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BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

RECORD NO. 1967/139

MIDDLE CREEK AND WIVENHOE DAM SITES SEISMIC SURVEY,

QUEENSLAND 1966

by

P.E. MANN and G.F. HART

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SUMMARY

The object of the survey was to determine the depth to bedrock and the nature of the bedrock at two dam sites, viz Middle Creek and Wivenhoe on the Brisbane River, for the Co-ordinator-General's Department, Queensland.

The seismic results indicate that foundation conditions are better at Middle Creek. However, test drilling is recommended for both sites to test the rock and the seismic interpretation.

1. INTRODUCTION

The Co-ordinator-General's Department, Queensland, proposes to construct a dam on the Brisbane River to augment the Brisbane water supply and to assist in flood mitigation. Two sites are being investigated, one about half a mile downstream of the Wivenhoe road-bridge on the Brisbane Valley Highway, the other at Middle Creek near Bryden. The approximate co-ordinates of the sites are 574600 and 568615 respectively on the Ipswich sheet of the Australia 1:250,000 map series.

In response to an application from the Co-ordinator-General's Department, the Bureau of Mineral Resources, Geology and Geophysics made a geophysical investigation of the sites to determine the depth to, and nature of, the bedrock. Approximately 35,000 feet of traverse was surveyed by the seismic refraction method. The survey was carried out between 25th October and 16th November 1966 by a party consisting of P.E. Mann (party leader and geophysicist), G.F. Hart (geophysicist), and D. Tarlinton (field assistant). The Department provided four field-hands and ancillary supplies and surveyed the traverse lines. The term bedrock used in this record refers to the deepest refractor with the highest measured seismic velocity.

2. GEOLOGY

Preliminary geological mapping and reconnaissance auger drilling at the dam sites has been carried out by the Geological Survey of Queensland (Warner, 1967).

In the survey areas the Brisbane River has eroded a valley in sedimentary and volcanic rocks of Mesozoic age, laid down in an ancient rift valley (Hill and Denmead, 1960).

Middle Creek dam site

The bedrock at Middle Creek is the Neara Volcanics. The main rock types of this stratigraphic unit are andesite, andesitic tuff, andesitic agglomerate, and volcanic breccia. The individual rock types were not mapped. The rock crops out to form a steep cliff on the left bank and at several places upstream of the axis near the stream gauging station. The rock is highly weathered and the joint spacing ranges from one to four inches.

On the right bank near test shaft No. 9 (Plate 1) about 20 feet of boulder conglomerate, probably of Tertiary age, overlies the volcanic rocks.

Alluvium at the dam site is divided into two types: Younger Alluvium and Older Alluvium. The lower alluvial terrace (Younger Alluvium) consists of medium and coarse-grained sand and gravel. The upper alluvial terrace (Older Alluvium) consists of about 60 feet of gritty clay overlying weathered bedrock.

Eleven test shafts were dug at the Middle Creek site, probably about 1899. Two auger holes were drilled in 1966 by the Mines Department on the proposed axis. Plate 1 shows the location of the test shafts and auger holes.

Wivenhoe dam sites

The bedrock at Wivenhoe is the Wivenhoe Sandstone. The rock is a massive thick-bedded, medium to coarse-grained argillaceous sandstone, commonly showing current bedding. The sediments are approximately horizontal and the joints vertical and widely spaced.

The lower alluvial terraces mapped as Younger Alluvium consist of medium to coarse-grained sand and gravel; the proportion of coarser particles generally increases with depth. Older Alluvium mapped at the dam site consists of clayey sand about 20 feet deep overlying weathered sandstone in auger hole No. 2 and about 60 feet of clay in auger hole No. 3.

Plate 4 shows the location of the auger holes drilled by the Mines Department in 1966.

3. METHODS AND EQUIPMENT

The method used is described in reports of previous surveys (e.g. Polak and Mann, 1959).

A 24-channel seismograph manufactured by South-western Industrial Electronics Company was used with Technical Instruments Co. geophones, of natural frequency 20c/s, to record the arrival of the longitudinal waves.

To determine the transverse wave velocity, three-component Hall-Sears geophones, model HS-1-LP-3D with natural frequency of 14 c/s and miniature three-component Hall-Sears geophones, model HS-1-LPJ-3D with a natural frequency of 7.5 c/s were used.

For 'normal' spreads, the geophone spacing was 50 feet. Five shots, in shallow holes about three feet deep, were fired for each spread, one at the centre of the spread and the others at 25 and 200 ft from each end of, and in line with, the spread. In addition, 'weathering' spreads with 10-ft geophone spacings were used to obtain the velocities of the upper layers.

