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GUIDELINES FOR
ESTIMATING COSTS OF TUNNEL CONSTRUCTION

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Public Utilities Department

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ABSTRACT

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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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. 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

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, there-
fore, 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 geo-
logical 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 pre-
dict the type, quality, and probable behavior of the vari-
ous 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, especially 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.