February 26, 1993

Mr. Numan H. Vasquez
Acting Director, Engineering and Construction Bureau
Panama Canal Commission
Balboa Heights, Republic of Panama

Dear: Mr. Vasquez

Re: Geotechnical Advisory Board

The fifth meeting of the Geotechnical Advisory Board was convened in Panama from February 22-26, 1993. The schedule for this meeting is included with this report as Attachment A.

The Board appreciates the opportunity to have met with the Administrator, Deputy Administrator, the Chief of the Engineering Division, and you in order to present our findings with regard to the various geotechnical issues of interest to you.

The Board wishes to express its appreciation to Dr. Luis Alfaro and the staff of the Geotechnical Branch for their conscientious preparation for this meeting, for their excellent field briefing, and for the presentation of study results, all of which contributed to the effective operation of the Board at this meeting.

In the following report, observations and recommendations are made under four separate sections, namely:

1. Stability of Gatun Dam

2. Cut Widening

3. Landslide Control Program

4. Closure

1. STABILITY OF GATUN DAM

1.1 Background

Gatun Dam creates Gatun Lake and hence is an essential component of the Canal concept. It has been subjected to occasional safety reviews, including seismic safety. In recent years the Geotechnical Branch has undertaken an annual inspection of the dam. Only matters of minor maintenance have been identified as requiring attention.

As a result of heightened awareness, the PCC has recognized that Gatun Dam is exposed to larger earthquakes than have been considered in the past. Hence, a re-assessment of seismic stability has been initiated. At the same time, the question has been raised whether the seepage emerging from the toe of the dam is of concern. This report focuses on these two issues.

1.2 Seismic Hazard

Information related to the historical seismicity of Panama has been assembled for the Geotechnical Branch by Dr. A. Vergara. This, together with available information on the seismo-tectonic regime affecting Panama, indicates that the Panama Deformed Belt (PDB), offshore to the North of Gatun Dam, is the likely source of the largest earthquakes that affect Gatun Dam.

It is now known that a large earthquake, originating from the PDB zone in 1882, created substantial damage in the Colon area and that there was considerable liquefaction along the Chagres River. A magnitude in excess of 7.5 has been attributed to this earthquake and it is the re-occurrence of a comparable event that must be addressed in a new seismic safety assessment.

In 1992 the PCC commisioned a scoping study with Woodward-Clyde Consultants that summarized information gathered by PCC staff. Their report concluded that the seismic safety problem requires attention and that comprehensive studies are needed to address the issue. The Board agrees with this view.

The work to date in which the problem has been identified and a plan of action prepared may be regarded as Phase I of the study. There are two choices available for the next phase. They are:

1) Assign the study to a consultant, more or less as outlined in the budget-level cost estimate submitted by Woodward-Clyde Consultants.

2) Proceed as far as practical with PCC staff, supplemented by specialist assistance as needed.

The Board recommends that Phase II be undertaken by maximizing the use of PCC staff.

Phase II should be regarded as a screening study intended to answer the questions: how serious is the potential for liquefaction failure of Gatun Dam. The study could result in the following conclusions: 1) There is no problem, or 2) The problem is sufficiently well-defined that remediation measures are clear and that they should be evaluated, or 3) More detailed and focused Phase III studies are needed.

Often a considerable effort is required to identify the design earthquake loading in order to initiate this type of screening study. However the Limon earthquake of April 22, 1991 originated in the westerly end of the PDB. It had a Magnitude of 7.5 and excellent strong motion records were obtained at the Siquirres station about 60 km from the epicenter. This record exercises such a dominant influence on the earthquake resistance design in the region that the Board believes that for Phase II, it is appropriate to omit additional seismic geology and field seismology investigations. Instead, the Siquirres record should be adopted as the basis for the screening study.

1.3 Earthquake Ground Motion

As summarized in Attachment B, reliable corrected digital data are available from the Siquirres strong motion record, Limon earthquake, 1991. This is a bedrock, or close to bedrock record, about 60 km from the epicenter, and it is proposed that it be used in Phase II of the Gatun Dam study. If a decision is made at a later date to design on the basis of a larger earthquake it can be magnified.

The Board recommends that the PCC obtain this record in digital form from the Instituto Costarricense de Electricidad, or other appropriate agency. It should be confirmed that:

i) the record is free of significant accelerograph instrument influence

ii) the record is free of significant shallow ground amplification.

1.4 Seismic Response Studies

The Gatun Dam is flat enough that a site response analysis can be conducted in one dimension. This analysis is usually undertaken by means of the computer program SHAKE. The Board recommends that the Geotechnical Branch obtain and became familiar with the operation of this program. Some specialized training assistance will be necessary which can be provided either by the Waterways Experiment Station or by private sector Consultants.

The objective of the SHAKE analysis is to obtain the variation of cyclic shear stress at various profiles in the dam, including the underlying Atlantic Muck. The Limon record is input at bedrock level and propagated upward through the Muck and the Dam. Ultimate properties for this analysis will be based on field and laboratory studies. Prior to fixing these, it will be useful to undertake sensitivity analyses varying the height of the fill in the section analysed, the depth of the muck, and assumed stiffness properties. The effect of upward scaling of the earthquake record should also be investigated.

Following the synthesis of field and laboratory information, a final set or range of properties will be selected to determine the cyclic shear stress distribution at various locations within the Dam.

1.5 Field Investigation

The assessment of liquefaction potential is made by comparing the cyclic stress ratio (see 1.4 above) with the cyclic resistance ratio. In order to determine the cyclic resistance ratio in a conservative manner, standard practice makes use of the Seed-Tokimatsu correlation. This correlation is based on the Standard Penetration Test (SPT). Modern practice dictates that these tests be performed truly in accordance with ASTM/ISSMFE standards.

Given the lack of knowledge with regard to energy transmission in PCC test practice, the Board also recommends that energy calibration be undertaken. Attachment C contains a summary of good test practice and a reference to a newly developed, commercially available energy measurement system. Other systems are also available.

The Board recommends that six transverse profiles be investigated. Two profiles should be nominally at the third points of the east dam and the additional four profiles should be spread more or less equally across the west dam, with one located in the zone of artesian water pressure, near the spillway (see Section C, Figure No. 10, Description of Gatun Dam. Its Construction and Recent Surveillance, Geotechnical Branch, September, 1992).

Each transverse profile should consist of four SPT holes and four sample holes. The SPT holes should be located at reservoir level, at the downstream edge of the crest, and at intermediate locations upstream of the rockfill toe. SPT's should be taken at 5 ft intervals to bedrock. Sample holes should be located about 5 - 10 ft away. Three inch Shelby tube samples should be obtained for laboratory tests, where possible, from the full sequence. Where gravelly soil can be sampled, the sample diameter should be enlarged to 5 in. All boreholes should be grouted upon completion. Casagrande piezometers should be installed at or near the base of the dam, in the hydraulic fill, in each core hole.

In addition to the six transverse sections, longitudinal profiles should be constructed for each portion of the Dam.

1.6 Laboratory Investigations

All samples obtained from the SPT investigation should be tested for grain size distribution, Atterberg Limits and moisture content. Silt and clay tube samples should be tested under UU condition and moisture contents determined.

1.7 Risk Factors

It is not the intent of the Board to make final recommendations with respect to design earthquake loading at this time. However, the Panama Canal Commission should be alerted that if there are hazards involving public safety, international standards of practice influence the level of the design earthquake, which is usually fixed at the Maximum Credible Earthquake (MCE). For the PDB, this might imply a Magnitude in excess of 8. If there is no threat to public safety, a lesser level can be countenanced, influenced by an economic decision. The requirements of the Canal's catastrophic risk insurance in this regard may merit assessment.

1.8 Water Levels in the Dam

Eighteen open hole wells are monitored several times annually to provide information on the water level within the earth dam. Of these, seven have been destroyed or clogged and are not providing information at the present time. One well, GDS 13, downstream and near the spillway consistently shows groundwater levels about 4 ft above the adjacent dam surface (except for 9/19/89). Some wells exhibit little change, as might be expected with the near constant lake level; others exhibit fluctuations of several feet during the year.

In 1988 inspection found that the dam surface, extending about 500 ft. W of Well GDS 13, was wet and soggy. The Geotechnical Branch designed a system of French drains, up to 4 ft deep and totalling about 1800 ft in length. These effectively dried the surface. However they did not change the level of water in the observation wells. GDS-13, has been consistently 4 ft above the dam surface at that point.

Because some of the wells exhibit little change, we recommend flushing the wells to remove debris or bacterial slime that can obstruct them. With the existing wells and piezometers in the new borings, plots of piezometric levels in the dam cross section should be developed.

Regular inspection of the dam toe has found concentrated seepage at a number of locations, many of which are associated with pipes installed during construction to drain the core pool. All of the seepage is measured by V-notch weirs, most on individual or clusters of seeps. A very few small seeps are joined by a collector ditch that terminates at a weir.

All weirs show highly variable seepage that closely reflects the rainfall during the previous week. This is to be expected in such a wide dam with extremely flat slopes. The total toe seepage during dry periods is a fraction of a cubic foot per second, negligible for such a large dam.

1.9 Surface Movement

The dam surface movements have not been observed at regular intervals since the dam was completed. During one interval, 1937-1959, continuous settlement and downstream movement were observed. The greatest total settlement exceeded 1 ft during this period. This occurred at locations where the Atlantic Muck thickness was greatest. However, the readings were discontinued in 1959. Readings resumed in 1981. Small movements were observed. Some were progressive and some erratic. No recent settlement data were furnished. Therefore it is not possible to reach conclusions regarding the present dam settlement or surface movement.

There are no visual indications of either excessive surface movement or excessive settlement that reflect instability in the Dam.

1.10 Recommendations

The old drain pipes, now rusting away, should be fitted with filters that will permit continuing drainage, but without providing an opportunity for seepage erosion. A pervious plug should be constructed in each exit. This could be of porous concrete, such as is utilized in porous concrete drain pipe. Essentially it is gap-graded concrete with a maximum aggregate size of 3/4 in. to 1 in. that is sufficiently undersanded that it is uniformly honeycombed. It is porous enough to drain freely but the pores are fine enough to restrict movement of coarse clean sand.

The mix is determined by extensive trial and error. The plug should be fitted with a 4 in. pipe at the top for pumping clean sand into the drain pipe after the plug is in place. The sand will minimize sudden collapse of the old drain pipe and will permit drainage without continued erosion. Hopefully the plug and sand filling will extend upstream as far as the upstream side of the originally dumped starter dikes.

Seeps issuing directly from the toe should be fitted with simple toe filters. A shallow excavation should be made to remove sloughed organic debris and soft soil. Filter sand is immediately placed on the exposed surface and then blanketed with coarse stone aggregate. The whole process typically can be completed in an hour or two. The dimensions of each are determined by the seepage; in most cases about 200 lb. of sand and 400 to 600 lb. of stone should be sufficient. Such filters should fit inside the existing weir walls.

A few small erosion gullies were observed where the toe is steep. These should be filled with fine stone to minimize continued erosion. Small "sink holes" on the dam surface reflect erosion of fill into the open voids of the underlying starter dikes. These should be filled by small broken stone to prevent children from falling into them.

2. CUT WIDENING PROGRAM

The Geotechnical Branch has devoted a major effort to developing plans for cut widening contracts during the past year. Four members of the Branch staff have devoted full time effort to preparation of contract drawings and other tasks related to cut widening. Six projects in the North Sector have been let to bid: Three of these have been completed, two are about 60 percent complete, and one is ready to begin construction. Four more projects are currently being designed. Site investigations, involving 32 new borings, are under way for the Central Sector at La Pita Curve.

2.1 Design Process and Computer Equipment

The information being used for design is managed through the use of Intergraph work stations. The Intergraph work stations have made it possible to use directly the topographic database developed by the Corps of Engineers, and to integrate information derived from geologic studies in a very effective manner. The Board is favorably impressed with the efficiency of this computer system. It has made possible rapid progress in the first design projects, and seems well suited for continued use in the Cut Widening Program.

2.2 Blasting Control

Dry excavation by contractors is used down to elevation 90 ft PLD. Below this elevation, excavation will be accomplished by the Panama Canal Commission Dredging Division. Drilling and blasting will be used to fragment the material below elevation 90 ft so that it can be removed by dredging.

It is important that the blasting used to fragment the material below elevation 90 ft should (1) be effective in breaking the material to be dredged into sizes that can be moved by the dredge, and (2) not cause slides or excessive weakening of the material left in place. Achieving these objectives will require careful control of blasting procedures.

Blasting is also being used prior to dry excavation where hard materials are encountered. The Board recommends that maximum particle-velocity measurements be made during these blasts, and that the degree of fragmentation be recorded as a function of blast design as excavation progresses, to obtain information that can guide the blasting operations by the Dredging Division. Additional blast monitoring will be needed to ensure that the blasting done by the Dredging Division does not result in particle velocities that are likely to cause significant damage to materials that will remain in place.

2.3 Areas of Great Geotechnical and Geological Sensitivity

The first widening projects have been in areas of somewhat modest geotechnical and geological sensitivities, where slides that could encroach on the navigation channel are less likely. As widening progresses farther south, it will enter areas of greater sensitivity, with potential for slides with serious consequences. The Board recommends that the possibilities for cut widening in these very sensitive areas be studied thoroughly and that this begin immediately even though there are no plans to excavate in these areas for a number of years. The Board feels that there are two important reasons for early consideration of the requirements and possible consequences of excavating in these areas:

(1) It may prove to be so costly to excavate some areas that widening some sections cannot be justified on the basis of cost/benefit ratio. The Board understands that the widening program will have economic benefit even if all sections are not widened.

(2) It may prove to be technically infeasible to excavate some areas (such as Gold Hill and adjacent slide areas) at any reasonable cost. This may control the alignment to a greater degree than now anticipated, and may require changes in the alignment farther to the north.

2.4 Use of Previous Widening Experience

After the first widening program a series of landslides occurred over a period of several years that required approximately 7 million cubic meters of additional excavation. These slides were most likely the result of swelling and softening of the materials following excavation. Such swelling and softening is a common phenomenon.

It is desirable that this earlier experience be used to the fullest extent possible in designing the slopes for the current widening program. The strengths and pore pressures used in stability analyses should be selected on the basis of long-term stability, and not simply stability during and immediately following construction.

A. The experience gained from the previous widening project can be summarized usefully in the form of cross sections that show:

(1) Geology
(2) Topography prior to the first widening
(3) Locations of slides, if any occurred in the section after widening
(4) Topography after repair of the slides in sections where slides occurred
(5) Topography as it will be be after the proposed new widening.

Calculated long-term factors of safety for each stage should be shown on the cross sections, to indicate the changes in factor of safety associated with each change in slope configuration.

It is desirable that observation be made to detect changes in material and instability during construction as early as possible, so that the designs of the slopes can be modified as necessary. However, because it is to be expected that the slopes will become less stable with time following construction, use of extensive or sophisticated instrumentation to monitor movements during construction is not warranted. This situation may change if and when widening progresses into more sensitive areas.

3. LANDSLIDE CONTROL PROGRAM

3.1 Background

The Landslide Control Program has been effectively and efficiently conducted by the Geotechnical Branch for the past several years. Not only has the slide activity in the Gaillard Cut been considerably reduced, but the concepts learned and used in recognition and control of Gaillard Cut landslides will be of great value in design of the more hazardous slopes to be encountered as cut widening progresses into the general area of Gold Hill. In addition, the experience gained in the Landslide Control Program has increased the level of technical awareness and expertise of personnel in the Geotechnical Branch.

In the past few years, the climate in Panama has not been conducive to widespread landslide activity, i.e., precipitation thresholds for slope-failure activity have seldom been exceeded. This should not lull the PCC into a false sense of security with regard to landslide hazards.

Specific comments on the Landslide Control Program and suggestions for improvement are as follows:

3.2 Drainage and Diversion Ditches

An important and effective new element of the Landslide Control Program has been the efficient drainage of water (some of which is ponded) from the Obispo, Camacho, and Rio Grande diversion ditches that parallel the Canal along the slopes above. These old diversion ditches were originally constructed to intercept surface water from above the construction areas; however, since construction, these low-gradient ditches have served as sources of water that seeps underground through marginally stable cut-slope areas in Gaillard Cut, contributing to increased pore pressures, lowered shear strength, and reduced levels of slope stability. Because these drainage ditches currently serve no positive function, they are being drained by down-slope impervious surface conduits that lead the water directly to the Canal. Since detailed topographic information to assist drainage design is difficult to obtain from airphotos, pre-design field surveying may contribute to improved drainage design.

3.3 Monitoring of Slope-Surface Movement

The EDM (electronic distance measurement) system, for monitoring movement of slope surfaces is working very well. The movement data obtained by this system is extremely valuable for delineating slopes in need of mitigation. The value of EDM data can be increased by acquisition of a state-of-the-art theodolite that can be used to locate EDM targets quickly and accurately in three dimensions, thus allowing three-dimensional analysis of movement of surface points. We agree with the Geotechnical Branch that the Wild T-3000 theodolite is best suited for the purpose, and recommend purchase of one of these instruments.

3.4 Efficient Field Inspection of Slopes

A critical component of the above monitoring program of surface movement is systematic on-site field inspection conducted in conjunction with reading of the EDM targets. This inspection is focused on field observation of new cracks, shears, bulges, springs, etc. Because of the rapid growth of nearly impenetrable elephant grass and brush on these slopes, the inspection element of the movement study is difficult and may be less effective than desired. We recommend that trails to all EDM targets be regularly maintained (i.e., grass and brush cut nearly to ground level) to facilitate slope inspection and inspection of drainage channels.

3.5 Horizontal Drains

Installation of horizontal drains as a slope-stabilization procedure in the Gaillard Cut has been particularly successful in recent years under the Landslide Control Program. Drains have been placed 500 ft or more into unstable slopes, and PCC equipment has the capability of placement to 1000 ft under ideal geologic conditions. Because these drains have proven successful as a method of slope stabilization in the Gaillard Cut and because the PCC has developed a proven capability of successful horizontal-drain installation, we recommend that these drains be used extensively for future slope stabilization and that a systematic strategy for their installation be developed.

3.6 Groundwater Hydrology

Surface-water hydrology, as it effects slope stability in the Gaillard Cut , appears to be well understood, and surface flow is being controlled as a mitigative measure. However, except for a few site-specific studies of the groundwater regime of active landslides, there seems to be little understanding of the overall groundwater regime in the Gaillard Cut, even though groundwater is a critical factor in the stability of the slopes. We feel that integrating the available groundwater data would be a valuable asset to slope design and maintenance in critical slope areas. This study would rely on groundwater knowledge already available from drill holes and piezometers, plus field study of springs, ponds, etc. As an initial effort, the Board recommends that the Geotechnical Branch integrate their data on the scale of the Gaillard Cut in a preliminary model.

4. CLOSURE

The Board Members appreciate the thought and work necessary for preparing the data and organizing for this meeting. Detailed recommendations for future work appear above in the main body of the report.

We suggest that the next meeting of the Board be called by the Commission when the additional investigations of Gatun Dam are complete and when the experiences gained in the present phase of canal widening design and construction can be critically reviewed.

James M. Duncan
Consultant

Norbert R. Morgenstern
Consultant

Robert L. Schuster
Consultant

George F. Sowers
Consultant

Attachments

cc:
Consultants (1 copy each)

ECEG
ECET

AGENDA FOR THE 5th MEETING OF THE GEOTECHNICAL ADVISORY BOARD
February 22 to 26, 1993

A

MONDAY, FEBRUARY 22 (Room 10)

7:30 MTD vehicle picks up consultants at the hotel
8:00 Meet with Chief, Engineering Division
8:15 Overview of Geotechnical Branch activities since last GAB meeting /L. Alfaro
9:30 Break
10:00 Briefing on Gatun Dam Seismicity /A. Vergara (PCC consultant)

12:00 Lunch with Chief, Engineering Division

1:00 Briefing on Gatun Dam Construction & Recent Surveillance /R. Rivera
2:30 Briefing on Gatun Dam Geology /P. Franceschi
4:15 MTD vehicle takes consultants to the hotel

TUESDAY, FEBRUARY 23 (Room 10 in the morning / Bldg. 630 in the afternoon)

7:30 MTD vehicle picks up consultants at the hotel
8:00 Briefing on the Landslide Control Program (LCP) /C. Reyes
9:30 Break
10:00 Rainfall patterns in Gaillard Cut for 1991-1992 /L. Fernández
10:30 Subsurface Instrumentation (Recent experience & future plans) /P. Franceschi

12:00 Lunch

1:00 Briefing on the Cut Widening Program (CWP) /J. Reyes
2:30 Drainage in Gaillard Cut /E. Saenz
3:30 Consideration of new instruments for Surface Monitoring /C. Reyes & J. Reyes
4:15 MTD vehicle takes consultants to the hotel

WEDNESDAY, FEBRUARY 24 (Field trip to Gatun Dam)

7:30 MTD vehicle picks up consultants at the hotel
8:00 Leave for Gamboa
8:30 Take launch for Gatun Dam
9:30 Inspect Gatun Dam

12:00 Lunch (Tarpon Club)

1:00 Continue Inspection of Gatun Dam
2:30 Take Launch back to Gamboa
3:30 Return to Administration Building
4:15 MTD vehicle takes consultants to the hotel

THURSDAY, FEBRUARY 25 (Field Trip to Gaillard Cut)

7:30 MTD vehicle picks up consultants at the hotel
8:00 Leave for Gaillard Cut
8:30 Inspect areas of interest on the West Bank
- CWP excavation projects 1-5
- Areas for CWP projects 6-10
- West Lirio Drainage
- Model Slope
- Cartagena (Reforestation)

12:00 Lunch (Horoko)

1:00 Continue Inspections on East Bank
- East White House Slide & rest of Sardinilla (Obispo Diversion)
- East Lirio Slide (Reforestation)
- Gold Hill (East Culebra & Cucaracha Slides)

3:30 Return to the Administration Building
4:15 MTD vehicle takes consultants to the hotel

FRIDAY, FEBRUARY 26 (Engineering Division's Conference Room)

7:30 MTD vehicle picks up consultants at the hotel
8:00 Meet with E&C Bureau Director and Chief, Engineering Division
9:00 Preparation of Report by Board Members

12:00 Lunch

1:00 Continue Report Preparation
4:15 MTD vehicle takes consultants to the hotel

SPECIFIC QUESTIONS THE PCC REQUESTS THE GEOTECHNICAL ADVISORY BOARD ADDRESSES DURING ITS FIFTH MEETING

1. How does the Board recommend we pursue the evaluation of Gatun Earth Dam?

2. If the evaluation of Gatun Earth Dam indicates that the structure, in its present state, is vulnerable during a large earthquake, what remedial measures does the Board envision that could be implemented? Can the Board define such remedial measures (at a conceptual level) to a degree that will enable us to estimate their order of magnitude costs?

3. With respect to the Landslide Control Program, how does the Board recommend we proceed on:

   a. Our plans to improve drainage in the Cut on a global basis.
   b. The use of new instruments for our surface and/or subsurface surveillance.
   c. The selection of areas in which to use subsurface instrumentation.
   d. Our reforestation policies.

4. With respect to the Cut Widening Program, what recommendations does the Board offer in relation to:

   a. Our design procedures.
   b. The use of monitored construction procedures when excavating potentially unstable areas in the future.
   c. Criteria to control damage to the slopes by Dredging Division's blasting operations during the final phase of widening.

ENGINEERING COURSE 1991-1992, IISEE-BRI, JAPAN

PROCESSING AND ANALYSIS OF STRONG EARTHQUAKE MOTIONS RECORDED IN COSTA RICA

BY

ALVARO CLIMENT MARTIN*

ABSTRACT

In this paper is presented seismological information and the results of the eight processed accelerograms of one large and two moderate earthquakes occurred in Costa Rica in 1990 and 1991.
Characteristics of instrument and site condition for each station where the accelerograms were recorded are given. Also are described the data processing procedures for obtaining a digital data set from analog strong motion. Finally the corrected time history acceleration, velocity and displacement and the response spectra of 24 seismic traces were calculated, and the time histories for the Limon Earthquake of Apr. 22, 1991 are presented.

INTRODUCTION

Due to the tectonic conditions of Costa Rica characterized by a high level of seismicity, the occurrence of large and destructive earthquakes are expected. Considering a high seismicity of the country and the importance to record real data of earthquake motion, accelerographs have been installed in different sites of the country since 1984. The seismic signal recorded by these instruments (accelerogram) is very useful for seismic design purposes, because it permits to obtain different parameters to characterize strong ground motion, such as peak acceleration, peak velocity, response spectral values and Fourier spectral values. Among them the response spectrum is the basis, either directly or indirectly, of most earthquake-resistant design. The accelerogram may be used in the dynamic analysis of structures, and is the basis for the relation, in building codes, between the lateral design-force coefficient and the period of the buildings [1].

After the installation of these instruments many seismic events have been recorded in the country and three of these events were selected for this study: the Piedras Negras earthquake of December 22, 1990, the Limon earthquake of April 22, 1991, and the earthquake of August 9, 1991. Representative accelerograms related with these events were used. For the first earthquake with local magnitude of 5.7, three accelerograms in near field were recorded on the base, abutment and crest of San

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Miguel Dam. This dam is located around 5 km from the epicenter The accelerograms of an aftershock recorded at the same plac were also processed.

For the second one with magnitude (M_S) of 7.5, an accelero gram recorded at the Siquirres station located 60 km from th epicenter was analyzed. For the last one (M_L = 4.9) an accelero gram recorded at the La Lucha station located 5 km from the epi center was also analyzed.

The objective of this study is to obtain a reliable digi tal data set of the analog accelerograms mentioned above. To do this, a processing technique of base-line and instrument correc tion, and high and low noise elimination was used.

SEISMOLOGICAL DATA

The pacific border of Costa Rica as well as the rest of Central America is located at proximity of interplates (Fig. 1). The subduction of the Cocos plate under the Caribbean plate is the cause of the majority of seismicity in the country. At the same time, it originates other tectonic phenomenon such as volca- noes, and local and regional faults [2]. Two local and one re- gional faults in the country were the seismic sources of the earthquakes treated in this study (Fig. 2).

The Piedras Negras Earthquake of Dec. 22, 1990

This event occurred at 11:27 a.m. of local time, with a local magnitude of 5.7 and focal depth of 6.5 km. The epicenter was located 4 km north of Santiago of Puriscal (Fig. 2), and is associated with a left-lateral strike slip local fault. The reported epicentral intensity was VII in the Modified Mercalli (MM) scale. The same value was reported at San Miguel Dam [3].

Even the magnitude is not so large many masonry houses of one and two floors, in a radius of 25 km from the epicenter, suffered big damage and collapse. This is due to the shallow focus of the event and the proximity of population centers to the epicentral area [3].

The Limon Earthquake of Apr. 22, 1991

The earthquake occurred at 15:57 p.m. of local time, in Talamanca Mountains in the east part of the country (Fig. 2), with a magnitude of 7.5 (M_S) and focal depth of 21.5 km. The seismic source of this event have been defined as a low angle thrust fault [4]. The reported epicentral intensity was IX. The intensity VII was reported at the Siquirres station.

The earthquake caused severe damages to homes and commer- cial buildings. Also soil liquefaction and landslides were ob- served. Thirty percent of the roads and bridges in the atlantic zone were damaged [4].

The Earthquake of Aug. 9, 1991

In August 9 of 1991 an moderate earthquake of local magni- tude of 4.9 occurred at 03:33 a.m. of local time. The epicenter was located 17 km southwest of the capital city, San Jose (Fig. 2) at depth of 5.3 km. The seismic source is related with a strike slip fault. The epicentral intensity is VI-VII. The intensity at the site of accelerogram record (La Lucha) was VI [5].

In the epicentral area moderate or severe damage to at least 100 houses was reported, 20 of these were declared inhabitable. The majority of the houses was built by poor construction methods.

The information of seismic parameters of the earthquakes is listed in Table 1.

DATA ACQUISITION

The accelerograms used for this study were recorded by mechanical-optical photographic recording accelerographs, model SMA-1 of Kinemetrics Co.. This kind of instrument, that contain two horizontal and one vertical transducers, produces a record as an analog trace of acceleration versus time in a photographic film (ESTAR AH Base) of 70 mm width [6].

The specification of the accelerographs at the sites is given in Table 2. The site characteristics of each stations are summarized in Table 3. Schematic sketches of the installation and geological condition for the three sites are showed in Fig. 3.

In the case of the Siquirres station the accelerograph it was installed provisionally in a storage house when an earthquake sequence followed by the Limon earthquake began. At that time was attached to poor concrete slab floor. From the preliminary geological information the soil profile at the site can be classified as a shallow stiff soil.

San Miguel Dam is an earth dam with 30 meters of height and 330 meters of crest length. This dam is founded over weathered and unweathered lava of basaltic composition, whose physical conditions are very good and massive [7].

To check seismic performance of the dam three accelerograph were installed, one on the left abutment (rock), one on the crest, and one on the base (downstream). The last one is installed over silt-clay soil. The accelerographs are orientated in that way that their longitudinal trace coincides with the longitudinal axis of the dam (334 azimuth). In this way, both horizontal traces of the record, coincide with the longitudinal and transversal movements of the dam.

DATA PROCESSING

The data processing procedure which is commonly accepted for the earthquake engineering community was used. The flow of the procedure is shown in Fig. 4a. The process through which the digital data of analog strong motion records are obtained is rather complex [8], because some kind of noise are included during the acquisition of data and to convert to digital data. Then in general the processing of seismic strong-motion records is essentially a process through which the signal is separated from the noise [8]. The processing makes the data free from noise.

Digitization errors are caused by many factor, but have been found that the major source of digitization noise is due to the width of the trace [9]. For earthquake engineering studies, the errors are important and must be carefully controlled. The integration of accelerograms to produce ground velocities and displacements requires a minimization of long period errors, and the differentiation processes involved in making transducer corrections to extend the high frequency system response require that the high frequency errors be reduced [6].

Having in mind the above and as the first step of the process, for improvement of the accuracy of digitization, seven (except the data of the Siquirres site) of the eight accelerograms were sent to enlarge, and accurate enlarged film copies were made. The length of the record enlarged was in the function of the duration of strong shaking of the record.

According with the quality of the record two process of digitization were selected, using digitizer table or scanning digitizer. In the case of the accelerograms recorded in the base and crest of San Miguel Dam of the main shock, in which the traces of three components were mix, an expert operator of Electric Power Development Co., Ltd. of Japan did manually the digitization using the Muto digitizer table model DL-48 (914 x 1219mm). In this way the digitization was done by picking all significant peaks and points of inflection. Operator judgment can be used to produce the best representation of the complex waveform. A x and y coordinates data output with unequal time intervals was obtained.

In the case of the another six records the digitization was done in the Division of Earthquake Engineering of Tokyo Instute of Technology using a semi-automatic analyzer consisting of a personal computer PC-9801/VX NEC and a scanning digitizer K-IS-A3 Kurabo (420 by 300 mm) [10]. In the case of enlarged accelerograms the density of scanning was selected 200 dots per inch (dpi) and 400 dpi in the case of Siquirres accelerogram. A x and y coordinates data output with equal time interval of sampling was obtained.

According to the flow chart of Fig 4b, the coordinates of each data output mentioned above were transformed to the acceleration time history using the time scale and the sensitivity of each accelerometer. Also the sample time interval was corrected using interpolation, and the density of points was changed to 100 points per second. After this process the baseline correction was made by removing a least-square-fitted straight line from the acceleration data [11], and the uncorrected acceleration time history was obtained.

The next step, to obtain the corrected time history (see Fig 4c), was to eliminate the low and high frequency noise and make the instrument correction. Both were made in frequency domain. To eliminate the noise a band-pass filter (Lamp Shape Filter) was used. For the high-cut filter, the cut-off and roll-off termination frequencies were set 25 and 30 Hz respectively. For the low cut filter the cut-off and roll-off frequencies were selected with reference of the noise-free low frequency limit of the record. The frequency limit can be determined by the spectral shape of the record [9] [12].

For the instrument correction, the complex response function of the accelerograph was calculated from the natural frequency and damping of the instrument. Finally a corrected time history acceleration data was obtained. The time history of velocity and displacement and the respective response spectra were calculated from the corrected data.

DATA ANALYSIS

As important points of data analysis, can be pointed the fact that during the Piedras Negras earthquake, the San Miguel Dam showed a fundamental period of about 0.5 seconds for up-stream/downstream direction, according with the Fourier spectra ratio of the base and crest data. This value is in concordance with another values recorded in dams with the same height [13].

Also from the analysis of the Siquirres record during the Limon earthquake is clear that the instrument was not triggered by the first arrival of P-waves, but the calculation of the strong motion duration at the site considering the fault rupture propagation and seismic wave propagation suggests that it was triggered by the first arrival of S-waves. This means that most of the strong shaking was included in the record. Also in the accelerogram is seen that horizontal ground motion was polarized in east-west direction, with a predominant period of 0.5 seconds.

In Fig. 5 is showed the time history of corrected acceleration, velocity and displacement of this record.

CONCLUDING REMARKS

Reliable corrected digital data set have been obtained for each of the accelerograms processed.

The records of La Lucha and Siquirres can be used as free field data in near field. In the case of the Siquirres site even this is located approximately 60 km from the epicenter, the closest distance between the site and the fault plane of the earthquake is around 20 km.

The further analysis of the data of San Miguel Dam (also in near field) will be useful to reveal structural behavior of this kind of dams during strong shaking.

ACKNOWLEDGMENTS

The author wishes to express his appreciation to Mr. Saburoh Midorikawa, supervisor of this study, Mr. Takumi Toshinawa and Mr. Masashi Matsuoka of Tokyo Institute of Technology for all their explanations and cooperation for this study.

REFERENCES

1. Joyner, W.B. and Boore D.M., 1988: Measurement, Characterization, and Prediction of Strong Ground Motion, Earthquake Engineering and Soil Dynamics II-Recent Advances in Ground Motion Evaluation, pp. 43-102.

2. Climent, A., 1992: Some Seismological and Earthquake Engineering aspects of Costa Rica, The 42th Open Seminar on Earthquake Engineering Seismology, Tokyo Institute of Technology, pp. 7-18.

3. Barquero, R., Boschini, I., Climent, A., Fernadez, M., Montero, W. and Rojas, W., 1991: La crisis sismica del Golfo de Nicoya y eventos sismicos relacionados, Costa Rica 1990. Red Sismologica Nacional, RSN:ICE-UCR. 163 pages.

4. Cole, E.E. (Edit), 1991: Costa Rica Earthquake of April 22, 1991. Reconnaissance Report, Earthquake Spectra, Supplement B to Volume 7. 127 pages.

5. Barquero, R., Rojas, W., Climent, A. and Montero, W., 1991: El temblor del 9 de agosto de 1991 Costa Rica, Informe Sismologico, Red Sismologica Nacional, RSN:ICE-UCR, 15 pages.

6. Hudson, D.E., 1979: Reading and Interpreting Strong Motion Accelerograms, Earthquake Engineering Research Institute, 112 pages.

7. Climent, A., 1991: Sismo del 22 de diciembre 1990. Analisis preliminar de acelerogramas registrados en la Presa San Miguel. Inf. Interno ICE, 15 pags.

8. Iai, S., 1988: State of The Art: Processing of Analog Strong-Motion Seismic Records. Second Workshop on Processing of Seismic Strong Motion Records (Part 2), IASPEI-IAEE, pp. 1-9.

9. Mori, A.W. and Crouse, C.B., 1981: Strong Motion Data From Japanese Earthquakes, World Data Center A for Solid Earth Geophysics. Report SE-29, 341 pages.

10. Toshinawa, T., Midorikawa, S., Ohmachi, T. and Nakamura, Y., 1991: A Computer Aided Analyzer for Analog Strong-MoTion Accelerograms Consisting of a Personal Computer and a Scanning Digitizer, Journal of Structural Engineering, Vol. 37A, pp. 903-910.

11. Brady, G., 1988: USGS Routine Processing. Digitizing and Preparation of Uncorrected Data. Second Workshop on Processing of Seismic Strong Motion Records (Part 2), IASPEI-IAEE, pp. 16-34.

12. Midorikawa, S., Riddell, R. and Cruz, E., 1990: Strong-Motion Array in Santiago, Chile (SMASCH Array), Pontificia Universidad Catolica de Chile, Escuela de Ingenieria DIE, 83 pages.

13. Okamoto, S., 1984: Introduction to Earthquake Engineering, Second Edition, University of Tokyo Press, 629 pages.

TABLE 1
Seismological Information

Event	OT (GMT)	M	Depth (km)	I(MM)	DERS (km)	Type of Fault
Dec. 22,1990	17:27	5,7*	6,5	VII	5	Left strike Slip
Aftershock	17:28	5,1*	4,8	__	10	
Apr. 22,1991	21:57	7,5+	21,5	IX	61	Thrust
Aug. 9,1991	9:33	4,9*	5,3	VI-VII	5	Strike Slip

OT Origen Time
M Magnitude, * M_L, + M_S
I(MM) Epicentral Intensity (MM)
DERS Distance from epicenter to record site

TABLE 2
Instruments Characteristics

Station	Code	SMA-1 Serial	Comp.	Nat. Freq.	Damp. (% crit.)	Sens. (mm/1g)
Siquirres	APHS	5650	N00E	26,3	60	18,6
			Vert.	25,2	60	17,9
			N270E	25,6	60	18,8
La Lucha	ALCR	509	N00E	26,9	60	17,6
			Vert.	26,0	60	17,8
			N270E	26,2	60	17,2
San Miguel Dam	APSMB	6342	N334E	26,2	60	17,2
			Vert.	25,6	60	19,6
			N244E	25,9	60	18,4
	APSME	6341	N334E	26,1	60	18,0
			Vert.	25,4	60	19,5
			N244E	25,7	60	18,4
	APSMC	6340	N334E	25,9	60	18,8
			Vert.	25,8	60	18,9
			N244E	25,9	60	18,8

APSMB: San Miguel Base Accelerograph
APSME: San Miguel Abutment Accelerograph
APSMC: San Miguel Crest Accelerograph

TABLE 3

Site Station Characteristics

Station Site	Code	Soil condition	Geographical coordinates	Geological Description
Siquirres	APHS	Slallow Stiff Soil	N10,07° W83,50°	Colluvium, Lava
La Lucha	ALCR	Rock	N09,74° W84,01°	Unweathered intrusive (dioritic)
San Miguel Dam	ASMB	Soil (Base)	N09,321° W84,330°	silt-clay
	ASME	Rock (Abutment)	N09,943° W84,322°	Unweathered Lava
	ASMC	Crest of Dam	N09,944° W84,326°	30 m. height Earth dam

TABLE 4
Peaks of Corrected Acceleration, Velocity and Displacement

Event	site of record and Component		Accel. (cm/sec^2)	Velocity (cm/sec)	Displ. (cm)
22/12/90	San Miguel Dam				
	Base	N244	632.6	24.4	2.6
		Vert	218.9	7.5	1.0
		N334	881.9	24.4	1.5
	Crest	N244	600.0	32.6	3.6
		Vert	439.5	18.8	2.7
		N334	508.5	28.1	2.9
	Abutment	N244	367.4	14.9	1.4
		Vert	205.6	5.2	0.6
		N334	494.6	19.7	1.4
Aftershock	San Miguel Dam				
	Base	N244	180.0	7.8	0.5
		Vert	81.9	3.4	0.3
		N334	142.4	6.5	0.6
	Crest	N244	233.3	15.8	1.1
		Vert	146.1	7.4	0.6
		N334	310.7	21.1	2.1
	Abutment	N244	98.4	7.4	0.5
		Vert	47.0	2.7	0.3
		N334	71.0	5.1	0.5
22/04/91	Siquirres				
		N270	761.3	43.4	12.7
		Vert	193.7	12.1	2.4
		N000	265.7	24.0	6.4
09/08/91	La Lucha				
		N270	205.4	6.4	0.5
		Vert	181.3	4.9	0.6
		N000	255.4	9.8	0.8

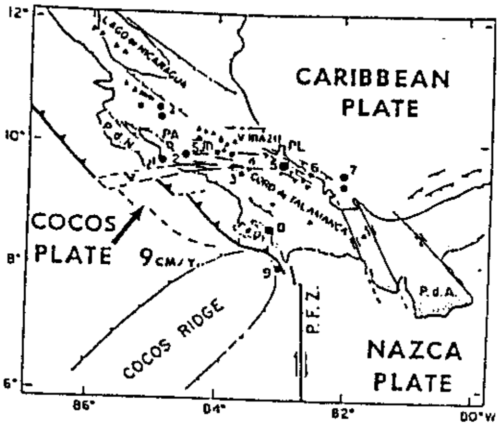
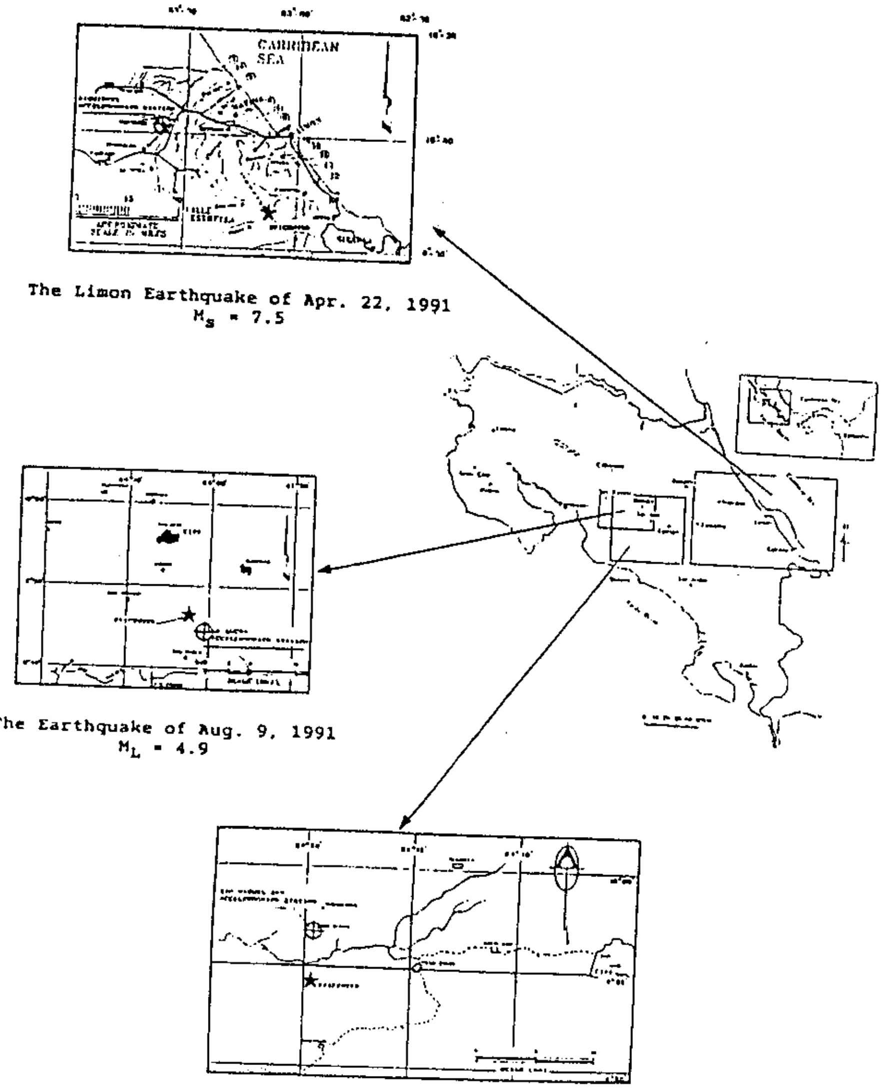


Fig. 1 Seismo-tectonic map of Costa Rica

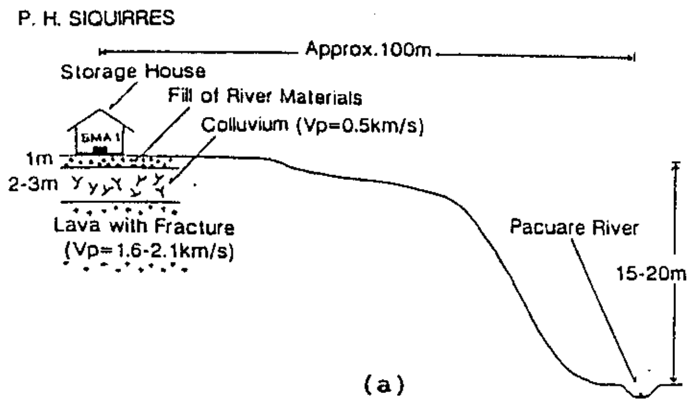


The Limon Earthquake of Apr. 22, 1991
$M_s = 7.5$

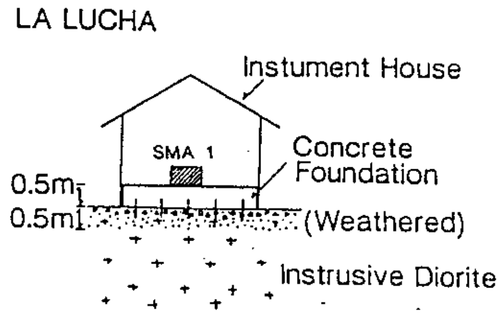
The Earthquake of Aug. 9, 1991
$M_L = 4.9$

