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GEOLOGICAL COMPLICATIONS AND COST OVERRUNS:

A SURVEY OF BANK-FINANCED HYDROELECTRIC PROJECTS

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ABSTRACT

This note reviews the significance of geological complications in hydroelectric projects and proposes guidelines for reducing their occurrence. It surveys 64 Bank-financed hydro projects and reveals that over 35% of them have experienced unexpected geological difficulties resulting in average civil works cost overruns of over 65%, with tunneling the main component of civil works affected. The paper also reveals that civil works cost contingency allowances for hydro projects in general, and those with geological problems in particular, have been far below the actual values, warranting need for a change in the Bank's approach to cost contingencies for civil works in such projects. The paper proposes development of a data base on hydro project parameters vs. cost overruns and for a review of alternative geo-science techniques for site investigation and their use in quantifying construction uncertainties.

GEOLOGICAL COMPLICATIONS AND COST OVERRUNS:

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Summary

1. The objectives of this paper are to: (i) evaluate the extent of geological complications in hydroelectric projects financed by the Bank; (ii) estimate the project cost overruns and completion delays due to geological problems; (iii) propose precautionary measures to reduce geological surprises; and (iv) propose directions for future studies.

2. The survey covered 64 Bank-financed 1/ hydroelectric projects and concludes that geological difficulties caused major cost overruns and completion delays in 23 projects (36%); civil works cost increased on average by over 65%.

3. Project risks arising from uncertain geology must be treated much more explicitly in preparing and appraising Bank projects subject to such uncertainties. Projects incorporating long tunnels (over 5 km), having large undergound works, or founded in karstic (soluble) limestone are *prima facie* candidates for more rigorous treatment including:

(i) analysis to determine the impact of risk on project justification;

(ii) a requirement that the engineering consultant establish a probability distribution for costs of risky components;

(iii) more involvement by panels of experts in reviewing risk aspects of projects, and

(iv) use of more generous physical contingency allowances for risky project elements when formulating financing plans.

4. There is a need to collect project information in an easily-accessible data base to be used by Bank staff in assessing project risk, and to prepare guidelines on state-of-the-art site investigation techniques.

Background

5. The impetus for this study came from an impression among Bank staff that geological complications were largely responsible for cost overruns and

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1/ Includes IDA.

completion delays in hydroelectric projects. This impression has been reinforced by some major geological problems in current Bank-financed hydro projects. For example, the 300-MW Chixoy Hydroelectric project in Guatemala, comprising a 108 m high rockfill dam and a 25.6 km long power tunnel, was to be completed in 1982 and cost $414 million. However, as of February 1985, the total cost estimate has been raised to $815.8 million with expected completion, four years behind schedule, in 1986. About 90% of the cost increase and the delay is attributed to numerous geological complications encountered during construction of the power tunnel and the dam.

6. Hydroelectric projects account for a large share of the power loans provided by the Bank. Table 1 compares the number and the amount of Bank loans for total power and for hydropower projects between 1976 and 1984. As shown in this table, 21% of power projects in this period are hydroelectric, accounting for 30% of total power loans. Furthermore, hydro projects are a major contributor to cost overruns in the power sector. The survey of 105 power projects, audited by the Operations Evaluation Department, indicates that hydroelectric projects' average cost overrun is over 40% compared to 18% for non-hydro. The large scale of hydroelectric lending plus associated high cost increases justify an attempt to understand uncertainties in project costs and also to improve the cost estimating process.

Table 1: WORLD BANK GROUP LENDING FOR ELECTRIC POWER 1976-1984

	No. of Projects		Bank Loans in $ million	
	Power	Hydro	Power	Hydro
1976	20	4	949.0	208.0
1977	17	5	952.0	186.0
1978	19	6	1,146.0	348.0
1979	19	3	1,355.0	183.0
1980	25	4	2,392.3	780.9
1981	17	4	1,323.0	845.6
1982	21	1	2,121.2	106.8
1983	15	9	1,585.0	495.0
1984	24	2	2,651.3	1,125.9
Total	177	38	14,474.8	4,279.2
Share	100%	21%	100%	30%

7. Cost overruns usually lead to immediate financial difficulties for power agencies. For one thing, the agency has to find additional capital to complete the project. In such cases neither the Bank nor other international or official lending agencies are eager to provide supplementary loans. The World Bank, specifically, has followed a restrictive policy on granting supplementary loans and only in a few selective cases have supplementary funds been provided. So the power agency may be forced to borrow from private sources at whatever terms are available. Completion delays can also have a more penetrating economic consequence by causing higher economic opportunity costs due to electricity shortages or supply unreliability. This is estimated to be one order of magnitude higher than the sale value of electricity.

8. In general, power projects are selected from a set of alternatives based on conventional least-cost program planning. The selection process is partially handled through computational tools where the net present cost of electricity generation is minimized over a planning period of up to 30 years. Comparative calculations in these schemes are based on the original cost and completion estimates at the feasibility or appraisal stages. So, major cost overruns and completion delays could directly, or indirectly through higher opportunity costs, make the initial selection process for the least expensive power supply alternative invalid. In such cases, the borrower will be forced to live with the expensive option and due to limited financial resource availability, forego future expansion plans.

Cost Estimates and Cost Overruns

9. The appraisal cost estimate for a project serves two purposes. The first is to determine whether the project being considered is a part of the optimal least cost expansion program. The second is to provide the basis for the analysis of the financial future of the agency and thus to indicate the amount of finance that needs to be obtained. As mentioned earlier, if a project turns out to cost substantially more than expected, the question of economic justification may come up and certainly some kind of financing problems will be present.

10. Due to understandable uncertainty in cost estimates, usually some form of cost contingency is allowed at the appraisal stage. Cost contingencies are of two kinds:

(i) price contingency, based on the expected level of inflation and price escalation during construction; and

(ii) physical contingency, based on the anticipated modifications in design, engineering and construction work due to unforeseen circumstances.

11. The comparison of actual versus appraisal estimated costs requires special care. In practice, if a cost overrun shows signs of developing, the borrower may attempt to reduce the scope of the project in some way to conform to the original amount of funding estimated, unless additional financing is easily available. On the other hand, if there is a cost underrun, the

borrower will usually try to expand the project to fully utilize the available funds. The result is that the completed project may be significantly different from the project as planned during the appraisal stage, so a simple cost comparison between them would be misleading. The problem becomes even more complicated when one tries to define the level of cost overrun due to a single attribute such as unforeseen geological difficulties. In practice, cost overruns, as well as completion delays, may occur due to a host of technical, managerial, financial and political factors. These factors often overlap, thus, establishing the level of cost overrun based on one factor becomes almost impossible.

12. There is, however, a way to quantify the relative impact of an unforeseen technical difficulty on the cost of the project. This can be done by identifying the single most important component of the project affected by the technical problem, and comparing its estimated with its actual costs. For geological problems, this component is the civil works. Usually, geological difficulties cause extra excavation, additional steel lining, and additional concrete and guniting requirements, all of which fall under civil works. However, comparison of actual and estimated civil works costs does not indicate the extra engineering and design work costs, neither does it show the extra interest during construction due to completion delays.

Geological Considerations in Hydroelectric Project Preparation

13. Thorough investigation to determine the most desirable and economic site for a hydro project precedes design and construction stages. Such investigation includes surveys, topographic mapping, geologic studies and subsurface analyses. The geological work required to establish the feasibility of a hydro site can be separated into three phases, described as follows:

(i) **Reconnaissance surveys and hydrological studies.** This work would include map studies, delineation of the water basin, preliminary estimates of flow and floods, and brief site visits.

(ii) **Pre-feasibility studies.** During this stage of investigation, the work on the selected site or sites would include site survey and geological investigations, with drilling confined to areas where foundation uncertainty would have a major effect on costs; a reconnaissance for suitable borrow areas; and production of individual reports on each site.

(iii) **Feasibility study.** In this stage, work would continue on the selected site with a major foundation investigation program; delineation and testing of all borrow areas; estimation of diversion, design and probable maximum floods; determination of the project design earthquake and the maximum credible earthquake and production of a comprehensive report on the site.

14. The findings of the feasibility study will be the basis for the final design and engineering planning of the project. A change in conditions associated with the geo-sciences input, after the system planning and engineering stage, can result in dramatic project cost increases. The advisable extent of geological investigations depends in part on the magnitude of the project and on how obvious the subsurface conditions are. For hydroelectric projects this would also be dependent upon the availability and cost of alternative power resources.

15. The past experience in hydro-preparation costs indicates that on the average less than one percent of the total project cost is spent on feasibility, pre-feasibility, reconnaissance and hydrological studies before the engineering design is undertaken. This is a remarkably low number compared to potential cost overruns. Although more expenditure on preparation studies does not always translate into more accurate project cost estimates, obviously additional work will usually be required and justified when the project contains risky elements. The key factor in making an accurate "a priori" assessment of costs associated with the geo-sciences is a good understanding of the uncertainty involved with the data, with the interpretation of the data, and the analyses in establishing uncertainties and potential overruns in costs. There are three main elements involved:

(i) The resolution capability of the data in relation to the degree of complexity of the site's geological, seismological and geotechnical conditions;

(ii) The variations with respect to the interpretation of the data and the degree of uncertainty associated with the expert's judgement based on the data; and

(iii) The uncertainty associated with the analyses, (in the geo-sciences, many of the analyses are based on empirical data and there is a potential increase in uncertainty because actual site data may differ from the data in the empirical relationships).

