THE EFFECT OF CRATER LAKE SNOW SLIDE ON THE PROPOSED BRIDGE WEST OF JACKSON, WYOMING

by

Hsieh W. Shen

Prepared for
The Bridge Division of the
Wyoming State Highway Department

Civil Engineering Department
Engineering Research Center
Colorado State University
Fort Collins, Colorado

March 1967 CER66-67HWS46

THE EFFECT OF CRATER LAKE SNOW SLIDE ON THE PROPOSED BRIDGE WEST OF JACKSON, WYOMING

by

Hsieh W. Shen

Prepared for

The Bridge Division of the

Wyoming State Highway Department

Civil Engineering Department
Engineering Research Center
Colorado State University
Fort Collins, Colorado.

March 1967

CER66-67HWS46

TABLE OF CONTENTS

Table of Contents - continued

Chapter I

INTRODUCTION

A. Studies - Authorization - and Report

On January 10, 1967, Hsieh W. Shen, Associate Professor of the Colorado State University was authorized by the Bridge Section of the Wyoming State Highway Department, to lead a preliminary investigation on "The Effect of the Crater Lake Snow Slide on the Proposed Bridge at Station 391 + 49.00". A copy of this authorization signed by Mr. R. G. Stapp, Superintendent and Chief Engineer, is enclosed as Exhibit A in Appendix I of this report.

This report presents the results of our investigation. All figures and sample computations are presented as exhibits in Appendices I and II of this report.

B. General Description of Area Studied

The Wyoming State Highway Department is considering building an arch bridge over the Crater Lake Snow Slide Path at Station 391 + 49.00, near Wilson, Wyoming. The approximate location of this bridge site is indicated on Exhibit B. Crater Lake snow slide obtains its snow supply from the southeast face of Mount Glory. The peak of Mount Glory is at an elevation of 10,095 feet, and the proposed bridge is to span over a ground elevation of 7,895 feet. A photograph and contour maps of this slide area are given as Exhibits C, D and E, respectively. The proposed bridge deck is at an elevation of 8010 feet and the span of the bridge is 400 feet between the centerlines of the two skew-backs as indicated by Exhibit F . Exhibits A, B, C, D, E and F were furnished by the Bridge Division of the Wyoming State Highway Department.

Chapter II

REVIEW OF LITERATURE

The physics and mechanics of snow as a material have been investigated rather extensively. The U. S. Army Cold Region Research and Engineering Laboratory has summarized these findings in June 1962 (1). Several international conferences on the physics of snow and ice have been held, with the most recent one being at Hokkaido University, Sapporo, Japan in the summer of 1966 (2).

The dynamics of a snow avalanche are very poorly understood due to the lack of reliable data. Avalanches usually occur during or near the end of a snow storm. A. Judson (3) found that large slides usually occurred when the water content in the snow accumulation is less than one inch.

The most comprehensive study on the destructive force of avalanches is given by A. Voellmy (4). Bruno Salm (5), A. V. Briukhanov (6), and M. Shoda (7) also presented their respective dynamic models.

A general description of a snow avalanche is given by the U. S. Department of Agriculture as Agriculture Handbook No. 194 (8), January 1961.

The following is a brief summary of previous pertinent findings:

	Items	Remarks	Reference
1.	Slope angle:	Avalanche occurred on slopes between 25^0 - 60^0. Common danger zone 30^0 - 40^0.	(7), (4)
2.	Slope orientation:	a) South exposure - less avalanche b) Windward slope - less avalanche	(7), (4)
3.	Density of snow:	Fresh deposited (.03 - 0.1) x density of water. Usually .06 - .07 in this area.	(7), (4)
		Powder avalanche (very close to ground) $\simeq$ 0.15 x density of water.	(4)
4.	Maximum velocity of avalanche:	$\simeq$ 360 ft/sec	(4)
5.	Impact force of snow jet:	a) Direction: Usually upward b) Magnitude: Seldom above 1,000 lb/ft^2 near the ground	(4) (4)
6.	Vertical location of maximum pressure in ground avalanche:	Maximum occurs at two meters above the ground and zero pressure at three meters above the ground.	(7)

Chapter III

DATA

Climatological data are given in the following publications:

a. "Precipitation Probabilities in Wyoming," by Agricultural Experiment Station, University of Wyoming, Laramie.

b. "Temperature Probabilities in Wyoming," by Agricultural Experiment Station, University of Wyoming, Laramie.

c. "Summary of Snow Survey Measurements, Wyoming 1919-1963," by George W. Perk and others, U. S. Department of Agriculture, Soil Conservation Service.

d. "Water Supply Outlook and Federal-State-Private Cooperative Snow Surveys for Wyoming," by U. S. Department of Agriculture, Soil Conservation Service and State Engineer of Wyoming.

Unfortunately, no snow precipitation record near Mt. Glory is available. Snow accumulation records at Teton Pass (Gage 10F13) and Togwottee Pass (Gage 10F-9 at elevation 9,600 feet) are given in item c as listed above. About 30 years record is available at Togwottee Pass gage, and only 21 years of record is available at Teton Pass gage.

Snow accumulations are measured once at the end of each month. The largest recorded snow accumulation at Teton Pass gage and Togwottee Pass gage were 130 inches and 116 inches, respectively. These gages were installed in the forest and snow depths greater than these records may have occurred on Mt. Glory.

Private informal consultations were made with Mr. George Peak of the U. S. Department of Agriculture, Casper, Wyoming; Mr. Mel Long of the U. S. Forest Service, Jackson Wyoming; Dr. M. Martinelli, Jr. and

Mr. Arthur Judson of the U. S. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado and Mr. Malcolm Mellor of the U. S. Army Cold Regions Research and Engineering Laboratory (CRREL). The confidence of finding a 50-year frequency flood from even a good existing record of 200 years is not really high. To determine a 50-year frequency snow avalanche from practically no existing record is about impossible. However, as will be shown from our analysis, the velocity of an avalanche is actually not sensitive to these data.

Chapter IV

BASIC CONSIDERATIONS

Avalanche motion can be divided into two broad catagories: 1) flowing, sliding or tumbling motion along the ground, 2) turbulent motion through the air (powder avalanche).

A. Voellmy (4) found that "the disintegration of the snow and its turbulent movement must, in all cases, begin after exceeding a flow velocity of about 30 ft/sec." Since the proposed bridge is at more than 100 feet above the ground elevation, ground avalanches will pass under the bridge without causing damage to the bridge, and thus only a powder avalanche will be considered.

After reviewing the movie "Avalanche Control," narrated by L. Thomas and made by the U. S. Forest Service, and consulting with several snow specialists, (M. Martinelli, Jr., A. Judson, M. Mellor and A. Roch) the following dynamic model, as shown in Figure 1, is formed to investigate a powder avalanche.

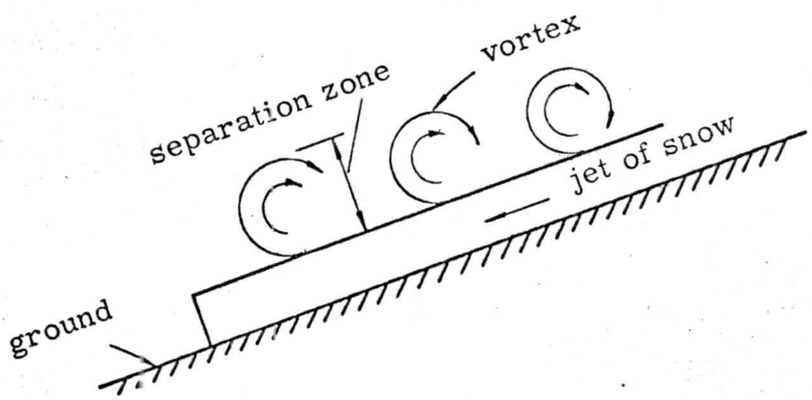


Figure 1. Dynamic Model of Powder Avalanche.

