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CANADA

DEPARTMENT OF MINES AND TECHNICAL SURVEYS

OTTAWA

MINES BRANCH INVESTIGATION REPORT IR 60-112

INVESTIGATION INTO THE STABILITY OF DUFFERIN TERRACE, QUEBEC CITY

by

A. BROWN AND F. L. CASEY

FUELS AND MINING PRACTICE DIVISION

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Mines Branch Investigation Report IR 60-112

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by

A. Brown* and F. L. Casey**

SUMMARY

At the request of the Department of Northern Affairs and National Resources an investigation into the stability of Dufferin Terrace was undertaken by the Mines Branch of the Department of Mines and Technical Surveys.

Investigations were initiated in June 1957, and were directed toward a study of any movements occurring in the structure, and an examination for fissures existing in the supporting rock escarpment. Because it was believed that climatic conditions could be important with respect to the stability of the structure, it was decided to continue observations over a number of years. The investigations were conducted from June 1957 to May 1960, and the data obtained during the course of the study are contained in the body of this report.

The results indicated that Dufferin Terrace is subject to movements of a sporadic nature. The investigation also showed that the rock escarpment is traversed by numerous fissures which can allow a ready penetration of water into the rock mass and contribute to the instability of the steeply pitching strata. A strong possibility therefore exists that, under present circumstances, sufficient instability will develop from time to time to cause substantial falls from the face of the cliffs and serious damage to Dufferin Terrace.

To retard the progressive destruction by weathering of this outstanding Canadian landmark, preventive action should be taken to stabilize the exposed and over-steepened cliff faces and to keep the interior of the fissured rock mass as dry as possible. Some suggestions along these lines are contained in the conclusions of this report.

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POUR USAGE OFFICIEL SEULEMENT

Direction des mines
Rapport d'investigation IR 60-112

ÉTUDE DE LA STABILITÉ DE LA TERRASSE DUFFERIN, À QUÉBEC

par

A. Brown* et F. L. Casey**

RÉSUMÉ

A la demande du ministère du Nord canadien et des Ressources nationales, la Direction des mines, du ministère des Mines et des Relevés techniques, a entrepris une étude de la stabilité de la terrasse Dufferin.

Les travaux ont débuté en juin 1957; ils consistaient en l'étude des mouvements dont la structure est la scène, et en une inspection visant à déceler les fissures existant dans l'escarpement rocheux qui lui sert de support. Comme on croyait qu'il se pouvait que les conditions climatiques influent fortement sur la stabilité de cette structure, on a décidé de poursuivre les travaux durant quelques années. Les travaux se sont poursuivis de juin 1957 à mai 1960, et les reseignements ainsi obtenus apparaissent dans le texte du présent rapport.

Il ressort des résultats que la terrasse Dufferin est soumise à des mouvements de nature sporadique, et que l'escarpement rocheux est très fissuré, si bien que l'eau peut facilement s'introduire dans la masse rocheuse et rendre ainsi plus instables les couches à fort pendage. Dans les conditions actuelles, il se peut fort bien que, de temps à autre, l'instabilité devienne assez grande pour produire de gros éboulements du front de la falaise et endommager la terrasse Dufferin de façon sérieuse.

Afin que les actions météoriques soient plus lentes à éroder progressivement ce remarquable site canadien, on recommande de prendre des mesures préventives afin de stabiliser les faces de la falaise qui sont exposées et rendues trop raides, et de maintenir aussi sec que possible l'intérieur de la masse rocheuse fissurée. Les conclusions du présent rapport contiennent quelques propositions en ce sens.

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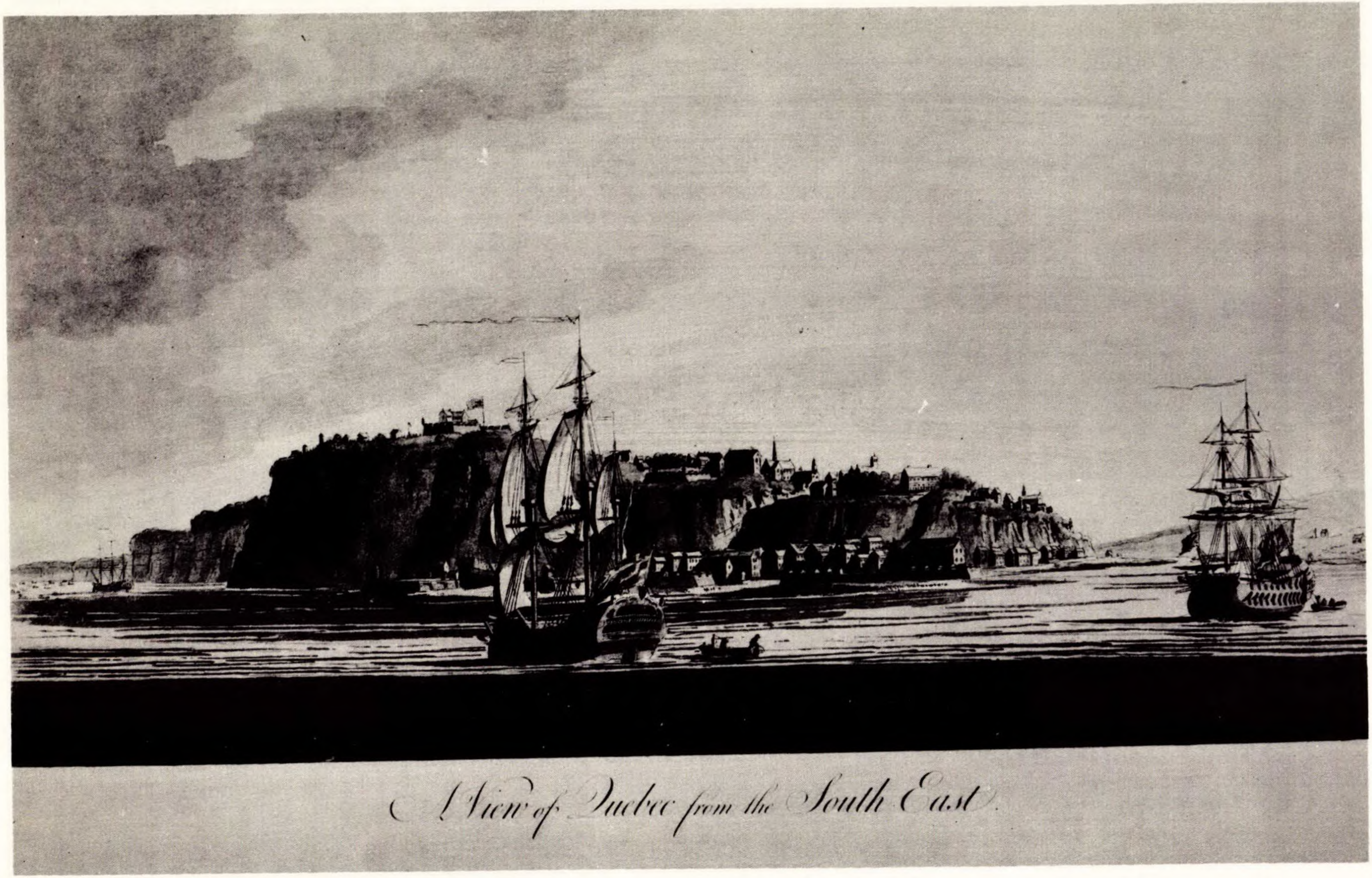


By J.F.W. Desbarres, c. 1759.
(Courtesy of Public Archives
of Canada, Ottawa)

INTRODUCTION

The Department of Northern Affairs and National Resources, through its National Parks Branch, controls certain properties in Quebec City, including portions of the rock escarpment fronting on the St. Lawrence river. This escarpment has a history of rock slides and the above Department is therefore concerned with the effects of such occurrences, particularly with regard to the stability of the cliffs at Dufferin Terrace.

Falls of rock from the face of these cliffs are usually limited to fragments that have become loosened from the parent mass but, at irregular intervals, more substantial slides occur. On the occasion of the last big landslide (in 1889) the rock fall was large enough to cause not only extensive damage to Dufferin Terrace but also loss of life and destruction of property at the foot of the cliffs.

In 1956, the Department of Northern Affairs and National Resources sought the advice of the Geological Survey of Canada and, in October of that year, a geological examination was made of the cliffs between Wolfe's Cove and the Rue de la Montagne, a distance of approximately one mile. This examination included the portion of the cliffs supporting Dufferin Terrace. The report[1] subsequently issued by the Geological Survey of Canada contained the comment: "The assessment of the geological factors on the recurrence of landslides is necessarily qualitative and as such is of limited value. For quantitative information a short-term program might be instituted to measure precisely the rate of separation of beds across one or more fissures beneath Dufferin Terrace."

On December 10, 1956, the Department of Northern Affairs and National Resources acted on the above suggestion by requesting the Department of Mines and Technical Surveys at Ottawa to make such observations as would provide information on the stability of Dufferin Terrace. Following correspondence between these two departments (on January 4, January 23, and March 4, 1957), it was agreed that the Mines Branch would undertake the study and that the work would be conducted by the Mining Research Section of its Fuels Division. The Mining Research Section was selected because of experience gained by investigations into ground control in underground mine workings. It was considered that techniques and apparatus developed for measuring rock deformations on a large scale in mines might be adapted for observing mass movements in the Quebec cliffs.

During the course of the above correspondence a preliminary meeting was held on January 15 between officers of the Engineering Services, National Parks Branch, and the Mining Research Section of the Fuels Division. The details of the meeting have already been reported.(2)

Upon receiving authorization to proceed with this study the above officers of the two departments initiated a co-operative program of observations based on:

1. The measurement of movements occurring in Dufferin Terrace.
2. An examination, through boreholes, of the physical condition of the cliffs to determine the location and dimensions of rock fissures. Boreholes were considered necessary, as the rock surface is covered with debris and the alternative of trenching to bed-rock would be much more costly and laborious.

Since time was required to develop new, or adapt existing observation equipment, and also because of severe icing conditions beneath the Terrace, the start of field observations was scheduled for the early summer of 1957. In the meantime, consideration was given at the Mines Branch to possible measuring equipment that could withstand long time exposures to the weather.

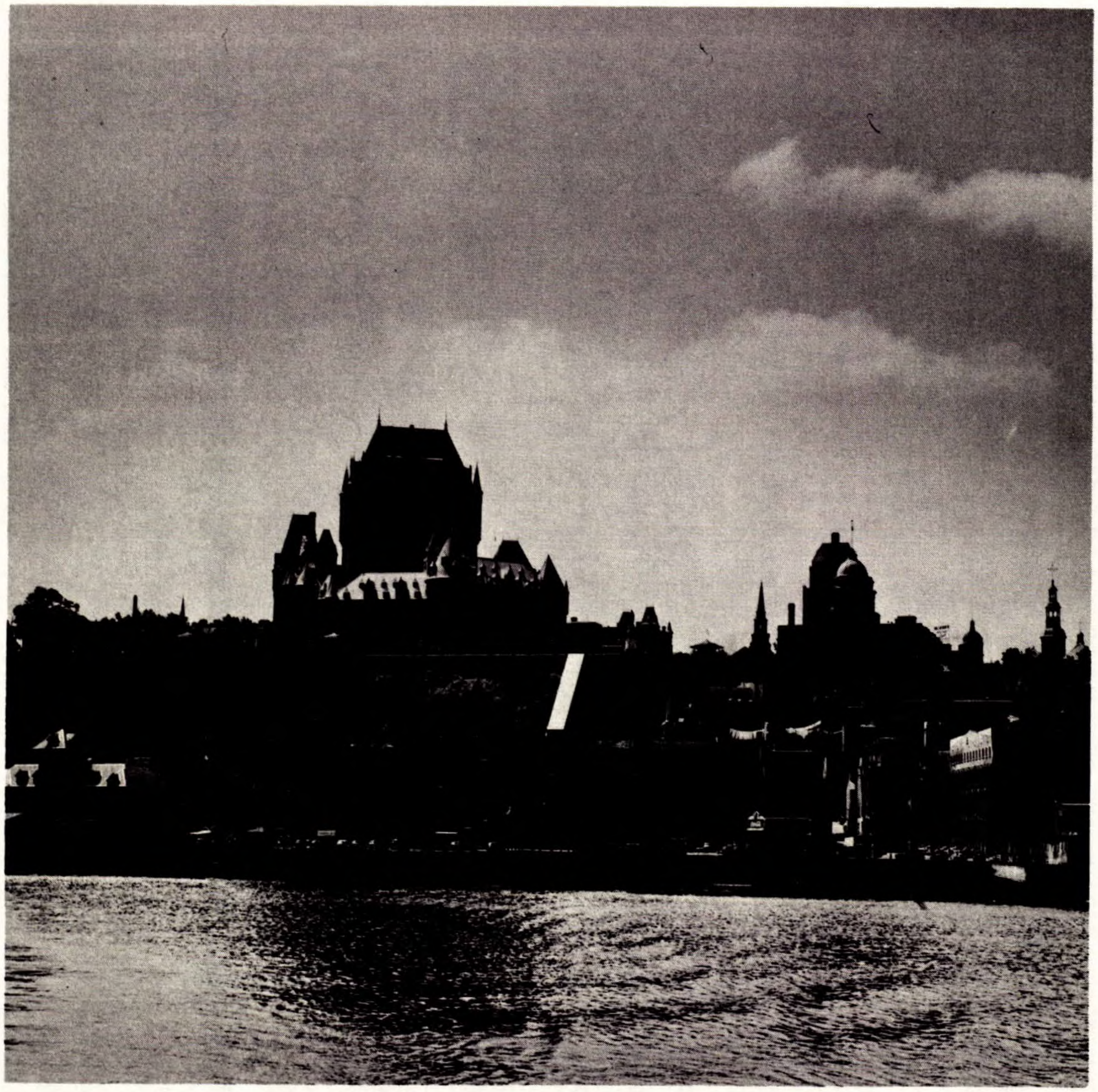
In April, 1957, officers of the National Parks Branch and the Mining Research Section visited Quebec City to examine conditions at Dufferin Terrace and to select the observation sites. Discussions were also held with individuals in Quebec City who might have information to impart that would provide additional insight into the problem. These included Messrs. L. Gagnon, Chief Engineer, and A. Piché of the City engineering department; Professor F. F. Osborne, Geological Department, Laval University; Major-General J. V. Allard, Commanding Officer, and Major H. A. Cameron, Area Engineer, of Eastern Quebec Area, Department of National Defence, and Dr. I. W. Jones of the Department of Lands and Forests, Province of Quebec.

During these discussions, requests were made to the above individuals for all records of past construction work done in the vicinity of the Terrace, including forts, gun emplacements, water reservoirs, and drains. Information was also requested about previous rock falls of major dimensions, and about any earlier investigations that had been conducted into the stability of the Quebec escarpment. The available information was kindly supplied, and was supplemented at a later date by an examination of records at the Public Archives in Ottawa. A report on this initial inspection visit to Dufferin Terrace has already been presented.(3)

Observations were initiated in June, 1957, and because it was considered that climatic changes could have significant influence on deformations occurring in the rock escarpment, and also in the man-made structure of Dufferin Terrace, both of which are fully exposed to the elements, the observations were continued over a number of seasons until May, 1960. The results and interpretations of these observations are contained in this report.

DESCRIPTION OF DUFFERIN TERRACE

As viewed from the St. Lawrence river and Lower Town in Quebec City, the most prominent feature of Dufferin Terrace (Figures 1 and 2) is the massive masonry wall built on the top of the rock escarpment, and extending along the cliffs for a length of approximately 1500 feet, from the Chateau Frontenac at its northern end to a point below the Citadel at its southern end. This wall rests on vertically-standing limestone strata. The top of the wall is about 185 feet above the level of the St. Lawrence river, and from its base the cliffs descend at steep angles to Champlain and Little Champlain streets in Lower Town. These cliffs are sparsely covered with bushes and light tree growth, which afford very little protection to the exposed and irregular rock surfaces. As a result of the continuing erosion, a talus deposit has formed at the front of the cliffs, and has piled up against the rear walls of the buildings on Little Champlain street. A portion of the cliffs, at the site of the large landslide of 1889, has been graded to a uniform slope and paved with rip-rap to retard further erosion. When viewed from above, the Terrace has a broad expanse of wooden promenade deck, about 1500 feet



Courtesy of National Film Board

Figure 1. The Quebec escarpment and Dufferin Terrace

Courtesy National Film Board

Figure 2. Dufferin Terrace as viewed from Champlain Street

long and from 30 to 70 feet wide. The weight of this plank deck is not carried by the front masonry wall, but is independently supported by a steel framework. The construction of this supporting framework is shown in Figure 3, which was taken below the promenade deck. In this picture, the front masonry wall can be seen on the right. Some idea can also be gained from this illustration of the amount of loose rubble that has accumulated over many years.

In former years, a wooden walkway extended from the southern end of Dufferin Terrace and ran along the cliffs beneath the Citadel to the Plains of Abraham. This walkway deteriorated over the years and only faint traces of it remains today. In 1958, the Department of Northern Affairs and National Resources began the construction of a new and much more substantial walkway, which will be completed in the near future.

Maintenance work on Dufferin Terrace is the responsibility of the Department of Northern Affairs and National Resources. In general, this includes annual repairs to the masonry wall, replacement of deck planking, and barring down of loosened rock from the cliffs.

HISTORY OF DUFFERIN TERRACE

Since the early days of the settlement at Quebec the present site of Dufferin Terrace on Cape Diamond has been occupied by construction of some sort, but it is only since 1879 that the Terrace has existed in its present shape and dimensions. Remnants of older construction still exist, for beneath the northern end of Dufferin Terrace lie the remains of old Fort or Chateau St. Louis which was destroyed by fire in 1834.

Figure 3. Understructure of Dufferin Terrace

Originally erected as a fort on the edge of the cliffs by Samuel de Champlain in 1620, Fort St. Louis was enlarged as a chateau by his successor, Governor Montmagny, in 1647, and later rebuilt and extended by Frontenac in 1684. For over two hundred years it was the residence of French and English governors. Following its destruction by fire in 1834, the Earl of Durham cleared the site and in 1838 erected an observation platform known as Durham Terrace. This platform was enlarged in 1854 by the Honourable Jean Chabot, Member for Quebec and Commissioner for Public Works. In 1878, and as part of a comprehensive plan for city improvements, the Earl of Dufferin was instrumental in having the platform increased about four times in size and constructed to its present shape and dimensions. The structure was officially opened and recognized as Dufferin Terrace in April, 1879.

Few records are available on the occurrence of landslides from the cliffs at Cape Diamond, but in recent times the two largest occurred in 1841 and 1889. The former occurred on May 17, 1841, from an area of cliff in direct prolongation of St. Denis street. Little information is available on the circumstances, or about any corrective action that might have been taken. Apparently, however, an uneasiness continued to exist regarding the stability of the cliffs for, in 1880, a Mr. Charles Baillairgé of Quebec City was commissioned by Sir. H. Langevin, Minister of Public Works, to make an examination of the crevasses in the cliffs below the Queen's Bastion. In his report,(4) Mr. Baillairgé recommended that the houses on both sides of Champlain street should be vacated and that buttresses should be built between the above street and the face of the cliff. As a result, the Government purchased the property at the foot of the cliffs, demolished the houses thereon, and erected a wall eight feet high and three to four feet thick to serve as a screen or fender. According to Mr. Baillairgé the houses on the opposite side of Champlain street were not purchased, and these were the ones overwhelmed by the landslide in 1889. Mr. Baillairgé's report on this disastrous occurrence of September 19, 1889, is the only comprehensive account available about a landslide at Dufferin Terrace. In summary, he reported[4] that the steeply dipping limestone beds are not in normal, intimate contact but have, over the years, separated from one another and opened up fissures of substantial widths. His ideas about the condition of the cliffs are well illustrated in Figure 4, which has been reproduced from the Baillairgé report. This illustration suggests that the fissures extend for substantial distances along the strike of the beds and to depths he postulates to be about 100 feet. Mr. Baillairgé also reported on the strongly-jointed condition of the limestone beds and expressed the opinion that these lines of weakness traversing the rock mass, in conjunction with the numerous fissures opened up along the bedding planes, create an unstable rock foundation beneath Dufferin Terrace. His report concluded that when these numerous fissures and open joint planes fill with water a hydrostatic force is developed within the rock mass that can, over a period of years, sufficiently weaken the escarpment and eventually cause a landslide. The need for adequate drainage of the escarpment was emphasized. Mr. Baillairgé also suggested the construction of a retaining wall at the foot of the cliffs, about 300 feet long, 40 feet high, and 20 feet thick at the base, tapering to 15 feet thick at the top.

The landslide of 1889 caused severe loss of life and property damage in the Lower Town section of Quebec City and brought about the

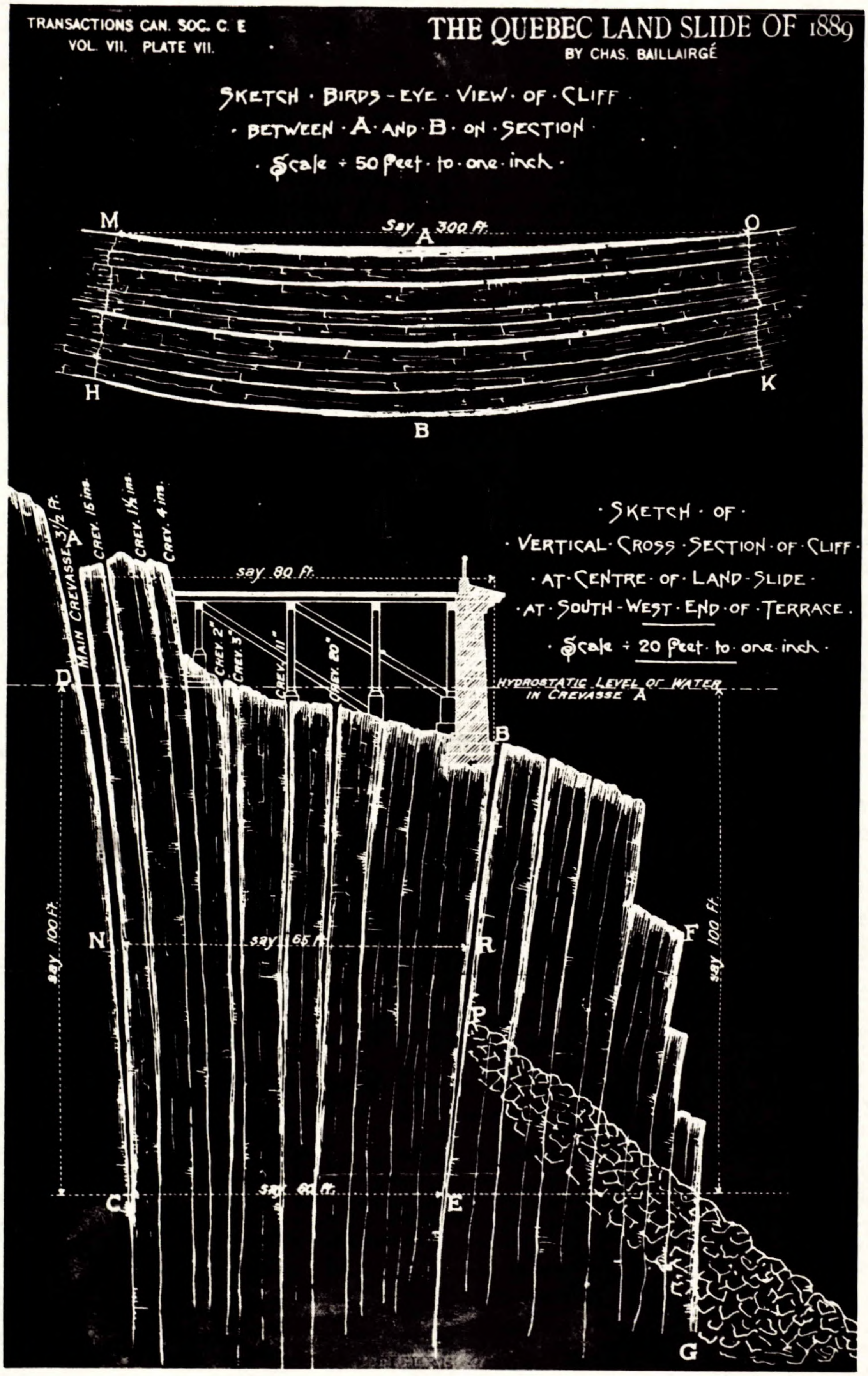


Figure 4. Fissures in cliffs according to C.Baillairgé

collapse of an extensive portion of the southern end of Dufferin Terrace. For three or four days preceding the landslide there had been heavy rainfall in Quebec City, and in the twelve hours immediately preceding the event the rainfall had amounted to 3.4 inches.

GEOLOGY OF QUEBEC CITY

A number of studies (5, 6) have been made on the geology of Quebec City and have provided useful information for this investigation. More recently, as has already been mentioned in this report, the Geological Survey of Canada made an examination in 1956 of the cliffs between Wolfe's Cove and the Rue de la Montagne, to assess the geological factors related to the recurrence of landslides.(1)

The rocks exposed on the escarpment at Dufferin Terrace belong to the Quebec City formation of Middle Ordovician age, and consist of dark grey, strongly-jointed limestone, and dark, calcareous shale. These rocks underlie most of the City of Quebec. The principal structural feature in the Quebec City area is a prominent syncline, known as the Quebec City syncline, that strikes northeast and plunges to the southwest. The steeply pitching southeast limb of this syncline forms the escarpment overlooking the St. Lawrence river. The strata exposed on the escarpment dip from 80 degrees northwest to 60 degrees southeast, and are in contact with the older, highly deformed, incompetent shales of the Citadel formation.

CLIMATE OF QUEBEC CITY

Because climatic conditions have a marked influence on the erosion rate of natural structures such as the Quebec City escarpment, it is useful to include in this report a few pertinent facts regarding the climate at Quebec City.