These matters are discussed later in this paper after the results of the survey are presented.

Survey of Hydroelectric Projects

16. The purpose of this survey is to evaluate the extent of geological complications in hydroelectric projects financed by the Bank and completed, or well under construction, in the period 1974-1984. This will include identifying projects with geological problems, assessing their total and civil works cost overruns, their completion delays and the nature of difficulties encountered. The projects are divided into two categories: (i) those with Project Performance Audit Reports; and (ii) those without. For the past ten years the Operations Evaluation Department has evaluated completed Bank projects. The annual evaluation reports (1975-1984) are the major source of information for the projects in the first category. The projects in the

second category are either not completed, or completed but not yet audited by OED. The information on these projects are collected from various appraisal and president's reports, and also from periodic supervision reports. The study covers only projects with loans approved before the end of 1982. The more recent ones have not proceeded far enough to allow a meaningful analysis. It should be noted that the distinction between the two categories is necessitated only by the degree of availability of data. This will enable us to make more explicit cost comparisons between projects with and without geological problems in the first category, and will help in deriving conclusions.

17. For the purpose of this survey, first, all Bank-financed hydroelectric projects were briefly reviewed and the ones with any kind of geological difficulty during construction were identified. For these projects the evaluation or supervision reports were carefully studied to specify the nature of the complication as well as its impact on cost overrun and completion schedule of the project. Since the civil works component of project cost is directly related to the geological conditions of the site, the study also reviews this item. The comparison of other relevant cost components is done only in cases where the information was available. Annexes I and II give the list of the evaluated projects along with a brief description of their geological complications, cost overruns and completion delays. The following two sections summarize the results of the survey.

A. Hydroelectric Projects with Evaluation Reports

The ten Annual Reviews of Project Performance Audit Results (1975-1984) include 41 hydroelectric projects among which 13, 32%, had geological complications during construction. Table 2 lists these projects.

Table 2: AUDITED PROJECTS WITH GEOLOGICAL PROBLEMS

Projects	Country	Loan Approval	Cost Overrun %	Civil Works Cost Overrun %	Completion Delay %	Problems
Jaguara Hydroelectric	Brazil	1966	28	130	1/	dam site
Fifth Power	Chile	1966	31	n.a.	100	tunneling
Third Power	Honduras	1968	12	30	18	tunnelling, reservoir
Second ENDE Power	Bolivia	1969	13	30	74	tunneling
Volta Grande Hydro	Brazil	1969	130	174	1/	dam site
Third Power	Costa Rica	1969	84	131	44	tunneling, reservoir

Table 2: AUDITED PROJECTS WITH GEOLOGICAL PROBLEMS (continued)

Projects	Country	Loan Approval	Cost Overrun %	Civil Works Cost Overrun %	Completion Delay %	Problems
Finchaa Hydro-electric	Ethiopia	1969	23	36	23	tunneling
Pumped Storage Power	Ireland	1969	79	143	24	reservoir
Marimbondo Power	Brazil	1970	53.6	51	-	dam site
Kidatu Hydro-electric I	Tanzania	1970	32	68	-	tunneling
Kamburi Hydro-electric	Kenya	1971	9	34	19	tunneling
Sixth Power	El Salvador	1973	70	64	1/	tunneling
Sigalda Hydro-electric	Iceland	1973	37	43	18	reservoir

1/ See Annex I for details.

Among the 13, eight projects encountered serious geological difficulties during the construction of one or more of their tunnels, contributing to cost overruns of up to 84%. These projects were in Bolivia, Chile, Costa Rica, El Salvador and Honduras in Latin America, and in Ethiopia, Kenya and Tanzania in East Africa.

19. The extent and nature of problems are different for each case. The common denominator, however, is that the actual geological and hydrological conditions were very different from the originally anticipated ones. The project in Bolivia encountered decomposed and broken rock in various sections of the tunnel and also heavy infilteration of water in the inclined pressure shaft. In Chile, geological difficulties in Vega Larga-Lane Laja tunnel were much greater than expected. In Costa Rica, presence of igneous rocks and their water conditions in the 14.5 km Rio Macho tunnel caused extensive construction complications. In El Salvador the design of the 60 km Ahuachapan discharge tunnel was originally based on small-scale (1/100,000) aerial photogrammetric maps which proved to be dramatically inadequate. The scheme was found impractical and new design was required with four years completion delay. This part of the project cost $23.24 million instead of the estimated $2.6 million. In Honduras, presence of clay and fractured rock zones in the upstream tunnel caused great construction difficulties. In Ethiopia, poor rock conditions were encountered in both the power tunnel and the road tunnel. In Kenya, a geological fault was encountered during the construction of the tailrace tunnel. Finally, in Tanzania, poor rock conditions in the

headrace tunnel not only caused construction difficulties and subsequent changes in the design of the tunnel, but also caused changes in the design of the dam. The dam was originally designed as a rockfill dam with rocks supplied from the tailrace tunnel excavation; however, due to the poor rock conditions, it was redesigned as an earth-fill dam. The projects in Costa Rica and Honduras also encountered some geological problems during the construction of their reservoirs.

20. Among the remaining five projects, three had geological difficulties in the dam site and two faced problems in the reservoir. Interestingly enough, the three projects with site problems are in Brazil--Jaguara Hydro, Volta Grande Hydro, and Marimbondo Power--all on Rio Grande, where the discovery of poor geological foundation conditions required extensive extra civil works. In the Jaguara project, during the construction of the dam, a weak schist layer was uncovered and the layout had to be revised. The engineering cost was increased by 284% and the civil works cost by 130%. In Volta Grande, the foundation at the left embankment was found to be too weak. It was also discovered that the concrete structures were designed on top of a contact between flows which was not watertight. There were also problems with existence of a fault joint around the penstocks and the spillway foundation. The above problems caused a civil works cost overrun of 174% and engineering cost overrun of 474%. In the Marimbondo Power project, the discovery of poor geological conditions in the spillway and tailrace areas required substantial increase in excavation and concrete work. The civil works cost increased by 51%.

21. The last two projects in this category, one in Ireland and the other in Iceland, encountered reservoir problems. The difficulties in the Sigalda Hydro project in Iceland arose out of heavier-than-anticipated leakage of water through sink holes and other porous areas of the reservoir. In the case of the project in Ireland, unforeseen rock conditions necessitated redesign of the upper reservoir. The civil works cost overruns for these two projects are 43% and 143% respectively.

22. Figure 1 compares cost overruns of projects with and without geological complications in this category. The cost overrun for each year is the weighted average for all projects evaluated during that year. As shown in this figure, the 13 projects with geological problems have substantially higher cost overruns than the remaining 28. The only exception is in 1977 (Sixth Annual Evaluation Report) where cost overruns for two groups are very close. It should be mentioned that the notion of years in this figure only refers to the time of evaluation and does not reflect the actual construction time.

23 If the weighted average cost overrun over all audited hydro projects with and without geological problems is calculated, the comparison is even more expressive. In this case the 13 projects with geological difficulties show an average cost increase of 52% compared to 33% for the remaining 28. The same exercise for civil works cost overruns indicates a weighted average increase of 76% for projects with geological problems compared with 39% for projects without.