The Piedras Negras Earthquake of Dec. 22, 1990
$M_L = 5.7$

Fig. 2 Accelerographs and epicenters location

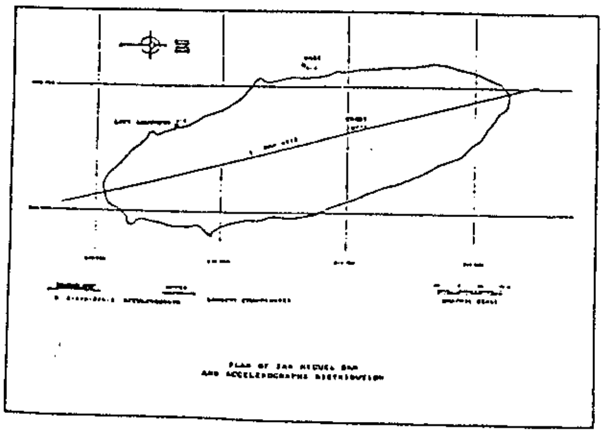


(a)

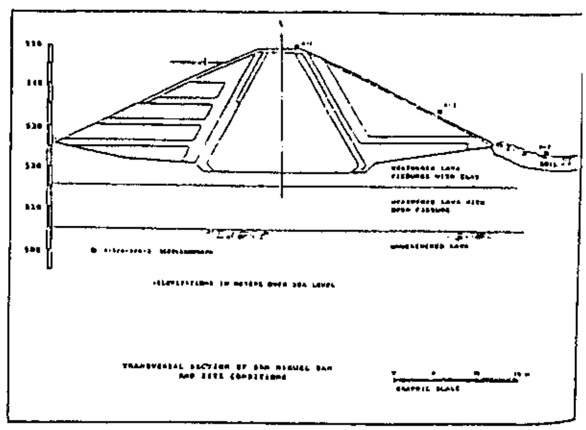


(b)

SAN MIGUEL DAM



(c)



(d)

Fig. 3

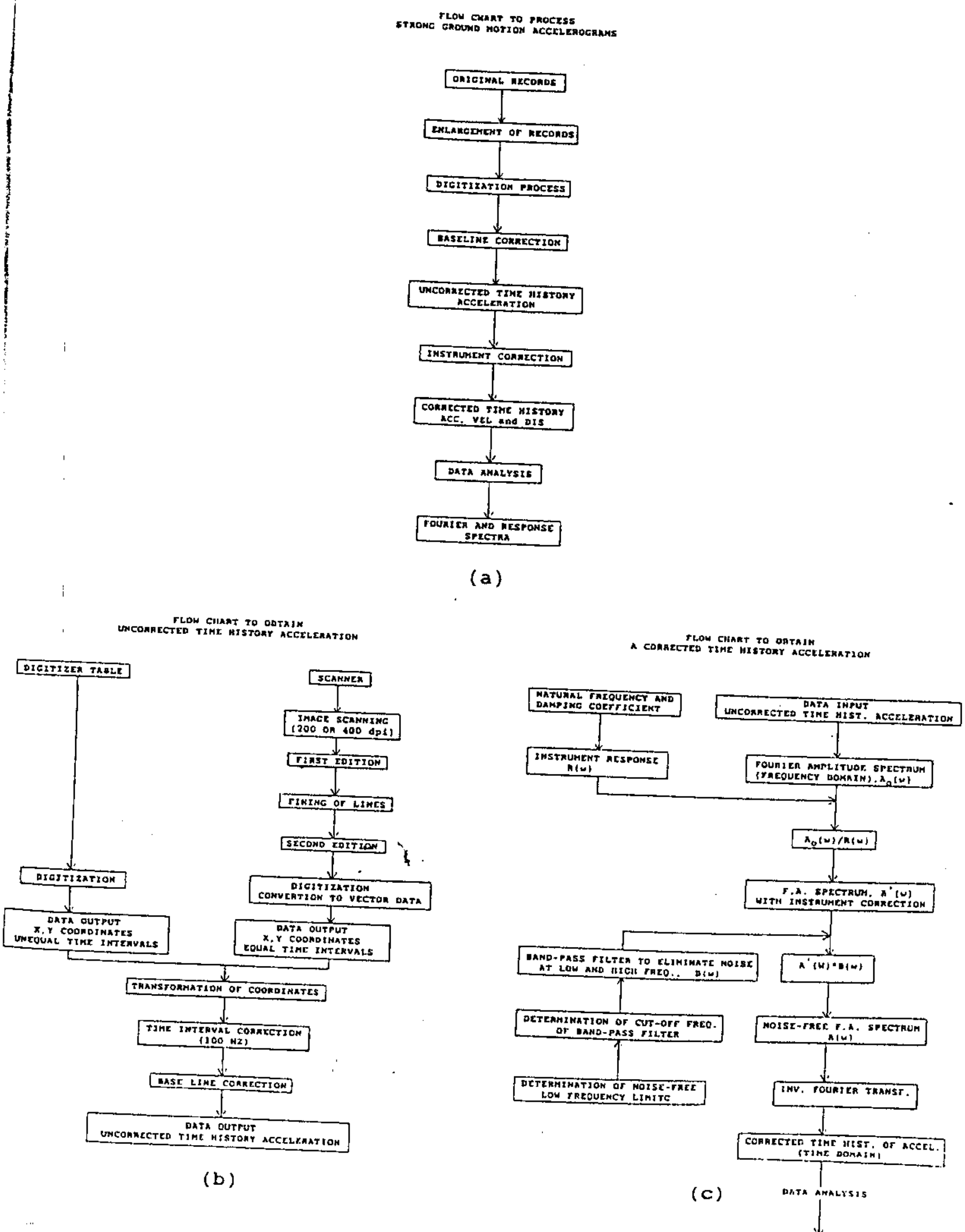

FLOW CHART TO PROCESS
STRONG GROUND MOTION ACCELEROGRAMS
ORIGINAL RECORDS
ENLARGEMENT OF RECORDS
DIGITIZATION PROCESS
BASELINE CORRECTION
UNCORRECTED TIME HISTORY ACCELERATION
INSTRUMENT CORRECTION
CORRECTED TIME HISTORY ACC. VEL and DIS
DATA ANALYSIS
FOURIER AND RESPONSE SPECTRA
(a)
FLOW CHART TO OBTAIN
UNCORRECTED TIME HISTORY ACCELERATION
DIGITIZER TABLE
SCANNER
IMAGE SCANNING (200 OR 400 dpi)
FIRST EDITION
FIXING OF LINES
SECOND EDITION
DIGITIZATION
DIGITIZATION CONVERTION TO VECTOR DATA
DATA OUTPUT X,Y COORDINATES UNEQUAL TIME INTERVALS
DATA OUTPUT X,Y COORDINATES EQUAL TIME INTERVALS
TRANSFORMATION OF COORDINATES
TIME INTERVAL CORRECTION (100 HZ)
BASE LINE CORRECTION
DATA OUTPUT UNCORRECTED TIME HISTORY ACCELERATION
(b)
FLOW CHART TO OBTAIN
A CORRECTED TIME HISTORY ACCELERATION
NATURAL FREQUENCY AND DAMPING COEFFICIENT
DATA INPUT UNCORRECTED TIME HIST. ACCELERATION
INSTRUMENT RESPONSE R(w)
FOURIER AMPLITUDE SPECTRUM (FREQUENCY DOMAIN) A0(w)
A0(w)/R(w)
F.A. SPECTRUM, A'(w) WITH INSTRUMENT CORRECTION
BAND-PASS FILTER TO ELIMINATE NOISE AT LOW AND HIGH FREQ.. B(w)
A'(W)*B(w)
DETERMINATION OF CUT-OFF FREQ. OF BAND-PASS FILTER
NOISE-FREE F.A. SPECTRUM A(w)
DETERMINATION OF NOISE-FREE LOW FREQUENCY LIMITS
INV. FOURIER TRANST.
CORRECTED TIME HIST. OF ACCEL. (TIME DOMAIN)
DATA ANALYSIS
(c)

Fig. 4

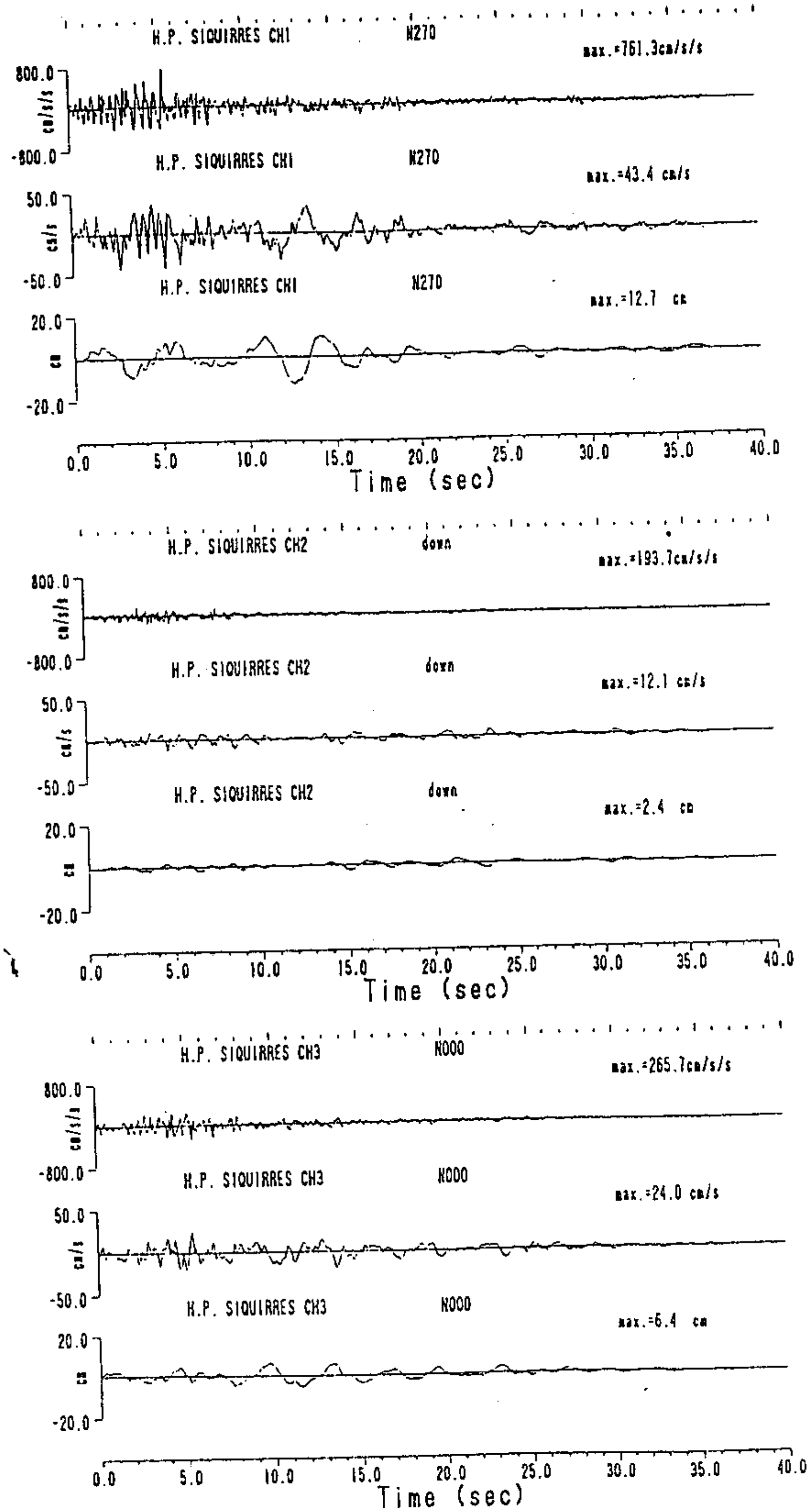


Fig. 5 Time history of Acceleration, Velocity and Dispalcement of the Limon Earthquake

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FAX COVER SHEET

Date: February 24, 1993

TO: *Fax No.:* **9-011-507-52-3321**
Name: **Dr. Luis Alfaro**
Address: Panama Canal Commision, Engineering Division
Geotechnical Branch

FROM: *Name:* Prof. P.K. Robertson

Fax: (403) 492-8198 *Phone:* (403) 492 - 5106

Number of Pages Including Cover Sheet: 10

MESSAGE:

Dear Dr. Luis Alfaro,

Re: SPT Energy Measurements

Prof. Morgenstern has asked me to send you a copy of a recent paper on SPT energy measurements. Included with this fax is a copy of our recent paper in the Canadian Geotechnical Journal. I will also send a copy by mail.

The SPT energy calibration system is now available from ConeTec Investigations Ltd., 9113 Shaughnessy Street, Vancouver, B.C., V6P 6R9, Tel (604) 327-4311, Fax (604) 327-4066. I have included a short handout from ConeTec about the system.

Best regards,

P.K. Robertson,
Professor of Civil Engineering

PKP/pr
Enclosure

Standard penetration test energy measurements using a system based on the personal computer

PETER K. ROBERTSON

Department of Civil Engineering, University of Alberta, Edmonton, Alta., Canada T6G 2G7

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Received September 10, 1991

Accepted March 4, 1992

According to the International Reference Test procedure for the standard penetration test (SPT), in situations where comparisons of SPT results are important, calibrations should be made to evaluate the efficiency of the equipment in terms of energy transfer. However, equipment to measure the energy transfer of the hammer anvil system is not commonly available. Ten years ago a system was developed and made commercially available. However, this system is no longer available. An SPT energy calibration system is described that has been developed based on a microcomputer. The load cell to measure the compressive stress wave beneath the SPT anvil consists of a 0.5-m length of strain-gauged AW rod. Specialized software has been developed to record the force–time record for each hammer blow on a portable microcomputer. Examples of energy measurements are presented and discussed.

Key words: standard penetration test, *in situ*, microcomputer, energy.

Selon la procédure d'évaluation de la référence internationale pour les essais normalisés de pénétration (SPT), dans les situations où des comparaisons des résultats du SPT sont importantes, des étalonnages devront être réalisés pour évaluer l'efficacité de l'équipement en terme de transfert d'énergie. Cependant, l'équipement pour mesurer le transfert d'énergie du système marteau enclume n'est pas couramment disponible. Il y a dix ans, un système a été développé et rendu disponible commercialement. Cependant, il ne l'est plus. L'on décrit un système d'étalonnage de l'énergie du SPT qui a été développé avec un micro-ordinateur comme base. La cellule de charge pour mesurer l'onde de compression sous l'enclume du SPT consiste en une longueur de 0.5 m de tige AW munie de jauges de déformation. Un programme spécial a été développé pour enregistrer sur un micro-ordinateur portatif les données force–temps pour chaque coup de marteau. Des exemples de mesures d'énergie sont présentés et discutés.

Mots clés : essai normalisé de pénétration, *in situ*, micro-ordinateur, énergie.

[Traduit par la rédaction]

Can. Geotech. J. 29, 551–557 (1992)

Introduction

The standard penetration test (SPT) was developed in the United States in 1927 and is used worldwide to a greater extent than any other *in situ* test. The SPT has several significant advantages: (*i*) the equipment is relatively simple and rugged, (*ii*) the procedure is easy to carry out and permits frequent tests, (*iii*) a sample of the soil is usually obtained, (*iv*) tests can be carried out in most soil types, and (*v*) many useful correlations have been developed. No other *in situ* test combines this range of flexibility.

The test is made by dropping a free-falling hammer weighing 63.5 kg (140 lb) onto the drill rods from a height of 760 mm (30 in.). The number of blows (N) necessary to achieve a penetration of 300 mm (below a seating drive of 150 mm) of a standard sample tube is termed the penetration resistance or N-value.

Details of the SPT procedure and sampler are given by ASTM (1991*a*). Many countries have similar standards. An International Reference Test procedure is also available that is similar to the ASTM standard (ISSMFE 1988).

Figure 1 shows a sketch of the basic SPT setup using a "cathead" and rope system along with a donut hammer. To raise the hammer, the operator pulls the rope in towards himself until the hammer is lifted to the prescribed fall height. To drop the weight, the operator rapidly slackens the rope on the cathead. It is usual to have two turns of the rope on the cathead for lifting the hammer, although sometimes three turns and rarely one turn have been used. The operator has the responsibility to ensure a 760-mm fall usually with the aid of a mark on the guide rod.

Unfortunately, there is a wide variability in equipment and test procedures encountered in practice throughout the world. Considerable research on individual aspects of the equipment and procedures has been carried out in North America and Japan in an effort to better understand the factors affecting the test (Schmertmann 1979; Kovacs and Salomone 1982; Yoshimi and Tokimatsu 1983).

To obtain reliable results the International Reference Test procedure (ISSMFE 1988) recommends that the SPT should be carried out under the following conditions: (*i*) the use of wash boring with a side-discharge bit or rotary drilling with a tricone drill bit and mud flush, (*ii*) the use of casing and (or) drilling mud to support the borehole, (*iii*) drilling mud to be maintained up to groundwater level, (*iv*) borehole diameter between 63.5 and 150 mm and preferably not more than 115 mm, and (*v*) blow count (N-value) recorded between 150 mm (6 in.) and 450 mm (18 in.) penetration, with the first 150 mm (6 in.) regarded as a seating drive.

Even with good site control the method of hammer release and type of anvil play a major role in the reliability of the results. Several hammer types and release systems exist. In general the three main hammer types are donut, safety, and trip hammers (ISSMFE 1988).

The four main methods of lifting and releasing the hammer are as follows: (*i*) manual lifting and release of the rope passing over the crown sheave (i.e., no winch cathead);

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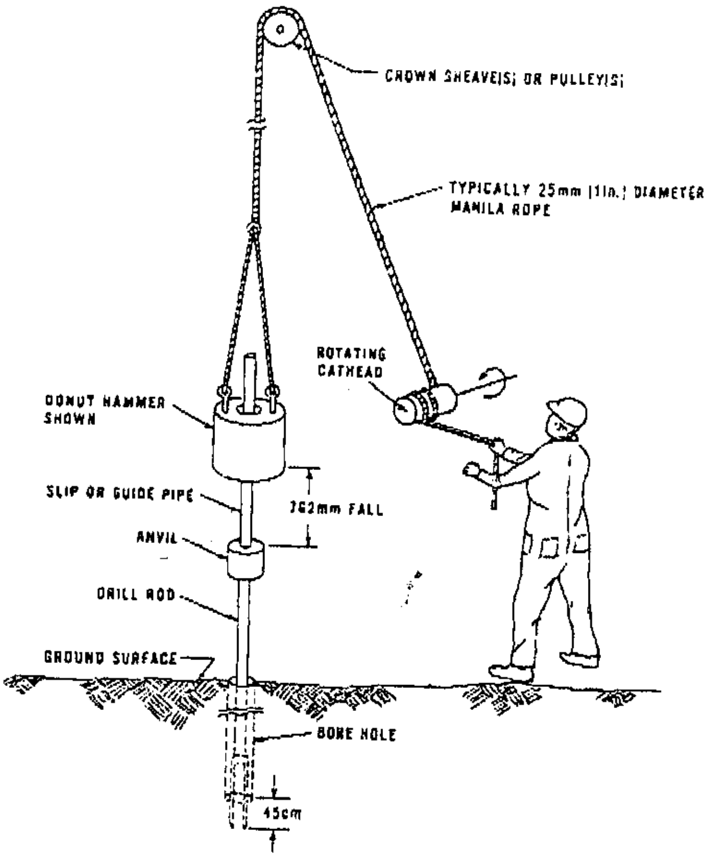

FIG. 1. Sketch showing typical SPT procedure using manual release and donut hammer (adapted from Kovacs and Salomone 1982). Crown sheave(s) and cathead can be either drill-rig or tripod mounted.

(*ii*) "slip-rope" or "rope and cathead" method (as shown in Fig. 1); (*iii*) trip hammer, such as the Pilcon or Dando hammers; and (*iv*) automatic trigger mechanism, such as the Central Mining Equipment (CME) automatic hammer and the Japanese "Tombi" system.

Many tests worldwide are still made using the rope and cathead release with generally two turns of the rope and visual control of the drop height.

In any *in situ* test procedure it is very important to have the ability to reproduce results. In the case of the SPT, the ability to obtain reproduceable and reliable results depends on the equipment, procedures, and operator characteristics. The most significant factor affecting the measured N-value is the amount of energy delivered to the drill rods from the hammer and anvil system.

Attempts to physically measure SPT hammer anvil energies began in the early 1970s (ISSMFE 1988). Studies on hammer fall velocity during the SPT were performed by Kovacs *et al.* (1975). Palacios (1977) developed a method of measuring stress-wave energy in drill rods immediately below the anvil. Results showed that the majority of energy for sample penetration was delivered in the first energy pulse down the rods. Force-time histories of stress waves were first measured at locations just below the anvil and just above the sampler. After confirmation by theoretical studies, the method was simplified to measure the energy content in the first compression wave measured just below the anvil. Based on the work by Palacios (1977) a commercial SPT energy-measurement system was first introduced in the early 1980s (Hall 1982). The system consists of a piezoelectric load cell attached near the top of the drill rods and a data-processing instrument that calculates the energy at the load-cell location. The energy for each hammer blow is read directly from the instrument as a percentage of the theoretical free-fall hammer energy of 475 J (4200 in · lb) in terms of a rod energy ratio (ER_i). The methodology developed by Palacios (1977) and incorporated into the commercial system by Hall (1982) has been successfully applied for many years. However, several disadvantages with the system have been observed. (*i*) The connectors to the load cell were easily damaged and required frequent repair. (*ii*) The piezoelectric load cell required special dynamic calibration procedures. (*iii*) The integration times and the nature of the force-time histories of the stress waves were not easily verified without the aid of an oscilloscope.

The commercial system (Hall 1982) has often been regarded as a "black-box" system that allowed little flexibility for verifying the results. Surprisingly very few of the SPT energy-measuring systems were sold and used in practice. This may be a reflection of the black-box nature of the device.

Energy measurements in the last decade have shown that the energy delivered to the rods during an SPT can vary from about 30 to 90% (Kovacs and Salomone 1982; Robertson *et al.* 1983). The energy delivered to the drill stem varies with the releasing-system, hammer, anvil, and operator characteristics. The type of hammer and anvil appears to influence the energy-transfer mechanism.

Palacios (1977) has shown that the SPT blow count is approximately inversely proportioned to the delivered energy. Kovacs *et al.* (1984), Seed *et al.* (1985), and Robertson *et al.* (1983) have suggested that an energy level of 60% appears to represent a reasonable historical average for most SPT-based empirical correlations. Seed *et al.* (1985) clearly suggested that for liquifaction analyses the SPT N-values must be corrected to an energy level of 60%.

N-values measured with a known or estimated ER_i value can be normalized to an energy level of 60% by the conversion

$$[1] \quad N_{60} = N\frac{ER_i}{60}$$

Based on data summarized by Skempton (1986) and Seed *et al.* (1985), recommended generalized energy ratios and conversion for SPT practice are given in Table 1. These values represent broad global corrections and should be used with caution.

Further adjustments are also needed for the effects of rod length, sampler type, and borehole diameter. Wave-equation studies (Schmertmann and Palacios 1979) show that the theoretical maximum energy ratio decreases with decreasing rod length. This decrease in measured energy is due in part to the rapid return of the tension wave before all the hammer energy can be transferred to the drill rods. Studies by Schmertmann (1979) also found that removing the liners from a SPT sampler designed for liners improved sample recovery but reduced the measured blow count by about 20%. Therefore, if the SPT sampler has no liners the N-value should be increased by a factor of about 1.2.

Although good modern practice has the SPT performed

TABLE 1. Generalized SPT energy ratios

Location	Hammer	Release[a]	ER_i (%)	$ER_i/60$
North and South America	Donut, safety	2TR	45	0.75
	Automatic	2TR	55	0.92
		Trip	55–83	0.92–1.38
Japan	Donut	2TR	65	1.08
	Donut	Auto-trigger	78	1.30
China	Donut	2TR	50	0.83
	Automatic	Trip	60	1
United Kingdom	Safety	2TR	50	0.83
	Automatic	Trip	60	1
Italy	Donut	Trip	65	1.08

NOTE: Based on Seed *et al.* (1985) and Skempton (1986).
[a]2TR, two turns on rope.

TABLE 2. Approximate corrections to measured SPT *N*-values (after Skempton 1986)

Rod length	
≥10 m	1.0
6–10 m	0.95
4–6 m	0.85
3–4 m	0.70
Standard sampler	1.0
U.S. sampler without liners	1.2
Borehole diameter	
65–115 mm	1.0
150 mm	1.05
200 mm	1.15

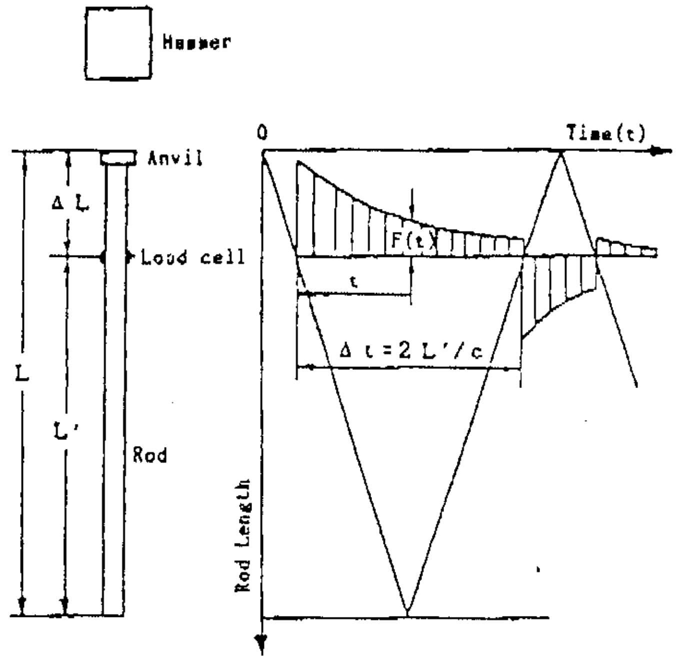

FIG. 2. Principle of SPT energy measurement (after ISSMFE 1988).

in a borehole with a diameter between 65 and 115 mm, many countries allow testing in boreholes of up to 200 mm. The effect of testing within relatively large diameter boreholes can be significant in sands and probably negligible in clays. Approximate correction factors for rod length, sample liners, and borehole diameter are given in Table 2.

The actual energy level at which different systems (hammer, anvil, release rods, sampler, drillhole, operator) are made to operate is very important. Of equal importance is the need for the variation in energy levels using the individual system to remain consistent. Table 1 provides only a guide to anticipated average energy levels. In situations where comparisons of SPT results are important or where project requirements merit, energy measurements should be made.

In recent years other systems based on the same basic principle have been developed to measure SPT energy (Clayton 1990; Sy and Campanella 1991*a*, 1991*b*). This paper describes a new system that was developed at the University of Alberta in early 1990. The system is based on the same basic principles used by Palacios (1977) but utilizes recent advances in microelectronics and computing.

Energy measurements

The recommended method for SPT energy measurement is specified in ASTM (1991*b*) and ISSMFE (1988) and is based on the force-measurement concept developed by Palacios (1977). The method consists of attaching a load cell near the top of the drill rods and below the anvil and measuring the force–time history of the stress wave during hammer impact. The basic principle of the stress-wave force integration method is shown in Fig. 2. An idealized force–time wave form recorded by a load cell in the drill rods is shown in Fig. 3. The stress-wave force integration method to determine the energy uses the following formula:

$$[2] \quad E_i = \frac{cK_1K_2K_c}{AE}\int_0^{\Delta t}[F(t)]^2\,dt$$

where $F(t)$ is dynamic compressive force in the drill rods as a function of time t, E_i is energy content in the first compression wave for the ideal case, Δt is time duration of the first compressive wave starting at $t = 0$, A is cross-sectional area of the connector rods above and below the load cell, E is Young's modulus of the connector rods, and c is theoretical velocity of compression wave in connector rods (usually $c = 5120$ m/s). K_1 and K_2 are correction factors to account for the load-cell position in the rods and the finite length of the drill rods, respectively. The K_c correction is

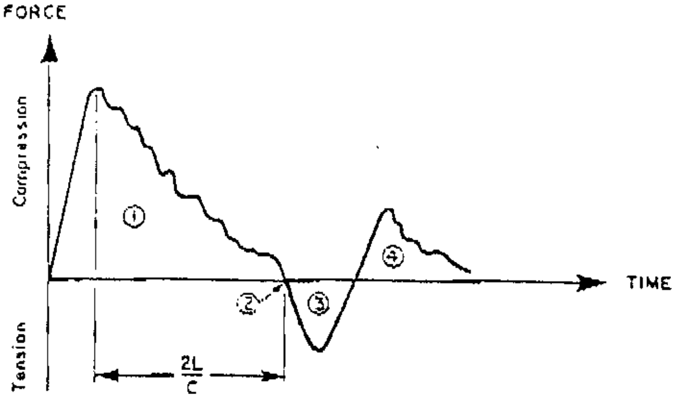

FIG. 3. Idealized force–time SPT wave form (modified from ASTM 1991*b*). 1, first compression pulse or wave; 2, cutoff time at the arrival of the first tension pulse; 3, first tension pulse reflected from the sampler; 4, second compression pulse reflected from the anvil.

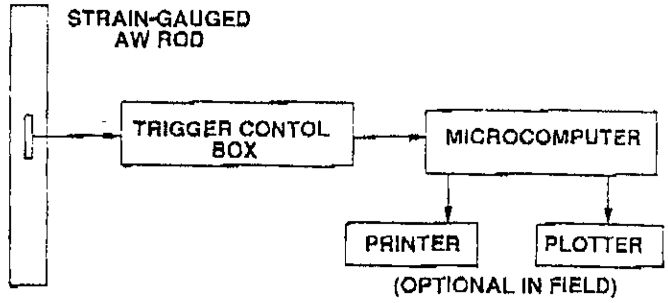

FIG. 4. PC-based SPT energy-measurement system.

based on the assumption that the total duration of the first compression pulse from $t = 0$ is the round-trip time for the stress wave to travel from the load cell near the top of the drill rods to the sampler bottom and return to the load-cell location. Hence

$$[3] \quad \Delta t = \frac{2L'}{cK_c}$$

where L' is the length of rod between the load cell and the bottom of the SPT sampler.

Sy and Campanella (1991*b*) have suggested that the theoretical $2L'/c$ corresponds to the time interval between the peak force and the tension cutoff point (as shown in Fig. 3), not from the start of the force trace ($t = 0$) to the cutoff point. Ideally, the rise time for the first compression pulse should be infinitely small (see Fig. 2), and the time difference between the start point and the peak force would be very small. Hence, the K_c correction should be unnecessary.

Based on dynamic monitoring of piles during driving (ASTM 1991*c*), Sy and Campanella (1991*a*) suggested the use of the force–velocity integration method. This method avoids the need to determine the integration time (Δt) and select an appropriate cross-sectional area of the drill rods (A). However, the force–velocity integration method does require the additional measurement of particle velocity (V), usually from the integration of acceleration using accelerometers. The accurate measurement of velocity using accelerometers is extremely difficult due to problems in electrical drift and response time (Poskitt and Wong 1991). The measurements presented by Sy and Campanella (1991*a*) showed that the energy determined from the force–velocity integration method was generally within 5–15% of that determined from the force integration method using [2]. Hence, considering the potential wide variation of energy per blow it would appear that the simpler force integration method specified in ASTM (1991*b*) and ISSMFE (1988) is sufficiently accurate.

New PC-based SPT energy-measurement system

In early 1990 a PC-based SPT energy-measurement system was developed at the University of Alberta to measure SPT energies for a tailings-dam project in China. The system is based on the force integration method but is also capable of performing the force–velocity integration method. A schematic layout of the SPT energy-measurement system is shown in Fig. 4.

The force in the drill rods is measured using a strain-gauged 0.5-m-long section of drill rod (typically AW size). The early work by Palacios (1977) and recently confirmed by Clayton (1990) showed that the force during the first compression wave could be accurately measured using a strain gauge load cell rather than a more expensive piezoelectric load cell. The strain-gauged drill rod has the advantage of being inexpensive, equal in cross-sectional area to the drill rods (typically AW), and simple to statically calibrate. A total of eight strain gauges are placed around the circumference of the drill rod to average the measured force.

The rod load cell is connected to a portable field microcomputer via a small custom-made trigger control box. The trigger control box provides two functions: (*i*) selection of force level to trigger the data-acquisition system, and (*ii*) balance the zero load output of the load cell before each SPT blow count series.

The field microcomputer contains a fast analog to digital (A/D) board to digitize the force measurement as a function of time. Optional printer or plotter can be connected to the microcomputer to obtain hard copies of the data. The data is stored in memory and backed up on disk.

Initially, basic software was developed to record the force–time record $F(t)$. Subsequently, specialized software and signal-conditioning functions were developed by Adara Systems Ltd. to record $F(t)$ as well as the integration time for the first compressive wave (Δt) and to calculate directly the energy (E_i) and rod energy ratio (ER_i) for each SPT hammer blow. The software also records the number of blows and calculates the average ER_i for the SPT. The system allows the operator to select a range of acceptable integration times for the energy calculation. The ISSMFE (1988) International Reference Test Procedure recommends an acceptable range of 0.9–1.2 of the theoretical integration time $2L'/c$.

Example data

The first application of the University of Alberta SPT energy-measurement system was for a tailings-dam investigation in China during April 1990. The site investigation was part of a Sino-Canadian Research project to study the stability of the Dashihe Tailings Dam during the 1976 Tangshan Earthquake. The SPT's were performed using Chinese equipment and procedures in general accordance with ASTM (1991*a*). A total of 175 SPT energy measure-

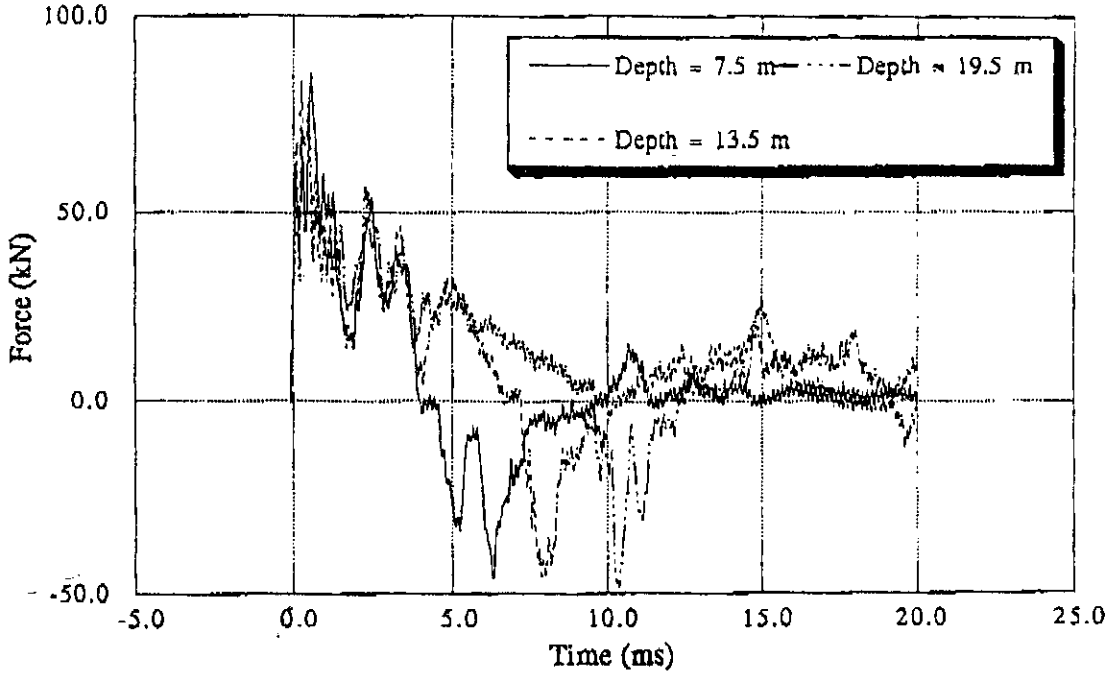

FIG. 5. Typical measured force-time records for Chinese automatic trip hammer.

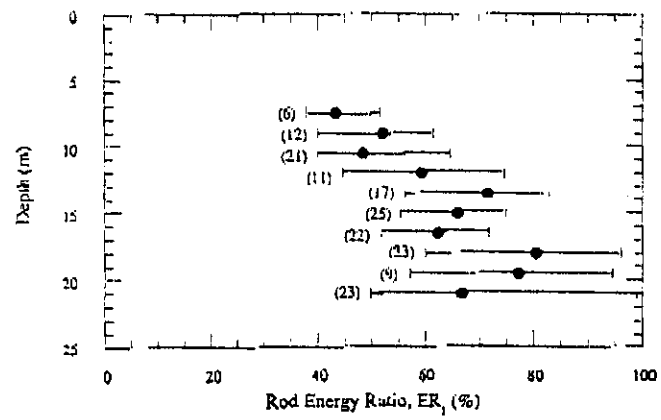

FIG. 6. Variation with depth of average, maximum, and minimum rod energy ratio (ER_i) for Chinese automatic trip hammer. SPT N-values are in parentheses.

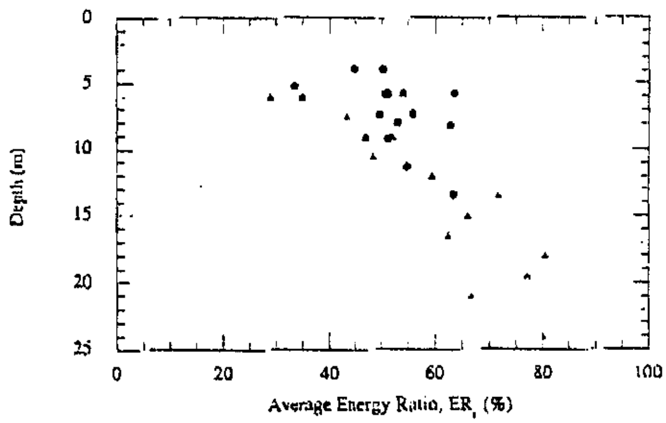

FIG. 7. Comparison of average rod energy ratio (ER_i) using PC-based system (▲) and ERTEC Inc. (1985) (●) data for Chinese automatic trip hammer.

ments were made on a Chinese automatic trip hammer. The trip hammer design regulated the height of fall to 760 mm by a mechanical release. During the tests, blows were applied at a rate of about 20 blows per minute. Hammer lift was accomplished by a hydraulic winch and wire cable.

A Chinese split-barrel sampler was used during SPT measurements. The sampler generally conformed to ASTM specifications. The sampler had a constant internal diameter, with no provision for liners. The Chinese drill rods had upset rod joints and therefore varied in cross-sectional area from about 581 mm^2 for the drill-rod shaft to about 2000 mm^2 for the upset-joint sections. A linear summation of rod areas was performed and an equivalent rod area per unit length was calculated (Douglas and Strutyusky 1984).

Typical force-time histories for three hammer blows at depths of 7.5, 13.5, and 19.5 m below ground surface was shown in Fig. 5. The initial portions of the force-time histories are very repeatable, with a peak force of about 85 kN at a time of about 0.5 ms. The time duration of each compressive wave increases with increasing rod length below the load cell according to the theoretical time of $2L'/c$.

Figure 6 shows a summary of rod energy ratios (ER_i) calculated using [2] for the 175 energy measurements made in one borehole during 1 day of investigation in terms of average, maximum, and minimum values of ER_i as a function of depth below ground surface. The numbers in parentheses are the SPT N-values. There is a clear trend for the measured ER_i to decrease at depths of less than about 12 m.

In 1984 ERTEC Inc. performed SPT energy measurements in China as part of a joint United States–China study (ERTEC Inc. 1985). The SPT energy measurements made by ERTEC Inc. were performed using the SPT calibrator (Hall 1982) with a piezoelectric load cell. The measurements were made on the same Chinese type of automatic trip hammer operated by the same Chinese contractor. Figure 7 shows a comparison between the average ER_is measured in

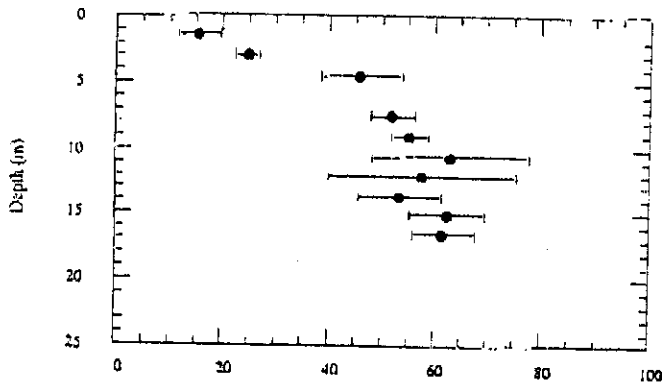

FIG. 8. Variation with depth of average, maximum, and minimum rod energy ratio (ER_i) for dunut hammer, rope, and cathead release SPT system, Vancouver, B.C.

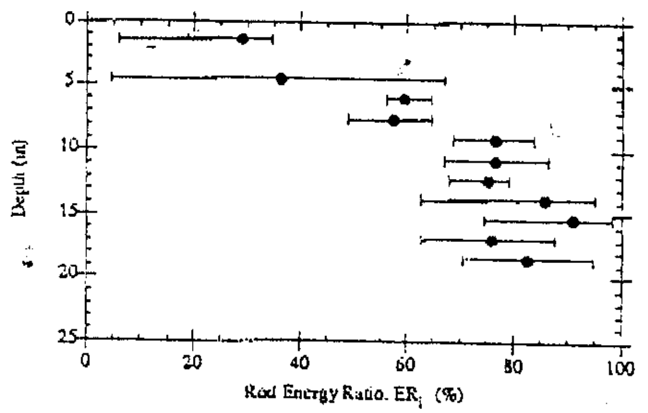

FIG. 9. Variation with depth of average, maximum, and minimum rod energy ratio (ER_i) for safety hammer, rope, and cathead release SPT system, Vancouver, B.C.

1984 by ERTEC Inc. and those measured in 1990 using the University of Alberta system. Although Fig. 7 shows a large range in ER_is, the ERTEC Inc. and University of Alberta data agree reasonably well. The ERTEC Inc. data at depths less than about 8 m are somewhat larger than the PC-based University of Alberta data. Since the intergration times for the ERTEC Inc. data were not recorded, it is not possible to check the 1984 data. However, errors in integration times could explain the differences at these depths. Although the energy measurements shown in Fig. 7 were made at different times, the results indicate generally good agreement between the two SPT energy-measurement systems.

Since the first application in 1990, the University of Alberta SPT energy-measurement system has been improved and used extensively on projects in western Canada. Figure 8 shows the average, maximum, and minimum values of measured ER_i for a donut hammer, rope, and cathead release SPT system in Vancouver, B.C. Figure 8 clearly shows a decrease in energy at depths less than about 12 m. The correction factor K_2 in [2] has been applied to the results in Fig. 8 and should correct the measured energy due to the short length of drill rod. However, Fig. 8 suggests that the current correction factor K_2 cannot fully compensate for short rod lengths.

Figure 9 shows a similar trend of measured rod energy ratios (ER_i) for a safety hammer, rope, and cathead release

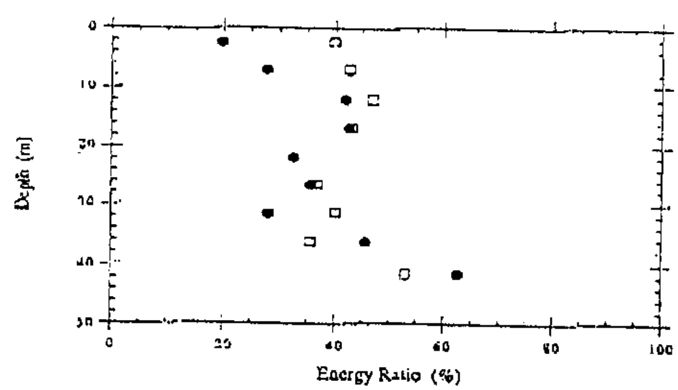

FIG. 10. Comparison of average energy ratio for Becker hammer using PC-based system (●) and pile-driving analyzer (□).