A photograph copy of a model study of this vortex development is included as Exhibit G of Appendix I.

As a jet stream of snow comes down from the upslope, a large shear stress is exerted on the stagnant air at the front of the flowing snow. This creates vortices which migrate slowly (relative to the snow jet underneath) downslope. But the vortex front, which is formed by a newly created vortex, moves rapidly with the jet stream of snow.

The commonly reported velocity of a powder avalanche is determined by timing the traveling distance of the vortex front, and thus is actually equal to the velocity of the snow jet stream.

This snow jet stream, moving at an extremely high velocity (up to 120 m/sec, reported by A. Voellmy (4)), has a great momentum and can be very destructive. A. Voellmy (4) stated that "the pressure effect in the thrust direction of the avalanche seldom exceeded five tons/m^2 (5 x 2, 200/10 = 1, 100 lb/ft^2) on the surface of the object struck..." Andre Roch has measured 20, 000 lb/ft^2 of pressure force when the velocity of an avalanche is 300 ft/sec. Using $p = \frac{1}{2}\rho v^2$, γ, the density of a flowing avalanche is found to be 9.3 lb/ft^3 which is a rather reasonable estimation. However, the destructive force of the vortex which consists of a snow and air mixture can be much less. Unfortunately, there is no known analysis on the variation of force with respect to distance from the ground in a powder avalanche.

M. Shoda (7) found, by actual measurement in a ground avalanche, that the maximum destructive force was at six feet from the ground, and almost no force existed at a distance of 10 feet from the ground.

A method will be suggested in Chapter V to estimate the lift and drag forces acting on the proposed bridge.

Chapter V

CALCULATIONS AND ASSUMPTIONS

Basic assumptions and principles of calculations are discussed in this chapter. Actual sample numerical calculations are presented in Appendix II of this report.

A. Volume of Snow Contained in A Single Avalanche

From past experience (8), the majority of large snow powder avalanches occurred during or at the end of the snow storms. After consulting with several snow specialists in this area, the authors chose as a design avalanche the following condition: A 36-inch snow storm falling uniformly in the entire snow basin and this entire amount of snow plus 36 inches of previously deposited snow starting to slide at the same instant to form the design avalanche. It is difficult to estimate the frequency of occurrence of this design condition. However, with proper operational procedure as recommended by this report in Chapter VII, the occurrence of this condition can be reduced. The snow, which had been deposited on the ground before this storm, could be dragged down by this avalanche which consists mainly of freshly deposited snow. If the operational procedure as recommended by this report is followed, the total maximum flowing snow depth cannot be greater than 72 inches (including 36 inches of previously deposited snow). This would be the same as having 60 inches of fresh deposited snow and 12 inches of previously deposited snow or any other combination.

The dashed and dotted lines, as indicated on Exhibits D and E, give the boundary of the snow basin. Since the snow-fracture line normally occurs at more than 100 feet from the peak, we have used the enclosed-dashed line B, as shown in Exhibits D and E, as our boundary of snow supply for this design avalanche.

B. Depth of Flowing Snow

The density of freshly deposited snow is about 0.07 x density of water, and the density of flowing snow is about 12% to 15% of the density of water. In order to be on the safe side, we have assumed the density of snow in the flow depth ot be 12% density of water. With this assumption and the other assumptions made in item A, the depth of the snow-jet stream is found to be less than 40 feet which is much less than the unobstructed distance of the proposed bridge above the ground. The proposed bridge will not be hit by the snow-jet stream. Note that as the snow is coming down the slope, the snow-jet stream depth should decrease slightly due to the loss of snow powder to the vortices.

C. Velocity of Snow Avalanche at the Proposed Bridge Site

The following two methods are used to estimate the velocity of a snow avalanche:

1) The first method is to find the terminal velocity (or equilibrium velocity) of flow in a hydraulically smooth boundary with a slope of 32^0. The first equation is:

$$V^2 = \frac{8}{f} gR \sin\theta \tag{1}$$

where V = average velocity of flow

f = friction factor

R = hydraulic radius

θ = inclination of bottom slope = energy slope for established uniform flow.

The second equation is:

$$f = \frac{0.316}{(N_R)^{\frac{1}{4}}} \qquad (2)$$

in a hydraulically smooth boundary where N_R is the Reynolds number $= \frac{4RV}{\nu}$ and ν is the kinematic viscosity of flowing snow. According to A. Voellmy (4), $\nu = 4.4 \times 10^{-2}$ ft²/sec. The terminal velocity of snow is found to be 420 feet per second for our design condition. The difficulty of this approach is to find the elevation at which the flow reaches its equilibrium condition. In other words, if the flow of snow reaches its equilibrium condition below the proposed bridge site, the velocity of the snow jet would be less than this magnitude of 420 feet per second.

2) The second approach is to estimate the amount of kinetic energy available at the bridge site. The kinetic energy available at the bridge site (Section 2) is equal to the drop of potential energy from the beginning of the snow avalanche (Section 1) to the bridge site, minus the head loss between Section 1 and Section 2. By assuming an average drop of 1, 355 feet, the velocity is found to be 260 feet per second. Since this value is less than 420 feet per second, as calculated in the

first method, we concluded that the equilibrium velocity would occur below the bridge site and 260 feet per second should be used as our design value. Note that the second approach is independent of flow depth, and thus 260 feet per second should be used as design velocity for snow depth greater than 40 feet, or a snow cover which starts to move, greater than 72 inches.

This is rather significant because the velocity of the avalanche is, at the proposed bridge site, independent of depth of snow in the basin.

The actual velocity cannot be greater than this value of 260 feet per second because the assumption of a hydraulically smooth boundary is used.

D. Maximum Velocity and Size of Vortex in the Separation Zone

According to the measurement made by J. Ostrowski, Senior Lecturer, Technical University of Warsaw, Poland, (private communication) the maximum velocity in the separation zone can be greater than the velocity of the snow avalanche; and the size of vortex or the thickness of separation zone cannot be greater than $2h$ where h, as defined in Exhibit G, is the depth of flowing snow (not the powder). h is found to be 40 feet for our design condition of 72 inches of total snow.

E. Maximum Estimated Velocities at the Bridge Deck Level

From private communication with J. Ostrowski who has contributed much research in the boundary layer separation problem, the maximum vertical and horizontal velocities at 1.8 h distance from the ground are less than 35% and 20%, respectively, of the velocity of the avalanche at ground level.

In other words, the expected maximum vertical velocity at the bridge level should be about $\frac{35}{100}$ x 260 ft/sec = 93 ft/sec and the expected maximum horizontal velocity at that level should be about $\frac{20}{100}$ x 260 ft/sec = 52 ft/sec.

F. Maximum Estimated Pressure Forces at the Bridge Deck Level

According to the recommendation made by the American Society of Civil Engineers (9), the drag coefficient is found to be 1.5 for our case. After consultation with Mr. Mellor of the U. S. Army, Mr. Martinelli of the U. S. Forest Service, and Mr. A. Roch and Mr. H. Frutiger of the Swiss Federal Institute for Snow and Avalanche Research, the density of snow-air mixture at the bridge level is assumed to be not greater than 0.5% of water. The estimated maximum uplift that can be expected at the bridge for the design condition is estimated to be $C_D \, \rho A \frac{V^2}{2} = 1.5 \times 0.5\% \times 1.94 \times \frac{93.2}{2}$ A or 63 pounds per square foot. The maximum side thrust is estimated to be 21 pounds per square foot.

G. Estimated Pressure Force at the Bridge Deck Level for Flowing Snow Greater than Selected Design Condition

The pressure force is extremely sensitive to h, the depth of flowing snow, for h greater than 50 feet. For instance, if the depth of flowing snow is 60 feet, the maximum velocity at the bridge deck can be as high as 260 ft/sec.