To determine the elastic constants in situ at each dam site, vertical and three-component geophones spaced 25 feet apart were laid out in spreads 500 feet long with centres at A18 at Middle Creek and A65 at Wivenhoe. Shot distances of 50 and 200 feet were used.

The total length of seismic traverses was approximately 13,000 feet at Middle Creek and 22,000 feet at Wivenhoe.

4. RESULTS

Middle Creek dam site

Plate 1 shows the locality map, seismic traverses, geology, and the position of test shafts and auger holes at the dam site.

Table 1 gives an interpretation of the seismic velocities in geological terms based on geological mapping, logs of auger holes and test shafts, and experience in other areas.

TABLE 1

Relation between seismic velocity and rock type

Longitudinal wave velocity (ft/s)	Rock type
1000 ±	Soil
2000-4000	Highly weathered bedrock;
	Older Alluvium predominantly clay; semiconsolidated boulder conglomerate
5000 ± 500	Water saturated alluvium-silt, sand, and gravel
5500-9000	Weathered to partly weathered bedrock
15,000-16,000	Unweathered bedrock

Plate 2 shows the seismic cross-sections. Generally the cross-sections are self-explanatory but a few points will be discussed. The depth to the highest velocity refractor interpreted as bedrock is greater along Traverses A,C,D, and E on the right bank than along Traverses B,F,G, and H on the left bank.

Between stations A23 and A31 (Plate 2) there is a deep depression in the seismic cross-section. On the bedrock contour plan (Plate 3) this area shows up as a deep gully. The extension to the south-east is unknown, but the contours suggest a river terrace bounded approximately by Traverses A, D, and E. The contour plan shows another gully intersecting Traverses A and C and a ridge centred near A12.

On the left bank the contours show a large block of unweathered bedrock which diverts the river. The difference in elevation of the bedrock on the right and left banks and the sharp bend in the river suggests a possible fault, with an east-west strike, beneath the river.

The bedrock contours indicate that the most favourable position for a dam is about 400 feet east of Traverse A.

A comparison of drilling logs with the seismic results is shown in Table 2.

The geological logs of some trial shafts are indefinite. For example, the question mark indicates that the only available log of TS4 gives the rock type but does not indicate whether the rock is weathered or unweathered. This fact and the paucity of drilling data does not permit a reliable comparison of drilling and seismic results to be made.

Accuracy of the seismic depth determination. The error in the depth determination depends on the error in the travel time of seismic waves and the error in the conversion factor.

The error in the travel time depends on the quality of the 'breaks' on the seismogram. The percentage error in travel time was estimated as 3%. The error in the conversion factor depends on the error involved in fitting straight lines to points of the time/distance curves to determine the velocity of the different layers and the error due to the extrapolation of these straight lines to determine the intercept times. By computing several different conversion factors for the same point the percentage error in the conversion factor was estimated as 15%.

Hence the percentage error in the depth was estimated as 15 + 3 = 18%.

At the intersections of traverses, two values of depth were obtained. The difference between the two values gives further information about the accuracy of the depth determination. Seven pairs of values were obtained. The greatest deviation from the mean was 17%, and the standard deviation was 10%.

Elastic constants. Young's modulus and Poisson's ratio of the bedrock were determined by measuring the longitudinal wave velocity Vp and the horizontally polarised transverse wave velocity Vs on Traverse A (dynamic method). The measurements were made between A13 and A23; thus, the calculated values represent average moduli along the measured length in the direction of measurement. Shots were fired at 50 feet and 200 feet, two values thus being obtained. The values are given in Table 3.

TABLE 2

Comparison of drilling logs with seismic results

Test Shaft (TS) Auger Hole (AH)	Drilling results		Seismic results	
	Depth (ft)	Rock type	Depth (ft)	Seismic velocity (ft/s)
TS9	0-5	Sandy clay	0-5	1000
	5-20.5	Conglomerate	5-	3200
TS5	0-4	Sandy clay		
	4-71	Highly weathered to weathered breccia and tuff		
	71-83.6	Unweathered (?) breccia and tuff		
TS4	0-8	Clay	0-5	1000
	8-10.5	Weathered breccia and tuff		
	10.5-25.5	Unweathered (?) breccia and tuff	5-	8500
TS10	0-5	Sandy clay		
	5-14.5	Weathered breccia and tuff		
	14.5-45	Unweathered breccia and tuff		
TS3	0-27.5	Clay	0-7	1000
	27.5-31.5	Weathered breccia and tuff	7-	4000
TS6	0-21.5	Clay		
	21.5-41	Weathered breccia and tuff		
TS2	0-9	Gravel and sand		
	9-30	Weathered andesite breccia and tuff		
	30-53	Unweathered breccia and tuff		
TS8	0-49	Gravel, sand, and clay	0-12	1000
	49-50.5	Weathered (?) breccia and tuff	12-36	2900
			36-	6500
AH6	0-16	Gravel and sand		
AH7	0-64	Gravel, sand, and clay		

TABLE 3

Elastic constants of bedrock - Middle Creek dam site

Traverse and Station	Longitudinal velocity (ft/s)	$\frac{Vp}{Vs}$	Poisson's ratio (σ)	Young's modulus (E) (10^6 lb/in^2)	(10^6 kg/cm^2)
A13 - A23	17,000	1.94	0.33	7.1	0.50
	14,000	2.00	0.33	6.9	0.49

Young's modulus was calculated assuming a density of 2.6 g/cm^3 (Jakosky, 1950).

