shown in Figure No. 1. Waste Dump No. 1 is located immediately downslope from the area where the portals for the mine will be located. Waste Dump No. 2 is so-called topsoil stripped from the mine area, and Waste Dump No. 3 was excess material which could not be dumped downhill from the mine portal.

Figure No. 2 and No. 3 show ground surface profiles through Waste Dump No. 1 before and after the dump placement. The slope of the ground relative to the horizontal is shown for both the natural slopes prior to the dump placement and for the dump slope. It will be observed that the maximum height of the dump is 90 feet.
Dump No. 2 is a relatively small dump and consists of topsoil removed from the mine area. Dump No. 3 is approximately the same height as Dump No. 1, except that it is more massive and has a number of large boulders stacked up at the top of the slope.

Based upon our observation of the site, the following comments are made.

A. The slope angle throughout the site prior to any excavation varies from 29 to 39.5 degrees.

B. An examination of the contour map of the area prior to any excavation at the site shows no indication of any slides throughout the general area of the mine. Hence, the existing overburden appears to have been entirely stable throughout this area for a number of years.

C. The existing slope angle of the 3 dumps existing throughout the area is about 36 degrees, which is not too different from some of the natural slopes throughout the site.

D. The precipitation which has occurred in the area during the past winter and spring is substantially greater than the normal precipitation throughout the area. Considerable rain has occurred in this area during the past few weeks.

E. No evidence of any springs or drainage of water from the canyon slope exists in this area.

F. There is no evidence that the fills are saturated at the present time or that they may become saturated. Even though precipitation has been high during the present year, erosion of the slope of dumps has not been appreciable.

G. Tension cracks exist at the top of the slope of Dump No. 1. However, no evidence of any slope movement exists along the face of the dump. No tension cracks were observed in either Dump No. 2 or No. 3, and no slope movement is occurring in these dumps at the present time.

2. Physical Characteristics of the Material Existing Within the Waste Dumps

In order to obtain an indication of the in-place density of the material within the dumps, in-place density tests were performed along the face of each of the 3 dumps. The in-place unit weights obtained along the face of the dumps are presented in Table No. 1, Summary of Test Data. It will be observed that the in-place unit weight of the dump material varied from 98.4 to 124 pounds per cubic foot and that in most instances, the unit weight exceeded 100 pounds per cubic foot.
It will also be noted that the natural moisture content varied from 12.9 to 26.2 percent. Classification tests were also performed on each of the samples obtained along the face of the dumps. The results of these tests are also presented in Table No. 1, Summary of Test Data.

It will be observed from the mechanical analyses that a substantial amount of material in the silt and clay-size range existed in the dump material. The results of the atterberg limits performed on this material indicate that the plasticity characteristics of the material in the silt and clay-size range are medium to low plasticity type soils.

No shear tests were performed on the waste dump material. However, the results of visual observations and laboratory tests indicate that the natural moisture content of the dump material is only a few percentage points above the plastic limit. Under these conditions, it is our opinion that a cohesion of 500 psf and a friction angle of 26 degrees is a reasonable estimate of the drained shear strength of this material.

As indicated above, all tests were performed on materials located along the face of the dump. It is our opinion that the in-place unit weight and the strength characteristics of materials taken in this area are smaller than at other locations throughout the dump material.

3. Stability Considerations

In order to obtain an indication of the stability of the existing waste dumps, a computer stability analysis was performed for Waste Dump No. 1. In performing the stability analysis, Spencer's method, which satisfies both force and moment equilibrium, was used in the analysis. A complete search for the most critical failure surface was performed in the analysis.

In performing the stability analysis, it was assumed that the waste dump material would have an in-place unit weight of 105 pounds per cubic foot and that the dump material would be not be saturated. It is our opinion that this is a reasonable assumption for the following reasons.

A. There are no environmental conditions throughout the area which would suggest seepage from the canyon walls into the dump.

B. If the dumps are properly drained, infiltration from the storms will be insufficient to saturate the dump.

C. The dumps are not saturated at the present time, even though a considerable amount of precipitation has occurred in the area during recent months.

The stability analysis was performed for various combinations of friction angles and cohesions. The various combinations required to provide a factor of safety of 1.5 are tabulated in Table No. 2 below.
TABLE NO. 2
REQUIRED FRICTION ANGLES AND COHESION TO OBTAIN A FACTOR OF SAFETY OF 1.5

<table>
<thead>
<tr>
<th>Cohesion (psf)</th>
<th>Friction Angle (degrees)</th>
<th>Factor of Safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>350</td>
<td>32</td>
<td>1.53</td>
</tr>
<tr>
<td>400</td>
<td>30</td>
<td>1.52</td>
</tr>
<tr>
<td>450</td>
<td>28</td>
<td>1.53</td>
</tr>
<tr>
<td>500</td>
<td>26</td>
<td>1.52</td>
</tr>
<tr>
<td>550</td>
<td>24</td>
<td>1.50</td>
</tr>
</tbody>
</table>

It is apparent from the above data that if the in-place material has a cohesion of 500 psf and a friction angle of 26 degrees, the slope has a factor of safety of 1.5. It may be desirable to perform a few triaxial shear tests on representative samples of the dump material to verify our estimate of the drained shear strength parameters.