Although the City has been assigned by climatologists to the region of the Lower Great Lakes, it lies at the extreme eastern boundary of this region and borders the region of the Atlantic Provinces and that of the Laurentian Plateau. Meteorological reports indicate that Quebec City has a long-term annual average of 39.85 inches of total precipitation (water), made up of 27.48 inches of rain and 123.7 inches of snow (equivalent to 12.37 inches of rain). With respect to this total annual precipitation, the City is exceeded only by 13 other Canadian centres, of which nine are located in the Atlantic coast areas, two are on the Pacific coast, and the remaining two are the relatively nearby communities of Montreal and Chibougamau. It is therefore apparent that Quebec has a long-term record of abundant precipitation. It is also worth mentioning that, included in its total annual precipitation, Quebec City has much more snow than the above-mentioned coastal communities. Consequently, during the annual spring "run-off" period, much more water would have to be disposed of in Quebec than in any of the coastal cities. Table 1 is a record of precipitation.

The long-term average daily temperature at Quebec City is 39.2°F. The long-term average by months ranges from 10.4° in January to 66.7° in July. Table 2 is a record of mean temperatures.

TABLE 1

Precipitation at Quebec City in Inches

(10 inches snow is equivalent to 1 inch of rain)

Year		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total Year
72 Years average (1)	Snow	29.3	23.1	20.8	8.7	0.5	0	0	0	Trace	1.8	14.4	25.1	123.7
	Rain	0.52	0.43	0.94	1.48	3.10	3.68	4.02	3.98	3.60	3.23	1.79	0.71	27.48
	Total	3.45	2.74	3.02	2.35	3.15	3.68	4.02	3.98	3.60	3.41	3.23	3.22	39.85
1957 (2)	Snow	19.3	9.6	6.3	3.9	Trace	0	0	0	Trace	Trace	10.5	40.8	90.4
	Rain	1.03	0.46	0.26	1.47	1.57	7.57	5.16	1.91	6.44	3.19	3.92	2.29	35.27
	Total	2.96	1.42	.89	1.86	1.57	7.57	5.16	1.91	6.44	3.19	4.97	6.37	44.31
1958 (2)	Snow	34.1	36.4	17.0	2.0	0	0	0	0	0	0	16.4	34.3	140.2
	Rain	0.25	0.02	0.05	1.71	1.80	6.48	4.89	6.33	4.42	2.90	1.50	0	30.35
	Total	3.66	3.66	1.75	1.91	1.80	6.48	4.89	6.33	4.42	2.90	3.14	3.43	44.37
1959 (2)	Snow	25.5	18.8	29.0	1.5	0	0	0	0	0	9.4	20.3	25.8	130.3
	Rain	0.71	0	0.05	2.55	1.44	5.21	2.31	6.14	3.41	5.22	4.97	0.74	32.75
	Total	3.26	1.88	2.95	2.70	1.44	5.21	2.31	6.14	3.41	6.16	7.0	3.32	45.78
1960 (2)	Snow	37.0	59.4	14.3	3.20									
	Rain	0.02	1.38	0.89	4.01									
	Total	3.72	7.32	2.32	4.33									

(1) Climatic Summaries for Selected Meteorological Stations in Canada. 1954. Meteorological Division, Department of Transport, Canada.

(2) Monthly Meteorological Summaries for Quebec City. Meteorological Division, Department of Transport, Canada.

TABLE 2

Mean Temperatures at Quebec City, °F

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
72 Year Average to 1954[1]	10	12	23	37	51	62	67	64	56	44	30	16
1957[2]	4	17	27	39	52	61	65	61	56	46	35	22
1958[2]	18	13	32	41	50	56	66	62	55	42	32	6
1959[2]	11	11	21	38	55	59	72	64	58	43	30	19
1960[2]	12	22	23	37								

[1] Climatic Summaries for Selected Meteorological Stations in Canada. 1954. Meteorological Division, Department of Transport, Canada.

[2] Monthly Meteorological Summaries for Quebec City. Meteorological Division, Department of Transport, Canada.

PROBABILITY OF DAMAGE FROM EARTHQUAKES

When considering the stability of the cliffs at Dufferin Terrace and other parts of the Quebec escarpment, consideration should be given to the probability of earthquakes and to their effect on natural and man-made structures. The Dominion Observatory has compiled a Seismic Probability Map for Canada in which the country is divided into zones according to the expected damage from future earthquakes. On this map, two zones are outlined in which major damage may be expected, one of these being the coastal region of British Columbia, and the other being the Ottawa-St. Lawrence valley area. Further to this, it is useful to present a few excerpts from the paper, "A Seismic Probability Map of Canada", prepared in 1956 by Dr. J. H. Hodgson, Dominion Seismologist:

'Studies by E. A. Hodgson show that the St. Lawrence valley has a history of seismic activity dating back to the time of Jacques Cartier. The largest Canadian earthquake on record occurred in 1663; its epicentre was probably near the site of the 1925 shock. To judge by contemporary reports, the earthquake (1663) must have been as large as the San Francisco earthquake. Whole areas of forest were levelled by it and landslides caused by the earthquake dammed the St. Maurice river below Shawinigan Falls, causing it to change its course.'

'The history for the West Coast has been traced back to 1841 by W. G. Milne. He finds that several earthquakes with magnitudes of 7 or more, and at least one with a magnitude probably greater than 7.5, occurred in the years prior to the installation of sensitive seismographs at Victoria.'

'It seems clear that large earthquakes have been occurring in these two areas as far back as records are available. Earthquake damage in Canada has been low, not because of the lack of earthquakes, but because the earthquakes have not happened close to the large cities and towns.'

'In the St. Lawrence earthquake of March 1, 1925, (magnitude, 7.0), almost every building within the epicentral zone was damaged. Most chimneys within fifteen miles of the epicentre were destroyed and some stone churches were completely demolished. Even frame buildings, which normally resist earthquakes, were twisted out of shape. At Quebec, distant 80 miles from the epicentre, damage was confined to areas of bad ground. Minor damage was reported at distances in excess of 200 miles.'

'Experience suggests that a building on the side of a hill is more subject to damage than one built on the level.'

The above evidence provides substantial warning that earthquakes of minor and major magnitudes can occur in the Quebec City area. This probability should be taken into account when considering the safety of cliff-side structures along the Quebec escarpment.

MINES BRANCH INVESTIGATIONS

Preliminary Inspection

With the object of exploring the problem at first hand, a visit was made to Quebec City on April 22-25, 1957, by officers of the Mines Branch and of the Department of Northern Affairs and National Resources.

The general topography of the cliffs was first examined along Petit Champlain, the short street lying immediately below the Terrace and bordering the foot of the cliff. Talus from the cliff face has encroached upon the rear walls of the buildings which line the west (cliff) side of this street. Although structural details of the rock slopes below the Terrace were considerably obscured by loose rock produced by weathering action, and also by a light tree growth, prominent features observed were the sites of the two rock slides of 1841 and 1889 and the protruding mass of strata that lies between the sites of these two slides. Geological studies of the Quebec escarpment have shown that the strata are essentially vertical and are composed of strongly-jointed, medium to thick bedded limestones of Middle Ordovician age, with interbedded shales. Such a structure would tend to create an unstable rock mass. This preliminary reconnaissance also indicated that the thin, interbedded shales are less resistant to weathering than the limestones. A faster rate of erosion of a shale bed would tend to undermine and render unstable a superincumbent slab of limestone strata.

Visual inspection of the cliffs below the Terrace did not reveal any obvious channels for surface water down the inclined slopes, but the trickling of water across Petit Champlain street, and a more substantial issue of water into the city sewers near the intersection of Petit Champlain and Champlain streets, suggested that water was percolating through the mass of the cliffs. A light rain had fallen the evening before this inspection and, in addition, a residual sheet of ice was still melting below the board walk of Dufferin Terrace.

A substantial retaining wall has been built along the foot of the cliffs below Dufferin Terrace. This masonry wall begins near the intersection of Petit Champlain and Champlain streets, and continues southerly along Champlain street for several hundred yards. This is effective in preventing talus and rolling rock from reaching the highway. As already indicated, the buildings on the cliff side of Petit Champlain street actually perform the same function, and the above-mentioned retaining wall is a southerly extension of this row of buildings.

While the immediate problem as presented to the Mines Branch had to do with the stability of the escarpment below Dufferin Terrace, advantage was taken of this initial reconnaissance to inspect the cliffs south of the Terrace and as far as Wolfe's Cove. Between the Terrace and the Montgomery plaque, which is located approximately half-way along the Citadel, the foot of the cliffs bordering Champlain street appeared to be in a quite unstable condition, and rock falls of appreciable proportions could readily occur. Fortunately, there are no buildings along this stretch of highway. South of the Montgomery plaque, the cliffs lean back at flatter angles and less critical conditions exist.

Following this inspection in Lower Town, an examination was made of Dufferin Terrace. The accompanying Figure 5 serves to illustrate a typical cross-section through this structure, and a profile of the rock surface on which it has been erected. As indicated earlier in this report, the wooden promenade deck is supported wholly by the steel framework, and the masonry front wall carries its own weight only. The steelwork, wood decking and masonry are in good condition, having been repaired or renewed in recent years by the Department of Northern Affairs and National Resources. An examination was made of the masonry front wall, particular attention being paid to signs of movement as evidenced by cracking of this brittle structure. From this preliminary examination it appeared that movement, if any, must be of a very slow order and perhaps, also, sporadic in nature. Some evidence of a regular system of horizontal cracks was observed in these walls along the northern half of the structure. These fissures were quite narrow, with small horizontal displacements, and occurred from one-third to half of the way up from the base of the walls. Some irregular cracking in the walls was also observed at the southern end of the Terrace. The rock surface on which the Terrace has been built was obscured by debris and, at the time of this visit, a layer of ice.

Earlier studies of the cliffs[4] indicated that the rock is heavily fissured through separation of the vertically standing layers of rock along their bedding planes. Later attempts were made by other investigators to relocate these fissures by trenching at a number of points, and such efforts have traced a few of the fissures over short distances. The largest fissure observed during the 1957 visit of

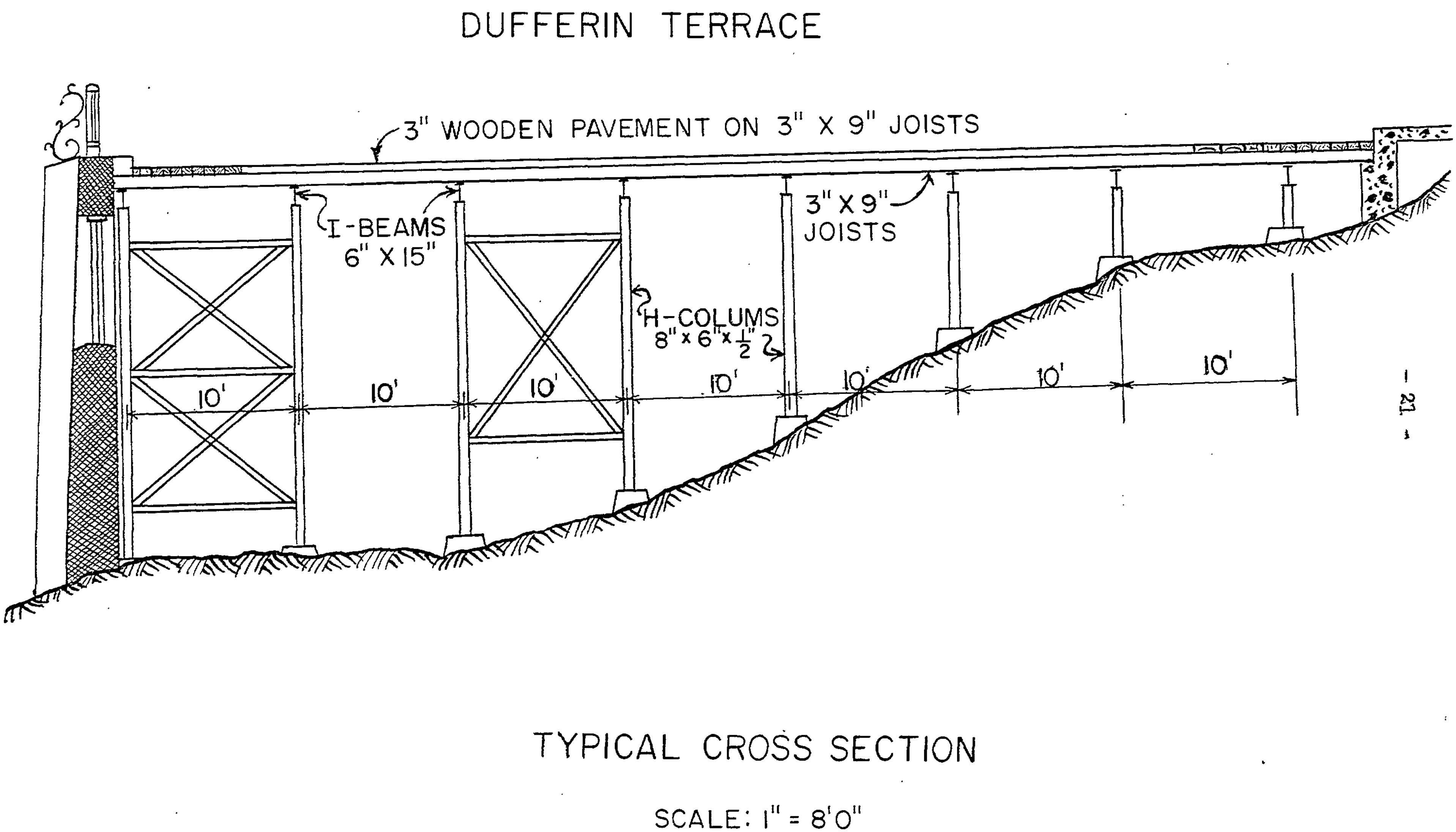


Figure 5. Cross-section of steel framework beneath Dufferin Terrace

inspection was located beneath the southern half of the Terrace. This fissure was approximately ten inches open at its widest part and, while ice projections on its sides prevented plumbing for depth, it appeared to extend downward for a considerable distance. Of interest was the fact that a concrete block had been placed between the sides of this fissure some years ago. Examination of this block in 1957 showed no sign of any appreciable movement having taken place between the sides of this fissure. The apparent inactivity of this fissure, which is located well back from the vertical face of the escarpment, raises questions as to its originating cause of fracturing and the rate at which it has been opened to its present width. It is difficult to accept differential weathering as a probable cause, but it is interesting to conjecture that a wrenching action during the two major rock slides, that have occurred from the cliff faces adjacent to this fissure, may have dynamically produced it as well as other fissures not observed during this examination.

It was also observed that a considerable volume of water was entering the strata behind the Terrace. This water was partly the result of natural run-off, but was being considerably added to by a habitual practice, adopted locally, of dumping snow and ice through hatches in the promenade deck. This snow and ice were cleanings from the toboggan slide and the skating rink that are annually constructed at the Terrace. Because this practice can only be detrimental to the stability of the Terrace, the Department of Northern Affairs and National Resources has taken steps to discourage it.

As a result of this preliminary inspection, it was decided that the investigations at Dufferin Terrace should have the following two objectives:

1. To observe, over a period of several years, the deformations occurring in the structure of Dufferin Terrace.

2. To learn the physical condition of the cliffs in this locality, particularly with regard to the existence of fissures of the size reported by C. Baillairgé.

To carry out this study on a cooperative basis, it was agreed that the Mines Branch would provide measuring apparatus and analyze the results, while the Department of Northern Affairs and National Resources would provide local assistants to take the readings and maintain the apparatus.

Observations of Structural Movements at Dufferin Terrace

Because no data were available from earlier studies the present investigation was faced with finding answers to the following questions:

1. What is the magnitude of ground movements, if any, at Dufferin Terrace?

2. Do any portions of the Terrace exhibit greater movements than the rest of the structure?

3. Are such movements seasonal in nature and perhaps associated with specific events such as a heavy rainfall?

Apparatus employed

To supply answers to the above it was considered necessary to install apparatus along most of Dufferin Terrace and to conduct observations over a cycle of one or more seasons. A further requirement was that the apparatus must be able to withstand exposure to wide variations of weather and over a considerable period. Furthermore, since the geologist's report indicated that movements across individual fissures were likely to be of small magnitude, it was considered necessary to select apparatus that would give the aggregate movement across a number of fissures.

For these studies, it was decided to employ suspended wire measuring assemblies, installed below the wood deck for protection against the weather as illustrated in Figure 6. Ten of these assemblies were installed along the Terrace as shown in Figure 7. Details at the anchoring points and the measuring scales are shown in Figures 8 and 9. When deciding on the type of wire to employ, consideration was given to Invar metal in order to reduce the effect of temperature changes but, since the manufacturer could not guarantee freedom from rusting, it was decided to use stainless steel wire of 1/16 inch diameter. The temperature coefficient of expansion of this wire is 0.000006 per degree Fahrenheit. The pulley used in the assembly was made of aluminum. It will be noted that each assembly was designed to give a vertical and a horizontal reading. Changes in the vertical reading, after due correction for temperature effects, would be indicative of movements occurring between the two anchoring points. Changes in the horizontal reading would indicate rotational movements in the main front wall of the Terrace, for the suspended weight on each assembly also functions as a plumb bob. It was appreciated that errors in readings could occur if slippage occurred at either anchor point in

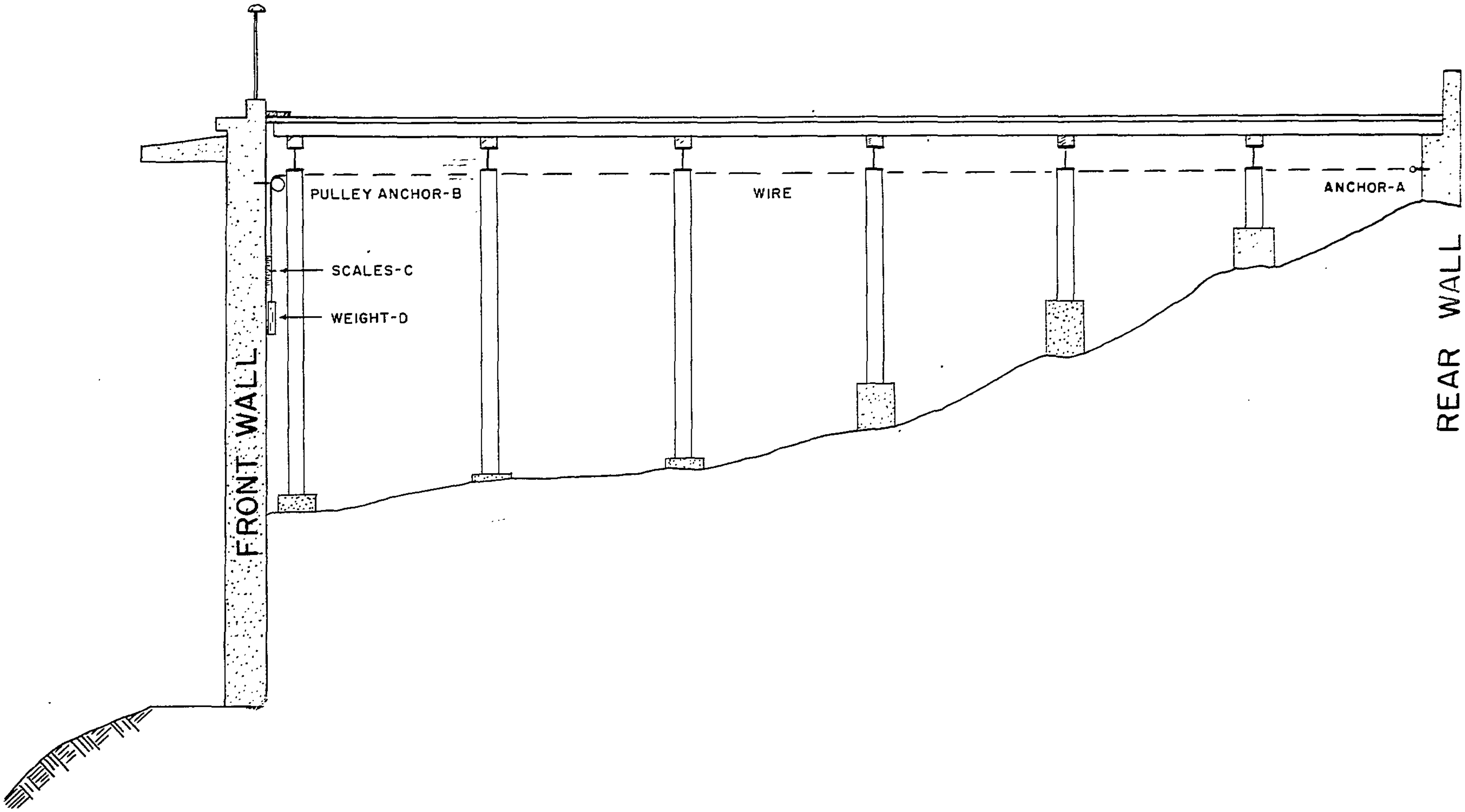


Figure 6. A typical suspended wire assembly

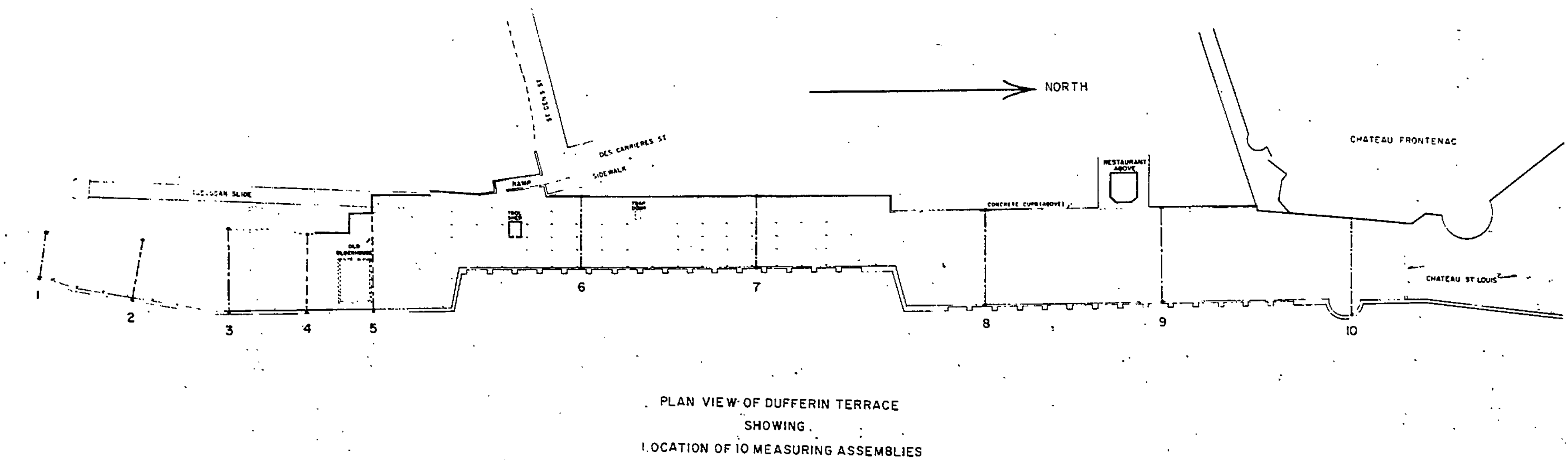


Figure 7. Location of ten observation stations at Dufferin Terrace

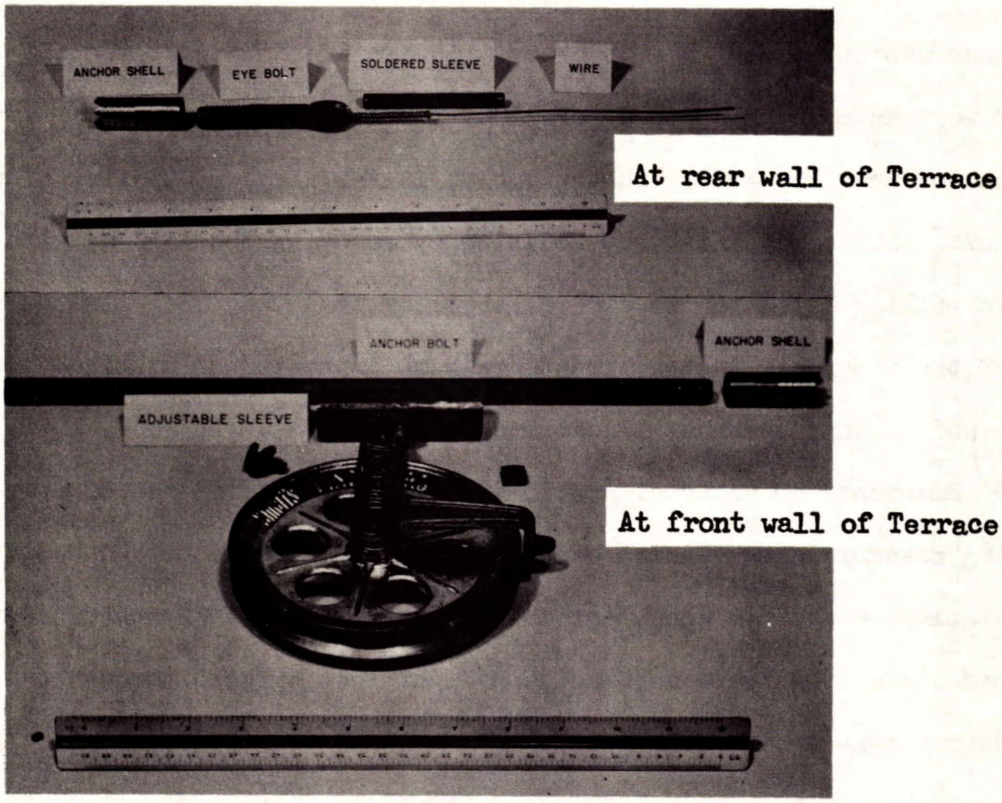
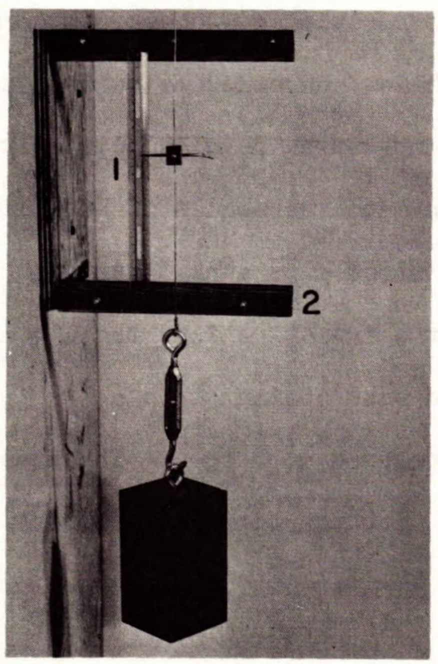


Figure 8. Details at anchoring points



1 - Vertical Scale.