H. Effect of Natural Wind Storms on Snow Avalanche

If the wind direction is opposite to the direction of the snow avalanche, the snow avalanche probably will not occur, and even if it occurs, the two forces would partly compensate each other. If the wind direction is the same as the direction of the snow avalanche, a powder avalanche will not occur because the relative velocity between the wind and the snow avalanche is small. In either case, wind will not add additional force to the proposed bridge.

I. Change of Ground Slope

As shown in Exhibits E and H, the ground slope changes two or three times upslope from the bridge. This would have dissipated much more energy than in our analysis which assumed a uniform ground slope. Since the last cliff is 1,000 feet upslope from the proposed bridge section, our analysis indicated that the snow jet stream would have fallen to the ground before reaching the proposed bridge section.

Chapter VI

REFERENCES

(1) Bader, H., Kuroiwa, D. "The Physics and Mechanics of Snow as a Material." U. S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, July 1962.

(2) Abstracts of the International Conference on Low Temperature Science, The Institute of Low Temperature Science, Hokkaido University, Sappora, Japan, 1966.

(3) Judson, A. "Snow Cover and Avalanches in the High Alpine Zone of Western United States," Proceeding of the International Conference on Low Temperature Science, Hokkaido University, Sappora, Japan, 1966 (in press).

(4) Voellmy, A. "On the Destructive Force of Avalanches," U. S. Department of Agriculture, Forest Service.

(5) Salm, B. "Contribution to Avalanche Dynamics," Federal Institute for Snow and Avalanche Research, Davos, Switzerland.

(6) Briukhanov, A. V. et al, "On Some New Approaches to the Dynamics of Snow Avalanches," Institute of Mechanics, Moscow State University.

(7) Shoda, M. 'An Experimental Study on Dynamics of Avalanching Snow," Snow Research Station, Railway Technical Research Institute, Japanese National Railways, January 1965.

(8) Agriculture Handbook No. 194, U. S. Department of Agriculture, January 1961.

(9) American Society of Civil Engineers, "Wind Forces on Structures," Paper No. 3269, Transactions Vol. 126, Part II, 1961.

Chapter VII

RECOMMENDATIONS

A. Design Requirements

1. We recommend that this bridge be designed for an upward vertical load of 80 pounds per square foot and for a horizontal load of 30 pounds per square foot. Although we have made conservative assumptions to the best of our knowledge, we do not feel that this load can be reduced because there are many unknown factors involved.

2. We recommend that someone shoot down the snow this year and measure the variation of pressure force at different elevations at the bridge section.

3. We recommend that the ground slope at 1,000 feet upslope from the bridge be smoothed out. This location is indicated by an asterisk (*) on Exhibit H, Appendix I.

4. We recommend that an automatic pressure measuring device be installed at the bottom of the bridge to measure the uplift due to different slides.

B. Operational Procedure

We recommend that the operation procedure, as stated in Exhibit J, be strictly observed. This procedure may be relaxed only after several years of operation experience.

Although we have used conservative assusptions, the magnitude of the forces acting on the bridge can be much greater if a snow depth of more than 50 feet should flow under the bridge as discussed in Section G of Chapter V.

APPENDIX I

EXHIBIT A

WYOMING STATE HIGHWAY COMMISSION

P. O. BOX 931 • CHEYENNE, WYOMING

RECEIVED
JAN 1 2 67

January 10, 1967

PHYSICAL RESEARCH
General

Mr. James R. Grace
Contracts and Grants Administrator
Colorado State University
Fort Collins, Colorado 80521

Dear Mr. Grace:

In your correspondence of December 2, 1966 you forwarded three preliminary proposals on research. A brief explanation of the status of those proposals will now be made.

The proposal by Dr. Shen on "The Effect of the Crater Lake Snow Slide on the Proposed Bridge at Station 391+49.00" has been accepted as a preliminary engineering investigation by the Bridge Section of the Wyoming State Highway Department.

The proposal by Dr. Barnes on "Super Critical Flow in Manhole Junction Boxes" has been reviewed by the Wyoming State Highway Department Research Board. The Board felt that there would not be significant use of this data in Wyoming to justify the expenditures. The proposal was therefore rejected.

The proposal by Dr. Cermak on "Wind Forces on Highway Sign Structure" has also been reviewed by the Department's Research Board. The Board decided, after reviewing the proposal, to postpone a decision until it could be determined what, if any, research has already been done on the subject. The matter is to be discussed with the appropriate Wyoming State Highway Department personnel in order that a final decision may be forthcoming at the February Research Board meeting.

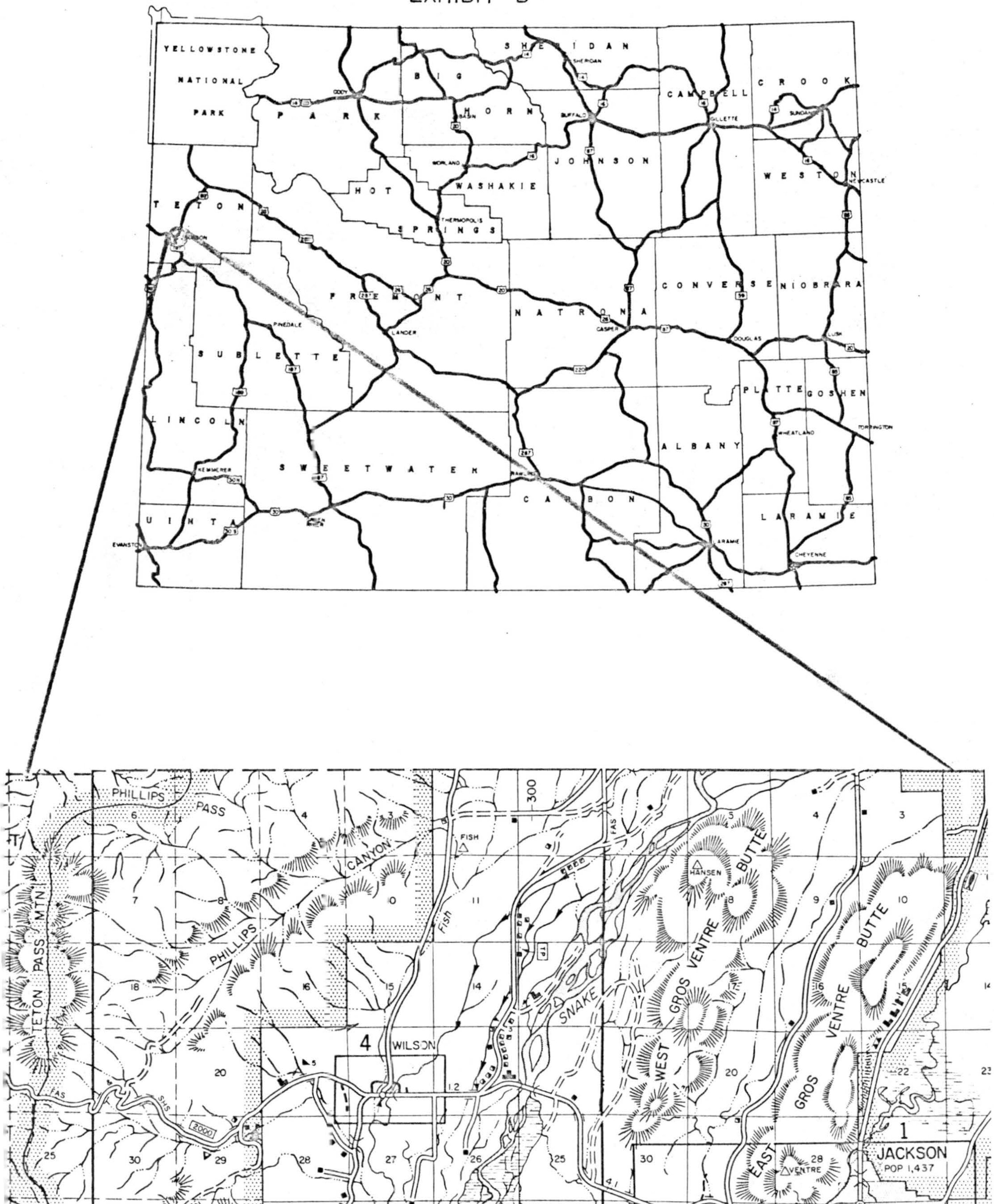
If any additional information is needed concerning the three proposals please feel free to contact our Planning and Research Division.