4. Conclusions and Recommendations

A. Conclusions

(1) Since no slope failure has occurred in any of the dumps as of this date, the existing factor of safety is greater than 1.0.

(2) Stable natural slopes exist throughout the site which have a slope angle equal to or greater than the slope angle of the dumps. However, the natural slope angle is less than the slope of the dumps in many cases.

(3) The dumps are not saturated at the present time, and it is our opinion that the materials within the dump will not become saturated if appropriate measures are taken to provide satisfactory drainage.

(4) In-place density tests performed on the face of the dumps indicated unit weights varying from about 98 to 104 pounds per cubic foot, with moisture contents varying from about 13 to 26 percent.

(5) The material making up the dumps consists of both granular and cohesive type soils. Cohesive material in excessive of 40 percent exists in much of the dump material.

(6) The plasticity characteristics of the dump material are relatively low and generally classify as a CL-1 type soil according to the Unified Soil Classification System.

(7) The erosion which has occurred along the dump surfaces is relatively small, even though a considerable amount of rain has occurred throughout the area during the last several weeks. The cohesive characteristics of the subsurface materials are responsible for the low rate of erosion occurring on the dump surfaces.
(8) A stability analysis performed for Dump No. 1, using the shear strength parameters obtained from the direct shear tests indicates a factor of safety of at least 1.5 for this dump in its existing condition.

(9) Since the height of the other dumps are no greater than Dump No. 1, it is our conclusion that these two dumps are stable with a factor of safety of at least 1.5 in their existing condition.

B. Recommendations

The stability analysis performed during this investigation assumed that the dumps would not become saturated during the interim period. In view of this consideration, it is imperative that the surface drainage be performed throughout the dump areas in such a manner that no appreciable infiltration will occur in the dumps.

The following recommendations regarding drainage are made.

(1) The surface of Dump No. 1 slopes toward the hillside and downward in a northerly direction. Water falling on the surface of this dump will flow readily off the surface. It is recommended, however, that the dump be graded in such a manner that no ponding will occur in any localized areas throughout the surface. It is also recommended that all large boulders existing on the surface or on the edge of the top of the slope be removed from the area.

(2) Dump No. 2 should be regraded and reshaped to permit a downward slope in all areas throughout the dump.

(3) The boulders which currently exist on the top of Dump No. 3 should be removed prior to any grading operations in this area. The top of this dump is wider than the other two dumps, and more care will be required in the grading operations at this location. Grading should be performed in such a manner that no ponding can occur throughout the top of the slope. A continuous downward slope should be established along the top of the slope to permit water to drain freely from the area.

(4) Excessive precipitation in the future may cause excessive erosion on the dump slopes. In order to reduce the likelihood of erosion along the dump slopes, it is recommended that a berm be constructed about half way down the slopes to intercept drainage water falling on the upper portion of the slope. The berm should be graded with a gentle downward slope to permit intercepted water to flow freely from the dump surface. This action will intercept any erosion channel which tends to develop along the slope surface.

It is our opinion that if the above action is taken, the dumps will remain stable in their existing condition with a satisfactory factor of safety.
Utah Power and Light Company
Page 6
May 12, 1980

If there are any questions relative to the information contained herein, please advise us.

Yours truly,

ROLLINS, BROWN AND GUNNELL, INC.

Ralph L. Rollins
Ralph L. Rollins

Enclosures
SCALE: 1" = 30'

ROLLINS, BROWN & GUNNELL, Inc.
CONSULTING ENGINEERS
AND LIGHT COMPANY
TOWOOD MINE WASTE DUMP STABILITY

Figure No. 2

51+00

--- Original Ground Line
--- Existing Ground Line

36° 29.5° 36° 35°
TONWOOD MINE WASTE DUMP STABILITY

Figure No. 3

- = Original ground line
- - - - = Existing ground line
<table>
<thead>
<tr>
<th>HOLE NO.</th>
<th>DEPTH BELOW GROUND SURFACE</th>
<th>STANDARD PENETRATION BLOWS PER FOOT</th>
<th>IN-PLACE</th>
<th>UNCONFINED COMpressive STRENGTH LB/FT²</th>
<th>FRICTION ANGLE °</th>
<th>CONSISTENCY LIMITS</th>
<th>MECHANICAL ANALYSIS</th>
<th>UNIFIED SOIL CLASSIFICATION SYSTEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>+10′ from road</td>
<td>124.0</td>
<td>15.1</td>
<td>18.8 15.7 3.1 22.7 29.0 48.3</td>
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</tr>
<tr>
<td></td>
<td>+35′ from road</td>
<td>113.0</td>
<td>20.2</td>
<td>26.0 14.9 11.1 8.2 24.4 67.4</td>
<td>CL-1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>+55′ from road</td>
<td>100.4</td>
<td>14.7</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>+6′ from base</td>
<td>109.6</td>
<td>19.8</td>
<td>26.7 18.3 8.4 18.8 29.6 51.6</td>
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<td></td>
</tr>
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<td>25.4 16.7 8.7 7.0 31.4 61.6</td>
<td>CL-1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>+25′ from base</td>
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<td>15.7</td>
<td>21.8 15.3 6.5 17.9 34.4 47.7</td>
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<td></td>
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<td>+5′ from bottom</td>
<td>114.2</td>
<td>27.5</td>
<td>31.5 20.2 11.3 18.0 37.8 44.2</td>
<td>CL-1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>+18′ from bottom</td>
<td>110.6</td>
<td>30.2</td>
<td>28.8 20.3 8.5 5.7 35.4 58.9</td>
<td>CL-1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>+30′ from bottom</td>
<td>108.1</td>
<td>32.1</td>
<td>29.6 21.3 8.3 15.3 34.4 50.3</td>
<td>CL-1</td>
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</tr>
<tr>
<td></td>
<td>+45′ from bottom</td>
<td>89.4</td>
<td>35.0</td>
<td>32.2 22.2 10.0 9.6 37.0 53.4</td>
<td>CL-1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
July 8, 1980