Poisson's ratio was computed using the formula

$$\sigma = \frac{1}{2}\left(\frac{Vp}{Vs}\right)^2 - 1 \Big/ \left(\frac{Vp}{Vs}\right)^2 - 1 \qquad (1)$$

The fractional error $\delta\sigma/\sigma$ in σ is given by

$$\frac{\delta\sigma}{\sigma} = (4\sigma - 6 + 2/\sigma)\, \delta\left(\frac{Vp}{Vs}\right) \Big/ \left(\frac{Vp}{Vs}\right) \qquad (2)$$

The percentage error in Vp/Vs is estimated as 8%. From equation 2, the percentage error in σ is about 11% when $\sigma = 0.33$.

Young's modulus was computed using the formula

$$E = \rho V_s^2 \frac{(3 V_p^2 - 4 V_s^2)}{(V_p^2 - V_s^2)} \qquad (3)$$

The fractional error $\delta E/E$ in E is given by

$$\frac{\delta E}{E} = \left(\frac{\partial E}{\partial V_p} \cdot \frac{V_p}{E}\right)\frac{\delta V_p}{V_p} + \left(\frac{\partial E}{\partial V_s} \cdot \frac{V_s}{E}\right)\frac{\delta V_s}{V_s} + \left(\frac{\partial E}{\partial \rho} \cdot \frac{\rho}{E}\right)\frac{\delta\rho}{\rho} \qquad (4)$$

From equation 3, with Vp = 14,000 ft/s and Vs = 7000 ft/s,

$$\frac{\partial E}{\partial V_p} \cdot \frac{V_p}{E} = \frac{2V_s^2 V_p^2}{(V_p^2 - V_s^2)(3V_p^2 - 4V_s^2)} = 0.33$$

$$\frac{\partial E}{\partial V_s} \cdot \frac{V_s}{E} = \frac{2(3V_p^2 - 2V_s^2)(V_p^2 - 2V_s^2)}{(V_p^2 - V_s^2)(3V_p^2 - 4V_s^2)} = 1.7$$

$$\frac{\partial E}{\partial \rho} \cdot \frac{\rho}{E} = 1$$

The percentage errors in Vp, Vs, and ρ were estimated as 3%, 5%, and 4% respectively. Thus the percentage error in E was found to be about 14%.

Wivenhoe dam site

Plate 4 shows the seismic traverses, geology, and the location of auger holes drilled at the dam site. Plate 7 shows the seismic traverses and cross-sections at a proposed spillway site.

Table 4 gives an interpretation of the seismic velocities in geological terms based on geological mapping, the logs of auger holes, and experience in other areas.

TABLE 4

Relation between seismic velocity and rock type

Longitudinal wave velocity (ft/s)	Rock type
1000	Soil
2700-5500	Highly weathered sandstone; water saturated alluvium - gravel, sand, and clay
6000-9000	Weathered to partly weathered sandstone
11000-14000	Unweathered bedrock

Plates 5 and 6 show the seismic cross-sections at the dam site. Again only a few points will be discussed briefly because the cross-sections are self explanatory.

Generally the seismic velocity of the bedrock is higher on the right bank than on the left bank. However, velocities observed on Traverses A, C, D, and L near the river are higher than elsewhere on the left bank.

At some traverse intersections different velocities were observed in different directions, e.g. Traverses A and F. Small differences of up to 500 ft/s may be due to observational errors, e.g. Traverses A, J, and K. Large differences of up to 1200 ft/s were observed at other intersections, e.g. Traverses B and C, and are probably due to velocity anisotropy. This is probably due to jointing.

The deepest refractor observed between stations A154 and A162 has a velocity of 7500 ft/s. Here, shots fired at the normal distance of 200 feet from the end of the spread were too close to give refractions from the 14,000-ft/s layer recorded elsewhere on the traverse.

The greatest depth to bedrock observed (178 feet) is at station A57. However, this large depth is due to the low velocity contrast between weathered and unweathered bedrock and the thickness of the weathered and unweathered bedrock and the thickness of the weathered bedrock.