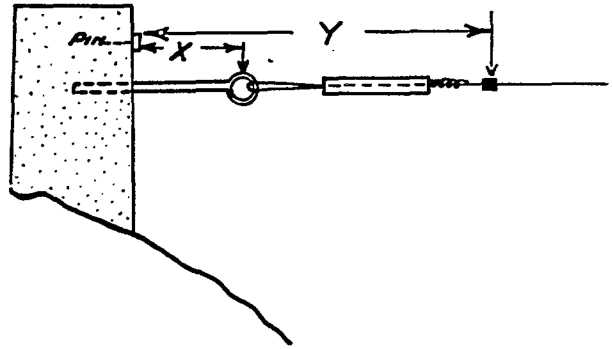
2 - Horizontal Scale.

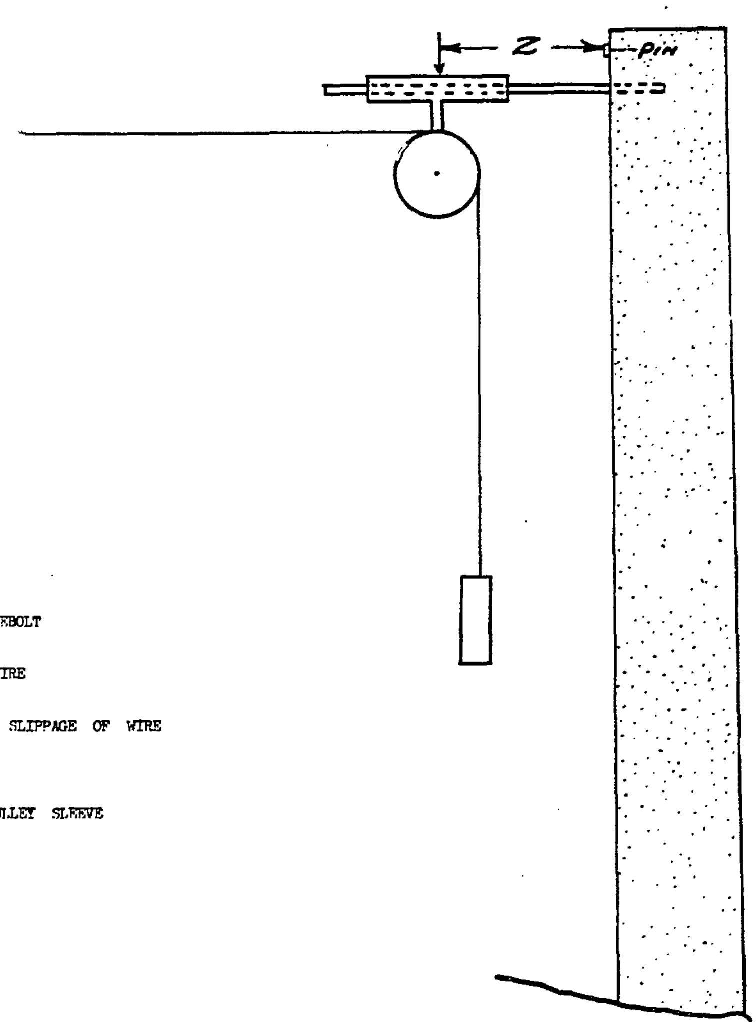
Figure 9. Details at measuring scales

each assembly, and as a check on this, reference measurements X, Y and Z were made as shown in Figure 10. The ten assemblies were installed on November 15, 1957. Subsequently, in February, 1959, five of these indicating assemblies were modified by removing the dead weights and installing automatic recorders, in order to obtain a continuous record of the movements. These recorders were installed at stations 1, 2, 4, 6 and 8, in the manner illustrated in Figure 11. In June, 1959, because of movements observed at stations 5 and 6, a special set of four recording assemblies was installed between stations 5 and 6, and between stations 6 and 7. These assemblies were installed on new concrete pedestals, that were carried down eight feet or more through the loose debris beneath the Terrace and anchor-pinned to the bed rock. These special pedestal assemblies are referred to in this report as stations 5-1/2 Upper, 5-1/2 Lower, 6-1/2 Upper, and 6-1/2 Lower. Figure 12 illustrates the pedestals and their attached recorders.

As a means of providing a check on the observations made with these wire assemblies suspended below the wooden deck of the Terrace, reference points were installed directly above each assembly on the top of the front and rear walls of Dufferin Terrace. These reference points were steel pins sunk flush with the concrete coping. During the course of the investigation, the distance between each pair of points was measured with a steel tape at various intervals, except when the Terrace was covered with snow. These measurements indicated any variations in the distance between the front and back walls of the Terrace.

Corrections were made to compensate for temperature effects





X - DISTANCE FROM POINT ON WALL TO NOTCH IN EYEBOLT

Y - DISTANCE FROM POINT ON WALL TO MARKER ON WIRE

THESE ARE CHECKS ON SLIPPAGE OF EYEBOLT ANCHOR AND SLIPPAGE OF WIRE FASTENING RESPECTIVELY.

Z - DISTANCE FROM POINT ON WALL TO NOTCH IN PULLEY SLEEVE

Figure 10. Reference points for checking anchor slip

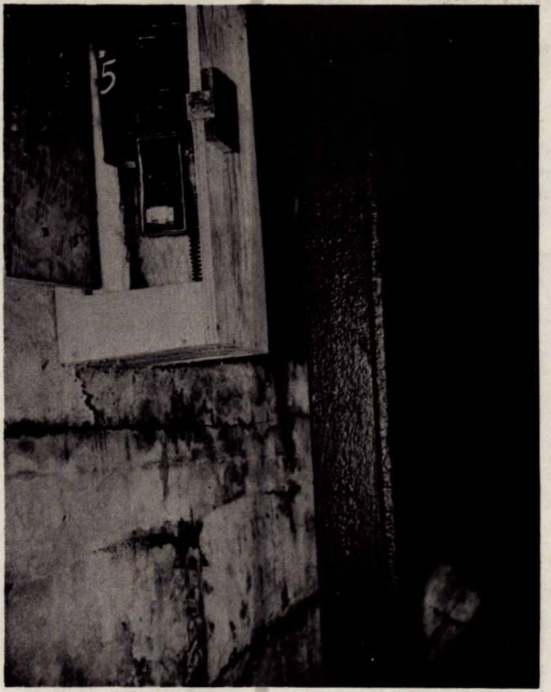


Figure 11. Automatic recorder installed on front wall of Terrace

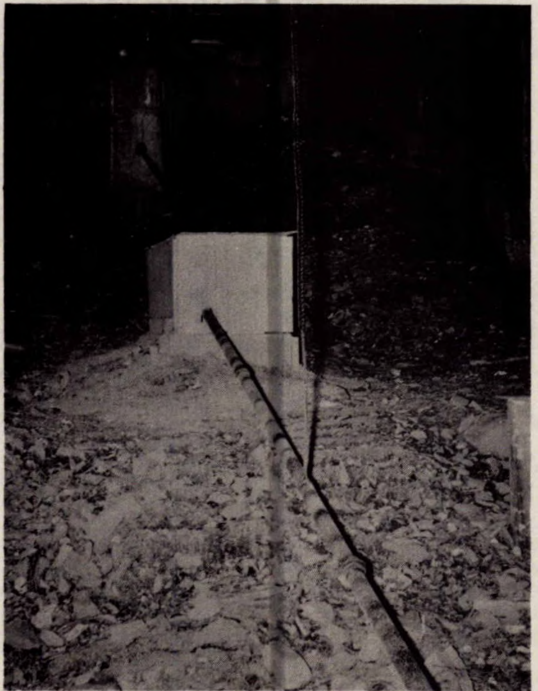


Figure 12. Special pedestals and attached automatic recorders

on the suspended wire assemblies and also the steel tape. In the beginning, an indicating thermometer was employed to obtain data on the temperature, but this was replaced later by a recording unit that was checked weekly. For additional details about the weather, particularly precipitation, arrangements were made with the Meteorological Division of the Department of Transport of Quebec to receive its monthly record of meteorological summaries.

As installed, therefore, the apparatus placed at Dufferin Terrace was as follows:

Ten suspended wire assemblies for observing total movements occurring between the front and back walls of the structure. The accuracy of reading with this kind of apparatus was considered to be around ± 1/8 inch.

Ten plumb-bob units to determine whether the movements observed with the ten assemblies were occurring in the main front rampart. Reading accuracy was considered as being approximately ± 1/8 inch.

Ten sets of top chaining points to serve as a check on the ten wire assemblies. Reading accuracy, about ± 0.02 foot.

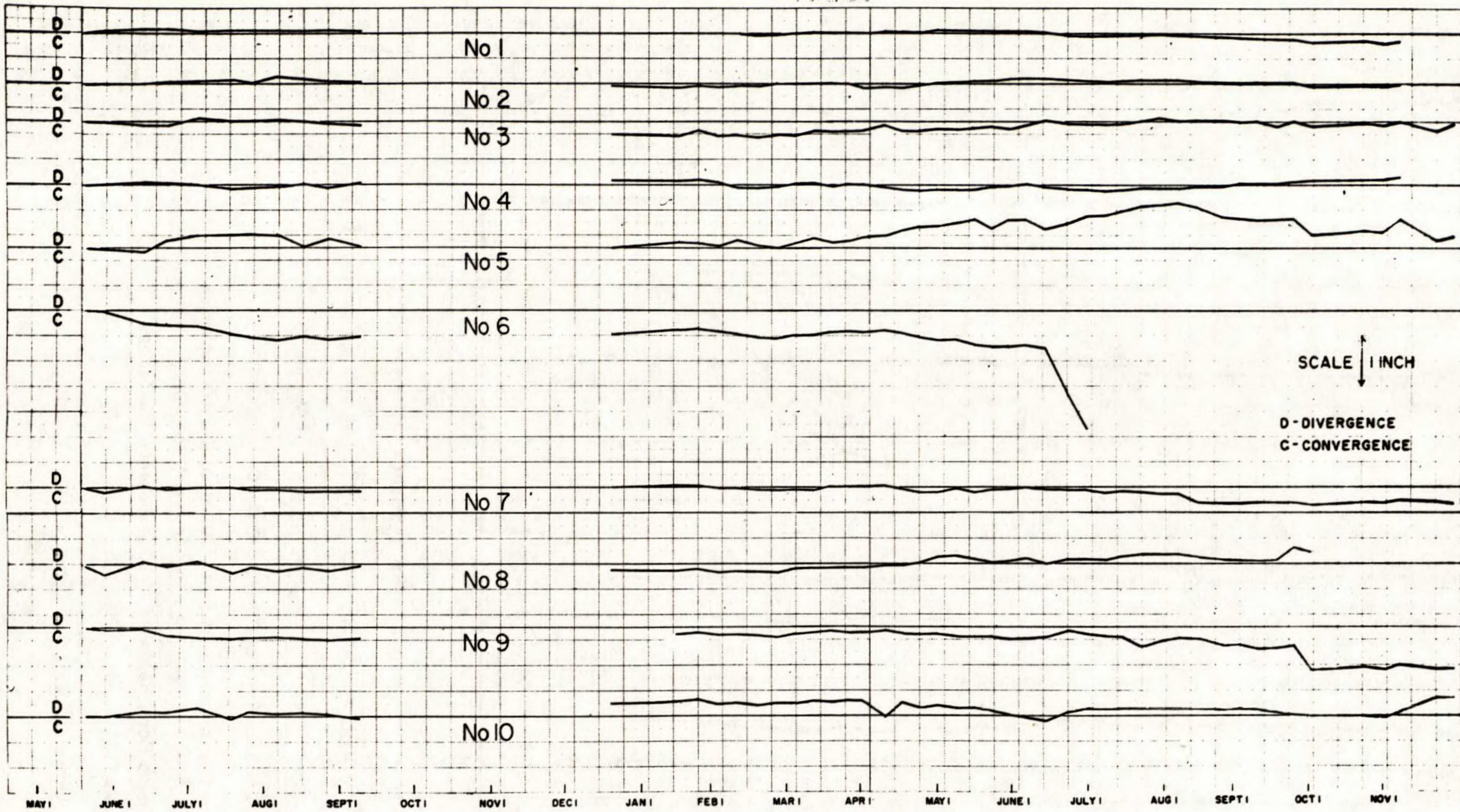
For a time, also, use was made of a dial type extensometer to observe movements occurring across one of the larger fissures exposed below the Terrace. This latter method was unproductive of results.

It must be reported that, despite precautions for protection the apparatus suffered heavily from vandals. The measuring assemblies installed in November, 1957, were all damaged to the extent that they had to be replaced in May, 1958. This nullified the observations during this first winter period. From time to time, thereafter, other parts of the apparatus were persistently tampered with or stolen. On each occasion the apparatus had to be examined, repaired, and a new reference point established from which to continue the measurements. These incidents are individually referred to in the accompanying data tables.

Results of observations of structural movements

The measurements made with the ten suspended wire assemblies are listed in Tables 3 to 17. These tables cover the whole period of observation, including the time when recording apparatus was in use at Stations 1, 2, 4, 6 and 8. The data have also been prepared in graph form, as illustrated in Figure 13, to show how the front and rear walls of Dufferin Terrace diverged or converged during the course of the study.

In further clarification of the movements illustrated in Figure 13, it may be added that divergence represents an outward movement (toward the river) of the front rampart of the Terrace. Conceivably, it could also represent an outward movement (toward the city) of the low rear wall of the Terrace, but such an outward movement of the rear wall is considered unlikely because this wall is built against earth fill or rock. Convergence, on the other hand, represents an inward movement of either the front rampart or the low rear wall of the Terrace. In order to determine whether the front rampart was participating in these converging or diverging movements, plumb-bob assemblies were installed, as already indicated, and the results are presented in Figure 14.



DUFFERIN TERRACE, QUEBEC CITY

OBSERVED MOVEMENTS AT STATIONS 1 TO 10

MAY 22, 1958 - NOVEMBER 14, 1959

Figure 13. - Movements observed at Stations 1 to 10.
(Net change from Base Date in inches)

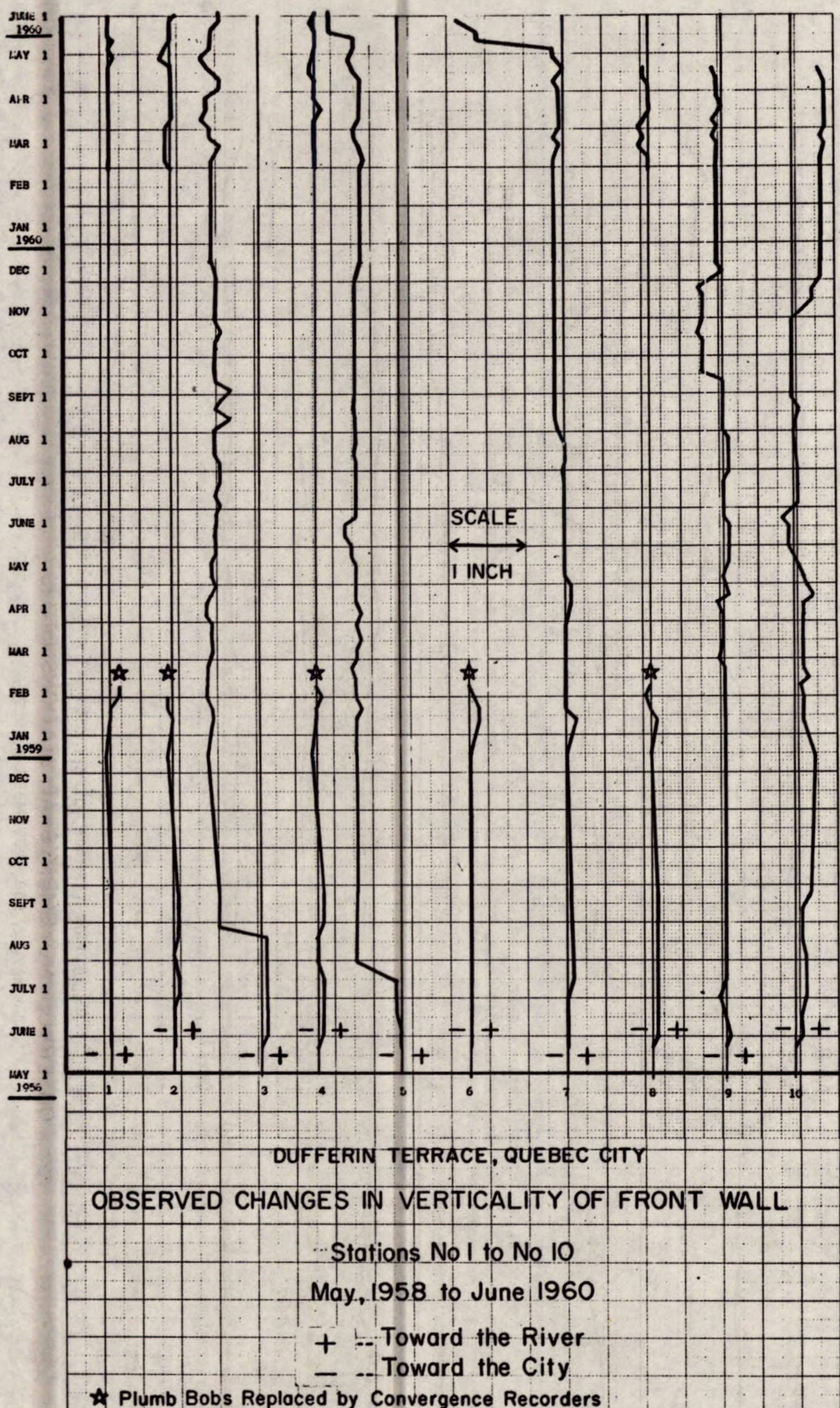


Figure 14. Changes in verticality of front wall of Dufferin Terrace

The observed changes in verticality of the front rampart of the Terrace are listed in Table 18, and graphically represented for all ten observation stations in Figure 14. For each station in Figure 14, any change to the left of its position in May, 1958, represents a shift of the front rampart toward the city , and any change to the right of this originally observed position represents a movement toward the river, or eastward . The observed movements could readily have been converted to degrees of inclination, but it is considered that a clearer idea of the magnitude of movement is imparted by presenting the actual movement, in inches, of the plumb-bob.

The measurements made with the four special pedestal assemblies are listed in Tables 19 to 22. It will be recalled that these assemblies were installed to investigate further the pronounced movements observed at Stations 5 and 6. These measurements have also been prepared in graph form, as illustrated in Figure 16, to show the amount of divergence and convergence that occurred between the anchoring points of each assembly.

Finally, the measurements made with a steel tape between points affixed to the front and rear walls of the Terrace are presented in Tables 23 to 32.

Before discussing the results of the observations, it is necessary to refer back to a statement, made earlier in this report, that the accuracy of reading the scales on the suspended wire assemblies, including plumb-bob readings, was ± 1/8 inch (± 0.12 inch), and for steel tape measurements it was ± 0.02 foot (± 0.24 inch). The data will therefore be analyzed in the light of these accuracies, and only those changes that are of a greater order of magnitude will be considered as indicating actual movements. Also, for readier reference, the discussions will be based on Figures 13 and 14, although the detailed lists of data in Tables 3 to 32 are available if required.

Referring to Figure 13, it will be observed that Stations 1, 2, 4 and 8 showed remarkable stability over the whole observation period, for the movements observed did not exceed the accepted observation error of ± 0.12 inch. This absence of movement is confirmed in Figure 14, where these same stations also indicate that no significant motion occurred in the main front wall at these four locations.

Stations 3, 7, 9 and 10 are a group of four stations that appeared to be stable during most of the observation period, but there are indications that sporadic movements did occur at each location. At Station 3, Figure 13, a convergence of approximately 1/4 inch was observed during the autumn of 1958, and this is confirmed reasonably well by the action shown at this station in Figure 14. The combined evidence indicates that around September, 1958, the front wall at Station 3 swayed toward the city (upper town) by approximately 1/4 inch. At Station 7, the Terrace remained quite stable until August, 1959, when, as illustrated in Figure 13, a convergence of approximately 1/4 inch occurred. The direction and time of this movement are confirmed in Figure 14, in which the front wall at Station 7 is shown as having moved toward the city (converged) in August, 1959. In May, 1960, as indicated in Figure 14, a more pronounced move of the front wall occurred at Station 7, and again in the direction of the city. This latter event occurred during the final month of the investigation, after the suspended wire assemblies had been removed. At Station 9 there is some evidence, as indicated in Figure 13, that a converging movement of something less than 1/4 inch occurred in June, 1958. Reference to this station in Figure 14 also indicates that there was some instability of the front wall in this same month. A more definite amount of convergence took place at Station 9 in September, 1959. This can be seen by reference to Figures 13 and 14. The movement was of the order of 1/4 to 1/2 inch, and was at least partly associated with a movement of the front wall toward the city. This movement could also have been partly caused by an inward movement of the low back wall of the Terrace. At Station 10, as illustrated in Figure 13, a diverging movement of around 1/4 inch occurred during the autumn of 1958. The direction and time of this movement are confirmed in Figure 14, on which the front wall at Station 10 is shown as having moved toward the river (diverged) in September, 1958. Subsequently, as shown in Figures 13 and 14, the data indicate that the front wall regained its original position early in 1959 and conditions then remained stable until November, 1959. At this latter date, the evidence is that the main front wall again moved, or swayed, toward the river (diverged) by an amount in excess of 1/4 inch.

The largest movements were observed at Stations 5 and 6. At Station 5, Figure 13, a diverging movement of approximately 1/4 inch occurred in June, 1958. Reference to this station, in Figure 14, also indicates front wall instability during June and July, 1958, but that the movement was a convergence, not a divergence. It is difficult to explain this inconsistency, unless the front wall moved outward at its foot and increased its inward slant at the same time. Further reference to Figure 13 indicates that a more pronounced divergence began at Station 5 in April, 1959, and continued to increase until the following August. The maximum movement involved during this period amounted to nearly one inch of divergence. During this same period, as shown in Figure 14, the front wall showed only brief and minor changes in its verticality, suggesting that it moved bodily outward with little change in inclination.

The most abrupt movements observed during the investigation occurred at Station 6. A definite convergence was observed in July and August, 1958, amounting to approximately 1/2 inch. Thereafter, until May, 1959, no appreciable movement was observed at this location. In May, 1959, there was evidence of renewed activity, followed by a sudden and quite substantial convergence on June 7 and 10. Figure 15 is a reproduction of the chart taken from the automatic movement recorder that was employed at Station 6. The abrupt nature of the movements is apparent, and it may be mentioned that this type of sudden movement is typical of what has been observed at Dufferin Terrace. Reference to Figure 14 will show that, despite the convergence observed in July, 1958, at Station 6, no changes were observed in the verticality of the main front wall, indicating that it was very likely remaining stationary. This left the possibility that the convergence was caused by an inward movement of the rear wall of the Terrace. Following the more substantial convergence of June, 1959, the rear wall was examined by the Department of Northern Affairs and National Resources, and it was found that the rear wall had cracked at this location and had been thrust forward. It is considered that the break was caused by earth pressure against the wall.

In Figure 16 are illustrated the movements observed with four

Assembly No 6

Dufferin Terrace, Quebec City.

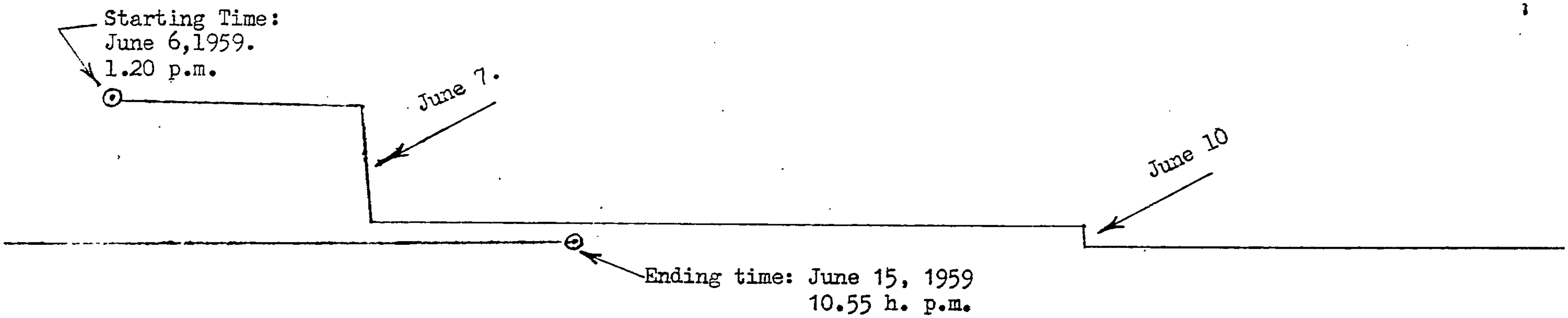
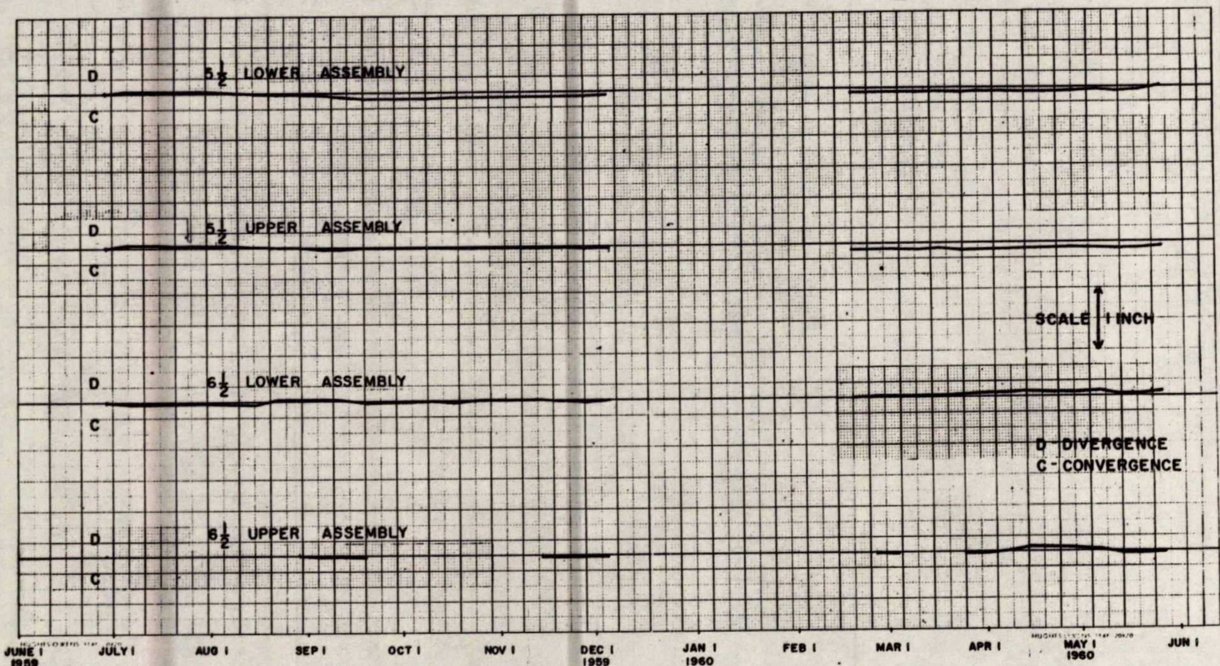


Figure 15. Automatic recorder chart for June 7 and 10, 1959



DUFFERIN TERRACE, QUEBEC CITY
OBSERVED MOVEMENTS AT STATIONS 5½ & 6½

SPECIAL PEDESTAL ASSEMBLIES USING DAVIS CONVERGENCE RECORDERS

JUNE 1959 - MAY 1960

Figure 16. Movements observed at special pedestal stations

special installations that were made to check the observed instability at Stations 5 and 6. From June 1959 to May 1960, during which time these stations were under observation, no significant amount of movement was recorded. This suggests a period of stability at this portion of Dufferin Terrace.