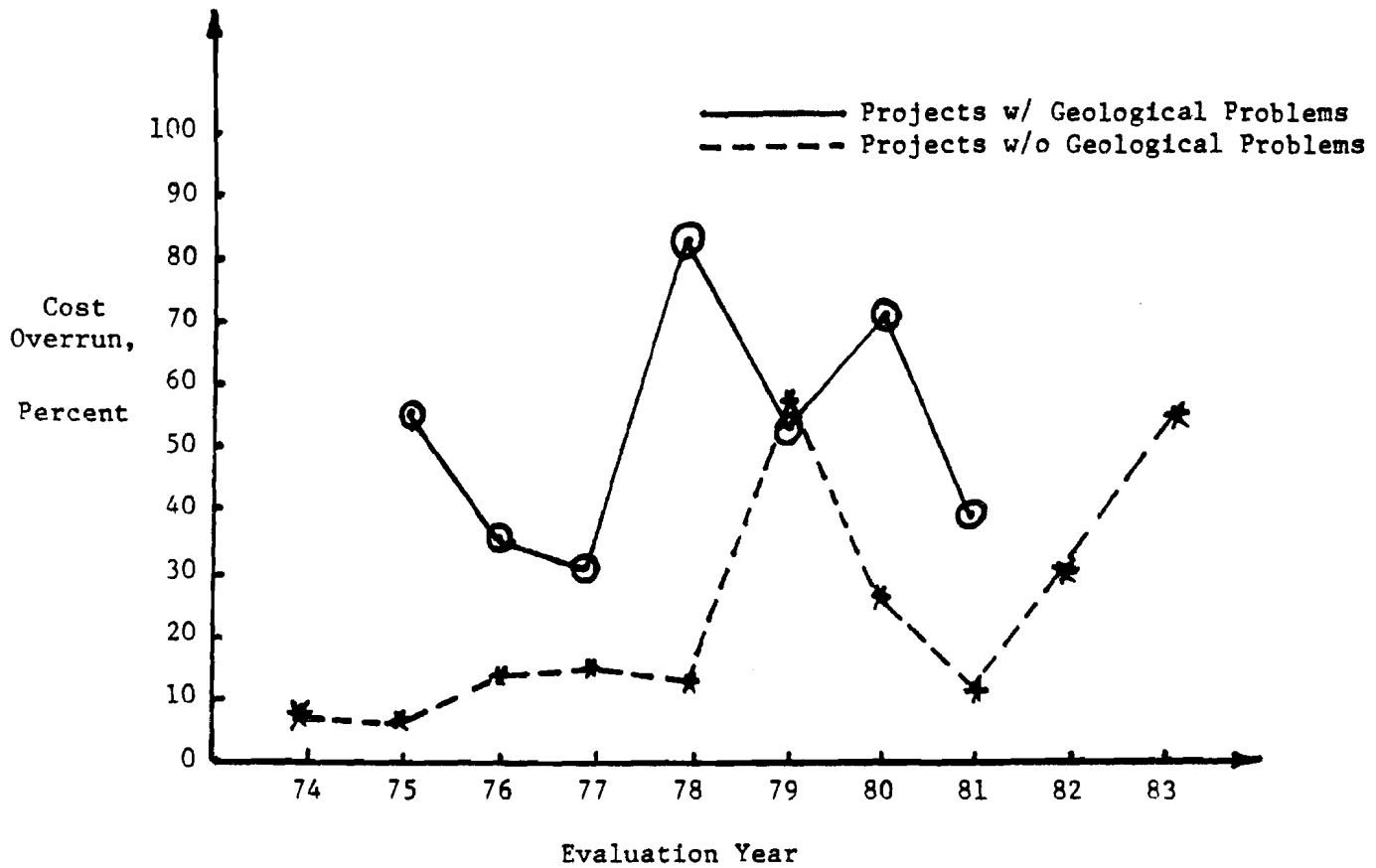

Figure 1: Weighted average cost overruns for hydroelectric projects with and without geological problems

B. Hydroelectric Projects without Evaluation Reports

24. In this category there are 23 projects with loans approved before the end of 1982. These projects are in different stages of construction and some are already completed. But, as of the end of 1984, evaluation reports have not been completed for any of the 23 (43%) which have encountered geological difficulties. In this group there are two projects in Colombia, two in Guatemala, and one in each of the following six countries: Honduras, Panama, Romania, Swaziland, Indonesia, and Nepal. Appendix II gives a summary of each project's cost, completion schedule and construction complications. Every project in this group has experienced some kind of geological problem during construction of one or more of its tunnels. This includes landslides, undetected faults, weak rock formations, soft and watery zones, etc. Three projects--one in Indonesia, one in Guatemala, and one in Panama--also encountered geological difficulties in other components.

25. Table 3 summarizes the results of the survey of projects in this category. As indicated in this table, four projects--Kulekhani Hydro in Nepal, Aguacapa Hydro in Guatemala, Fortuna Hydro in Panama, and Nispero Hydro in Honduras--are already in commission. All four encountered geological difficulties during tunneling. The Fortuna project in Panama also faced geological complications in the underground powerhouse, and the site of the right abutment which required additional design work and more excavation than expected. The cost overruns for these projects are 80%, 76%, 95% and 22% respectively with civil works cost overruns between 76% and 90%. For Nispero hydro project the civil works cost increased by 82% compared with 22% increase in total cost. This indicates the large scale of geological problems.

Table 3: NON-AUDITED PROJECTS WITH GEOLOGICAL PROBLEMS

Project	Country	Loan Approval	Estimated Cost Overrun %	Estimated Civil Works Cost Overrun %	Estimated Completion Delay (yr)	Problems
Riul Mare-Retezat Hydro	Romania	1976	16	n.a.	4	tunneling
Kulekhani Hydro-electric 1/	Nepal	1976	80	88	2	tunneling
Aguacapa Hydro 1/	Guatemala	1977	71	76	1	tunneling
Fortuna Hydro 4th Power 1/	Panama	1977	95	90	1	tunneling & other
Chixoy Hydro	Guatemala	1978	120	134	4	tunneling & other
Nispero Hydro 1/	Honduras	1978	22	82	2	tunneling

Table 3: NON-AUDITED PROJECTS WITH GEOLOGICAL PROBLEMS (continued)

Project	Country	Loan Approval	Estimated Cost Overrun %	Estimated Civil Works Cost Overrun %	Estimated Completion Delay (yr)	Problems
Mesitas Hydro	Colombia	1979	56	n.a.	3	tunneling
Tenth Power	Indonesia	1981	4	31	2	tunneling & other
Guavio Hydro	Colombia	1981	11	-3	2	tunneling
Third Power	Swaziland	1981	18	n.a.	1	tunneling

1/ Project is completed

26. For uncompleted projects, cost comparisons are not as readily possible but the following examples indicate that geological difficulties are also present in on-going projects.

(i) The Riul-Mare hydro project in Romania with extensive tunneling difficulties has so far had a cost overrun of 16% and there is no re-estimate of its civil works cost. The boring of the headrace tunnel is the main problem affecting the project. In 1983, parts of the pressure tunnel were blocked by clay-like material from a fault. This project so far is four years behind schedule although partly for reasons unrelated to civil works problems.

(ii) The Chixoy project in Guatemala, probably the most troublesome of all projects reviewed here, has so far experienced total and civil works cost overruns of 120% and 134% respectively. This project, too, is already four years behind schedule. It should be noted that because of the expected geological complications in this project, a civil works cost contingency of 24% was allowed during the appraisal. This is the highest physical cost contingency allowed among the projects studied in this report. The problems in this project are due to very complex rock composition in the long (25 km) power tunnel, and the dam site. During construction, extensive karstic limestone was found at the dam site and along the tunnel. It was also discovered that rock at the spillway was highly-fissured. In addition, several landslides occurred along the access roads, and the power tunnel caved in at a few places after showing an unacceptable level of water loss.

(iii) The Mesitas project in Colombia, with three years delay, so far has had a 56% cost overrun. There is no estimate of civil works cost increases for this project. Since this project encountered major managerial and technical problems, it is not

possible to pinpoint the extent of cost overruns due to geological difficulties.

(iv) The Tenth Power project in Indonesia, so far has a total cost overrun of 4% and a civil works cost overrun of 31%. The geological problems in this project are numerous and widespread and include landslides, geological weaknesses, poor rock conditions and rockfalls. The physical contingency allowed for this project is 15%.

(v) The project in Swaziland, with a six-month delay, has had a cost overrun of 18%. There is no estimate of civil works increases but the quantity of tunneling has increased by 40% so far. The geological problems for this project include: presence of large boulders mixed with soft material, presence of fault zones, lower bedrock than expected and mud-rush.

(vi) The Guavio hydro project in Colombia, the last one in this group, has had numerous underground and above ground geological problems which includes massive landslides, poor rock conditions and soft zones. However, the supervision reports indicate an estimated cost overrun of 11% and a civil works cost underrun of 3%. The project is currently scheduled for completion in 1989 with two years delay. The civil works cost underrun in this case is misleading since the quantity of civil works due to geological difficulties has greatly increased. There are two reasons for this inconsistency:

(a) Since the project was initiated during a high inflation period, a price cost contingency of 40% was allowed. The physical cost contingency was 15%. However, since the start of the project inflation has subsided and as a result part of the allowance for price escalation paid for extra quantities of civil works.

(b) It was originally envisioned that about two-thirds of the civil works would be done by foreign contractors paid with US dollars. It turned out that most of the work was contracted to local firms and the high value of the US dollar helped keep the total civil works cost down.

The estimated weighted average total and civil works cost overruns for projects with geological problems in this category are 33% and 63% respectively.

Conclusions and Recommendations

27. The survey of 64 Bank-financed hydroelectric projects indicates that geological difficulties have caused major cost overruns and completion delays for 23 projects (36% of total). Among 41 projects with evaluation reports 13, 32%, encountered geological complications during construction causing weighted average total and civil works cost overruns of 52% and 76% respectively;

compared to 33% and 39% for the 28 projects without geological problems. Among 23 projects without evaluation reports 10, 43%, faced geological problems causing an average increase of 35% in total cost and 63% in civil works cost. Completion delays of one to four years were observed frequently. Tunneling was the single most recurring component of civil works affected by geological problems. Among 23 projects with geological difficulties 18 encountered tunneling problems. This number represents 28% of all hydroelectric projects. Problems included landslides, undetected faults, weak rock conditions, soft and watery zones, presence of clay formations, etc. Leakage from reservoirs and poor dam-site conditions caused problems for eight projects.

28. Remedying the situation requires taking measures to: (i) reduce the occurrence of geological surprises, and (ii) recognize the extent of uncertainty involved and planning for it. It should be acknowledged that the Bank has been aware of the situation. Some evaluation reports, as early as 1975, pointed out the recurrence of geological problems and suggested more careful site investigation during appraisal. The Bank, in 1974, also developed a set of guidelines (GAS 6, attached as Annex III) with specific consideration for geological problems. But there is no indication of any systematic attention to the guidelines, neither is there any indication of improvement in reducing the occurrence of geological problems or the adequacy of cost-estimating procedures for hydro projects over time. As the results of this study show, the projects in the second category, with loans approved between 1975-1982, do not indicate a better track record than the first group, with loans approved between 1966-1974.

