

1. QUANTITY SURVEY AND COST ESTIMATION

1.1 METHODOLOGY

1.1.1 STAGES OF WORK

As already mentioned in the chapter of "Layout and Sizing" the reliability and detail of the estimated quantities and costs depend on the stage of development of the project.

Identification Stage

During the identification stage only a preliminary estimation of quantities is possible. This work can be done with help of computer programs, such as HPC. These programs normally use standard structures for the different project components.

In case such software is not available, the calculations have to be done by hand. This requires at least a preliminary dimensioning of each project component. Often charts, tables and other design aids are used for this purpose.

The costs of the structures are frequently normally calculated on basis of cost functions and/or according to unit prices, which are developed on basis of international prices for civil works as well as hydro-mechanical and electrical equipment.

A reasonable amount should be added to the cost to take care of contingencies.

Feasibility Stage

During feasibility stage quantities are calculated with help of the preliminary design of all power plant components with corresponding tentative calculations and analyses such as stability analysis, hydraulic calculations, and structural analysis. The calculation of the major quantities, activities and material requirements is mainly dependent on their geometrical dimensions and unit requirements respectively.

The major quantities are usually as follows:

- Access roads
- Site installation, mobilisation and demobilisation
- River diversion
- Earth works (Excavation of soil and rock, filling, compaction, etc)
- Foundation works (diaphragm walls, sheet piling, etc)
- Mass concrete works
- Masonry works
- Reinforced concrete
- River protection (geo-textile, rip-rap, gabions, etc,)
- Steel works (gates, penstocks, steel lining, etc)
- Hydro-mechanical equipment (turbines and governors)
- Auxiliary hydro-mechanical equipment (valves, pumps, etc.)
- Electro-mechanical equipment (generators and transformers)
- Auxiliary electrical equipment (MV/LV installations, protection system, panels and controls, lighting, etc.)
- Switch yard and switch gear

The costs during feasibility stage consist of

- Direct costs
Direct costs can be calculated by multiplication of quantities with unit rates. The unit rates can be evaluated by analysing and comparing following informations:
 - Unit price list
 - Available icb of similar projects

- WAPDA schedule of rates
- Budgetary prices
- Local and foreign components
- Indirect costs
 - Indirect costs can be calculated on the basis of the costs of different main parts in hydropower developments such as civil works (c), hydro-mechanical (m) and electro-mechanical (e) components. Following indirect costs have to be considered:
 - Transportation 7% to 10%
 - Erection of mechanical equipment 12-15%
 - Erection of electrical equipment 5-7%
 - Contingencies 5-20%
 - Engineering and supervision; civil 4%
 - Engineering and supervision, e&m 2.5%
 - Administration, audit and account 4% of civil works
 - Miscellaneous 1.5% of civil works
 - Import charges 1-5 %
 - Overheads 1-5 %
- Interest during construction (idc)

The total cost of the hydropower development is calculated as the sum of the base costs, which includes direct and indirect costs, and the interests during construction.

Tender Stage

After the feasibility stage is finished detailed engineering works proceed according to the detailed explanations given in the chapter "Engineering Design". All power plant components are designed in detail with corresponding accurate calculations and analyses, hydraulic calculations, and structural analysis. The result of all engineering works with exact geometrical dimensions of the structures, detailed planning of auxiliary components can be found in the drawings, which are the basis for the construction work. Based on the detailed engineering drawings the exact quantities can be determined. The main and most important quantities that have to be calculated are, as already mentioned in the part of identification stage, the civil works.

Therefore the needed quantities for excavation, concrete, reinforcement etc. can be established from the detailed engineering drawings prepared during the design phase of the hydropower development. Apart from the quantities, other important items for construction have to be taken into account, such as activities, material, manpower and equipment according to their geometric dimensions, weights and/or unit requirements respectively.

In the following a methodology is introduced suitable for the quantity survey and cost estimation for projects during feasibility stage and tender stage. As mentioned above, the main difference is in the detail of engineering design and thereby the detail of engineering drawings. In the appendix two examples are enclosed of hydropower developments in the North of Pakistan based on the feasibility studies. The basic approach for the cost estimation is the same, it differs only in some small respects. It has to be added in this context, that the enclosed cost estimations include local as well as foreign distribution.

1.1.2 ACCURACY OF COST COMPUTATION

There are several methods for the cost computation of the main structures. Each method has its own level of accuracy. In some cases they can be calculated quite exactly, in other cases there might be still some uncertainties, which cannot be calculated exactly. In the following they are given with decreasing accuracy:

- As a product of a given quantity multiplied by the appropriate unit price

- As a product of a quantity, computed by using an empirical formula, multiplied by a unit rate
- By means of an empirical cost formula
- As a fixed lump sum
- As a percentage of other costs

It is obvious, that the determination of the unit price has a considerable impact on the total costs of the hydropower development. If the estimation is too high, the hydropower project can become economically and financially unattractive. In case the unit prices are optimistically assumed too low, the implementation of the hydropower project may be subjected to delays and cost overruns. It may even collapse due to the high financial risk. Therefore experience and a comprehensive, up to date database are needed to determine realistic unit prices.