Very truly yours,

R. G. Stapp
Superintendent and Chief Engineer

cc: Joseph J. Evans, State Design Engineer
Mainard A. Wacker, Hydraulics Engineer

EXHIBIT B



YELLOWSTONE NATIONAL PARK
SHERIDAN
BIG HORN
CAMPBELL
CROOK
PARK
JOHNSON
WESTON
HOT SPRINGS
WASHAKIE
TETON
FREMONT
NATRONA
CONVERSE
NIOBRARA
SUBLETTE
LINCOLN
SWEETWATER
CARBON
ALBANY
PLATTE
GOSHEN
LARAMIE
UINTA
CODY
SHERIDAN
BUFFALO
GILLETTE
SUNDANCE
NEWCASTLE
WORLAND
THERMOPOLIS
LANDER
PINEDALE
CASPER
DOUGLAS
LUSK
WHEATLAND
TORRINGTON
KEMMERER
RAWLINS
EVANSTON
CHEYENNE
PHILLIPS PASS
PHILLIPS CANYON
TETON PASS MTN
FISH
Fish
SNAKE
HANSEN
BUTTE
WEST GROS VENTRE BUTTE
EAST GROS VENTRE BUTTE
4
WILSON
1
JACKSON
POP 1,437
VENTRE
BOYLES HILL
BLACK CAN
PARALLEL
NORTH
PASS
300
2000
FAS
SHS

EXHIBIT C

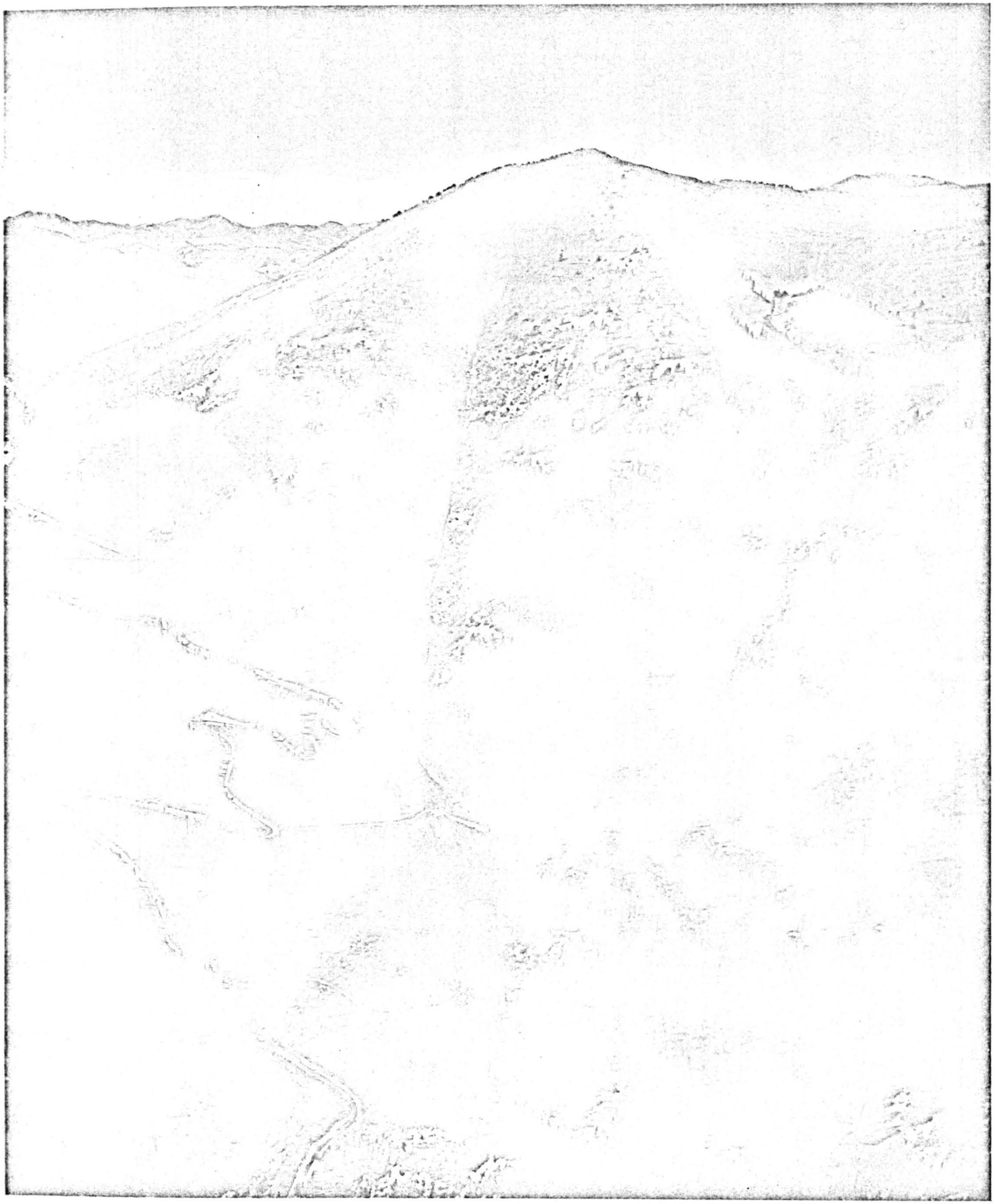
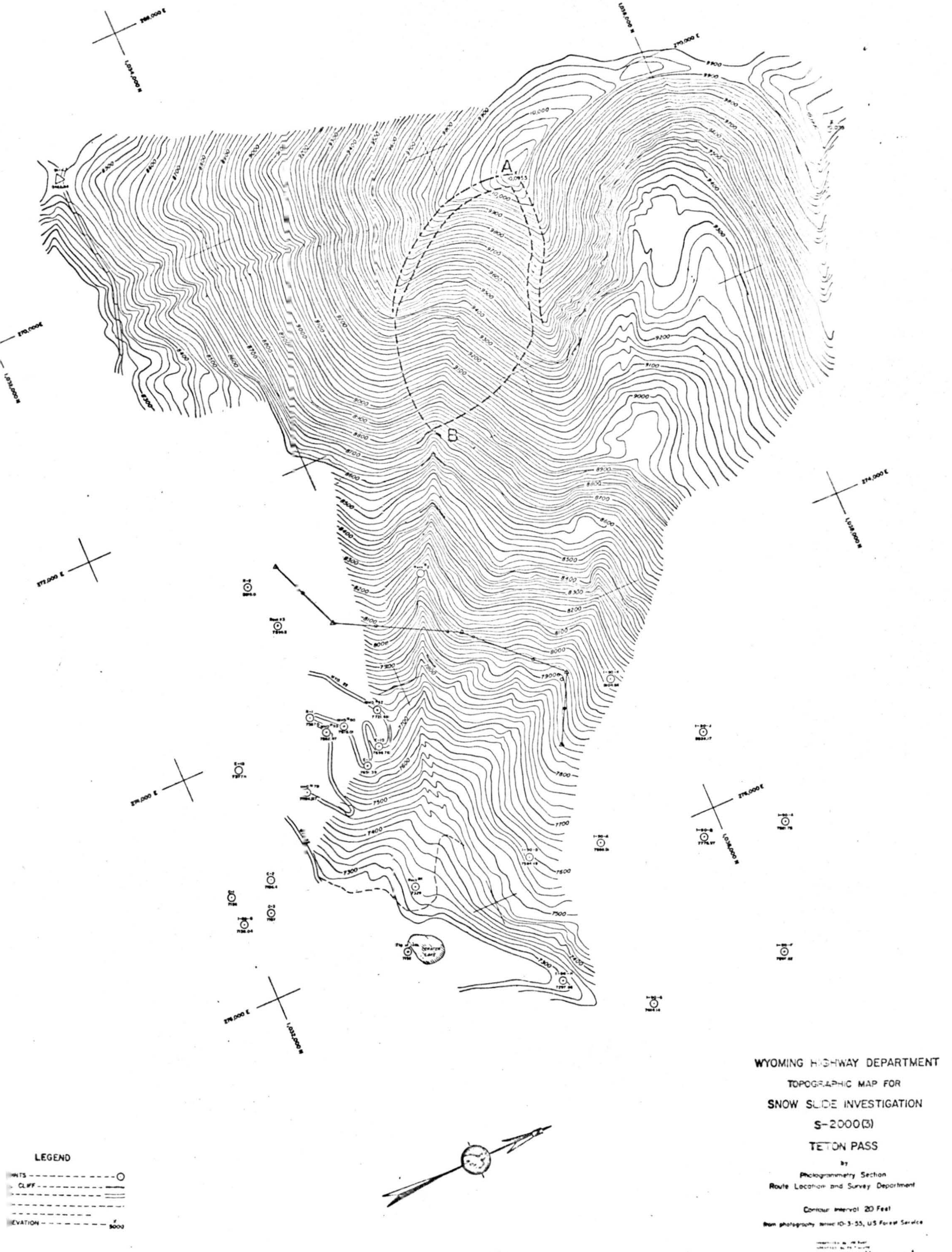
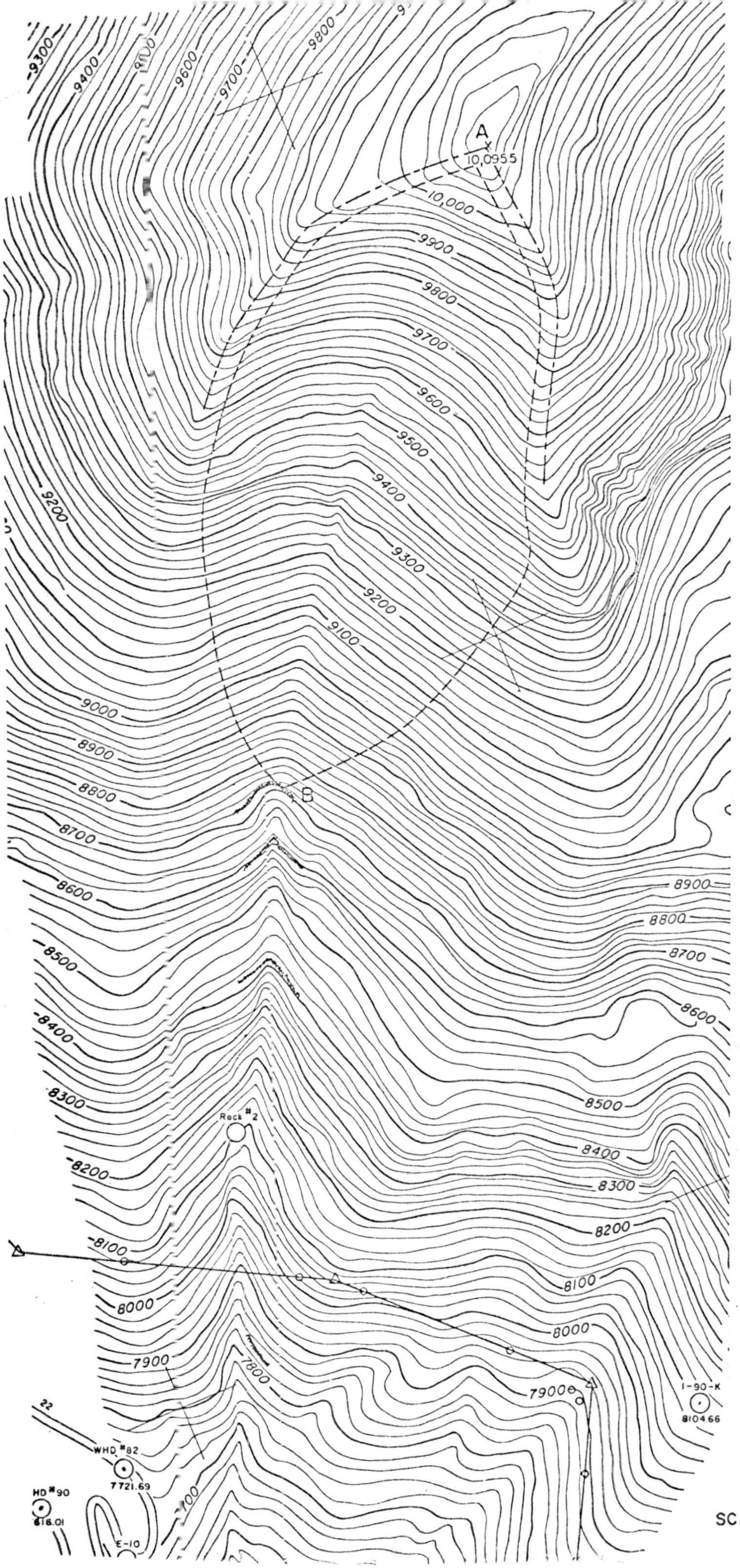