29. This experience indicates that project risks arising from uncertain geology must be treated much more explicitly in appraising projects having such uncertainties. However, given the current state of the art in evaluating geological conditions, it is impossible to prescribe specific approaches or minimum parameters such as total length of core drilling, number of adits required etc. which should be required for any given project because this aspect of engineering is still as much art as science. Given the current state of the art, Bank engineers should treat with skepticism all cost estimates which are based on extrapolation of site geology and, in effect, assume that costs of risky project components are unknowable within a broad range, say 50-300% of the estimate.

30. This suggests an approach for dealing with such uncertainties in project appraisal, involving establishing the robustness of project justification by testing the sensitivity of the justification to changes in costs of the civil works components of the project. The procedures outlined in OPN 2.02 1/ can be used provided the equalizing discount rate is known (the

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1/ Operations Policy Note No. 2.02 (issued as Central Projects Note 2.02, 12/77, 7/80), "Risk and Sensitivity Analysis in the Economic Analysis of Projects".

rate at which the present value of project costs equals the cost of the alternative development program). Alternatively, several runs of simulation models such as WASP may be required to establish maximum permissable levels of costs and construction time for the uncertain components, beyond which the project would no longer be part of the least-cost program. If the probability of exceeding these costs or delaying the project is high (i.e. above 30%) then additional site investigations should be required to reduce the uncertainty or the project should be dropped. The results of these studies should always be discussed in the Project Risks section of appraisal reports.

31. Probabilistic planning models are available which treat uncertainty rigorously; however, as yet none have been identified which are fully satisfactory for power development program planning, in general because the information requirements are large. Nonetheless, to anticipate the availability of such techniques it is desirable that terms of reference for project studies require that the engineer use probabilistic methods for developing estimates of project cost and construction time, especially for those components which are likely to be risky.

32. In this respect, it is possible to identify certain project characteristics which are prima facie risky. Chief among these is tunnels. The survey showed that all projects with long tunnels (more than 5 km) faced serious geological complications, with civil works cost overruns of over 60%. Defining what constitutes a "long" tunnel is subjective and depends primarily on the extent and quality of the site investigations. The geological conditions in a relatively long tunnel may still be reasonably well known if frequent test bores are available--say not less than every 1 km--or if the tunnel penetrates rock of known character (this extrapolation itself is risky!). On the other hand, even if frequent borings are available, extensive underground works such as powerhouse caverns are inherently risky because of the large dimensions. For example, an undetected fault in the power cavern of a project in Africa led to large time and cost overruns and was at least partly responsible for bankrupting the contractor.

33. Other obvious areas of risk include projects built in karstic limestone. Here uncertainties include not only the cost and difficulty of completing underground works, but also peripheral problems such as reservoir leaks. The quality and extent of site investigations is especially important in karstic areas and in such cases Bank engineers should take particular care to satisfy themselves that those undertaking the actual site investigations understand the nature of the potential problems. For example, it was discovered during construction of a large hydro project located in karstic formations that some of the site borings had gone completely through karstic caverns, yet the caverns had not been noted in the boring logs.

34. Dam foundations are also subject to large uncertainties in cost due to large variations in the amount and type of excavation required. For this reason, foundation excavation and treatment should always be costed separately from the dam itself. Not surprisingly, unit costs for dams proper are relatively predictable and in general the variations are small unless there are large changes in the volume of the dam, or in the dam type (e.g. shift

from rockfill to earthfill) because of unfortunate discoveries during construction. However, even changes of this magnitude can usually be accommodated within the usual ranges of contingency allowances. In part, this situation exists because consultants are able to calculate dam volumes and similar features (spillways) quite precisely. This is important because these features account for a large share of the project's cost, but emphasis on this work at the expense of focus on the less certain project components is a common problem during project preparation.

35. The range of problems identified during this study imply that the role of the board of experts constituted to review the safety aspects of the project, in accordance with OMS 3.80, 1/ might usefully be expanded to cover an assessment of the geological risks associated with the project, and the resulting probability matrix for cost and time overruns. If this assessment is not already included in the terms of reference of the engineering consultants, Bank staff should require the borrower to include such an assessment in the tasks assigned to the panel of experts. In fact, a review of this aspect of the project by the panel of experts may be desirable even if already included in the design consultants' terms of reference.

36. Part of the solution also has to do with the availability of means for understanding and reducing the level of uncertainty in geo-engineering analysis and cost estimation. There are two specific steps to be taken in this regard:

(i) The information on geological problems and cost overruns available from Bank projects should be collected in an easily accessible database where appraisal staff can compare similar parameters for different projects. For example, a database could be constructed to show historical cost overruns with respect to tunnel length, rock type, geological formations, regions, etc. In practice, a project officer intuitively uses the database available in his own memory. This systematic approach expands the memory and structures it more clearly. Such an effort requires careful selection of parameters and clear definition of dependencies among them. The survey shows, for example, that all projects with long tunnels faced serious geological complications, with civil works cost overruns of over 60%, a fact to be remembered for future projects. This report, along with GAS 6 should be used in the meantime to increase awareness of the extent and the uncertainty due to geological problems in hydro projects.

(ii) There is a need for a review of geo-science techniques in evaluating underground geological conditions for hydroelectric projects. This review should include comparison of different

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1/ Operational Manual Statement No. 3.80, "Safety of Dams".

site investigation techniques and their ability to quantify uncertainties. This in addition to the above-mentioned database will enable the project officers to better judge the accuracy or relative uncertainty associated with site characteristics and cost estimates.

Both of these tasks will be incorporated in future research programs.

37. For purposes of developing the financing plan for the project there is also need for a change in policy with regard to physical contingency allowances. This study reveals that among the 64 hydroelectric projects surveyed only four had civil works cost overruns of under 17%, and yet the maximum contingency allowance was 15% (with the exception of Chixoy project with 24% allowance). As stated earlier the average civil works cost overruns for projects with difficult geology was over 60% and for those without, over 40%. This contrast calls for a more realistic approach to project cost estimates.

38. In cases where there will be considerable uncertainty about underground conditions and related civil works costs, more liberal contingency allowances should be made for those particular components. This can be done within the guidelines for physical contingencies set out in OMS 2.28, paragraph 7, provided the contingency allowances for the entire project can be brought within the limits specified therein. Again the important determination is whether the probability of cost or time overruns is sufficiently high that the project would no longer be a part of the least-cost development program. No project should be allowed to go forward if this risk is high. Alternatively, if the project justification is robust, contingency allowances used for determining the required financing may be somewhat more generous than prescribed in OMS 2.28. 1/

39. In any case, where project costs are uncertain, the impact of potential cost and time overruns on the borrower's financial position should be evaluated, and potential sources of finance under these circumstances should be identified. The results of these analyses should be indicated in the staff appraisal report. If large cost overruns could be potentially disastrous to the borrower, then further site investigations, or other

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1/ Operational Manual Statement No. 2.28, "State of Project Preparation Necessary for Loan Approval". It should be noted that receipt of bids prior to Board presentation, as suggested in paragraph 3 of OMS 2.28, is not in itself an assurance that there will not be cost overruns on risky projects because contracts for complex works are almost always awarded on the basis of unit costs, with provisions for price escalation and changes in quantities. In only a few of the projects covered by the survey were the original contract prices significantly out of line with the base cost estimate.

measures to mitigate the impact of potential cost overruns, must be undertaken before the project proceeds. However, these other measures must not include onerous provisions such as fixed-price contracts for risky elements, or other schemes to transfer the risk to the project contractors. High risks do not justify a departure from the general contracting principle that risks should be borne largely by the project sponsor, although contract incentives to share with contractors the benefits of risk reduction are certainly encouraged.

ANNEX I: Description of Projects with Evaluation Reports

Project: Third Power

Country: Costa Rica

Loan No.: 631-CR **Date:** July 10, 1969

Project Performance Audit Report No.: 760 **Date:** May 29, 1975

Project Description: The principal component of the project was the Topanti scheme, extension of the existing Rio Macho plant. An intake on the Reventazon River and a 14.5 km tunnel were to be constructed to deliver additional water to the Rio Macho plant, where 2 x 30 MW generating units were to be installed. The project also included the installation of spillway gates with associated civil works to raise the reservoir level at Cachi by 20 meters.

	Estimate	Actual	Change %
Total Cost ($M)	25.7	47.3	84
Civil Works Cost ($M)	9.45	21.86	131
Construction Time (Months)	39	56	44

Remarks: The project faced major geological complications during the construction. The progress was on schedule for the first 3.4 km of the Rio Macho tunnel. However, the picture drastically changed for the worse once the tunnels reached the igneous rocks and their associated water conditions where average excavation program reached only 8 meters per week. The cost increase on the Topanti scheme (excluding interest during construction) accounted for 76% of the total project cost increase.

The cost increase on Cachi Reservoir accounted for 14% of total project cost increase. This part of the project was completed eleven months behind schedule. The delay, as well as the increase in cost, was mainly due to the permeability of the rock on the left abutment which proved to be much higher than expected. As a result additional grouting work was required.