Utah Power and Light Company
Mining and Exploration Division
1407 West North Temple
Salt Lake City, UT 84110

ATTENTION: WILLIE J. WHITNEY, JR.

Gentlemen:

In response to your recent request, we have investigated the waste dumps associated with the proposed Cottonwood Mine in Cottonwood Canyon west of Orangeville, Utah.

The purpose of this investigation was to address two items concerning the fills that were observed by the Division of Oil, Gas and Mining personnel on their visit June 5, 1980. At that time, it was expressed that there was some evidence of a slope failure on waste pile No. 1 across the road from the Trails Mountain Mine's sediment pond.

During our visit, a number of shrinkage cracks were observed along the top of the fill. However, an examination of the slope reveals no evidence of slope failure. At the time of our visit, a great deal of oversize rock material had been worked to the bottom of the slope. It is our opinion that at the present time no problems associated with slope stability of waste pile No. 1 exist.

We have been informed that continued working of the slopes to remove the oversize material is anticipated. It was observed during our visit that some drainage and ponding has occurred either near or over the edge of the slopes of waste pile No. 1. We feel that grading toward the hillside, so that drainage can occur away from the waste pile, would be helpful.
An answer to a second item pointed out by the Division of Oil, Gas and Mining concerning the drainage ditch constructed along the road at the base of the fills is in order. It was felt that during the visit of June 5 the drainage ditch had undercut the toe of the fill and that perhaps this undercut might lead to a problem with slope stability. It was observed during our visit that the maximum cut for the drainage ditch was two feet, and in most cases the slope was not cut by the excavation for the ditch. Again, it is our opinion that there is no need for concern for slope stability due to the construction of this ditch.

If there are any further questions regarding this matter or our original report of May 18, 1980 concerning the slope stability for the Cottonwood Mine portal, please feel free to contact us.

Yours truly,

ROLLINS, BROWN AND GUNNELL, INC.

Ralph L. Rollins

MTC/lgw
September 23, 1980

Utah Power and Light
1407 West North Temple
Salt Lake City, UT 84116

ATTENTION: Bill Whitney

Gentlemen:

In accordance with your request, two triaxial shear tests have been performed on representative samples obtained from the main dump area at the proposed location of the Cottonwood Mine near Castle Dale, Utah. The Mohr Envelope for each of the tests is attached hereto.

Sample No. 2 was obtained approximately 15 feet from the top of the slope, while Sample No. 6 was obtained at a distance of 90 feet from the top of the slope. Each sample was compacted to a dry density of 108 pounds per cubic foot at the natural moisture content. This unit weight corresponds approximately to the in-place dry unit weight of the dump materials obtained during a previous investigation.

It will be observed that the friction angles obtained from the tests are within the bounds of the friction angles estimated in the stability analysis for the dumps. It will also be observed that the cohesion obtained from the tests is substantially greater than the cohesion used in the stability analysis. Since the shear strength parameters defined by the two triaxial shear tests are within the range of our stability analysis, it is our opinion that the slope of the main dump, immediately west of the proposed mine portal, has a factor of safety of at least 1.5 at its existing moisture content.

If the dump area is properly drained, it is not anticipated that a significant change will occur in the moisture content within the dump.

Yours truly,

ROLLINS, BROWN AND GUNNELL, INC.

Ralph L. Rollins

1435 WEST 820 NORTH, P.O. BOX 711, PROVO, UTAH 84601 TELEPHONE 374-5771
Figure 1 - Shear Test Results

Type of Test: Triaxial shear test

Test Pit No.: Sample #2 Depth 15' from top of slope


Sample Density: 108 lbs/ft^3  Sample Size: ____

Project: Cottonwood Mine Dump Stability
Figure 2
SHEAR TEST RESULTS
Type of Test: triaxial shear test
Test Pit No.: Sample #6, Depth 90' from top of slope
Sample Density: 103 ___ lbs/ft^3, Sample Size: ___
Project: COTTONWOOD MINE DUMP STABILITY

\[ c = 2160 \]
\[ \phi = 27.3^\circ \]
values calc. @ 15% strain