With regard to the measurements made with the steel tape, it was found that this method was not accurate enough for observing the small movements occurring in the walls. As already indicated, it was expected, at the start of the investigation, that the observation error would be at least of the order of $\pm$ .02 foot, or approximately 1/4 inch. Consequently, the tape measurements were expected to be useful only if relatively large movements occurred, say in excess of 1/2 inch. In only a few instances, mainly in the cases of Stations 5 and 6, were movements of this magnitude observed. It is therefore considered that the tape measurements provided no useful information on the movements observed during the course of this study.

Having reviewed the movements observed at various times along Dufferin Terrace, it will be useful at this stage to comment on the precipitation records that cover the period of investigation, and to see how these are related to the movements observed. Reference to Table 1 will show that the years 1957, 1958 and 1959 had appreciably greater total precipitation than the 72-year average. The summer of 1958 was very wet, particularly during June and August, when the rainfall amounted to 6.48 inches and 6.33 inches, respectively. The 72-year averages for these two months are 3.68 inches and 3.98 inches. Dur- this summer period of 1958, increased movements were observed at

Stations 3, 6 and 5. In 1959, the months of October and November had exceptionally heavy precipitation. A good deal of this was snow, but since the mean temperatures for these two months were 43 degrees and 30 degrees respectively (Table 2), it can reasonably be assumed that this snow turned to ground water relatively soon. During these months, particularly in November, increased movements were observed at Station 10. In 1959, also, there was greater than average rainfall during June and August. During these months increased movements were observed at Stations 5, 6 and 7. It would therefore appear, from the above observed relationship between precipitation and observed movements, that there is some association between the two. It would also appear that precipitation does not have a uniform effect along the Terrace, but that certain portions of the structure may be more prone to movement than others as a result of precipitation.

In summary of the investigations into the structural movements at Dufferin Terrace, the results indicate that the Terrace is subject to wall movements of a sporadic nature, with some indication that these movements are partly associated with precipitation. The Dufferin Terrace cannot therefore be considered as a stable structure over the long term.

Observations of Strata Conditions at Dufferin Terrace

An early report[4] had indicated the existence of fissures of very substantial widths, up to 3-1/2 feet, and considerable lateral and vertical dimensions. It was considered useful, therefore, to explore the cliffs below Dufferin Terrace and obtain information on the location and dimensions of fissures in these vertically standing limestone and shale strata. As indicated earlier in this report, the largest fissure observed during the initial inspection of April, 1957, was approximately ten inches wide.

Two methods for examining the fissures were considered. One was to trench to bed rock and expose the strata, and the other was to examine the rock through boreholes. The latter method was adopted because of the deep layer of broken material covering the rock beneath most of the Terrace, the undesirability of trenching through lawns on the landward side of the Terrace, and the hazards of excavating on the steep forward slopes of the escarpment. It was also decided that the drilling should be carefully supervised and conducted with the object of obtaining the maximum amount of information. For this latter reason, the drilling was not contracted to a private drilling firm, which might be more interested in a fast drilling rate than in obtaining information. The drilling was carried out by the Department of Northern Affairs with the assistance of Mines Branch officers.

The necessary drilling was started in June and completed in July of 1957. The locations of the 2-1/4 inch diameter boreholes and the directions in which they were drilled are shown in Figure 17. The manner in which the boreholes traversed the cliffs beneath the southern

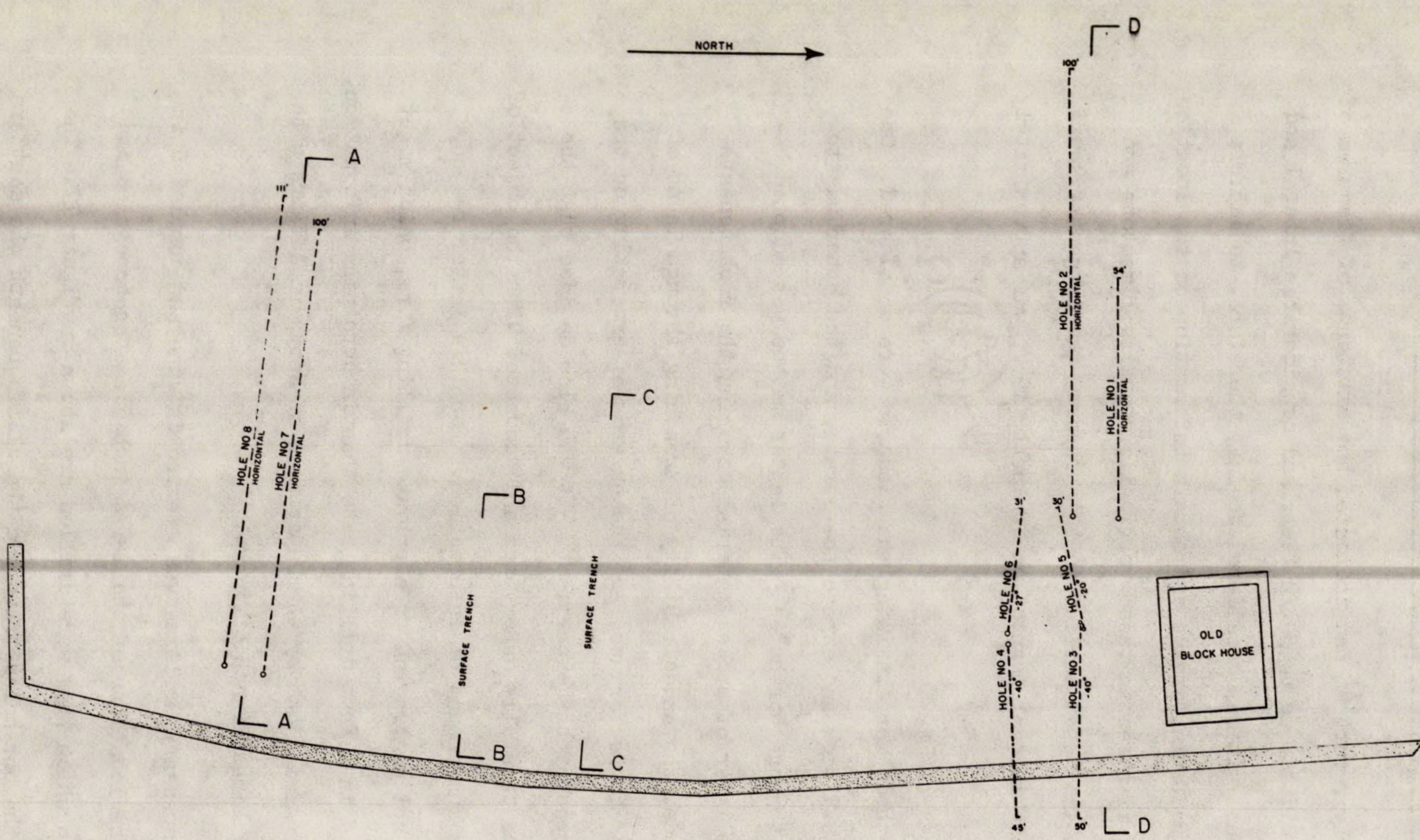
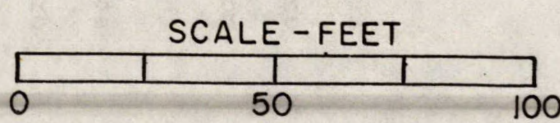


Figure 17. Exploratory holes drilled at Dufferin Terrace



end of Dufferin Terrace is illustrated in Figure 18. This is the area specifically referred to in the Baillairgé report as being dangerous.

At two locations, B - B and C - C, in Fig. 17, beneath the southern end of Dufferin Terrace, the rocks were sufficiently exposed to justify a limited amount of trenching. The information on fissures obtained in these shallow trenches was used to supplement that obtained from the boreholes.

The rock cores obtained by this diamond drilling program were examined later by Dr. D. K. Norris of the Geological Survey of Canada. Dr. Norris' report on the log of horizontal hole Number 2 is given in Appendix A of this report.

Apparatus employed

It was proposed to examine the walls of the boreholes and determine the number, location and approximate widths of the fissures. No apparatus was available for this kind of borehole observation, although the United States Bureau of Mines had developed a scope that was limited in use to a borehole depth of around 20 feet, and also had a light source of fixed intensity for illuminating the borehole. It was therefore necessary to develop a borehole viewer suitable for the Quebec requirements. This unit, developed by L.C. Richards of the Mining Research Section, is illustrated in Figure 19. The cylindrical unit in the foreground encloses the prism and light source, and is fed along the borehole with a 1/8 inch diameter rod. Viewing was done with a transit telescope set up at the mouth of the borehole. The control

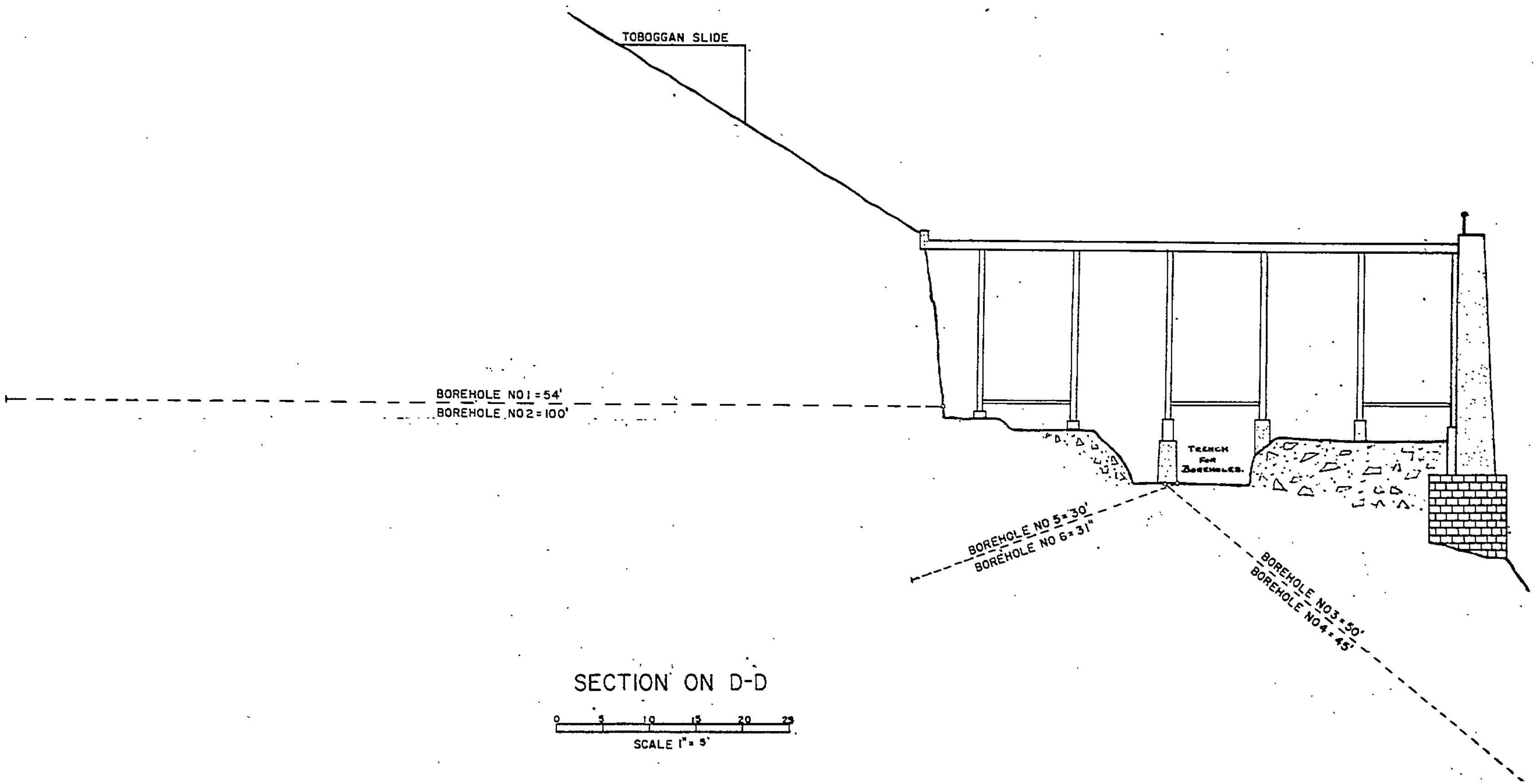


Figure 18. Sectional view through boreholes at Dufferin Terrace

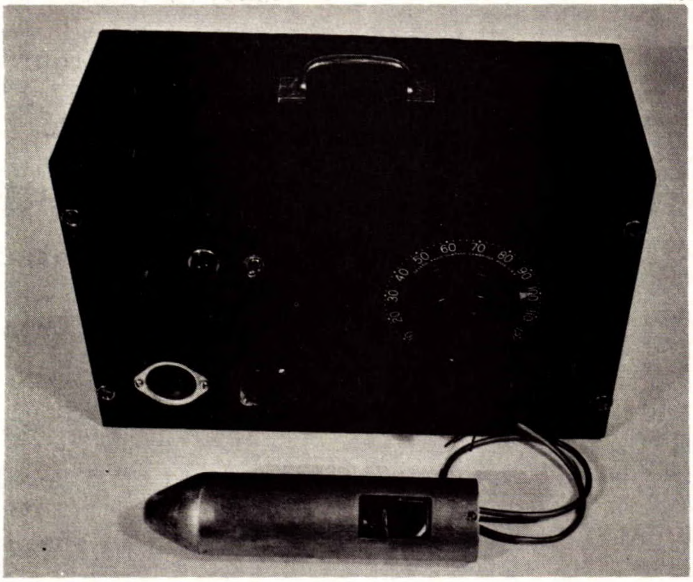


Figure 19. Borescope employed at Dufferin Terrace

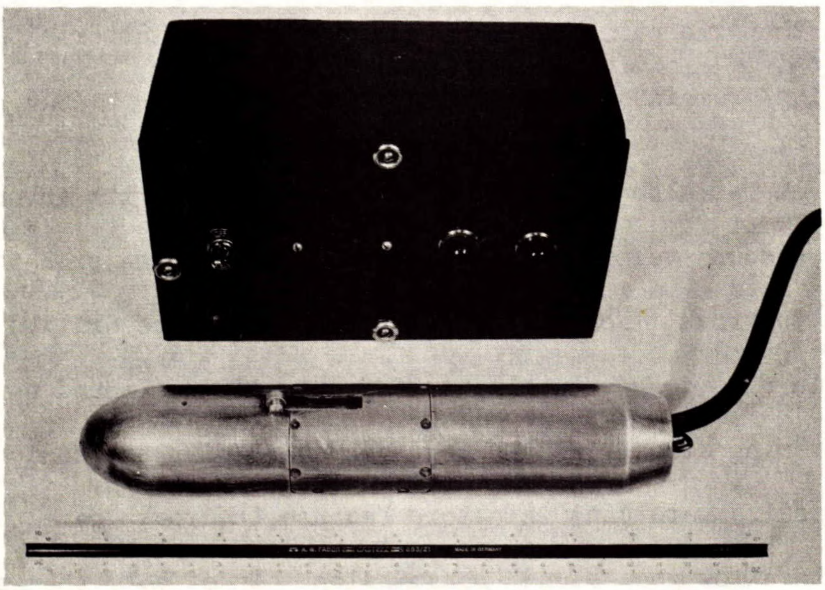


Figure 20. Electrical crack detector

box in the background of Figure 19 contained a variac transformer for increasing or decreasing the power fed to the light source, and thus controlling light intensity on the borehole walls. This ability to increase light intensity was found to be essential, particularly at depth in the hole. At distances of up to 50 or 60 feet, fissures as small as 1/8 inch in width could be readily observed and their sizes estimated.

Another borehole examining device was also developed by L.C. Richards. This unit, illustrated in Figure 20, is essentially a "feeler" device that is moved along the borehole and actuates an electrical contact whenever a fissure is encountered. A green light on the control panel indicates unbroken wall in the borehole, but a red light flashes on when the feeler enters a fissure, and remains on until the fissure is passed. The unit was satisfactory for fissures crossing a hole at sharp angles, but failed when fissures were encountered that ran parallel to the hole. In this latter situation, the red light remained on constantly.

It was also proposed, at the beginning of the investigation, to employ a sound-velocity method for determining the presence of breaks in the rock. For this reason, the holes were drilled in pairs, as shown in Figure 17, to allow the propagation of sound waves across the intervening strata. Tests were conducted with the sonic apparatus, but the results were unsatisfactory because the rocks were much too fissured to allow good sound transmission. In effect, the apparatus which was designed for underground use was much too sensitive an indicator of breaks to use in the presence of open fissures of substantial widths.

Considerable difficulty was experienced during the borehole examinations because the strata were even more broken than was anticipated. This resulted in a continual dropping of small pieces of rock from the sides of fissures into the borehole. At times, the obstructions appeared to be fine material, such as mud filling from the fissures. The holes also contained water. As a result it was not usually possible to explore the holes to the full depth to which they had been drilled. Information about these unexplored parts was obtained by examination of the recovered core for evidence of fissuring.

Results of observations of strata conditions

Figures 21 and 22 illustrate the fissures observed in the boreholes drilled in the escarpment. As already indicated, advantage was taken of two favorable locations in the vicinity of the boreholes to trench to bed rock and expose the tops of certain fissures. The results are illustrated in Figures 23 and 24. The widest fissures exposed by this trenching were 8 inches and 22 inches, respectively. In summary of the results of the borehole examinations and surface trenching, the main fissuring was observed to follow the planes of stratification, and was associated with less prominent breaks perpendicular to these bedding planes. No fissures were observed as wide as those reported by earlier investigators but despite this it is considered that the views expressed by C. Baillairgé with respect to water infiltration are still sound, for a multitude of smaller fissures can be quite as effective as a few larger crevasses in allowing water to enter the rock mass.

To summarize, the examination of the steeply inclined strata at Dufferin Terrace indicates that they are heavily fissured and permeable to water. The escarpment should therefore be regarded as a weak geological structure.