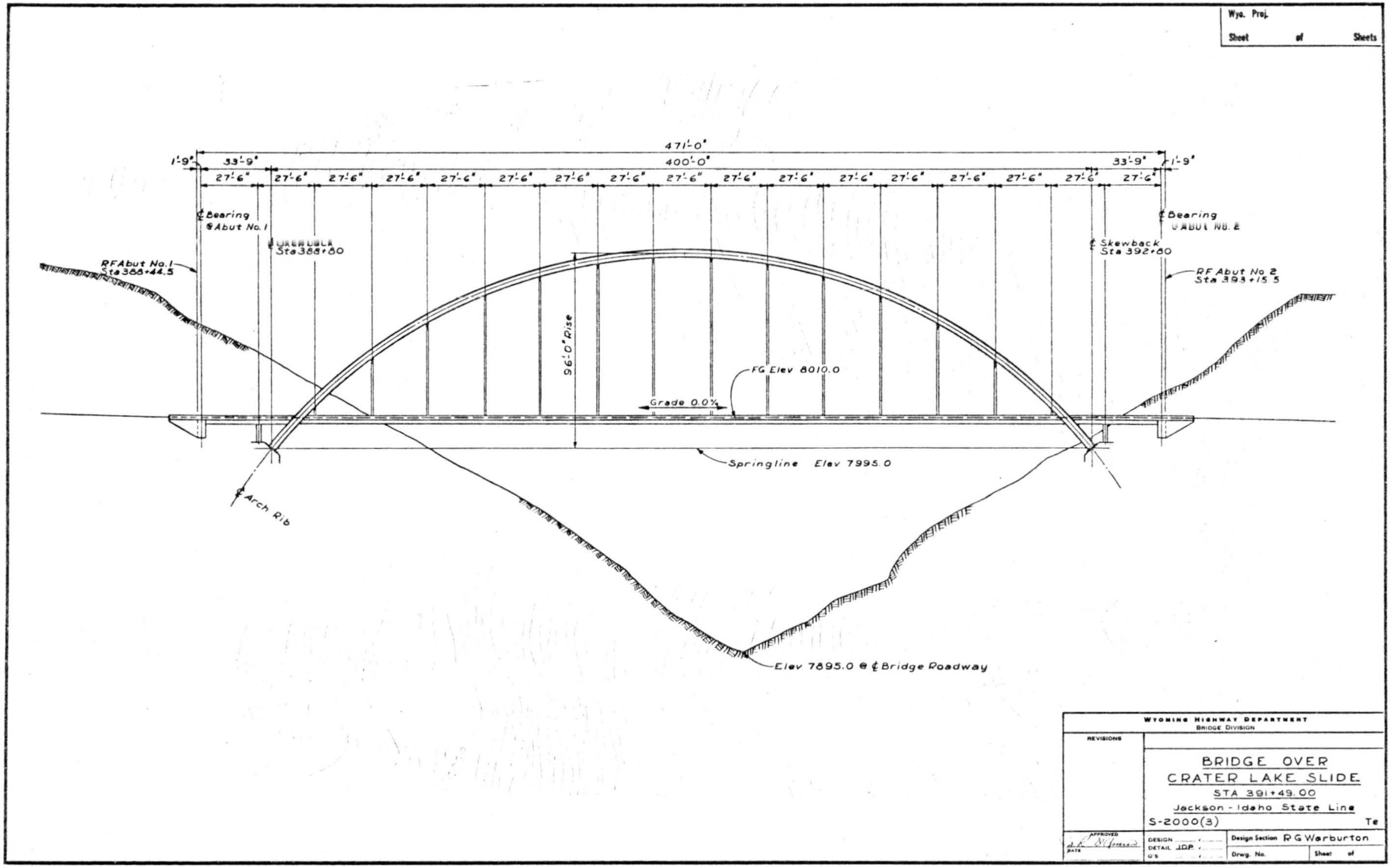
EXHIBIT D
TOPOGRAPHIC MAP




A
10,095.5
B
Rock #2
WHD #82
7721.69
HD #90
816.01
E-10
I-90-K
8104.66
22
10,000
9900
9800
9700
9600
9500
9400
9300
9200
9100
9000
8900
8800
8700
8600
8500
8400
8300
8200
8100
8000
7900
7800

SCALE 1" = 500'

EXHIBIT F



Wyo. Proj.
Sheet of Sheets
471'-0"
400'-0"
1'-9"
33'-9"
27'-6"
℄ Bearing @ Abut No. 1
Sta 388+80
RF Abut No. 1 Sta 388+44.5
℄ Bearing
℄ Skewback Sta 392+80
RF Abut No 2 Sta 393+15.5
96'-0" Rise
FG Elev 8010.0
Grade 0.0%
Springline Elev 7995.0
℄ Arch Rib
Elev 7895.0 @ ℄ Bridge Roadway
WYOMING HIGHWAY DEPARTMENT
BRIDGE DIVISION
REVISIONS
BRIDGE OVER
CRATER LAKE SLIDE
STA 391+49.00
Jackson - Idaho State Line
S-2000(3)
Te
APPROVED
DATE
DESIGN
DETAIL JDP
Design Section R G Warburton
Drwg. No.
Sheet of

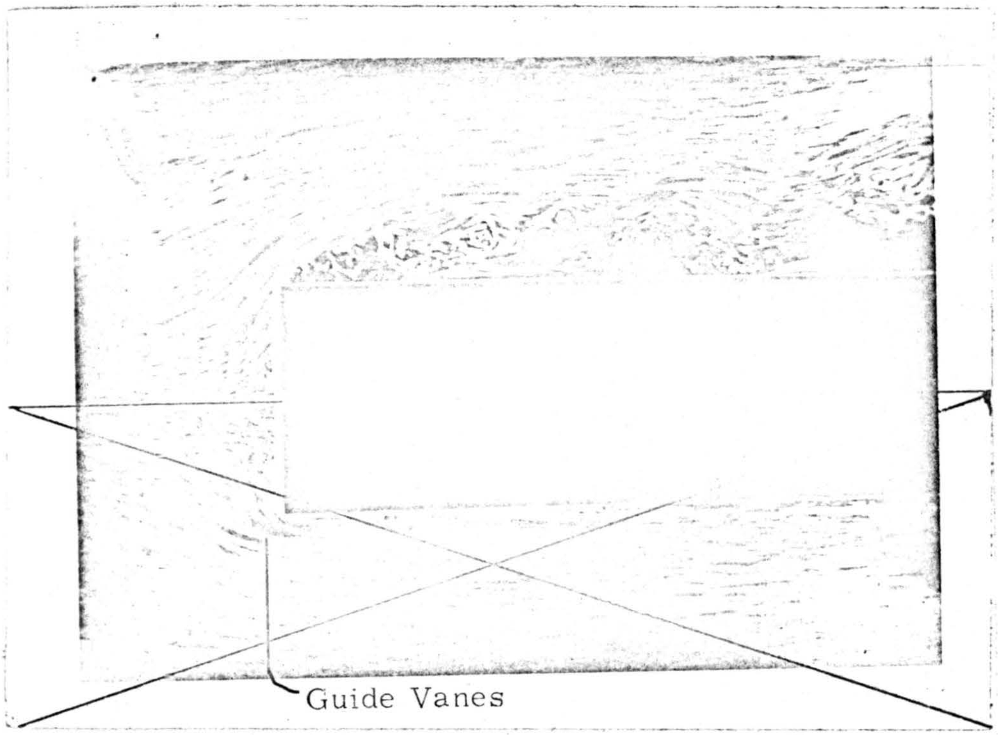


EXHIBIT G - Dynamic Model of Powder Avalanche.
(top half of the photograph)