SPT system. The drill rods were BW, which are heavier than the more commonly used AW rods. The average ER_i at depth is about 80%, and again there is a decrease in energy at depths less than 12 m. The blow count at a depth of 4.6 m was 12; however, the first six blows provided measured ER_is less than 10% owing to the gradual uncoupling of the drill near the anvil. The test was stopped and the rods tightened. Energy values measured after rod tightening were near 60%. This illustrates the importance of procedure, such as loose couplings near the anvil, to provide repeatable SPT results. The software used in the PC-based SPT energy system has been recently upgraded to show the force–time plot in real time on the screen of the computer so that the operator can evaluate the maximum force and intergration time for each blow during the SPT test. The printout after the test includes the maximum force and intergration times for each blow.

The results shown in Figs. 8 and 9 illustrate the need to measure SPT energies rather than rely on the global energy ratios provided in Table 1.

In western Canada the Becker hammer test (BHT) is used extensively in areas of gravelly soils and for liquefaction analyses in gravelly soils. The BHT is a large-scale penetration test that uses a Becker hammer drill, which consists of a double-acting diesel pile hammer to drive a double-walled casing. The BHT consists of driving a closed-ended casing and recording the blows for each 300 mm of penetration. The drive casings commonly used are 138 mm (5.5 in.) and 185 mm (6.6 in) outside diameter. The diesel hammer is an International Construction Equipment model 180. The main advantage of the test is its ability to penetrate most dense soil formation at a relatively fast rate, making it particularly useful in gravel and cobble deposits. Like the SPT, the BHT results are strongly controlled by the delivered energy from the hammer. Harder and Seed (1986) proposed an energy correction for liquefaction analyses based on BHT bounce chamber pressure. However, the bounce pressure is also influenced by the soil resistance and ambient atmospheric pressure.

Energy measurements were recently made on a Becker hammer simultaneously using the PC-based SPT energy-measurement system and a commercially available pile driving analyzer (PDA). A short section of double-walled casing was strain gauged and installed below the diesel hammer. Pairs of strain gauges and accelerometers were also installed for the PDA measurements to record the force–time and velocity–time histories for each blow according the ASTM (1991*a*). Figure 10 presents the average measured energy ratios using both systems. The average energy, as a percent of the theoretical rated energy of the hammer, varies from 20 to 60%. Although these results are preliminary, both systems appear to have recorded similar energy values and similar variations of energy for each blow count (i.e., range from maximum to minimum energy) and with depth.

Summary

A PC-based SPT energy-measurement system has been developed based on the basic principles specified in ASTM (1991*b*) and ISSMFE (1988). The system incorporates a short section of strain-gauged drill rod as a load cell connected to a microcomputer via a trigger control box. Specialized software has been developed to record the force–time record of each SPT hammer blow and present the rod energy ratio (ER_i) for acceptable integration times.

Data collected using this PC-based SPT energy-measurement system have shown that the system provides reliable results. The results presented in this paper confirm the observation that the actual energy produced by any hammer anvil system is highly variable. The generalized energy ratios presented in Table 1 should only be used as a guide. For projects where comparisons of SPT results are important, such as liquefaction studies or where major project decisions rely on the SPT, energy measurements should be made.

The data presented have also shown the importance of the rod length correction (Table 2) for rod lengths less than 12 m. For very shallow depths (< 5 m) the SPT energy could be significantly less than the generalized values shown in Table 1, and hence the SPT values can significantly overestimate the strength of the tested soil at these shallow depths.

Preliminary measurements have also been presented to suggest that the basic SPT energy-measurement system can also measure the energy during a Becker hammer test.

The PC-based energy-measurement system described has recently been modified to also monitor data from accelerometers so that the force–velocity integration method can be applied to calculate energy. This would enable the PC-based system to monitor pile driving according to ASTM (1991*c*) similar to various pile-driving analyzers.

Acknowledgements

The authors would like to acknowledge the valuable assistance of the University of Alberta, Department of Civil Engineering, technical staff, namely G. Cyre, D. Lathe, and R. Gitzel, as well as Glen Jolly of Adara Systems Ltd. The authors would also like to acknowledge the assistance of the British Columbia Ministry of Transportation and Highways staff, namely A. Brown, D. Munich, R. Crider, and D. Gillespie, for their assistance with the Becker Hammer testing.

ASTM. 1991*a*. Standard method for penetration tests and split-barrel sampling of soils (D1586-84). *In* 1991 Annual Book of ASTM Standards, sect. 4, vol. 04.08. ASTM, Philadelphia. pp. 232–236.

ASTM. 1991*b*. Standard test method for stress wave energy measurement for dynamic penetrometer testing systems (D4633-86). *In* 1991 Annual Book of ASTM Standards, sect. 4, vol. 04.08. ASTM, Philadelphia. pp. 872–875.

ASTM. 1991*c*. Standard test method for high-strain dynamic testing of piles (D4945-89). *In* 1991 Annual Book of ASTM Standards, sect. 4, vol. 04.08. ASTM, Philadelphia. pp. 1018–1024.

Clayton, C.R.I. 1990. SPT energy transmission: theory, measurement and significance. Ground Engineering, 23(10): 35–43.

Douglas, B.J., and Strutynsky, A.I. 1984. Cone penetration test pore pressure measurements and SPT hammer energy calibration for liquefaction hazard assessment. Report to the United States Geological Survey, ERTEC Inc., Huntington Beach, Calif.

ERTEC Inc. 1985. In-situ testing II, People's Republic of China. Report prepared for National Science Foundation, NSF Grant No. CEE 8311873, 84-141-13. ERTEC Inc., Huntington Beach, Calif.

Hall, J.R. 1982. Drill rod energy as a basis for correlation of SPT Data. Proceedings, 2nd European Symposium on Penetration Testing (ESOPT-II), Amsterdam, pp. 57–60.

Harder, L., and Seed, H.B. 1986. Determination of penetration resistance for coarse-grained soils using the Becker hammer drill. University of California, Berkeley, Publications in Engineering, UCB/EERC-86/06.

ISSMFE. 1988. Standard penetration test (SPT): International Reference Test Procedure. International Society of Soil Mechanics and Foundation Engineering Technical Committee on Penetration Testing. International Symposium on Penetration Testing (ISOPT-1), Orlando, Fla., vol. 1, pp. 3–26.

Kovacs, W.D. 1981. Results and interpretation of SPT practice study. Geotechnical Testing Journal, 4(3): 126–129.

Kovacs, W.D., and Salomone, L.A. 1982. SPT hammer energy measurement. ASCE Journal of the Geotechnical Engineering Division, 108(GT4): 599–620.

Kovacs, W.D., and Salomone, L.A. 1984. Field evaluation of SPT energy, equipment, and methods in Japan compared with SPT in the United States. United States National Bureau of Standards Report NBSIR 84-2910.

Palacios, A. 1977. The theory and measurement of energy transfer during standard penetration testing. Ph.D. thesis, Department of Civil Engineering, University of Florida, Gainesville, Fla.

Poskitt, T.J., and Wong, K.L.Y. 1991. Frequency response problems to instrumented pile tests. Ground Engineering, 24(4): 28–39.

Robertson, P.K., Campanella, R.G., and Wightman, A. 1983. SPT–CPT correlations. ASCE Journal of Geotechnical Engineering, 109: 1449–1459.

Schmertmann, J.H. 1979. Statics of SPT. ASCE Journal of the Geotechnical Engineering Division, 105(GT5): 655–670.

Schmertmann, J.H., and Palacios, A. 1979. Energy dynamics of SPT. ASCE Journal of the Geotechnical Engineering Division, 105(GT8): 909–926.

Seed, H.B., Tokimatsu, K., *et al.* 1985. Influence of SPT procedures in soil liquefaction resistance evaluations. ASCE Journal of Geotechnical Engineering Division, 111: 1425–1445.

Skempton, A.W. 1986. Standard penetration test procedures and effects in sands of overburden, relative density, particle size, aging and over-consolidation. Géotechnique, 36: 425–447.

Sy, A., and Campanella, R.G. 1991*a*. An alternate method of measuring SPT energy. Proceedings, 2nd International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, St. Louis, Mo., pp. 499–505.

Sy, A., and Campanella, R.G. 1991*b*. Wave equation modelling of the SPT. Proceedings, ASCE Geotechnic Engineering Congress, Boulder, Colo., pp. 225–240.

Yoshimi, Y., and Tokimatsu, K. 1983. SPT practice survey and comparative tests. Soils and Foundations (Japanese Society of Soil Mechanics and Foundation Engineering), 23: 105–111.

SPT ENERGY CALIBRATOR

SPT ENERGY CALIBRATION USING A MICROCOMPUTER

The SPT ENERGY CALIBRATOR, used with a PC or compatible, allows for the accurate determination of ENERGY, delivered by the SPT System.

The SPT ENERGY CALIBRATOR determines the energy delivered by the SPT system to the SPT sampler. Knowing the energy of a system allows for the adjustment of N values whereby providing a more accurate assessment of the geotechnical site conditions and strength parameters.

Every SPT system delivers a different amount of energy to the sampler. Energies typically range from 20% to 80% of the theoretical maximum of 350 ft-lbs.

- *The system works with any IBM PC or compatible*
- *An 808286 808386 is desirable for rapid data processing*
- *The system saves each individual wave trace*
- *SPT energy is computed for every blowcount*
- *Graphics display of energy vs depth and individual wave forms*
- *System can also be expanded to monitor the energy delivered by BECKER HAMMER Systems*
- Figure 1 at right shows a typical Force vs Time plot for an individual hammer blow.
- Figure 2 at right shows the results of an SPT system calibration.

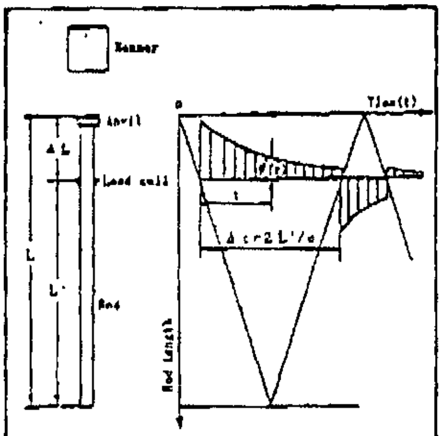

Fig. 1. Principle of measurement of E_i

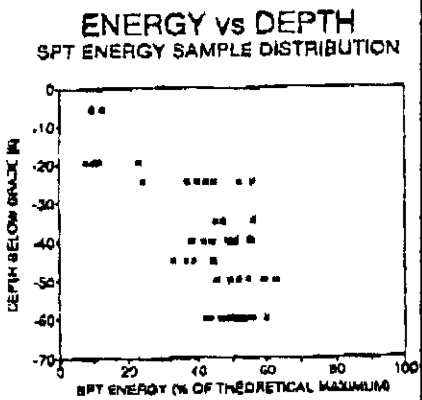

Fig. 2

CONETEC — IN SITU TESTING CONTRACTORS

SPT ENERGY CALIBRATOR

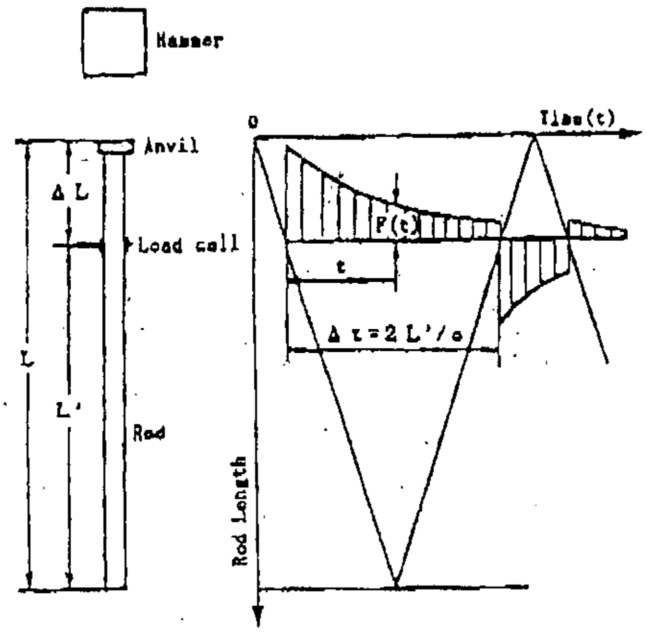

Fig.1 (reference)

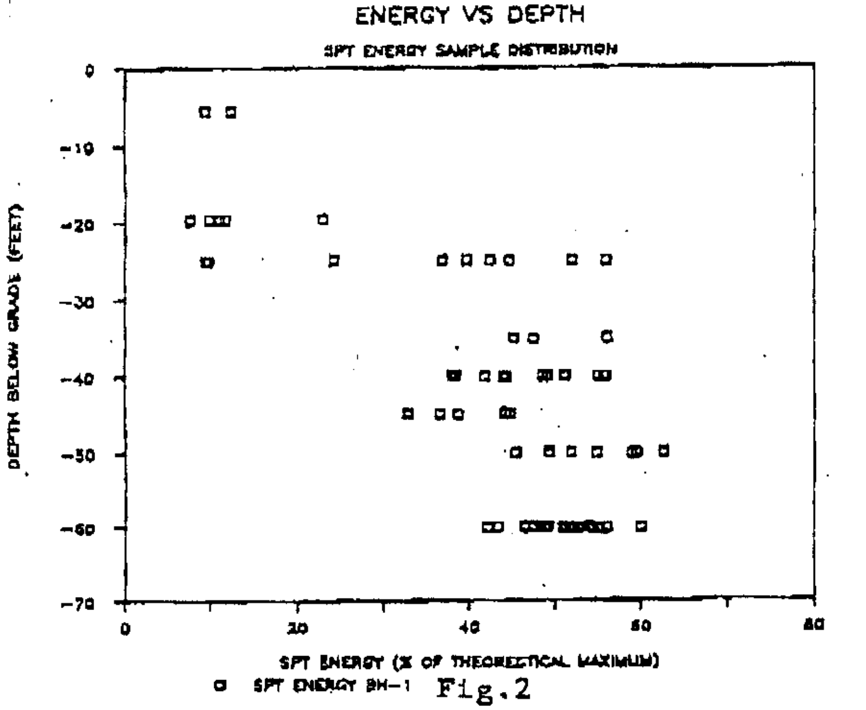

Fig.2

The International Reference Test Procedure for the Standard Penetration Test (SPT) (1989) states that "In situations where comparisons of SPT results are important, calibrations shall be made to evaluate the efficiency of the equipment in terms of energy transfer". The SPT Energy Calibrator provides a reliable means of calibrating standard penetration testing (SPT) systems. The SPT system is a complicated dynamic mechanical system involving the hammer, anvil, rods, sampler, rope and cathead (or winch). The energy delivered to the SPT sampler is always some percentage less than the theoretical maximum.

In order to correctly interpret the SPT blow counts, it is essential to measure energy and correct the SPT blow counts for the mechanical system's efficiency. ConeTec's SPT Energy Calibrator allows energy to be recorded in two ways. The calibrator is capable of measuring force vs time and acceleration vs time. From each of these data sets two independant estimates of the overall SPT system efficiency can be computed. Figure 1 illustrates the principle of the SPT system and force vs time record.

An illustration of the variation of SPT energy vs depth for a site is presented in Figure 2.

January 13, 1995

Mr. Numan Vasquez
Director, Engineering and Construction Bureau
Panama Canal Commission
Balboa Heights, Republic of Panama

Dear Mr. Vasquez:

Re: Geotechnical Advisory Board, Meeting 6

The sixth meeting of the Board took place in Panama from January 9-13, 1995. The schedule for the meeting is included as Attachment A. The Board appreciates meeting with the Administrator, the Chief of the Engineering Division, and you to summarize our findings and elaborate briefly on issues of particular interest to you.

Because of the concern for the potential effects of a nearby earthquake on the Gatun Dam, two specialists have been added to the Board. Dr. Robert L. Wesson, Geophysicist, of the U.S. Geological Survey, Reston, Va, is a specialist in earthquake hazards. Dr. William F. Marcuson, III, Director of the Geotechnical Laboratory, Waterways Experiment Station of the Corps of Engineers, U.S. Army, is a specialist in evaluating the effects of earthquake motions on dams, including hydraulic fill structures such as Gatun Dam.

The continuing Board members welcome the added expertise of the new members who have already contributed greatly to our insights and discussions.

Reports on the studies and analysis of your Geotechnical staff were submitted by the various groups of the Geotechnical Branch, accompanying their verbal summaries and their responses to Board's questions. The Board appreciates the great efforts of Dr. Luis Alfaro and the staff of the Geotechnical Branch for their excellent and thorough briefings and presentations of the results of their studies. They helped greatly in the effective operation of the Board.

This report consists of observations, comments and recommendations under the following three headings:

1. The seismic stability of Gatun Dam and ancillary structures.

2. The continuing landslide monitoring and landslide mitigation program.

3. The cut widening program.

4. Closure

1. SEISMIC STABILITY OF GATUN DAM AND ANCILLARY STRUCTURES

1.1 Recommendations Arising from Fifth Meeting of Board

At its last meeting, the Board agreed that the seismic safety problem of Gatun Dam required attention and that comprehensive studies were needed to address the issue. In evaluating how this might proceed, the Board recommended that the next phase of the study, Phase II, be undertaken by maximizing the use of PCC staff. This phase would be regarded as a screening study to evaluate how serious is the potential for liquefaction failure of Gatun Dam. In order to initiate this screening study the Board further recommended:

i) that the Siquirres record of the Limon, 1991 earthquake be adopted and be obtained from the Instituto Costarricense de Electricidad (ICE).

ii) that PCC staff obtain and become familiar with the use of the computer program SHAKE.

iii) that a field investigation consisting of SPT testing and undisturbed sampling be undertaken.

iv) that liquefaction susceptibility be evaluated based on the results of the field program.

and,

v) that a preliminary inquiry be made with regard to the requirements of the Canal's catastrophic risk insurance.

In the following, progress to date is summarized, outstanding issues are identified, and recommendations are made in order to bring this Phase II study to resolution.

1.2 Progress to Date

Progress of this Phase II study was delayed by the inability of the PCC forces to service the needs of the field investigation and the time required to set up and complete an external contract for the undisturbed sampling. After these initial obstacles were overcome, the study has progressed effectively.

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1. The seismic stability of Gatun Dam and ancillary structures.

2. The continuing landslide monitoring and landslide mitigation program.

3. The cut widening program.

4. Closure

1. SEISMIC STABILITY OF GATUN DAM AND ANCILLARY STRUCTURES

1.1 Recommendations Arising from Fifth Meeting of Board

At its last meeting, the Board agreed that the seismic safety problem of Gatun Dam required attention and that comprehensive studies were needed to address the issue. In evaluating how this might proceed, the Board recommended that the next phase of the study, Phase II, be undertaken by maximizing the use of PCC staff. This phase would be regarded as a screening study to evaluate how serious is the potential for liquefaction failure of Gatun Dam. In order to initiate this screening study the Board further recommended:

i) that the Siquirres record of the Limon, 1991 earthquake be adopted and be obtained from the Instituto Costarricense de Electricidad (ICE).

ii) that PCC staff obtain and become familiar with the use of the computer program SHAKE.

iii) that a field investigation consisting of SPT testing and undisturbed sampling be undertaken.

iv) that liquefaction susceptibility be evaluated based on the results of the field program.

and,

v) that a preliminary inquiry be made with regard to the requirements of the Canal's catastrophic risk insurance.

In the following, progress to date is summarized, outstanding issues are identified, and recommendations are made in order to bring this Phase II study to resolution.

1.2 Progress to Date

Progress of this Phase II study was delayed by the inability of the PCC forces to service the needs of the field investigation and the time required to set up and complete an external contract for the undisturbed sampling. After these initial obstacles were overcome, the study has progressed effectively.

PCC staff have obtained the Siquirres record and have gained an initial understanding of it, as well as other information related to the seismicity and strong motion response of the region. This has been consistent with the direction from the Board.

Also, as requested by the Board, energy calibration of PCC SPT testing techniques has been completed. This provides an improved basis for utilizing SPT data obtained by PCC forces in the liquefaction screening studies.

The field investigation has also been completed in a manner consistent with the recommendations of the Board. The Board is impressed by the care given to the undisturbed sampling program and to the quality of the reporting.

Laboratory testing of samples is still underway. However, sufficient progress has been made for preliminary conclusions to be obtained by PCC staff. Using the preliminary liquefaction triggering analysis agreed upon at the last meeting of the Board, the general conclusion from the analyses conducted to date (which concentrated in Sections B and C of the new field investigation) was that almost all of the dam and underlying foundation material was liquefiable.

A major finding of the investigation, which was not apparent to the Board at its last meeting, is that both the fill composing the dam and the material in its foundation are relatively fine-grained. As a result, these materials may not be susceptible to liquefaction and therefore the preliminary results obtained to date may be excessively conservative.

The Board has identified a series of issues that require further resolution. These are listed in the next section and the sections that follow provide guidance to bring the Phase II study to completion.

1.3 New and Outstanding Issues

1) Design Earthquakes: The Siquirres record has been adopted in preliminary work because it is representative of seismic response to large earthquakes in the region. Recent progress in seismicity and strong motion studies provide a basis for defining the design earthquakes in a more comprehensive manner.

2) Shear Wave Velocity: To date shear wave velocity profiles needed for SHAKE response analysis have been estimated from existing correlations. Obtaining site specific information is warranted.

3) Liquefaction Trigger Analysis: As noted above, the liquefaction susceptibility of the material being evaluated may be less than assumed previously and a broader evaluation is necessary.

4) Post-Earthquake Stability and Deformation Analysis: A testing program is needed to provide data to conduct a post-earthquake stability and deformation analysis regardless of whether liquefaction is an issue or not.

5) Ancillary Structures: The stability of Gatun Dam is only one aspect of the seismic assessment. Consideration must also be given to the spillway, the lock and the saddle dams.

6) Risk Assessment: The Board is adopting internationally recognized standards of safety in its work. The existence of catastrophic risk insurance might provide a basis for relaxing these standards and guidance from PCC to the Board is needed in due course.

1.4 The Design Earthquakes

1) Earthquakes: From a review of recent work and regional seismicity and faulting the Board is of the view that two earthquake scenarios must be considered in the analysis of the Gatun Dam and ancillary structures: an earthquake of Magnitude 7.5-8 associated with the North Panama Deformed Belt and an earthquake of Magnitude 6.5 associated with the Gatun Fault, representing a possible local earthquake. The earthquake on the Gatun Fault should be considered at a distance of 10 km from the Dam. In as much as the ground motions at the Dam from the Magnitude 7.5-8 earthquake will be sensitive to the assumed distance of the earthquake from the dam, some additional analysis is recommended. The Board recommends that the PCC Geotechnical staff work with appropriate outside experts to recommend the appropriate distance. The attenuation curves recently developed for Central America can be used.

2) Ground Motions: The strong motion accelerogram recorded at Siquirres, Costa Rica, from the 1991 Limon earthquake is particularly relevant. A discussion via telephone with Dr. Climent of ICE suggests that this record may reflect significant amplification from local site conditions. The Board recommends that the PCC Geotechnical staff perform its own analysis of the Siquirres record to confirm Dr. Climent's conclusion and to determine the factor by which the Siquirres record should be scaled (or deconvolved) to estimate bed rock motions. Studies of this amplification performed for ICE at the Norwegian Geotechnical Institute should also be obtained. The scaled (or deconvolved) Siquirres record could then be scaled by the attenuation factor appropriate for the assumed distance from the Magnitude 7.5-8 earthquake to provide an assumed input motion for analysis of the Dam and ancillary structures. Because the response of the different parts of the embankment, spillway, and locks are sensitive to different input

frequencies, the Board recommends that the PCC staff, working with outside experts as appropriate, select one or two additional accelerograms (scaled appropriately) to represent the Magnitude 7.5-8 earthquake and two or three accelerograms to represent the Magnitude 6.5 earthquake on the Gatun Fault. In selecting and scaling these accelerograms, attention should be addressed to the frequency content and durations of the input motions, as well as the peak ground acceleration. Attention to frequency content of earthquake records is needed in order to be sure that records are not deficient in frequency content of interest, specifically, near the fundamental frequencies of the structures to be analyzed. The Board would be pleased to review the selected accelerograms at a future meeting.

3) Local Faulting: Based on the presentations from the staff, the Board is concerned about the possibility of faults in the immediate vicinity of the dam which might possibly result in displacements in or around the dam or spillway in the event of a local earthquake. The Board recommends that PCC staff, assisted by outside expertise as required, review construction records, available geologic mapping and borings, carry out reconnaissance mapping or investigations as required, and, if indicated, recommend a program of borings and/or trenching, to determine whether fault displacement should be considered in analyzing the behavior of the dam in the event of a large local earthquake. Sub bottom seismic profiling in Gatun Lake adjacent the dam may prove useful.

4) Additional Understanding of Earthquake Potential: While understanding of the earthquake hazard in Panama is increasing, much remains unknown. The Board believes that an earthquake with Magnitude 7.5-8 is a reasonable extreme event for the basis of design in accord with standard practice. Although evidence is strong that the Panama earthquake of 1882 was of this size, the Board recognizes that information on the past frequency of such earthquakes is lacking. As time and resources are available, the Board recommends geologic studies aimed at determining the dates and sizes of past large earthquakes. Such studies could be carried out by PCC staff and/or appropriate outside experts, and could include studies of vertical movements along the coast (e.g., submerged terraces), paleoliquefaction and other techniques of Quaternary geology.

5) Outside Expertise: The Board is impressed with the expertise on seismicity and strong ground motions available locally in Panama and Central America. The Board would like to encourage the PCC to take advantage of this local capability in formulating recommendations to the Board. However, as desired, members of the Board are prepared to assist the staff in identifying appropriate sources of expertise in U.S. government agencies or other contractors.

1.5 Shear Wave Velocity (V_s) Input

In order to conduct an analysis using the computer program SHAKE several input parameters are needed. To date V_s has been determined from correlations with SPT blow counts and material types. In order to refine the results from SHAKE, it is recommended that cross hole surveys be conducted as a function of depth at several cross sections in the dam in order to obtain actual in situ V_s values. The Board recommends surveys be conducted at Sections B and C, since they appear to be the deep sections on the East and West embankment; Section E, since this section has considerable cohesionless material and low blow counts; and on each spillway abutment.

The Board recommends at least 2 borings spaced about 15 ft apart at the crest and downstream toe for each section. Care should be taken to survey the holes with a bore hole inclinometer for verticality. V_s measurements should be made at 5 ft to 10 ft intervals in each set of holes. The location of each hole set should be adjacent to an existing recent boring. Data should be gathered from depths as deep as practical. This work should proceed as soon as practical since V_s is an important input parameter.

1.6 Analysis to Valuate Triggering Liquefaction

In order to evaluate whether liquefaction will trigger, one must establish whether the materials are susceptible to liquefaction and if so, are the seismically induced stresses sufficient to trigger liquefaction. To evaluate liquefaction susceptibility and triggering the Board recommends using the Chinese criteria (based on water content, liquid limit, plasticity index and grain size analysis) for susceptibility and the Seed - Tokimatsu approach (based on SPT N values) for triggering. Since the Chinese criteria are based on bulk properties and the strata, particularly the hydraulic fill, are stratified, a test program to evaluate the applicability of the Chinese criteria is also recommended.

The Chinese criteria (with and without the 5 micron criterion) should be used to determine if the material is susceptible to liquefaction. This analysis should allow dam cross sections to be developed showing zones/layers of material that are susceptible to seismically induced liquefaction.

With this information in hand, the Board recommends evaluating liquefaction triggering using the Seed - Tokimatsu approach using both the original curves (Seed at al, 1985) and the more recently developed curves (Fear & McRoberts, in press) plotting field observations in terms of average cyclic stress ratio and normalized STP N values, $(N_1)_{60}$.

This approach uses normalized data for level ground at an effective overburden stress of 1 TSF. Because of the relativity flat slopes at Gatun Dam, the Board believes the level ground approach is reasonable ($K_\alpha=1$). However, susceptibility to liquefaction is a function of effective overburden pressure. Consequently, the Board recommends reviewing the literature to evaluate the current state of knowledge concerning K_σ. Based on this literature review, the Board would like to revisit the K_σ issue and evaluate the need to develop site specific $K\sigma$ data using laboratory test results.

Inspection of cores from the hydraulic fill reveals stratification that is characteristic of these materials. This presents special problems in material characterization that are not recognized by the Chinese criteria, the results of SPT testing and classification based upon blending specimens for testing. To overcome this, the Board recommends that additional field and laboratory testing be undertaken as follows:

1) Piezocone profiles should be obtained near the same locations as V_s. testing.

2) Three vertical test locations from three different boreholes in hydraulic fill should be selected over a 10 ft. interval which includes three SPT readings. All the core within this interval should be extruded and a detailed classification of the stratified core should be undertaken, based on moisture content, Atterberg limits, grain size distribution and clay content. The core should be photographed. The intent of this is to evaluate scale effects with respect to classification data and continuity of thin layers.

3) A summary should be made of the locations, character, and utilization of the borrow sites used in constructing the hydraulic fill.

With this information and the results of SHAKE, a liquefaction triggering analysis can be completed. Dam cross sections can be developed showing where liquefaction is expected. Overlaying cross sections will provide information regarding both liquefaction susceptibility and triggering, which provides a basis for assessing post-earthquake stability and deformation.

1.7 Post Earthquake Stability and Deformation

In order to evaluate post-earthquake stability and evaluation, it is necessary to develop:

1) Stress-strain relationships to peak strength prior to liquefaction.

2) For the materials that are predicted to liquify, undrained stress-strain relationships to the post peak liquefaction strength.

3) For the materials for which liquefaction is not predicted, post earthquake undrained stress-strain relationships.

The Board believes that these properties can be determined from a combination of undrained simple shear, cyclic simple shear, monotonically loaded triaxial and cyclic triaxial tests. This will be a complicated laboratory testing program and the Board or a sub-set of the Board should be invited to review the proposed procedures and the plan of tests prior to the initiation of testing.

The Board also suggests that a literature review be conducted to develop information from other similar case studies regarding undrained stress-strain relationships and peak strength before and after seismic shaking and before and after liquefaction. Comparisons between the proposed test results and those found in the literature will be useful.

1.8 Predicted Permanent Deformations

The Board recommends evaluating the seismic safety of Gatun Dam based on deformations as well as Factors of Safety. This approach requires two dimensional non-linear dynamic analysis be conducted for various cross sections of the dam. Such analysis might be conducted using TARA, FLAC or other appropriate codes currently available. Results from this analysis will provide insight into permanent deformations that might be expected during and immediately after seismic shaking. If these deformations are small and acceptable no further action may be required. On the other hand, if for some reason the earthquake response of the dam needs improvement, the analysis will prove useful in evaluating various remediation alternatives.

1.9 Ancillary Structures

Attention to date has focussed on the stability of the Gatun Dam subject to earthquake loading, but attention also must be paid to the spillway, locks, and saddle dams. The spillway, in particular, raises concerns both about how it will respond itself, as well as the effects of the differing responses of the spillway and the embankment. The Gatun Locks are founded on variable materials which complicate the dynamic response.

The Board recommends:

1) That longitudinal and transverse sections of the spillway foundation conditions be developed with special attention paid to interfaces between the spillway and fill.

2) That a review of the joint details and dam interfaces be carried out.

3) That data be gathered for the locks and the saddle dams.

Based on a review of the construction history and the geological conditions, a process of problem identification should be undertaken and a program of study be developed for review with the Board.

1.10 Risk Assessment

Decisions to invest in improvements to the Gatun facilities involve a number of factors. These factors include the cost of improvements, the severity of the design earthquakes, the economic consequences of failure (both damage and loss of revenue), the extent to which economic losses might be compensated by insurance, and the social consequences of failure, including possible loss of life.

In particular, the Board recommends that the PCC determine whether its existing insurance coverage would be applicable in the event the facilities are not improved. This requires an evaluation of any exclusion that might affect the coverage provided by the Catastrophic risk policy.

2. LANDSLIDE CONTROL PROGRAM

2.1 Background

The Landslide Control Program has continued to progress, and has achieved a very effective and efficient mode of operation. The procedures that have been developed for observation and analysis of surface movement are at the state-of-the-art worldwide, and the Board suggests that a paper describing the system in use should be prepared for presentation at the 8th International Symposium on Landslides in Norway in June, 1996. The stabilization and drainage projects undertaken since the last meeting of the Board have been timely and effective.

2.2 Surface Movement Monitoring Program

Surface movements are monitored by measuring the positions of EDM targets using high-accuracy theodolite observations from one master station per target. The master station positions are located using GPS technology. The accuracy of locating targets is approximately 30 mm horizontally. It is planned to purchase a GPS receiver that will be suitable for locating individual targets, and this may result in as high as 10 mm accuracy.

A very efficient method has been developed for analyzing and evaluating the surface movement data, using EXCEL and AUTOCAD. Velocities greater than or equal to 30 mm per month, or total movement greater than 100 mm, trigger field inspection for cracks or scarps. The Board believes that the velocity criterion is more significant, and provides the preferable basis for screening.

Personnel involved in performing the EDM surveys, drainage ditch maintenance, and access road maintenance have been trained to examine the ground carefully for signs of landslide movement. This process was very effective in detecting the first signs of movement at the East White House slide.

2.3 Subsurface Monitoring

Due to breakdown of a field vehicle, no new observations have been made of piezometers or inclinometers. The Board considers these observations to be of significant value, and hopes that they can be resumed soon.

2.4 Surface Drains and Diversion Drainage

The technology of construction and maintenance of surface drains has been developed very effectively. Drains are lined with rip-rap or shotcrete, and are cleaned prior to and during each rainy season to ensure their effectiveness. The Hagan Spillway has been constructed to provide better drainage from the Obispo Diversion.

2.5 Stabilization Projects

Five stabilization projects have been undertaken since the last meeting of the Board. These projects have been effective in stopping movements at the East White House slide area, and providing additional security against sliding in other areas. Stabilization of the East White House slide area was accomplished in two stages. When additional surface drainage did not stop movements, excavation was used to flatten the slope.

2.6 Groundwater Hydrology

Due to the press of other duties, no progress has been made toward development of a surface water and groundwater hydrology model. The Board believes that such a model would be a valuable asset for slope design and landslide remediation, and would like to encourage its development as soon as time and resources permit.

3. CUT WIDENING PROGRAM

The Geotechnical Branch has continued its major effort in developing plans for widening contracts during the past two years. Four members of the Branch have devoted full-time effort in preparation of contract drawings and other tasks related to cut widening. Ten projects in the North Sector have been let to bid for dry excavation. Six of these have been completed; two are at least 75 percent complete; one is approximately 45 percent complete; and excavation started on the other (Central La Pita) in late December 1994. Project 11 (East Lirio) is in the design stage. Site investigations, involving geologic field work, study of historical data, and 50 new borings, are underway for projects 12, 13, and 14 (West Bank of the Lirio Curve and the Culebra Reach).

3.1 Cut Widening Design Process

The cut widening design process has been organized as follows:

1) Channel alignment study,

2) Site investigation efforts,

3) Planning and scheduling execution of work (excavation and disposal sites), and

4) Production of contract drawings for excavation projects.

The information being used for design is managed through the use of Intergraph work stations, which have made it possible to use directly the topographic data base developed by the Corps of Engineers, and to effectively integrate information derived from geologic studies. The Board has been favorably impressed by the efficiency of this computerized system. It has made possible rapid progress of the design phases of the projects thus far constructed, and seems well suited for continued use in the Cut Widening Program.

3.1.1 Channel Alignment Study

The objectives of the channel alignment study are:

1) Safe slope design,

2) Avoidance of landslide-prone areas,

3) Minimization of slide effects,

4) Use of natural drainage pattern, and

5) Achievement of lowest overall cost.

The design parameters used to obtain the above are:

1) Maintenance of CAORF navigational geometry,

2) Geologic zonation,

3) Slope design criteria developed by the Geotechnical Branch, and

4) Avoidance (as much as possible) of the Cucaracha slide section, including Gold Hill.

The Board feels that these are reasonable design parameters which should remain in effect through the design and construction phases. In meeting these parameters, channel alignment alternatives have been developed. The Board favors those alternatives that meet the CAORF criteria for curve geometry and yet have alignments that impinge as little as possible on Gold Hill and existing major slide areas.

3.1.2 Site Investigation Efforts

The board feels that the geologic site investigations are being conducted satisfactorily. The number of boreholes appears to be adequate. The use of historic data and new data obtained from these boreholes is effective and is resulting in geologic cross sections that are very useful for design.

The Board also feels that data obtained from field observations that develop a field stability curve would also contribute to slope design. These observations will help assure that the results of the more formal analysis are conceptually sound.

3.1.3 Planning and scheduling execution of work (excavation and disposal sites)

The Geotechnical Branch is producing the needed geotechnical design information well ahead of construction efforts. However, the Board notes that more time will be required for comprehensive field investigation that will be needed to assess potential slide activity in the vicinity of East Culebra, Gold Hill, and Cucaracha.

3.1.4 Production of Contract Drawings for Excavation Projects

These are ahead of schedule and well ahead of the construction process.

3.1.5 Location and Design of Disposal Sites

The disposal sites are being located and designed to meet the following criteria:

1) Avoidance of instability of Canal slopes and spoil embankment slopes,

2) Avoidance of drainage problems,

3) Minimization of impact on the Old La Pita Road,

4) Minimization of clearance of tropical forests, and

5) Minimization of overall costs.

Of these, the avoidance of instability of canal slopes and spoil embankment slopes is the important geotechnical issue. The Board feels that this element has been accounted for by careful site selection, by continual compaction by construction equipment of embankment lifts with thicknesses of 1 ft. or less, and by design of bench slopes based on Hoek-Brown and Barton strength criteria. The Board feels that routine inspection of the embankments should be conducted to insure that lift thicknesses do not exceed 1 ft.

3.2 Blasting Control

Dry excavation by contractors is being used down to elevation 90 ft PLD. Below this level, drilling and blasting will be used to fragment the material so that it can be removed by the PCC Dredging Division. It is important that the blasting used to fragment this material should be effective in producing small enough sizes to enable dredging, yet not be strong enough to induce slope failure or cause excessive weakening of material left in place.

In its 1993 report, the Board recommended that maximum particle-velocity measurements be made during blasting for dry excavation, and that the degree of fragmentation of the various geologic units be recorded as a function of blast design as excavation progresses, to obtain information that can guide the blasting operation by the Dredging Division.

3.3 Areas of Great Geologic and Geotechnical Sensitivity

The widening projects completed thus far have been in areas of modest geologic and geotechnical sensitivities, where slides that might encroach on the channel are not likely. However, as cut widening progresses farther south, it will affect slopes of greater sensitivity (particularly in the vicinity of Gold Hill), with potential for slides with serious consequences. The Board is pleased to learn that an investigation program is planned for Gold Hill. However, the details of this program have yet to be clarified. This program should provide information that will help determine the stability of Gold Hill and adjacent slide areas.

The Board requests that the plan for Gold Hill exploration be elaborated to include discussions of objectives and justification of costs. This plan will be reviewed by the Board, and comments will be submitted by fax as soon as possible.

3.4 Long-Term Slope Stability

It is to be expected that long-term strength reduction due to softening and swelling of cut-slope materials can possibly lead to slope failures as much as several years after excavation. Data obtained from the first cut widening program can be utilized in design of slopes for long-term stability on an effective stress basis. Calculated long-term factors of safety for each stage should be shown on the cross sections to indicate possible changes in factor of safety associated with each change in slope configuration.

4. CLOSURE

The Board members appreciate the efforts that were necessary to process and present the work effectively at this meeting. Particularly the increasing use of computer generated displays and the proficiency of the staff in organizing their presentations has been both impressive and useful; we thank them for making our week's work both fascinating and challenging.

A considerable technical effort is required in the near future in order to maintain progress in the stability evaluation of Gatun Dam and the field work at Gold Hill. In the near term, it is necessary to:

1) conduct field work at the dam using Vs and CPT techniques,

2) undertake special stratification studies in the laboratory,

3) undertake both liquefaction susceptibility and triggering analyses, and

4) Completion of the earthquake motions.

All of these activities should be complete prior to selection of samples for advanced testing and initiating advanced analysis. As a result, the Board recommends an interim meeting with selected Board members when these activities are largely complete, and limited tests for stress strain and strength are available, in order to review the scope and procedures for final testing. It is recommended that the entire Board be convened when the data are complete and analysis sufficiently advanced that the Board can aid in their evaluation and in recommending development of remedial measures, if required.

James M. Duncan

William F. Marcuson, III

Norbert R. Morgenstern

Robert L. Schuster

George F. Sowers

Robert L. Wesson

Enclosure
Attachment A

AGENDA FOR THE 6th MEETING OF THE GEOTECHNICAL ADVISORY BOARD

January 9 to 13, 1995

Monday, January 9 (Room 10)

7:30 MTD vehicle picks up consultants at the hotel
8:00 Meet with the Chief, Engineering Division
8:15 Overview of Geotechnical Branch activities since the last GAB meeting (L. Alfaro)
9:45 Break
10:15 Geologic Investigation of Gatun Dam (P. Franceschi)

- SPT Energy Calibrations (J. Schmertmann)
- 24 SPT borings (PCC's Dredging Division)
- 24 Shelby Tube borings (Contractor -- Patrick Drilling . Inc.)
- Revised Geology of Gatun Dam site

12:00 Lunch

1:00 Above topic continued
2:00 Summary of Lab work for the Gatun Evaluation (G. Guerra)
3:00 Visit to the Geotechnical Laboratory (description of new equipment by M. De Puy, G.Guerra)
4:15 MTD vehicle takes consultants to the hotel

Tuesday, January 10 (Room 10)

7:30 MTD vehicle picks up consultants at the hotel
8:00 Liquefaction susceptibility evaluations for Gatun Dam (R.Rivera)

- Scope of the evaluation
- Technical Discussions on SHAKE at Vicksburg (WES)
- General Description of SHAKE
- Field data
- Material Properties
- Results of the Analyses
- Conclusions

9:30 Break
10:00 Above topic continued

12:00 Lunch

1:00 Discussion by Board Members
3:00 Comments and Impressions on the Seismicity of the area (R. Wesson)
4:15 MTD vehicle takes consultants to the hotel

Wednesday, January 11 (Room 10)

7:30 MTD vehicle picks up consultants at the hotel
8:00 Progress on the Landslide Control Program (C. Reyes, L. Fernandez)

- Scope of Work
- Description of rainfall data
- Progress on our predictive capabilities
  - Assumptions and formulation of programs
  - Description of equipment used
  - Case histories
  - Summary and conclusions
- Remedial measures implemented in the last two years

10:00 Break
10:30 Progress on the Cut Widening Program (J. Reyes, I. Diaz, J.F. Garcia, L. Cortizo)

- Overview of the CWP
- Geological database
- Stability Analyses
- Design Process
- End Products
- Case Histories

12:00 Lunch

1:00 Above topic continued
2:30 Progress on the Study of Soft Rock Slope Stability with reference to the Panama Canal (Max De Puy's Ph.D. Thesis)
4:15 MTD vehicle takes consultants to the hotel

Thursday, January 12 (Field Trip to Gaillard Cut and Gatun Dam)

7:30 MTD vehicle picks up consultants at the hotel
8:00 Visit to Gaillard Cut/Gatun Dam by boat

12:00 Lunch at Tarpon Club

1:00 Continue inspection of Gatun Dam (possible visit to the Gatun Locks overhaul)
4:15 MTD vehicle takes consultants to the hotel

Friday, January 13 (Engineering Division's Conference Room)

7:30 MTD vehicle picks up consultants at the hotel
8:00 Preparation of Report

12:00 Lunch

1:00 Preparation of Report (continuation)
2:00 Meeting with Administrator and Deputy Administrator (Administrator's Board Room)
3:00 Preparation of Report (continuation)
4:15 MTD vehicle takes consultants to the hotel

November 22, 1996

Mr. Numan H. Vasquez
Director, Engineering and Construction Bureau
Panama Canal Commission
Balboa Heights, Republic of Panama

Dear Mr. Vasquez:

Re: Geotechnical Advisory Board, Meeting No. 7

The seventh meeting of the Board took place in Panama from November 18-22, 1996. The schedule for the meeting is included as Attachment A. The Board appreciates meeting with the Administrator, Mr. Alberto Aleman, the Acting Chief of the Engineering Division, Mr. James Hannigan, your Deputy Chief, Mr. T. Drohan, and you to exchange views. The Board particularly appreciates Mr. Aleman's interest and understanding of the geotechnical problems faced by the Panama Canal Commission (PCC), and most of all appreciates his commitment to address these problems directly and to provide resources required for their investigation, state-of-the-art solution, and follow-up monitoring and remediation, as required.

The Board notes with sorrow the recent passing of Professor George F. Sowers, an original member of the current Board, and appreciates the recognition of his contribution by the staff of the Geotechnical Branch.

During the course of the meeting, the Board was joined by Dr. Frank Patton of Westbay Instruments Inc. Dr. Patton's contributions of insight and experience with regard to the multipoint piezometers recently installed in the Gaillard Cut area, and with regard to a range of slope stability issues were most helpful.