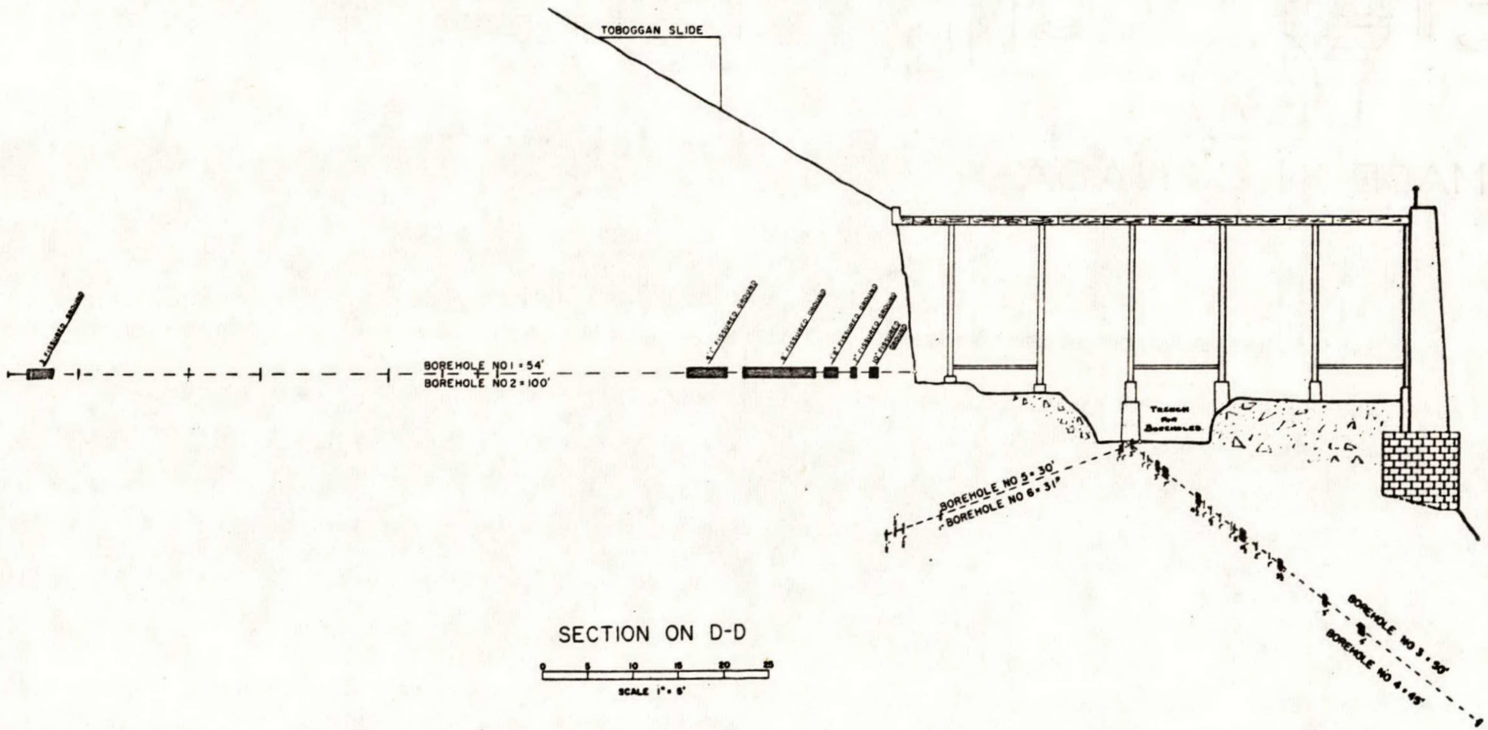


Figure 21. Fissures observed in boreholes 1 to 6

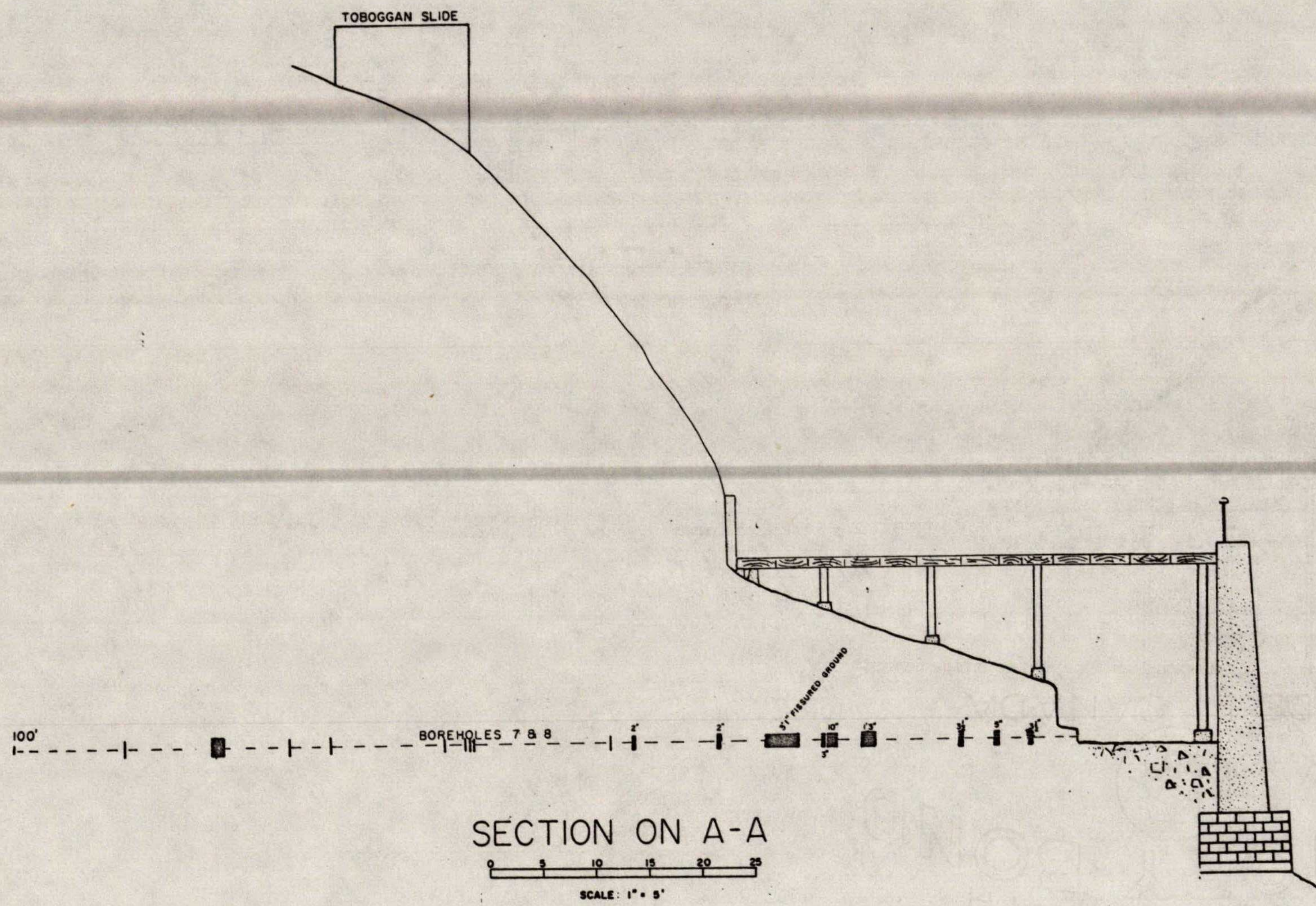
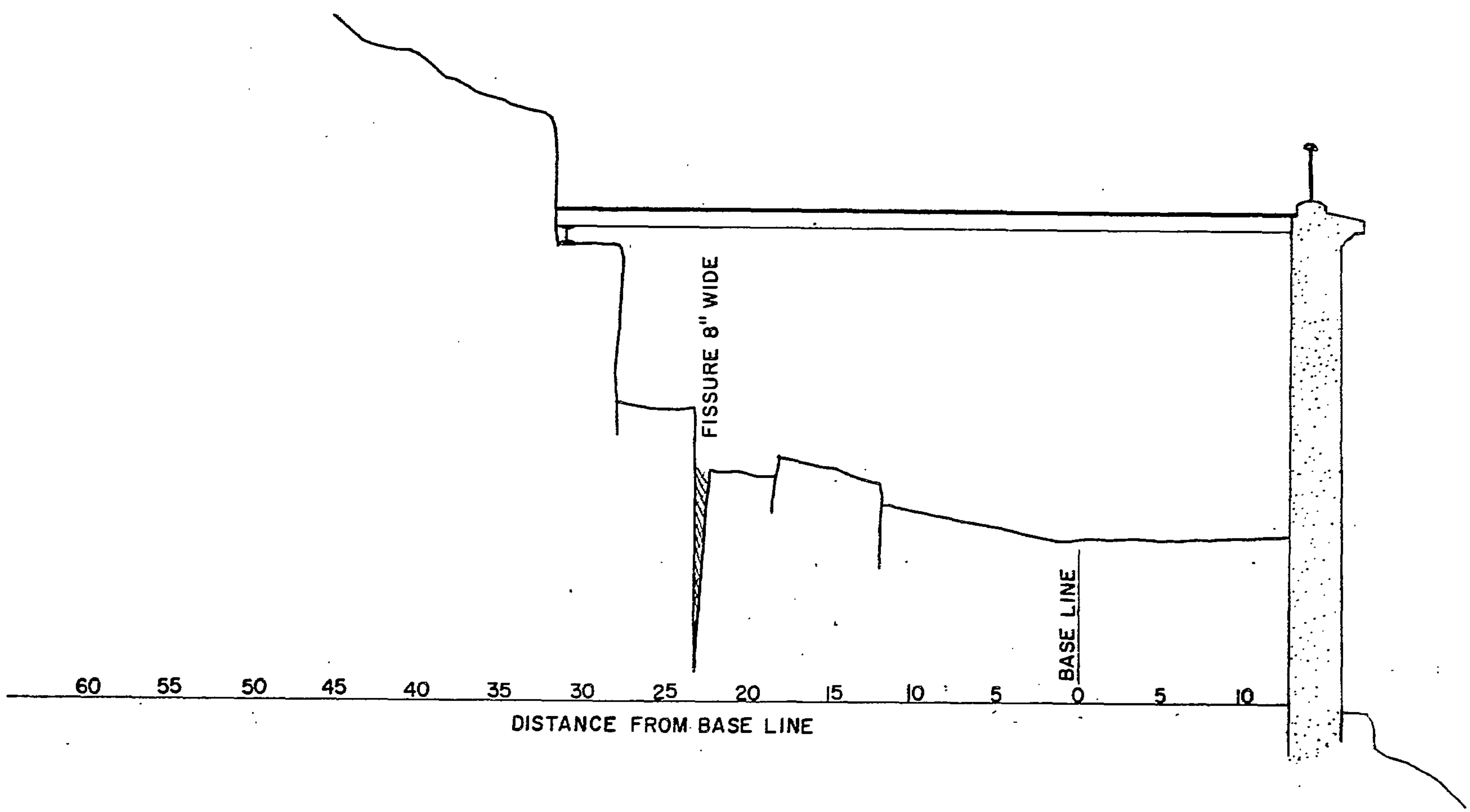
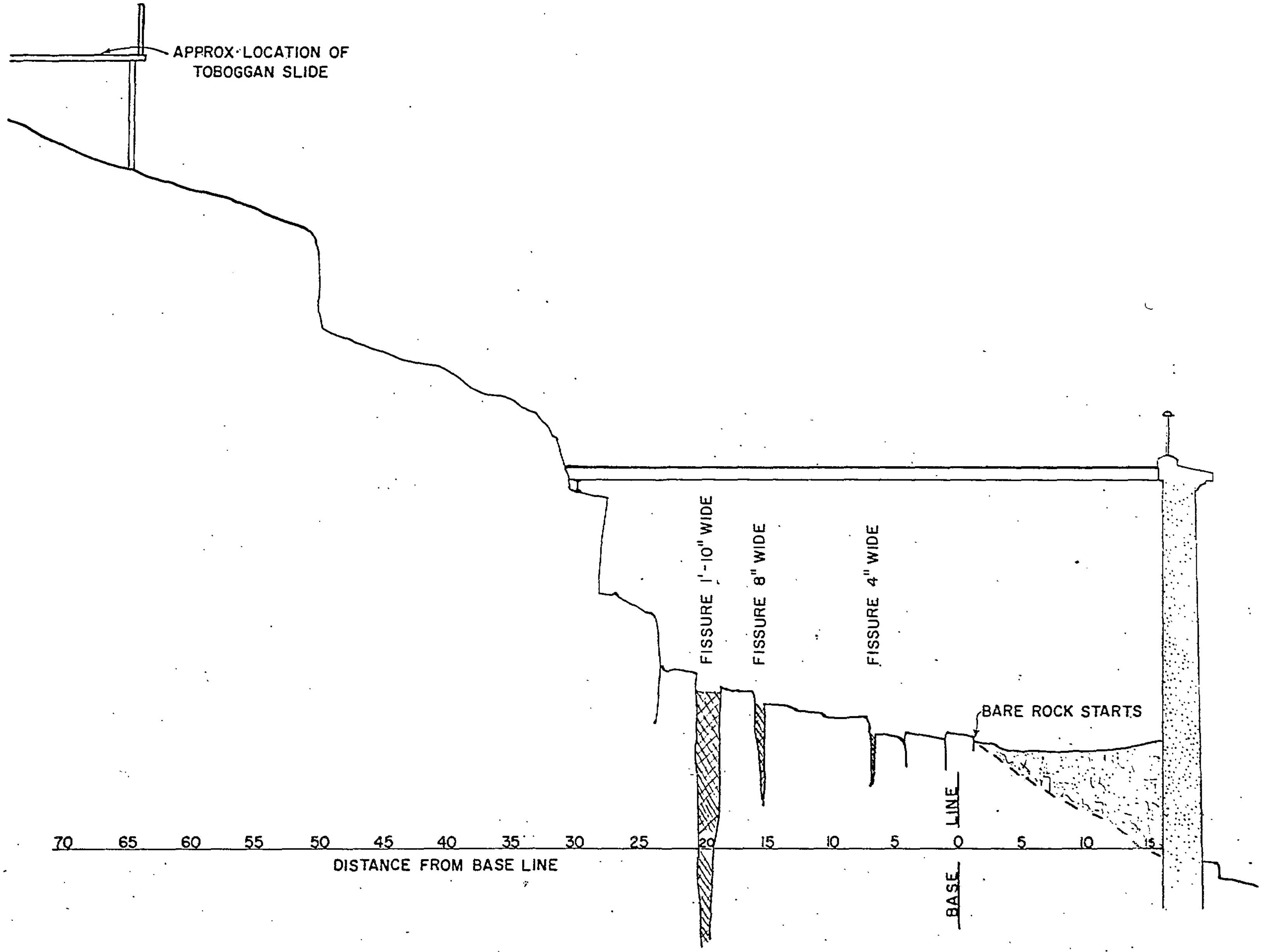


Figure 22. Fissures observed in boreholes 7 and 8



SECTION ON B-B

Figure 23. Fissures observed in trench at section B-B, Figure 17



SECTION ON C-C

Figure 24. Fissures observed in trench at section C-C, Figure 17

ROCK BOLTING AT DUFFERIN TERRACE

On June 20, 1958, the Public Works Department of Quebec City requested the Department of Northern Affairs and National Resources to take remedial action with respect to a rock exposure near the southern end of Dufferin Terrace. Because the rock in question lay on the dividing line between property owned by the Department of Northern Affairs and National Resources and property under the control of the Department of National Defence, the latter Department was also requested by the City of Quebec to assist in any remedial action. The City recommended two possible courses of action: one, to take down the rock; and the other, to buttress it. A view of the rock exposure as seen from on top of the wooden promenade deck of the Terrace is given in Figure 25, and the continuation of the same rock below the deck is shown in Figure 26.

Upon receipt of the above request, the Department of Northern Affairs and National Resources sought the advice of the Mines Branch. Recommendations as to corrective measures were not within the scope of the Mines Branch investigation, which was limited to a study of rock movements, but when requested for an opinion by the Department of Northern Affairs and National Resources it was indicated that a form of buttressing was considered preferable to taking down the rock slabs in question, as this latter method would involve blasting. It was further indicated that buttressing or consolidating by a rock bolting

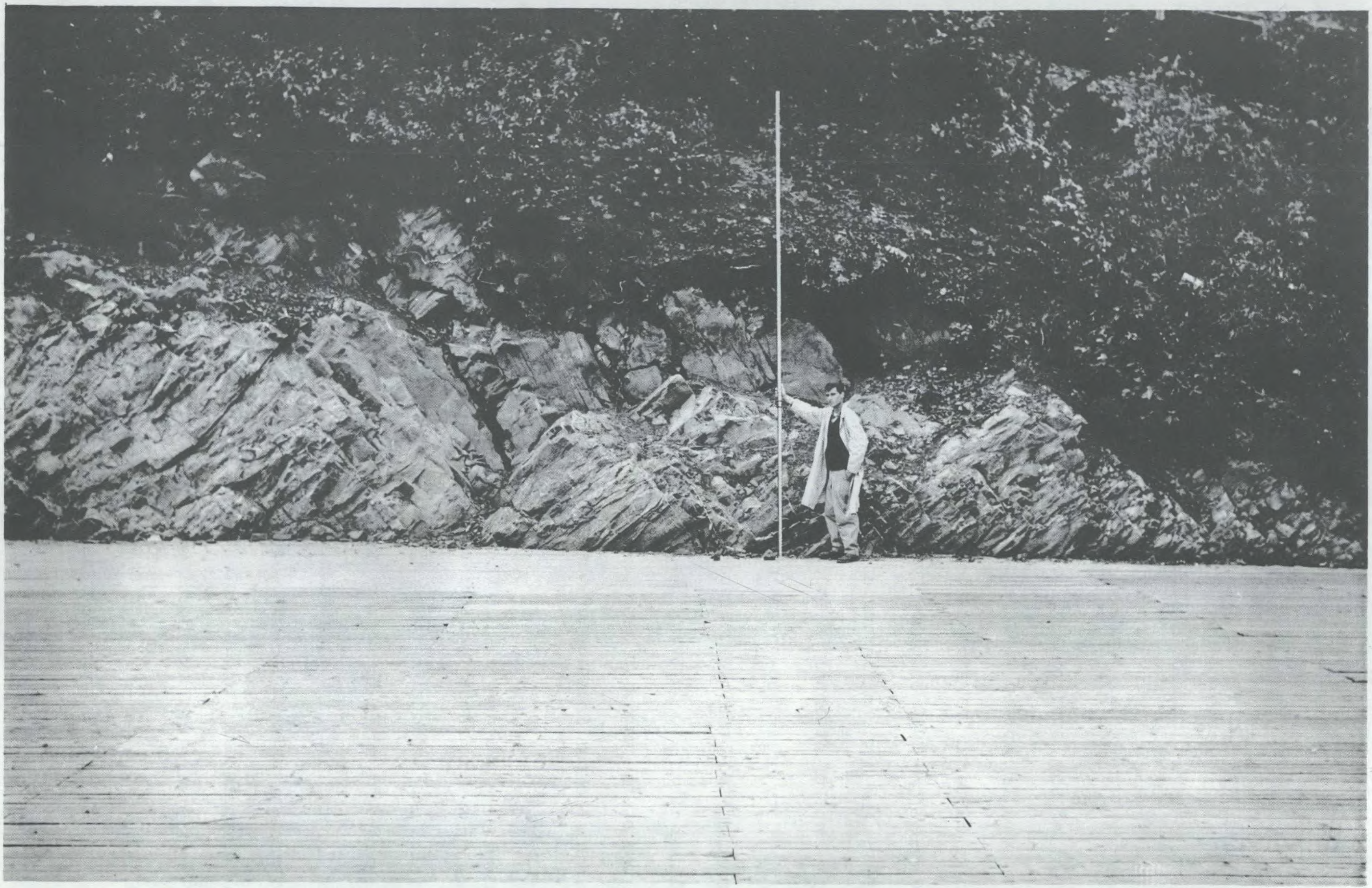


Figure 25. Site of rock bolting, above promenade deck of Terrace

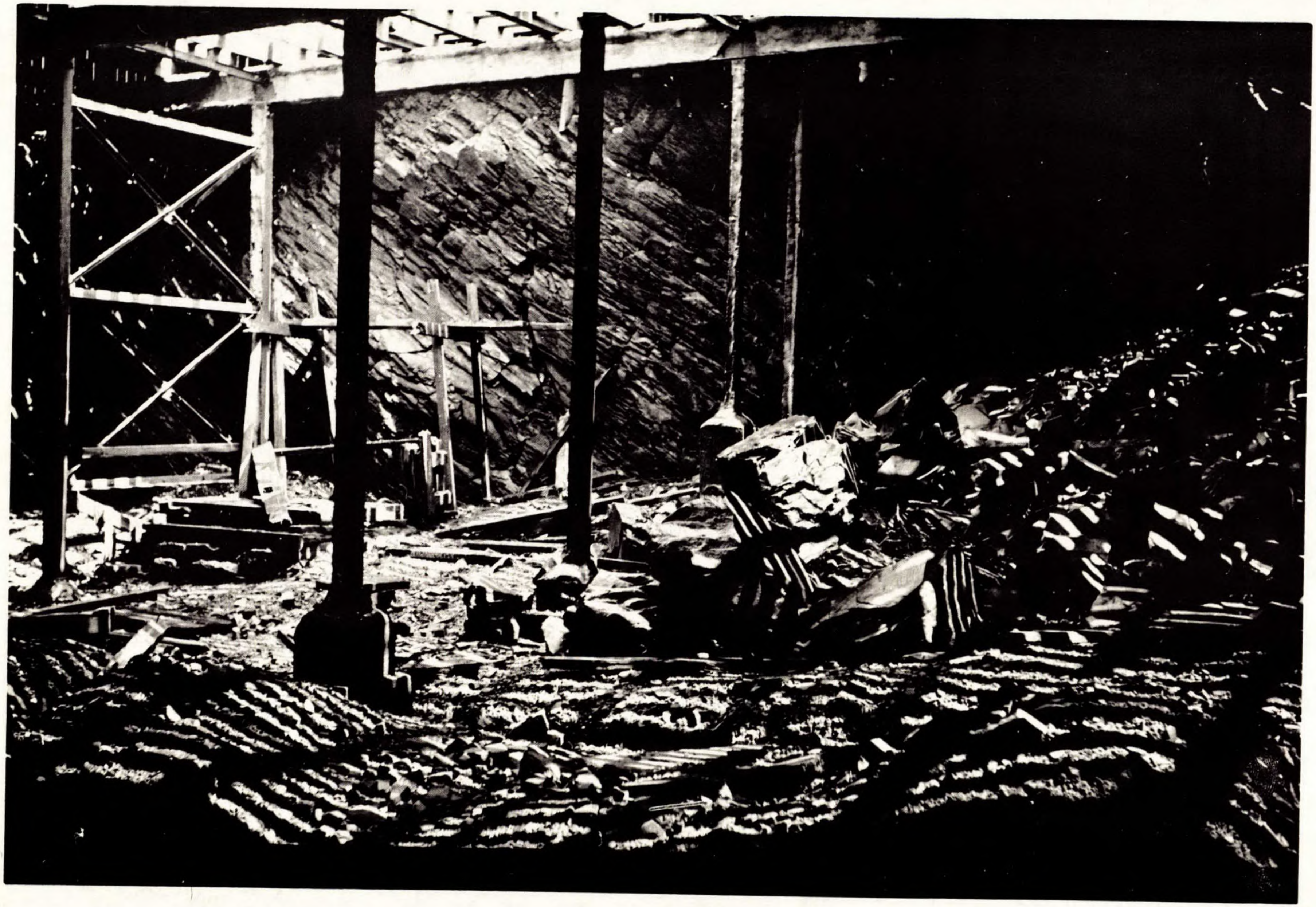


Figure 26. Site of rock bolting,below promenade deck of Terrace

technique was considered preferable to constructing a massive concrete retaining wall on the questionable footing that exists below the Terrace. It should be emphasized that rock bolting is not considered to be a sound method for most of the cliffs at Dufferin Terrace, because of the very fissured condition of the rock. This opinion particularly applies to the exposed and steep cliff faces that lie between the front wall of the Terrace and Champlain Street below. However, the rock face in question does not form part of the main front cliffs but lies about sixty feet back on the landward side, and mainly below the wooden promenade deck of the Terrace. Because of the limited expanse of rock face involved and its relatively protected position, rock bolting was considered feasible for this particular locality.

The practice of rock bolting is extensively used in underground mines for supporting weak roof, and employs a technique for binding together several plies of rock so as to form a composite beam that is considerable stronger than the sum of the strengths of the individual plies. In principle, it resembles the practice of bolting rigidly together a number of boards to form a wood beam. An essential requirement when dealing with rock is that the bolting must be done as soon as possible after the rock surface has been exposed by mining operations, and before the rock plies have sagged into the mine openings and developed extensive fissuring. The thickness of rock bolted together in this technique is usually from four to six feet. In practice, a hole is drilled to the desired depth, following which a steel rod is inserted and firmly anchored at the inside end of the hole by a wedging device. This rod is long enough to project about six inches from the mouth of the borehole, and the projecting end is threaded to take a tightening nut. A flat steel plate with a centre hole is slipped over the bolt and brought to bear against the rock face, following which the tightening nut is run on to the bolt and the whole assembly is tightened to the desired torque.

When discussing rock bolting methods with the Department of Northern Affairs and National Resources it was pointed out that, for a Dufferin Terrace installation, the prime considerations were long life and adequate depth of bolt anchorage. Because of the prevalence of limestone it was not considered that acid waters would be present to corrode the steel bolts, but nevertheless, because of long-term rusting, it was suggested that bolts of one-inch-diameter steel be employed and that each bolt should be given a heavy tar coating. It was also recommended that the exterior steel bearing straps and tightening nuts should be protected with heavy-duty bridge paint, which could be renewed when required. Regarding the anchoring depth, it was recommended that the holes be drilled ten feet long, but it was cautioned that any hole should be continued beyond the ten-foot mark if a fissure were encountered at this depth. It was also advised, because of the broken condition of the rock face, that wide steel straps should be used to span the distance between adjacent bolts so as to provide a broad area of support and thus retard further weathering.

A trial installation of ten bolts was made in October, 1958, and after observing these bolts for several months, the rest of the installation was completed early in 1959. A total of 59 rock bolts were installed in the pattern illustrated in Figure 27. In general, the bolts were spaced about six feet apart, but some irregularity of spacing was unavoidable because of the irregular shape of the rock face. Figure 28 is a side view of the bottom row of bolts installed below the Terrace deck. Initially, as shown in Figure 28, these bolts were fitted with square plates of mild steel, 24 inches by 24 inches by 1/2 inch in dimensions. These plates were employed during observations with rock bolt dynamometers, which were especially made for the study, and may be seen installed on two bolts in Figure 28. The results obtained with the rock bolt dynamometers were not significant, mainly because of an insufficient number of readings. Subsequently, these test bolts and all the rest were fitted with wide straps that reached from bolt to bolt. Beneath the Terrace deck, it was considered that appearances were of secondary importance and consequently the straps were installed in random directions and as considered best to support the maximum amount of rock face between the bolts. Above the deck, and in public view, an attempt was made to run the strapping as inconspicuously as possible.

During installation, each rock bolt was tightened to a torque range of 200 to 250 foot-pounds. Following installation, the bolts were checked for tension with a torque wrench once per month until July, 1959, as a precaution against warmer weather causing elongation of the steel bolts and consequent drop in tensional load. It is recommended that the bolts should be checked with a torque wrench at least once per year and maintained in the installation range of 200 to 250 foot-pounds. To provide an idea of the total holding power of the 59 bolts that have been installed to stabilize this rock exposure, a torque of 250 foot-pounds

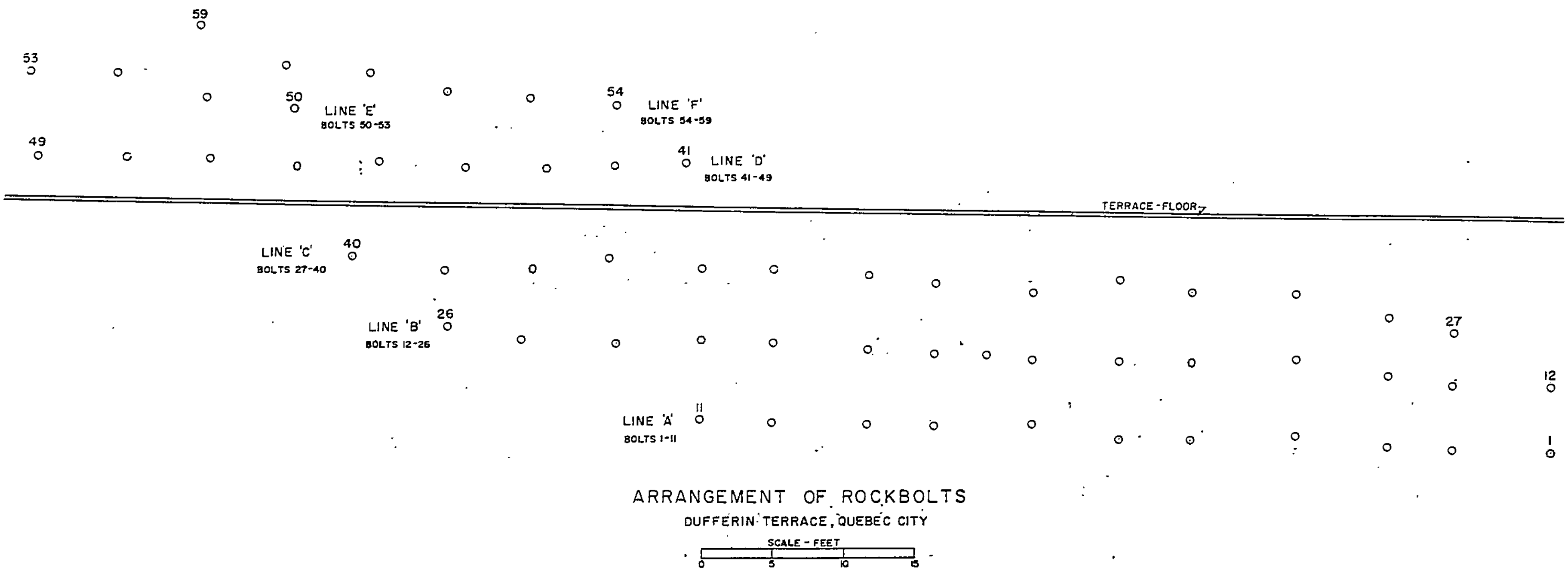


Figure 27. Installation pattern of 59 rock bolts placed at Dufferin Terrace

Figure 28. Installed rock bolts

(on a one-inch-diameter rock bolt) corresponds to a tensional load of 5 tons per bolt.

CONCLUSIONS

The investigation indicated that the Dufferin Terrace is not a quiescent structure but is subject to sporadic movements. The investigation also showed that the escarpment on which the Terrace is built is traversed by numerous fissures, which allow a ready penetration of water into the rock mass and contribute to the instability of the vertically standing strata. It is therefore considered that, under present circumstances, Dufferin Terrace is being subjected to the effects of constant erosion, with the strong possibility that sufficient instability will develop from time to time to cause serious damage to the structure and substantial falls from the face of the cliffs.

The following suggestions are made in the hope that they might prove useful in preserving this outstanding Canadian landmark.

The land rises to the rear of Dufferin Terrace along most of its length, and the natural drainage flow for a considerable land area is toward the Terrace. It is suggested that the possibilities should be examined of intercepting as much as possible of this water, and leading it off to the city sewers.

Further to the above suggestion, attention could be paid to the present condition of catch basins, cisterns, and cesspools in the

Citadel. Quite a few of the old buildings in the Citadel were constructed with underground cisterns that had capacities in excess of 100,000 gallons and were designed to catch the rainfall in the Citadel area. A number of these old cisterns were directly abutting on the cliffs, just to the south of Dufferin Terrace. It is possible that water still drains into these cisterns but that their water-retaining property has deteriorated over many years.