Some 60% of the transmission lines and sub-stations originally included in this project were postponed so that funds could be available to cover part of the cost overruns of the Topani and Cachi projects.

Project: Third Power

Country: Honduras

Loan No.: 541-HO/Credit 116-HO **Date:** June, 1968

Project Performance Audit Report No.: 763 **Date:** May 30, 1975

Project Description: The principal component of the project was the Rio Lindo hydroelectric scheme. Water discharged from the Canaveral plant would be conducted through a steel pipeline, about 1350 m long, then through a 900 m tunnel to a regulating reservoir created by a 25 m high earth and rock-fill dam. A 350 m power tunnel and a long 5200 m steel penstock would bring the water to the power station. The project also included three transmission developments.

	Estimate	Actual	Change %
Total Cost ($M)	17.7	20.2	12
Civil Works Cost ($M)	11.6	15.1	30
Construction Time (Months)	39	46	18*

Remarks: The cost overrun and completion delay were primarily caused by the geological problems encountered during construction. In the upstream tunnel, initial excavation was slowed by clay and fractured rock zones of 25 to 50 meters near both portals and some shear zones with either clay seams or cavities in the central portion; tunnel sections in these zones had to be reinforced. Second stripping of the dam foundation revealed sinkholes ranging from 2 to 5 m in depth and widening beneath the surface, in much larger number than expected. As many as 92 were then encountered in the floor of the regulating reservoir, and all of these too had to be filled.

The Bank has taken the view that these geological problems should have been foreseen.

The 138 KV transmission line to San Pedro Sula was dropped from the project. This part accounted for 4% of originally estimated costs.

* The construction delay for the Rio Lindo scheme was 25%.

Project: Pumped Storage Power

Country: Ireland

Loan No.: 591-IRE **Date:** March, 1969

Project Performance Audit Report No.: 1085 **Date:** March 16, 1976

Project Description: The project consists of: 1) an underground power cavern with four 73-MW reversible pump-turbine units, penstock connection to an artificial asphalt-lined reservoir and improvements to a natural lake, Lough Nahanagan, serving as the lower reservoir; 2) a 220-KV switchyard, control equipment and transmission lines.

	Estimate	Actual	Change %
Total Cost ($M)	31.5	56.4	79
Civil Works Cost ($M)	10.8	26.2	143
Construction Time (Months)	50	62	24

Remarks: During the project construction unforeseen rock conditions necessitated redesign of the upper reservoir and additional excavation and a more elaborate system of compaction of the embarkment.

Project: Finchaa Hydroelectric

Country: Ethiopia

Loan No.: 596-ET **Date:** May, 1969

Project Performance Audit Report No.: 1102 **Date:** March 23, 1976

Project Description: The project comprises the construction of the 100 MW Finchaa hydroelectric power station together with the associated transmission line and terminal substation. Civil works include: (i) a low earthfill dam with a height of about 20 meters and a length of about 340 meters; (ii) a 3 meter diameter pressure tunnel 4200 meters long leading to the penstock; (iii) a power station building and an access road, partly in tunnel, from the dam site at the top of the scarpment to the power station, approximately 7 km in length.

	Estimate	Actual	Change %
Total Cost ($M)	30.3	37.4	23
Civil Works Cost ($M)	17.3	23.6	36
Construction Time (Months)	40	49	23

Remarks: There was a delay of nine months in comissioning the first unit. The delay was mainly due to the poor rock formation whih was encountered when excavating the road tunnel. This required the installation of arch supports and gunniting throughout the entire length of the tunnel. Similar trouble was encountered in the construction of the power tunnel which necessitated many steel supports. These problems were also the main causes of the cost overrun.

Project: Kamburu Hydroelectric Power

Country: Kenya

Loan No.: 745-KE **Date:** June, 1971

Project Performance Audit Report No.: 1230 **Date:** July 14, 1976

Project Description: The project comprises the construction of the Kamburu hydroelectric power station together with the associated transmission lines and substations. The civil works include: (i) a rockfill dam with a height of 52 m and a crest of 730 m; (ii) a reinforced concrete spillway upstream from the dam with a headgate controlling the flow into the concrete lined intake shaft, (iii) a surge chamber; (iv) an underground powerhouse; (v) a tailrace tunnel 3040 m long leading into a short (70 m) open cut to the river.

	Estimate	Actual	Change %
Total Cost ($M)	37.5	40.8	9
Civil Works Cost ($M)	19.1	25.5	34
Construction Time (Months)	26	31	19

Remarks: An area of fault was encountered during excavation of the tailrace tunnel. This slowed down progress and was the principal reason for the delay of five months in commissioning the power plant.

Project: Second ENDE Power

Country: Bolivia

Loan No.: Credit 148-BO **Date:** April 28, 1969

Project Performance Audit Report No.: 1496 **Date:** March 7, 1977

Project Description: (a) Construction of the Santa Isabel Hydroelectric plant of 36 MW including a small compensating reservoir between Corani and Santa Isabel plants; (b) a 8 km long transmission line; (c) engineering services for design and supervision of the project; (d) consultant services.

	Estimate	Actual	Change %
Total Cost ($M)	10.4	11.8	13
Civil Works Cost ($M)	4.6	6.0	30
Construction Time (Months)	23	40	74

Remarks: Construction of the compensating reservoir was deferred (estimated cost of $450,000). The completion delay and cost overrun were mainly because of difficult geological conditions encountered in tunneling and the rupture of the penstock. The geological complications consisted of: (a) presence of decomposed and broken rock in various parts of the tunnel and the surge chamber; (b) heavy infilteration of water in the inclined pressure shaft.

Project: Fifth Power

Country: Chile

Loan No.: 479-CH, 478A-CH **Date:** March, 1966; April 1974

Project Performance Audit Report No.: 1603 **Date:** May 23, 1977

Project Description: (a) The 400 MW El Toro hydroelectric station, almost entirely underground using water conveyed through a 9 km tunnel from a deep intake in Lake Laya; (b) an ancillary scheme known as Alto Polcura Diversion, to yield additional 400 GWM, by diverting waters from Polcura river and two small streams into Lake Lega by means of some 13 km of tunnels and two small dams; (c) transmission systems; (d) distribution systems.

	Estimate	Actual	Change %
Total Cost ($M)	188.1	247.2	31
Civil Works Cost ($M)	n.a.	n.a.	n.a.
Construction Time (Months)	60	120	100

Remarks: The El Toro station was built with no cost overrun as planned with one year delay. Alto Polcura Diversion scheme faced major cost overruns and delays. This part of the project was to take five years from mid-1967 to mid-1972, but at the time of evaluation report was not completed yet (1977). The estimated cost was $21.3 million. By 1977 $50.9 million was spent. The major factor in the cost overrun was the much greater than expected geological difficulties encountered in construction of the Vega Larga - Lake Laja tunnel.

Apparently, extensive geological studies, including use of seismic methods, were carried out before construction started. The Bank also hired its own geologist consultant to visit the site. He concluded that most of the rock for tunneling appears good, that the need for steel supports and lining will be limited. It is believed that in this case, too, little attention was given to the tunnels as compared with the dam site.

In 1974, the Bank approved a $6.7 million supplementary loan for this project.

Project: Jaguara Hydroelectric

Country: Brazil

Loan No.: 442-BR **Date:** 1966

Project Performance Audit Report No.: 1852 **Date:** January 13, 1978

Project Description: The project consisted of: (a) a rockfill dam, 40 m in height on the Rio Grande; (b) a powerhouse with 4 generating units of 100 MW each and provisions for 2 future units; (c) a concrete spillway with tainter gates; (d) a substation; (e) a section bay at the Estreito plant.

	Estimate	Actual	Change %
Total Cost ($M)	83.2	106.9	28
Civil Works Cost ($M)	22.86	52.71	130
Construction Time (Months)	57	1/	1/

Remarks: During the construction of the dam a weak schist layer was uncovered. The layout had to be revised. This caused a significant increase in engineering and civil works costs, 284% and 130% respectively, primarily for special excavation and additional concrete filling. The construction was delayed by seven months.

1/ The major parts of the project were completed with 7 months delay. The transmission line was expanded and the final project closing date happened with 3 1/2 years delay.

Project: Volta Grande Hydroelectric

Country: Brazil

Loan No.: 566-BR **Date:** 1969

Project Performance Audit Report No.: 1852 **Date:** January 13, 1978

Project Description: The project consisted of: (a) an earthfill dam of about 30 m in height on the Rio Grande; (b) a powerhouse with 4 generators with rated capacity of 100,000 KVA; (c) a concrete spillway with tainter gates; (d) transmission lines; (e) substations.

	Estimate	Actual	Change %
Total Cost ($M)	95.3	218.9	130
Civil Works Cost ($M)	35.94	98.57	174
Construction Time (Months)	1/	1/	1/

Remarks: The concrete structure and the left embarkment foundation is partly rock and partly saprolite. During the design stage, investigations were carried out to decide if the saprolite was a suitable foundation for the earth dam. The tests showed it had low strength and high compressibility and part of the saprolite was removed. Measurements of the settlements have shown that the actual compressibility of the foundations is less than anticipated.