The meeting focussed almost entirely on the accelerated Cut Widening Program now underway in the Gaillard Cut. Presentations were made by staff of the Geotechnical Branch summarizing available geologic information, slope stability experience and designs for excavations for the five projects involved in the Cut Widening Program. Results of supporting laboratory investigations were presented as well. In addition, relevant information was presented by Mr. David McEachern of Westbay Instruments, Mr. Jorge Espinosa of the PCC's meteorological group, and Mr. George Berman, Coordinator for Cut Widening. The Board had the opportunity to view the areas of ongoing and proposed excavation in Gaillard Cut by boat, and to visit the Gold Hill area by car. The Board appreciates the great efforts of Dr. Luis Alfaro and the staff of the Geotechnical Branch for their excellent and thorough briefings and presentations of their studies and designs. They helped greatly in the effective operation of the Board.

This report consists of observations, comments, and recommendations under the following headings:

1. Progress on recommendations of the 6th meeting of the Board.
2. Design methodology and cut widening projects CWP-12, 13, 15 and 16.
3. Cut widening project CWP-14, Gold Hill.
4. Construction-related stability.
5. Landslide Control Program.
6. Summary.
7. Next meeting.

1. PROGRESS ON RECOMMENDATIONS OF THE 6th MEETING OF THE BOARD

At our 6th meeting, January 9-13, 1995, the Board made several recommendations aimed at an effort to characterize the seismic environment and seismic stability of Gatun Dam. The Board is aware that some progress has been made in meeting those recommendations. However, in view of the acceleration of the Cut Widening Program, staff of the Geotechnical branch have focussed their attention on the latter. The Board understands that issues related to Gatun Dam will be addressed at the next meeting.

At the 6th meeting and in subsequent correspondence the Board also reviewed and commented on plans for site investigation in preparation for the Cut Widening Program as it was planned at the time. The Board is pleased that its recommendations have been carried out, particularly with regard to site investigations at Gold Hill. Although the investigations have proceeded more rapidly than was anticipated at the time, the Board is generally satisfied with the results. Detailed comments on specific issues follow.

2. DESIGN METHODOLOGY AND WIDENING PROJECTS CWP-12, 13, 15 AND 16

2.1 Design Methodology

The methodology being used for design is consistent with the long term policy that minor slides are tolerable but major slides that impinge on the shipping prism must be avoided.

In reaches of Gaillard Cut where landslides have occurred, the designs for the new slopes of the widened cut have been made consistent with this experience. The following paragraphs summarize our understanding of the procedures used to incorporate landslide experience in the new slope designs and our suggestions for some changes in these procedures. It is worthy of note that the design for Gold Hill is not encompassed within this methodology, because there have been only minor slabbing failures on the face of Gold Hill, and no slides of consequence that provide an experience base for the excavation required for cut widening. The Gold Hill excavation design is considered separately.

The landslides that have occurred within each section of Gaillard Cut were "back analyzed" to determine shear strengths for the formations within which the sliding occurred. The back analyses were performed using conservative piezometric conditions, and were guided by the results of Bromhead ring shear tests performed on the materials. Where landslides had occurred in previously stable slopes, the back-calculated strengths were reasonably consistent with fully softened peak shear strengths measured in laboratory tests. Where old landslides had been reactivated, the back-calculated shear strengths were often slightly larger than residual shear strengths measured in laboratory tests.

Factors of safety against slope instability for various possible slope mechanisms were calculated for the existing configuration in sections representative of each geologic condition along the reach covered by the cut widening projects. These analyses were performed using the strengths determined by the back-analysis and the highest piezometric levels consistent with the field measurements. The calculated factors of safety served as a standard of comparison, to show whether the slope regrading involved in cut widening would have an adverse or beneficial effect on slope stability.

Following the same procedures, factors of safety were calculated for the slopes as they would be after cut widening. The same shear strengths were used in these analyses, together with piezometric conditions judged to be a reasonable upper bound to those that would prevail during the life of the slope.

The impact of cut widening was assessed by considering the change in factor of safety due to widening, and the acceptability of the after-widening slope configuration was judged in terms of the magnitude of the factor of safety after widening. Although it was considered desirable that the factor of safety should not decrease as a result of widening, this was not an absolute requirement. In some cases designs were judged to be acceptable even though the analysis indicated they would be less stable than the pre-widening slope configuration, because the calculated factor of safety for the design conditions was larger than 1.00.

This analysis-based process of design has been followed by a program of visual monitoring during construction, and remediation where slope instability has developed during construction. Visual monitoring will continue during the second phase of construction, involving excavation under water. The least stable slope configuration will be the final one, after excavation both above and below water has been completed.

The Board agrees with the following aspects of this design methodology: use of back analysis to evaluate shear strengths; use of conservative (high) piezometric levels; examination of several possible mechanisms of instability; and use of change in calculated factor of safety as a basis for judging the acceptability of design slope configurations.

However, the Board wishes to emphasize that the absolute values of factor of safety that are calculated are less reliable than the increments of factor of safety. The Board feels that it is not appropriate to use design configuration that will result in reduction in factor of safety simply because the calculated factor of safety for the design condition is greater than unity. Designs that result in reduction of factor of safety should only be considered acceptable if the factor of safety for the post-widening condition is considerably larger than one (say 1.3 or higher), and there have been no signs of appreciable movement for the pre-widening condition. Slopes that have exhibited appreciable movement should be treated cautiously.

Slopes like Model Slope and Escobar, which have not been affected by landslides, should also be treated cautiously. There is a greater potential for strength loss in such slopes if movements do occur, because the shear strength can be reduced from the fully softened peak to the residual value, with consequent large and possibly rapid movements.

The Board believes that the designs for some sections should be made more conservative, because they appear to rely too much on the magnitude of the calculated factor of safety, without sufficient regard for the change in factor of safety that will result from excavation during widening. Detailed comments on these cases are included in the following sections.

As work continues on cut widening design, greater emphasis should be placed on achieving consistency in shear strengths and design criteria.

The designs should each be documented in design memoranda that document geologic information, records of previous movements and landsliding, shear strengths, piezometric levels, and calculated factors of safety. These design memoranda should be supplemented by memoranda that document observations during construction, slope movements or failures during construction, and design modifications.

The fresh exposures that will be created by excavation will afford a valuable opportunity to learn about the geology in the project areas in great detail. The Board recommends that photogrametric methods be used to record these exposures while they are fresh, to preserve this valuable information for future use.

The Board wishes to emphasize the need to re-establish EDM for the Landslide Control program in the excavated areas as quickly as possible. It is fortunate that it will be possible to accomplish this before the wet excavation takes place in many of the most critical areas.

2.2. Cut Widening Project - 12:Empire

The Empire Project consists of two sectors: the Empire Sector and the Lirio Sector; it extends from Station 56k+800 to Station 58k+500.

Additional data: Two multipoint piezometers, HODMP-1 and 2, have recently been installed near Station 58k+465. Both of these piezometers are yielding interesting data. However, hydrostatic water pressure was assumed in all analyses for this reach, a conservative and reasonable approach.

Projected Failure Modes: In general, the failure modes were circular, and were along and across bedding planes as appropriately dictated by geology. These projected failure modes occur mainly in the Pedro Miguel formation in the vicinity of Station 56k+898, and in the Culebra and Gatuncillo Formations near Station 57k+973 and Station 58k+479. In general, the bedding dips toward the Canal.

The Board noted that the factor of safety for the design condition is lower for the existing condition for a number of sections. This is particularly disturbing when the factors of safety are low, for example Stations 57k+973, 58k+217, and 58k+479. The analysis as presented appears to have been conducted correctly. However, changes in surface geometry are recommended to improve stability. In addition the design should be more sensitive to the existing movement data.

Recommendations: Where the change in factors of safety is in the wrong direction, the Board recommends flattening the slopes. The Board also questions the need for benches as presented.

Proposed revisions: If changes in surface geometry are not sufficient to raise the factors of safety to that of the existing condition, pre-construction dewatering of the sections should be considered. This can be accomplished by ditching and/or horizontal drains.

2.3 Cut Widening Project - 13:Hodges

The Hodges project includes the following sectors between Stations 58 km + 440 and 60 km + 040: Hodges Hill, West Culebra Slide, and Model Slope.

Additional data -- In the Hodge's Hill sector, five new multipoint piezometers were installed during 1995 and 1996, providing additional hydrologic data.

Projected Failure Modes -- The projected modes of failure occur mainly in the Cucaracha and Pedro Miguel Formations, which dip favorably (i.e., slightly away from the Canal). Thus, the geology has not particularly influenced the geometry of the failure surfaces, which have been assumed to be circular. This approach is rational.

Recommendations -- In the slope stability analyses conducted for the three sectors in this reach, several of the analyzed sections presented reduced factors of safety after excavation as compared to pre-excavation. This has occurred in spite of the proposed adoption of excavated profiles that are generally parallel to or slightly less steep than the pre-excavation profiles. Thus, the Board perceives that the reduction in factor of safety seems to be unrealistic. It is thought that the analyses are faulty in that it appears that the same piezometric surface has been used for both the pre-excavation slopes and the excavated slopes, a condition that is unrealistic. A modified piezometric surface should be used for the post-excavation case. The best guess for the new phreatic surface would be to assume that its long-term position will be the same relative to the ground surface as it was before excavation. Use this new location for the piezometric surface to re-analyze the post-excavation slopes. The new analyses will probably indicate no reduction in factor of safety.

If, after re-analysis, certain slopes continue to show a reduction in factor of safety, some can be stabilized by removal of material at the head of the projected landslide. An example where this "top excavation" should be considered is the slope section at Station 59 km + 485 in the West Culebra Slide area.

Slopes subjected to this additional excavation in their uppermost parts should be re-analyzed to determine new factors of safety. If they remain unstable, pre-construction dewatering should be considered by means of surface ditches and/or subsurface horizontal drains. We do not recommend the use of the suggested deep trench drain for the Model Slope Sector because of its expense as compared to the use of horizontal drains.

2.4 Cut Widening Project Contractor's Hill

The Contractor's Hill Reach includes the following three cross sections that have been subjected to stability analysis: Cross Section A (Station 59 km + 985), Cross Section B (Station 60 km + 510) and Cross Section C (Station 60 km + 240).

Additional data: Fourteen new holes were available.

Projected Failure Modes:

Section A: The failure modes are all circular, passing through the Cucaracha and Pedro Miguel Formations without deflection. In some cases, the circles are based on resistant layers. These geometries are satisfactorily in conformance with the geology.

Section B: The projected failure mode is circular through Cucaracha Formation beds that dip away from the Canal. This is a realistic scenario, which provides a reasonable estimate of stability.

Section C: For this section, widening is being accomplished by moving back an historically stable designed cut face in the Pedro Miguel agglomerate and tuff that is located close to the Canal prism to a position approximately parallel to the existing face. This is a reasonable approach. If failure were to occur, it would most likely be a combination of circular failure through the lower Pedro Miguel agglomerate and the underlying Cucaracha Formation and a plane failure surface along a potential vertical tension crack in the tuff of the upper Pedro Miguel Formation. This is a reasonable proposed failure surface.

Recommendations:

Section A: Design of section A is satisfactory. Even though calculated factors of safety are low, the existing cross section has performed satisfactorily, and the proposed excavation provides a slight increase in factors of safety. We see no reason for additional changes.

Section B: Design of Section B is satisfactory. In spite of a fairly low calculated factor of safety, the proposed excavation provides a slight increase in factor of safety. However, if a further increase in factor of safety is desired, it can be obtained easily and inexpensively by flattening the slope (i.e. by taking advantage of the slight depression that exists headward from the intersection of the failure circle and the ground surface).

Section C: At Section C all reasonable proposed excavation designs result in reduced factors of safety, the most severe being a reduction of nearly 50 percent to a calculated factor of safety of only 0.78. However, the existing cross section has performed satisfactorily, and scrutiny of the existing and proposed profiles indicates that the driving force will be slightly reduced by removal of a small amount of extra agglomerate and overburden from the head and top of the slope. However, the driving force apparently will be increased by existence of a vertical tension crack in the agglomerate which could be filled with water, thus reducing the factor of safety to an unsafe level. Because of this possibility, we recommend close observation and monitoring. Consideration should be given to the use of horizontal drains to relieve the hydrostatic pressure driving this section toward instability.

2.5 Cut Widening Project - 16:Escobar

The Escobar Project extends from Station 60 km + 500 to Station 62 km + 420.

Additional Data: The Board was presented with new hydrologic, geologic and materials properties data as a result of recent drilling in this reach of the Canal.

Projected Failure Modes: All analyses assumed a circular failure surface, sometimes truncated by a fault or an assumed open water-filled crack in the basalt. The projected modes of failure occur mainly in the Cucaracha, La Boca and Pedro Miguel formations, which dip favorably (i.e., away from the Canal). Again, as mentioned previously, the change in factor of safety is in the wrong direction; however, these lower factors of safety exceed 1.3. These negative changes in reasonably low factors of safety occur primarily for slip surfaces not deeper than the toe of the slope.

Recommendations: A considerable excavation is planned for purposes of rockfall control. Savings can be achieved by eliminating most of this excavation and utilizing a rockfall collection fence.

Proposed Revisions: None.

3. CUT WIDENING PROJECT - 14:GOLD HILL

Cut widening into Gold Hill differs from the other cut-widening projects in that, 1) the persistent stability of Gold Hill is vital to the integrity of the operation of the Canal in the reach, 2) the geology of Gold Hill differs substantially when compared with the other widening projects, 3) and there is no experience associated with recent widening, since the previous cut widening was restricted to the opposite bank. As a result, the design and construction process for CWP-14 stands alone when compared with the others considered in this Report. Although separate, there is nevertheless a considerable amount of information on file and recently gathered with regards to the geology and groundwater conditions within Gold Hill, as well as its deformation measured over a number of years, that require both integration and evaluation.

Since the last meeting of the Board a major drilling and sampling program in Gold Hill, involving 17 holes, some as deep as 470 m, has been completed. This has added substantially to information available from previous drilling of Gold Hill and the Board is content with its understanding of the geology of Gold Hill. More recently, multi-point piezometers have been installed in Gold Hill leading to an improved understanding of the hydro-geologic regime as well. Surface mapping of rock fabric features has also been undertaken in order to characterize the rock mass. The Board is of the view that sufficient information with regard to the geology, groundwater and geomechanical characteristics of Gold Hill has been gathered to provide a basis for informed judgement regarding the proposed excavation into Gold Hill.

It is proposed to excavate approximately 58 m into the west face of Gold Hill with subsidiary flanking excavations to the north (Culebra Slide) and south (Cucaracha Slide) respectively. In support of this proposal various potential failure modes have been evaluated, the movement history at and adjacent to Gold Hill has been reviewed and matters related to constructability have been considered.

Canal operation records and movement monitoring data reveal that significant uplift of Cucaracha shale had occurred in front of Gold Hill in the 1950's but there is no evidence of on-going upward squeezing of this material in recent years. A review of survey measurements of Gold Hill itself suggests that there have been no significant systematic movements, although a comparison of photographic profiles indicates a face retreat of about 10 m since construction. A crack appeared in Gold Hill in 1954 but it may be related more to proximate geologic contacts than to any movements. The Board is of the view that the movement history does not preclude excavation into Gold Hill but the recorded heave of Cucaracha Shale indicates the presence of abnormal conditions.

The large rock mass of Gold Hill presents two sets of slope stability issues: first those related to the stability of the mass itself, and second, those related to the role of Gold Hill in buttressing the adjacent slides.

Two overall potential failure modes have been investigated. The first involves rotational failure through the basalt and agglomerate. Analyses indicate that this potential failure mode is not aggravated by the proposed excavation and the Board accepts the conclusion that overall stability in this regard is not of concern. The Board notes that the stability of Gold Hill as a whole is subjected to substantial side shear as a result of the adjacent landslides restrained by Gold Hill. This condition is abnormal in that side effects usually result in increased resistance rather than reduced stability. Nevertheless, Gold Hill is sufficiently embedded in the Cucaracha Formation for the Board to accept these abnormal conditions as adequately safe.

The other overall potential failure mode reviewed by the design team is sliding through the rock. Rock Quality Designment (RQD) index data reveal very strong rock, except in the core of Gold Hill, without any continuous through-going weak zone, and therefore instability from this mode can be discounted.

Both experience and analysis of rock fabric data reveal that shallow failure modes such as topples and rock wedge failures are to be anticipated. The Board agrees with this conclusion and is of the opinion that neither process is likely to be sufficiently aggressive to inhibit the proposed excavation, provided that controlled blasting is implemented throughout for final rock faces.

In order to avoid excessively steep excavation into the toe of the Culebra and Cucaracha Slides, the excavation of Gold Hill is turned along these slide areas so that the slide material can be trimmed back. The Board was concerned that unloading the toe might trigger movements in the Culebra Slide and, to a lesser degree, in the Cucaracha Slide. However the Board is content that landslide stabilization measures in recent years, particularly improved drainage and excavation, have resulted in a sufficient increase in stability that this concern is reduced. Thus, the Board recommends that these areas be inspected carefully for movement when the excavations near the toe are being undertaken.

Toppling and wedge instability during excavation should be anticipated. Insufficient capability for rock reinforcement during construction could lead to dangerous working conditions. The Board notes that typical Cut Widening Project specifications include provision for scaling and controlled blasting. It is anticipated that controlled blasting will be used for all final faces on Gold Hill and that excavation procedures will be developed to minimize loose and fly-rock falling from the face. In addition the Board recommends provision in the specification for drainage by drilling horizontal or inclined drain holes and for rock reinforcement of potential topples and wedge failures by means of rock bolts. The Board anticipates that fresh faces will be mapped and inspected for potential instability in an on-going manner.

The Board is generally comfortable with regard to the limited excavation into Gold Hill and wishes to caution against anything more aggressive at this time. Gold Hill provides a restraining buttress preventing the coalescence of the Cucaracha Slide with the Culebra Slide. The loading of this adjacent ground onto Gold Hill is abnormal and not readily understood. The history of heave of the Cucaracha Formation at the toe of the Gold Hill is also abnormal and not readily understood. Therefore, it is prudent to proceed cautiously.

The Board recommends that the monitoring of the top of Gold Hill be up-graded to a best available technical level making use of both EDM and GPS technology and that observation and reports of movements during construction be undertaken every two weeks. In addition, the Board recommends that additional information be obtained on the characteristics of the Cucharacha Formation within the Canal in front of Gold Hill. This can be obtained in a cost-effective manner by means of seismic reflection techniques and the USGS contract could be extended to embrace this work.

4. CONSTRUCTION-RELATED INSTABILITY

The ability to meet the accelerated schedule of the Cut Widening Program is inhibited by the available dredging capability. In order to save dredging volumes and achieve economies at the same time, it is proposed to excavate the upper 10m of wet excavation from a dry bench. The material will be pre-blasted and readily handled by a truck and excavator operation.

The Board notes that the excavator will be at risk due to slope instability along weak clay seams that daylight into the face of the excavation. Instability can be triggered by the weight of the equipment or by excavation pulling forces. Pre-blasting increases stability by disrupting the continuity of clay seams. Nevertheless, the Board recommends that where weak clay seams are known or suspected to dip out of the excavation, continuous monitoring of the excavation will be necessary. Monitoring can be restricted to visual identification of cracking to ensure that the excavator is in a safe mode of operation at all times.

5. LANDSLIDE CONTROL PROGRAM

The Cut Widening Program is disruptive of the landslide control program. The Board wishes to emphasize that the Program should be re-instated immediately following construction. It is this program that ultimately manages the risk of landslides to Canal operations and its significance should not be diminished in the face of other apparently more urgent needs.

6. SUMMARY

Sufficient geologic and ground water information is available to provide a reliable basis for the Cut Widening Program slope designs.

The geotechnical laboratory has provided much useful information that has been a valuable supplement to available field data and observations.

Comprehensive calculations have provided a basis for the Cut Widening Program slope designs.

The Board has advised that a more consistent and conservative approach should be followed in the designs analyses. This will result in changes in designs for some projects.

The proposed excavation for widening at Gold Hill appears to be suitable; rock slope stabilization capability and frequent comprehensive monitoring of movement during construction should be incorporated in the plans and specifications.

Documentation of the data and analyses that form the basis for the Cut Widening program designs should be prepared for each project in a timely manner.

The Landslide Control Program should be reinstated as quickly as possible.

7. NEXT MEETING

It has been suggested that the next meeting of the Board be convened in November, 1997. The Board concurs and suggests the week of November 9-15. At that time it will be possible 1) review the progress of the excavations in geotechnically sensitive areas, 2) to review the documentation of the design memoranda for the Cut Widening Program, 3) to assess the reinstatement of the Landslide Control Program and 4) to return to the evaluation of seismic stability of Gatun Dam and ancillary facilities.

James M. Duncan

Robert L. Schuster

Norbert R. Morgenstern

Robert L. Wesson

William F. Marcuson III

Enclosure
Attachment A

AGENDA FOR THE 7th MEETING OF THE GEOTECHNICAL ADVISORY BOARD

November 18-22, 1996

Monday, November 18 (Room 10)

7:30 MTD vehicle picks up consultants at the hotel
8:00 Meeting with the Deputy E&C Bureau Director and Chief, Engineering Division
8:15 **Presentation No. 1:** "Overview of Geotechnical Branch activities since the last GAB meeting" (L. Alfaro)
9:45 Break
10:15 **Presentation No. 2:** "Experience with the Multipoint piezometers" (L. Fernández)
12:00 Lunch
1:00 **Presentation No. 3:** "Briefing on Recent Activities of the Geotechnical Laboratory " (G. Guerra) (to take place in the Lab at Building 630)
2:30 **Presentation No. 4:** "Advances in the characterization of the shear strength of the Materials in Gaillard Cut" (M. De Puy)
3:45 **Presentation No. 5:** "Recent Findings regarding Rainfall Behavior in Panama" (J. Espinosa)
4:15 MTD vehicle takes consultants to the hotel

Tuesday, November 19 (Room 10)

7:30 MTD vehicle picks up consultants at the hotel
8:00 **Presentation No. 6:** "Summary of Geologic Information for Gold Hill" (Franceschi, Diaz, Arrocha)
9:00 **Presentation No. 7:** "Design of CWP-14: Gold Hill" (M. De Puy)
10:30 Break
11:00 **Presentation No. 8:** "Summary of Geologic Information for Contractors Hill" (Franceschi, Diaz, Arrocha)
12:00 Lunch
1:00 **Presentation No. 9:** "Design of CWP-15: Contractors Hill" (L. Cortizo)
2:30 **Presentation No. 10:** "Summary of Geologic Information for Escobar" (Franceschi, Diaz, Arrocha)
3:30 **Presentation No. 11:** "Design of CWP-16: Escobar" (R. Rivera)
5:00 MTD vehicle takes consultants to the hotel

Wednesday, November 20 (Room 10)

7:30 MTD vehicle picks up consultants at the hotel
8:00 **Presentation No. 12:** "Summary of Geologic Information for Hodges" (Franceschi, Diaz, Arrocha)
9:00 **Presentation No. 13:** "Design of CWP-13: Hodges" (J.F. Garcia)
10:30 Break
11:00 **Presentation No. 14:** "Summary of Geologic Information for Empire" (Franceschi, Diaz, Arrocha)
12:00 Lunch
1:00 **Presentation No. 15:** "Design of CWP-12: Empire" (C. Reyes)
2:00 Meeting with the Administrator and the Deputy Administrator (Administrator's Board Room)
3:00 **Presentation No. 16:** "Progress on CWP dredging activities" (G. Berman)
4:30 MTD vehicle takes consultants to the hotel

Thursday, November 21 (Room 10 and Field Trip to Gaillard Cut)

7:30 MTD vehicle picks up consultants at the hotel
8:00 **Presentation No. 17:** "Discussion on the Performance of the Excavations at La Pita Hill" (C. Reyes & J.F. Garcia)
9:00 Travel to Las Cruces Landing
9:30 Visit to Gaillard Cut by boat
12:00 Lunch
1:00 Visit to Gold Hill by car
2:30 Discussion period on subjects selected by the Board Members
4:15 MTD vehicle takes consultants to the hotel

Friday, November 22 (Engineering Division's Conference Room)

7:30 MTD vehicle picks up consultants at the hotel
8:00 Preparation of Report
12:00 Lunch
1:00 Preparation of Report (continuation)
4:15 MTD vehicle takes consultants to the hotel

UNITED STATES GOVERNMENT
memorandum

DATE: January 22, 1997

REPLY TO ATTN OF: ECET

SUBJECT: Summary of recommendations made by the Geotechnical Advisory Board after Meeting No. 7

TO: For the Record
Through: Chief, Engineering Division (ECEG)

1. The 7th. Geotechnical Advisory Board Meeting was an important milestone in the process of designing the Cut Widening Program. We were able to achieve the following objectives:

a. Receive endorsement for our proposed excavation designs for CWP-14: Gold, CWP-15: Contractors, and CWP-16: Escobar.

b. Decide which of the stabilization measures we proposed for improving the safety of Model Slope (part of CWP-13: Hodges) was the most convenient.

c. Receive recommendations to improve our excavation designs for areas already contracted (CWP-12: Empire and CWP-13: Hodges).

d. Reinforce the decision to maintain the widening on the West Bank of Gaillard Cut, in the Southern Sector of the Cut, to avoid large potential problems in Gold Hill and surrounding large slide areas, and in front of the Paraiso townsite.

2. Specific recommendations made by the Board in their report, are divided into three groups: General Recommendations, Design recommendations, and Recommendations on the Acquisition of New Resources. Following is a listing of the three groups.

a. **General Recommendations:**

(1) Establish EDMs for the areas affected by Cut Widening as soon as possible. This is specially important before dredging. (action: ECET, ECEV)

(2) Prepare design memoranda for each excavation project. These should include: geologic information, records of previous movements and landslides, shear strengths, piezometric levels, and calculated factors of safety. Each report should be supplemented by memoranda that document observations during construction, slope movements or failures during construction, and design modifications. (action: ECET)

OPTIONAL FORM NO. 10
(REV. 1-80)
GSA FPMR (41 CFR) 101-11.6
5010-114
*U.S. GPO: 1989-201-760/90272

b. **Design Recommendations (action: ECET)**

(1) For CWP-12: Empire:

(a) Evaluate flattening the slopes; consider explicitly existing movement data.

(b) Consider de-watering before dredging, to avoid reducing factors of safety with the excavation.

(c) The benches included in the excavation scheme were questioned by the Board. Although we agree that these benches do not add to the stability of the area, our experience with the 1988 excavations in West Lirio (part of what is now CWP-12: Empire) indicates that the benches prevent extensive erosion by breaking the speed of the running surface water. This is specially important in areas such as this one, dominated by the very erosion-prone La Boca Formation.

Summary: The above considerations may lead to a change order with the present contractor, to accommodate the suggested flattening. If horizontal holes are needed, these would be added later by PCC with the equipment described in section 2c(3) of this memo.

(2) For CWP-13: Hodges:

(a) In Model Slope use the horizontal drains we proposed, instead of the deep trench drain we considered. In addition, the Board suggested more surface drains to further improve stability.

(b) Reevaluate the stability analyses for Hodges Hill with less conservative piezometric surfaces.

(c) Consider reducing the driving forces promoting sliding of the West Culebra Slide through an excavation that reduces loads at the head of the slide. We will implement this once we verify that it will have no negative impact on the infiltration of water at the head of the slide. If performing this excavation removes a natural "seal" of soil, debris, organic matter, etc., we may need to design an impervious layer on the material left after the excavation, to avoid a possible large increase in the rate of infiltration.

Summary: PCC will install horizontal drains in the Model Slope area before dredging takes place (action: ECET, ECDR). Additional excavation to unload the head of the West Culebra Slide will be studied to define the appropriate scope for this measure. We can consider including this work as a change order in the present contract, or performing it later as a separate contract, or having it performed later by Maintenance Division (action: ECET and performing unit).

(3) For CWP-14: Gold:

(a) Use controlled blasting techniques with care. Make pre-splitting mandatory.

(b) Monitor movements during construction with EDMs and GPS. They suggested at least 10 points and reading frequencies no greater than 2 weeks. During our discussions, they even considered telemetry to send the GPS information directly to our office. Note: the telemetry could afford us the capability of correlating possible movements with rainfall patterns (which have important variations in periods much shorter than 2 weeks). It would also save Surveys Branch a great deal of time.

(c) Add provisions to the Specifications for horizontal holes and rock reinforcement anchors to control potential topples and small wedge failures as needed.

(d) Inspect and map exposed rock surfaces in an ongoing manner, to anticipate the need for anchors and/or drainage.

(e) Inspect closely the excavation of the flanks (into the Cucaracha and East Culebra Slides) during construction.

(f) Collect all existing information on the early 1950's heave of the Canal bottom in front of Gold Hill and try to explain the observations.

(g) Consider carrying out seismic reflection along the Canal's bottom in front of Gold Hill, through an ISSA with the USGS, or any other means. This will help understand what the Board calls "abnormal conditions" concerning the heave in the Cucaracha Formation in front of Gold Hill.

(h) Do not alter the alignment in a way that would result in a more aggressive excavation into Gold Hill.

ECET, January 22, 1997
Subject: Summary of recommendations made by the Geotechnical Advisory Board after Meeting No. 7

Summary: We will include recommended changes to the Specifications (action: ECET, ECEX); will improve our GPS capabilities (action: ECEV); will make routine surface surveys during construction (ECET); will monitor material behind the flank excavations with EDMs and/or GPS receivers (ECET, ECEV); will reevaluate bottom heave in the Cucaracha Formation in front of Gold Hill (ECET), and will consider preparing an ISSA to perform seismic reflection surveys in this area (ECET).

(4) For CWP-15: Contractors:

(a) We will consider flattening the slope a little along Section B.

(b) We will observe and monitor the formation of a possible crack along Section C (with new EDMs), and consider the use of horizontal drain holes to improve stability if needed.

Summary: We will evaluate the suggested changes and implement them before the project is advertised. Will monitor during construction.

(5) For CWP-16: Escobar:

(a) We will replace most of the excavation in the basalt by a rockfall collection fence that will be much less expensive than the former.

Summary: We will proceed as planned, incorporating the above recommendation before advertising the project.

(6) Land-based Dredging Work:

(a) Although pre-blasting disrupts the continuity of weak seams, thus improving stability, the Board recommends continuous monitoring of the excavation in areas where such seams could form sliding mechanisms with the toe of the slide above the toe of the slope. We will monitor accordingly. (action: ECET)

c. **Recommendations on the acquisition of new resources:**

(1) Acquire land-based photogrammetric equipment to record the geology uncovered by the fresh excavations. Record this information for future use. We know the German camera manufacturer Leica make a system such as this one. Others may be available. The estimated cost for the photographic equipment, the corresponding

computer and interface hardware, and the required software is in the range of $80-100K. (action: purchase ECET/ECEV, use ECEV).

Note: ECEV can have many other uses for this equipment, when a map of a small area needs to be developed rapidly.

(2) Acquire additional receivers for the GPS monitoring of the excavation in Gold Hill. They recommended 10 points. Consider data loggers or telemetry to improve reporting time, enable the correlation of possible movements with rainfall, and reduce the workload for Surveys Branch. Estimated cost of additional receivers and data loggers or telemetry: $250K (action: ECEV).

(3) The recommendation to make horizontal drain holes in Model Slope, Empire, and Hodges, in effect requires that PCC have rigs with the capability to drill inclined holes. The Ingersoll-Rand "Resca" currently owned by PCC became seriously deteriorated during the drilling and blasting operations for the widening at the north end of the Cut. Important consideration must be given to the idea of purchasing one or two new drills with this capability. This is one of the most cost-effective stabilization measures we can implement, and many will be needed soon. Estimated cost of one rig: $250-300K (action: ECET, ECDR).

3. Although not in the report, the Board suggested that we hold a workshop, including all PCC geologists, Robert and Joanne Stewart, and a few other geological experts to discuss the integration into our databases, of the great amount of new geological data acquired in the last few years (mainly for the widening). This effort could yield large benefits, by providing the geologists with a transfer of "high" technology, similar to what the branch engineers receive from the Board. We recommend including Dr. Robert Schuster, who is a geologist as well as a member of our Geotechnical Advisory Board. Through his participation, he can provide an input to the workshop, that reflects the experiences of the board from the last ten years, and help guide the discussions to landslide related issues. He can also communicate to our other Board members, the results of this geological workshop. We also recommend including Dr. Eugene Schweig from the U.S.G.S. in the workshop. His expertise in Structural Geology and his recent experience assisting us in characterizing the earthquake hazards in relation to our Gatun Dam Evaluation, make him a valuable addition.

4. A great amount of information was presented to the Board in three days. The fourth day of the meeting was mostly field visits, and the fifth day was devoted to the preparation of their report. The Board members required approximately 12 hours on

that fifth day to conclude their report. It is understandable that some ideas did not come across as clearly as we would have liked during the presentations, given the vast amounts of data, assumptions, interpretations, calculations, conclusions, and recommendations. Unfortunately we were not aware of these misconceptions until after we read their report (after they had left) and were fixed through a series of phone calls and faxes. To improve these conditions in the future, we recommend that one and a half days be devoted to the preparation of the Board's report, and that a final session be held with the Branch members to provide feedback, and clear up any issues that were not transmitted well, or that require clarification. Also, Board meetings should perhaps be scheduled more closely, so there is not such a large amount of information to discuss in a single meeting.

Luis D. Alfaro

Luis D. Alfaro
Chief, Geotechnical Branch

cc:
ECET
ECEV
ECEG
ECDR
EC Rdg.
Dr. James Michael Duncan
Dr. W.F. Marcuson III
Dr. Norbert R. Morgenstern
Dr. Robert L. Schuster
Dr. Robert L. Wesson

LA:mnh

September 12, 1997

Mr. T. Drohan
Engineering and Construction Bureau Director
Panama Canal Commission

Dear Mr. Drohan:

The purpose of this letter is to document the discussions held with engineers and scientists of the Panama Canal Commission (PCC), during my trip to Panama during September 7-13, 1997 .

First let me thank the Organizing Committee of the Universal Congress of the Panama Canal for inviting me to participate in Session Two - "Capacity Improvements Channel Widening" on September 8. Let me thank Dr. Luis Alfaro, Mr. Max De Puy and Mr. Rolando Rivera for their logistical support, hospitality and attention to the detailed arrangements of my visit. I also want to express my appreciation to Mrs. Alina de Casal for her help with regard to administrative and contractual matters, and to Mrs. Ana Cano for typing this letter report.

I participated in the Universal Congress on September 8 and 9. The afternoon of September 9 I toured the cut widening effort with Dr. Alfaro and Congress attendees. I observed the operation of below water excavation of material using the new Liebherr Model 994. From my position on the boat, it appeared that the equipment was operating close to the waters edge. Caution was suggested to Dr. Alfaro concerning potential stability problems associated with this mode of equipment operation and the need to reemphasize this concern to the equipment operators .

I participated in discussions with Mr. Max De Puy and Mr. Rolando Rivera on September 10, 11, and 12. Mr. Rivera gave me an excellent update on the on going regional and local siesmological investigation being conducted by the USGS. Important tentative conclusions are:

- A Mag 8 earthquake might occur along the N. Panama Deformed Belt at a distance of about 50 Kms (30 miles) from Gatun Dam.
- The Rio Gatun Fault may not be as long as originally thought. Consequently, a local earthquake, probably less than Mag 7, may occur in the vicinity of Gatun Dam (distance of about 10 Km).
- There may be a third fault very close or underneath Gatun Dam.

- The USGS is going to deploy a micro-seismic instrumental array in the area of Gatun Dam in October 1997 to gather additional seismological data.

- Low angle thrust faulting is associated with the N. Panama Deformed Belt and normal faulting is associated with the Rio Gatun Fault.

I suggested that the PCC ask the USGS to identify existing earthquake accelerograms obtained with similar faulting mechanisms and from similar Mag earthquakes at similar distances. Such accelerograms will prove useful in upcoming analyses.

Mr. De Puy, Mr. Rivera and I also discussed draft reports prepared by the Waterways Experiment Station (WES) for the PCC entitled "Influence of Confining Stress on Liquefaction Resistance" and "Cone Penetrometer Test (CPT) Field Investigation and Data Evaluation, Gatun Dam, Panama Canal, Republic of Panama". As a result of these discussions, I agreed to :

- provide a comparison of Olsen's correlation of cone data to cyclic resistance ratio with other correlations; such as, Mitchell and Tseng, Robertson and Campanella and others.

- provide any empirical data WES has that formed the basis for the so called "Chinese Criteria".

- investigate the possibility of a visit to WES by PCC engineers to conduct seismic stability analyses of Gatun Dam. This visit was tentatively scheduled in November 1997.

Because of the similarity of Gatun Dam and the Lower San Fernando Dam (dates and method of construction) and similarity of earthquake and potential earthquake excitation, I suggested that the material properties of the two dams be compared. If the index properties and gradations are similar, then other properties might be assumed similar. This would greatly assist in the development of a range of engineering properties needed for seismic analyses of Gatun Dam. I agreed to send the PCC information at WES on material properties of the Lower San Fernando Dam.

Mr. De Puy, Mr. Rivera, Mr. Guerra, and I opened and inspected an undisturbed sample of the hydraulic fill material from Gatun Dam. As expected, the sample consisted of layers (some as thin as 0.5 cm) of sand, silty sand, silty and clayey material.

Obtaining representative material properties of this material in the laboratory appears difficult. I suggested procedures for preparing specimens for laboratory testing using the method of pluviation through water. Depending on the particular test to be conducted and the equipment available, testing could be done by the PCC , WES or other contractors.

I suggested that when any and all samples from Gatun Dam are opened that the material be classified (at least visually). The location of the sample should be determined and then a comparison of material classification should be made with the sections/profiles developed by WES using CPT data. Such comparisons are necessary to validate the WES sections/profiles.

I also suggested that the PCC take the steps to initiate an investigation of the seismic stability of the concrete spillway and lock structures at Gatun Dam.

I discussed a slide that occurred during August 1997 at Hodges Hill with Mr. De Puy, Mr. Rivera and Mr. Garcia. Mr. Garcia presented a clear and concise briefing regarding the events associated with the slide. From the information presented, the following points are key issues:

- The rainy season in Panama during 1997 has been relatively dry compared to other years.
- No storms this year have produced the amount of water that fell during the storm of record (1986) and Hodges Hill experienced no noticeable deformation after the 1986 storm of record.
- The storm of late July probably did load the slide.
- A major change in conditions at Hodges Hill which would tend to decrease the slope stability was the fact that a contractor was excavating material at toe of the slide.

- Other factors which may also contribute to changing the stability of the slope are: 1) clearing and grubbing of the area - which I expect increased the run off and decreased infiltration thereby improving stability and 2) the horizontal drains at Hodges Hill may have been clogged. If data are available, this needs to be checked.

Based on the information presented to me it appears that, the excavation at the toe prior to the slide was a major factor contributing to slope instability. The engineers and geologists of the PCC have done an excellent job of minimizing the effects of the slide by immediately recommending that toe excavation be stopped as specified in Section 2.315.14a of the contract specification and that material at the head of the slide be removed instead. This has been done and no significant movements have occurred since August 15, 1997.

I continue to find the geotechnical issues associated with the operation and maintenance of The Panama Canal to be technically challenging. I enjoy my interaction with the PCC engineers and scientists very much. I look forward to future activities associated with the Geotechnical Advisory Board. If you have any questions, please call me at (601) 634-2234.

Again , thank you for allowing me to participate in this interesting work.

Sincerely,

W.F. Marcuson, III

cc:
N.R. Morgestern
J.M. Duncan
R.L. Schuster
R.L. Wesson

PANAMA CANAL COMMISSION

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BALBOA
REPUBLIC OF PANAMA

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July 18, 1998

Mr. T. W. Drohan
Engineering and Industrial Services Director
Panama Canal Commission
Balboa Heights, Republic of Panama

Dear Mr. Drohan:

Re: Geotechnical Advisory Board, Meeting No. 8

The eighth meeting of the Board took place in Panama from July 13-18, 1998. The schedule for the meeting is included as Attachment A. The Board appreciates the opportunity of meeting with the following people and briefing them on its observations and preliminary recommendations prior to the completion of this report:

Mr. Alberto Aleman, Administrator

Mr. Joseph W. Cornelison, Deputy Administrator

Mr. Roberto Roy, Member, Panama Canal Authority

Mr. T. W. Drohan, Engineering and Industrial Services Director

Dr. Luis D. Alfaro, Manager, Engineering Division

Mr. Maximiliano De Puy, Manager, Geotechnical Branch

In addition to meeting with the staff of the Geotechnical Branch, the Board also received presentations from Dr. Eugene Schweig, U.S. Geological Survey, and Dr. Mary E. Hynes and Mr. Donald E. Yule, of the U. S. Army Engineer Waterways Experiment Station (WES). Dr. Hugh Cowan, Consultant, joined the meeting for the presentation and discussion on regional seismicity.

The Board was up-dated on the progress of the Cut Widening Program (CWP). Many of its individual projects have proceeded without technical incident. The last two components

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(Cartagena and Tie-Up Station) are in planning and design. In the following, the status of the CWP will be summarized and special attention will be given to the problem areas of Gold Hill, West Empire Hill, and Hodges Hill. The design concepts being adopted for Cartagena will also be reviewed.

The Landslide Control Program (LCP) is an integral part of the geotechnical responsibilities. The status of the LCP in FY 97 and 98 was presented to the Board. The activities within this Program and the need for continuation are presented in a subsequent section of this report.

It should be noted that the Board had not participated in any review of the Gatun Dam Seismic Study (GDSS) since its sixth meeting in January 1995. The seventh meeting was devoted to the CWP. Considerable progress has been made with regard to the Gatun Dam Seismic Study in the intervening 3 ½ years. Therefore the remainder of the time was spent on review of the developments within the GDSS. A separate section of this report presents the views of the Board on the GDSS and makes recommendations for a program of work to bring it to a state whereby the outcome of the evaluation can be relied upon for decision making.

The Board viewed both the CWP and Gatun Dam by boat and inspected the excavation at Gold Hill on foot. The Board appreciates the opportunity to be reminded of the complex geology and challenging geotechnical issues associated with the safe operation of the Panama Canal.

A considerable effort went into preparing and delivering presentations to the Board, both by Mr. De Puy and the staff of the Geotechnical Branch, and by their Consultants. These briefings were thoughtful and well prepared. The Board wishes to recognize the quality of these presentations, which contributed enormously to its effective operation.

This report consists of observations, comments, and recommendations under the following headings:

1. Progress on Recommendations of the 7th Meeting of the Board.
2. Cut Widening Program (CWP).
3. Landslide Control Program (LCP).
4. Gatun Dam Seismic Study (GDSS).
5. Summary.
6. Upcoming Meetings.

1. PROGRESS ON RECOMMENDATIONS OF THE 7TH MEETING OF THE BOARD

The 7th meeting of the Board, held from November 18-22, 1996, concentrated on the CWP, construction-related stability, and the LCP. A number of detailed design recommendations were made and, as documented in a Memorandum to File [Jan 22, 1997), Chief, Engineering Division (ECEG)], most have been adopted. For example, the reduction in rock excavation in CWP-16 (Escobar) resulted in substantial savings.

Special attention was paid to the excavation of Gold Hill; particularly with regard to shallow instability modes involving topples and wedges. Recommendations were made to provide in the contract for drainage and rock reinforcement, and these have been implemented. Other recommendations related to monitoring and studies of the adjacent Cucaracha material also have been implemented.

In general the Board is content that its recommendations have been adopted to the degree practical.

2. CUT WIDENING PROGRAM

2.1 General

At the time of this meeting, 16 of the 18 Cut Widening Projects had been designed and let to bid. Preliminary design analysis has been made for Cartagena (CWP-17), and it is expected that a contract for this work will be awarded by the end of 1998. Only the Tie-Up Station (CWP-18) remains to be designed.

Of the 25 million m^3 of dry excavation for the Cut Widening Program, about 20 million m^3 have been accomplished as of July 1998. Of the 10 million m^3 of wet excavation, about 4 million m^3 have been completed.

Designing these projects and preparing contract drawings has been an impressive geotechnical accomplishment, and the Board commends the personnel of the Geotechnical Branch for their efficient and effective execution of this important work.

The alteration of the Canal cross sections involved in cut widening has led to instability in some cases, and it has to be expected that more will occur. It is essential that the Landslide Control Program be reinstated as soon as possible after each Cut Widening Project is completed. If Landslide Control Program surveillance is not reinstated quickly following construction, there is a danger that minor movements will extend and expand, creating major problems that will require very expensive stabilization, and which could threaten Canal operations, as did the 1986 landslide in the Cucaracha Reach. The Landslide Control Program has been an effective cost reduction measure in the past, and the Board views it, combined with a vigilant maintenance program, as the most effective form of insurance against a repeat of the 1986 incident.

The Board supports the approach to designing the Cut Widening Projects that has been employed by the Geotechnical Branch. The elements of this approach are: (1) Design the slopes in critical locations so that the factor of safety after construction will not be lower than the factor of safety before construction and (2) Specify a sequence of excavation that ensures that the factor of safety at any time during construction will not be lower than the factor of safety before construction.