Some unit prices are derived and/or updated on basis of information obtained from international sources (i.e. Engineering News Record and others).

1.2 COST ESTIMATION

In this paragraph the different costs components are introduced and briefly explained. It should be mentioned in this context, that the costs are very much site specific. Depending on the local conditions and the choice of engineering solutions, the amount and distribution of costs might differ. However the basic principle and the methodology is the same, which should be explained here. Considerations are related to a typical high head hydropower development.

The basic cost of a hydropower comprises following main groups:

- Preliminary works
- Civil works
- Hydraulic steel works
- Hydro-mechanical equipment
- Electro-mechanical equipment
- Transmission system
- Engineering and administration
- Other costs

The basic construction cost estimate contains all work and supply items included in the construction of permanent project works, investigation and planning costs, engineering and administration services and the cost of all preliminary works.

A contingency allowance is included as a separate item in the estimate for each project component. The purpose of this allowance is to cover minor differences between actual and estimated quantities, unforeseen items and quantities of work, possible minor changes and other contingencies.

Finally, as foreign investment would be needed, the cost estimate should be split into foreign and local components.

1.2.1 PRELIMINARY WORKS

Preliminary works involve of the following

- The environmental impact mitigation costs can be assessed on basis of the investigations explained in the chapter "Data Collection and Data Processing" in respect to the environmental and socio-economic aspects. These include mitigation works such as:
 - Resettlements
 - Protection of graves
 - Compensation of owners and water mills
 - Soil cover over disposed mucking material
 - Plantation around reservoir and powerhouse area

- Land leasing cost over the construction period
- Realignment of existing roads, if applicable
- Constructions of new access roads to powerhouse and important structures, such as surge tank or intake.

Existing roads might be effected by the construction of a reservoir. Furthermore new access roads have to be constructed to important projects structures and for transportation of heavy equipment, and for later on for operation and maintenance.

The sum of the above mentioned items can be considered as the total cost for preliminary works.

1.2.2 CIVIL WORKS

Based on the engineering design of the project, the quantities are calculated for the individual work items.

The computed unit prices include the cost of labour, material and equipment, with due consideration for the local conditions and foreign markets. Therefore, required expenditures in local and foreign currency should be accounted for. This is especially important in countries and periods with high inflation rates.

Usually the estimates for civil works should be established in the following sequence:

- Calculation of quantities
- Computation of unit prices

1.2.2.1 CALCULATION OF QUANTITIES

Since civil works usually represent the main part in the construction of a high head hydropower development, it is recommended to subdivide the main structures in lots, such as:

- Reservoir
- Dam
- Waterways
- Powerhouse

The number of lots will depend on the size and characteristics of the project. Subdividing the work in various lots opens the opportunity to different contracting companies, which would be interested in executing different aspects of the work. On the other hand, a large number of lots will always require more intensive administrative and co-ordination efforts, which in some cases may lead to conflicts in the scope of responsibilities of the contractors. Therefore, in many cases a small number of lots is adopted for a better definition of responsibilities and a reduction of having to deal with too many claims during project construction.

Contingencies for the civil works are normally taken between 5 and 15% of the basic cost, reflecting uncertainties of conditions and minor changes of work.

Based on the engineering design drawings, the quantities of the civil works can be calculated. If the different main working steps for the construction of the structures are known, the quantities for a complete erection can be calculated with a spreadsheet.

In the appendix some examples of the civil works of the Khan Khwar Hydropower Project are included:

- Excavation of dam at different cross sections
- Concrete placement at dam structure
- Intake structure; layout and longitudinal section

- Pressure tunnel, concrete lined with rock class c
- Excavation powerhouse; layout, cross section and longitudinal section
- Powerhouse; concrete placement turbine shaft

From the sketches included in the appendix in layout view and different sections, the quantities of civil work items can be calculated. In the spreadsheets, which are only enclosed in the appendix for a few structures, the working stages of each step are given in more detail with corresponding quantities. To illustrate the principle of this approach two examples should be given. For instance the construction of a grout curtain can be subdivided into several working stages, such as:

Table 1.1: Different items of a grout curtain for cost estimation [1]

Item	Total Quantity
Drilling of grout meters	5300 m
Drilling of control meters	500 m
Injection of grouting material with cement consumption	1000 to
Injection of grouting material with bentonite consumption	50 to
Pumping hours	2500 h
Operation building, cubical content, 6.5m x 8.5m x 3.5m	200 m ³

To give another example, the cost calculation of the intake structure is also split into different activities, each having its own quantity, such as:

Table 1.2: Different items of intake structure for cost estimation [1]

Item	Total Quantity
Excavation of open rock at the intake and at houses	2400 m ³
Excavation of rock gate shaft	450 m ³
Excavation of rock at the horizontal intake	1100 m ³
Shotcrete of 10 cm at intake and gate shaft	1500 m ²
Rock bolts 150 kN, 2-4m at the gate shaft	700 m
Reinforced concrete B 25 at the intake, spillway, gate shaft and houses	1550 m ³
Formwork at the intake, spillway, gate shaft and houses	3300 m ²
Reinforcing steel bar	80 ton
Reinforcing steel wire mesh	15 ton
Pouring concrete at the intake and gate shaft	20 m ³
Backfill concrete at the intake	300 m ³
Excavation backfill material at the houses	1000 m ³
Temporary shotcrete of 10 cm at the intake and houses	750 m ²
Rock bolts 200 kN 2-5 m	550 m
Foil gate shaft	600 m ²

All working steps for different civil works can not be discussed in detail in this work, therefore only a few examples are picked, *the full detailed work is available in the Khan Khwar Hydropower Project Feasibility Report, which can be found at GTZ.*

1.2.2.2 COMPUTATION OF UNIT PRICES

The specified prices are composite rates including labour, materials, construction, removal of site facilities, cost of equipment and cost of site management etc. by the contractor.

Based on international data basis for civil engineering works, the unit prices are calculated while considering the local conditions as follows:

- Equipment/Plant
- Labour
- Material

Subdivided in local and foreign components. It should be mentioned that the distribution in foreign and local components is likely different for each country and they may vary even regionally within the same country due to better accessibility, nearness to supply sources, etc.

Plant Crew Hours

Plant crew hours include all equipment, necessary per unit of defined pay items. Provision of foreign, up-to-date equipment is taken into consideration to meet the requirements the construction time schedule.

Labour Crew Hours

The amount of labour crew hours per unit of the individual pay items is being derived from the database as well. According to the technical requirements, the labour crew hours are split into local and foreign components, such as:

Surface structures	80% local	20% foreign
Underground structures	20% local	80% foreign
Mean wages of foreign manpower	10 to 12 US\$/hour	
Mean wages of local manpower	1 US\$/hour	

Cost Of Material

The cost of material is derived by local evaluations. Some competent unit rates are listed as follows:

Table 1.3: Examples of unit rates [1]

Item	Costs
Cement	102 US\$/ton
Concrete	77.50 US\$/m ³
Formwork	8.50 US\$/m ²
Re-steel	514 US\$/ton
Rock bolts, 100 - 200 kN, length 2 m	16 US\$/m

Some examples of estimated unit rates (price level 1996) for civil works of main structures are listed as follows. A detailed overview is given in the Appendix 8A of the Khan Khwar Hydropower Project Feasibility Study, 1997. It should be noted, that contingencies of 15% as considered for civil works are not included in those unit rates.

Dam Structure:

River diversion tunnel cross sectional area 60 m ²	5600 US\$/m
Rock excavation	16 US\$/m ³
Provision and placing of concrete	80-90 US\$/m ³
Provision and placing for formwork	25 US\$/m ²
Provision and bending of steel bars	650 US\$/tonne

Headrace Tunnel:

Cross section area	12 m ²
Excavation, support and concrete lining	2975 US\$/m

Surge Tank:

Vertical Shaft

High Head Hydropower
Economic and Financial Analysis

Cross section area	65 m ²
Excavation, support and concrete lining Lower Chamber	7375 US\$/m
Cross section area	20 m ²
Excavation, support and concrete lining Upper Chamber	4300 US\$/m
Cross section area	28 m ²
Excavation, support and concrete lining	3900 US\$/m
Pressure Shaft:	
Vertical Shaft	
Cross section area	8.3 m ²
Excavation by raiseboring method, support and concrete lining	2550 US\$/m
Horizontal pressure tunnel concrete lined:	
Cross section area	8.3 m ²
Excavation, support and concrete lining	2650 US\$/m
Horizontal pressure tunnel steel lined:	
Cross section area	7.1 m ²
Excavation, support and concrete lining without cost of steel lining	2400 US\$/m
Powerhouse	
Excavation of powerhouse shaft including support	26 US\$/m ³
Provision and placing of concrete powerhouse shaft	107 US\$/m ³
Provision and placing of formwork for powerhouse shaft	35 US\$/m ²
Provision and bending of steel bars	720 US\$/tonne

1.2.3 HYDRAULIC STEEL WORKS

Weights and prices of hydraulic steel structures can be estimated on the basis of carefully analysed supplier tenders and available characteristic indices from the European market for similar equipment. Imported hydraulic steel works are normally expensive, having an impact on the cost proportion of transport and assembly works. Whenever it is suitable, local companies may deliver some smaller components of particular items. The cost estimate should include 5% of contingencies for the main structures.