It is also suggested that a study should be made of grouting to seal off the fissures below and on the landward side of the Terrace, with the object of restricting the percolation of ground water into the fissured rock mass below the Terrace. To deal with water that does continue to enter the escarpment, the possibility of improving the drainage of the cliffs by drilling boreholes could be investigated.

It is also suggested that the toboggan slide be removed to another locality in Quebec City, and that the practice of making an ice rink each winter at Dufferin Terrace be discontinued. Both the toboggan slide and the ice rink have been serious offenders in introducing water beneath the Terrace. Associated with both, also, was the undesirable practice of dumping a wet mixture of sand, snow, and ice beneath the Terrace floor. This has substantially contributed to the thick deposit of fine-sized, unconsolidated debris that now lies beneath the Terrace. This deposit rests on a sloping surface and when it becomes water-saturated it can, conceivably, exert an outward thrust against the main front wall of the Terrace.

Of very considerable importance is the necessity of preventing or retarding further deterioration of the exposed cliff below the Terrace.

The most effective long-term solution would appear to be the establishment of a regular slope line, by dumping rock fill, grading it to the minimum possible inclination, and then surfacing the graded fill with rip-rap. This operation would require adequate buttresses along the toe of the cliff, and would include problems of relocating Little Champlain street and parts of Champlain street.

It is also suggested that the roof-bolting installation, made during the course of this investigation, should be examined at least once annually; and this examination should include testing of all bolts with a torque wrench, and maintaining each bolt at a torque of 200 to 250 foot-pounds.

It is appreciated that from time to time decisions will be made for new construction work around Dufferin Terrace and that this work could include the removal of rock. It is cautioned that the use of explosives in such work be carefully supervised and be kept to a minimum.

Finally it is recommended that observations be continued, say several times per year, into the verticality of the main front wall of the Terrace, as this part of the structure is a sensitive indicator of ground movements.

ACKNOWLEDGMENTS

The investigation was conducted with the full support of Mr. G. L. Scott, Chief Engineer, and Mr. N. P. Robinson, Assistant Chief Engineer, of the National Parks Branch, Department of Northern Affairs and National Resources. It is also a pleasure to make a special acknowledgment of the work carried out by Mr. R. D'Amours, Quebec representative of the National Parks Branch, who conducted the observations, in fair weather and foul, over several years. The courtesies and assistance provided by officers of the Engineering Department of Quebec City, and of the Public Archives, Ottawa, are gratefully acknowledged. The authors also wish to thank Messrs. L. C. Richards and T. S. Cochrane of the Mines Branch for their valuable contributions to this study.

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TABLE 3

DATA ON MOVEMENTS OBSERVED
DUFFERIN TERRACE, QUEBEC CITY

Station: No. 1

Apparatus Employed: Suspended Wire Assembly - Indicating Type

Length of Wire in Assembly: 34.3 feet

Coefficient of linear expansion = 0.000006 per degree Fahrenheit

Type of Movement: + Divergence = increased distance between anchor pins.
- Convergence = decreased distance between anchor pins.

Date	Reading, inches	Temperature, °F	Temperature Correction, inch	Corrected Reading, inches	Net Change from Base Date, inch
1958 May 22	5.81	60	0	5.81	Base Date
May 30	5.75	59	0	5.75	+.06
Jun.16	5.69	45	+.03	5.72	+.09
Jun.25	5.69	55	+.01	5.70	+.11
Jul. 7	5.75	61	0	5.75	+.06
Jul.21	5.75	63	-.01	5.74	+.07
Jul.28	5.75	67	-.01	5.74	+.07
Aug. 7	5.75	71	-.02	5.73	+.08
Aug.18	5.75	56	+.01	5.76	+.05
Aug.28	5.75	60	0	5.75	+.06
Sep. 9	5.75	53	+.01	5.76	+.05

TABLE 4

DATA ON MOVEMENTS OBSERVED
DUFFERIN TERRACE, QUEBEC CITY

Station: No. 2

Apparatus Employed: Suspended Wire Assembly - Indicating Type

Length of Wire in Assembly: 46.1 feet

Coefficient of linear expansion = 0.000006 per degree Fahrenheit

Type of Movement: + Divergence = increased distance between anchor pins.
- Convergence = decreased distance between anchor pins.

Date	Reading, inches	Temperature, °F	Temperature Correction, inch	Corrected Reading, inches	Net Change from Base Date, inch
1958					
May 22	5.75	60	0	5.75	Base Date
May 30	5.75	59	0	5.75	0
June 16	5.69	45	+.05	5.74	+.01
June 25	5.69	55	+.02	5.71	+.04
July 7	5.69	60	0	5.69	+.06
July 21	5.69	63	-.01	5.68	+.07
July 28	5.75	67	-.02	5.73	+.02
Aug. 7	5.63	71	-.03	5.60	+.15
Aug. 18	5.63	56	+.01	5.64	+.11
Aug. 28	5.69	60	0	5.69	+.06
Sep. 9	5.69	53	+.02	5.71	+.04
Dec. 18	5.63	8	+.16	5.79	-.04
1959					
Jan. 13	5.69	21	+.12	5.81	-.06
Jan. 21	5.69	31	+.09	5.78	-.03
Jan. 29	5.69	17	+.13	5.82	-.07

TABLE 5

DATA ON MOVEMENTS OBSERVED
DUFFERIN TERRACE, QUEBEC CITY

Station: No. 3

Apparatus Employed: Suspended Wire Assembly - Indicating Type

Length of Wire in Assembly: 56.3 feet

Coefficient of linear expansion = 0.000006 per degree Fahrenheit

Type of Movement: + Divergence = increased distance between anchor pins.
- Convergence = decreased distance between anchor pins.

Date	Reading, inches	Temperature, °F	Temperature Correction, inch	Corrected Reading, inches	Net Change from Base Date, inch
1958					
May 22	6.19	60	0	6.19	Base Date
May 30	6.19	59	0	6.19	0
June 16	6.19	46	-.06	6.13	-.06
June 25	6.25	55	-.02	6.23	-.06
July 7	6.25	61	0	6.25	+.06
July 21	6.19	63	+.01	6.20	+.01
July 28	6.19	67	+.03	6.22	+.02
Aug. 7	6.19	71	+.04	6.23	+.04
Assembly repaired and new base date of Aug.18 adopted					
Aug. 18	5.38	56	0	5.38	0
Aug. 28	5.31	60	+.02	5.33	-.05
Sept. 9	5.31	54	-.01	5.30	-.08
Dec. 18	5.31	8	-.19	5.12	-.26
1959					
Jan. 13	5.25	22	-.14	5.11	-.29
Jan. 21	5.31	31	-.10	5.21	-.17

(Continued ....

TABLE 5 (Continued)

Date	Reading, inches	Temperature, °F	Temperature Correction, inch	Corrected Reading, inches	Net Change from Base Date inch
Jan. 29	5.25	17	-.16	5.09	-.29
Feb. 5	5.25	18	-.15	5.10	-.28
Feb. 13	5.25	12	-.18	5.07	-.31
Feb. 21	5.31	9	-.19	5.12	-.26
Feb. 28	5.25	19	-.15	5.10	-.28
Mar. 7	5.31	26	-.12	5.19	-.19
Mar. 14	5.31	23	-.13	5.18	-.20
Mar. 21	5.31	28	-.11	5.20	-.18
Mar. 27	5.31	26	-.12	5.19	-.19
Apr. 4	5.38	34	-.09	5.29	-.09
Apr. 11	5.31	32	-.10	5.21	-.17
Apr. 18	5.31	29	-.11	5.20	-.18
Apr. 25	5.25	52	-.02	5.23	-.15
May 2	5.25	52	-.02	5.23	-.15
May 9	5.25	55	0	5.25	-.13
May 16	5.31	48	-.03	5.28	-.10
May 23	5.25	53	-.01	5.24	-.14
May 30	5.25	72	+.05	5.30	-.08
June 6	5.44	45	-.04	5.40	+.02
June 15	5.34	55	0	5.34	-.04
June 23	5.31	64	+.03	5.34	-.04
June 30	5.31	61	+.02	5.33	-.05
July 6	5.31	71	+.06	5.37	-.01

(Continued...

TABLE 5 (Concluded)

Date	Reading, inches	Temperature, °F	Temperature Correction, inch	Corrected Reading, inches	Net Change from Base Date, inch
July 14	5.31	79	+.09	5.40	+.02
July 21	5.38	78	+.09	5.47	+.09
July 29	5.31	83	+.11	5.42	+.04
Aug. 5	5.38	66	+.04	5.42	+.04
Aug. 15	5.38	65	+.04	5.42	+.04
Aug. 22	5.38	57	0	5.38	0
Aug. 29	5.38	60	+.02	5.40	+.02
Sept. 5	5.31	56	0	5.31	-.07
Sept.12	5.38	60	+.01	5.39	+.01
Sept.19	5.38	37	-.08	5.30	-.08
Oct. 10	5.38	49	-.03	5.35	-.03
Oct. 17	5.38	42	-.06	5.32	-.06
Oct. 24	5.38	56	0	5.38	0
Nov. 7	5.31	32	-.10	5.21	-.17
Nov. 14	5.44	32	-.10	5.34	-.04

TABLE 6

DATA ON MOVEMENTS OBSERVED
DUFFERIN TERRACE, QUEBEC CITY

Station: No. 4

Apparatus Employed: Suspended Wire Assembly - Indicating Type

Length of Wire in Assembly: 59.9 feet

Coefficient of linear expansion = 0.000006 per degree Fahrenheit

Type of Movement: + Divergence = increased distance between anchor pins.
- Convergence = decreased distance between anchor pins.

Date	Reading, inches	Temperature, °F	Temperature Correction, inch	Corrected Reading, inches	Net Change from Base Date, inch
1958					
May 22	6.06	60	0	6.06	Base Date
May 30	6.06	59	0	6.06	0
June 16	5.94	46	+.06	6.00	+.06
June 25	6.00	55	+.02	6.02	+.04
July 7	6.06	61	0	6.06	0
July 21	6.13	63	-.01	6.12	-.06
July 28	6.13	67	-.03	6.10	-.04
Aug. 7	6.13	71	-.04	6.09	-.03
Aug. 18	6.00	56	+.02	6.02	+.04
Aug. 28	6.13	60	0	6.13	-.07
Sept. 9	6.00	54	+.02	6.02	+.04
Dec. 18	5.75	8	+.21	5.96	+.10
1959					
Jan. 13	5.81	22	+.15	5.96	+.10
Jan. 21	5.81	31	+.12	5.93	+.13
Jan. 29	5.81	17	+.17	5.98	+.08
Feb. 5	5.94	18	+.17	6.11	-.05

TABLE 7

DATA ON MOVEMENTS OBSERVED
DUFFERIN TERRACE, QUEBEC CITY

Station: No. 5

Apparatus Employed: Suspended Wire Assembly - Indicating Type

Length of Wire in Assembly: 73.2 feet

Coefficient of linear expansion = 0.000006 per degree Fahrenheit

Type of Movement: + Divergence = increased distance between anchor pins.
- Convergence = decreased distance between anchor pins.

Date	Reading, inches	Temperature, °F	Temperature Correction, inch	Corrected Reading, inches	Net Change from Base Date, inch
1958					
May 22	5.94	60	0	5.94	Base Date
June 16	5.94	46	-.07	5.87	-.07
June 25	6.13	55	-.03	6.10	+.16
July 7	6.19	61	+.01	6.20	+.26
	Assembly repaired and new base date of July 21 adopted				
July 21	6.69	63	0	6.69	New Base
July 28	6.69	67	+.02	6.71	+.02
Aug. 7	6.69	71	+.04	6.73	+.04
Aug. 18	6.50	56	-.04	6.46	-.23
Aug. 28	6.63	60	-.02	6.61	-.08
Sept. 9	6.50	54	-.05	6.45	-.24
	Assembly repaired and new base date of Dec. 18 adopted				
Dec. 18	6.13	8	0	6.13	New Base
1959					
Jan. 13	6.19	22	+.07	6.26	+.13
Jan. 21	6.13	31	+.12	6.25	+.12

(Continued ....

TABLE 7 (Continued)

Date	Reading, inches	Temperature, °F	Temperature Correction, inch	Corrected Reading, inches	Net Change from Base Date inch
Jan. 29	6.13	17	+.05	6.18	+.05
Feb. 5	6.25	18	+.05	6.30	+.17
Feb. 13	6.19	12	+.02	6.21	+.08
Feb. 21	6.13	9	+.01	6.14	+.01
Feb. 28	6.19	19	+.06	6.25	+.12
Mar. 7	6.25	26	+.09	6.34	+.21
Mar. 14	6.19	23	+.08	6.27	+.14
Mar. 21	6.19	28	+.10	6.29	+.16
Mar. 27	6.25	26	+.09	6.34	+.21
Apr. 4	6.25	34	+.13	6.38	+.25
Apr. 11	6.38	32	+.12	6.50	+.37
Apr. 18	6.44	29	+.11	6.55	+.42
Due to possible vandalism, new base date of April 25 adopted.					
Apr. 25	6.63	52	0	6.63	New Base
May 2	6.69	54	+.01	6.70	+.07
May 9	6.75	55	+.02	6.77	+.14
May 16	6.63	48	-.02	6.61	-.02
May 23	6.75	55	+.02	6.77	+.14
May 30	6.75	58	+.03	6.78	+.15
June 6	6.63	43	-.05	6.58	-.05
June 15	6.66	55	+.02	6.68	+.05
June 23	6.75	64	+.06	6.81	+.18
June 30	6.81	61	+.05	6.86	+.23
July 6	6.84	70	+.09	6.93	+.30

(Continued ....

TABLE 7 (Concluded)

Date	Reading, inches	Temperature, °F	Temperature Correction, inch	Corrected Reading, inches	Net Change from Base Date, inch
July 13	6.88	80	+.14	7.02	+.39
July 21	6.94	78	+.13	7.07	+.44
July 29	6.94	84	+.16	7.10	+.47
Aug. 5	6.94	64	+.06	7.00	+.37
Aug. 15	6.75	65	+.07	6.82	+.19
Aug. 22	6.75	60	+.04	6.79	+.16
Aug. 29	6.75	58	+.03	6.78	+.15
Sep. 5	6.75	59	+.04	6.79	+.16
Sep. 12	6.75	60	+.04	6.79	+.16
Sep. 19	6.50	38	-.07	6.43	-.20
Oct. 10	6.56	49	-.02	6.54	-.09
Oct. 17	6.56	42	-.05	6.51	-.12
Oct. 24	6.75	56	+.02	6.77	+.14
Nov. 7	6.44	32	-.10	6.34	-.29
Nov. 14	6.50	32	-.10	6.40	-.23

TABLE 8

DATA ON MOVEMENTS OBSERVED
DUFFERIN TERRACE, QUEBEC CITY

Station: No. 6

Apparatus Employed: Suspended Wire Assembly - Indicating Type

Length of Wire in Assembly: 63.3 feet

Coefficient of linear expansion = 0.000006 per degree Fahrenheit

Type of Movement: + Divergence = increased distance between anchor pins.
- Convergence = decreased distance between anchor pins.

Date	Reading, inches	Temperature, °F	Temperature Correction, inch	Corrected Reading, inches	Net Change from Base Date, inch
1958					
May 30	3.07	60	0	3.07	Base date
June 16	3.25	46	+.06	3.31	-.24
June 25	3.31	55	+.02	3.33	-.26
July 7	3.38	61	0	3.38	-.31
July 21	3.56	63	-.01	3.55	-.48
July 28	3.63	67	-.03	3.60	-.53
Aug. 7	3.69	71	-.04	3.65	-.58
Aug. 18	3.56	56	+.02	3.58	-.51
Aug. 28	3.63	60	0	3.63	-.56
Sept. 9	3.56	54	+.02	3.58	-.51
Dec. 18	3.31	8	+.21	3.52	-.45
1959					
Jan. 13	3.31	22	+.15	3.46	-.39
Jan. 21	3.31	31	+.12	3.43	-.36
Jan. 29	3.31	17	+.17	3.48	-.41
Feb. 5	3.38	18	+.17	3.55	-.48

TABLE 9

DATA ON MOVEMENTS OBSERVED
DUFFERIN TERRACE, QUEBEC CITY

Station: No. 7

Apparatus Employed: Suspended Wire Assembly - Indicating Type

Length of Wire in Assembly: 44.5 feet

Coefficient of linear expansion = 0.000006 per degree Fahrenheit

Type of Movement: + Divergence = increased distance between anchor pins.
- Convergence = decreased distance between anchor pins.

Date	Reading, inches	Temperature, °F	Temperature Correction, inch	Corrected Reading, inches	Net Change from Base Date, inch
1958					
May 22	6.06	60	0	6.06	Base Date
May 30	6.13	59	0	6.13	-.07
June 16	6.00	46	+.04	6.04	+.02
June 25	6.06	55	+.02	6.08	-.02
July 7	6.06	61	0	6.06	0
July 21	6.06	63	-.01	6.05	+.01
July 28	6.13	67	-.02	6.11	-.05
Aug. 7	6.13	71	-.03	6.10	-.04
Aug. 18	6.13	56	+.01	6.14	-.08
Aug. 28	6.13	60	0	6.13	-.07
Sept. 9	6.13	54	+.02	6.15	-.09
Dec. 18	5.94	8	+.12	6.06	0
1959					
Jan. 13	5.94	22	+.11	6.05	+.01
Jan. 21	5.94	31	+.09	6.03	+.03
Jan. 29	5.94	17	+.13	6.07	-.01

(Continued ....

TABLE 9 (Continued)

Date	Reading, inches	Temperature, °F	Temperature Correction, inch	Corrected Reading, inches	Net Change from Base Date inch
Feb. 5	5.94	18	+.13	6.07	-.01
Feb. 13	5.94	12	+.15	6.09	-.03
Feb. 21	5.94	9	+.15	6.09	-.03
Feb. 28	6.00	19	+.12	6.12	-.06
Mar. 7	6.00	26	+.10	6.10	-.04
Mar. 21	5.94	28	+.09	6.03	+.03
Mar. 27	5.94	26	+.10	6.04	+.02
Apr. 4	5.94	34	+.08	6.02	+.04
Apr. 11	6.00	32	+.08	6.08	-.02
Apr. 18	6.06	29	+.09	6.15	-.09
Apr. 25	6.13	52	+.02	6.15	-.09
May 2	6.06	54	+.02	6.08	-.02
May 9	6.13	55	+.02	6.15	-.09
May 16	6.06	48	+.03	6.09	-.03
May 23	6.06	55	+.02	6.08	-.02
May 30	6.06	58	+.01	6.07	-.01
June 6	6.06	43	+.05	6.11	-.05
June 15	6.09	55	+.02	6.11	-.05
June 23	6.13	64	-.01	6.12	-.06
June 30	6.16	61	0	6.16	-.10
July 6	6.16	70	-.03	6.13	-.07
July 14	6.19	80	-.06	6.13	-.07
July 21	6.25	78	-.05	6.20	-.14
July 29	6.25	84	-.07	6.18	-.12

(Continued ....

TABLE 9 (Concluded)

Date	Reading, inches	Temperature, °F	Temperature Correction, inch	Corrected Reading, inches	Net Change from Base Date inch
Aug. 5	6.38	64	-.01	6.37	-.31
Aug.15	6.38	65	-.01	6.37	-.31
Aug.22	6.38	60	0	6.38	-.32
Sep. 5	6.38	59	0	6.38	-.32
Sep.12	6.38	60	0	6.38	-.32
Sep.19	6.38	38	+.07	6.45	-.39
Oct.10	6.31	49	+.03	6.34	-.28
Oct.17	6.31	42	+.05	6.36	-.30
Oct.24	6.31	56	+.01	6.32	-.26
Nov. 7	6.25	32	+.08	6.33	-.27
Nov.14	6.31	32	+.08	6.39	-.33

TABLE 10

DATA ON MOVEMENTS OBSERVED
DUFFERIN TERRACE, QUEBEC CITY

Station: No. 8

Apparatus Employed: Suspended Wire Assembly - Indicating Type

Length of Wire in Assembly: 76.0 feet

Coefficient of linear expansion = 0.000006 per degree Fahrenheit

Type of Movement: + Divergence = increased distance between anchor pins.
- Convergence = decreased distance between anchor pins.

Date	Reading, inches	Temperature, °F	Temperature Correction, inch	Corrected Reading, inches	Net Change from Base Date, inch
1958					
May 22	7.44	60	0	7.44	Base Date
May 30	7.63	59	+.01	7.64	-.20
June 16	7.31	46	+.07	7.38	+.06
June 25	7.44	55	+.03	7.47	-.03
July 7	7.50	61	-.01	7.49	+.05
July 21	7.63	63	-.02	7.61	-.18
July 28	7.56	67	-.04	7.52	-.08
Aug. 7	7.63	71	-.06	7.57	-.13
Aug. 18	7.50	56	+.02	7.52	-.08
Aug. 28	7.56	60	0	7.56	-.12
Sept. 9	7.44	54	+.03	7.47	-.03
Dec. 18	7.31	8	+.26	7.57	-.13
1959					
Jan. 13	7.38	22	+.19	7.57	-.13
Jan. 21	7.38	31	+.16	7.54	-.10
Jan. 29	7.38	17	+.22	7.60	-.16
Feb. 5	7.38	18	+.21	7.59	-.15

TABLE 11

DATA ON MOVEMENTS OBSERVED
DUFFERIN TERRACE, QUEBEC CITY

Station: No. 9

Apparatus Employed: Suspended Wire Assembly - Indicating Type

Length of Wire in Assembly: 63.6 feet

Coefficient of linear expansion = 0.000006 per degree Fahrenheit

Type of Movement: + Divergence = increased distance between anchor pins.
- Convergence = decreased distance between anchor pins.

Date	Reading, inches	Temperature, °F	Temperature Correction, inch	Corrected Reading, inches	Net Change from Base Date, inch
1958					
May 22	6.19	60	0	6.19	Base Date
May 30	6.19	59	+.01	6.20	-.01
June 16	6.13	46	+.07	6.20	-.01
June 25	6.31	55	+.03	6.34	-.15
July 7	6.38	61	-.01	6.37	-.18
July 21	6.44	63	-.02	6.42	-.23
July 28	6.44	67	-.04	6.40	-.21
Aug. 5	6.44	71	-.06	6.38	-.19
Aug. 18	6.38	56	+.02	6.40	-.21
Aug. 28	6.44	60	0	6.44	-.25
Sept. 9	6.38	54	+.03	6.41	-.22
1959					
Jan. 13	6.13	22	+.19	6.32	-.13
Jan. 21	6.13	31	+.16	6.29	-.10
Jan. 29	6.13	17	+.22	6.35	-.16
Assembly repaired and new base date of February 5 adopted					

(Continued ....

TABLE 11 (Continued)

Date	Reading, inches	Temperature, °F	Temperature Correction, inch	Corrected Reading, inches	Net Change from Base Date, inch
Feb. 5	5.50	18	0	5.50	New Base Date
Feb.13	5.50	12	+.03	5.53	-.03
Feb.21	5.50	9	+.05	5.55	-.05
Feb.28	5.50	19	-.01	5.49	+.01
Mar. 7	5.50	26	-.04	5.46	+.04
Mar.14	5.50	23	-.03	5.47	+.03
Mar.21	5.50	21	-.02	5.48	+.02
Mar.27	5.50	26	-.04	5.46	+.04
Apr. 4	5.50	34	-.08	5.42	+.08
Apr.11	5.56	32	-.07	5.49	+.01
Assembly repaired and new base date of Apr. 25 adopted					
Apr. 25	6.00	52	0	6.00	New Base Date
May 2	6.00	54	-.01	5.99	+.01
May 9	6.06	55	-.02	6.04	-.04
May 16	6.00	48	+.02	6.02	-.02
May 23	6.06	55	-.02	6.04	-.04
May 30	6.13	58	-.03	6.10	-.10
June 6	6.00	43	+.05	6.05	-.05
June 15	5.94	55	-.02	5.92	+.08
June 23	6.06	64	-.06	6.00	0
June 30	6.06	61	-.05	6.01	-.01
July 6	6.13	70	-.09	6.04	-.04
July 14	6.38	80	-.14	6.24	-.24
July 21	6.25	78	-.13	6.12	-.12
July 29	6.25	84	-.16	6.09	-.09

(Continued ....

TABLE 11 (Concluded)

Date	Reading, inches	Temperature, °F	Temperature Correction, inch	Corrected Reading, inches	Net Change from Base Date, inch
Aug. 5	6.19	64	-.06	6.10	-.10
Aug. 15	6.31	65	-.07	6.24	-.24
Aug. 22	6.25	60	-.04	6.21	-.21
Aug. 29	6.31	58	-.03	6.28	-.28
Sept. 5	6.31	59	-.04	6.27	-.27
Sept.12	6.25	60	-.04	6.21	-.21
Sept.19	6.63	38	+.07	6.70	-.70
Oct. 10	6.63	49	+.02	6.65	-.65
Oct. 17	6.63	42	+.05	6.68	-.68
Oct. 24	6.63	56	-.02	6.61	-.61
Nov. 7	6.56	32	+.10	6.66	-.66
Nov. 14	6.56	32	+.10	6.66	-.66

TABLE 12

DATA ON MOVEMENTS OBSERVED
DUFFERIN TERRACE, QUEBEC CITY

Station: No. 10

Apparatus Employed: Suspended Wire Assembly - Indicating Type

Length of Wire in Assembly: 82.0 feet

Coefficient of linear expansion = 0.000006 per degree Fahrenheit

Type of Movement: + Divergence = increased distance between anchor pins.
- Convergence = decreased distance between anchor pins.