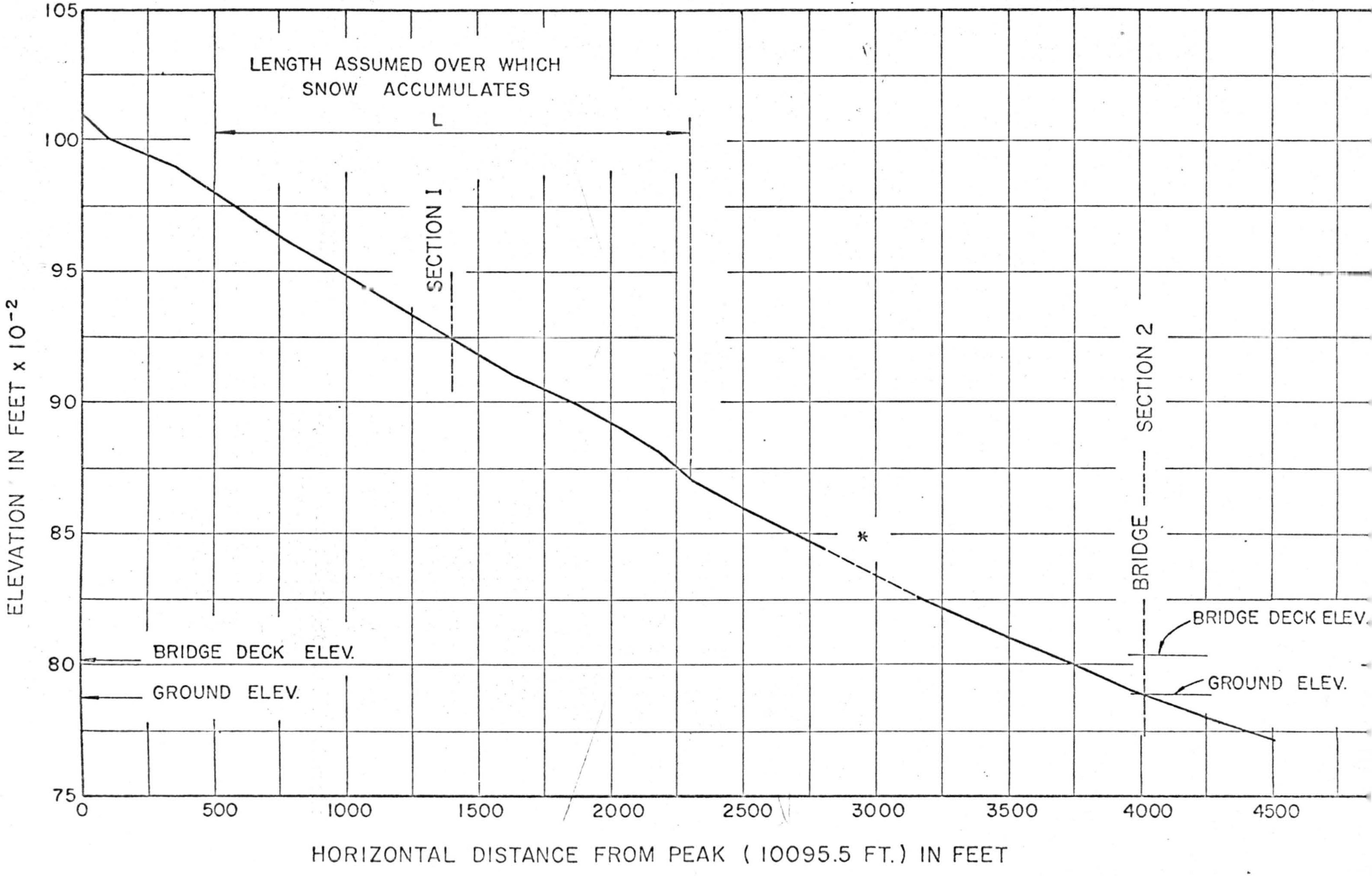

LENGTH ASSUMED OVER WHICH SNOW ACCUMULATES
L
SECTION I
SECTION 2
BRIDGE
*
BRIDGE DECK ELEV.
GROUND ELEV.
BRIDGE DECK ELEV.
GROUND ELEV.
ELEVATION IN FEET x 10^{-2}
105
100
95
90
85
80
75
0
500
1000
1500
2000
2500
3000
3500
4000
4500
HORIZONTAL DISTANCE FROM PEAK (10095.5 FT.) IN FEET

EXHIBIT I

CONSIDERATIONS ON THE DANGER OF AVALANCHES ON THE PROJECTED BRIDGE ON TETON PASS NEAR WILSON, WYOMING

After extended discussion with H.S. Shen, J. Guessler, and M. Martinelli, the impression is that their work is extremely competent. The calculation of the possible force of avalanches on the bridge requires several assumption which were discussed and seem reasonable.

However, experience of the measurements we tried to make of the force of avalanches in Switzerland has shown that avalanches developed always more force than expected.

For this reason, I would recommend to do everything possible in order to avoid the destruction of the bridge.

1. Shape of the Bridge

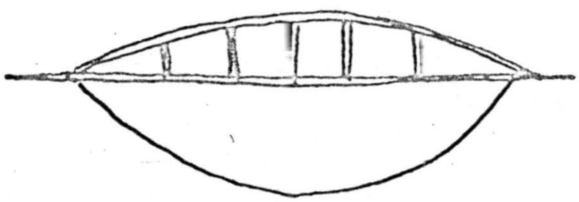
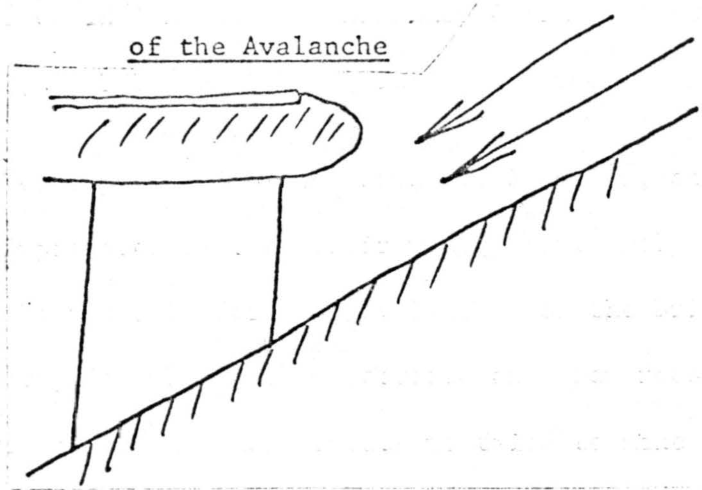


Fig. 1a Fig. 1b

As planned (Fig. 1a), the bridge presents a large area to the wind pressure of the avalanche in the middle of the main stream. I would suggest a shape like on the figure 1b.

2. Profile of the Bridge Structure Against the Flow of the Avalanche



The profile of the bridge against the flow of the avalanching snow should be as aerodynamic as possible in order to give the smallest possible resistance.

3. The Cross Profile of the Gully Under the Bridge

From a certain distance above the bridge ~ 150 feet to a little way downstream ~ 50 feet, the cross section of the canyon should be smoothed and rounded in order that nothing would break the speed of the avalanche and cause more turbulence which could throw the current against the bridge (Fig. 2).

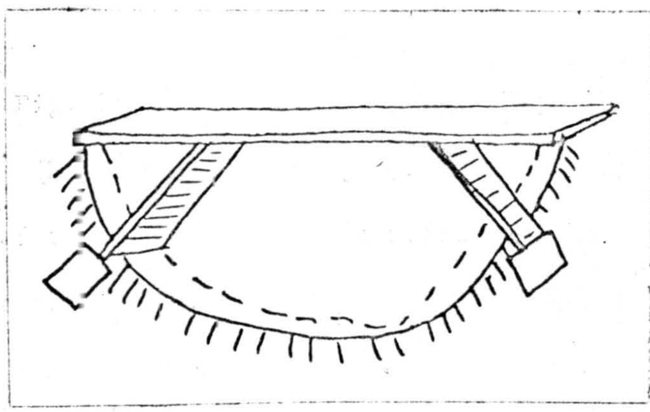


Fig. 2

4. Shooting to Release the Avalanche

Even if the bridge is not destroyed by an avalanche, there is a danger that a car passing over the bridge at the moment of the avalanche could be thrown in the canyon by the air pressure.

In order to avoid this possibility, it is advisable to shoot with a cannon on the slope where the avalanche usually starts. The shooting should take place after every important storm.

During the shooting the traffic should be stopped.

If the shooting is successful, the avalanche has come down and the danger is over for the moment.

If the avalanche does not start, it means that it is not ready and may come on the next shooting.

The crew will rapidly gain valuable experience on the efficiency of the shooting in relation to snow conditions.

It is advisable to shoot at the same time at the twin avalanches which start near the top of the glory.

5. Remarks

Avalanches may slide under the bridge once a year or more often and not cause any damages. These are not the ones which endanger the bridge. The dangerous ones are the important avalanches which are released after one or two weeks of storm and move as a powder snow avalanche. This may happen every 10 or 20 years.

Andre' Roch
8 March 1967

EXHIBIT J

FORM 6200-8 (1/64)
UNITED STATES GOVERNMENT

Memorandum

Department of Agriculture---Forest Service

Rocky Mountain Forest and Range Experiment Station
Room 221, Forestry Building
Fort Collins, Colorado 80521

TO : Dr. H. W. Shen, Room 200, Engineering Research Center, Foothills Campus

File No. 4300

FROM : M. Martinelli, Jr., Project Leader

Date: March 14, 1967

SUBJECT: Avalanche Control--Glory Avalanche, Jackson, Wyoming

Your reference:

The enclosed report is by Andre Roch. It summarizes briefly a few of the points concerning the bridge over the Glory Avalanche that he discussed with you and the Wyoming Highway Department representatives.

You also ask for some suggestions concerning shooting at this site to reduce the danger of a large avalanche. The most important points can be summarized as follows:

1. Artillery control is intended to reduce the chances of a major buildup that could lead to a large, fast-moving powder avalanche. It should be pointed out that such control does not guarantee safety for the bridge. It is possible under extreme conditions that an artificially released avalanche could damage or even destroy the bridge. Should this happen, the only consolation would be the fact that traffic would be stopped during the shooting and the chance of catching automobiles on the bridge would be eliminated.

2. Once there is enough snow on the ground to smooth the surface roughness (approximately 30 inches at the bridge site or no more than 40 inches at the Pass) the avalanche should be shot after every major storm. Until more data is available, a major storm can be considered 12 inches of new snow without appreciable wind, or 6 inches of snow accompanied by 10 hours or more of winds 40 miles per hour or greater. Snow depths are measured at or near the bridge site but the winds should reflect conditions on the ridge crest.