It is considered that the traverses are too widely spaced to be able to construct a bedrock contour plan.

A comparison of the seismic sections between stations B13 and B54, and between A97 and A129 shows that the bedrock conditions along Traverse A are probably better than along Traverse B. The cross-section of Traverse B suggests a high-level alluvial terrace between station B23 and B48; a similar terrace along Traverse A is not as well developed. A depression in the bedrock profile near A122 and B38 may represent the old river bed.

The accuracy of the seismic depth determinations was calculated in a way similar to that given above for the Middle Creek dam site results. The percentage error in the depth was estimated as 17%. From data obtained at the intersection of traverses the greatest deviation from the mean was 16% and the standard deviation was 9%.

Elastic constants. Young's modulus and Poisson's ratio of the weathered bedrock were determined by measuring the longitudinal wave velocity and the vertically polarised transverse wave velocity on Traverse A between stations A60 and A70. The values obtained are given in Table 5.

TABLE 5

Elastic constants of weathered bedrock - Wivenhoe dam site

Traverse and Station	Vp (ft/s)	Vp/Vs	Poisson's ratio (σ)	Youngs modulus (E) (10^6 lb/in^2)	Youngs modulus (E) (10^6 kg/cm^2)
A60	9000	1.94	0.32	1.7	0.12
A70	8000	2.00	0.33	1.3	0.09

Young's modulus was calculated assuming a density of 2.2 g/cm^3 (Jakosky, 1950). The percentage error in σ is about 26% when σ = 0.27. The percentage error in E was found to be about 12% assuming the same error in ρ, Vp, and Vs as was found for the Middle Creek dam site results and taking Vp = 9000 ft/s and Vs = 4600 ft/s.

Plate 7 shows the seismic traverse layout and cross-sections at the spillway site. The relatively high seismic velocity (13,000 ft/s), interpreted as bedrock, suggests that the fault zone mapped in a gully near the traverses does not give a wide shear zone intersecting the seismic traverses. However, there may be minor shear zones near stations V3, V35, and V40.

5. CONCLUSIONS

At both dam sites, foundation conditions on one bank are better than the other, viz at Middle Creek the left bank is better and at Wivenhoe the right bank. On both these banks, bedrock or weathered bedrock with seismic velocity of 6000 ft/s or greater is shallow and may be considered suitable foundation rock for a certain type of dam.

On the right bank at Middle Creek, south of A32, bedrock that is probably weathered may prove suitable for foundations. On the left bank at Wivenhoe, foundation conditions are probably better between A97 to A130 than between B13 and B54. Again, weathered bedrock of 6000 ft/s observed on Traverse A may be used for foundations.

Values of Young's modulus of the bedrock at Middle Creek measured in the field is 7.0×10^6 lb/in^2; the value for weathered bedrock at Wivenhoe is 1.5×10^6 lb/in^2.

To check the seismic results andthe quality of the bedrock, test drilling is recommended for each dam site; at Middle Creek near A1, A26, and A45; at Wivenhoe near A32, A122, A137, B40, and B68.

6. REFERENCES

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POLAK, E.J. and MANN, P.E.	1959	Geophysical survey at the Barron Falls hydro-electric scheme, Kuranda, Queensland. <u>Bur. Min. Resour. Aust. Rec</u>. 1959/93.
WARNER, K.R.	1967	Brisbane River dam site geological reconnaissance. <u>Geological Survey of Queensland</u> Report (unpubl.)

PLATE 1


MIDDLE CREEK DAM SITE QLD
SEISMIC TRAVERSES, GEOLOGY, AND LOCALITY MAP
LEGEND
Fence
Track
Traverse with station number
Test shaft
Auger hole (approximate position)
Younger Alluvium
Older Alluvium
Andesitic rocks
Boundary of rock outcrop
Approximate geological boundary
TRAVERSE A
TRAVERSE B
TRAVERSE C
TRAVERSE D
TRAVERSE E
TRAVERSE F
TRAVERSE G
TRAVERSE H
BRISBANE
RIVER
Boulder conglomerate
Gully
NEW ROAD
T.N.
M.N.
FEET
200 0 200 400 600
LOCALITY MAP
MILES
MIDDLE CREEK DAM SITE
Bryden
WIVENHOE DAM SITE
SPILLWAY
BRISBANE
RIVER
BRISBANE VALLEY HIGHWAY
DARLING DOWNS HIGHWAY
IPSWICH
L. Manchester
Based on Co-ordinator-Generals Department Plan SI 157
and Geological Survey of Queensland Plan E90-A-2
TO ACCOMPANY RECORD No.1967/139
Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics. G56/B5-46