The effectiveness of this approach is shown by the fact that, where the sequence of construction has been in accordance with specifications, only minor instabilities have occurred.

The Board was briefed on the status of the Cut Widening Project and stability problems at West Empire (CWP-12), Hodges Hill (CWP-13), Gold Hill (CWP-14), Contractor's Hill (CWP-15), Escobar (CWP-16), and Cartagena (CWP-17).

2.2 West Empire (CWP-12)

The geologic structure of the West Empire area is highly complex. Fault-controlled slide movements, in a direction oblique to the Canal, have occurred in the 1960's, the 1970's, and the 1980's.

Excavation for cut widening in this area resulted in a reduction of the computed factor of safety in the neighborhood of 10%. Toward the end of April 1998, when nearly all the excavation had been completed and the first rainfall of the season occurred, movements commenced in the same area as the earlier slide, in a direction more nearly perpendicular to the Canal axis. By June 30, 1998, the movement was about 2 m. Using the empirical relationships between slope geometry and runout distance developed by Luis Alfaro, it is estimated that this slide, left unchecked, has the potential to move as far as the center of the Canal.

Plans have been developed to stabilize this area as quickly as possible by excavation of material from the head of the slide, and by installing the horizontal drains that were part of the design. Surface drainage is also to be improved. The Board agrees with this plan for remediation, and urges that it be accomplished as quickly as possible, given its importance.

2.3 Hodges Hill (CWP-13)

The Hodges Hill cross section includes Pedro Miguel agglomerate, basalt, and Culebra and Cucaracha clay-shale deposits, dipping away from the Canal, which are likely dissected by faults. Surface cracking had been observed in this area, but no slide movements had been noted between 1968 and 1997.

The Cut Widening design was predicated on fully softened strengths because factors of safety calculated for the before-construction condition were found to be smaller than 1.0, when residual strengths were used.

Excavation began in January 1997. A large landslide (about 340 m long) occurred in July 1997. Another small slide (about 140 m long) occurred in September 1997, and the large slide moved again in January 1998.

The Board agrees with the Geotechnical Branch analysis of these events, and with the conclusion that the large slide was precipitated by failure to excavate the head of the slide before the toe. It appears that the slide movements, which in total amounted to several meters, have reduced the shear strengths along the rupture surface to their residual values. Significant additional excavation is required, beyond that involved in the original cut widening design, to achieve a stable condition at the end of wet excavation.

2.4 Gold Hill (CWP-14)

The contract to excavate CWP-14 was awarded on March 3, 1997, with notice to proceed delivered on April 3, 1997. The scheduled completion date was July 21, 1998.

The contract involves 1,485,000 m^3 and is about 35% complete at this time. Evidently production has always been behind schedule. This was aggravated by the rockslide that occurred on May 12, 1998. In the view of the Board, it is important that the Geotechnical

Group work closely with the Construction Management Group, in order to provide guidance to the Contractor and avoid the possibility for claims. Close inspection, continuous face mapping of joints, and early installation of bolts where needed are essential to minimize rockslides and provide a safe working environment.

The rock conditions encountered in the excavation are essentially as anticipated in the design, with basalt overlying agglomerate. The columnar characteristics of the basalt are clearly evident and the associated jointing makes the prevention of face ravelling difficult. The wedge failure that developed in May 1998 involved a structure that fell within the family of structures anticipated by pre-construction mapping. The kinematic freedom, involving adjacent joints, that allows movement to take place, is not entirely predictable based on the results of design studies. In order to prevent re-occurrence of such failures it is essential that the face mapping promptly identify potential failures and that the PCC construction managers be advised of any stabilization measures required to promote face safety. Intimate interaction between face-mapping and construction control is required. This is in addition to the requirement that the Contractor take measures on his own to provide a safe working environment.

The Board was advised that the Contractor's blasting has been within the specifications. However, there is a concern with regard to the length and/or extent of the blast zone. If overly long, too many structures are exposed at one time, thereby inhibiting precautionary measures. Any attempt to limit the Contractor will have to be made on an assessment of field conditions and safety considerations.

Monitoring of Gold Hill and adjacent areas is continuing, utilizing both EDM and GPS procedures. There is a discrepancy between the two and the Board recommends that this discrepancy be resolved.

GPS monitoring of Gold Hill shows no significant overall movements. However, EDM: GOL 89-2 suggests a displacement of 81mm from April 26, 1993, to June 19, 1998. No response due to recent construction is detectable in the trend of this EDM point. While the Board is content with the view that no overall movements of Gold Hill can be attributed to recent excavation, the validity of the observations at EDM : GOL 89-2 should be reviewed.

Monitoring the adjacent Cucaracha and Culebra Slides is also on going during the excavation of Gold Hill. The accumulation of possibly as much as 100,000 m^3 of excavation material from Gold Hill on the surface of the East Culebra Slide triggered substantial movements. This attests to the delicate equilibrium achieved in stabilizing these slides. Further, it underlines the need to minimize excavation debris accumulation on the adjacent slide masses and to maintain a vigilant monitoring program. The Cucaracha slide near Gold Hill has not shown any significant re-activation.

The current design of the excavation employs 12-14 m long rock bolts for rock reinforcement and horizontal drains at the base of each bench. All benches are to be paved to prevent infiltration of surface water.

The proposed reinforcement is appropriate to stabilize critical wedges or other larger scale features when they have been identified. However the dominant mode of deterioration is face ravelling. To protect against face raveling, 2-m bolts with wire mesh and local use of shotcrete should be adequate.

The designers are considering maintaining the benches permanently. This would require additional bolting and extensive use of shotcrete. On-going maintenance costs would be substantial. The Board is not convinced that this is worthwhile, and recommends that the Geotechnical Group re-assess the long-term requirements to maintain all the benches.

2.5 Contractor's Hill (CWP-15)

The geology of Contractor's Hill is dominated by the relatively hard Pedro Miguel agglomerate. Consequently, steep slopes are possible.

Excavation was begun in June 1997, and has proceeded with only minor problems. In one location near the viewing area, weaker material was encountered, making it necessary to flatten the slope, and increasing the volume of excavation by 14,000 m^3 (about 0.7%). A small slide occurred after one of the blasts, and rolling boulders have damaged a sailing line target and the Gaillard Monument, and have fallen into the Canal. Where the boulders impinged on the sailing lane, they have been removed by the Dredge Goliath. At the end of June 1998 about 40% of the required 1.9 million m^3 had been excavated.

2.6 Escobar (CWP-16)

The geologic cross section at Escobar shows Cucaracha clay shale near the Canal, with basalt behind.

Excavation at Escobar began in November 1997, and is on schedule. The total volume planned is about 1.2 million m^3. The work also includes construction of a new spillway and a new road to replace the section of the Borinquen Highway affected by the work.

Only minor instabilities have occurred, which will be treated as part of the regular program for maintenance of slopes in Gaillard Cut. The requirement (by the U.S. Army) to maintain usability of the highway throughout construction has resulted in a $320,000 claim for changed conditions from the Contractor.

The Board suggests that consideration be given to the use of gabions for lining the spillway, rather than reinforced concrete. Using gabions, which are more tolerant to movement, may reduce life-cycle costs.

2.7 Cartagena (CWP-17)

The geologic section at Cartagena includes basalt on top, with La Boca Formation in front, underlain by Pedro Miguel agglomerate.

This section is being designed at the time of this meeting. The Board agrees with the method being used, which involves back analysis to establish a minimum strength of the contact between La Boca and the underlying Pedro Miguel. Past landslide flow deposits are also to be removed. The Board wishes to emphasize that it is necessary that the strength of all materials be consistent in the design analyses and back analyses.

The Board recommends that the basalt area at the top of the hill be paved to reduce infiltration.

3. LANDSLIDE CONTROL PROGRAM

3.1 Background

The Landslide Control Program was instituted directly as a result of the observation of open cracks in Hodges Hill in 1968. During the approximately 30 years of its existence, this program, which has as its main objective the minimization of slope-failure hazards in the Gaillard Cut, has been efficiently and effectively conducted by the Geotechnical Branch. Not only has landslide activity in the Gaillard Cut been considerably reduced, but the concepts learned and used in recognition and control of Gaillard Cut landslides have been of great value in design of hazardous slopes that have been encountered during cut widening. In addition, the experience gained has greatly increased the expertise and technical awareness of Geotechnical Branch personnel in regard to landslide activity.

However, the active Cut Widening Program and Gatun Dam Studies have necessarily been disruptive to the Landslide Control Program because they require time commitments from Geotechnical Branch personnel who had been involved in the Landslide Control Program. This disruption has occurred at the same time that cut widening has progressed southward within the Gaillard Cut, affecting slopes of greater sensitivity with potential for slide activity with serious consequences. Many of the slopes resulting from the cut widening process exist in a state near critical equilibrium. Thus, periods of abnormally heavy rainfall, long-term stress reduction due to swelling and/or softening of cut-slope materials, dynamic loading due to earthquake activity, and possible reduced efficiency of drains could lead to re-activation of new slide activity as much as several years after cut excavation.

It also should be noted that for the past few years the Panamanian climate has not been conducive to widespread landslide activity, i.e., precipitation thresholds for slope-failure activity have seldom been exceeded. Thus, the PCC should not be lulled into a false sense of security with regard to the existence of landslide hazards.

3.2 Current Status of Landslide Control Program

The components of the Landslide Control Program are: (1) field inspections, (2) surface monitoring, (3) subsurface instrumentation, (4) drainage maintenance, (5) road maintenance, and (6) design of remedial measures. The current status of these elements and suggestions for improvements are as follows:

(1) Field Inspections:

The very important field inspections of Gaillard Cut slopes are not on a fixed schedule, a process that would prove to be extremely costly if applied to all slopes. Instead, inspections of specific slopes are conducted as needed, based on information from instrument observations and from maintenance personnel, and on the occurrence of heavy rainfall. Especially noted in the inspections are tension and shear cracks, local topographic irregularities, impaired drainage and roadway facilities, and new springs and seeps. These inspections should continue to be made in conjunction with regular reading of field instruments.

(2) Monitoring of Slope Surface Movements:

The EDM system currently monitors movements of approximately 290 survey points on Gaillard Cut slope surfaces. The movement data obtained by this system are extremely valuable for delineating slopes in need of mitigation. Recently, locations of selected important (i.e., "master") EDM survey points have begun to be checked by GPS, a method of comparable accuracy to that of the EDM procedure, but which may prove to be less expensive to operate. At present, however, discrepancies are being noted between the results of the Gaillard Cut EDM and GPS measurements. An effort should be made to determine the reason(s) for this lack of agreement between the two data sets, found to be inaccurate.

(3) Subsurface Instrumentation:

The Landslide Control Program currently includes the following numbers of subsurface instruments in Gaillard Cut slopes: open wells – 76; Casagrande piezometers – 7; electro-piezometers – 27; multi-point piezometers – 29 (21 are fully operational; two are in the process of installation; five have been damaged; and one can no longer be accessed); and horizontal drains – 21 (about 10 more have been sheared off by the 1997 Hodges Hill slide).

The only continuous readings that have been made by the above instruments are for a few of the multi-point piezometers for certain periods of time. The Board requests that certain of these continuous records be studied in an effort to correlate rainfall patterns with rise and fall of the water table.

(4) Drainage Maintenance:

Drainage maintenance includes the recording of incidents in which surface or subsurface drains have required maintenance. This information can be used to help recognize or foresee landslide activity.

(5) Roadside Maintenance:

Damage to roads that require maintenance should be noted as indications of active or impending landslide activity.

(6) Design of Remedial Measures:

If actual or impending slope movements are noted by one or more of the above methods, remedial measures, such as avoidance, surface and/or subsurface drainage, changes in slope geometry, or retaining structures can be used to forestall possible slope failure.

3.3 New/Additional Efforts in Surface and Subsurface Monitoring

The following improvements are needed as part of the Landslide Control Program while efforts at Cut Widening and Gatun Dam Studies are ongoing:

(1) Planning of installation of new instruments.

(2) Coordination of instrument reading schedule with Surveys Branch.

(3) Development and implementation of a more efficient reporting system to manage the data. This should include continuous recording for data from the more important multi-point piezometers. We feel that telemetering of data is not desired because it will reduce the use of field inspection, a necessary function.

(4) Correlation of instrument data with rainfall duration and amount.

3.4 Summary and Recommendations

The Landslide Control Program has very successfully warned of and reduced landslide activity in the Gaillard Cut. However, the Board wishes to strongly reiterate the recommendation voiced in its November 22, 1996, report that the program be fully re-instituted as a continuing, long-term effort to be phased in with completion of the Cut Widening Program. It is our considered opinion that the Landslide Control Program is a needed function in the considered exercise of due diligence in management of the risk of landslide interruption of Canal operations. Expenditures of relatively small amounts of money to continue the program will serve to reduce or eliminate much larger future costs under possible crisis modes.

4. GATUN DAM SEISMIC STUDIES

4.1 General Overview

The analysis of the seismic stability of Gatun Dam is a complex and difficult problem. The dam is a unique and complicated structure. This kind of problem has not previously been addressed by the PCC staff and indeed extends the state of practice within the region. The PCC staff has done an outstanding job of gathering the tools and developing the capabilities to perform this analysis and, with some assistance from the USGS and CoE, gathering the basic field data required. At the outset, for example, relatively little was known about the relevant properties of the materials that make up the dam itself, or about the possible sources, frequencies of occurrence and magnitudes of earthquakes that might affect the dam. Today the Board believes that data adequate to proceed with the analysis are in hand.

Given the criticality of the dam and ancillary structures to the integrity of the Canal and the potentially high cost of modifications to the dam if they are needed, the Board believes it is essential that the analysis and evaluation be as realistic and thorough as possible. Thus, while a great deal has been accomplished to date, significant tasks remain before the final evaluation can be completed.

4.2 Seismicity

The PCC staff was assisted by a team from the USGS in defining the seismic hazard faced by the dam. The USGS team carried out three basic tasks. First, the team carried out investigations of potential active faults to evaluate their locations, ages of movement and potential for generating large earthquakes. As part of this work, geological studies were performed of sandy fluvial deposits at localities susceptible to liquefaction to identify possible evidence of earthquake induced liquefaction in the past. Second, the geological investigations of faults and land were supplemented by seismic reflection profiling in Limon Bay, in the channel below Gatun Locks, and in Gatun Lake. Third, background seismicity of the Canal Zone and adjacent areas was monitored for a period of 6 months, using a portable seismograph network, to identify currently active seismic zones, and to further characterize tectonic models and the resulting seismic sources.

Principal findings of these investigations include the following:

The primary source of large earthquakes of concern to the dam is a southeast-dipping zone of thrust faulting associated with the North Panama Deformed Belt. This zone of faulting is believed to be responsible for both the 1882 earthquake (magnitude 7.5 +) and the 1991 Limon, Costa Rica, earthquake (magnitude 7.5 +). Depths of small earthquakes recorded during the monitoring period indicate that the fault zone is located at the depth of about 35 km beneath the site of the dam.

- Evidence for paleoliquefaction is less than would be expected if the region were repeatedly struck by earthquakes of magnitude 8 or larger (the magnitude previously estimated by some authors for the earthquake in 1882).

- The Rio Gatun fault, despite its impressive topographic expression east of Gatun Lake, does not appear to have been active in the last 10,000 years. The fault also has a relatively slow long-term rate of movement, on the order of 0.1 mm/year or less, i.e., requiring at least 10,000 years to accumulate 1 m of displacement.

- Numerous small, possibly young, faults were identified beneath Limon Bay and the channel below Gatun Locks by seismic reflection profiling. Similar efforts to confirm the existence of faults beneath the dam and to place constraints on their ages of displacement were inconclusive, as were the results of seismic profiling in Gatun Lake.

- One fault near Palmas Bellas, about 15 km west of Gatun Dam, clearly displaces river channels and marine terraces that are geologically young. It appears highly likely that this fault has been active in the last 10,000 years, although precise age control is lacking.

These finds led the USGS team to recommend the following sources to be considered in the seismic evaluation of the dam:

Source Zone	Moment Magnitude	Site Distance	Slip per event	Rupture area	Recurrence Interval
	(M)	(km)	(m)	(km^2)	(years)
1	7.7	35	3.3	3300	330-1,000
2	6.8	13	0.8	450	10,000-20,000
3a	5.0	2	0.2	12	200
3b	6.0	2	0.5	100	2000

While there are many remaining questions about the tectonics of the region, and the locations, activity and rates of movement of specific faults, the Board believes that the available information is adequate to provide the basis for selecting input ground motions for use in evaluating the stability and response of the dam and ancillary structures. Further, the Board recommends that for the purposes of the engineering evaluation of these structures the ground motions from possible earthquakes in source zone 1 be considered in a deterministic context, while those from source zones 2 and 3 be considered in a probabilistic context. That is, the Board recommends that ground motions appropriate for a magnitude 7.7 earthquake on the fault zone associated with the North Panama Deformed Belt, at a slant distance of 35 km, be used in the analysis and evaluation of the dam. The Board anticipates that this event will dominate the results of the analysis.

By considering possible earthquakes from source zones 2 and 3 in a probabilistic context the anticipated frequency of occurrence will also be taken into account. The frequency of occurrence for earthquakes in source zone 2, with an estimated recurrence interval of 10,000 to 20,000 years, is sufficiently low that such earthquakes would not be considered by the international standard of practice for seismic safety analysis of an existing dam. The Board recommends this source zone be eliminated from further consideration. In source zone 3, earthquakes are postulated to occur on several possible faults, possibly including currently unknown faults, throughout the northern Canal Zone and adjacent regions. The Board recommends that the USGS be requested to provide, as a part of its final report, a probabilistic seismic hazard curve for ground motions at the dam site resulting from this set of possible earthquakes. Standard of practice indicates that ground motions corresponding to a return time of 5000 years are appropriate for use in evaluating the dam. The Board also recommends that the USGS be requested to provide in its final report a discussion of the relevant aspects of the recent earthquakes in Costa Rica, specifically the 1991 Limon, earthquake.

The Board would like to reach an adequately documented conclusion as soon as possible on the appropriate ground motions and specific accelerograms to be scaled and used in the evaluation. The ground motions considered to date provide a significant start on this effort. However, the Board recommends that a task force composed of PCC, USGS and CoE staff be formed to consider and recommend a specific suite of ground motions for use in the evaluation. The task force should also provide ground motions adequate to perform a sensitivity analysis of the evaluation of the dam as a function of the magnitudes of the controlling earthquakes. This will be needed to assess the vulnerability of the facility to lesser earthquakes. These ground motions need to be site specific and based on the results of the local and regional geological and seismological studies, as well as the engineering/analytical aspects associated with this study. These recommendations should be contained and documented in a report that describes the rationale for their selection and in addition recommends the manner and conditions for the introduction of the ground motions in the evaluation using the program SHAKE and other dynamic analysis programs.

Special attention should be paid to the transference of the Siquirres record (Limon earthquake) to the rock conditions at Gatun.

4.3 Site Characterization

The Board believes that all field and laboratory test data need to be assembled and integrated, and then used to produce idealized cross sections thru Gatun Dam. This information includes boring logs, Standard Penetration Test (SPT) N values, Cone Penetration Test (CPT) results, shear wave velocity (Vs) profiles, and laboratory test results. While developing these cross sections, the data need to be continually checked and cross checked for consistency and, when inconsistencies occur, weight should be given to laboratory test results and boring-log data.

Cross sections should be developed using CoE protocols available on Intergraph facilities.

Results of investigations to evaluate the shear wave velocities (V_s) as a function of depth at five sites along three cross sections of Gatun Dam and both sides of the spillway were presented. The results indicate that the hydraulic fill has V_s values averaging about 190 mps with a standard deviation of about 24 fps. The Atlantic Muck has similar values, averaging about 220 mps $\pm$ 48 mps.

Rock was encountered under Gatun Dam at depths ranging from 12 to 76 m. The rock is of variable character and has V_s values ranging from 245 to 520 mps for weathered or highly fractured rock to 520 to 1000 mps for sound rock.

The Board believes that use of these seismic velocity values will be adequate for the analysis.

Cone Penetration Test (CPT) results were obtained for several cross sections at Gatun dam. These data were used to preliminarily characterize the material in these sections. The data were further processed to develop cyclic resistance ratio (CRR) profiles. The Board suggests that the results of this work be carefully compared to cross sections independently developed at more or less the same locations using boring-log information. The applicability of these cross sections needs to be further evaluated after these comparisons are made.

4.4 Laboratory Characterization

Mr. Gustavo Guerra presented the results of the laboratory evaluation of Gatun Dam and foundation material. Specifically, results from index tests required for classification, results of triaxial, direct shear, and Bromhead ring shear tests, and the results of consolidation tests were presented. These results were obtained from material coming from 24 boreholes located along six cross sections across Gatun Dam.

The results indicate that the Atlantic Muck has an effective angle of internal friction of about 28^O and a cohesion intercept of 16 kpa. The hydraulic fill material has a similar effective angle of internal friction (27^O) and a cohesion intercept of 21 kpa. The undrained strength obtained from results of quick triaxial tests are about 5 kpa for the hydraulic fill material and range from 4 to 54 kpa for Atlantic Muck.

The Board believes the index test results are sufficient to use in screening the material for liquefaction susceptibility using the "Chinese Criteria". The Board recommends that the "Chinese Criteria" be used as a first screening tool to evaluate liquefaction susceptibility in the cross sections constructed in (4.3), above. The Board recommends that a catalog of existing samples be developed, such that, if additional laboratory data are needed, further testing could be initiated in an efficient and timely manner.

4.5. Liquefaction Analysis

After the site ground motions, the idealized cross sections, and representative soil/rock properties have been developed and reviewed by the Board, analysis of liquefaction potential should proceed based on assessed liquefaction susceptibility. The cyclic stress ratios (CSR) can be determined using the computer program SHAKE for various locations in the dam. Input parameters for these analyses are available based on material characterization and the to be agreed upon earthquake motions.

The cyclic resistance ratios (CRR) can be determined for potentially liquefiable material from SPT and CPT values. The Board (Morgenstern and Marcuson) will ensure that the PCC has the latest literature outlining this process (Seed & Harder; Dobry & Baziar; Olsen; Fear, McRoberts & Robertson). This will allow a factor of safety against triggering of liquefaction (FS_L) to be developed for various locations in the dam. The Board reviewed the evaluation of the influence of confining stress on liquefaction resistance of cohesionless soils presented by Dr. Hynes of WES. The state of practice is to incorporate this influence into dynamic analysis using the factor $K\sigma$. Based on the results presented, the Board recommends the use of $K\sigma=1.0$ for initial calculations of the CRR values. Depending on the results of these initial analyses, $K\sigma$ can be reduced to some lower- bound value if appropriate. The results of this liquefaction evaluation should be used to estimate the pore pressure ratios (R_U) developed in the material as a result of shaking.

Where liquefaction is predicted to be triggered, post-liquefaction residual shear strength values need to be evaluated. The Board recommends the use of results from SPT's and CPT's and empirically developed charts for this evaluation. (Seed & Harder; Stark; Wride, et.al..; etc.). Again Board members (Morgenstern, Marcuson) will ensure that relevant literature is sent to the PCC. Where liquefaction is not predicted to be triggered in the cohesionless material, shear strength should be appropriately degraded (reduced) based on R_U values for initial stability evaluation. The Board recommends that the CPT data be processed and used to develop strength data for the cohesive material. After these strengths have been determined, the published literature should be used to appropriately degrade the strengths and stiffnesses as a result of seismic shaking.

Post-earthquake static slope stability analysis should be performed using these soil properties. After these stability analysis have been completed and evaluated, a deformation analysis can be conducted using a computer program such as FLAC. Such analysis will be helpful for forming judgements regarding the post-earthquake deformed shape of the dam and to estimate the extent of potential damage.

The Board is convinced that PCC has in-house talent and capability to perform these calculations and analyses. We were impressed with the work that was presented during this meeting. The Board presently has a more optimistic outlook regarding the seismic stability of Gatun Dam than that presented during this meeting. This is based primarily on our belief that PCC has made conservative assumptions and in some cases these conservative assumptions have been compounded during the analyses. It is because of these views that the Board proposes the serial process with review points proposed at intervals as outlined above.

4.6 Ancillary Structures

Preliminary results of a seismic analysis of the spillway and locks were presented to the Board during the meeting. These preliminary results are based on linear elastic assumptions, which may not be appropriate.

The Board recommends that PCC conduct a thorough review of its construction records to make a detailed assessment of the conditions at the foundation-structure interface at the locks and spillway. This interface is critical in the formulation of the boundary conditions needed for the dynamic structural response analysis. The Board recommends that an expert in dynamic analysis of concrete locks and spillways be retained to assist in guiding and reviewing the dynamic structural analyses. Names of possible experts were suggested during the meeting.

After a review of the interface condition and recommended boundary conditions to be used in dynamic structural response calculations, these calculations can proceed using appropriate linear and non-linear analysis techniques.

During the meeting the Board received no information regarding saddle dams that may exist at other locations along the rim of Gatun Lake. At a future meeting the Board requests that it be informed about the characteristics of these structures.

After completion of these analyses the Board, along with our structural colleague, will review the results and will be prepared to make recommendations regarding any potential remediation work that may or may not be required.

4.7 Study Sequence

The Board believes this investigation should proceed in a staged process. During Stage 1, the results of the field investigations should be plotted using standard CoE's plotting procedures so, that the result can be easily reviewed, correlated, and synthesized into idealized cross sections. This should be documented in a report and presented to the Board for review. In conjunction with this work, the site-specific ground motions need to be developed using a multidisciplinary approach. The report documenting the selection of ground motions needs to be prepared and presented to the Board.

The results of field investigations along with the results of laboratory index tests need to be combined with the Chinese criteria to eliminate consideration of material that is not prone to liquefaction susceptibility.

After this work in Stage 1 is completed, the Board wishes to review it. The outcome of this review process will be acceptance, subject to some modification as appropriate, and direction to proceed.

In conjunction with other Stage 1 work, construction records need to be reviewed to determine the foundation conditions at the base of the spillway and locks. This information needs to be synthesized and documented, so that the Board, during its first review, can help develop and formulate the boundary conditions to be used in the structural-response analysis. It is recommended that the structural reviewer be brought on board prior to this first review so that he/she can become familiar with the project and make contributions. In parallel, a report needs to be prepared documenting the characteristics on all saddle dams on Gatun Lake.

During Stage 2 the liquefaction assessment needs to be completed. This should be followed by a post-earthquake stability assessment and documented in a report. At this point the Board would like to review and approve the progress to date. The outcome of this review will likely be approval and possibly direction with regard to the permanent deformation analyses still remaining.

4.8 Commentary

As mentioned previously, the Board is greatly impressed by the capabilities developed by the Geotechnical Branch and the potential of the Branch to bring the study to a successful resolution. However, the Board recommends that decisions regarding possible remediation measures, if indicated, be based on an evaluation that is as realistic as possible. That is, the evaluation needs to be based on analyses and assumptions that are in accord with current international standards of practice, with appropriate, but not undue, levels of conservatism at each stage.

The Board believes that the capabilities and data required to meet these criteria are for the most part in hand, and is optimistic that the evaluation can be completed within the next 9 to 12 months.

Taking a long-range view, the Board observes that the PCC has made a considerable investment in the development of technical staff to perform this work. The Board urges the PCC to recognize the need to maintain this level of expertise and to augment it with the selective hiring of high quality young engineers and geoscientists as they become available.

5. SUMMARY

The Geotechnical Advisory Board met in Panama from July 13 through July 18, 1998, to review progress since the 7th Board Meeting in November 1996. The Board was impressed with the quantity and quality of the work accomplished since the last meeting, and compliments the personnel of the Geotechnical Branch on their accomplishments.

The Cut Widening Program has proceeded well, with 16 of the 18 projects now designed and completed or under construction. Some stability problems have developed as the slopes were excavated, most notably at West Empire and Hodges Hill. The Board believes that these projects were properly designed, and concurs with the plans that have been developed to stabilize these slides. Gold Hill has experienced one significant rock-slide during excavation , and will continue to require detailed attention for safe and timely completion of the project.

The Landslide Control Program continues to play an extremely important role in preventing expansion of slope instabilities into major problems that would be very costly to remediate. The importance of the Landslide Control Program is of special significance for the newly excavated Cut Widening Project areas.

The study of the seismicity at the Gatun Dam site has been completed, and provides a sufficient basis for establishing ground motions for use in analysis. The Board recommends that this be accomplished by a team effort including PCC, USGS and CoE/WES personnel.

The Board recommends a series of steps leading to the final seismic evaluations of Gatun Dam, Gatun spillway, and Gatun locks beginning with the selection of the ground motions. The Board recommends that a structural engineer experienced in seismic analysis of concrete hydraulic structures be retained to guide and review the evaluation of the spillway and the locks.

The Board recommends that two interim teleconferences or meetings be held to review progress at critical stages of the work. The next full meeting of the Board is anticipated for June 1999, by which time when it is expected that all of the seismic evaluations will have been completed.

6. UPCOMING MEETINGS

As noted above, over the next several months the Board plans to review interim reports issued by various teams in response to our requests. These review activities can be conducted most efficiently and inexpensively by mail, telephone conference calls, or one to two day meetings at low-cost destinations in the United States. The next formal, full-scale meeting of the Board should be scheduled to occur after the seismic analysis of Gatun Dam and ancillary structures has been completed, a time estimated to be at least 9 months from now. We recommend that this one-week review meeting be held in Panama in June 1999, and we suggest the week of June 6-12. This meeting will be devoted primarily to review of the seismic stability of Gatun Dam and ancillary structures. At conclusion of the meeting, the Board plans to make recommendations as to possible need for remedial measures. Discussions will also be held on the long-term effects of Cut Widening and on the status of reinstatement of the Landslide Control Program.

Mr. T. W. Drohan, July 18, 1998
Subject: Geotechnical Advisory Board, Meeting No. 8

James M. Duncan

Robert L. Schuster

Norbert R. Morgenstern

Robert L. Wesson

William F. Marcuson III

Enclosures:

Attachment A

ATTACHMENT A

Agenda for the 8th Geotechnical Advisory Board Meeting (July 13-18, 1998)

July 13:
Part I: Cut Widening and Landslide Program

8:00 - 8:45	Overview of the Geotechnical Branch Activities in FY 97 & 98 (De Puy)
8:45 - 9:45	Gold Hill - CWP-14 (De Puy, Arrocha)
9:45 - 10:00	Break
10:00 - 11:00	Escobar - CWP-16 (Rivera, Franceschi)
11:00 - 12:00	Contractor's Hill - CWP-15 (Cortizo, Franceschi)
12:00 - 1:00	Lunch
1:00 - 2:00	West Empire Hill Reactivation Slide (Reyes, Franceschi
2:00 - 3:00	Hodges Hill Reactivation Slide (Garcia, Franceschi)
3:00 - 4:00	Cartagena - CWP17 -Preliminary Design (Garcia)
4:00 - 4:30	Discussions

July 14:

8:00 - 8:30	Travel from Adm. Bldg. to Las Cruces Landing
8:30 - 11:00	Boat Ride through Gaillard Cut
11:00 - 1:00	Land visit to Gaillard Cut Projects
1:00 - 2:00	Lunch
2:30 - 3:00	Summary of the Landslide Control Program in FY 97 & 98 (Reyes, Fernandez)
3:00 - 4:00	Discussions on Performance of Excavated Slopes

July 15:
Part II: Gatun Dam Seismic Study

8:00 - 10:30	Summary of work done by WES (presented by WES personnel)
10:30 - 10:45	Break
10:45 - 12:30	Summary of work done by USGS (presented by USGS personnel)
12:30 - 1:30	Lunch
2:00 - 3:00	Summary of Laboratory Work by PCC (Guerra, Rivera)
3:00 - 4:00	Discussions

July 16:

8:00 - 10:00	Summary of Dynamic Analysis of Gatun Spillway and Locks (Abrego)
10:00 - 10:30	Break
10:30 - 12:30	Summary of Liquefaction Analysis using most recent data (Rivera, Cortizo)
12:30 - 1:30	Lunch
1:30 - 3:30	Summary of Post-earthquake and Large Deformation Analysis (Abrego)
3:30 - 4:30	Period of Questions and Answers (round table)

July 17:
Part III: Report Preparation

8:00 - 9:00	Period of Questions and Answers (continuation)
9:00 - 3:00	Begin GAB Report
3:00 -4:00	Meeting with the Director of Engineering and Industrial Services

July 18:

8:00 - 4:00	Finish GAB Report

PANAMA CANAL COMMISSION

BALBOA
REPUBLIC OF PANAMA

U.S. MAILING ADDRESS:
UNIT 2300
APO AA 34011-2300

September 4, 1999

Mr. T.W. Drohan
Engineering and Industrial Services Director
Panama Canal Commission
Balboa Heights, Republic of Panama

Dear Mr. Drohan:

Re: Geotechnical Advisory Board, Meeting No. 9

The 9th Meeting of the Board took place in Panama from August 30 – September 4, 1999. The schedule for the meeting is included as Attachment A. The Board appreciates the opportunity of meeting with the following people and briefing them on its observations and preliminary recommendations prior to the completion of this report:

Mr. T. W. Drohan, Engineering and Industrial Services Director

Dr. Luis D. Alfaro, Manager, Engineering Division

Mr. Maximiliano De Puy, Manager, Geotechnical Branch

In addition to meeting with the staff of the Geotechnical Branch, the Board received a presentation on the preliminary seismic analysis of the spillway at Gatun Dam from Professor Anil K. Chopra of the University of California, Berkeley. Professor Chopra and Dr. Robert L. Hall of the U.S. Army Engineer Waterways Experiment Station (WES) participated in the Board's discussion of the issues related to the spillway on August 30.

The Board was briefed on the progress of the Cut Widening program (CWP) and the status of the Landslide Control Program (LCP). The dry excavation portion of the CWP is nearing completion and the marine portion is more than half completed. A contract for the final project of dry excavation, that at Cartagena, has been awarded. The Commission and the Geotechnical Branch are to be congratulated on the progress and success of the CWP to date, as this massive project has progressed in a timely, cost effective and safe manner. In the following, the status of the CWP will be summarized with particular attention given to issues related to the design at Cartagena, problems at Model Slope, field observations made by the Board, and the geophysical observations in the Canal at the toe of Gold Hill.

The Landslide Control Program (LCP) continues to be an integral part of the responsibilities of the Geotechnical Branch. The current status of the Program was presented to the Board and will be reviewed in the following.

The Board focused considerable attention and effort on the Gatun Dam Seismic Study (GDSS). Selection of earthquake ground motions, characterization of the dam embankment, analysis of the possible liquefaction in the embankment during earthquake loading, and analysis of post-earthquake deformations were presented by the staff of the Geotechnical Branch and discussed by the Board. A detailed commentary on these issues is contained in the following. In general the Board is very impressed with the increase in the level of expertise shown by the staff of the Geotechnical Branch in these analyses.

Based on the experience of the GDSS to date, the Board has come to the view that the seismic analysis of the Gatun Dam should be considered as only one component in an overall seismic risk analysis of the operations of the Canal. Recommendations to this effect are included in the following.

The Board viewed the CWP in the Gaillard Cut by boat and inspected on foot monuments showing recent movements on the Cucaracha South Extension Slide. During the field excursion, the Board was particularly impressed with the success to date of the excavation at Gold Hill.

A quite considerable effort went into preparing and delivering presentations to the Board by Mr. De Puy and the staff of the Geotechnical Branch. The Board wishes to recognize the quality of these presentations, which contributed enormously to its effective operation.

This report consists of observations, comments and recommendations under the following headings:

1. Progress on Recommendations of the 8th Meeting of the Board.
2. Cut Widening Program (CWP)
3. Landslide Control Program (LCP)
4. Gatun Dam Seismic Study (GDSS)
5. Seismic Risk Analysis

6. Summary

7. Next Meeting

1. PROGRESS ON RECOMMENDATIONS OF THE 8TH MEETING OF THE BOARD

The 8th Meeting of the Board, held from July 13-18, 1998, concentrated on the GDSS. In addition, a number of CWP design and construction-related issues were considered and the status of the LCP was assessed.

With regard to the LCP, the Board emphasized the need to fully re-institute all LCP measures as a continuing, long-term effort to be phased in with completion of the CWP. The Board is pleased to note that this has become PCC practice.

Recommendations were made with regard to design and construction on several of the CWP contracts, particularly Gold Hill. Subsequent practice has generally been in conformance with these recommendations, at least for major issues. The CWP is almost completed and performance has generally been good. Critical wet excavation remains and careful monitoring is needed to completion.

The GDSS is progressing in an iterative manner and at the last meeting the Board outlined in detail a number of activities, including evaluation of data and calculations, that are required to advance the study. These have been completed prior to the 9th Meeting.

In general, the Board is content that the recommendations arising from the 8th Meeting have been adopted in an acceptable and reasonably complete manner.

2. CUT WIDENING PROGRAM

2.1. General

At the time of this meeting, 17 of the 18 Cut Widening projects have been designed. Project No. 17 (Cartagena) has been awarded. Project No. 18 (The Tie-up Station) cannot be designed until the plans for the Tie-up Station are complete.

About 94% of the 22.3 million m^3 of dry excavation has been completed, 76% of the drilling and blasting for underwater excavation has been completed, and 57% of the underwater excavation has been completed.

Accomplishing this improvement of the Canal in a period of 8 years has been a very significant achievement, and the Board commends the personnel of the Geotechnical Branch for their effective work on this program.

As the marine excavation continues, the stability of the slopes in the affected reaches will be reduced, and it must be anticipated that some slides will take place as a result. It is important that the EDM network be re-established as quickly as possible following the dry excavation, and that ground surveillance be pursued diligently, to minimize the extent and consequences of these slides.

1.2 Field Observations

Excavation of a portion of Gold Hill represents a singular major accomplishment of the Cut Widening Program. Rock bolting has been effective in stabilizing the steep excavated faces in areas where the quality of the rock and the orientations of joints were adverse. Continued raveling of these slopes is to be expected, however. To prevent dislodged boulders from bouncing into the Canal, or onto passing ships, the Board recommends that a mesh be installed, draping across the slope at the northwest and southwest corners of the excavated face, where raveling and dislodged boulders are most likely. The mesh will not prevent raveling, but will restrain the dislodged rock, and will improve safety.

Many small slides have occurred, and are continuing to occur, in the Las Cascadas Formation along the west side of the Canal in the Bas Obispo reach north of the Borinquen Slide. The heads of these slides are on the low bank, and the toes of the slides are below water. The regression of the canal bank that has resulted from these slides in as much as 4 m and has damaged lights, and threatens power poles. The slide material has not entered the canal prism. Whether these slides are caused by over-steep underwater excavation, or by underwater erosion due to waves or propeller wash, is not clear. Until the cause is identified, an effective remedy cannot be designed. The Board recommends that hydrographic surveys be made to develop underwater cross sections in this area as soon as possible, and that further surveys be made periodically to investigate the morphology of these slides.

2.3 Cartagena

The Board was briefed on the design of Project No. 17 (Cartagena), which has been awarded. This is a difficult area, involving five separate landslides – the Cartagena Extension Slide, the Cartagena Slide, and the Cartagena Mudflow Slide, the Upper Cartagena Slide, and the Cartagenita Slide. It has been difficult to achieve the objective of designing the slopes so that the computed factors of safety increase as a result of the excavations required for cut widening in this area. The Board is concerned that the underwater excavation in this area may result in slides if the underwater slopes are steeper than intended, as has been the case in other areas. The Board recommends that a comprehensive surveillance program be followed during the excavation, particularly during the underwater excavation.

2.4 Gold Hill Geophysical Surveys

In an attempt to define possible tectonic deformation in the vicinity of Gold Hill, a contract was let with the U.S. Geological Survey in 1997 to conduct land and marine high-resolution seismic reflection profiling in the Gaillard Cut. The goal was to image the major landslides and underlying strata along the edges of the Canal. Two sets of profiles were collected: a series of three marine seismic reflection profiles parallel to and perpendicular to the channel and seven land profile on various landslides on the vicinity of Gold Hill. The land profile consisted of short seismic lines that were oriented perpendicular to the canal, running up or down the slides. The goals of these studies were to determine if this technique could detect slide activity, faults, folding, or warping beneath the Canal that might be associated with possible major movements near Gold Hill. In some slide areas, particularly at the Cucaracha slide, the technique was successful in imaging the slide (i.e., failure) surface. In other areas, the results were less definitive.

In particular, the results from the profiles beneath the Canal do not identify any features that increase the Board's concern regarding the stability of Gold Hill.

2.5 Model Slope

Model Slope (so named because it did not fail during Canal construction) began to show movement before widening was begun. Horizontal drains, installed in 1992, were effective in slowing or stopping these movements. Due to earthwork in this area, these drains have been lost, and they are no longer functional. During this past year one of the EDMs in this area has moved about a meter, with a large increment in December 1998. The dry excavation has been completed, but the underwater excavation has not. One set of slope stability analyses indicates that the profile after excavation will have a smaller factor of safety than the profile before excavation. Another set of analyses indicates that there will be no change in factor of safety as a result of the cut widening excavation.

The Board is concerned that the loss of the horizontal drains has made the slope less stable, and that the movements during the past year may portend a significant slide. We recommend that horizontal drains be re-established in this slope, penetrating the lower fault, as did the earlier drains. They should be installed as soon as possible and prior to the excavation. In addition, we recommend careful surveillance in this area during the underwater excavation, and rapid remedial action if signs of impending failure are noted, because analyses indicate that the shear strength of the Cucaracha Formation has not been reduced to residual in this area. A slide with sufficient displacement to reduce the shear strength to residual would result in a much worse condition than currently exists. In the extreme it could impinge on the navigation prism.

3. LANDSLIDE CONTROL PROGRAM

3.1 The components of the Landslide Control Program are

(1) field inspections, (2) monitoring of surface movement by means of EDM's, (3) subsurface instrumentation consisting of: a) open wells, b) horizontal drains, c) individual piezometers, and d) multi-point piezometers, (4) drainage maintenance, (5) road maintenance, and (6) design of remedial measures.

The current status of these components and suggestions for improvements are as follows:

(1) Field Inspections

In the interest of economy, field inspections of Gaillard Cut slopes are not on a fixed schedule, which would be extremely costly. Instead, inspections of specific slopes are conducted as needed, based on information from instrument observations and from maintenance personnel, and on the occurrence of heavy rainfall. Especially noted in the inspections are tension and shear cracks, local hummocky topography, impaired drainage and roadway facilities, and newly active seeps and springs. These inspections should continue to be made for the life of the canal.

(2) Monitoring of Slope Surface Movements

As of July 1999, the EDM system monitored movement of approximately 350 EDM survey points on Gaillard Cut slopes, an increase of about 60 points since our last report in July 1998. The surface movement data obtained by this system are extremely valuable for delineating slopes in need of mitigation. In the past couple of years, locations of selected important (i.e., "master") EDM survey points have begun to be checked by GPS (Global Positioning System), a method that may be prove to have accuracy comparable to that of the EDM procedure, but is less expensive to operate. At present, however, the comparisons between EDM and GPS values in the Gaillard Cut present large enough discrepancies that the comparisons can still be considered to be in the research phase. The Board notes that different degrees of resolution are needed with the LCP and recommends that the PCC continues with the GPS comparisons to determine the range of appropriate applications.

(3) Subsurface Instrumentation

As of July 1999, the Landslide Control Program included the following numbers of subsurface instruments on Gaillard Cut slopes: open-well piezometers, 91; Casagrande piezometers (clusters), 1; electro-piezometers (clusters), 12; multi-point piezometers, 11. In addition, 21 horizontal drains were added between July 1998 and July 1999.

The only continuous readings that have been made by the above instruments were for a few of the multipoint piezometers for certain periods of time. The Board recommends that these continuous records be maintained and studied in order to correlate rainfall patterns with rise and fall of piezometric levels and efficiency of drainage measures.

(4) Drainage Maintenance

Drainage maintenance includes the recording of incidents for which surface or subsurface drains have required maintenance. This information can be used to help recognize or predict landslide activity.

(5) Roadside Maintenance

Requirements for road maintenance should be noted as a possible indication of active or impending landslide activity.

(6) Design of Remedial Measures

If actual or impending slope movements are noted by one or more of the above methods, remedial measures, such as avoidance, changes in slope geometry, surface and/or subsurface drainage, restraining or anchoring structures, or vegetation can be used to mitigate slope movements and to prevent possible failure.

3.2 Active Sectors in the Gaillard Cut

The following sectors continue to be active: Cucaracha South Extension, Northeast Culebra, South La Pita, Model Slope, and Borinquen.

Cucaracha South Extension -- Shows the most significant movement of current slide areas. Between 1993 and July 1999, maximum EDM movement on the South Cucaracha slide has been 934 mm. Significant tension cracks and scarps have developed at the head of the slide during this period. The velocity of movement from May to July 1999 was as much as 52 mm/month. The height and volume of this slide combined with its recent movement indicate that it should continue to be carefully monitored.