3. It is important to shoot promptly after the first major storm of the winter. Moving the snow out at this time will reduce the amount of depth hoar at the bottom of the snow pack and increase stability for the rest of the winter.

4. During prolonged storms--2 or more days--the area should be shot after every 12 inches of new snow measured at the bridge.

5. Shooting should be done early in the morning following the storm to avoid exposure to the sun which would help stabilize the snow and reduce the chances of bringing out an avalanche.

6. The gun position must be well away from the avalanche path to assure safety for the crew. It should permit firing at the top of the Twin Avalanches as well as the Glory Avalanche if this is possible.

7. Arrangements should be made for blind firing so the area can be controlled even if low clouds and poor visibility obscure the target.

8. When firing on the area, shots should be directed to the roll of snow just below the crest. Shooting should proceed from left to right across the top with a minimum of 3 to 4 shells in this area. Attention can then be directed toward any steep places in the lower part of the bowl where the snow would be under tension from down-slope creep. As experience is gained, the best target will become more obvious.

9. The 75 mm recoilless rifle is recommended. This is a military weapon. The commanding officer of the local National Guard unit is the person to contact for information on obtaining such weapons and ammunition for them.

10. Help and suggestions for this type of avalanche control and for the use of the weapons can probably be obtained from the Forest Service personnel at the Jackson Hole Ski area. Contact here is: Supervisor Teton National Forest, Jackson, Wyoming. Additional information could be obtained from the Colorado State Highway Department by contacting: Chief Engineer, Colorado Highway Department, 4201 East Arkansas Ave., Denver, Colorado.

Enclosures

M. Martinelli Jr.

APPENDIX II

SAMPLE CALCULATIONS

A. Snow Depth at bridge site:

Total depth of accumulated snow including the freshly deposited snow $= 72''$

Area of snow accumulation from the map of scale $1'' = 400'$ is $10.42\ in^2$. $= 10.42\,(400)^2\ ft^2$

Volume of sliding snow $= 10.42\,(400)^2 \times 6$

$= 10.0 \times 10^6$ cft.

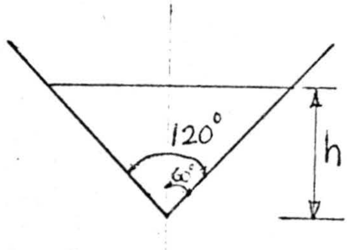
Reduced volume (assuming the densities of snow in freshly deposited and flowing states to be 0.07 and 0.12 times that of water) $= 10.0 \times 10^6 \times \frac{0.07}{0.12}$

$= 5.84 \times 10^6$ cft.

Length of stream between elev. 9800 ft. and elev. 8700 ft. $= \sqrt{1848^2 + 1100^2}$

$= 2150$ ft.

Area of cross section at the bridge site can be approximated as shown in the sketch to $\sqrt{3}\,h^2$ for a depth h.



Cross Section at bridge site.

Equating the volumes, the estimated snow depth at bridge site is given by

$\sqrt{3}\,h^2\,(2150) = 5.84 \times 10^6$ or $h = 39.6$ ft.

B. VELOCITIES OF FLOWING SNOW

Slope of stream:

An average slope is considered adequate for the velocity computations between elevations 10,000 ft. and 8700 ft.

Vertical difference = 1300 ft. Horizontal distance = 2100 ft.

Average slope, $\tan\theta = 1300/2100 = 0.62$ or $\theta = 31° 48'$

$\doteq 32°$

Velocity:

The velocity is computed with the slope and depth obtained above which would be the terminal velocity that the snow would attain at some elevation maintaining the same thereafter as it slides down.

For uniform flow,

$$V^2 = \frac{8}{f} g R \sin\theta \qquad \text{-----(a)}$$

V = Velocity, f = friction factor, R = hydraulic radius

g = accn. due to gravity, θ = angle of slope.

Assuming hydraulically smooth flow and that f is given by Blasius formula

$$f = \frac{0.316}{(N_R)^{1/4}} \quad \text{where } N_R = \text{Reynolds number.}$$

Hydraulic radius for the assumed cross section $= \frac{\sqrt{3}h^2}{4h} = \frac{\sqrt{3}h}{4}$

Kinematic viscosity, $\nu = \mu/\rho$.

Assuming $(\mu)_{snow} = \frac{\gamma_{snow}}{2000}$ where γ_{snow} is in kg/m^3

$$\nu = \left(\frac{\gamma_{snow}}{2000}\right) \Big/ \left(\frac{\gamma_{snow}}{g}\right) = \frac{9.8}{2000} = 4.9 \times 10^{-3} \text{ m}^2/\text{sec}$$

$$\doteq 4.4 \times 10^{-2} \text{ ft}^2/\text{sec}.$$

Substituting for f and ν in eq. (a)

$$V^{1.75} = 706 \, R^{5/4}$$

V = Velocity in m/sec. and R = Hyd. radius in m.

For a total depth of 72" of snow $h = 39.6' = 13\,m$.

Hydraulic radius, $R = \frac{\sqrt{3}}{4} h = 5.75\ m = 17.5\ ft.$

$V^{1.75} = 706\ (5.75)^{5/4}$ or $V = 148\ m/sec = 450\ '/sec.$

Reynolds number, $N_R = \frac{4RV}{\nu} = \frac{4 \times 5.75 \times 148}{4.9 \times 10^{-3}}$

$$= 6.95 \times 10^{5} \quad > 10^{5}$$

Since this falls outside the range of validity of Blasius formula, the friction factor for this N_R value is read out from a standard pipe friction diagram for hydraulically smooth flow to be 0.0125 then using eq (a) for Velocity

$$V^2 = \frac{8}{0.0125} (9.81)(5.75)(\sin 32^\circ)$$

$$V = 138\ m/sec. \quad \text{or} \quad 420\ ft/sec.$$

Terminal Velocity $= 420\ '/sec.$

FREE FALL VELOCITY

The snow is assumed to flow down from an elevation corresponding to the mean of elevations 9800 feet and 8700 feet (between which the snow is assumed to accumulate) down to the bridge site (elevation 7895 feet).

Elevation difference $= \frac{9800 + 8700}{2} - 7895 = 1355$ feet.

However, it is considered that the frictional resistance due to contact with the surface of the sloping ground could safely be deducted from this in estimating the free fall velocity.

Velocity after a fall of d feet, $V = \sqrt{2gd}$ in ft/sec.

Head loss Δh_L in a length ΔL is given by

$$\Delta h_L = \frac{f}{4R} \Delta L \frac{V^2}{2g} = \frac{f}{4R} \Delta L \; L \sin\theta$$

where $\frac{V^2}{2g} = d = L \sin\theta$

L being measured along the slope.

Head loss in a length L along slope $= \int_0^L \frac{f}{4R} \sin\theta \; L \; dL$

The following values are assumed to Compute head loss.

$f = 0.013$ (Corresponding to 24" - 36" of natural Snow depth)

$\sin\theta = 0.4$ (Considering the flat slopes u/s of bridge)

$R = 17.5'$ (Corresponding to 72" depth of snow.)

$L = 1355/\sin 32 = 2554$ ft. (Length along slope between elevations 9250 ft. and 7895 ft.)

These values are chosen to pick up a possibly lower value for h_L and a Conservative estimate for V.

$$h_L = \frac{0.013}{4(17.5)} (0.4) \frac{2554^2}{2} = 243 \text{ ft.}$$

Velocity head available at bridge site $= 1355 - 243 = 1112$ ft.

and $V = \sqrt{2 \times 32.2 \times 1112} = 259$ '/sec.

$\doteq 260$ '/sec.

The actual velocity of flow in any case at the bridge site is believed unlikely to exceed this value.

Thus:

For an accumulated natural snow depth of 72"

Estimated Depth of flowing Snow at bridge site $\doteq 40$ feet.

Estimated Velocity (maximum) at bridge site $= 260$ feet/second.