PLATE 2
TRAVERSE A
SOUTH
NORTH
TRAVERSE B
SOUTH
NORTH
TRAVERSE H
SOUTH-WEST
NORTH-EAST
TRAVERSE C
NORTH-WEST
SOUTH-EAST
TRAVERSE D
NORTH-WEST
SOUTH-EAST
TRAVERSE E
NORTH-WEST
SOUTH-EAST
TRAVERSE F
SOUTH-EAST
NORTH-WEST
TRAVERSE G
SOUTH-EAST
NORTH-WEST
ELEVATION (FEET)
Datum 00
STATION NUMBER
STATION ELEVATION (FEET)
DEPTH TO BEDROCK (FEET)
LEGEND
I.Pt Traverse intersection point
(1000) Seismic velocity (ft/s) in formation
— 6' Depth to formation with different seismic velocity
Unweathered bedrock boundary
TS Test shaft
soil or Older Alluvium
21' depth to geological boundary
boulder conglomerate
43'
Andestic rocks
73'
Younger Alluvium
106' depth of shaft
MIDDLE CREEK DAM SITE
SEISMIC CROSS-SECTIONS
FEET
100 0 100 200 300
(Horizontal and vertical)
Based on Co-ordinator-Generals Department Plan SI 158
RECORD No 1967/139
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G56/B5-47

PLATE 3

MIDDLE CREEK DAM SITE

BEDROCK CONTOURS BASED ON SEISMIC RESULTS

Based on Co-ordinator-Generals Department Plan SI 157
and Geological Survey of Queensland Plan E90-A-2

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PLATE 4

WIVENHOE DAM SITE
SEISMIC TRAVERSES AND GEOLOGY

Based on Co-ordinator-General's Department Plan SI 361 and Geological Survey of Queensland Plan E 90-A-2

TO ACCOMPANY RECORD No. 1967/139

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PLATE 5

WIVENHOE DAM SITE

TRAVERSES A,K,J,H,G,D,E,F AND M

SEISMIC CROSS-SECTIONS

Based on Co-ordinator-Generals Department Plans SI 362 and SI 363

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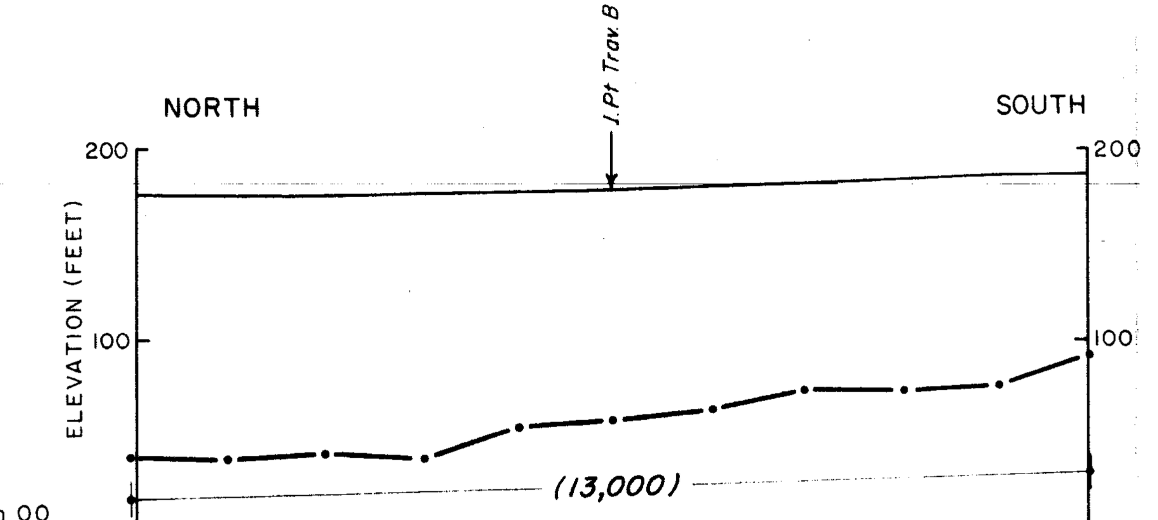
TRAVERSE B

STATION NUMBER	78					73					68					63					58		56
STATION ELEVATION (FEET)	236	234	232	229	227	223	219	217	213	208	204	199	194	189	184	179	174	170	165	158	151	143	133
DEPTH TO BEDROCK (FEET)	146	151	159	155	159	144	155	162	151	144	148	157	157	144	133	132	135	129	98	100	107	100	89