Some time after the excavation of the foundations for the concrete structures, some problems occured in spillway and powerhouse areas. The foundation of the spillway was right above a contact between flows. This contact was thought to be closed and watertight, but four months after excavation, the contact was found to be somewhat open, possibly triggered by nearby detonations.

In the excavation of the power house, some 12 m high promontories of rock were left between penstocks in order to save concrete. There was a "fault-joint" about 1 m above the base of the promontories; right after cleaning the excavation debris it was found that the rock of the promontories above the joint had moved outwards up to 15 cm. It was concluded that the movement was caused mainly by the blasting procedure. The spillway foundation had to be re-excavated and the promontories removed.

The above problems and some price increases caused a cost overrun of 130%. Civil works cost increased by 174%, engineering costs by 474%.

The project was delayed for about one year.

1/ The detailed construction schedule had not been worked out at the time of appraisal, but award of major contracts was expected to take place in 1969 and the entire plant completed by 1974. The actual completion date was August 1975.

Project: Marimbondo Power Project

Country: Brazil

Loan No.: 677-BR **Date:** May, 1970

Project Performance Audit Report No.: 2768 **Date:** Dec. 21, 1979

Project Description: (a) The 1400 MW Marimbondo hydroelectric plant on Rio Grande consisting of: (i) an earth embankment, 3000 m long with a maximum height of 65 m with a volume of 20 million m^3; (ii) a gated concrete chute spillway, 150 m wide; and (iii) (a) a powerhouse intake structure, connected by short steel penstocks to an enclosed, above ground powerhouse 220 m long; (b) transmission lines; (c) additional generator; (d) engineering, training, etc.

	Estimate	Actual	Change %
Total Cost ($M)	286.7	440.3	53.6
Civil Works Cost ($M)	71.05	107.49	51.0
Construction Time (Months)	84	84	0

Remarks: The discovery of poor geological foundation conditions in the spillway and tailrace areas required a substantial increase in excavation and concrete work, partially offset by reduced volume of earthfill due to slope and cofferdam volume reduction. This was the main cause of the cost overrun. The Marimbondo plant cost increased from estimated $126.20 million to $249.92 million. The PCR states that geological conditions at this dam site should have been investigated more extensively during project preparation. In this connection, it is interesting and relevant to compare the experience of the Marimbondo project with that of Jaguara and Volta Grande Hydroelectric Projects also in Brazil. These hydroelectric plants are also on Rio Grande. Volta Grande is about 60 km and Jaguara about 200 km from Marimbondo.

Project: Kidatu Hydroelectric Project I

Country: Tanzania

Loan No.: 715-TA, 715-2TA **Date:** Dec. 1970; June, 1974

Project Performance Audit Report No.: 2765 **Date:** Dec. 19, 1979

Project Description: (a) Construction of the first stage (2 x 50 MW) of a hydroelectric development at Kidatu on the Great Ruaha River; the principal elements of the development included a regulating dam with a storage capacity of about 125 million m^3, a 10 km long headrace and a tailrace tunnel, and an underground generating station; (b) a 15-MW extension of the existing Ubungo diesel station; (c) transmission line and distribution station; (d) consulting services.

	Estimate	Actual	Change %
Total Cost ($M)	50.4	66.6	32
Civil Works Cost ($M)	26.08	43.73	68
Construction Time (Months)	45	45	-

Remarks: The initial phase of construction proceeded satisfactorily. Thereafter, during underground excavations, the contractor encountered unfavorable rock conditions. Apparently, during the feasibility stage, the true extent of the bedrock was not discovered. Consequently, the length of the headrace tunnel was later extended by about 50 m due to realignment and about 800 m (about 7%) of the total of 11 km headrace tunnel was concrete lined and more than 2,000 m (about 20%) were heavily gunnited and bolted.

Kidatu was originally designed as an earth and rock-filled dam. Rockfill would have been obtained from the excavation of the headrace tunnel. Due to the unsuitability of rocks obtained from the excavation of the headrace tunnel, the original dam design was changed and the dam was constructed as an earth-fill dam with extended semi-impervious fill. Thirty-five (35) percent of the overall cost increase is attributed to the unforeseen bad rock conditions. Price escalation and currency fluctuations account for 55% of cost overruns.

The geological conditions encountered during excavation were very different from those anticipated by consultants. It was known that there was a deep lateritic soil and deeply weathered rock, but the excavation problems during construction were not foreseen.

The project was completed on schedule, but the geological problems caused a delay in the construction stage (2-6 months). The tailrace tunnel took 1 1/2 years longer to complete.

In 1974, the Bank approved a $5.0 million supplementary loan for this project.

Project: Sixth Power Project

Country: El Salvador

Loan No.: 889-ES **Date:** April, 1973

Project Performance Audit Report No.: 3053 **Date:** June 27, 1980

Project Description: a) the 135 MW Cerron Grande hydroelectric plant on Lempa River, consisting of an earth-and-rock fill dam, surface powerhouse, and switchyard; (b) the first unit (30 MW) at the Ahuachapan geothermal plant, plus switchyard, and a 60 km gravity-flow canal to discharge waste water into the Pacific; c) transmission facilities and lines; d) telemetering center; e) preparation studies; f) training.

	Estimate	Actual	Change %
Total Cost ($M)	91.1	154.9	70
Civil Works Cost ($M)	53.44	87.39	64
Construction Time (Months)	20	65	225

Remarks: It was found impractical to build the discharge tunnels (Ahuachapan) originally planned for crossing mountain terrain, the consultants redesigned the canal with syphon gorge crossings, which led to a new route and an extension of the length of the canal from 60 km to 76 km. So, instead of costing about $2.6 million and being operational in Dec. 1974, the canal and diffuser pipe cost $23.24 million and was not fully operational until Oct. 1978. The original plan was based on small-scale (1/100,000) aerial photogrammetric maps.

Project: Sigalda Hydroelectric Project

Country: Iceland

Loan No.: 951-IC **Date:** December 1973

Project Performance Audit Report No.: 3519 **Date:** June 30, 1981

Project Description: Construction of a hydropower station having two 50-MW generating units with provisions for an additional 50-MW unit; and a double circuit transmission line.

	Estimate	Actual	Change %
Total Cost ($M)	64.3	88.0	37.0
Civil Works Cost ($M)	37.3	53.5	43.0
Construction Time (Months)	34	40	18

Remarks: Difficulties of the civil contractor arose out of heavier than anticipated leakage of water through the porous terrain into the powerhouse excavation. Problems of leakage through sink holes and other porous areas of the reservoir were handled by repeated partial, and progressively greater filling of the reservoir, interspersed with complete drainage and application of impervious material over the areas identified as porous. The cost overrun was due to worse than anticipated geological conditions and domestic inflation.

ANNEX II: Description of Projects Without Evaluation Reports

Project: Fortuna Hyro, 4th Power

Country: Panama

Loan No.: 1470-PAN **Date:** July 1, 1977

Project Description: The project consists of: (1) The Fortuna 255-MW hydroelectric power plant consisting of: (a) diversion works; (b) rockfill dam; (c) power tunnel (about 6,000 m long), surge tank and penstock (about 1,400 m long); (d) underground powerhouse; (e) tailrace tunnel about 8,300 m long); and (f) access roads; (2) transmission system; (3) organizational improvement.

	Appraisal Estimate	Latest Estimate 1/
Total Cost ($M)	253.60	495.0
Civil Works Cost ($M)	154.4	293.0
Completion Time	1983	1984

Remarks: The delay and cost overruns in this project were mainly due to geological complications in the underground powerhouse, power tunnel, and at the site of the right abutment which required additional design work and more excavation than expected.

In 1983, the Bank approved a supplementary loan of $31.3 million for this project.

1/ Actual

Project: Aguacapa Hydro

Country: Guatemala

Loan No.: 1426-GU **Date:** June 10, 1977

Project Description: The project comprises the construction of: (a) dam in the Aguacapa river and a reservoir of 300,000 m^3 for daily regulation; (b) a 12 km power tunnel; (c) a 3,700 km steel penstock; (d) a power station with three 30MW generating units; (e) transformation facilities; (f) a switching station; (g) transmission lines.

	Appraisal Estimate	Latest Estimate 1/
Total Cost ($M)	100	171.5
Civil Works Cost ($M)	58	102.2
Completion Time	1980	1981

Remarks: The project faced some problems during the power tunnel construction which caused a delay of 29 months. The repair on the tunnel consists of 4400 m steel lining (37% of total tunnel length), 810 m reinforced gunite (7%) and 5400 m (45%) of chemical treatment (Thorospan and Sinadur) of longitudinal cracks.

Total project cost was $171.5 million, 71% over appraisal estimate. 51% of cost overrun was for tunnel repairs.

1/ Actual

Project: Riul Mare-Retezat Hydro

Country: Romania

Loan No.: 1242-RO **Date:** April 28, 1976

Project Description: The project's main components include: (a) a reservoir to be formed by a 173 m high clay-cored rockfill dam across the valley of the Riul Mare river with 25 secondary intakes and an 18.4 km long pressure tunnel to convey the water to the power station; (b) a two unit underground plant of 335 (MW) and a 14 MW above ground powerhouse; (c) transmission system; (d) roads.