Model Slope - - Has moved about 40 cm in the past year. If no remedial measures are undertaken, additional movement is foreseen as excavation of the toe of the slope takes place under the Cut Widening Program. For this reason, plans are being made to unload the head of the sliding area and to install horizontal drains (see Section 2 Cut Widening Program).

Northeast Culebra - - Slide developed in December 1998 due to heavy rain. Temporary excavation by in-house PCC forces mitigated the slide. A permanent excavation of 80,000 m^3 for planned stabilization is out for bids.

South La Pita - - This slide was caused by cut widening. It was most recently reactivated on August 10, 1999. An excavation of 150,000 m^3 under the same contract as the Northeast Culebra remediation is planned for stabilization.

Borinquen - - Slide occurred in June 1997 after both dry and wet excavation were complete, probably as a result of oversteepened underwater slopes and ponded water at the head of the slide that has now been drained. A contract has been awarded to stabilize the slope by excavation of 36,000 m^3.

3.3 New/Additional Efforts in Monitoring

Unlike the Cut Widening and Gatun Dam Studies, which will be completed within a few years, the Landslide Control Program should be considered to be a long-term effort involving the following:

(1) Continuing installation and maintenance of new monitoring instruments.

(2) Continuing cooperation between the Geotechnical Branch and the Surveys Branch.

(3) Development and implementation of a more efficient reporting and recording system to manage the data base. This should include continuous recording of data from the more important of the multipoint piezometers. The Board feels that telemetering of data is not desirable because it will reduce field inspection, a necessary function.

(4) Correlation of instrument data with rainfall intensity, duration, and amount.

3.4 Development of a Protocol for Response to Landslide Activity

Thus far, efforts on landslide prediction and prevention in the Canal Zone have dealt primarily with slope design for protection of the shipping prism from intrusion by slide material. Little effort has been dedicated to evaluation of long-term risks, to study of consequences and relative costs, to planning for emergency response efforts, and to environmental effects in the Canal Area and the Republic of Panama.

A high priority should be given to developing long-term operating plans (i.e., an operational protocol) that interrelate these factors and their relationship to the landslide characteristics (e.g., size, velocity, run-out distance, etc.) and climate factors that have thus far been determined. Of particular value will be risk and emergency-response plans for important elements of the Gaillard Cut, such as those slopes that have shown movement. The Board recommends that the Geotechnical Branch develop a draft policy covering practice and design criteria to be considered at the next meeting of the Board. Toward this end a brief paper prepared by Professor Duncan is included as Attachment B.

4. GATUN DAM SEISMIC STUDIES

4.1 Design Earthquake Ground Motions

At the 8th Meeting of the Board evidence was presented for three earthquake source zones capable of potentially affecting Gatun Dam. The Board recommended that the first of these source zones, a magnitude 7.7 earthquake at a distance of 35 km and with a recurrence interval of 330-1,000 years, be considered in a deterministic context; that is, that the dam be required to maintain the reservoir after being subjected to reasonably expectable ground motions from such an event. The Board anticipated that this event would dominate the results of the analyses. The Board further recommended that the second and third source zones be considered in a probabilistic context, that is, by also taking the anticipated frequency of occurrence into account. The estimated frequency of occurrence for earthquakes in the second zone, 10,000 to 20,000 years, is sufficiently low that such earthquakes would not be considered by the international standard of practice for the seismic safety analysis of an existing dams, and this source zone was eliminated from further consideration. The Board recommended that a probabilistic seismic hazard curve be prepared for possible ground motions at the dam site from the third source zone.

A workshop was held January 11-12, 1999, at the Waterways Experiment Station (WES) to discuss design ground motions. The workshop included attendees from the staff of the PCC Geotechnical Branch, the U.S. Geological Survey (USGS), as well as WES staff. Following that workshop, a report was prepared by Dr. William B. Joyner, of the USGS, recommending design ground motions for use in the seismic evaluation of the dam.

Joyner considered ground motions from the 1985 Michoacan, Mexico, and 1985 Valparaiso, Chile, earthquakes as representing sources analogous to the first source zone. Joyner argued that the data from the Mexican earthquake were biased on the low side. He recommended use of an attenuation relationship modified after Midorikawa based on the Chilean data alone. The relationship yields median and 84th percentile values of peak ground acceleration of 0.313 g and 0.544 g, respectively, at a distance of 35 km on rock for rupture propagation toward the site. The Board accepts these values as a basis for a conservative analysis of the dam. Joyner further recommended several records from the Chilean earthquake for use as input in the evaluation. The Board accepts these recommendations, scaled to the values given above, as a basis for the analysis.

While the Board is generally satisfied with the ground motions described above, two issues remain to be addressed, although the Board does not anticipate that they will significantly affect the final results for the dam. First, the Board recommends that the Siquirres ground motion record from the 1991 Limon, Costa Rica, earthquake, deconvoluted to 0.444 g to represent the response of a rock site, then scaled to the 84^{th} percentile value of 0.544 g be included among the records used in the analysis. The Board makes this recommendation because the Siquirres record is the most significant ground motion recorded within the region of the dam site, and notes that the peak values from this recording fall within the family of observations from the 1985 Chilean earthquake. Secondly, the Board notes that the probabilistic seismic hazard curve for ground motions at the dam site from the third source zone, including nearby but smaller earthquakes, has not been completed. The Board recommends that this work be brought to conclusion for use as a check to assure that the ground motions from the first source zone do indeed dominate the analysis.

4.2 Gatun Dam

The Board reviewed the progress to date regarding the seismic stability assessment of Gatun Dam and is pleased with progress made since the last meeting. The stability assessment involves the following steps.

1) A determination if potentially liquefiable material in terms of the modified Chinese criteria.

2) The calculation of the cyclic shear stress-making use of the prescribed ground motion, shear wave velocity observations, soil description and WESHAKE computation.

3) The calculation of the cyclic resistance ratio based on SPT tests, the Seed–Tokimatsu relations, and various correction factors.

4) The calculation of the factor of safety after the earthquake by means of limit equilibrium analysis, using appropriate soil strength for undrained failure.

5) The calculation of the post-earthquake deformations using strength and stiffness degraded as appropriate.

In the following the Board discusses each step separately.

The Board has noted that the modified Chinese criteria have been used in an inconsistent manner. Often material characterized as SM has been taken as liquefiable when in fact it is not regarded as so. Therefore the Board recommends that the modified Chinese criteria be adopted in a stricter manner. Details have been transmitted verbally. When constructing cross sections for purposes of stability and deformation analysis, there has been a tendency to join zones based on soil classification data. The Board believes that this does not properly recognize hydraulic fill construction techniques, which result in heterogeneous deposits and is of the view that zonation should be biased to the horizontal. This will result in more lenticular and discontinuous zonation.

The Board agrees with the methods adopted for correlation V_s distribution with N values across the site and agrees with the results of the CSR analyses insofar as they are complete. Additional calculations are needed for the scaled Siquirres record.

The Board accepts as conservative the calculations of CRR using Seed – Tokimatsu and the Seed – Harder Kσ(SIGMA) relation. All other corrections adopted reflect widely accepted practice for the magnitude of earthquake in these analyses. The Board notes that some low N values are evidently sample disturbance (see boring GDI-3. Samples 24 and 27, Section C) and borehole interpretation should eliminate the use of such data.

To calculate the factor of safety after the earthquake the Board accepts the use of $N1_{60}$ (clean sand) data correlated to Su/σv'- as per Mesri-Stark. Typically a range from 0.04 to about 0.1 or more is anticipated. For non-liquefiable material the Board recommends a Su/σv' = 0.4 with a 20% reduction for cyclic and structural effects. For potentially liquefiable material that is not triggered to liquefaction the Board recommends Su/σv' = Su(peak)/σv', when $r_u = 0$, and Su/σv' = Su/σv', when $r_u = 1$. The Board recognizes that this is conservative.

The Board recommends that post earthquake deformations be calculated uncoupled from the earthquake loading. The same strength parameters used in the stability analysis should be used here. Moreover the Poisson's Ratio should be increased about 0.48.

The Board looks forward to the results for this next iteration of the analysis.

The Board welcomed the additional contribution to this problem from the laboratory studies but notes that the cyclic stress tests do not adequately mimic earthquake loading to be directly applicable.

The Board would be pleased if in the future all cross sections and borings logs clearly showed:

1. The foundation dam interface

2. The phreatic surface

3. A vertical and horizontal scale, and

4. Top of rock if appropriate.

The Board also notes that in some slope stability calculations the critical circle was not tangent to the stronger lower layer. This generally indicates that a finer grid for the center of the circle is needed in order to calculate the minimum factor of safety.

4.3 Ancillary Structures

The ancillary structures include the spillway, locks and saddle dams. So far only the saddle dams and spillway have received detailed attention.

PCC staff have identified the El Caño Saddle Dam as being the most significant saddle dam and have subjected it to a liquefaction evaluation using the same methodology as that developed for Gatun Dam. The history of the structures was reviewed. Four borings were performed to obtain samples for characterization. Pre-earthquake and post-earthquake stability analyses were undertaken.

The dam developed cracks in 1933 that were suggestive of instability and repairs were carried out. Details of what was done are not available. The Board recommends that new topography be obtained to compare with the pre-slide topography that is available. The static factor of safety in the downstream direction is in excess of 2 indicating adequate stability at this time. It is conceivable that the cracks that developed in 1933 were not related to potential shear instability.

Preliminary post-earthquake stability analyses conducted by PCC staff indicate factors of safety less than unity, symptomatic of potential loss of containment. In this analysis, material classified as SM has been taken as potentially liquefiable. On detailed review of the boring logs, the Board noted that none of this material is potentially liquefiable in terms of the modified Chinese Criteria adopted from the GDSS. The Board is of the view that the El Caño Saddle Dam is not potentially liquefiable and that post-earthquake movements will not result in loss of containment. Some slip and cracking in event of a severe earthquake are to be anticipated.

Possible failure modes of the spillway include sliding along the base and by earthquake induced cracking in the concrete, affecting gate operations.

PCC Staff has reviewed the construction of Gatun Spillway; they have cored the concrete and rock interface and have conducted strength tests on the concrete. These investigations have been of a high quality and they provide valuable information for the stability assessment.

Under the direction of the Board, a two-dimensional sliding analysis of the spillway was formulated. Preliminary calculations indicate that displacements of a few cm and recognizing the additional three-dimensional restraints associated with sliding and the extra resistance that arises from drainage beneath the apron, the Board is of the view that failure by sliding is unlikely. PCC should assemble the results of this analysis in a report for review. The sensitivity to high acceleration local earthquakes should be checked and drainage holes should be put into the apron if they are not already there.

Stress analyses of the spillway have been conducted under the guidance of Professor A. Chopra and Dr. Robert Hall (WES). These analyses have assumed that the spillway is firmly coupled to the foundation. As noted above, it has now been shown that sliding does not control and therefore this assumption is correct.

The results of the stress analysis of the concrete structures have been reviewed independently by Professor A. Chopra and further studies have been recommended. The Board anticipates that cracking of the concrete piers under the design ground motions will be predicted and the implications on spillway operations will have to be assessed in due course.

5. SEISMIC RISK ANALYSIS

The GDSS may be considered to be one component of an overall seismic risk assessment. At this time the Board anticipates that the completed GDSS will demonstrate that loss of containment of Gatun Lake due to major movements of either of Gatun Dam or ancillary structures is unlikely. Damage to the narrow piers on the spillway is likely under the design ground motion.

Notwithstanding the outcome of various analyses, a number of damage scenarios can be anticipated that are not amenable to analysis. For example, cracking might occur at the dam-spillway interface, followed by internal erosion. If this potential failure mode is likely (and it has not been assessed yet) prudent practice would require the adoption of some mitigative measures. Other examples that might impede PCC operations can also be identified. The behavior of the locks, towers, communication systems power supply and Gold Hill come to mind.

So far, the seismic risk analysis has been driven by geotechnical considerations and now structural assessments, such as for the spillway, have been initiated. Each set of assessments will eliminate concern over some potential failure modes but will likely identify others.

The Board does not believe that it is in the best interest of the PCC to develop a response plan to the identified issues on a piece-meal basis and recommends that the PCC initiate a system-wide seismic risk analysis. This need not be a complex undertaking.

The seismic risk analysis should ask the following questions:

i) What potential failure modes could seriously disrupt the operation of the PCC?

ii) How do we analyze their likelihood?

iii) What actions should we take to mitigate those that have been identified as likely?

The GDSS obviously is focussed only on the loss of containment of Gatun Lake.

The first step in the risk analysis is the identification of potential failure modes. They may arise not only from inadequate geotechnical or structural performance, but also from mechanical, electrical, hydraulic, communication or other failures that dominates system operations. In the view of the Board, the potential failure mode analysis is best undertaken by PCC staff, assisted by an external facilitator, familiar with risk analysis procedures. Such a facilitator may be found in corporations that perform seismic risk analysis. Possible failure modes of facilities at the Southern end of the canal should be considered in the light of possible seismic sources in that region.

Following on from this potential failure mode analysis, the PCC would be better informed to develop an appropriate strategy to undertake the relevant analyses and evaluate mitigation measures. This could involve a modified and expanded Advisory Board or a series of Boards depending upon the identified needs.

6. SUMMARY

The Geotechnical Advisory Board met in Panama from August 30-September 4, 1999. The Board was impressed with the quantity and quality of the work accomplished since the last meeting, and compliments the personnel of the Geotechnical Branch on their accomplishments.

The Cut Widening Program has proceeded well. The modest stability problems that have arisen have been addressed appropriately. The remaining excavations, at Cartagena and within the canal, require particular care and diligent monitoring.

The Board is pleased that the Landslide Control Program has received renewed emphasis and encourages continued monitoring. The Board recommends development of a draft policy on practice and design criteria for remedial measures for landslides.

The Gatun Dam Seismic Study is nearing completion. The primary tasks remaining are a careful and diligent application of all the agreed criteria and synthesis of the component parts of the analysis. It is also important that final reports be prepared for review documenting the characterization of the dam, the analysis procedures and the final conclusions. The Board looks forward to concluding this study at its next meeting.

As discussed above, the Board recommends that the PCC undertake an overall seismic risk analysis, to provide a context for risk management decisions, including those arising from the Gatun Dam Seismic Study.

7. NEXT MEETING

The Board anticipates the need for a meeting in about one year. Topics to be addressed include completion of the Gatun Dam Seismic Study, overall seismic risk analysis, policy for remedial measures for landslides, and other topics at the option of the PCC.

James M. Duncan

Robert L. Schuster

Norbert R. Morgenstern

Robert L. Wesson

William F. Marcuson III

Attachment A

Attachment B

Mr. T. W. Drohan, September 4, 1999
Subject: Geotechnical Advisory Board, Meeting No. 9

ATTACHMENT A

Agenda for the 9th Geotechnical Advisory Board Meeting
(August 30 to September 4, 1999)

DATE	TIME	ACTIVITY	SPEAKER
30-Aug		**Special Session on Gatun Spillway**	
	8:00 AM	Travel from Hotel to Adm. Building	R. Lam
	8:30 AM	Prof. Chopra Meeting with The Director of Engineering and Industrial Services	
	9:00 AM	Introduction	M. De Puy
	9:30 AM	Design Earthquake for the Evaluation of the Seismic Stability of Gatun Dam (Summary of USGS Study)	A. Abrego
	10:00 AM	Concrete Sampling Program and Geological Characteristics of Rock Foundation	P. Franceschi
	10:30 AM	Concrete Testing Program and Engineering Properties of Rock Foundation	G. Guerra
	11:00 AM	Response Spectrum Design for Gatun Spillway Simplified Analysis of Gatun Spillway (2D)	A. Abrego
	12:00 PM	Lunch Break	
	1:30 AM	3D Analysis of Piers of Gatun Spillway	A. Abrego
	2:30 PM	Period of Questions and Answers (round table)	
	4:30 PM	Travel from Adm. Bldg. To Hotel	R. Lam
		Part I: Cut Widening and Landslide Program	
31-Aug	8:00 AM	Travel from Hotel to Adm. Building	R. Lam
	8:30 AM	Overview of the Geotechnical Branch Activities in FY 99	M. De Puy
	9:00 AM	Summary of the Landslide Control Program in FY 99	C. Reyes
	10:00 AM	North East Culebra	C. Reyes
	10:15 AM	South La Pita	J. F. Garcia
	10:30 AM	Borinquen Slide	M. Barrelier
	12:00 PM	Lunch Break	
	1:00 PM	Design of Cut Widening Projects: CWP-17, Cartagena	J. F. Garcia
	2:00 PM	Discussions on Performance of Excavated Slopes	
	4:30 PM	Travel from Adm. Bldg. To Hotel	R. Lam
1-Sep	8:00 AM	Travel from Hotel to Adm. Building	R. Lam
	9:00 AM	Visit to Gaillard Cut	
	12:30 PM	Lunch Break (Lake View, Pedro Miguel)	

DATE	TIME	ACTIVITY	SPEAKER
		Part II: Gatun Dam Seismic Study	
1-Sep	2:00 PM	Introduction	M. De Puy
	2:30 PM	Design Ground Motions and Time Histories used in the Analysis	M. Barrelier
	3:00 PM	Shear Strength Testing and Correlation Results	M. Barrelier
	3:30 PM	Liquefaction Susceptibility and Chinese Criteria Review of Gatun Dam	M. Barrelier & G. Guerra
	4:30 PM	Travel from Adm. Bldg. To Hotel	R. Lam
2-Sep	8:00 AM	Travel from Hotel to Adm. Building	R. Lam
	8:30 AM	Shake Analysis Results	M. Barrelier
	9:30 AM	Pre-Earthquake Stability Analysis (Limit Equilibrium) of Gatun Earth Dam	M. Barrelier
	10:30 PM	Post-Liquefaction Stability Analysis of Gatun Earth Dam	M. Barrelier
	11:30 PM	Pre-Earthquake and Post-Liquefaction Stability Analysis of El Caño Saddle Dam	J. F. Garcia
	12:30 PM	Lunch Break	
	1:30 PM	Procedures to Model Large Deformation and Liquefaction	M. De Puy
	2:00 PM	Large Deformation Analysis of Gatun Earth Dam	A. Abrego
	4:30 PM	Travel from Adm. Bldg. To Hotel	R. Lam
		Part III: Report Preparation	
3-Sep	7:30 AM	Travel from Hotel to Adm. Building	R. Lam
	8:00 AM	Meeting with the Director of Engineering and Industrial Services	
	10:00 AM	Meeting with the Administrator of the Panama Canal Commission	
	10:30 AM	Begin GAB Report	
	12:30 PM	Lunch Break	
	4:30 PM	Travel from Adm. Bldg. To Hotel	R. Lam
4-Sep	8:00 AM	Travel from Hotel to Adm. Building	R. Lam
	8:30 AM	Finish GAB Report	
	4:30 PM	Travel from Adm. Bldg. To Hotel	R. Lam
5-Sep		Travel from Panama to your Country	

ATTACHMENT B

Suggested factors of Safety for Landslide Stabilization By J. M. Duncan

The Geotechnical Branch has developed an effective procedure for design of measures to stabilize landslides generally by drainage and/or excavation. The principal elements of this method are: (1) Back analysis, using the best available information, and adjusting shear strengths and piezometric conditions so that a factor of safety equal to unity (F=1.00) is calculated for the conditions at this time of failure, and (2) use of this information to evaluate stability for the stabilized slope, which is designed so that the factor of safety is increased (F>1.00).

This procedure requires selection of appropriate factors of safety for the stabilized slope. In selecting appropriate values of F, the principal factors to be considered are:

1. The fact that the computations are based on back analysis. This greatly improves the reliability of the computations. While a 5% change in computed factor of safety would not be considered significant if computations were based on strengths from laboratory or in situ tests, a 5% change in computed factor of safety is of significance when based on back analysis.

2. The reliability of the information available. The most important elements in this regard are the complexity of the geologic conditions, the amount of geologic information available, the information available regarding groundwater conditions at the time of failure, the information available regarding the mechanism of failure, and the accuracy with which the landslide can be represented by a two-dimensional cross section for analysis.

3. The consequences of failure, and the risk represented by recurrence of the slide. The most important elements in this regard are the potential for encroachment on the canal prism, as signified by the elevation of the potential slide mass above the toe; the distance of the potential slide mass from the canal prism; and the potential for large movements. The potential for large movement is greater where sliding can occur along a plane, and where the strength is greater than residual and could be reduced to residual by slide displacement.

Considering the reliability of the available information, and the likely consequences of failure, the following ranges of factor of safety are suggested as appropriate guidelines:

a. Small uncertainty in conditions, and small risk associated with slide recurrence. Target F = 1.05 to 1.1.

b. Small uncertainty in conditions, and large risk associated with slide recurrence. Target F = 1.1 to 1.2.

c. Large uncertainty in conditions, and small risk associated with slide recurrence. Target F = 1.1 to 1.2.

d. Large uncertainty in conditions, and large risk associated with slide recurrence. Target F = 1.2 to 1.4.

LDA

Mr. T. W. Drohan
Director, Engineering & Industrial Services
Panama Canal Commission
Balboa Heights, Republic of Panama

Re: Seismic Analysis of Concrete Structures at Panama Canal

Dear Mr. Drohan

My involvement in the dynamic analysis of the Gatun Spillway and Gatun Locks started when I was asked to review the report dated October 2, 1998 on this subject, prepared bt the PCC Geotechnical Branch. This review was followed by discussions and meetings on January 11-12, 1999 at the Waterways Experiment Station (WES), U.S. Army Corps of Engineers. Participants at these meetings included your staff and Dr. Robert Hall, Chief of Structural Analysis Group, in the Structures Laboratory at WES.

The work planned at these meetings was later implemented by your staff in consultation with Dr. Hall. During the past two days (August 28-29), I have met with your staff to review the work completed since the January 1999 meetings. Through these discussions and a visit to the site, we identified modifications to the draft report dated August 10, 1999 and additional analyses which were completed yesterday. This review is based on these draft documents.

Gatun Spillway

The simplified two-dimensional dynamic analyses of the Gatun Spillway completed by your staff are satisfactory, although, in general, a three-dimensional analyses is necessary to predict accurately the earthquake-induced stresses in this horseshoe-shaped structure with shear keys between monoliths. An evaluation based on two-dimensional analyses is expected to be conservative because the increase in load-carrying capacity of the structure due to its curved plan is neglected. The computed stresses are below the measured tensile strength of concrete, taken conservatively as 200 psi, the mean-minus-one-standard-deviation value of the data obtained by testing 39 concrete cores. However, any stress concentration around the gallery remains to be considered, although such consideration is not expected to change the conclusions from the present safety evaluation.

The 200-psi value for tensile strength of concrete is especially conservative because it is based on tests conducted at slow rates of loading. This value can be modified to account for the increase in concrete strength at rates of loading representative of earthquake conditions to determine the "seismic tensile strength". The common practice is to modify this tensile strength value further to account for the nonlinearity of the stress-strain relation near failure of concrete before using it to interpret the stresses computed by linear dynamic analysis. As can be seen from the recommended design charts in Figure. 1, these two effects double the estimated tensile strength from $1.7\ f'_c{}^{2/3}$ to $3.4\ f'_c{}^{2/3}$, where f'_c is the compressive strength. Thus 400 psi could possibly be justified for the tensile strength of the Gatun Spillway concrete. To confirm and refine this estimate if desired, splitting tension tests should be conducted under dynamic conditions with 0.04 sec as the time to failure; this value is based on the present computations of the vibration period of the spillway. Perhaps some of the concrete cores could be tested at WES to obtain independent data.

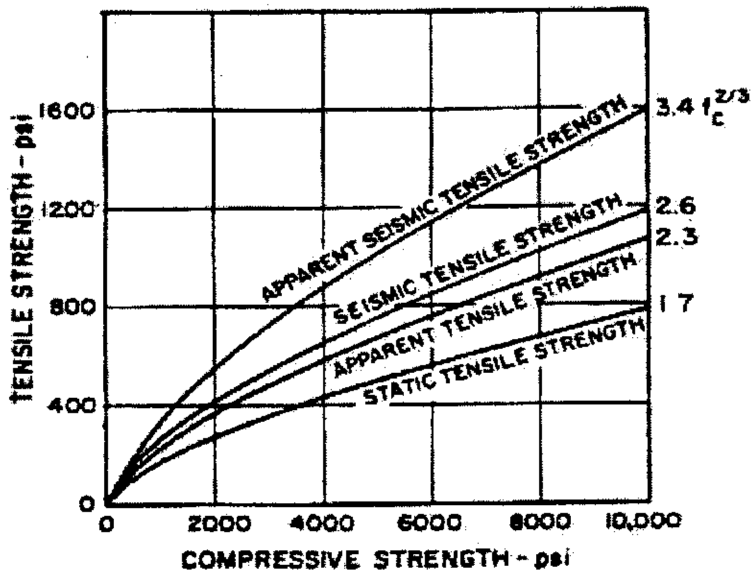

Fig. 1 Design Chart for tensile strength of concrete (Raphael 1984)

In summary, Gatun Spillway is expected to withstand the ground motion considered without any significant cracking of concrete. This conclusion is based on an evaluation that is conservative in two respects: the tensile strength of concrete is under-estimated and the contribution of the curved plan to the structural capacity is not considered. However, this conclusion is limited to the main body of the dam; possible sliding displacements at the dam-rock interface or the performance of the rock underlying the spillway during an earthquake have not been evaluated. Similarly, the seismic safety of the intake structure, including the wall immediately upstream of the intake structure, and of the concrete walls at the interface between the spillway structures and the Gatun embankments remain to be evaluated.

Gatun Spillway Piers

The dynamic analysis of the piers completed so far are limited to cross-stream ground motion and preliminary in the sense that several factors have been neglected: (i) curvature of the spillway; (ii) hydrodynamic effects; (iii) dam-foundation interaction (foundation flexibility and damping- - material and radiation damping); and (iv) effects of the gate systems. Stresses in the 15 ft.-wide piers determined by this preliminary analysis exceed the tensile strength of concrete, implying potential damage to the piers.

The above-mentioned factors influencing the earthquake response of piers should be considered in an improved analysis of both 10 ft and 15 ft wide piers for upstream and cross-stream components of ground motion.

The above-mentioned factors influencing the earthquake response of piers should be considered in an improved analysis of both 10 ft and 15 ft wide piers for upstream and cross-stream components of ground motion.

Gatun Locks

Preliminary analyses of the Gatun locks were included in the October 1998 report prepared by your office. The following comments pertain to those analyses.

1. The simplified analysis procedure, as described briefly in the report, should be improved in several aspects: hydrodynamic effects should be included, structure- foundation interaction should be considered, retained soil effects should be included, and dynamic analysis should be improved.

2. Finite element analysis of locks should include the dynamic effects of water(contained in one or both chambers), structure-foundation interaction effects, and retained soil effects.

The analysis of Gatun Locks is a very complicated problem in structural dynamics because of the above-mentioned factors that influence the earthquake response of these locks. Furthermore, experience with seismic design and safety evaluation of locks seems to be limited to a few organizations in the United States, primarily the U.S. Army Corps of Engineers. A summary of the state of knowledge on this subject should be compiled, perhaps by WES, to provide a basis for planning the direction and scope of work necessary for a state-of-the-art evaluation of Gatun Locks, including the gates and control house.

General Comments

For the continued operation of the Panama Canal it is obviously essential that the concrete structures mentioned in this report perform satisfactorily during future earthquakes. Also assured should be the seismic safety of several structures that have not been evaluated so far. These include Miraflores Spillway, Miraflores Locks, Pedro Miguel Locks, and Madden Dam. It is my recommendation that: (1) PCC should organize a staff task force with a sufficient number of professionals from pertinent disciplines to work on the seismic safety evaluation of the several concrete structures; (2) a Structural Advisory Board with diversity of expertise should be formed to review the work of the PCC staff as they continue to evaluate the seismic safety of existing concrete structures, and later design and construct retrofit schemes if these structures are found to be deficient.

Sincerely

Anil K. Chopra

Anil K. Chopra

AUTORIDAD DEL CANAL DE PANAMÁ

Memorándum

Fecha: 21 de febrero de 2001

De: EI

Asunto: Décima reunión de la Junta de Consultores Geotécnicos

Para: Administrador (AD)

1. Adjuntamos copia del informe que preparó la Junta de Consultores Geotécnicos durante su décima reunión en Panamá del 12 al 16 de febrero de 2001.

2. Como referencia, también adjuntamos un resumen de las fechas en que se ha convocado dicha Junta; así como los temas tratados en cada una de las diez reuniones.

3. Como ha sido en el pasado, la reunión logró una transferencia formidable de tecnología geotécnica de punta a nuestra personal, tal como indica el contenido del informe.

Luis D. Alfaro

Luis D. Alfaro
Director Encargado de Ingeniería
y Servicios Industriales

c:
DA
CC
ES

ACP AUTORIDAD DEL CANAL DE PANAMÁ

AUTORIDAD DEL CANAL DE PANAMÁ

Balboa-Ancón
República de Panamá
www.pancanal.com

February 16, 2001

Dr. Luis D. Alfaro
Acting Director, Engineering and Industrial
Services Department
Autoridad del Canal de Panamá
Balboa Heights, Republic of Panama

Dear Dr. Alfaro:

Re: Geotechnical Advisory Board, Meeting No. 10

The 10th Meeting of the Board took place in Panama from February 12 to 16, 2001. The agenda for the meeting is included as Attachment A.

Prof. Morgenstern, who was unable to attend due to an unavoidable prior commitment, provided his input via a conference call on February 14. The Board appreciated the opportunity to meet with the following people, and to brief them on its observations and preliminary recommendations, prior to the completion of this report:

Mr. Alberto Alemán Z., Administrator, Autoridad del Canal de Panamá

Dr. Luis D. Alfaro, Acting Director, Engineering and Industrial Services Department

Mr. Manuel A. Alvarado, Acting Manager, Engineering Division

Mr. Maximiliano De Puy, Manager, Geotechnical Branch

In addition to meeting with the staff of the Geotechnical Branch, the Board reconnoitered the Canal via helicopter, paying particular attention to the site for the proposed Trinidad Dam. The Board also toured the Gaillard Cut and Trinidad Dam site by launch.

The Board was briefed on the progress of the Landslide Control Program (LCP) and the Cut Widening Program (CWP), and was given a summary of EDM data. The Board was also briefed about a proposed new bridge across the Gaillard Cut about 1.5 km south of Gold Hill. The Authority, and the Geotechnical Branch, are to be congratulated on the progress and success of the CWP, which is almost completed.

The Board focused considerable attention and effort on the proposed Trinidad Dam and its construction feasibility. A detailed commentary on issues and recommended path forward is contained in the following. In general, the Board is impressed with the level of expertise shown by the staff of the Engineering Division in this study.

This report consists of observations, comments and recommendations under the following headings:

1. Trinidad Dam Project
2. Cut Widening Program
3. Landslide Control Program
4. Foundations for the New Bridge
5. Progress on Recommendations of the 9th Meeting of the Board
6. Next Meeting

1. TRINIDAD DAM PROJECT

1.1 General

The primary purpose of this meeting of the Board was to review information related to the proposed dam across the Trinidad Arm of Gatun Lake, and to offer opinions on the feasibility of the project, applicable technologies, and design and construction. Copies of the 1963 reports on this project by Shannon and Wilson, Inc., and by Tudor Engineering Company, were provided to the Board in advance of this meeting. During the meeting, the Board heard presentations on site geology, on properties of the Atlantic Muck, and on foundation settlement, deformation, and stability. Although the engineering studies are in very preliminary stages, the briefings were helpful in highlighting the technical challenges inherent in the project.

1.2 Site and Embankment Characteristics

The proposed alignment of the dam is essentially the same as considered in the 1963 study by Tudor Engineering Company. The main section of the dam extends from Punta Mala on the west to Guacha Island on the east. Smaller sections extend from Guacha Island to Tern Island, and from Tern Island to the east shore.

Approximately 6000 feet of the embankment will be underlain by the Atlantic Muck formation, varying in thickness from 25 feet to 160 feet. The Atlantic Muck consists of peat, clay, and silty sand, and is weak and highly compressible, particularly in the upper parts. The Board's comments below assume that the embankment would be constructed with fill derived from the dry excavation phase of future widening of the Gaillard Cut.

The principal difficulties associated with construction of the dam at this site are:

(1) Because of the high compressibility of the Atlantic Muck, the load of the embankment will cause very large settlement, on the order of tens of feet beneath the highest parts of the embankment.

(2) Because of the low strength of the Atlantic Muck, foundation stability will be a controlling factor for the steepness of the embankment slopes and the rate at which the embankment can be constructed.

(3) Because a large part of the embankment will be constructed by dumping fill through water, the fill will be loose and susceptible to liquefaction during earthquakes unless it is densified.

1.3 Technical Feasibility

In spite of the problems resulting from the characteristics of the Atlantic Muck and the loose condition of fill dumped through water, it is the Board's firm conviction that construction of the dam is technically feasible. This conviction is based on precedents established by recent projects where fills have been placed by dumping through water, using wick drains to accelerate consolidation of soft foundation materials, and using vibratory probes to densify the fill after placement.

A concrete structure would not be suitable for this site. If it was founded directly on the Atlantic Muck, a concrete structure would be severely damaged by the large and differential settlement it would experience. If a concrete structure were founded on piles, driving the piles would disturb the Atlantic Muck, which would subsequently settle away from the base of the structure, creating a path for flow of water, resulting in hydraulic failure of the dam.

An embankment dam built on the Atlantic Muck will undergo large settlements. However, embankment dams are more flexible than concrete structures, and a well-designed and well-constructed embankment dam will be capable of withstanding these settlements and possible fault offsets without cracking or loss of integrity.

1.4 Precedents and Applicable Technologies

Several recent projects involving construction of underwater fills on weak and compressible foundations employed technologies that are applicable to Trinidad Dam.

Wick drains can be used to accelerate the rate of consolidation of soft clay foundations under fills. With suitably designed wick drains, settlement occurs rapidly, and less settlement occurs after construction. In addition, the strength of the foundation increases rapidly, improving stability and making steeper slopes and smaller embankment volume possible.

Wick drains would be inserted into the Atlantic Muck through water, before fill placement. Wick drains have been installed through water at the Kansai International Airport site (near Osaka, Japan), and at reclamation sites in Hong Kong and Singapore, and have been installed to very great depths at the Kennecott tailings dam in Utah to depths much greater than required for this project. These experiences can provide helpful guidance for design and construction of a wick drain system at the Trinidad Dam site.

Underwater fills have been densified after placement using vibratory probes, most notably at Kansai International Airport. The Kansai experience, and perhaps others as well, can provide guidance with respect to allowable maximum particle size in the fill materials, probe size, and operational characteristics.

A welded steel mat was used between the foundation and the embankment at Mohicanville Dike No. 2, Ohio, to prevent the fill from sinking into the foundation, and to improve stability. A welded steel mat could be used at Trinidad Dam to prevent the larger particles in the fill from penetrating into and disturbing the Atlantic Muck. These technologies and construction techniques, as they were used in the projects noted, have the potential for designing and constructing the Trinidad Dam embankment more efficiently and effectively than would have been possible in the 1960s.

1.5 Tentative Design Concepts

While it is not the purpose here to prescribe the form of the design for the Trinidad Dam embankment, the Board believes it may be useful to describe the design concepts it has discussed, to provide some guidance as studies continue.

The Board believes that the problems attendant on construction of an embankment dam at the Trinidad site might be addressed as follows:

(1) Remove the trees remaining within the footprint of the embankment.

(2) Excavate the top 15 feet or so of the Atlantic Muck, over all or over a major portion of the embankment footprint.

(3) Place a welded steel mat on the excavated surface of the Atlantic Muck.

(4) Place a drainage blanket, perhaps 5 feet thick, by bottom dumping. Particle sizes in this drainage blanket would be controlled to ensure that there will be sufficient permeability to provide efficient drainage at the top of the wick drains.

(5) Insert wick drains through water, into the Atlantic Muck over all or a major portion of the embankment footprint.

(6) Continue placing embankment fill by bottom dumping through water. Particle sizes throughout the fill would be controlled to ensure that the fill does not contain particles large enough to prevent insertion of the vibratory compaction probes.

(7) Continue filling in shallow water and for 5 feet or so above water by clamshell, conveyor belt, or end dumping.

(8) Densify the fill using vibratory probes.

(9) Construct the remaining above-water portion of the embankment using conventional placement and compaction procedures.

While these suggestions may provide a suitable framework for design, the Board is aware that a number of important issues such as short-term stability, long-term settlement, seepage through the embankment, and possible breakdown of clay shale if it used in the fill, can only be fully assessed through detailed studies of likely behavior and examination of alternatives.

For ease of construction and reliability of performance (especially seismic performance), it is desirable that this embankment be homogeneous. If the permeability of the base blanket or the entire embankment is so high that leakage would be excessive, it will be necessary to incorporate a zone of lower permeability material within the cross section. This might be done by using finer-grained fill in part of the embankment, or by constructing a slurry trench cutoff through the completed embankment. In either case, it will be important to ensure that filter criteria are satisfied between adjacent zones, and that all zones are wide enough to maintain integrity in case of fault offset during an earthquake.

1.6 Recommended Approach

If a decision is reached to proceed with the Trinidad Dam project, the Board believes that the further work could effectively be organized into four phases:

(1) Detailed feasibility study to collect information on applicable technologies and precedents, and to assess economic feasibility in more detail than has so far been possible. This study would be accomplished by a team consisting of an external firm experienced in dam design assisted by engineering personnel of the ACP. Participation of an experienced and recognized dam designer will be essential to produce "bankable documents" if the project is eventually found to be economically as well as technically feasible. Duration: about 6 months.

(2) Preliminary design, including an underwater test section at or near the proposed dam site. Construction of a test section will provide valuable information on material processing, effectiveness of the proposed construction procedures, and permeability of the fill in place, among other important issues. Information gained in this phase will ensure that the final design is constructable, and that the dam will perform as intended. Duration: about 18 months.

(3) Final design. Duration: about 6 months.

(4) Construction. Duration: 4 to 5 years.

The above schedule assumes timely award of contracts.

Use of wick drains will result in faster gain in strength of the Atlantic Muck, will make possible steeper embankment slopes and smaller embankment volume than considered heretofore, and should reduce the length of time required for construction.

2. CUT WIDENING PROGRAM

2.1 General

At the time of the meeting, construction of 16 of the 18 cut widening projects has been completed. Of the two projects still under construction, Cartagena will be completed in March 2001, and the new Tie Up Station, across from Cartagena near Nitro Hill, is scheduled for completion in December 2001. For the entire Cut Widening Program, the following amount of required excavation activity has been performed thus far:

- 99 percent of the 22.3 million m^3 of dry excavation.
- 94 percent of drilling and blasting, and
- 87 percent of dredging.

Accomplishing this major improvement to the Canal in a period of 9 years has been a very significant achievement; the Board commends the Geotechnical Branch and other units of the Autoridad del Canal de Panamá for their effectiveness in carrying out this program. As was to be expected, the stability of the slopes in widened reaches was reduced by toe excavation, resulting in localized slide activity. An example was the June 1999 slide at Old Lirio; however, effective engineering design of the cut slopes has minimized such activity.

2.2 Cartagena

Of particular design and construction difficulty has been Project No. 17 (Cartagena), which included five separate landslides – Cartagena Extension Slide, Cartagena Slide, Cartagena Mudflow, Upper Cartagena Slide, and Cartagenita Slide. The Board was concerned that underwater excavation in the Cartagena reach might result in slope failures (as had been the case in previously widened reaches). Thus, the Board had recommended in its September 4, 1999, report that a comprehensive surveillance program be followed during Cartagena excavations, particularly the underwater excavations. Following this recommendation, two EDM targets were installed on shore at Cartagena before excavation began to allow detection of slope displacements. Thus far, no significant slope movement has occurred.

2.3 Gold Hill

The stability of Gold Hill, both overall stability of the rock mass and local stability of parts of its steep cut slopes, has been a critically important issue in the Cut Widening Program. The possibility of instability (i.e., tilting) of the entire mass has been considered since inception of the project. To monitor any such movement, EDM targets were installed atop Gold Hill. As of now, EDM records indicate no discernible movement. During the Board's field trip, we noted minor rock-fall problems on the cut faces of Gold Hill. We reiterate our previous recommendation that the effects of rock-fall activity be reduced by installation of rock-fall netting on affected faces.

2.4 Model Slope

Model Slope was another reach at which problems were anticipated during and after excavation. Model Slope had begun to undergo movement before widening began. Horizontal drains, installed in 1992, were effective in reducing these movements. However, earthwork in this area destroyed these drains, which are no longer functional. Anticipating slope problems, the Geotechnical Branch installed 15 EDM targets at Model Slope. One of the targets moved about one meter during 1998-99. Eight of the targets have moved enough since excavation to cause an alert as defined below. Three targets have moved a meter or more since excavation.

As the Board noted in our September 1999 report, we were concerned that loss of the horizontal drains had made the Model Slope less stable than before, and that these drains should be replaced. In response, 12 horizontal drains were installed on Model Slope during FY2000. All of these drains are now flowing, and one of them has produced as much as 5 gal/min. Thus, it seems likely that drain installation has improved the stability of Model Slope.

3. LANDSLIDE CONTROL PROGRAM

3.1 Components of the Landslide Control Program

The Landslide Control Program (LCP) includes these activities:
(1) field inspection, (2) monitoring of surface movement by means of EDM systems, (3) subsurface instrumentation (open wells and piezometers) (4) drainage maintenance, (5) road maintenance, and (6) design of remedial measures. All of these components are being used in what is proving to be a very effective program.

3.2 Monitoring of Slope Surface Movements by EDM Systems

Of the above components of the Landslide Control Program, only changes in the EDM system will be discussed here. The surface-movement data obtained by this system are extremely valuable for identifying those slopes needing mitigation. In July 1998, about 290 EDM survey points existed on the Gaillard Cut slopes. By July 1999, the number of survey points had risen to approximately 350. However, by December 2000, the total number of survey points had fallen to 315, a reduction of about 35 points. This loss of EDM survey points has been caused mainly by destruction during excavation. We recommend that these points be replaced. We further recommend that additional survey points be added at needed locations.

3.3 Use of Global Positioning System (GPS) to Monitor Surface Movements

In the Board's September 1999 report, we noted that the locations of selected (i.e., "master") EDM surface points were being checked by GPS, a method that may prove to have accuracy comparable to that of the EDM procedures, and to be less expensive to operate. We recommend that comparisons of GPS and the laser-based EDM system be continued. The Geotechnical Branch would benefit from access to "state of the art" techniques and equipment that will provide lateral accuracy of ~ 1 cm. Availability and use of a GPS of this quality could result in considerable manpower savings in reading the 300+ survey points.

3.4 Use of "Alert" Criteria as Warning of Potential Slope-Failure Problems

At the 7th International Symposium on Landslides (Trondheim, 1996), criteria for a condition called "Alert" were established to identify slope-movement circumstances that could lead to slope failures (i.e., to landslide activity). The criteria are: "Alert" occurs when the horizontal movement along the current resultant vector has a monthly increment greater than 30 mm or a total accumulated value greater than 100 mm. The Alert criteria are now being applied effectively by the Geotechnical Branch to slopes along the Gaillard Cut. Results of the Alert warnings are being used to identify slope areas that deserve emergency study and possible remediation.

3.5 Contract Procedures for Emergency-Response Remediation

A problem that has arisen in the important process of emergency slope remediation, is the sometimes unacceptable amount of time between (1) recognition of a slope problem and (2) beginning of slope remediation measures. This occurs because of the current time-consuming process of selection of a contractor and the subsequent assembling of his work force and equipment. We recommend that the ACP issue a standing contract (or contracts) that would select one or more construction companies who would be on "stand-by" to immediately begin remedial work when requested by the Geotechnical Branch. In other organizations, such agreements are called "stand-by", "task-order", or "indefinite-deliverable" contracts. This procedure would allow slope remediation to begin as soon as signs of impending instability are noted by the Geotechnical Branch, thus reducing the likelihood of slope failures with serious consequences. We note that at the Culebra Village slope, the Maintenance Division fulfilled this fast "emergency-response" function, rapidly carrying out remedial measures at the request of the Geotechnical Branch, and probably preventing a serious slope failure. Appropriate magnitudes of such contracts can be gauged in terms of historic expenditures for landslide control, which have averaged about $500,000 per year for the past six years.

4. FOUNDATIONS FOR THE NEW BRIDGE

The Board was briefed on the plans for a new bridge to be constructed across the Canal in the southern portion of the Gaillard Cut, 1.5 km south of Gold Hill and immediately south of the new Tie-Up station. The bridge will be built by the Ministerio de Obras Públicas (MOP) utilizing design and construction contractors. Foundations for the main towers on each side of the Canal will be located within the zone of concern for potential slope instability that might affect the Canal. Discussions between the MOP staff and the ACP staff concerning slope stability and other factors led to selection of the proposed alignment, which avoids historic landslides.