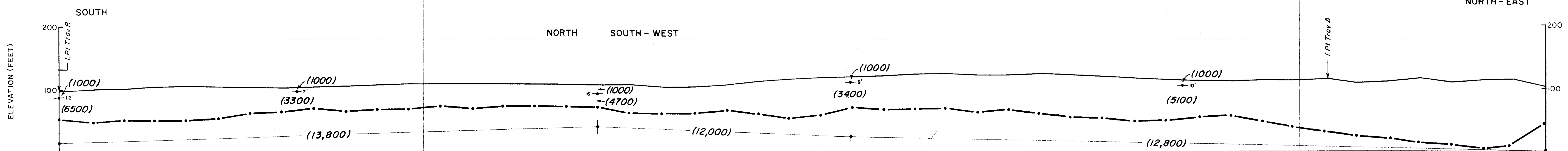
STATION NUMBER	54						48					43					38					33					28					23					18					13					8					3		1
STATION ELEVATION (FEET)	97	103	116	117	120	126	151	158							163	162	161	160	158	154	153	150	150	150	150	150	151	152	154	156	158	160	162	163	164	165	166	167	169	170	171	172	174	176	177	178	179	177	174	169	162	149	136	128
DEPTH TO BEDROCK (FEET)	46	56	67	75	78	70	96	100	102	105	105	105	105	103	107	113	107	105	104	98	93	84	76	65	54	49	38	38	31	29	26	20	26	28	27	27	35	30	31	36	40	47	46	49	48	41	42	41	41	39	36	46	29	27

TRAVERSE N



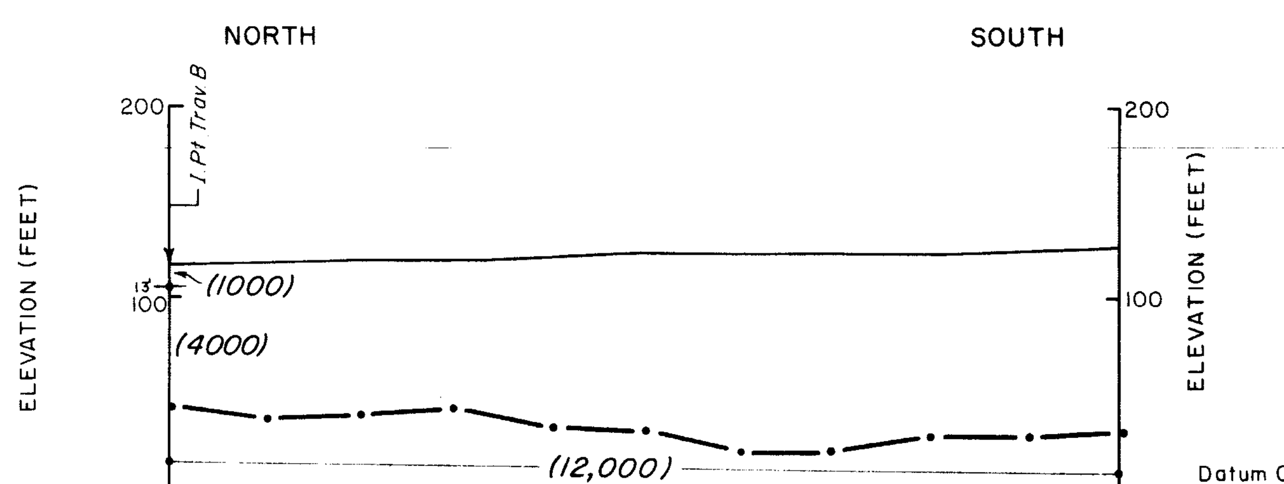
STATION NUMBER	1					6					11
STATION ELEVATION (FEET)	177	176	176	177	178	179	181	182	183	185	186
DEPTH TO BEDROCK (FEET)	138	138	135	138	124	132	117	110	110	110	96

TRAVERSE C



STATION NUMBER	48					43					38					33		31					26					21					16					11					6					1
STATION ELEVATION (FEET)	97	100	102	104	106	105	103	102	103	104	106	107	107	107	107	108	107	106	108	102	102	105	111	115	117	118	121	123	123	122	121	123	120	118	116	114	112	111	112	113	115	109	111	117	110	114	113	103
DEPTH TO BEDROCK (FEET)	46	53	50	54	54	51	41	39	34	39	38	40	35	38	34	36	36	36	46	41	42	40	52	61	59	48	54	57	56	59	56	64	67	67	68	65	58	56	67	75	84	85	92	102	98	109	106	59

TRAVERSE L



STATION NUMBER	1					6					11
STATION ELEVATION (FEET)	117	119	119	120	121	123	123	123	123	124	126
DEPTH TO BEDROCK (FEET)	75	83	83	78	90	94	106	106	98	99	98

LEGEND

- I.P.I — Traverse intersection point
- (1000) — Seismic velocity (ft/s) in formation
- —6' — Depth to formation with different seismic velocity
- —•— Unweathered bedrock boundary
- AH3 — Auger hole