Date	Reading, inches	Temperature, °F	Temperature Correction, inch	Corrected Reading, inches	Net Change from Base Date, inch
1958 May 22	6.00	60	0	6.00	Base Date
May 30	6.00	59	0	6.00	0
June 16	5.81	46	+.08	5.89	+.11
June 25	5.88	55	+.03	5.91	+.09
July 7	5.81	61	0	5.81	+.19
July 21	6.06	63	-.01	6.05	-.05
June 28	5.94	67	-.04	5.90	+.10
Aug. 7	6.00	71	-.07	5.93	+.07
Aug. 18	5.88	56	+.02	5.90	+.10
Aug. 28	5.94	60	0	5.94	+.06
Sept. 9	5.88	54	+.04	6.02	-.02
Dec. 18	5.44	8	+.31	5.75	+.25
1959 Jan. 13	5.50	22	+.23	5.73	+.27
Jan. 21	5.50	31	+.17	5.67	+.33
Jan. 29	5.50	17	+.26	5.76	+.24
Feb. 5	5.50	18	+.25	5.75	+.25

(Continued ....

TABLE 12 (Continued)

Date	Reading, inches	Temperature, °F	Temperature Correction, inch	Corrected Reading, inches	Net Change from Base Date, inch
Feb. 13	5.50	12	+.29	5.79	+.21
Feb. 21	5.44	9	+.31	5.75	+.25
Feb. 28	5.50	19	+.25	5.75	+.25
Mar. 7	5.50	26	+.20	5.70	+.30
Mar. 14	5.50	23	+.22	5.72	+.28
Mar. 21	5.50	28	+.19	5.69	+.31
Mar. 27	5.50	26	+.20	5.70	+.30
Apr. 4	5.88	34	+.15	6.03	-.03
Apr. 11	5.56	32	+.17	5.73	+.27
Apr. 18	5.63	29	+.19	5.82	+.18
Apr. 25	5.75	52	+.05	5.80	+.20
May 2	5.81	54	+.04	5.85	+.15
May 9	5.81	55	+.02	5.83	+.17
May 16	5.81	48	+.07	5.88	+.12
May 23	5.94	55	+.03	5.97	+.03
May 30	6.00	58	+.01	6.01	-.01
June 6	6.00	43	+.10	6.10	-.10
June 15	5.88	55	+.03	5.91	+.09
June 23	5.88	64	-.02	5.86	+.14
June 30	5.88	61	0	5.88	+.12
July 6	5.88	70	-.06	5.82	+.18
	Assembly repaired and new base date of August 5, adopted				
Aug. 5	6.00	64	0	6.0	Base Date
Aug. 15	6.00	65	0	6.0	0

(Continued ...

TABLE 12 (Concluded)

Date	Reading, inches	Temperature, °F	Temperature Correction, inch	Corrected Reading, inches	Net Change from Base Date inch
Aug. 22	5.94	60	+.02	5.96	+.04
Aug. 29	5.94	58	+.04	5.98	+.02
Sept. 5	6.00	59	+.03	6.03	-.03
Sept.19	5.94	38	+.16	6.10	-.10
Oct. 10	6.00	49	+.09	6.09	-.09
Oct. 17	6.00	42	+.13	6.13	-.13
Oct. 24	6.00	56	+.02	6.02	-.02
Nov. 7	5.56	32	+.19	5.75	+.25
Nov. 14	5.56	32	+.19	5.75	+.25

TABLE 13

DATA ON MOVEMENTS OBSERVED

DUFFERIN TERRACE, QUEBEC CITY

Station: No. 1

Apparatus employed: Suspended Wire Assembly - Recording Type

Length of Wire in Assembly: 38 feet

Coefficient of Linear Expansion: 0.000006 per degree Fahrenheit

Type of Movement: + Divergence = increased distance between anchor pins.
- Convergence = decreased distance between anchor pins.

Observation Interval From	To 1959	Observed Movement, inch	Temperature Change in Interval, °F	Movement, Corrected for Temperature, inch
Feb. 6	Feb.13	0	- 6	-.02
Feb.13	Feb.21	0	- 3	-.01
Feb.21	Feb.28	0	+10	+.03
Feb.28	Mar. 7	0	+ 7	+.02
Mar. 7	Mar.14	0	- 3	-.01
Mar.14	Mar.21	0	+ 5	+.01
Mar.21	Mar.27	+.025	- 3	+.01
Mar.27	Apr. 4	0	+ 8	+.02
Apr. 4	Apr.11	0	- 2	-.01
Apr.11	Apr.18	0	- 3	-.01
Apr.18	Apr.25	0	+22	+.06
Apr.25	May 2	0	+ 3	-.01
May 2	May 9	0	0	0
May 9	May 16	0	- 9	-.03
May 16	May 23	0	+ 2	+.01

(Continued...

TABLE 13 (Concluded)

Observation Interval 1959 From	To	Observed Movement, inch	Temperature Change in Interval, °F	Movement, Corrected for Temperature, inch
May 23	May 30	0	+ 8	+.02
May 30	June 6	0	-17	-.05
June 6	June 15	-.07	+12	-.04
June 15	June 23	-.035	- 4	-.02
June 23	June 30	0	0	0
June 30	July 6	-.025	+ 6	-.00
July 6	July 14	0	+ 8	+.02
July 14	July 21	0	0	0
July 21	July 29	0	+ 1	0
July 29	Aug. 5	0	-13	-.04
Aug. 5	Aug. 15	-.02	- 3	-.01
Aug. 15	Aug. 22	-	- 4	-
Aug. 22	Aug. 29	-.05	- 1	-.05
Aug. 29	Sept. 5	0	+ 2	+.01
Sept. 5	Sept.12	0	- 4	-.01
Sept.12	Sept.19	0	-18	-.06
Sept.19	Oct. 10	0	+11	+.03
Oct. 10	Oct. 17	0	-14	-.04
Oct. 17	Oct. 24	0	+10	+.03

TABLE 14

DATA ON MOVEMENTS OBSERVED
DUFFERIN TERRACE, QUEBEC CITY

Station: No. 2

Apparatus employed: Suspended Wire Assembly - Recording Type

Length of Wire in Assembly: 50 feet

Coefficient of Linear Expansion: 0.000006 per degree Fahrenheit

Type of Movement: + Divergence = increased distance between anchor pins.
- Convergence = decreased distance between anchor pins.

Observation Interval From 1959	To	Observed Movement, inch	Temperature Change in Interval, °F	Movement, Corrected for Temperature, inch
Jan.30	Feb. 6	-.025	+ 1	-.02
Feb. 6	Feb.13	0	- 6	-.03
Feb.13	Feb.21	+.08	- 3	+.07
Feb.21	Feb.28	-.075	+10	-.03
Feb.28	Mar. 7	0	+ 7	+.03
Mar. 7	Mar.14	0	- 3	-.01
Mar.14	Mar.21	0	+ 5	+.02
Mar.21	Mar.27	-.11	- 3	-.12
Mar.27	Apr. 4	0	+ 8	+.03
Apr. 4	Apr.11	0	- 2	-.01
Apr.11	Apr.18	-	- 3	-
Apr.18	Apr.25	0	+22	+.08
Apr.25	May 2	0	+ 3	+.01
May 2	May 9	+.05	0	+.05
May 9	May 16	+.05	- 9	+.02

(Continued......

TABLE 14 (Concluded)

Observation Interval From	To	Observed Movement, inch	Temperature Change in Interval, °F	Movement, Corrected for Temperature, inch
1959				
May 16	May 23	0	+ 2	+.01
May 23	May 30	0	+ 8	+.03
May 30	June 6	+.05	-17	-.01
June 6	June 15	-.10	+12	-.06
June 15	June 23	0	-4	-.01
June 23	June 30	-.025	0	-.02
June 30	July 6	0	+ 6	+.03
July 6	July 14	0	+ 8	+.03
July 14	July 21	0	0	0
July 21	July 29	0	+ 1	0
July 29	Aug. 5	0	-13	-.05
Aug. 5	Aug. 15	0	- 3	-.01
Aug. 15	Aug. 22	0	- 4	-.01
Aug. 22	Aug. 29	0	- 1	0
Aug. 29	Sept. 5	0	+ 2	+.01
Sept. 5	Sept.12	0	- 4	-.01
Sept.12	Sept.19	0	-18	-.07
Sept.19	Oct. 10	-.025	+11	+.01
Oct. 10	Oct. 17	+.05	-14	0
Oct. 17	Oct. 24	0	+10	+.04

TABLE 15

DATA ON MOVEMENTS OBSERVED

DUFFERIN TERRACE, QUEBEC CITY

Station No. 4

Apparatus employed: Suspended Wire Assembly - Recording Type

Length of Wire in Assembly: 63 feet

Coefficient of Linear Expansion: 0.000006 per degree Fahrenheit

Type of Movement: + Divergence = increased distance between anchor pins.
− Convergence = decreased distance between anchor pins.

Observation Interval 1959 From	To	Observed Movement, inch	Temperature Change in Interval, °F	Movement, Corrected for Temperature, inch
Feb. 6	Feb.13	-.05	- 6	-.08
Feb.13	Feb.21	+.05	- 3	+.04
Feb.21	Feb.28	+.01	+10	+.06
Feb.28	Mar. 7	0	+ 7	+.03
Mar. 7	Mar.14	-.05	- 3	-.06
Mar.14	Mar.21	0	+ 5	+.02
Mar.21	Mar.27	-	- 3	-
Mar.27	Apr. 4	-.075	+ 8	-.03
Apr. 4	Apr.11	-.075	- 2	-.08
Apr.11	Apr.18	0	- 3	-.01
Apr.18	Apr.25	-.075	+22	+.02
Apr.25	May 2	0	+ 3	+.01
May 2	May 9	0	0	0
May 9	May 16	+.10	- 9	+.06
May 16	May 23	0	+ 2	+.01

(Continued....

TABLE 15 (Concluded)

Observation Interval From (1959)	To	Observed Movement, inch	Temperature Change in Interval, °F	Movement, Corrected for Temperature, inch
May 23	May 30	0	+ 8	+.04
May 30	June 6	0	-17	-.08
June 6	June 15	-.075	+12	-.01
June 15	June 23	0	- 4	-.02
June 23	June 30	-.05	0	-.05
June 30	July 6	0	+ 6	+.03
July 6	July 14	0	+ 8	+.04
July 14	July 21	0	0	0
July 21	July 29	0	+ 1	0
July 29	Aug. 5	+.10	-13	+.04
Aug. 5	Aug.15	0	- 3	-.01
Aug.15	Aug.22	+.075	- 4	+.05
Aug.22	Aug.29	0	- 1	0
Aug.29	Sept.5	0	+ 2	+.01
Sept.5	Sept.12	+.075	- 4	+.05
Sept.12	Sept.19	+.10	-18	+.02
Oct.10	Oct. 17	-	-14	-
Oct.17	Oct. 24	0	+10	+.05

TABLE 16

DATA ON MOVEMENTS OBSERVED
DUFFERIN TERRACE, QUEBEC CITY

Station: No. 6

Apparatus employed: Suspended Wire Assembly - Recording Type

Length of Wire in Assembly: 67 feet

Coefficient of Linear Expansion: 0.000006 per degree Fahrenheit

Type of Movement: + Divergence = increased distance between anchor pins.
- Convergence = decreased distance between anchor pins.

Observation Interval From 1959	To	Observed Movement, inch	Temperature Change in Interval, °F	Movement, Corrected for Temperature, inch
Feb. 6	Feb.13	0	- 6	-.03
Feb.13	Feb.21	0	- 3	-.01
Feb.21	Feb.28	0	+10	+.05
Feb.28	Mar. 7	0	+ 7	+.03
Mar. 7	Mar.14	+.05	- 3	+.04
Mar.14	Mar.21	0	+ 5	+.02
Mar.21	Mar.27	-.025	- 3	-.03
Mar.27	Apr. 4	0	+ 8	+.04
Apr. 4	Apr.11	-.05	- 2	-.06
Apr.11	Apr.18	-.075	- 3	-.08
Apr.18	Apr.25	-.175	+22	-.06
Apr.25	May 2	0	+ 3	+.01
May 2	May 9	-.09	0	-.09
May 9	May 16	0	- 9	-.04
May 16	May 23	0	+ 2	+.01

(Continued......

TABLE 16 (Concluded)

Observation Interval From 1959	To	Observed Movement, inch	Temperature Change in Interval, °F	Movement, Corrected for Temperature, inch
May 23	May 30	0	+ 8	+.04
May 30	June 6	0	-17	-.08
June 6	June 15	-.90	+12	-.84
June 15	June 23	-.725	- 4	-.74

TABLE 17

DATA ON MOVEMENTS OBSERVED
DUFFERIN TERRACE, QUEBEC CITY

Station: No. 8

Apparatus employed: Suspended Wire Assembly - Recording Type

Length of Wire in Assembly: 80 feet

Coefficient of Linear Expansion: 0.000006 per degree Fahrenheit

Type of Movement: + Divergence = increased distance between anchor pins.
- Convergence = decreased distance between anchor pins.

Observation Interval From 1959	To	Observed Movement, inch	Temperature Change in Interval, °F	Movement, Corrected for Temperature, inch
Feb. 13	Feb. 21	0	- 3	-.02
Feb. 21	Feb. 28	0	+10	+.06
Feb. 28	Mar. 7	0	+ 7	+.04
Mar. 7	Mar. 14	0	- 3	-.02
Mar. 14	Mar. 21	0	+ 5	+.03
Mar. 21	Mar. 27	0	- 3	-.02
Mar. 27	Apr. 4	0	+ 8	+.05
Apr. 4	Apr. 11	0	- 2	-.01
Apr. 11	Apr. 18	+.075	- 3	+.05
Apr. 18	Apr. 25	0	+22	+.13
Apr. 25	May 2	0	+ 3	+.02
May 2	May 9	-.075	0	-.07
May 9	May 16	0	- 9	-.05
May 16	May 23	0	+ 2	+.01
May 23	May 30	0	+ 8	+.05

(Continued....

TABLE 17 (Concluded)

Observation Interval From 1959	To	Observed Movement, inch	Temperature Change In Interval, °F	Movement, Corrected for Temperature, inch
May 30	June 6	0	-17	-.10
June 6	June 15	+.025	+12	+.09
June 15	June 23	0	- 4	0
June 23	June 30	-.025	0	-.02
June 30	July 6	+.025	+ 6	+.06
July 6	July 14	0	+ 8	+.05
July 14	July 20	0	0	0
July 20	July 29	0	+ 1	+.01
July 29	Aug. 5	0	-13	-.08
Aug. 5	Aug. 15	0	- 3	-.02
Aug. 15	Aug. 22	0	- 4	-.02
Aug. 22	Aug. 29	0	- 1	-.01
Aug. 29	Sept. 5	0	+ 2	+.01
Sept. 5	Sept.12	+.265	- 4	+.24
Sept. 12	Sept.19	0	-18	-.10

TABLE 18

DATA ON MOVEMENTS OBSERVED
DUFFERIN TERRACE, QUEBEC CITY

Stations: No. 1 to 10

Apparatus Employed: Plumb-bob on front wall.

Movement of Wall: + Toward River
(in inches) - Toward City.

Date	Stations									
	1	2	3	4	5	6	7	8	9	10
1958										
May 22	0	0	0	0	0	0	0	0	0	0
May 30	0	0	+.06	+.06	0	0	0	+.06	+.06	+.06
Jun. 16	0	0	+.06	+.06	-.06	0	0	+.06	0	+.06
Jun. 25	0	+.06	+.06	+.06	-.06	0	0	+.06	-.06	+.13
Jul. 7	0	+.06	+.06	+.06	0	0	+.06	+.06	0	+.13
Jul. 21	0	0	+.06	0	0	0	+.06	+.06	0	+.13
Jul. 28	0	0	+.06	0	-.56	0	+.06	+.06	0	+.13
Aug. 7	0	+.06	+.06	0	-.56	0	+.06	+.06	0	+.06
Aug. 18	0	+.06	-.56	+.06	-.56	0	+.06	+.06	0	+.06
Aug. 28	0	+.06	-.56	+.06	-.56	0	+.06	+.06	0	+.06
Sep. 9	0	+.06	-.56	+.06	-.56	0	+.06	+.06	0	+.19
Dec. 18	-.06	-.06	-.69	-.07	-.56	0	0	0	(b)	+.25
1959										
Jan. 13	0	0	-.62	0	-.56	+.13	+.06	+.06	-	+.12
Jan. 21	0	-.06	-.62	0	-.50	+.13	0	+.06	-	+.12
Jan. 29	+.13	-.06	-.69	+.06	-.56	+.06	0	-.06	(b)	+.12
Feb. 5	+.13	(a)	-.69	0	-.56	0	0	0	0	+.06
Feb. 13	(a)		-.69	(a)	-.56	(a)	0	(a)	0	+.19
Feb. 21			-.69		-.62		0		0	+.12

(Continued ...

TABLE 18 (Continued)

Date	Stations									
	1	2	3	4	5	6	7	8	9	10
Feb. 28			-.62		-.56		0		-.06	+.12
Mar. 7			-.62		-.56		0		0	+.12
Mar. 14			-.62		-.50		0		0	+.12
Mar. 21			-.62		-.56		0		0	+.12
Mar. 27			-.69		-.50		0		0	+.12
Apr. 4			-.69		-.56		+.06		-.06	+.12
Apr. 11			-.62		-.56		+.06		+.06	+.25
Apr. 18			-.56		-.56		+.06		(b)	+.19
Apr. 25			-.62		-.56		0		0	+.12
May 2			-.62		-.56		0		+.06	+.06
May 9			-.56		-.62		0		+.06	0
May 16			-.56		-.62		0		+.06	-.06
May 23			-.56		-.69		0		+.06	-.06
May 30			-.56		-.69		0		+.06	-.13
June 6			-.56		-.56		0		0	-.13
June 15			-.50		-.56		0		0	+.06
June 23			-.56		-.56		0		0	+.06
June 30			-.50		-.56		0		0	+.06
July 6			-.50		-.56		-.03		+.06	+.06
July 14			-.50		-.56		0		+.06	-
July 21			-.56		-.59		0		+.06	-
July 29			-.56		-.56		0		+.06	-
Aug. 7			-.56		-.56		-.09		0	0
Aug. 15			-.37		-.56		-.13		0	-

(Continued ...

TABLE 18 (Continued)

Date	Stations									
	1	2	3	4	5	6	7	8	9	10
Aug. 22			–.56		–.59		–.13		0	+.06
Aug. 29			–.50		–.56		–.13		0	0
Sep. 5			–.37		–.56		–.13		0	0
Sep. 12			–.56		–.56		–.13		0	–
Sep. 19			–.56		–.56		–.13		–.25	0
Oct. 10			–.56		–.56		–.13		–.25	0
Oct. 17			–.50		–.56		–.13		–.31	0
Oct. 24			–.56		–.56		–.13		–.25	0
Nov. 14			–.56		–.56		–.13		–.25	+.25
Nov. 21			–.56		–.56		–.13		–.31	+.25
Nov. 28			–.56		–.56		–.13		0	+.37
Dec. 5			–.62		–.50		–.13		–.06	+.37
1960	New plumb bob assemblies placed at Stations 1 to 10									
Feb. 13	0	0	–.62	0	–.50		–.13	0	–.06	+.37
Feb. 19	0		–.62	0	–.44		–.13	0	–.06	+.37
Feb. 26	0	–.06	–.56	0	–.50		–.06	–.13	–.06	+.43
Mar. 4	0	–.06	–.62	0	–.56		–.13	–.06	–.12	+.37
Mar. 11	0	–.06	–.62	0	–.56		–.06	–.13	–.06	+.43
Mar. 18	0	0	–.75	0	–.50		–.06	–.06	–.12	+.43
Mar. 25	0	0	–.68	+.06	–.50		–.06	0	0	+.43
Apr. 1	0	0	–.68	0	–.50		–.06	0	–.06	+.43
Apr. 8	0	0	–.56	0	–.50		–.06	0	–.06	+.43
Apr. 14	0	0	–.56	0	–.50		–.13	–.06	–.06	+.43
Apr. 22	0	0	–.62	–.06	–.56		0	–.06	–.12	+.37

(Continued ...

TABLE 18 (Concluded)

Date	Stations									
	1	2	3	4	5	6	7	8	9	10
Apr. 29	+.06	-.13	-.75	-.06	-.63		-.13	(c)	(c)	(c)
May 7	0	-.06	-.62	0	-.56		-.13			
May 13	+.06	0	-.62	0	-.56		-1.13			
May 20	0	0	-.62	0	-.88		-1.13			
May 27	0	0	-.56	-.06	-.88		-1.38			
June 3	0	+.06	-.56	0	-.88		-.13			

(a) Recorder installed and plumb bob assembly removed.

(b) Repaired after vandalism and a new reference point selected.

(c) Destroyed by vandalism near end of study.

NOTE: The plumb bob assemblies were originally installed in November, 1957, but were destroyed by vandalism and had to be completely renewed in May, 1958.

TABLE 19

DATA ON MOVEMENTS OBSERVED
DUFFERIN TERRACE, QUEBEC CITY

Station: 5-1/2 Upper

Apparatus employed: Suspended Wire Assembly - Recording Type

Length of Wire in Assembly: 18.0 feet

Coefficient of Linear Expansion: 0.000006 per degree Fahrenheit

Type of Movement: + Divergence = increased distance between anchor pins.
- Convergence = decreased distance between anchor pins.

Observation Interval From 1959	To	Observed Movement, inch	Temperature Change in Interval, °F	Movement, Corrected for Temperature, inch
June 30	July 6	0	+ 6	+0.01
July 6	July 14	-0.01	+ 8	0
July 14	July 20	-0.01	0	-0.01
July 20	July 29	0	+ 1	0
July 29	Aug. 5	+0.01	-13	-0.01
Aug. 5	Aug. 15	-0.01	- 3	-0.01
Aug. 15	Aug. 22	-0.01	- 4	-0.01
Aug. 22	Aug. 29	0	- 1	0
Aug. 29	Sept. 5	+0.02	+ 2	+0.02
Sept. 5	Sept.12	-0.01	- 4	-0.01
Sept.12	Sept.19	0	-18	-0.02
Nov. 21	Nov. 28	0	+ 2	0
Nov. 28	Dec. 5	0	0	0

(Continued....

TABLE 19 (Concluded)

Observation Interval From (1960)	To	Observed Movement, inch	Temperature Change in Interval, °F	Movement, Corrected for Temperature, inch
Feb. 19	Feb. 26	0	+ 3	0
Feb. 26	Mar. 4	0	+ 1	0
Mar. 4	Mar. 11	0	− 5	−0.01
Mar. 11	Mar. 18	0	+ 8	+0.01
Mar. 18	Mar. 25	0	−14	−0.02
Mar. 25	Apr. 1	0	+ 4	+0.01
Apr. 1	Apr. 8	0	0	0
Apr. 8	Apr. 14	+0.01	− 2	+0.01
Apr. 14	Apr. 22	0	+ 1	0
Apr. 22	Apr. 29	0	+ 5	+0.01
Apr. 29	May 7	−0.02	+ 9	−0.01
May 7	May 13	0	− 9	−0.01
May 13	May 20	0	+ 4	+0.01
May 20	May 27	−0.02	+24	+0.01

TABLE 20

DATA ON MOVEMENTS OBSERVED
DUFFERIN TERRACE, QUEBEC CITY

Station: 5-1/2 Lower

Apparatus employed: Suspended Wire Assembly - Recording Type

Length of Wire in Assembly: 32.15 feet.

Coefficient of Linear Expansion = 0.000006 per degree Fahrenheit.

Type of Movement: + Divergence = increased distance between anchor pins.
- Convergence = decreased distance between anchor pins.

Observation Interval From (1959)	To	Observed Movement, inch	Temperature Change in Interval, °F	Movement, Corrected for Temperature, inch
June 30	July 6	0	+ 6	+0.01
July 6	July 14	0	+ 8	+0.02
July 14	July 20	0	0	0
July 20	July 29	0	+ 1	0
July 29	Aug. 5	0	-13	-0.03
Aug. 5	Aug. 15	0	- 3	-0.01
Aug. 15	Aug. 22	0	- 4	-0.01
Aug. 22	Aug. 29	0	- 1	0
Aug. 29	Sep. 5	0	+ 2	0
Sep. 5	Sep. 12	0	- 4	-0.01
Sep. 12	Sep. 19	0	-18	-0.04
Oct. 10	Oct. 17	0	-14	-0.03
Oct. 17	Oct. 24	0	+10	+0.02
Nov. 21	Nov. 28	0	+ 2	0
Nov. 28	Dec. 5	0	0	0

(Continued....

TABLE 20 (Concluded)

Observation Interval From (1960)	To	Observed Movement, inch	Temperature Change in Interval, °F	Movement, Corrected for Temperature, inch
Feb. 19	Feb. 26	0	+ 3	+0.01
Feb. 26	Mar. 4	0	+ 1	0
Mar. 4	Mar. 11	0	- 5	-0.01
Mar. 11	Mar. 18	0	+ 8	+0.02
Mar. 18	Mar. 25	0	-14	-0.03
Mar. 25	Apr. 1	0	+ 4	+0.01
Apr. 1	Apr. 8	0	0	0
Apr. 8	Apr. 14	0	- 2	0
Apr. 14	Apr. 22	0	+ 1	0
Apr. 22	Apr. 29	0	+ 5	+0.01
Apr. 29	May 7	0	+ 9	+0.02
May 7	May 13	0	- 9	-0.02
May 13	May 20	0	+ 4	+0.01
May 20	May 27	0	+24	+0.06

TABLE 21

DATA ON MOVEMENTS OBSERVED

DUFFERIN TERRACE, QUEBEC CITY

Station: 6-1/2 Upper

Apparatus employed: Suspended Wire Assembly - Recording Type

Length of Wire in Assembly: 16.0 feet

Coefficient of Linear Expansion: 0.000006 per degree Fahrenheit

Type of Movement: + Divergence = increased distance between anchor pins.
- Convergence = decreased distance between anchor pins.