The Board perceives the interests of the ACP in the bridge foundations to be threefold. First, the position of the bridge foundations will place a limit on future widening of the Canal, at least for the life of the bridge. Second, the design and construction of the bridge foundations must be safe with respect to slope or other failure, which might impinge on the Canal. Third, the ACP would like to have completed excavation (or at least blasting) for the next planned phase of cut widening prior to construction of the foundation on the west side of the Canal. The Board was briefed on the foundation conditions on both sides of the Canal and was presented with preliminary designs for excavations, giving consideration to both cut widening and bridge foundations.

The first area of interest to the ACP is beyond the scope of the Board. With regard to the latter two, the Board recommends that the ACP assure that the full responsibility for the stability of the bridge foundations and surrounding slopes be assumed by the owner of the bridge and the contractors engaged in the design and construction of the foundations, and that all parties recognize this assumption of responsibility. Specifically, the Board recommends that the ACP's requirements, including at least those for the cut-widening excavation and subsequent slope stability, be communicated to the contractors and that the ACP maintain the right to review and approve the design, and to oversee the construction of the foundations. The Board does not believe that it would be prudent for the ACP to be in the position of recommending a specific design, because this could lead to a presumption that the ACP shares the responsibility for the stability of the foundations.

It should be noted that the consequences of slope failures in a standard cut-widening project are very much less (and the tolerable deformations are much greater) than the consequences of slope failure and tolerable deformations associated with the foundations of the proposed bridge. Therefore the factor of safety, for which a value as low as 1.1 might be acceptable in a standard cut-widening project, must be substantially higher and must be determined to be in accord with the consequences of failure of the foundations.

Indeed it should be the responsibility of the design contractor for the foundations to determine the appropriate factor of safety in accord with standards of practice for bridges of this type, subject to approval by the ACP.

The Board recommends that legal counsel for the ACP be requested to explore these issues. The aim is to ensure that the ACP's rights and interests are protected, and that the responsibility for the stability of the bridge foundations and adjacent slopes is recognized by all parties to rest with the bridge owner and contractors.

The Board also recommends that the ACP complete all blasting for the cut widening that might affect the area of the bridge foundations prior to construction of the foundations.

5. PROGRESS ON RECOMMENDATIONS OF THE 9TH MEETING OF THE BOARD

The 9th Meeting of the Board, held August 30– September 4, 1999, emphasized progress on the Gatun Dam Seismic Studies. This topic was not formally discussed during our 10th Meeting and the Board anticipates that it will be discussed during our 11th Meeting.

The Board would like to re-emphasize the need:

(1) to initiate a system-wide seismic risk analysis, and

(2) to prepare final reports documenting the characterization of the dam, the analysis procedures used, and the final conclusions.

The Board was pleased to learn that a mesh across the slope at the northwest and southwest corners of the excavated face of Gold Hill has been designed and that the project is now out for bid.

With regard to the many small slides in the Canal in the Bas Obispo reach north of the Borinquen Slide, the Board understands that this area was evaluated and erosion was determined to be the source of the problem. Shoreline protection has been installed.

The Board was pleased to note that multipoint piezometers and associated equipment have been purchased for use in the Landslide Control Program. These piezometers need to be installed so that records can be maintained and studied in order to correlate rainfall patterns with the rise and fall of piezometric levels and efficiency of drainage measures.

The Board was told informally that its recommendations concerning the Gatun Dam Seismic Studies effort should be considered as "work in progress". These studies will be the focus of discussions at the 11th Meeting of the Board. It would be desirable if the reports documenting this work were made available to the Board for review prior to Meeting No. 11.

6. NEXT MEETING

The Board anticipates a meeting in the second half of 2001. The week of October 29 – November 2 would be desirable. Topics to be addressed include 1) the completion of the Gatun Dam Seismic Study, 2) overall seismic risk analysis, 3) policy for remedial measures for landslides, and 4) other topics at the option of the ACP.

Dr. Luis D. Alfaro, February 16, 2001
Subject: Geotechnical Advisory Board, Meeting No. 10

James M. Duncan

Robert L. Schuster

William F. Marcuson III

Robert L. Wesson

cc: Professor Morgenstern

Attachment A

ATTACHMENT A

DATE	TIME	ACTIVITY	SPEAKER
11-		Travel	
12-Feb			
	8:00 AM	Pick up at Hotel	
	8:30 AM	Meeting with EI, EIE, and Engineering Staff	
	AM	Welcome and Summary of EIEG activities	M. De Puy
		<u>PART I</u>: LANDSLIDE CONTROL PROGRAM & CUT WIDENING PROGRAM	
	11:00 AM	Cut Widening Program Performance and Summary of EDM data	L. Fernandez
	AM	Stabilization of Old West Lirio & Culebra Village Slide	C. Reyes
	12:00 m	Break for Lunch	
		<u>PART II</u>: THE NEW BRIDGE ACROSS GAILLARD CUT	
	1:00 PM	West Excavation Design for the New Bridge over the Canal	R. Rivera
	3:00 PM	East Excavation Design New Bridge over the Canal	M. Barrelier
	5:00 PM	Return to Hotel.	
13-Feb			
	8:00 AM	Pick up at Hotel	
	8:30 AM	Helicopter & Launch Trips	
	3:30 PM	Round table on Gaillard Cut Issues and New Bridge	
	5:00 PM	Return to Hotel.	
14-Feb			
		<u>PART III</u>: THE TRINIDAD DAM PROJECT	
	8:00 AM	Pick up at Hotel	
	8:30 AM	Introduction to Trinidad Dam Project	M. De Puy
		•General Geology of Trinidad Dam Area	P. Franceschi
		•Engineering Properties of the Atlantic Muck	M. De Puy
		•Analysis of Settlement of the Gatun Locks Center Wall, A Back Analysis	F. Guerra
	12:00 m	Break for Lunch	
	1:30 PM	Private conference call with Prof. Morgenstern	

ATTACHMENT A

	2:30 PM	•Analysis and Stability of the Proposed Dam	M. De Puy, M. Barrelier, A. Abrego
	4:00 PM	Round table on Trinidad Dam	
	5:00 PM	Return to Hotel	
15-Feb		**PART IV: REPORT PREPARATION**	
	8:00 AM	Pick up at Hotel	
	8:30 AM	Prepare for meeting with the Administrator	
	9:00 AM	Meeting w/Administrator and EI, EIE,EIEG	
	AM	Report Preparation	
	AM	Break for Lunch	
	1:00 PM	Report Preparation	
	5:00 PM	Return to Hotel	
16-Feb		**PART V: REPORT PREPARATION**	
	8:00 AM	Pick up at Hotel	
	8:30 AM	Report Preparation	
	12:00 m	Break for Lunch	
	1:00 PM	Report Preparation	
	5:00 PM	Return to Hotel	
17-Feb		Travel	

HISTORIAL DE REUNIONES DE LA JUNTA DE CONSULTORES GEOTÉCNICOS DEL CANAL DE PANAMA

REUNIONES PRELIMINARES CON LOS INTEGRANTES:

29 de junio al 4 de julio de 1987

Temas:
- Control de derrumbes en el Corte Gaillard
- Derrumbe de Cucaracha – 1986

- **Participante:** Norbert R.Morgenstern

6 y 7 de julio de 1987

Temas:
- Problemas de Derrumbe en el Canal de Panamá
- Derrumbe de Cucaracha – 1986

- **Participantes:** James M. Duncan y George F. Sowers

REUNIONES DE LA JUNTA DE CONSULTORES GEOTECNICOS:

Primera Reunión – 2 de septiembre al 7 de septiembre de 1987

Temas:
- Información General
- Estudios del Derrumbe de Cucaracha – 1986
- Programa de Control de Derrumbes

Participantes: James M. Duncan, Norbert R. Morgenstern y George F. Sowers

Segunda Reunión - 24 de febrero al 28 de febrero de 1988

Temas:
- Información General
- Exploración e Instrumentación
- Estudios y estabilización del derrumbe de Cucaracha
- Estabilización del lado este de Culebra
- Drenaje de Hodge's Hill
- Estudios de Gold Hill
- Programa de Vigilancia y análisis de riesgos de derrumbe

HISTORIAL DE REUNIONES DE LA JUNTA DE CONSULTORES GEOTÉCNICOS

Participantes: James M. Duncan, Norbert R. Morgenstern, Robert L. Schuster y George F. Sowers

Tercera Reunión - 19 de octubre al 23 de octubre de 1988

Temas:

- Observaciones Generales e Inspección
- Progreso del Trabajo de Investigación
- Estudios de Penetración de material en Canal de Navegación
- Monitoreo y Vigilancia de los taludes
- Investigación del Derrumbe de Cucaracha
- Plan de medidas de mitigación de derrumbes

Participantes: James M. Duncan, Norbert R. Morgenstern, Robert L. Schuster y George F. Sowers.

Cuarta Reunión – 18 de febrero al 20 de febrero de 1991

Temas:

- Geología y Estabilización de Gold Hill
- Estudios de estabilidad de Model Slope
- Programa de Vigilancia
- Instrumentación
- Programa de Reforestación en el Corte Gaillard

Participantes: James M. Duncan, Norbert R. Morgenstern, Robert L. Schuster y George F. Sowers.

Reunión Especial – 23 de noviembre al 25 de noviembre de 1991
Visita del Dr. James M. Duncan

Temas:

- Nuevo laboratorio de Geotécnia
- Programa de Control de Derrumbes
- Estabilidad Sísmica de la represa de Gatún

HISTORIAL DE REUNIONES DE LA JUNTA DE CONSULTORES GEOTÉCNICOS

Quinta Reunión – 22 de febrero al 26 de febrero de 1993

Temas:

- Estabilidad de la represa de Gatún
- Ensanche del Corte Gaillard
- Programa de control de derrumbes

Participantes: James M. Duncan, Norbert R. Morgenstern, Robert L. Schuster y George F. Sowers

Sexta Reunión – 9 de enero al 13 de enero de 1995

Temas:

- Estabilidad Sísmica de la represa de Gatún y estructuras auxiliares
- Continuidad del monitoreo de derrumbes y programa de mitigación de derrumbes
- Programa del Ensanche del Corte Gaillard

Participantes: James M. Duncan, William F. Marcuson, III, Norbert R. Morgenstern, Robert L. Schuster, George F. Sowers y Robert L. Wesson.

Séptima Reunión – 18 de noviembre al 22 de noviembre de 1996

Temas:

- Progreso en las recomendaciones de la 6ta. Reunión
- Metodología de Diseño y proyectos de ensanche del Corte Gaillard CWP-12,13, 15 y 16
- Proyecto del Ensanche del Corte Gaillard CWP-14, Gold Hill
- Estabilidad relacionada al procedimiento de excavación
- Programa de control de derrumbes

Participantes: James M. Duncan, William F. Marcuson, III, Norbert R. Morgenstern, Robert L. Schuster y Robert L. Wesson

HISTORIAL DE REUNIONES DE LA JUNTA DE CONSULTORES GEOTÉCNICOS

Octava Reunión - 13 de julio al 18 de julio de 1998

Temas:

- Progreso en las recomendaciones de la 7ma. Reunión
- Proyecto de Ensanche del Corte
- Programa de Control de Derrumbes
- Estudio Sísmico de la represa de Gatún

Participantes: James M. Duncan, William F. Marcuson, III, Norbert R. Morgenstern, Robert L. Schuster y Robert L. Wesson

Novena Reunión – 30 de agosto al 4 de septiembre de 1999

Temas:

- Progreso en las recomendaciones de la 8ava. Reunión
- Programa de Ensanche del Corte Gaillard
- Programa de Control de Derrumbes
- Estudio Sísmico de la represa de Gatún
- Análisis de riesgo sísmico

Participantes: James M. Duncan, William F. Marcuson, III, Norbert R. Morgenstern, Robert L. Schuster, Robert L. Wesson y como invitado especial el Dr. Anil K. Chopra

Décima Reunión – 12 de febrero al 16 de febrero de 2001

Temas:

- Proyecto de Trinidad
- Programa de Ensanche del Corte Gaillard
- Programa de Control de Derrumbes
- Fundaciones para el Nuevo Puente

Participantes: James M. Duncan, William F. Marcuson, III, Robert L. Schuster y Robert L. Wesson.

E/ [signature]

LAlfaro

From: Jose Francisco Garcia [jfcogarciad@hotmail.com]

Sent: Thursday, February 22, 2001 11:43 AM

To: lalfaro@pancanal.com

Cc: EIEG@pancanal.com

Luis/Max:
Como andan por alla, sobrevivieron al Board, aqui les envio un articulo que creo que es una de las razones por la cual Dr. M no pudo asistir. Esto aparecio en la pagina principal del website de Uof A (www.ualberta.ca)
Cuentenme como les fue con el Board y que hay de nuevo.
Pancho

'Mr. Earthquake' and China expert join Order of Canada

By Ryan Smith

February 21, 2001 - Two former University of Alberta professors will receive Canada's highest honour for lifetime achievement at a ceremony in Ottawa next week. Drs. Norbert Morgenstern and Brian Evans are among 63 new members of the Order of Canada, it was announced last Wednesday.

A professor emeritus in the Department of Civil and Environmental Engineering, Morgenstern has published nearly 300 research articles in the fields of geotechnical engineering and geoenvironmental engineering, a field Morgenstern has played a major role in pioneering, said U of A Dean of Engineering David Lynch. Morgenstern's research focuses on the stability of earth and materials, as well as on the movement of materials in the earth, which encompasses issues such as pollution containment.

"Dr. Morgenstern has been involved in a large number of significant research breakthroughs, both fundamental and applied, and he's one of the world's foremost experts in his field," Lynch said.

"Whenever there's a geotechnical project anywhere in the world, he's one of the first people to be called. In Japan he's known as 'Mr. Earthquake' for his work there to make buildings stable in case of an earthquake," he added.

"Over his 30 year career, I cannot think of a major development project in Canada, from hydro-electric projects to oil-sands development, that he has not had some involvement in," said Dr. David Sego, a colleague of Morgenstern's in the Department of Civil and Environmental Engineering.

"I cannot say enough about him," Sego added. "He's one of those rare prizes at the U of A who has helped make our faculty one of the top in North America and the world."

February 16, 2001

Dr. Luis D. Alfaro
Acting Director, Engineering and Industrial
Services Department
Autoridad del Canal de Panamá
Balboa Heights, Republic of Panama

Dear Dr. Alfaro:

Re: Geotechnical Advisory Board, Meeting No. 10

The 10th Meeting of the Board took place in Panama from February 12 to 16, 2001. The agenda for the meeting is included as Attachment A.

Prof. Morgenstern, who was unable to attend due to an unavoidable prior commitment, provided some reactions and his input via a conference call on February 14. The Board appreciated the opportunity of meeting with the following people, and briefing them on its observations and preliminary recommendations, prior to the completion of this report:

Mr. Alberto Alemán Z., Administrator, Autoridad del Canal de Panamá

Dr. Luis D. Alfaro, Acting Director, Engineering and Industrial Services Department

Mr. Manuel A. Alvarado, Acting Manager, Engineering Division

Mr. Maximiliano De Puy, Manager, Geotechnical Branch

In addition to meeting with the staff of the Geotechnical Branch, the Board reconnoitered the Canal via helicopter paying particular attention to the site for the proposed Trinidad Dam. The Board also toured the Gaillard Cut and Trinidad Dam site by launch.

The Board was briefed on the progress of the Landslide Control Program (LCP), Cut Widening Program (CWP) and was given a summary of EDM data. The Board was also briefed about a proposed new bridge across the Gaillard Cut just south of Gold Hill. The Authority, and the Geotechnical Branch, are to be congratulated on the progress and success of the CWP which is almost completed.

The Board focused considerable attention and effort on the proposed Trinidad Dam and its construction feasibility. A detailed commentary on issues and recommended path forward is contained in the following. In general, the Board is impressed with the level of expertise shown by the staff of the Engineering Division in this study.

This report consists of observations, comments and recommendations under the following headings:

1. Trinidad Dam Project
2. Cut Widening Program
3. Landslide Control Program
4. Foundations for the New Bridge
5. Progress on Recommendations made in the Board report from Meeting No. 9
6. Summary
7. Next Meeting

The principal difficulties associated with construction of the dam at this site are:

(1) Because of the high compressibility of the Atlantic Muck, the load of the embankment will cause very large settlement, on the order of tens of feet beneath the highest parts of the embankment.

(2) Because of the low strength of the Atlantic Muck, foundation stability will be a controlling factor for the steepness of the embankment slopes and the rate at which the embankment can be constructed.

(3) Because a large part of the embankment will be constructed by dumping fill through water, the fill will be loose and susceptible to liquefaction during earthquakes unless it is densified.

1.3 Technical Feasibility

In spite of the problems resulting from the characteristics of the Atlantic Muck and the loose condition of fill dumped through water, it is the Board's firm conviction that construction of the dam is technically feasible. This conviction is based on precedents established by recent projects where fills have been placed by dumping through water, using wick drains to accelerate consolidation of soft foundation materials, and using vibratory probes to densify the fill after placement.

A concrete structure would not be suitable for this site. If it was founded directly on the Atlantic Muck, a concrete structure would be severely damaged by the large and differential settlement it would experience. If a concrete structure were founded on piles, driving the piles would disturb the Atlantic Muck, which would subsequently settle away from the base of the structure, creating a path for flow of water, resulting in hydraulic failure of the dam.

An embankment dam built on the Atlantic Muck will undergo large settlements. However, embankment dams are more flexible than concrete structures, and a well-designed and well-constructed embankment dam will be capable of withstanding these settlements and possible fault offsets without cracking or loss of integrity.

1.4 Precedents and Applicable Technologies

Several recent projects involving construction of underwater fills on weak and compressible foundations employed technologies that are applicable to Trinidad Dam.

Wick drains can be used to accelerate the rate of consolidation of soft clay foundations under fills. With suitably designed wick drains, settlement occurs rapidly, and less settlement occurs after construction. In addition, the strength of the foundation increases rapidly, improving stability and making steeper slopes and smaller embankment volume possible.

Wick drains would be inserted into the Atlantic Muck through water, before fill placement. Wick drains have been installed through water at the Kansai International Airport site (near Osaka, Japan), and at reclamation sites in Hong Kong and Singapore, and have been installed to very great depths at the Kennecott tailings dam in Utah to depths much greater than required for this project. These experiences can provide helpful guidance for design and construction of a wick drain system at the Trinidad Dam site.

Underwater fills have been densified after placement using vibratory probes, most notably at Kansai International Airport. The Kansai experience, and perhaps others as well, can provide guidance with respect to allowable maximum particle size in the fill materials, probe size, and operational characteristics.

A welded steel mat was used between the foundation and the embankment at Mohicanville Dike No. 2, Ohio, to prevent the fill from sinking into the foundation, and to improve stability. A welded steel mat could be used at Trinidad Dam to prevent the larger particles in the fill from penetrating into and disturbing the Atlantic Muck. These technologies and construction techniques, as they were used in the projects noted, have the potential for designing and constructing the Trinidad Dam embankment more efficiently and effectively than would have been possible in the 1960s.

1.5 Tentative Design Concepts

While it is not the purpose here to prescribe the form of the design for the Trinidad Dam embankment, the Board believes it may be useful to describe the design concepts it has discussed, to provide some guidance as studies continue.

The Board believes that the problems attendant on construction of an embankment dam at the Trinidad site might be addressed as follows:

(1) Remove the trees remaining within the footprint of the embankment.

(2) Excavate the top 15 feet or so of the Atlantic Muck, over all or over a major portion of the embankment footprint.

(3) Place a welded steel mat on the excavated surface of the Atlantic Muck.

(4) Place a drainage blanket, perhaps 5 feet thick, by bottom dumping. Particle sizes in this drainage blanket would be controlled to ensure that there will be sufficient permeability to provide efficient drainage at the top of the wick drains.

(5) Insert wick drains through water, into the Atlantic Muck over all or a major portion of the embankment footprint.

(6) Continue placing embankment fill by bottom dumping through water. Particle sizes throughout the fill would be controlled to ensure that the fill does not contain particles large enough to prevent insertion of the vibratory compaction probes.

(7) Continue filling in shallow water and for 5 feet or so above water by clamshell, conveyor belt, or end dumping.

(8) Densify the fill using vibratory probes.

(9) Construct the remaining above-water portion of the embankment using conventional placement and compaction procedures.

While these suggestions may provide a suitable framework for design, the Board is aware that a number of important issues such as short-term stability, long-term settlement, seepage through the embankment, and possible breakdown of clay shale if it used in the fill, can only be fully assessed through detailed studies of likely behavior and examination of alternatives.

For ease of construction and reliability of performance (especially seismic performance), it is desirable that this embankment be homogeneous. If the permeability of the base blanket or the entire embankment is so high that leakage would be excessive, it will be necessary to incorporate a zone of lower permeability material within the cross section. This might be done by using finer-grained fill in part of the embankment, or by constructing a slurry trench cutoff through the completed embankment. In either case, it will be important to ensure that filter criteria are satisfied between adjacent zones, and that all zones are wide enough to maintain integrity in case of fault offset during an earthquake.

1.6 Recommended Approach

If a decision is reached to proceed with the Trinidad Dam project, the Board believes that the further work could effectively be organized into four phases:

(1) Detailed feasibility study to collect information on applicable technologies and precedents, and to assess economic feasibility in more detail than has so far been possible. This study would be accomplished by a team consisting of an external firm experienced in dam design assisted by engineering personnel of the ACP. Participation of an experienced and recognized dam designer will be essential to produce "bankable documents" if the project is eventually found to be economically as well as technically feasible. Duration: about 6 months.

(2) Preliminary design, including an underwater test section at or near the proposed dam site. Construction of a test section will provide valuable information on material processing, effectiveness of the proposed construction procedures, and permeability of the fill in place, among other important issues. Information gained in this phase will ensure that the final design is constructable, and that the dam will perform as intended. Duration: about 18 months.

(3) Final design. Duration: about 6 months.

(4) Construction. Duration: 4 to 5 years.

The above schedule assumes timely award of contracts.

Use of wick drains will result in faster gain in strength of the Atlantic Muck, will make possible steeper embankment slopes and smaller embankment volume than considered heretofore, and should reduce the length of time required for construction.

2. CUT WIDENING PROGRAM

2.1 General

At the time of the meeting, construction of 16 of the 18 cut widening projects has been completed. Of the two projects still under construction, Cartagena will be completed in March 2001, and the new Tie Up Station, across from Cartagena near Nitro Hill, is scheduled for completion in December 2001. For the entire Cut Widening Program, the following amount of required excavation activity has been performed thus far:

- 99 percent of the 22.3 million m^3 of dry excavation.
- 94 percent of drilling and blasting, and
- 87 percent of dredging.

Accomplishing this major improvement to the Canal in a period of 9 years has been a very significant achievement; the Board commends the Geotechnical Branch and other units of the Autoridad del Canal de Panamá for their effectiveness in carrying out this program. As was to be expected, the stability of the slopes in widened reaches was reduced by toe excavation, resulting in localized slide activity. An example was the June 1999 slide at Old Lirio; however, effective engineering design of the cut slopes has minimized such activity.

2.2 Cartagena

Of particular design and construction difficulty has been Project No. 17 (Cartagena), which included five separate landslides – Cartagena Extension Slide, Cartagena Slide, Cartagena Mudflow, Upper Cartagena Slide, and Cartagenita Slide. The Board was concerned that underwater excavation in the Cartagena reach might result in slope failures (as had been the case in previously widened reaches). Thus, the Board had recommended in its September 4, 1999, report that a comprehensive surveillance program be followed during Cartagena excavations, particularly the underwater excavations. Following this recommendation, two EDM targets were installed on shore at Cartagena before excavation began to allow detection of slope displacements. Thus far, no significant slope movement has occurred.

2.3 Gold Hill

The stability of Gold Hill, both overall stability of the rock mass and local stability of parts of its steep cut slopes, has been a critically important issue in the Cut Widening Program. The possibility of instability (i.e., tilting) of the entire mass has been considered since inception of the project. To monitor any such movement, EDM targets were installed atop Gold Hill. As of now, EDM records indicate no discernible movement. During the Board's field trip, we noted minor rock-fall problems on the cut faces of Gold Hill. We reiterate our previous recommendation that the effects of rock-fall activity be reduced by installation of rock-fall netting on affected faces.

2.4 Model Slope

Model Slope was another reach at which problems were anticipated during and after excavation. Model Slope had begun to undergo movement before widening began. Horizontal drains, installed in 1992, were effective in reducing these movements. However, earthwork in this area destroyed these drains, which are no longer functional. Anticipating slope problems, the Geotechnical Branch installed 15 EDM targets at Model Slope. One of the targets moved about one meter during 1998-99. Eight of the targets have moved enough since excavation to cause an alert as defined below. Three targets have moved a meter or more since excavation.

As the Board noted in our September 1999 report, we were concerned that loss of the horizontal drains had made the Model Slope less stable than before, and that these drains should be replaced. In response, 12 horizontal drains were installed on Model Slope during FY2000. All of these drains are now flowing, and one of them has produced as much as 5 gal/min. Thus, it seems likely that drain installation has improved the stability of Model Slope.

3. LANDSLIDE CONTROL PROGRAM

3.1 Components of the Landslide Control Program

The Landslide Control Program (LCP) includes these activities:
(1) field inspection, (2) monitoring of surface movement by means of EDM systems, (3) subsurface instrumentation (open wells and piezometers) (4) drainage maintenance, (5) road maintenance, and (6) design of remedial measures. All of these components are being used in what is proving to be a very effective program.

3.2 Monitoring of Slope Surface Movements by EDM Systems

Of the above components of the Landslide Control Program, only changes in the EDM system will be discussed here. The surface-movement data obtained by this system are extremely valuable for identifying those slopes needing mitigation. In July 1998, about 290 EDM survey points existed on the Gaillard Cut slopes. By July 1999, the number of survey points had risen to approximately 350. However, by December 2000, the total number of survey points had fallen to 315, a reduction of about 35 points. This loss of EDM survey points has been caused mainly by destruction during excavation. We recommend that these points be replaced. We further recommend that additional survey points be added at needed locations.

3.3 Use of Global Positioning System (GPS) to Monitor Surface Movements

In the Board's September 1999 report, we noted that the locations of selected (i.e., "master") EDM surface points were being checked by GPS, a method that may prove to have accuracy comparable to that of the EDM procedures, and to be less expensive to operate. We recommend that comparisons of GPS and the laser-based EDM system be continued. The Geotechnical Branch would benefit from access to "state of the art" techniques and equipment that will provide lateral accuracy of ~ 1 cm. Availability and use of a GPS of this quality could result in considerable manpower savings in reading the 300+ survey points.

3.4 Use of "Alert" Criteria as Warning of Potential Slope-Failure Problems

At the 7th International Symposium on Landslides (Trondheim, 1996), criteria for a condition called "Alert" were established to identify slope-movement circumstances that could lead to slope failures (i.e., to landslide activity). The criteria are: "Alert" occurs when the horizontal movement along the current resultant vector has a monthly increment greater than 30 mm or a total accumulated value greater than 100 mm. The Alert criteria are now being applied effectively by the Geotechnical Branch to slopes along the Gaillard Cut. Results of the Alert warnings are being used to identify slope areas that deserve emergency study and possible remediation.

3.5 Contract Procedures for Emergency-Response Remediation

A problem that has arisen in the important process of emergency slope remediation, is the sometimes unacceptable amount of time between (1) recognition of a slope problem and (2) beginning of slope remediation measures. This occurs because of the current time-consuming process of selection of a contractor and the subsequent assembling of his work force and equipment. We recommend that the ACP issue a standing contract (or contracts) that would select one or more construction companies who would be on "stand-by" to immediately begin remedial work when requested by the Geotechnical Branch. In other organizations, such agreements are called "stand-by", "task-order", or "indefinite-deliverable" contracts. This procedure would allow slope remediation to begin as soon as signs of impending instability are noted by the Geotechnical Branch, thus reducing the likelihood of slope failures with serious consequences. We note that at the Culebra Village slope, the Maintenance Division fulfilled this fast "emergency-response" function, rapidly carrying out remedial measures at the request of the Geotechnical Branch, and probably preventing a serious slope failure. Appropriate magnitudes of such contracts can be gauged in terms of historic expenditures for landslide control, which have averaged about $500,000 per year for the past six years.

4. FOUNDATIONS FOR THE NEW BRIDGE

The Board was briefed on the plans for a new bridge to be constructed across the Canal in the southern portion of the Gaillard Cut, 1.5 km south of Gold Hill and immediately south of the new Tie-Up station. The bridge will be built by the Ministerio de Obras Públicas (MOP) utilizing design and construction contractors. Foundations for the main towers on each side of the Canal will be located within the zone of concern for potential slope instability that might affect the Canal. Discussions between the MOP staff and the ACP staff concerning slope stability and other factors led to selection of the proposed alignment, which avoids historic landslides.

The Board perceives the interests of the ACP in the bridge foundations to be threefold. First, the position of the bridge foundations will place a limit on future widening of the Canal, at least for the life of the bridge. Second, the design and construction of the bridge foundations must be safe with respect to slope or other failure, which might impinge on the Canal. Third, the ACP would like to have completed excavation (or at least blasting) for the next planned phase of cut widening prior to construction of the foundation on the west side of the Canal. The Board was briefed on the foundation conditions on both sides of the Canal and was presented with preliminary designs for excavations, giving consideration to both cut widening and bridge foundations.

The first area of interest to the ACP is beyond the scope of the Board. With regard to the latter two, the Board recommends that the ACP assure that the full responsibility for the stability of the bridge foundations and surrounding slopes be assumed by the owner of the bridge and the contractors engaged in the design and construction of the foundations, and that all parties recognize this assumption of responsibility. Specifically, the Board recommends that the ACP's requirements, including at least those for the cut-widening excavation and subsequent slope stability, be communicated to the contractors and that the ACP maintain the right to review and approve the design, and to oversee the construction of the foundations. The Board does not believe that it would be prudent for the ACP to be in the position of recommending a specific design, because this could lead to a presumption that the ACP shares the responsibility for the stability of the foundations.

It should be noted that the consequences of slope failures in a standard cut-widening project are very much less (and the tolerable deformations are much greater) than the consequences of slope failure and tolerable deformations associated with the foundations of the proposed bridge. Therefore the factor of safety, for which a value as low as 1.1 might be acceptable in a standard cut-widening project, must be substantially higher and must be determined to be in accord with the consequences of failure of the foundations.

Indeed it should be the responsibility of the design contractor for the foundations to determine the appropriate factor of safety in accord with standards of practice for bridges of this type, subject to approval by the ACP.

The Board recommends that legal counsel for the ACP be requested to explore these issues. The aim is to ensure that the ACP's rights and interests are protected, and that the responsibility for the stability of the bridge foundations and adjacent slopes is recognized by all parties to rest with the bridge owner and contractors.

The Board also recommends that the ACP complete all blasting for the cut widening that might affect the area of the bridge foundations prior to construction of the foundations.

5. PROGRESS ON RECOMMENDATIONS OF THE 9TH MEETING OF THE BOARD

The 9th Meeting of the Board, held August 30– September 4, 1999, emphasized progress on the Gatun Dam Seismic Studies. This topic was not formally discussed during our 10th Meeting and the Board anticipates that it will be discussed during our 11th Meeting.

The Board would like to re-emphasize the need:

(1) to initiate a system-wide seismic risk analysis, and

(2) to prepare final reports documenting the characterization of the dam, the analysis procedures used, and the final conclusions.

The Board was pleased to learn that a mesh across the slope at the northwest and southwest corners of the excavated face of Gold Hill has been designed and that the project is now out for bid.

With regard to the many small slides in the Canal in the Bas Obispo reach north of the Borinquen Slide, the Board understands that this area was evaluated and erosion was determined to be the source of the problem. Shoreline protection has been installed.

The Board was pleased to note that multipoint piezometers and associated equipment have been purchased for use in the Landslide Control Program. These piezometers need to be installed so that records can be maintained and studied in order to correlate rainfall patterns with the rise and fall of piezometric levels and efficiency of drainage measures.

The Board was told informally that its recommendations concerning the Gatun Dam Seismic Studies effort should be considered as "work in progress". These studies will be the focus of discussions at the 11th Meeting of the Board. It would be desirable if the reports documenting this work were made available to the Board for review prior to Meeting No. 11.

6. NEXT MEETING

The Board anticipates a meeting in the second half of 2001. The week of October 29 – November 2 would be desirable. Topics to be addressed include 1) the completion of the Gatun Dam Seismic Study, 2) overall seismic risk analysis, 3) policy for remedial measures for landslides, and 4) other topics at the option of the ACP.

ORIGINAL SIGNED
James M. Duncan

ORIGINAL SIGNED
Robert L. Schuster

ORIGINAL SIGNED
William F. Marcuson III

ORIGINAL SIGNED
Robert L. Wesson

cc: Professor Morgenstern

Attachment A

Dr. Luis D. Alfaro, February 16, 2001
Subject: Geotechnical Advisory Board, Meeting No. 10

Agenda for the 10th Geotechncial Advisory Board Meeting

February 12 Briefing by the Engineering Staff
- Summary of proposals for Canal Expansion
- Proposed Trinidad Dam

February 13 Site Visit
- Gaillard Cut
- Trinidad Dam Site
- Gatun Dam

February 14 Discussion and Conference call to Professor Morgenstern

February 15 Report Preparation
- Meeting with the Administrator of the APC
- Begin writing report

February 16 Complete Report Preparation

ATTACHMENT A

DATE	TIME	ACTIVITY	SPEAKER
11-		Travel	
12-Feb			
	8:00 AM	Pick up at Hotel	
	8:30 AM	Meeting with EI, EIE, and Engineering Staff	
	10:30 AM	Welcome and Summary of EIEG activities	M. De Puy
		PART I: LANDSLIDE CONTROL PROGRAM & CUT WIDENING PROGRAM	
	11:00 AM	Cut Widening Program Performance and Summary of EDM data	L. Fernandez
	11:30 AM	Stabilization of Old West Lirio & Culebra Village Slide	C. Reyes
	12:00 m	Break for Lunch	
		PART II: THE NEW BRIDGE ACROSS GAILLARD CUT	
	1:00 PM	West Excavation Design for the New Bridge over the Canal	R. Rivera
	3:00 PM	East Excavation Design New Bridge over the Canal	M. Barrelier
	5:00 PM	Return to Hotel.	
13-Feb			
	8:00 AM	Pick up at Hotel	
	8:30 AM	Helicopter & Launch Trips	
	3:30 PM	Round table on Gaillard Cut Issues and New Bridge	
	5:00 PM	Return to Hotel.	
14-Feb			
		PART III: THE TRINIDAD DAM PROJECT	
	8:00 AM	Pick up at Hotel	
	8:30 AM	Introduction to Trinidad Dam Project	M. De Puy
		•General Geology of Trinidad Dam Area	P. Franceschi

		•Engineering Properties of the Atlantic Muck •Analysis of Settlement of the Gatun Locks Center Wall, A Back Analysis	M. De Puy F. Guerra
	12:00 m	Break for Lunch	
	1:30 PM	Private conference call with Prof. Morgenstern	

	2:30 PM	•Analysis and Stability of the Proposed Dam	M. De Puy, M. Barrelier, A. Abrego
	4:00 PM	Round table on Trinidad Dam	
	5:00 PM	Return to Hotel	
15-Feb		**PART IV: REPORT PREPARATION**	
	8:00 AM	Pick up at Hotel	
	8:30 AM	Prepare for meeting with the Administrator	
	9:00 AM	Meeting w/Administrator and EI, EIE,EIEG	
	10:00 AM	Report Preparation	
	12:00 AM	Break for Lunch	
	1:00 PM	Report Preparation	
	5:00 PM	Return to Hotel	
16-Feb		**PART V: REPORT PREPARATION**	
	8:00 AM	Pick up at Hotel	
	8:30 AM	Report Preparation	
	12:00 m	Break for Lunch	
	1:00 PM	Report Preparation	
	5:00 PM	Return to Hotel	
17-Feb		Travel	

November 2, 2001

Mr. Agustín Arias
Director of Engineering and Projects Department
Autoridad del Canal de Panamá
Balboa Heights, Republic of Panama

Dear Mr. Arias:

Re: Geotechnical Advisory Board, Meeting No. 11

The 11th Meeting of the Board took place in Panama from October 28 to November 2, 2001. The agenda for the meeting is included as Attachment A.

The Board appreciated the opportunity to meet with the following people, and to brief them on its observations and preliminary recommendations, prior to completion of this report:

Mr. Alberto Alemán Zubieta, Administrator, Autoridad del Canal de Panamá

Mr. Agustín Arias, Director, Engineering and Projects Department

Dr. Luis D. Alfaro, Manager, Engineering Division

Mr. Maximiliano De Puy, Manager, Geotechnical Branch

The Board welcomed the opportunity to inspect selected sites within the Gaillard Cut, both by launch and on foot. It is important for the Board to assess the field conditions as encountered in order to remain sensitive to the complex geological and hydrological conditions associated with slopes along the cut.

The Board was briefed on the variety of activities undertaken by the Geotechnical Branch. They cover a number of site specific geotechnical designs, erosion control, breakwater rehabilitation, the Cut Widening Program (CWP), the Landslide Control Program (LCP) and the Gatun Dam Seismic Study (GDSS). In addition, the Geotechnical Branch has made a number of contributions to the capacity expansion projects, such as the new Cut Deepening Project (CDP).

In the debriefing meeting with the Administrator, issues associated with canal deepening were raised. The Board responded that this is not without risk and the implications will have to be evaluated carefully.
The major items reviewed by the Board pertained to the LCP and the GDSS. Extensive presentations were made to the Board by the staff of the Geotechnical Branch. Both the written

and the oral presentations were at a uniformly high quality. The familiarity of the staff with many important details was impressive, and adds to the confidence that the Board has developed in the work of the staff.

The Board, in various forms, has been advising the Engineering Division of the Panama Canal Authority for about fifteen years. This was marked by a special celebration that essentially coincides with the successful completion of the Second Gaillard Cut Widening Program. The Board is grateful for this recognition and looks forward to being of further service to the Authority in the years to come.

This report consists of observations, comments, and recommendations under the following headings:

1. Progress on Recommendations of the 10th Meeting of the Board
2. Cut Widening Program (CWP)
3. Landslide Control Program (LCP)
4. Cut Deepening Project (CDP)
5. Gatun Dam Seismic Study (GDSS)
6. Summary
7. Next meeting

1. PROGRESS ON RECOMMENDATIONS OF THE 10th MEETING OF THE BOARD

The 10th Meeting of the Board, held from February 12-16, 2001, concentrated on an assessment of the feasibility of the Trinidad Dam Project. Progress with respect to the CWP and LCP was also discussed. The Board also considered the role of PCA staff in the design of the foundations of the new bridge across the Canal.

The Board recommended:

(1) That it believed the Trinidad Dam to be technically feasible; a way forward to a full feasibility study was outlined.
(2) That additional survey points (EDM) be added, as well as replaced, in the LCP.
(2) That comparisons between GPS and EDM surveys be pursued further within the LCP.
(3) That the PCA establish contract procedures for emergency-response remediation of slope movements.
(4) That PCA staff avoid taking responsibility for the foundations of the new bridge proposed to cross the Canal.

In response to these recommendations. The Board was advised that:

(1) The Mobile District of the C of E has been retained to conduct a feasibility study of the Trinidad Dam concept to a level comparable with competing concepts. It is anticipated that the Board will review this study at its next meeting.
(2) Additional survey points have been added to the EDM system.
(3) No specific progress has been made with respect to items (3) and (4) above.
(4) The PCA will not assume responsibility for the foundations of the new bridge.

In addition, the Board recommended at the 10th Meeting that a number of items be considered at the 11th Meeting, and they all appear on the agenda. In general, the Board is content that the recommendations arising from the 10th Meeting have been adopted in an acceptable and reasonably complete manner.

2. CUT WIDENING PROGRAM

The Board was pleased to learn that with the anticipated completion of the Tie Up Station (CWP 18) in December 2001, the entire Cut Widening Program will be complete. This program has been completed on time, and within budget, to the credit of the staff of the Geotechnical Branch. As anticipated, the program has caused some unavoidable disturbance to the ensitive slopes in the Gaillard Cut, which will be discussed below. To date there have been no major problems, but continued monitoring and vigilance are required.

In the report of the 9th Meeting, the Board recommended that steel mesh be installed on portions of the freshly excavated faces of Gold Hill to prevent dislodged boulders from bouncing into the Canal, or onto passing ships. This work has now been completed, and in addition, most of the lower portion of the face (composed of agglomerate) has now been covered with shotcrete. The benefit of the shotcrete is somewhat offset by the impediment to drainage that it presents. It should be anticipated that long-term maintenance of the shotcrete will be required. Nonetheless, the mesh and shotcrete will improve safety beneath the face.

3. LANDSLIDE CONTROL PROGRAM

3.1 Components of the Landslide Control Program

The Landslide Control Program (LCP) currently includes the following activities:
(1) field inspection, (2) monitoring of surface movement by means of EDM systems, (3) subsurface monitoring by means of open wells and piezometers, (4) drainage maintenance, (5) road maintenance, and (6) design of remedial measures. During the past year, these activities have been intensified as a result of slope-failure activity related to widening of Gaillard Cut.

3.2 Monitoring of Slope Surface Movements by EDM Systems

Of the above active components of the Landslide Control Program, only the changes and summarization of the results of the EDM system will be discussed here. The surface-movement data obtained by this system have proved to be extremely valuable in identifying those slopes needing mitigation, particularly when filtered through the "Alert!!" warning system. In general, the number of EDM survey points in the Gaillard Cut has decreased somewhat in the past couple of years, mainly by destruction during excavation for canal widening. In July 1999, there were approximately 350 EDM survey points in the Cut; by December 2000, the number had fallen to 315, and, by September 2001, to 304. Since the slopes of the Gaillard Cut continue to be at high risk because of climate, seismicity, and sensitivity to recent cut widening and possible future channel deepening, we recommend that this system not be further depleted, and that additional EDM survey points be installed.

3.3 Alert!! Criteria

At the International Symposium on Landslides (Trondheim, 1996), the following criteria were proposed as a warning for potentially dangerous slope movements: Alert!! occurs when the horizontal movement along the current resultant vector has a monthly increment greater than 30 mm or a total accumulated value greater than 100 mm. As of September 2001, 58 of the 304 EDM survey points (19%) exceeded the Alert!! criteria. The sectors with the greatest number of EDM points exceeding Alert!! criteria were Sardinilla (9), Hodges (9), Model (8), Culebra (7), Lirio (6), and Cucaracha (6). This does not mean that slopes in these sectors are in a state of imminent failure; it does mean that they should continue to be observed closely.

3.4 Current Notably Active Areas

At this meeting, four significant individual Gaillard Cut landslides were described as having undergone recent or continuing activity. These were: the West Culebra, East Culebra, Purple Rock, and Cucaracha South Extension slides. The Board visited each of these in the field.

3.4.1 West Culebra landslide

The 2001 West Culebra landslide is most likely a reactivation of the 1915 West Culebra slide. Earlier slide activity was reported in the area between 1900 and 1914. No dry excavation was carried out in the area for canal widening; however, underwater excavation was being undertaken at the time of sliding, and probably was the immediate trigger for reactivation.

By December 2000, horizontal displacement on the slide ranged from 1-2.5 m. Because movement of the toe of the slide impinged on the channel, maintenance forces immediately removed some of the toe portion, which probably reduced the overall stability of the mass. Movement apparently is continuing, and remediation is needed.

The Board see the possibility of one or more of the following remedial measures: (1) changing the driving force by removing material from the head of the slide, (2) installation of an underwater buttress or shear key, and/or (3) drainage.

Of these, drainage will probably prove to be the cheapest; both surface and horizontal drains should be considered. However, it may be that much of the slide area is too flat to be drained effectively by horizontal drains.

Removing material from the head of the slide at first seemed to be an obvious solution. However, cursory field observation showed us that the geology in the head area is only poorly understood. Removal of material in this area may lead to unforeseen head-wall instability, and possible failure. Thus, the geology in the area at the head of the West Culebra slide (particularly at the north end of the slide) should be determined in detail before any substantial unloading is proposed from this part of the slide. Mapping of the geology in this area will be a low-cost endeavor that should be undertaken irrespective of which remedial measures are used. Detailed examination of the crack patterns should be undertaken to lead to a better understanding of the kinematics of the slide.

Installation of a buttress or shear key at the toe of the slide (in the channel) can proceed independently. Details of such a measure should be carefully considered in regard to possible future deepening of the channel.

3.4.2 East Culebra landslide

In spite of no cut widening in this stretch of the canal, the toe of East Culebra slide has impinged on the channel more than 2 m in the past 2-3 years. This movement is evidenced in the field by scarps that are continuing to develop at the north and south margins of the head of the slide. A survey traverse should be run along the road connecting these two scarps to see if both scarps are related to a single slide movement. This traverse should be resurveyed about once a month. The board recommends no additional remediation on this slide at present.