WIVENHOE DAM SITE
TRAVERSES B, C, N AND L
SEISMIC CROSS-SECTIONS

FEET
100 0 100 200 300
(Horizontal and vertical)

Based on Co-ordinator-Generals Department Plans SI 362 and SI 363

TO ACCOMPANY RECORD No. 1967/139
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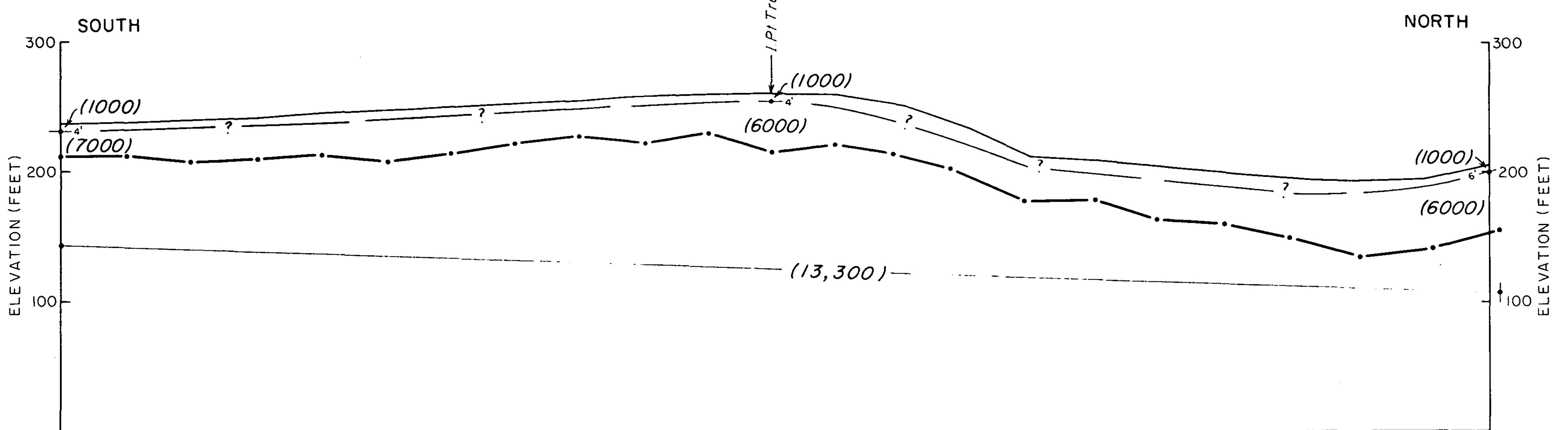
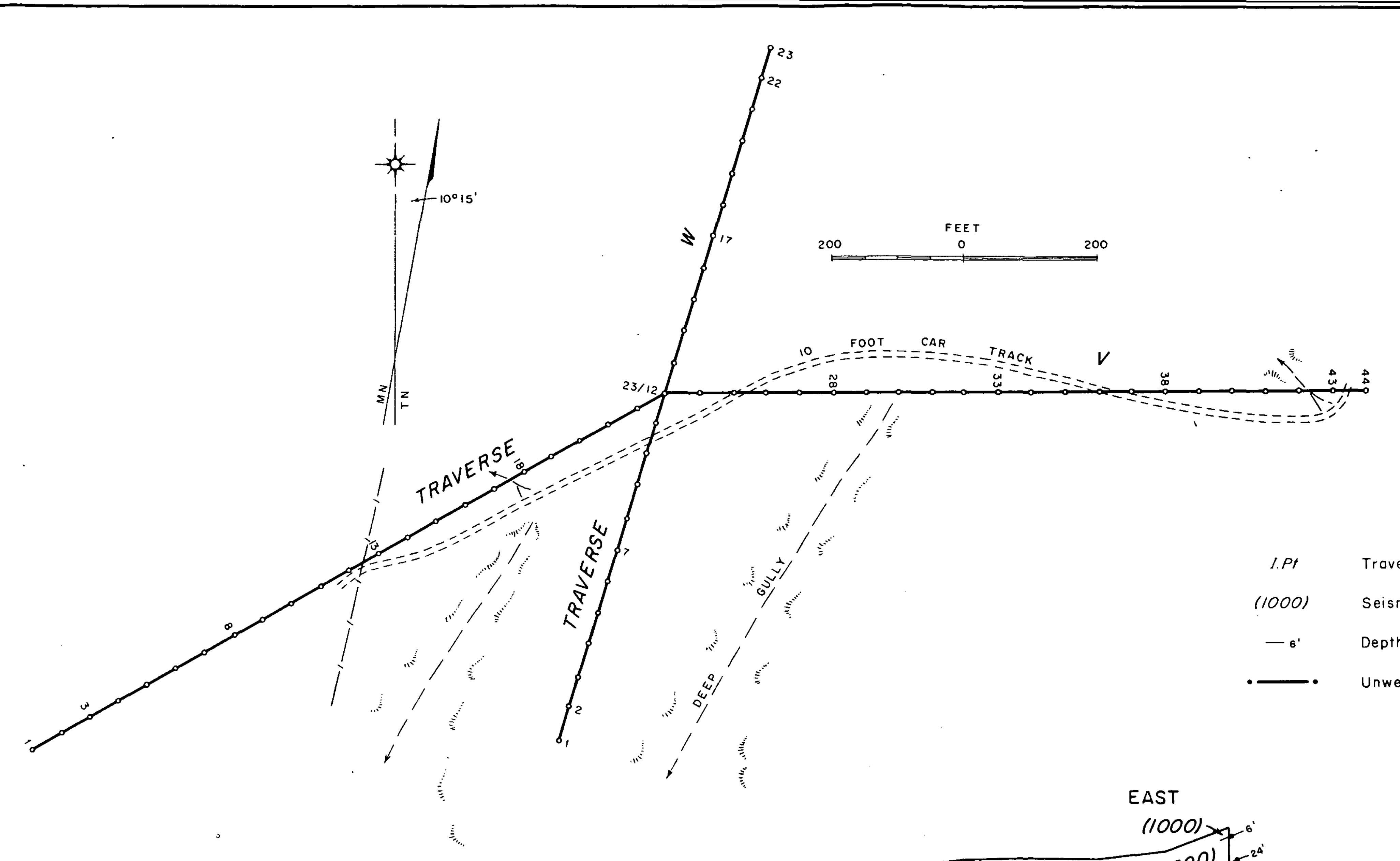
G56/B5-50