Observation Interval From 1959	To	Observed Movement, inch	Temperature Change in Interval, °F	Movement, Corrected for Temperature, inch
Aug. 29	Sept. 5	-0.01	+ 2	-0.01
Sept. 5	Sept. 12	0	- 4	0
Sept.12	Sept. 19	0	-18	-0.02
Nov. 14	Nov. 21	+0.01	-19	-0.01
Nov. 21	Nov. 28	+0.01	+ 2	+0.01
Nov. 28	Dec. 5	+0.01	0	+0.01
1960				
Feb. 26	Mar. 4	0	+ 1	0
Mar. 25	Apr. 1	0	+ 4	0
Apr. 1	Apr. 8	+0.03	0	+0.03
Apr. 8	Apr. 14	+0.07	- 2	+0.07
Apr. 14	Apr. 22	-0.01	+ 1	-0.01
Apr. 22	Apr. 29	-0.02	+ 5	-0.01
Apr. 29	May 7	0	+ 9	+0.01
May 7	May 13	-0.03	- 9	-0.04
May 13	May 20	-0.02	+ 4	-0.02
May 20	May 27	-0.03	+24	0

TABLE 22

DATA ON MOVEMENTS OBSERVED
DUFFERIN TERRACE, QUEBEC CITY

Station: 6-1/2 Lower

Apparatus employed: Suspended Wire Assembly - Recording Type

Length of Wire in Assembly: 30.8 feet.

Coefficient of Linear Expansion: 0.000006 per degree Fahrenheit.

Type of Movement: + Divergence = increased distance between anchor pins.
- Convergence = decreased distance between anchor pins.

Observation Interval From 1959	To	Observed Movement, inch	Temperature Change in Interval, °F	Movement, Corrected for Temperature, inch
June 30	July 6	-0.04	+ 6	-0.03
July 14	July 20	0	0	0
July 20	July 29	+0.01	+ 1	+0.01
July 29	Aug. 5	+0.01	-13	-0.02
Aug. 5	Aug. 15	0	- 3	-0.01
Aug. 15	Aug. 29	+0.08	- 5	+0.07
Aug. 29	Sept. 5	0	+ 2	0
Sept. 5	Sept.12	0	- 4	-0.01
Sept.12	Sept.19	0	-18	-0.04
Sept.19	Oct. 10	-0.01	+11	+0.02
Oct. 10	Oct. 17	0	-14	-0.03
Oct. 17	Oct. 24	+0.01	+10	+0.04
Nov. 14	Nov. 21	+0.03	-19	-0.01
Nov. 21	Nov. 28	-0.03	+ 2	-0.03
Nov. 28	Dec. 5	+0.04	0	+0.04

(Continued....

TABLE 22 (Concluded)

Observation Interval From 1960	To	Observed Movement, inch	Temperature Change in Interval, °F	Movement, Corrected for Temperature, inch
Feb. 19	Feb. 26	0	+ 2	0
Feb. 26	Mar. 4	+0.01	+ 1	+0.01
Mar. 4	Mar. 11	0	- 5	-0.01
Mar. 11	Mar. 18	-0.01	+ 8	+0.01
Mar. 18	Mar. 25	+0.06	-14	+0.03
Mar. 25	Apr. 1	0	+ 4	+0.01
Apr. 1	Apr. 8	0	0	0
Apr. 8	Apr. 14	0	- 2	0
Apr. 14	Apr. 22	0	+ 1	0
Apr. 22	Apr. 29	+0.01	+ 5	+0.02
Apr. 29	May 7	+0.01	+ 9	+0.03
May 7	May 13	0	- 9	-0.02
May 13	May 20	-0.01	+ 4	0
May 20	May 27	0	+24	+0.05

TABLE 23

DATA ON MOVEMENTS OBSERVED
DUFFERIN TERRACE, QUEBEC CITY

Station: No. 1

Apparatus Employed: Steel Tape

Coefficient of Linear Expansion = 0.000006 per degree Fahrenheit.

Type of Movement: + Divergence = increased distance between anchor pins.
− Convergence = decreased distance between anchor pins.

Date	Measurement, feet	Temp. °F	Measurement Corrected for Temperature, feet	Net Change from Base, feet
May 22, 1958	32.77	60	32.77	0
June 16,	32.76	46	32.76	- .01
July 7,	32.77	61	32.77	0
July 21,	32.76	63	32.76	- .01
July 29,	32.76	67	32.76	- .01
Aug. 7,	32.76	71	32.76	- .01
Aug. 18,	32.76	56	32.76	- .01
Aug. 28,	32.76	60	32.76	- .01
Sep. 9,	32.76	54	32.76	- .01
June 6, 1959	32.79	43	32.79	+ .02
June 15,	32.79	55	32.79	+ .02
June 23,	32.78	64	32.78	+ .01
July 14,	32.75	80	32.75	- .02
July 21,	32.76	78	32.76	- .01
July 29,	32.76	84	32.76	- .01
Aug. 5,	32.76	64	32.76	- .01
Aug. 15,	32.76	65	32.76	- .01
Aug. 22,	32.76	60	32.76	- .01
Sep. 5,	32.76	55	32.76	- .01
Sep. 12,	32.78	62	32.78	+ .01
Sep. 19,	32.78	39	32.78	+ .01
Oct. 10,	32.78	48	32.78	+ .01
Nov. 7,	32.80	31	32.79	+ .02
Nov. 14,	32.79	29	32.78	+ .01
Nov. 21	32.79	16	32.78	+ .01
May 13, 1960	32.76	42	32.76	- .01
May 20,	32.78	46	32.78	+ .01
May 27,	32.77	70	32.77	0

TABLE 24

DATA ON MOVEMENTS OBSERVED
DUFFERIN TERRACE, QUEBEC CITY

Station: No. 2

Apparatus Employed: Steel Tape

Coefficient of Linear Expansion = 0.000006 per degree Fahrenheit.

Type of Movement: + Divergence = increased distance between anchor pins.
− Convergence = decreased distance between anchor pins.

Date	Measurement, feet	Temp. °F	Measurement Corrected for Temperature, feet	Net Change from Base, feet
May 22, 1958	45.60	60	45.60	0
June 16,	45.61	46	45.61	+ .01
July 7,	45.63	61	45.63	+ .03
July 21,	45.63	63	45.63	+ .03
July 29,	45.63	67	45.63	+ .03
Aug. 7,	45.62	71	45.62	+ .02
Aug. 18,	45.62	56	45.62	+ .02
Aug. 28,	45.62	60	45.62	+ .02
Sept. 9,	45.62	54	45.62	+ .02

Station destroyed by construction work May 1959.

TABLE 25

DATA ON MOVEMENTS OBSERVED
DUFFERIN TERRACE, QUEBEC CITY

Station: No. 3

Apparatus Employed: Steel Tape

Coefficient of Linear Expansion = 0.000006 per degree Fahrenheit.

Type of Movement: + Divergence = increased distance between anchor pins.
− Convergence = decreased distance between anchor pins.

Date	Measurement, feet	Temp. °F	Measurement Corrected for Temperature, feet	Net Change from Base, feet
May 22, 1958	64.61	60	64.61	0
June 16,	64.59	46	64.58	− .03
July 7,	64.62	61	64.62	+ .01
July 21,	64.62	63	64.62	+ .01
July 28,	64.62	67	64.62	+ .01
Aug. 7,	64.62	71	64.62	+ .01
Aug. 18,	64.62	56	64.62	+ .01
Aug. 28,	64.62	60	64.62	+ .01
Sept. 9,	64.61	54	64.61	0
June 6, 1959	64.64	43	64.63	+ .02
June 15,	64.64	55	64.64	+ .03
June 23,	64.64	64	64.64	+ .03
July 14,	64.64	80	64.65	+ .04
July 21,	64.63	78	64.64	+ .03
July 29,	64.64	84	64.65	+ .04
Aug. 5,	64.64	64	64.64	+ .03
Aug. 15,	64.64	65	64.64	+ .03
Aug. 22,	64.64	60	64.64	+ .03
Aug. 29,	64.64	61	64.64	+ .03
Sept. 5,	64.63	55	64.63	+ .02
Sept.12,	64.64	61	64.64	+ .03
Sept.19,	64.64	38	64.63	+ .02
Oct. 10,	64.64	48	64.64	+ .03
Nov. 7,	64.66	31	64.65	+ .04
Nov. 14,	64.65	29	64.64	+ .03
Nov. 21,	64.66	16	64.64	+ .03
May 13, 1960	64.64	42	64.63	+ .02
May 20,	64.65	46	64.64	+ .03
May 27,	64.65	70	64.65	+ .04
July 8,	64.66	65	64.66	+ .05

TABLE 26

DATA ON MOVEMENTS OBSERVED
DUFFERIN TERRACE, QUEBEC CITY

Station: No. 4

Apparatus Employed: Steel Tape

Coefficient of Linear Expansion = 0.000006 per degree Fahrenheit.

Type of Movement: + Divergence = increased distance between anchor pins.
− Convergence = decreased distance between anchor pins.

Date	Measurement, feet	Temp. °F	Measurement Corrected for Temperature, feet	Net Change from Base, feet
May 22, 1958	57.55	60	57.55	0
June 16,	57.51	46	57.51	− .04
July 7,	57.52	61	57.52	− .03
July 21,	57.52	63	57.52	− .03
July 28,	57.52	67	57.52	− .03
Aug. 7,	57.52	71	57.52	− .03
Aug. 18,	57.52	56	57.52	− .03
Aug. 28,	57.53	60	57.53	− .02
Sept. 9,	57.56	54	57.56	+ .01
June 6, 1959	57.55	43	57.54	− .01
June 15,	57.56	55	57.56	+ .01
June 23,	57.54	64	57.54	− .01
July 14,	57.53	80	57.54	− .01
July 21,	57.53	78	57.54	− .01
July 29,	57.53	84	57.54	− .01
Aug. 5,	57.53	64	57.53	− .02
Aug. 15,	57.53	65	57.53	− .02
Aug. 22,	57.54	60	57.54	− .01
Aug. 29,	57.54	61	57.54	− .01
Sept. 5,	57.54	55	57.54	− .01
Sept.12,	57.54	61	57.54	− .01
Sept.19,	57.54	38	57.53	− .02
Oct. 10,	57.54	47	57.54	− .01
Nov. 7,	57.57	31	57.56	+ .01
Nov. 14,	57.57	29	57.56	+ .01
Nov. 21,	57.57	16	57.55	0
May 13, 1960	57.54	42	57.53	−.02
May 20,	57.56	46	57.56	+.01
May 27,	57.51	70	57.51	−.04
July 8,	57.53	66	57.53	−.02

TABLE 27

DATA ON MOVEMENTS OBSERVED
DUFFERIN TERRACE, QUEBEC CITY

Station: No. 5

Apparatus Employed: Steel Tape

Coefficient of Linear Expansion = 0.000006 per degree Fahrenheit.

Type of Movement: + Divergence = increased distance between anchor pins.
- Convergence = decreased distance between anchor pins.

Date	Measurement, feet	Temp. °F	Measurement Corrected for Temperature, feet	Net Change from Base, feet
May 22, 1958	71.35	60	71.35	0
June 16,	71.32	46	71.31	- .04
July 7,	71.33	61	71.33	- .02
July 21,	71.32	63	71.32	- .03
July 28,	71.33	67	71.33	- .02
Aug. 7,	71.33	71	71.33	- .02
Aug. 18,	71.33	56	71.33	- .02
Aug. 28,	71.33	60	71.33	- .02
Sept. 9,	71.33	54	71.33	- .02
June 6, 1959	71.35	43	71.34	- .01
June 15,	71.35	55	71.35	0
June 23,	71.34	64	71.34	- .01
July 14,	71.31	80	71.32	- .03
July 21,	71.31	78	71.32	- .03
July 29,	71.31	84	71.32	- .03
Aug. 5,	71.32	64	71.32	- .03
Aug. 15,	71.31	65	71.31	- .04
Aug. 22,	71.34	60	71.34	- .01
Aug. 29,	71.34	61	71.34	- .01
Sept. 5,	71.31	55	71.31	- .04
Sept.12,	71.33	61	71.33	- .02
Sept.19,	71.33	38	71.32	- .03
Oct. 10,	71.33	47	71.32	- .03
Nov. 7,	71.36	31	71.35	0
Nov. 14,	71.37	29	71.36	+ .01
Nov. 21,	71.38	16	71.36	+ .01
May 13, 1960	71.33	42	71.32	- .03
May 20,	71.32	46	71.31	- .04
May 27,	71.29	70	71.29	- .06
July 8,	71.31	66	71.31	- .04

TABLE 28

DATA ON MOVEMENTS OBSERVED
DUFFERIN TERRACE, QUEBEC CITY

Station: No. 6

Apparatus Employed: Steel Tape

Coefficient of Linear Expansion = 0.000006 per degree Fahrenheit.

Type of Movement: + Divergence = increased distance between anchor pins.
− Convergence = decreased distance between anchor pins.

Date	Measurement, feet	Temp. °F	Measurement Corrected for Temperature, feet	Net Change from Base, feet
May 22, 1958	55.15	60	55.15	0
June 16,	55.14	46	55.14	− .01
July 7,	55.16	61	55.16	+ .01
July 21,	55.15	63	55.15	0
July 28,	55.15	67	55.15	0
Aug. 7,	55.15	71	55.15	0
Aug. 18,	55.15	56	55.15	0
Aug. 28,	55.15	60	55.15	0
Sept. 9,	55.15	54	55.15	0
June 6, 1959	55.15	43	55.14	− .01
June 15,	55.16	55	55.16	+ .01
June 23,	55.15	64	55.15	0
July 14,	55.14	80	55.15	0
July 21,	55.14	78	55.15	0
July 29,	55.14	84	55.15	0
Aug. 5,	55.14	64	55.14	− .01
Aug. 15,	55.14	65	55.14	− .01
Aug. 22,	55.15	60	55.15	0
Aug. 29,	55.14	61	55.14	− .01
Sept. 5,	55.14	55	55.14	− .01
Sept.12,	55.14	61	55.14	− .01
Sept.19,	55.14	38	55.13	− .02
Oct. 10,	55.14	47	55.14	− .01
Nov. 7,	55.15	31	55.14	− .01
Nov. 14,	55.15	29	55.14	− .01
Nov. 21,	55.17	16	55.16	+ .01
May 13, 1960	55.14	42	55.13	− .02
May 20,	55.12	46	55.12	− .03
May 27,	55.11	70	55.11	− .04
July 8,	55.13	67	55.13	− .02

TABLE 29

DATA ON MOVEMENTS OBSERVED
DUFFERIN TERRACE, QUEBEC CITY

Station: No. 7

Apparatus Employed: Steel Tape

Coefficient of Linear Expansion = 0.000006 per degree Fahrenheit.

Type of Movement: + Divergence = increased distance between anchor pins.
- Convergence = decreased distance between anchor pins.

Date	Measurement, feet	Temp. °F	Measurement Corrected for Temperature, feet	Net Change from Base, feet
May 22, 1958	56.42	60	56.42	0
June 16,	56.42	46	56.42	0
July 7,	56.42	61	56.42	0
July 21,	56.42	63	56.42	0
July 28,	56.42	67	56.42	0
Aug. 7,	56.42	71	56.42	0
Aug. 18,	56.42	56	56.42	0
Aug. 28,	56.42	60	56.42	0
Sept. 9,	56.42	54	56.42	0
June 6,	56.43	43	56.42	0
June 15,	56.43	55	56.43	+ .01
June 23,	56.43	64	56.43	+ .01
July 14,	56.42	80	56.43	+ .01
July 21,	56.42	78	56.43	+ .01
July 29,	56.42	84	56.43	+ .01
Aug. 5,	56.43	64	56.43	+ .01
Aug. 15,	56.42	64	56.42	0
Aug. 22,	56.43	60	56.43	+ .01
Aug. 29,	56.41	61	56.41	- .01
Sept. 5,	56.42	55	56.42	0
Sept. 12,	56.42	61	56.42	0
Sept. 19,	56.42	38	56.41	- .01
Oct. 10,	56.42	47	56.42	0
Nov. 7,	56.44	31	56.43	+ .01
Nov. 14,	56.44	29	56.43	+ .01
Nov. 21,	56.45	16	56.43	+ .01
May 13, 1960	56.43	42	56.42	0
May 20,	56.40	46	56.40	- .02
May 27,	56.39	70	56.39	- .03
July 8,	56.41	68	56.41	- .01

TABLE 30

DATA ON MOVEMENTS OBSERVED
DUFFERIN TERRACE, QUEBEC CITY

Station: No. 8

Apparatus Employed: Steel Tape

Coefficient of Linear Expansion = 0.000006 per degree Fahrenheit.

Type of Movement: + Divergence = increased distance between anchor pins.
- Convergence = decreased distance between anchor pins.

Date	Measurement, feet	Temp. °F	Measurement Corrected for Temperature, feet	Net Change from Base, feet
May 22, 1958	71.49	60	71.49	0
June 16,	71.49	46	71.49	0
July 7,	71.49	61	71.49	0
July 21,	71.49	63	71.49	0
July 28,	71.49	67	71.49	0
Aug. 7,	71.49	71	71.49	0
Aug. 18,	71.49	56	71.49	0
Aug. 28,	71.49	60	71.49	0
Sept. 9,	71.49	54	71.49	0
June 6, 1959	71.49	43	71.48	- .01
June 15,	71.49	55	71.49	0
June 23,	71.48	64	71.48	- .01
July 14,	71.47	80	71.48	- .01
July 21,	71.47	78	71.48	- .01
July 29,	71.47	84	71.48	- .01
Aug. 5,	71.48	64	71.48	- .01
Aug. 15,	71.47	55	71.47	- .02
Aug. 22,	71.48	60	71.48	- .01
Aug. 29,	71.50	61	71.50	+ .01
Sept. 5,	71.47	55	71.47	- .02
Sept.12,	71.48	64	71.48	- .01
Sept.19,	71.47	38	71.46	- .03
Oct. 10,	71.47	47	71.46	- .03
Nov. 7,	71.52	31	71.51	+ .02
Nov. 14,	71.53	29	71.52	+ .03
Nov. 21,	71.54	16	71.52	+ .03
May 13, 1960	71.48	42	71.47	- .02
May 20,	71.47	46	71.46	- .03
May 27,	71.46	70	71.46	- .03
July 8,	71.47	69	71.47	- .02

TABLE 31

DATA ON MOVEMENTS OBSERVED
DUFFERIN TERRACE, QUEBEC CITY

Station: No. 9

Apparatus Employed: Steel Tape

Coefficient of Linear Expansion = 0.000006 per degree Fahrenheit

Type of Movement: + Divergence = increased distance between anchor pins.
− Convergence = decreased distance between anchor pins.

Date	Measurement, feet	Temp. °F	Measurement Corrected for Temperature, feet	Net Change from Base, feet
May 22,1958	71.97	60	71.97	0
June 16,	71.98	46	71.97	0
July 7,	71.98	61	71.98	+ .01
July 21,	71.97	63	71.97	0
July 28,	71.97	67	71.97	0
Aug. 7,	71.97	71	71.97	0
Aug. 18,	71.97	56	71.97	0
Aug. 28,	71.97	60	71.97	0
Sept. 9,	71.98	54	71.98	+ .01
June 6,1959	71.98	43	71.97	0
June 15,	71.98	55	71.98	+ .01
June 23,	71.96	64	71.96	− .01
July 14,	71.97	80	71.98	+ .01
July 21,	71.96	78	71.97	0
July 29,	71.96	84	71.97	0
Aug. 5,	71.96	64	71.96	− .01
Aug. 15,	71.96	55	71.96	− .01
Aug. 22,	71.96	60	71.96	− .01
Aug. 29,	71.97	61	71.97	0
Sept. 5,	71.97	55	71.97	0
Sept.12,	71.96	64	71.96	− .01
Sept.19,	71.96	38	71.95	− .02
Oct. 10,	71.96	47	71.95	− .02
Nov. 7,	71.99	31	71.98	+ .01
Nov. 14,	71.99	29	71.98	+ .01
Nov. 21,	72.00	16	71.98	+ .01
May 13,1960	71.97	42	71.96	− .01
May 20,	71.96	46	71.95	− .02
May 27,	71.95	70	71.95	− .02
July 8,	71.96	69	71.96	− .01

TABLE 32

DATA ON MOVEMENTS OBSERVED
DUFFERIN TERRACE, QUEBEC CITY

Station: No. 10

Apparatus Employed: Steel Tape

Coefficient of Linear Expansion = 0.000006 per degree Fahrenheit.

Type of Movement: + Divergence = increased distance between anchor pins.
- Convergence = decreased distance between anchor pins.

Date	Measurement, feet	Temp. °F	Measurement Corrected for Temperature, feet	Net Change from Base, feet
May 22, 1958	75.15	60	75.15	0
June 16,	75.15	46	75.15	0
July 7,	75.16	61	75.16	+ .01
July 21,	75.15	63	75.15	0
July 28,	75.15	67	75.15	0
Aug. 7,	75.15	71	75.16	+ .01
Aug. 18,	75.15	56	75.15	0
Aug. 28,	75.15	60	75.15	0
Sept. 9,	75.15	54	75.15	0
June 6, 1959	75.16	43	75.15	0
June 15,	75.17	55	75.17	+ .02
June 23,	75.17	64	75.17	+ .02
July 14,	75.16	80	75.17	+ .02
July 21,	75.16	78	75.17	+ .02
July 29,	75.16	84	75.17	+ .02
Aug. 5,	75.17	64	75.17	+ .02
Aug. 15,	75.16	65	75.16	+ .01
Aug. 22,	75.17	60	75.17	+ .02
Aug. 29,	75.18	61	75.18	+ .03
Sept. 5,	75.17	55	75.17	+ .02
Sept. 12,	75.17	64	75.17	+ .02
Sept. 19,	75.17	38	75.16	+ .01
Oct. 10,	75.17	47	75.16	+ .01
Nov. 7,	75.18	31	75.17	+ .02
Nov. 14,	75.19	29	75.18	+ .03
Nov. 21,	75.19	16	75.17	+ .02
May 13, 1960	75.16	42	75.15	0
May 20,	75.18	46	75.17	+ .02
May 27,	75.18	70	75.18	+ .03
July 8,	75.16	70	75.16	+ .01

APPENDIX

LOG OF HORIZONTAL HOLE NO. 2, QUEBEC CITY

(98' full length, in direction approximately perpendicular to the bedding)

SUMMARY

This core consists almost exclusively of black, strongly calcareous mudstone and dark grey and black, strongly argillaceous, dolomitic limestone, grading imperceptibly into one another. The rock types are differentiated with difficulty in hand specimens, so that it would be virtually impossible to correlate lithological variations in the core with variably resistant weathered outcrops above the hole.

Depth	Description
0-3.3'	Mudstone, strongly calcareous, black, highly broken along planes making 20° to direction of the hole; grades imperceptibly into strongly argillaceous, black limestone.
3.3-18.5'	Mudstone, strongly calcareous, black, unbroken except for separation along thin (less than 1/16") mineralized planes perpendicular to core axis and presumably bedding. Occasional mineralized fractures at 15°-30° with direction of core and essentially perpendicular to the bedding fractures and offsetting them 1/4"-1/2".
18.5-20.7'	Mudstone as in immediately preceding unit, broken up along fractures at 10°-30° to core axis, in pieces 1"-3" long.
20.7-25.0'	Mudstone, strongly calcareous as in preceding, parting largely on mineralized fractures at 75° to core axis in pieces mostly 3"-8". Locally the rock may be more a strongly argillaceous, finely crystalline limestone.
25.0-31.0'	Mudstone, strongly calcareous, black as in preceding, with mineralized fractures at $\pm 18^\circ$ to core axis, again offsetting mineralized bedding partings (?) 1/4"-1/2" and essentially perpendicular to them. Some fractures open up to 1/4" and, with euhedral quartz crystals, up to 1/4" diameter. Local intervals of strongly argillaceous, black limestone with imperceptible boundaries with the mudstone.

31.0-36.0'	Mudstone as in immediately preceding, with fine silty layers. Core broken into pieces 1"-7" with edges rounded from attrition. Drilling looked difficult here from roughness of sides of core.
36.0-47.3'	Mudstone, strongly calcareous, slightly silty, black with thin (less than 1/4") bands of black strongly calcareous mudstone. Sparse mineralized fractures at 5°-15° to core axis.
47.3-48.1'	Mudstone, strongly to slightly calcareous, black, highly broken in pieces 1/2"-1" long, subrounded by attrition; some partings at 5°-15° to core axis.
48.1-60.9'	Mudstone, strongly calcareous, black as in preceding, with occasional mineralized fractures at ±10° to core axis and broken along them. Local interbeds up to 3" of medium grey, strongly argillaceous, finely crystalline limestone at 49.0-49.5'. As well as imperceptibly gradational zones up to 1 foot thick of black, strongly argillaceous limestone.
60.9-61.8'	Limestone, strongly argillaceous, medium dark grey, in sharp contact on side nearest outside of hole and with light grey fine-grained mineral (clasts of carbonate). Completely gradation contact into beds towards inside of hole. Prominent mineralized fractures (quartz and carbonate) at ±10° to core axis and offsetting mineralized (bedding?) planes less than 1/4" at angle of about 80°.
61.8-73.2'	Mudstone, strongly calcareous, black, with occasional silt bands up to 1/4" and occasional thin (less than 1/32") mineralized fractures up to 28° to core axis.
73.2-75.0'	Mudstone, black, calcareous, highly broken (pieces generally 2"-4") along mineralized and unmineralized fractures at 15°-30° to core axis.
75.0-78.7'	Mudstone, strongly calcareous, black as in preceding.
78.7-79.9'	Limestone, strongly argillaceous, medium dark grey, very finely crystalline, with sparse fractures at ±18° to core axis and completely gradational with beds to outside of hole, sharp contact on inside.
79.9-80.3'	Mudstone, strongly calcareous, black, broken along unmineralized fractures at 18° to core axis, in pieces 1"-4".
80.3-87.5'	Mudstone, strongly calcareous, black, broken along one set of fractures at about 65° to core axis (unmineralized) and another at about 10° to core axis (mineralized) in pieces generally ±0.8 feet.

87.5-88.3' Mudstone, strongly calcareous, black, broken along partings parallel to bedding (?) and along mineralized fractures at ±10° to core axis; in pieces 1"-3".

88.3-93.7' Mudstone, strongly calcareous, black, as in preceding with mineralized fractures at about 18° to core axis.

93.7-94.6' No core.

94.6-98.0' Mudstone, strongly calcareous, black, as in preceding with mineralized fractures at 10° or less to core axis and broken along some of these. Highly broken in last 0.5 feet of hole. Thin silty layers in lowest 0.5 feet.

Bottom of hole.
(Core recovery approximately 95%)

(signed) D. K. Norris,
Geological Survey of Canada

January, 1959.