3.4.3 Purple Rock slide

Although Purple Rock is undergoing continued movement, this activity appears to be both shallow and deserves additional study.

3.4.4 South Cucaracha Extension slide

The total horizontal movement of this slide between 1995 and July 2001 was about 300 mm. To date, the slide is being monitored, but no remediation has been attempted. The Board recommends that the following remediation options be studied: (1) removal of material from the head of the slide, (2) installation of horizontal drains, and (3) improvements in surface drainage. These active measures should be compared with the alternate of removal after encroachment into the Canal.

3.5 Landslide Control Program Development

The Landslide Control Program is entering a new phase following completion of the Cut Widening Program. The Board recommends that an operational protocol for the LCP be developed, as outlined in the Board's report of September 1999. This protocol should include consideration of landslide characteristics such as volume, potential velocity and potential run-out distance, in relation to risk of encroachment on the shipping prism and the need for emergency response plans. The protocol should address landslide detection, identification of mechanisms, analysis, design of stabilization measures, and the need for catchments to contain landslide debris.

The 1988 report prepared by Luis Alfaro, "The Risk of Landslides in Gaillard Cut", provides an excellent basis for evaluation of these risks and an evaluation of field data through 1988. Updating this report to the current conditions after cut widening will provide a very valuable tool for development of the operational protocol.

An essential part of assessment of the significance of slope movements and design of appropriate remedial measures is the correct identification of the sliding mechanism. It is important that study of the geologic conditions and evaluation of movement data be reviewed carefully to be certain that the sliding mechanism is understood before performing computer analyses of stability.

As outlined in our report of February 2001, the Board recommends that the ACP issue one or more "stand-by" or "task-order" contracts for slope remediation work, to reduce the length of time between identification of the need for slope remediation and the beginning of construction work in the field.

The Board was informed that EDM data will be entered into a GIS database being developed to serve various purposes for management and maintenance of the Canal. It is recommended that the personnel of the Geotechnical Branch perform a study to explore the potential use of the GIS system for geotechnical purposes, and that they work with the database developers to ensure that the structure of the system will be able to accommodate current and future geotechnical needs. The use of GPS for remote continuous monitoring of ground movements has been discussed with personnel of the Geotechnical and Survey Branches. At the Board's suggestion, it has been agreed that a trial will be performed, using the two available radio-GPS units, to monitor movements on the West Culebra slide. The result of this trial will be used to assess the potential for use of GPS for monitoring ground movements in other areas.

4. CUT DEEPENING PROGRAM

A new proposal to deepen the existing canal is under consideration. This is planned to include additional blasting below the proposed excavation depth in order to eliminate additional drilling and blasting costs from any subsequent deepening project. As a result, the sum total of excavation and blasting will either remove or damage rock to a depth of about 20 feet, depending upon the reach. This will reduce the passive resistance providing support against landslides encroaching into the Canal.

The loss of toe restraint associated with cut deepening increases the risk of initiating a large mobile landslide. The Cut Deepening Program is advancing rapidly. Therefore, a priority geotechnical consideration is to: (1) screen out those reaches where cut deepening may proceed without aggravating serious landslide risk and then, (2) evaluate whether mitigation is needed to reduce risk on the remainder.

The Board looks forward to reviewing progress on this assessment at its next meeting.

5. GATUN DAM SEISMIC STUDY

5.1 Commentary on Studies

At the 9th Meeting of the Board, specific recommendations were made regarding the completion of the seismic analysis of the Gatun Dam embankment. The Board is pleased to receive and review the results of this work. The PCA engineers and scientists have completed a complex, state of the art, dynamic analysis of the embankment. The Board will offer some comments and suggestions regarding soil structure interaction issues under section 5.3. The Board looks forward to the completion of the reports and urges that the results be considered for publication.

The Board is pleased to receive the results of the review of construction records, drawings and photographs. This information was useful in developing five detailed cross sections considered typical of the embankment.

5.2 Site Characterization

Historical and recent boring logs were used to develop and refine the five cross sections considered in the analyses. Field and laboratory test data were evaluated to develop soil properties to be used in both the static and dynamic analyses required to evaluate the behavior of the dam during and immediately after the design earthquake. Once the cross sections had been developed, the so called "Chinese Criteria" were used to subdivide the materials into potentially liquefiable and non-liquefiable zones as recommended in the Board's report of Meeting No. 8. Because the soil property values vary rather widely, analyses were conducted using ranges of property values. Cyclic Stress Ratios (CSR) were computed using WESHAKE, a one dimensional wave propagation computer code used to compute dynamic stresses in the embankment generated by the design earthquake. A critical input parameter is the acceleration record. For this analysis, a number of actual records recorded during the 1985 Chilean and 1991 Limon earthquakes were used. These records were scaled to a peak ground acceleration of about 0.55g, which represents a mean plus one standard deviation of the world-wide data for M 7.7 events of the anticipated type 35 km from the source. Of these earthquake records, the Siquirres record of the 1991 Limon earthquake imposed the most severe loading on the embankment. This is because the record is rich in motion in the range of 2 Hertz.

Cyclic Resistance Ratios (CRR) were determined for the potential liquefiable material from SPT and CPT values. Values of K(sigma), K(alpha) and K(magnitude) were chosen based on the Board's recommendations of Meeting No.8. For potentially liquefiable material, the CSR values were greater than CRR values, and liquefaction was predicted to trigger. Work by Stark and Mesri was used to estimate the post-liquefaction residual strength. For the non-liquefiable material, the peak undrained strength was reduced by 20% as an element of conservatism. The values used were consistent with those recommended by the Board at Meeting No.9.

Limit equilibrium slope stability analyses were conducted on each cross section for the post earthquake condition using undrained degraded and residual strengths. Factors of safety close to 1.0 were calculated for specific assumed failure surfaces in the downstream slopes of Sections A and E. It should be noted that the critical slip surface was near the downstream toe in Section E, and does not intersect the crest of the dam in either Section A or E.

State of the art permanent deformation analyses of the cross sections were performed using these degraded and residual undrained strengths within the computer codes PLAXIS and FLAC. Small vertical and horizontal movements (less than a meter) were predicted for the downstream slope in Section A. Tolerable vertical (less than 2 meters) and horizontal movements (less than 10 meters) were predicted for the downstream slope near the toe in Section E. Other minor damage, such as minor cracking and small lateral spreads, is to be expected. None of these expected deformations pose a threat to the safety of the dam.

5.3 <u>Commentary on Conclusions</u>

The Board agrees with the conclusions presented. If an earthquake of M 7.7 generating motions similar to those in the Siquirres record of the 1991 Limon earthquake occurs on the North Panama Deformed Belt, producing a peak ground acceleration at Gatun Dam of 0.55g, tolerable deformations are predicted in the embankment. The Board concludes that these deformations do not constitute a threat to dam safety because:

a. The occurrence of a M 7.7 earthquake at 35 km producing a maximum of 0.55g with a frequency content similar to the Siquirres record is a rare event.

b. Under normal operating conditions, Gatun Dam has 5.5 m freeboard.
c. The downstream slope is 1 on 12, which is relatively flat. This slope is about 400 m in length. Permanent deformations are predicted to be small in comparison to the length of the slope, and the deformations are expected to be near the toe.
d. No predicted failure surface intersects the crest of the dam.

In summary, the predicted behavior of the Gatun embankment will not result in release of the reservoir, and is therefore not a risk to the safe operation of the Panama Canal or a hazard to life or property downstream.

5.4 Additional Comments

Despite the conclusion that Gatun earth dam would survive the design earthquake with only superficial and repairable damage, studies remain to be completed on the spillway, locks, and other structures.

The Board was concerned that the installation of a filter might be required adjacent to the walls of the spillway to assure that a crack caused by differential movement between the spillway and the embankment could not lead to piping. To its delight, the Board discovered, based on construction records, that the spillway walls were constructed with concrete keys extending into the embankment from the spillway wall, which should prevent the possibility of piping caused by differential movement.

The Board was made aware of the progress in evaluating the seismic response of the spillway in a cooperative effort involving the staff of the Geotechnical Branch, Professor Anil Chopra of the University of California, Berkeley, and Dr. Robert Hall of the Engineer R&D Center, U.S. Army Corps of Engineers. Work is being carried out on the seismic adequacy of the Gatun Spillway, the Miraflores Spillway, and the Madden Dam.

To date, the principal area of concern to emerge from the analysis is a possible inadequacy of the spillway piers in the Gatun Dam. Further analysis of these piers is on-going.

As part of the effort to evaluate the seismic adequacy of all these structures, Drs. Chopra and Hall have recommended the development of probabilistic equal-hazard spectra. The Board supports this recommendation. The preparation of these design spectra should be a straightforward extension of the analyses already completed.

It is important that the evaluation of individual components of the Canal system be carried out in the context of an overall analysis of the vulnerability and system risk to the safety and operation of the Canal. In other words, what are the overall requirements for the performance of the Canal? Next, how would damage to, or the failure of, one of these components impact the functioning of the Canal? In this way performance requirements can be established for each component to address both safety and operational issues, and to determine what level of damage, if any, is acceptable.

The Board calls attention to the recommendation on seismic risk analysis contained in the report of its 9th Meeting. It would appear that modern techniques of vulnerability and risk analysis will be an important management tool to defend against possible disruptions in the operation of the Canal in the face of many other possible threats in addition to earthquakes.

6. SUMMARY

The Geotechnical Advisory Board met in Panama from October 28 – November 2, 2001. The Board received a number of high quality presentations and debriefed the Administrator prior to the preparation of this report.

The Board was pleased to see the successful completion of the Cut Widening Project (CWP). The face of Gold Hill has been protected from raveling. The Board anticipates that the shotcrete cover will require maintenance in the future.

The Landslide Control Program (LCP) has identified a number of areas where slope movements have occurred, following the Cut Widening Program. Of these, the West Culebra landslide is the most hazardous and requires more detailed study. The Board has given direction in this regard. Comments on the other active area have also been provided.

The Board has reiterated its recommendations that, following the completion of the CWP, the LCP should produce a manual to establish its design and operational protocols. This should include landslide risk assessment, involving estimates of encroachment, and the need for emergency plans. Guidance has also been offered on the extent of the EDM network, the development of a GIS database and the use of GPS.

With regard to the proposed Cut Deepening Program (CDP), the Board has noted that it is not without risk of initiating significant landslide movements and that studies of its impact should proceed as a high priority.

The Board was also pleased to see the finalization of the Gatun Dam Seismic Study (GDSS), subject to completion of reports. This has been a major undertaking and has resulted in a positive conclusion; namely, that any deformation of the embankment associated with the design earthquake does not constitute a threat to dam safety.

The Board has reminded the PCA of the merit in extending the seismic risk assessment to the Canal as a whole, viewed as a system.

The Board was advised that review of the proposed Trinidad Dam will be considered at its next meeting, scheduled for April 17-22, 2002.

7. NEXT MEETING

The Board anticipates a meeting during the week of April 17-22, 2002. Topics to be addressed include a review of the feasibility analysis for the Trinidad Dam, issues related to the planned deepening of Gaillard Cut, and the ongoing efforts of the Landslide Control Program to deal with currently active slopes. The Board recommends that the Mobile District, Corps of Engineers be advised of this next meeting and of our desire to receive a copy of their final report six weeks prior to its meeting.

James M. Duncan

Robert L. Schuster

William F. Marcuson III

Robert L. Wesson

Norbert R. Morgenstern

Attachment A

ATTACHMENT A

Agenda for the 11th Geotechnical Advisory Board Meeting

October 28 – November 2, 2001

GEOTECHNICAL ADVISORY BOARD MEETING No. 11
Agenda of sessions for October 29 - November 2, 2001

Sunday, October 28
Travel

Monday, October 29

INTRODUCTION

8:00 a.m.	Pick up from hotel to Administration Building
8:30 a.m.	Welcome and Summary of Geotechnical Branch activities (M. De Puy)

PART I: LANDSLIDE CONTROL PROGRAM & CUT WIDENING PROGRAM

9:00 a.m.	Cut Widening Project Performance, Summary of EDM Data and Landslide Control Performance (L. Fernandez)
10:00 a.m.	Break
10:15 a.m.	Events at Gaillard Cut: (C. Reyes) South Cucaracha Purple Rock West Culebra Slide East Culebra Slide
11:30 a.m.	Break for Lunch
1:00 a.m.	Rock Fall Protection at Gold Hill & Contractors (J. Arrocha)
2:00 p.m.	Construction of the Panama Canal (Dr. W. F. Marcuson)
4:30 p.m.	Return to Hotel

Tuesday, October 30

8:30 a.m.	Pick up from Hotel to Administration Building
9:30 a.m.	Launch Visit to Gaillard Cut
11:30 a.m.	Break for lunch
1:00 p.m.	Land Visit to Gaillard Cut East Side: Gold Hill, South Cucaracha, Purple Rock & East Culebra West Side: West Culebra & Hodges
3:00 p.m.	Open Discussion with Geotechnical Branch Staff
4:30 p.m.	Return to Hotel

PART II: DAM SAFETY PROGRAM, GATUN EARTH DAM

Wednesday, October 31

8:30 a.m.	Pick up from Hotel to Administration Building
9:00 a.m.	Review of Site Characterization and Stratigraphy of Gatún Dam (M. Barrelier) Review Cyclic Resistance Ratio (CRR) (M. Barrelier)

	Review of Weshake Analysis (M. Barrelier)
	Ru estimation from Factor Safety against Liquefaction (M. Barrelier)
10:30 a.m.	Break
10:45 a.m.	Estimation of Undrained Shear Strength Ratio (M. Barrelier)
	Pre and Post-Earthquake Stability Analysis of Gatún Earth Dam (M. Barrelier)
12:00 a.m.	Break for Lunch
1:00 p.m.	Large Deformation Analysis (A. Abrego & M. De Puy)
4:30 p.m.	Return to Hotel

Part III: REPORT PREPARATION

Thursday, November 1

8:00 a.m.	Pick up from Hotel to Administration Building
8:30 a.m.	Meeting with the Administrator Mr. Alberto Alemán and the Director of the Department of Engineering and Projects Mr. Agustin Arias
9:30 a.m.	Open for discussion and Report Preparation
12:00 p.m.	Break for Lunch
1:00 p.m.	Open Discussion with Geotechnical Branch Staff
2:30 p.m.	Report Preparation
4:30 p.m.	Return to Hotel

Friday, November 2

8:30 a.m.	Pick up from Hotel to Administration Building
9:00 a.m.	Report Preparation
12:00 p.m.	Break for Lunch
1:00 p.m.	Report Preparation
4:30 p.m.	Return to Hotel

Saturday, November 3

Travel

April 21, 2002

Mr. Agustín Arias
Director of Engineering and Projects Department
Autoridad del Canal de Panamá
Balboa Heights, Republic of Panama

Dear Mr. Arias:

Re: Geotechnical Advisory Board, Meeting No. 12

The 12th Meeting of the Board took place in Panama from April 18 to 21, 2002. The agenda for the meeting is included as Attachment A.

The Board appreciated the opportunity to meet with the following people, and to brief them on its observations and preliminary recommendations, prior to completion of this report:

Dr. Luis D. Alfaro, Manager, Engineering Division, and Acting Director, Engineering and Projects Department

Mr. Jorge de la Guardia, Manager, Canal Capacity Projects Division

Mr. Maximiliano De Puy, Manager, Geotechnical Branch

The Board welcomed the opportunity to inspect selected sites within the Gaillard Cut, both by launch and foot, and a spoil storage area from the current phase of channel deepening.

Prior to arrival in Panama, the Board had been sent and reviewed certain materials related to the proposed Lower Trinidad Dam Project. These included Panama Canal Reconnaissance Study, Identification, Definition and Evaluation of Water Supply Projects, Vol. I, December 31, 1999; Vol. III (draft), March 1, 2002; letters commenting on the proposed Trinidad Project by David E. Kleiner and John Clark; memoranda commenting on Vol. III by ACP Staff, and the scope of work given to the U. S. Army Corps of Engineers for Vol. III.

While in Panama, the Board was briefed on selected activities of the Geotechnical Branch, including the Channel Deepening Program (CDP) and activities of the Landslide Control Program (LCP) related to the West Culebra Slide, the Southeast Cucaracha Slide and Purple Rock. In addition, the Board was briefed by Mr. Jorge de la Guardia on Water Studies and Channel Deepening Alternatives, and by Mr. Robert W. Chamlee, Chief, Geotechnical and Dam Safety Section, Mobile District, U.S. Army Corps of Engineers, on the proposed Lower Trinidad Dam.

The principal focus of the meeting was the Lower Trinidad Dam. In particular, focus was on consideration of the adequacy of work completed to date as a basis for determining the feasibility and cost of this project in comparison with other projects that the ACP is considering to increase the water supply to the Canal.

The oral presentations made by ACP Staff were of high quality. As always, the familiarity of the staff with many important details was impressive, and reinforced the confidence of the Board in the work of the staff.

This report consists of observations, comments, and recommendations under the following headings:

1. Progress on Recommendations of the 11th Meeting of the Board
2. Channel Deepening Program
3. Landslide Control Program (LCP)
4. Proposed Lower Trinidad Dam
5. Summary
6. Next meeting

1. PROGRESS ON RECOMMENDATIONS OF THE 11th MEETING OF THE BOARD

The 11th Meeting of the Board, held from October 28 to November 2, 2001, focused on the CWP, LCP and the Gatun Dam Seismic Study (GDSS).

The Board recommended:

(1) Additional geologic mapping, and analysis of remedial options for the West Culebra Landslide.
(2) Analysis of remedial options for Southeast Cucaracha Landslide and Purple Rock.
(3) Periodic survey traverses across the East Culebra Slide to determine whether the observed scarps are related to a single slide movement.
(4) Testing of Geographic Information System (GIS) and real-time global Positioning System (GPS) technology for use in the LCP.
(5) The development of a manual to establish design and operational protocols for the LCP.
(6) That studies of the impact of the CDP on slope stability proceed with high priority.
(7) That seismic risk assessment be extended to the Canal as a whole, viewed as a system.

At this, the 12th Meeting, the Board was briefed on:

(1) Remedial plans for the West Culebra and Southeast Cucaracha Landslides, and Purple Rock in response to items (1) and (2) above.

(2) An analysis of the impact of the CDP on slope stability within the Gaillard Cut in response to item (6) above.

In addition, the Board was informed that a baseline had been established across the East Culebra Slide in response to item (3) above. Additional surveys will be made during the rainy season.

No specific progress was reported on items (4), (5) and (7) above. In so far as the primary focus of the current meeting was on the proposed Lower Trinidad Dam and in view of the relatively short interval since the last meeting, the Board understands that there has been insufficient time to complete these tasks. However, the continuing need for an articulation of the strategy underlying the LCP is reiterated in Section 3.1 below.

2. CHANNEL DEEPENING PROGRAM

In January 2002, work was initiated to increase the depth of the Canal by lowering the bottom elevation from 37 ft PLD to 34 ft PLD. The purpose of the current work, which is being done with in-house forces, is to increase the reliability of the Canal for handling traffic with draft of 39.5 ft. This modest deepening of the channel is not expected to have a significant effect on slope stability in Gaillard Cut.

Two possible additional channel deepening projects are being considered to meet future demand. The first of these would reduce the channel bottom elevation to 29 ft PLD, and the second would lower the channel bottom elevation to 24 ft PLD. These greater reductions in channel bottom elevation would significantly affect the stability of many slopes in Gaillard Cut.

During the past few months the Geotechnical Branch has performed a study to evaluate the effects of the two possible additional deepening projects on the slopes. This study is summarized in a three-volume report entitled "Study on the effect of deepening on Gaillard Cut slopes," dated April 2002.

The primary purpose of the study was to identify those reaches of Gaillard Cut where deepening of the channel will de-stabilize the slopes sufficiently to require stabilization measures, and to estimate the extent of the required stabilization measures for budgeting purposes. The studies provide a solid basis for cost estimating, and they also serve as a suitable means of identifying those areas that would be most affected by channel deepening.

If the deepening projects are undertaken, detailed design studies will be required at each of the sections where the slopes require stabilization.

The studies included consideration of 10 different conditions for each slope, as shown in the table below:

Case No.	Channel bottom elevation, and description
Case 1	32 ft PLD – current condition, allows for 2 ft of overdredging
Case 2	32 ft PLD – with very soft or weak (blasted) material from 32 ft to 27 ft PLD
Case 3	27 ft PLD – allows for 29 ft bottom elevation with 2 ft of overdredging
Case 4.1	27 ft PLD – with underwater excavation only
Case 4.2	27 ft PLD – with underwater and dry excavation to stabilize slopes where this was found to be necessary
Case 5	32 ft PLD – with very soft or weak (blasted) material from 32 ft to 22 ft PLD
Case 6	22 ft PLD – allows for 22 ft bottom elevation with 2 ft of overdredging
Case 7.1	22 ft PLD – with underwater excavation only
Case 7.2	22 ft PLD – with underwater and dry excavation to stabilize slopes where this was found to be necessary
Case 8	22 ft PLD – with very soft or weak (blasted) material from 22 ft to 16 ft PLD

Consideration is being given to drilling and blasting below the depth of excavation to eliminate the necessity of a second or third phase of drilling and blasting should a second or third phase of channel deepening be undertaken. The "pre-blasted" material left in the bottom of the Canal would have low strength, a fact that was accounted for in the analyses of Cases 2, 5, and 8.

Deepening the channel bottom using a cutter-head dredge capable of excavating even the hardest materials without drilling and blasting would have the advantage that the strength of the material below the channel would not be affected.

The shear strengths and stability mechanisms used in the stability analyses were selected based on the geologic conditions in each reach. Separate stability models were used to represent each of the various geologic conditions along the Cut. Groundwater conditions used in the analyses were based on water levels observed in traveler pipes, multi-point piezometers, Casagrande piezometers, and core logs where available. Where information was lacking, piezometric levels were based on judgment. In cases where the average pore pressure ratio (r_u) was less than 0.3, the piezometric levels were raised to establish an average pore pressure ratio of 0.3.

The Board believes that the methods used in the study were appropriate for the purpose, and commends the Geotechnical Branch personnel for accomplishing such an extensive and highly effective study so efficiently.

The risk of triggering slope failures as a result of channel deepening are greatest where one or more of these conditions prevail:

- Stability in the pre-deepening condition relies significantly on toe resistance, which will be diminished or eliminated by the deepening.
- Stability in the pre-deepening condition relies on fully softened strength or higher strength, and slope failure has the potential to reduce the shear resistance to its lower residual value.
- Stability in the pre-deepening condition is marginal, and the potential for improving stability by slope flattening is limited. Many slopes where past failures have occurred have marginal stability at present.

The hazard posed by channel deepening is greatest where slides have the greatest potential for high mobility, i.e., rapid movement of material into the navigation prism.

The study report identified three areas as problematic. These are the East Culebra Slide, the West Culebra Slide, and the Purple Rock Slide.

The stability of the East Culebra Slide is marginal (computed factor of safety = 0.9). The slide mass is moving slowly, with cracks and scarps visible in the moving mass. Excavation for channel deepening will reduce the factor of safety. Excavation to flatten the slope is contemplated as a remedy. The Board suggests that, in addition to the section perpendicular to the canal axis that has been analyzed, a diagonal section extending from the base of Gold Hill to the northwest should also be analyzed, to examine the possible consequences of the excavation on the stability of Gold Hill.

The stability of the West Culebra Slide is also marginal (computed factor of safety = 1.0). The area is undergoing slow movements toward the Canal, with cracks opening throughout the area between the Canal and the steeper upland slope. The mechanism apparent in the field casts doubt on the effectiveness of excavation as a remedy. The Board believes that sealing cracks, grading, and establishing vegetation to improve runoff and reduce infiltration of surface water will address the condition more effectively.

The stability of the slope in front of Purple Rock is also marginal (computed factor of safety = 0.8). Excavating the softer material in front of Purple Rock will expose more of the face, which shows signs of raveling. The Board believes that it will eventually be desirable to stabilize the face of the Purple Rock, and to establish a monument near the front of the rock to make it possible to determine if the massive part of Purple Rock is moving. The monument should be founded deep enough so that it will not be affected by superficial phenomena.

3. LANDSLIDE CONTROL PROGRAM (LCP)

3.1 Principles of Landslide Control Program (LCP)

While the LCP has not been a dominant portion on the agenda for this meeting, the Board is of the opinion that it would be timely and productive to review the principles and the general aspects of practice that guide the LCP.

In the view of the Board, the LCP has two objectives:

a. To avoid volumes of landslide debris entering the navigational channel of the Canal of such magnitude that it would impact traffic operations.
b. To contribute to the cost-effective management of the actual and potential landslides along the Canal right-of-way.

The major tools utilized in the LCP include the following:

a. landslide recognition
b. landslide monitoring
c. limit equilibrium analyses
d. calculated percentage change in factor of safety as a design criterion
e. re-grading, primarily slope flattening
f. ground water drainage
g. surface water drainage

The Board requests that Canal Staff summarize for discussion their views on the principles and practice that guide the LCP. This had been recommended in the report of Meeting No. 11.

Experience suggests that the risk to navigation only arises when landslides occur that display extreme mobility. The Board notes that an updated synthesis of Canal experience with regard to noteworthy runout events is lacking. Such a synthesis could be useful in guiding landslide risk assessment. The Board recommends that such a synthesis be assembled, to incorporate slope geometry, material type, rainfall history, and mobility. A discussion of some non-runout events during periods of high rainfall would also be of value. This synthesis should be an item of discussion at the next meeting of the Board.

3.2 West Culebra Landslide

In its November 2, 2001, report, the Board noted that underwater excavation for canal widening was probably the immediate trigger for the 2000 reactivation of this slide. By December 2000, horizontal displacement on the slide ranged from 1-2.5 m. Because movement of the toe of the slide impinged upon the channel, maintenance forces immediately removed some of the toe portion, which undoubtedly reduced the stability of the slide mass. Preliminary remedial work consisted of excavation of surface load from the head and the toe of the slide. While removal of material from the head of the slide proved beneficial, this effort was limited by existing large basalt boulders in the area and by contact with a near-vertical basalt contact on Zion Hill at the head of the slide, which imposed serious limitations to excavation. Excavation of surface materials from the toe area of the slide had a negative effect on stability. New EDMs installed on the slide detected horizontal displacement of the excavated toe slopes on the order of 1-1.8 m within 3 months after the excavation was completed.

At present, the slide mass continues to exist in an unstable condition. Movement continues toward the channel. Cracks and grabens continue to form in the toe area of the slide.

The Board agrees with Geotechnical Branch plans to reduce the active load on the slide by additional excavation in the head area (estimated volume of excavation: 340,000 m^3). As part of this excavation, large basalt boulders derived from Zion Hill will have to be removed. It also will be necessary to install a protective barrier (probably a wire mesh) to control falling rock from the basalt and Pedro Miguel agglomerate faces of Zion and Hodges' Hills during this excavation. The wire mesh will protect against minor rock falls. However, extreme caution should be exercised in this inherently hazardous work, and a safe work plan should be developed.

Assistance in establishing stability of the overall West Culebra landslide mass can also be gained by a slight re-grading of the currently almost flat toe area of the slide. The Board recommends that the toe area be re-graded to the following approximate specifications:

(1) Fill all cracks.
(2) Overall slope ~ 0.5% toward the canal and drainage swales.
(3) Fine-grained compacted and grassed surface soils.
(4) Grassy swales with good surface drainage.

One of the concerns voiced in the Board's report of November 2, 2001, was that the geology in the Zion/Hodges Hill area is only poorly understood. Thus, there remains the possibility that removal of material from the head of the landslide may lead to unforeseen head-wall instability and possible catastrophic failure. Thus, the geology, including mapping of joints, in the area at the head of the West Culebra slide (particularly at the north end of the slide) should be determined in detail before any substantial excavation is attempted from this part of the slide. It is important that the geologic structure of this mass be understood to the same degree as that of Gold Hill. Mapping of the geology in the Zion/Hodge's Hill area will be a low-cost endeavor that should be undertaken irrespective of which remedial measures are used.

3.3 Southeast Cucaracha Slide

The Southeast Cucaracha Slide (also known as the South Cucaracha Extension slide) occurred on November 27, 2001, with an approximate volume of 25,000 m^3, of which about 7,000 m^3 crossed into the navigation prism. However, traffic was not interrupted by the slide. The dredge Christensen removed slide material that had moved into the channel. The shallow, mobile slide (maximum thickness ~ 15 m) apparently occurred along a semicircular failure surface in the Cucaracha formation, with tension cracks in the head area and a head scarp abutting the Pedro Miguel agglomerate and some basalt, which prevented headward progression. EDM readings indicate that the landslide mass is continuing to move slowly toward the Canal; maximum lateral movement since November 27, 2001, has been approximately 80 mm during the dry season.

In its November 2, 2001, report, the Board recommended that the following remediation options be studied:

(1) Removal of material from the head of the slide.
(2) Installation of horizontal drains.
(3) Improvements in surface drainage.

Theoretical back analysis of this mobile mass by the Geotechnical Branch arrived at a remedial solution consisting primarily of costly excavation of Pedro Miguel agglomerate beyond the current head scarp. The Board believes that this excavation will be unnecessarily expensive, and that it is not warranted by the minor risk to the Canal entailed by this shallow landslide.

Instead of excavation of the mass of Pedro Miguel agglomerate above the head scarp, the Board recommends the following less-intrusive, and less-costly, remedial measures:

(1) Collect and direct upslope water away from the slide area.
(2) Construct a lateral surface drainage ditch immediately upslope from the tension cracks in the landslide head area to direct surface water away from the cracks.
(3) Remove potential Cucaracha landslide material from the crest, of the slide.
(4) Install a system of horizontal drains in the Pedro Miguel agglomerate.

The Board feels that these less costly measures will inhibit mobility at this site so that movement into the channel can be controlled at maintenance level.

3.4 Purple Rock

In its report on Meeting No. 11, the Board noted that the on-going movements at Purple Rock were shallow and suggested that they deserve additional study.
ACP Staff have evaluated the conditions at Purple Rock, and they observed that degradation has been by weathering, with much of the exposed rock ultimately entering the navigation channel. A number of limit equilibrium analyses of the slope in front of Purple Rock have been carried out; these analyses reveal only marginal stability. Ultimately, channel deepening would likely destabilize the frontal mass, exposing more of Purple Rock and leading to additional disintegration by surface fragmentation. ACP Staff proposed stabilization and protection of the current exposed face.

The Board does not regard the current raveling of Purple Rock to be a significant failure mode, unless is can be argued that it severely impacts Canal operations. Therefore, the Board judges the proposal to remedy "Purple Rock to be a low priority, given the current competition for available funds. The Board recommends that Purple Rock be kept under observation and that the need to implement stabilization measures be re-visited at a later time.

4. PROPOSED LOWER TRINIDAD DAM

4.1 Background

The Panama Canal Reconnaissance Study dated 31 December 1999, by the Mobile District, Corps of Engineers, evaluated some 34 options for increasing the water supply for the operation of the Canal, municipal use and power generation. This study ranked the Lower Trinidad Project 13th with a benefit/cost ratio of 1.4. As a result of this study and the relatively low ranking of the Trinidad Project, the ACP asked the Board to review the project, paying specific attention to work performed under contract to the PCC in the early 1960's. The ACP called Board Meeting No. 10 with the main purpose being to review information related to the Lower Trinidad Dam Project. Copies of the 1963 reports on this project by Shannon and Wilson, Inc., and Tudor Engineering Co. were provided to the Board. During this 10th Meeting, the Board received briefings on site geology, on properties of the Atlantic Muck, and on foundation settlement, deformation, and stability. The Board suggested tentative design concepts and outlined a recommended approach. Step (1) of the recommended approach was to conduct a detailed feasibility study to be accomplished by a team experienced in dam design assisted by engineering personnel of the ACP.

Prior to this 12th Meeting, the Board received and reviewed:

- Panama Canal Reconnaissance Study Vol. I, dated 31 Dec 1999 (Sections 1, 2, 3, 4, and 16), prepared by the Mobile District of the Corps of Engineers.

- Panama Canal Reconnaissance Study vol. II (Section 35), prepared by the Mobile District of the Corps of Engineers.
- Panama Canal Reconnaissance Study Vol. III (draft), dated 1 March 2002 (Sections 36 to 45), prepared by the Mobile District of the Corps of Engineers.
- Letter from David E. Kleiner, dated February 8, 2002, with an addition to conclusion and recommendation on a separate undated sheet.
- Updated letter from John Clark
- Memorandum from ACP to IPC, dated Feb 13, 2002.
- Memorandum from ACP to IPC, dated Mar 13, 2002.
- Scope of work for the USACE, reconnaissance study of the Trinidad Dam project.
- Compact disk (Power Point presentation), prepared by the ACP Geotechnical Branch.

Section 36 – Panama Canal Reconnaissance Study, Vol. III (draft), presents a reconnaissance-level assessment of Lower Rio Trinidad 22.9 m to 30.5 m., and estimates the total project first costs to be $812,304,000.

During the 12 th Meeting, a comparison among Indio, Lower Trinidad and Channel Deepening to 27.5 PLD was presented as competing options with project construction costs estimated to be $280,000,000; $812,000,000; and $300, 000,000, respectively. The Board also received a presentation by Robert W. Chamlee, Mobile District, Corps of Engineers, regarding the Corps' recent reconnaissance study discussed in Draft Vol. III, dated 1 March 2002.

The Mobile District reconnaissance study proposed a dam with submerged slopes of 1(V) to 15 (H) and suggests that construction of the embankment might require phased construction allowing time for foundation consolidation and associated strength gain between phases.

4.2 Commentary

The Board is disappointed in the results of the Mobile District work. It does not seem to the Board that the study made sufficient use of the following:

- The Tudor and Shannon & Wilson work of 1963,
- the current literature regarding submarine construction on soft soils,
- the input from ACP geotechnical staff,
- experience with complex construction in similar geologic environments, involving construction techniques such as placing geotextiles and wick drains in a marine environment.

The Board believes that the necessary data exist to conduct a detailed feasibility study producing a cost estimate with a reliability similar to those for Indio and Channel Deepening. This is envisioned as a desk study requiring no further fieldwork. The Board also believes that the current cost estimate might be significantly reduced by more accurate embankment material costs and more realistic embankment volumes. After study completion, valid comparisons among the three options (Indio, Trinidad and Channel Deepening) can be made. Such comparisons are not possible today.

4.3 Recommended Approach

The Board recommends that ACP assemble a Study Team consisting of ACP engineers and scientists, geotechnical engineering embankment design consultants, (the Study Team Consultant), contractors with experience in marine earthwork and dredging (the Study Team Contractor), and specialty contractors, such as wick drain contractors. This Study Team should have the experience and background needed to produce a bounded, reliable cost estimate and to design a test-fill which will be required to further refine the cost estimate.

The Board anticipates that this study would provide the following:

(1) Establish in a transparent manner whether or not the Lower Trinidad Dam is feasible based on existing proven technology.
(2) Provide a cost estimate for the proposed design(s) utilizing experience–based costs, appropriate to Panamanian conditions.
(3) Indicate the likely uncertainty associated with the cost estimates.
(4) Indicate the value of a test fill in reducing the uncertainty associated with the cost estimates.

The Board expects the feasibility study to evaluate, but not be restricted to, the following elements of design and construction:

(1) Grubbing, Shallow Dredging and Waste Storage, and Silt control: The Board anticipates that the submerged trees will have to be removed, and that shallow dredging of very soft sediments will be required from the footprint of the dam. The method statement and cost estimate are best obtained from ACP Staff and the Study Team Contractor.
(2) Separation layer: The Board anticipates that a geotextile or equivalent, will be placed between the Atlantic Muck and an overlying sand/gravel blanket. Experience with reclamation in Asia may be relevant. Some input is needed from the Study Team Consultant. The method statement and cost estimate will be obtained from the Study Team Contractor.
(3) Sand/Gravel Blanket: The Board anticipates that a sand/gravel blanket will be placed over the separation layer. It must provide drainage for the wick installation, and must not be liquefy under the design earthquake. The thickness, composition and density will be defined by the Study Team Consultant. The method statement and cost estimate are best obtained from the Study Team Contractor.

(4) Wick Drains: The Board anticipates that wick drains will be utilized, with wick drains installed at a pre-determined spacing and depth. Considerable experience with deep installations is available from Asian reclamation works and the Kennecott Tailings Dam, Salt Lake City. The Study Team Consultant will provide the design. The method statement and cost estimate are best obtained from a Specialist Contractor.

(5) Separation Layer: The Board anticipates that an additional separation layer will be used between the sand/gravel blanket and the overlying fill. This replicates the input described in (2) above.

(6) Fill Characterization: The characteristics of the fill and its scheduled availability control the design, construction and cost of the underwater fill (submerged berm). The Board anticipates that ACP strategic planning will guide the initial choice of fill sources and their availability. With this guidance, the Study Team Consultant can establish the likely material characteristics while the Study Team Contractor advises on the method statement and the unit cost estimate. The Board perceives two different conditions under which the dam may be constructed, but there may be more. They are:

(a) Construction of the dam without construction of new locks.
(b) Construction of the dam with new locks.

In the first instance, fill would be available from the current Channel Deepening Phase, previously accumulated spoil dumps, prescribed dry borrow areas, or advanced excavation for new locks and associated deepening. In the second, available fill from lock construction and associated deepening would likely be more attractive.

(7) Submerged Berm: The Board anticipates that the design of the submerged berm will indicate the required geometry to provide adequate stability and the measures, if any, required for seepage control. All submerged berm construction will be performed by means of floating plant. The Study Team Consultant will provide the design and the Study Team Contractor will provide the method statements and unit cost estimates. There may be a number of alternatives that merit consideration.

(8) Sub-aerial Dam: The sub-aerial dam will require special consideration of long term settlements and the provision of seepage control measures. Fill placement is expected to employ conventional measures, but hydraulic fill placement need not be excluded. The Study Team Consultant will provide the design while the Study Team Contractor provides the method statements and unit cost estimates.

(9) Specialty Measures: In addition to wick drains, a number of specialty measures may be needed, such as cutoff installation, non-traditional wave protection measures, vibro-densification, etc. The Board expects the Study Team to consult with experienced specialty contractors to establish acceptable method statements and unit cost estimates.

(10) Test Fill Design: The Board is of the view that a test-fill will be necessary as input to final design, and as a result, the design of a test-fill is a specific task for this Study Team. The Board expects that the Study Team will demonstrate that the Lower Trinidad Dam is feasible. In addition, the Board anticipates that there will remain an undesirably large uncertainty associated with the cost estimate, driven primarily by uncertainty regarding construction methods, dam foundation performance, and their impact on schedule. The primary objective of the test-fill would be to reduce this uncertainty.

The test fill would be constructed at a location on the dam center-line and at an appropriate scale. The test would pilot Items 1-6 outlined above. The Study Team would provide the design, construction method and cost estimate for the test-fill. Following the submission of the report by the Study Team, the ACP will be in a position to evaluate the merits of proceeding with the proposed test-fill.

The Board believes that a duration of one year is appropriate to complete the envisaged study. It involves no new fieldwork and could be accelerated, if that is in the interest of the ACP.

During this meeting, the Board orally briefed Dr. Luis Alfaro, Mr. Jorge de la Guardia and Mr. Maximiliano De Puy, and at that time suggested examples of firms that had the background and hands-on experience necessary to participate in the feasibility study as team members.

The Board recommends that the planning and contractual arrangement for this feasibility study include the following considerations:

- The work should be procured in a manner that is based heavily on experience with similar marine earthwork construction and with similar soft foundation conditions.
- The solicitation should contain a technical section which will require the bidder to discuss in some detail previous work experience directly related to marine construction, placement of dredged material, foundation stabilization/treatment using wick drains, etc.
- Another portion of the Request for Proposals (RFP) should be a cost proposal for unit prices for labor.
- A weighting scheme can be developed to weight various aspects of the proposal, to assure that team members have the needed capability.

The Board would be pleased to participate in the initial meeting of the Study Team to be sure that the objectives, scope, purpose and desired outcomes are effectively and articulately communicated. Additionally, the Board would welcome the opportunity to periodically review study progress and/or provide additional direction and focus.

5. SUMMARY

The Geotechnical Advisory Board met in Panama from April 18-21. Prior to arrival, the Board reviewed materials relevant to the proposed Lower Trinidad Dam. In Panama, the Board received additional presentations on Lower Trinidad Dam, on the Channel Deepening Program (CDP) and on the Landslide Control Program (LCP). The Board met with senior ACP Staff prior to preparation of the report.

The Board was impressed with the extent of analysis applied to potential slope stability problems associated with the CDP. Appropriate caution is being directed to the slopes with the largest potential for problems, particularly East Culebra, West Culebra and Purple Rock.

The Board remains concerned about the need for an overall strategy for decision making in the LCP and urges completion of a review and synthesis of experience and development of a integrated strategy.

The Board recommends that geologic studies be expanded in the area of Zion and Hodges Hill above the head of the current West Culebra Slide, and that the remediation efforts on that slide emphasize reducing infiltration on the lower portion of the slide.

The Board believes that the proposed excavation of the Southeast Cucaracha Slide is not warranted. Instead, the Board recommends an increased effort to improve drainage of the slope, and only minor excavation.

The Board recommends that Purple Rock be kept under observation and that the need to implement stabilization measures be reviewed at a future time.

The Board does not believe that the analysis carried out to date is adequate to compare the proposed Lower Trinidad Dam project with the other competing projects in terms of feasibility and cost.

The Board recommends the assembly of a Study Team consisting of experienced consultants, contractors and ACP Staff, to conduct a feasibility study and cost estimate of the proposed Lower Trinidad Dam project. The Board recommends that this Study Team be assembled with great care to insure that its members have modern experience in similar marine earthwork on a soft foundation. The Board recommends that the deliverables of this study consist of a refined conceptual design taking into account proven construction techniques, a definitive conclusion about the feasibility of construction, a cost estimate with significantly reduced uncertainty, and the design of a test-fill. Based on these results, the Board believes that the ACP would be in position to compare the Lower Trinidad Dam project with the other competing projects.

6. NEXT MEETING

The Board is prepared to meet within the next several months to participate in a startup meeting with the recommended Study Team for the Lower Trinidad Dam feasibility study, if the ACP accepts this recommendation. Otherwise, the Board anticipates that its next meeting would focus on the Landslide Control Program and would occur in Spring 2003.

Mr. Agustín Arias, April 21, 2002
Subject: Geotechnical Advisory Board, Meeting No. 12

James M. Duncan

Robert L. Schuster

William F. Marcuson III

Robert L. Wesson

Norbert R. Morgenstern

Attachment A

12th Geotechnical Advisory Board Meeting, April 16 – 22

<u>Tuesday, April 16</u>

GAB review of sent documents in USA

<u>Wednesday, April 17</u>

Travel

<u>Thursday, April 18</u>

<u>Part I</u>: EFFECT OF CHANNEL DEEPENING ON GAILLARD CUT SLOPES

8:00 a.m.	Pick up at Hotel El Panama
8:30 a.m.	Welcome (L. D. Alfaro)
9:00 a.m.	Introduction (M. De Puy)
10:00 a.m.	Study on the Effects of Channel Deepening on the existing Gaillard Cut Slopes (staff)
12:00 a.m.	Break for lunch

<u>Part II</u>: LANDSLIDE CONTROL PROGRAM

1:00 p.m.	Stabilization Analysis of West Culebra Slide (C. Reyes)
2:00 p.m.	Stabilization Analysis of South Cucaracha Slide (M. Barrelier)
3:00 p.m.	Discussion
4:00 p.m.	Return to Hotel

<u>Friday, April 19</u>

<u>Part III</u>: REVIEW OF LOWER TRINIDAD PROJECT

8:00 a.m.	Pick up at Hotel
8:30 a.m.	Canal Capacity Division presentation (J. de la Guardia)
9:30 a.m.	Presentation of Lower Trinidad Project (USACE and Canal Capacity Division Staff)
10:30 a.m.	Coffee Break
11:00 a.m.	Discussion with USACE, CC and IPIG personnel
12:00 a.m.	Break for Lunch
1:00 p.m.	Discussion with USACE, CC and IPIG personnel
4:00 p.m.	Return to Hotel

Saturday, April 20

8:00 a.m.	Pick up at Hotel
8:30 a.m.	Field visit to South Cucaracha and West Culebra Slide
11:00 a.m.	Return to Building

Part IV: **REPORT PREPARATION**

11:00 a.m.	Discussion with Geotechnical Br. Staff
12:00 a.m.	Break for lunch
1:00 p.m.	Report Preparation
4:00 p.m.	Return to Hotel

Sunday, April 21

8:00 a.m.	Pick up at Hotel
8:30 a.m.	Report Preparation
12:00 a.m.	Break For lunch
1:00 p.m.	Report Preparation
3:30 p.m.	Return to Hotel

Monday, April 22

Travel