PLATE 7

TRAVERSE W



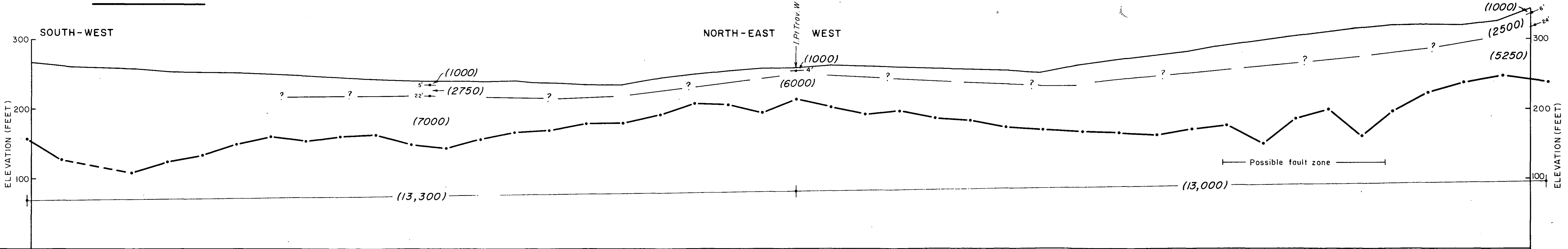
STATION NUMBER	1	2					7					12					17					22	23
STATION ELEVATION (FEET)	237	238	240	242	244	247	250	253	255	258	260	261	260	252	234	223	209	204	198	194	192	197	204
DEPTH TO BEDROCK (FEET)	25	27	32	32	32	38	36	29	27	36	29	45	38	38	34	34	29	41	38	45	58	52	49



LEGEND

I.P.I	Traverse intersection point
(1000)	Seismic velocity (ft/s) in formation
—6'	Depth to formation with different seismic velocity
•—•	Unweathered bedrock boundary

TRAVERSE V



STATION NUMBER	1		3					8					13					18					23
STATION ELEVATION (FEET)	267	263	260	258	256	255	254	251	248	246	243	242	241	240	241	238	235	235	244	251	257	259	261
DEPTH TO BEDROCK (FEET)	110	134		149	130	120	103	91	93	84	79	91	96	82	73	67	55	55	53	43	49	63	45

STATION NUMBER					28					33					38					43	44
STATION ELEVATION (FEET)	263	262	261	259	258	256	254	262	269	275	281	289	296	303	309	316	320	322	321	326	345
DEPTH TO BEDROCK (FEET)	59	68	62	70	73	82	82	95	105	113	111	113	147	117	111	156	123	98	82	78	108

WIVENHOE DAM SITE
SPILLWAY TRAVERSES V AND W

TRAVERSE LAYOUT AND SEISMIC CROSS-SECTIONS

FEET
100 0 100 200 300
(Horizontal and vertical)

Based on Co-ordinator-Generals Department Plan SI 364

TO ACCOMPANY RECORD No. 1967/139

GEOPHYSICAL BRANCH, BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

G56/B5-51