	Appraisal Estimate	Latest Estimate 1/
Total Cost ($M)	250.1	291
Civil Works Cost ($M)	82	n.a.
Completion Time	1982	1986

Remarks: As of 1985 this project is still far from being complete. The boring of the headrace tunnel is the main problem affecting the project. In 1983 unexpected geological conditions were encountered resulting in the blocking of part of tunnel by clay-like material issuing from a fault. Part of the delay is attributed to causes other than site conditions.

1/ As of November 2, 1983

Project: Chixoy Hydroelectric Power

Country: Guatemala

Loan No.: 1605-GU **Date:** July 21, 1978

Project Description: (a) generation: (i) rockfill dam 108 m high with a volume of 2.8 million m^3, the dam will be located about 58 km upstream of the confluence of the Chixoy and Quixal rivers; (ii) power tunnel 25.6 km long, concrete lined, 4.8 m in diameter, to develop a gross head of 550 m; (iii) surface powerhouse with 5 x 60 MW generating units driven by vertically mounted turbines; (b) transmission substation and lines; (c) consulting.

	Appraisal Estimate	Latest Estimate 1/
Total Cost ($M)	372.68	818.8
Civil Works Cost ($M)	253.30	591.60
Completion Time	1982	1986

Remarks: It was acknowledged, during the appraisal, that a special risk of the project is that it involves construction of a 25.6 km tunnel in an area containing heterogeneous geological and karstic formations. A cost contingency of 24% for civil works was allowed.

As of January 1985, the total project cost was estimated at $815.8 million with completion scheduled for 1986 with four years delay.

As early as 1980, major difficulties were experienced in the construction of civil works under the project. The composition of rock in the reservoir and power tunnel areas was found to be much more complex than predicted. Extensive karstic limestone formations were found at the dam foundation and along the tunnel; rock at the spillway was highly fissured; several landslides along the access roads occurred during construction, and the power tunnel caved in at a few places after showing an unacceptable level of water loss.

At present, the seismic risk at the site has been recalculated and a more stringent design adopted, resulting in the relocation of the powerhouse, a three meter increase in the dam's height, lower dam slopes, and reinforcement of hydraulic structures. These changes required a six-fold increase of the grouting curtain area, a ten-fold increase in drilling works for the grouting curtain, a five-fold increase in cement required for such grouting, larger reinforced concrete sections at the spillway, increased grouting and steel lining of 1400 meters of the tunnel, and construction of an additional bottom discharge tunnel.

The civil works cost of the power tunnel is presently estimated at $130 million as compared with the appraisal estimate of $169.5 million.

The Bank approved a $37.3 million supplementary loan for this project in 1985.

1/ As of January 9, 1985

Project: Kulekhani Hydroelectric

Country: Nepal

Loan No.: 600-NEP (Credit) **Date:** January 9, 1976

Project Description: The project, located about 30 km southwest of Kathmandu, would entail the construction of: (a) a 107 m high rockfill dam; (b) an open channel spillway controlled by two radial gates; (c) an intake structure connected to a headrace or tunnel of about 2.5 m in diameter and 5.8 km long; (d) a surge tank; (e) a penstock 1.6 m in diameter and 1340 m long; (f) underground powerhouse containing 2 x 30 MW turbo-generating units; (g) a tailrace tunnel of 1 km long; (h) others.

	Appraisal Estimate	Latest Estimate 1/
Total Cost ($M)	68	122.6
Civil Works Cost ($M)	47.8	89.9
Completion Time	1980	1982

Remarks: This project faced numerous technical, managerial, and labor difficulties, mostly during the construction of the tunnel. In 1981 there were major failures at different locations in the head race tunnel where there were voids between the tunnel lining and the rock. It was concluded that the problems were due to inadequate construction techniques. The major geological complication in this project consist of a number of landslides which happened after the construction had started and also after the completion in 1983. These resulted in some design changes. The project cost over $120 million and was completed about 2 years behind the appraisal estimate.

In 1979 a supplementary credit of $14.8 million was granted to Nepal on this project.

1/ Actual

Project: Nispero Power

Country: Honduras

Loan No.: 1629-HO

Date: November, 1978

Project Description: The project comprises: (i) the Nispero hydro plant (22.5 MW) and its connection to the national transmission network; (ii) diesel units at Puerto Cortes; (iii) consultant services; (iv) training; (v) distribution expansion program.

	Appraisal Estimate	Latest Estimate 1/
Total Cost ($M)	57.9	70.6
Civil Works Cost ($M)	22.0	40.0
Completion Time	1980	1982

Remarks: Construction of the generation component of this project was completed in 1982, about 18 months later than expected mainly because of construction delays resulting from difficult geological conditions. The faulting, solution voids, cavities, and finely crushed rock in the vicinity of the tunnel were a major source of delay, as extra time was needed to install extra reinforcing materials. Further, the tunnel was twice flooded (March and June 1981), resulting in some damage and construction delay.

1/ Actual

Project: Mesitas Hydroelectric Power

Country: Colombia

Loan No.: 1628-CO **Date:** April 9, 1979

Project Description: The project consists of: (a) construction of the Mesitas Hydro consisting of two surface powerhouses, each with three generating units totalling 600 MW, and tunnels and penstocks, as well as a pumping station for an existing head pond and three 230 kv transmission lines; (b) strengthening of the Sequite dam; (c) an asset evaluation study; and (d) technical assistance.

	Appraisal Estimate	Latest Estimate 1/
Total Cost ($M)	260.8	407
Civil Works Cost ($M)	82.4	
Completion Time	1982	1985

Remarks: This project's delay and cost overrun were partially due to geological difficulties in a number of tunnels. During the construction some soft and watery spots in the main tunnel (Granada II) were discovered. The soft spots had to be by-passed. This required new design and more excavation.

In November 1983, part of Chingaza tunnel collapsed. This tunnel was to divert the inflow for Mesitas' generation and for water supply.

This project is expected to be completed by mid-1985.

1/ As of March 7, 1984

Project: Third Power

Country: Swaziland

Loan No.: 2009 SW

Date: September 21, 1981

Project Description: The project consists of: (a) a rockfill dam at Lupoho, about 40 m in height and 400 m and length, to provide an effective reservoir capacity of about 20 million m^3 on the Little Usuto river; (b) a tunnel and penstock system consisting of an unlined low-pressure power tunnel 4.4 km long; a 600-m long steel-lined tunnel and a surface penstock system; (c) a powerhouse with two 10-MW turbine generators, with a short tailrace channel; (d) consultant services.

	Appraisal Estimate	Latest Estimate 1/
Total Cost ($M)	58.6	69
Civil Works Cost ($M)	26.5	
Completion Time	1984	1985

Remarks: The project experienced substantial cost overruns and as of 1984 was about six months behind the construction schedule. The increases are attributed largely to changes in the main civil works contract. Due to unforeseen geological and geophysical conditions, the amount of excavation for tunneling works has been substantially increased and made more difficult by presence of large boulders mixed with soft material. Other geological problems include: the presence of fault zones, lower bedrock than expected and mud-rush (inundated the high pressure tunnel). To overcome these problems the contractor had to realign the tunnel axis. The quantity of tunneling works was increased about 40% over that originally expected.

In 1984, the Bank approved a $5.6 million supplementary loan for this project.

1/ As of May 4, 1984

Project: Tenth Power

Country: Indonesia

Loan No.: 1950-IND

Date: March 6, 1981

Project Description: The project consists of: (a) the 700 MW Saguling hydroelectric power facility; including construction of a 97.5 m high rockfill storage dam on the Citram river; a 6.5 km long water conductor system comprising tunnels, surge tanks, and penstocks; and a power station with an associated 500 KV step-up substation; (b) equipment; (c) engineering services; (d) consulting services.

	Appraisal Estimate	Latest Estimate 1/
Total Cost ($M)	726.7	752.8
Civil Works Cost ($M)	287.8	378.4
Completion Time	1985	1987

Remarks: Major difficulties were experienced in the construction of civil works under the project in 1982 and 1983. During this period extraordinary geological and geotechnical problems were encountered. The principal problems were the following: (a) Heavy rains in late April 1982 caused severe landslides, which disrupted access roads to the penstock and the midpoint and intake adits of the main tunnel, and delayed the start of underground tunnel work at various points by six to twelve months. (b) Unexpected land movements at the powerhouse site occurred from June to October 1982. These land movements necessitated remedial work to clean away landslides and consolidate slopes at the powerhouse site, which delayed work at the site by twelve months. (c) Geological weaknesses revealed after excavation commenced in the spillway penstock slope areas required far more extensive slope stabilization measures than had been provided for in the original designs. Excavation requirements increased two-fold in a number of areas, which required identification of new spoil areas and additional access roads. (d) The incidence of extremely poor quality rock in some critical sectionsof the main tunnel caused rockfalls in 1983 which delayed work by several months. (e) The discovery of poor quality rock in a primary quarry intended to supply rock for works in the powerhouse area required abandonment of that quarry in favor of a more distant site; involving greater transport, time and cost and increased excavation. (f) Landslips and rockfalls at the dam site, combined with foundation difficulties observed after excavation began, caused delays and required deepening of the dam foundation.

The Bank approved a supplementary loan of $50 million for this project in 1984.

1/ As of January 30, 1985

Project: Guavio Hydro Power

Country: Colombia

Loan No.: 2008-CO

Date: May 13, 1981

Project Description: The project comprises: (1) the Guavio hydroelectric plant on the Guavio river including: (a) river diversion, rockfill dam and spillway tunnels; (b) intake and diversion tunnels (about 4 km) to conduct waters of the Chiror and Batatas River into the reservoir; (c) pressure tunnel (about 15 km), underground powerhouse and transformer with access tunnel (about 2 km), and tailrace (about 5 km); (2) others including equipment and services.

	Appraisal Estimate	Latest Estimate 1/
Total Cost ($M)	1053.1	1165.5
Civil Works Cost ($M)	465	450.8
Completion Time	1987	1989

Remarks: In the early stages of construction in this project frequent landslides occurred during the excavations for permanent works and access roads. A critical zone was the Bocatoma area where four workers were killed in Sept. 1982. On July 28, 1983 a large landslide swept over the platform area near the portals of the power and diversion tunnels where tunneling crews were at the end of the day shift and burried about 120 workers.

Additional bad geological conditions at an access to the discharge tunnel have caused further delays.

As of October 1984, the completion time is estimated to be 1989.

1/ As of October 3, 1984

ANNEX III

GAS 6

INTERNATIONAL BANK FOR RECONSTRUCTION AND DEVELOPMENT

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INTERNATIONAL DEVELOPMENT ASSOCIATION

PUBLIC UTILITIES DEPARTMENT

GUIDELINES SERIES

GUIDELINES FOR ESTIMATING COSTS OF TUNNEL CONSTRUCTION

January 17, 1974

Central Projects Staff
Public Utilities Department

GUIDELINES FOR ESTIMATING COSTS OF TUNNEL CONSTRUCTION

A B S T R A C T

This paper deals with the problems of estimating costs to execute underground works where uncertainties may be great. It suggests areas to which special attention should be given, and advocates the routine collection of data on costs as experience is gained so that the basis for judging estimates may be broadened.

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January 17, 1974

GUIDELINES FOR ESTIMATING COSTS OF TUNNEL CONSTRUCTION

Introduction

1. The Bank frequently finances projects in the agriculture, public utility, and transportation sectors which include tunnels or similar underground works carried out under conditions of uncertainty. From time to time execution of these structures has proven to be much more costly than anticipated, giving rise to financial problems on the part of the owner enterprise, and casting doubt over the economic merits of having embarked upon the project in the first instance. The Bank has ready-to-hand reliable cost information on only a relatively few tunnels because tunnels are usually only elements of projects and costs are generally not reported on separately.[1/] These data, while sparse, do tend to show that tunnelling costs are likely to be underestimated.

2. The purpose of these Guidelines is to reiterate the need for special care in estimating costs (paragraph 4); to remind Bank staff that special skills may be required (paragraph 5); and to suggest that generous allowances for contingencies be provided in line with the degree of uncertainty involved (paragraph 6). The need for sensitivity analyses (paragraph 7) and broadening the Bank's data base (paragraph 9) are mentioned.

3. A tunnel, as considered in this paper, is in practice any large underground structure. The following list is typical, but not necessarily all-inclusive:

(i) Conveyance tunnels for irrigation, hydroelectric, and water supply projects;

(ii) underground powerhouses with penstocks and tailrace tunnels;

(iii) railway and highway tunnels; and

(iv) diversion tunnels for various river projects.

The Magnitude of the Problem and Need for Special Skills

4. As is the case with all heavy civil works construction, the problem of cost estimating for tunnels is proportional to the degree of ignorance of the natural conditions to be encountered; and tunnels, by their nature are the most difficult structures for which an accurate prediction of these conditions can be made. The comparative level of difficulty of making cost estimates for the various kinds of structures covered by the

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1/ For example, where the diversion scheme for a hydroelectric development includes a tunnel, although it may be a major construction activity, it may nevertheless be executed under a general civil works contract as regards reporting of costs.

above definition of "tunnels" cannot be categorically stated, but in general the more extensive the structure is and the deeper it lies underground, the higher the level of difficulty. The difficulty is influenced by the nature of the rock being penetrated, the ground water conditions, the presence of gas, and in volcanic areas by heat. The basic problem of cost estimating is finding out what these conditions are. Thus, diversion tunnels, some short highway and railway tunnels, and underground powerhouses are among the least difficult underground structures to estimate since a reasonable number of borings and adits can be carried out economically and which can give fairly accurate information of the natural conditions. It may, therefore, be concluded that long (over a few kilometers) tunnels under deep cover (more than 150 meters) offer the greatest estimating problems because thorough direct examination of the natural conditions by borings and adits becomes impractical due to the excessive costs involved. Conveyance tunnels make up the majority of the projects in this category, but there may be some railway and highway tunnels, and occasionally some other types. In all cases the degree of uncertainty is influenced by the complexity of the geological conditions and the amount of factual material which may be available from previous operations in the vicinity.

5. The two most important classes of personnel needed for adequate tunnel estimating are engineering geologists and engineers with extensive experience in actual tunnel construction. The Bank customarily requires the employment of consulting firms with these classes of personnel on their rosters. Greater pains should be taken to assure that the personnel is the best available, and if not, to require the firm to employ other, more qualified individuals. Furthermore, if available, there should be some personnel involved with experience in the area in which the project is located, who can provide more intimate knowledge of local conditions.

(i) The basic duty of the engineering geologist is to examine the underground conditions by the most direct means which are practical to employ and to estimate these conditions on the basis of general geologic knowledge when direct means cannot be used. The engineering geologist (or geologists) should visit the site of the project, explore the ground surface for rock outcrops and signs of faults, examine all relevant existing data, and specify additional data to be obtained including aerial photography where drilling or adits are not practical. On the basis of all information available he should prepare geological sections along the principal axis (axes) of the structure and predict the type, quality, and probable behavior of the various types of rock involved based on his previous knowledge and the examination of the nearest local exposures of the types involved. Especially if high heat or gas may be expected to be present, a few deep drill holes may have to be put down to check. Ground water levels should be

established by examining springs, wells, or by drilling if the type of rock promises to have serious water problems. Its behavior with water flowing out of it must be predicted.

(ii) The basic duty of the engineer is to develop a construction plan which meets the underground conditions predicted by the geologist, and to estimate the cost of the work. The engineer should consider the schedule of operations including drilling, shooting, mucking, and hauling out depending on the length of tunnel, number of points of access, and applicable haulage equipment; or alternatively, the use of mining machines or moles. (Since the latter type of equipment is scarce, difficult to bring to a site, not suited to all types of rock, and is not labor-intensive, it should not always be specified as an alternative which contractors must consider in formulating offers.) Upon the advice of the geologist, the engineer should consider the need and size of pumps, ventilating equipment, and gas surveillance arrangements, and the practicability of the use of shotcrete, wire mesh, and rock bolting to stabilize the tunnel, as well as of the more expensive ring beams, steel plates and dry packing in some parts of the structure. He will need to judge the ability of local labor to acquire the necessary skills and especially to perform as parts of a highly organized and carefully timed operation. The engineer should have the ability to judge the probable cost based on his conclusions of the above-mentioned considerations as compared with his experience elsewhere.

Appropriate Contingency Allowances

6. In spite of every reasonable precaution there will be cases, expecially in connection with long, deep tunnels in complicated geology with doubtful rock quality, where there will be considerable uncertainty about underground conditions and where a cost estimate cannot be expected to be accurate within customary limits. In such cases the best procedure appears to be to add liberal contingency allowances to the estimated direct costs. Specific tunnel contingencies should be added to the cost of the tunnel itself. The Bank's experience suggests that such provisions should be not less than 25% of the direct estimated cost, and where uncertainties are unusually large, it is possible that they may have to be as high as 50%. Normal contingencies would be used on other parts of the project. Where such provisions would have a substantial impact on the overall project cost -- and hence the proposed Bank Group financing -- the situation should be discussed in detail with the proposed borrower. Excessive contingency allowances have a cost in terms of commitment charges, but it is generally more desirable to incur these than accept a large risk that funding will prove inadequate.

7. In projects where high contingency allowances are deemed necessary because of uncertainty, sensitivity analyses should also be made systematically. In the event the analysis indicates inclusion of generous allowances under conditions of uncertainty would throw doubt on the project's justification, it probably should be redesigned or the alternative schemes reexamined to select the most acceptable.

Collection of Data

8. It would be desirable to broaden the Bank's data base with respect to tunnel costs. Over time, it might then be possible to suggest more precisely what levels of contingency allowances would be appropriate under different circumstances. Moreover, identification of factors tending to produce inaccurate estimates might be possible, and means of taking them into account developed.

9. Where it can conveniently be done, supervision and appraisal missions should collect relevant data on tunnelling costs. It would be particularly helpful in cases where actual costs incurred have substantially exceeded estimates to know the cause (i.e., inadequate subsurface exploration, unusually bad geologic conditions, poorly prepared estimates, etc.). In addition to whatever use is made of this information in project monitoring, it should be made available as well to the Public Utilities Department. It will be collected on a global basis as experience is gained with a view towards improving these Guidelines.