Hydraulic steel works are mainly concerned with the dam structure and the intake. At the dam structure any type of gates are used for the spillway structure, but also for the bottom outlets. Stoplogs in case of emergency and cranes are also needed, as discussed in the chapter of "Engineering Design". Furthermore hydraulic steel works are used at the intake, in form of gates, stoplogs and especially trash racks.

Alternatively the estimation of the costs of hydraulic steel works can also be done as part of the concerned main structure, because it is also needed for the proper function of the structure. It has to be considered in any case one or the other category, especially due to the high relative cost, which they may represent in some projects.

1.2.4 HYDRO-MECHANICAL COMPONENTS

It is known, that the prices quoted by suppliers of hydro-mechanical equipment such as hydraulic turbines, valves and governors strongly depend on market conditions. Consequently, fluctuations up to 100% are not uncommon. Therefore prices have to be estimated after careful analysis and on base prices taken from recent tenders. Depending on the market situation in respect to possible suppliers in the country, an import of the turbine and all other auxiliary

equipment might be needed. In some countries, for instance, local manufacturing does not exist and 100% foreign delivery of the complete equipment has to be assumed.

The costs of the turbine and other equipment as valves and governors mainly depend on the layout of the power station and the design of the hydraulic turbine. These items were already discussed in context of the chapters "Layout and Sizing" as well as "Engineering Design".

1.2.5 ELECTRO-MECHANICAL COMPONENTS

Based on the electrical layout of the high head hydropower development a cost estimation should also be carried out for the electrical components of the hydropower project. As already mentioned in the chapter "Engineering Design", the electrical equipment is mainly governed by the number and selection of turbines, as well as the boundary conditions of the connecting grid.

Experience has shown that, depending on the market situation, equipment such as generators, transformers and switchgear are quoted by the suppliers at rates which vary up to 200%. In countries without local manufacturing this type of equipment, prices are usually at the upper end of the scale.

As can be seen in the appendix, in case of the hydropower project Khan Khwar in North Pakistan prices can be elaborated after careful analysis and on base prices mainly taken from recent tenders in a country for equal or very similar equipment. It must be understood, that restriction upon access to the international markets may increase cost of concerned items significantly, sometimes up to 3 times. Contingencies of 5%, including price and physical contingencies, have to be added.

The estimate has to be carried out for the following electro-mechanical components:

- Generator
- Transformer
- Switch gear
- Low voltage and dc supply
- Control, alarm, protection, telecommunication and watches
- Lightning and small power and emergency diesel
- Various other small components

1.2.6 TRANSMISSION SYSTEM

Many high-head projects are located up in the mountains, where very often high-voltage transmission lines are not available. Under these circumstances, the cost estimation for the erection of the transmission system has to be taken into account. The prices can be taken from usual contract valid in the country. The main parameter in the costs of the transmission line is the distance to the grid as well as the type of transmission line. Contingencies of 5% should be taken into account.

Nevertheless the economic cost of interconnection of a high head hydropower development with the grid has to be distinguished from the investment costs. The reason is that transmission lines may be constructed for more that one project and therefore the associated cost cannot be assigned to one single project. For the economic analysis including transmission lines, sharing of costs and benefits needs to be critically assessed.

1.2.7 ENGINEERING AND ADMINISTRATION COSTS

Engineering and administration should be taken in some cases to include the requirements of foreign and local consultants to do further site investigations, preparation of contract documents and supervision of the construction works. The cost of these activities can be taken as 6% of the engineering work excluding the preliminary works.

1.2.8 OTHER COSTS

Other costs, which a private investor would have to meet, include the following:

- Bank clearance charges and local insurance; it can be taken as 1% of the engineering works and engineering and administration
- Customs duty of 2% on imported equipment, machinery and plant cost, e.g. In Pakistan according to the "policy framework and package of incentives for private sector hydel power generation projects", May 1995
- Income tax of 4% on payments to the contractors in Pakistan according to above mentioned policy.

1.2.9 SUMMARY OF PROJECT COSTS

The sum of all above mentioned costs components gives the cost summary. A breakdown of the construction costs of the aforementioned Khan Khwar Hydropower Project with 42 MW reflects the percentage of the total costs excluding escalation and interest during construction. This project can be considered as one typical example of a high head hydropower development of its size in the North of Pakistan. The detailed cost estimation for civil works is available as appendix to the feasibility study.

Table 1.4: Summary of Project Costs

Cost Group	Costs [Mio. US\$]	Percentage [%]
Preliminary Works	2.277	2.7
Civil Works	45.469	52.9
Hydraulic Steel Works	6.049	7.0
Hydro-Mechanical Equipment	7.864	9.1
Electro-Mechanical Equipment	11.149	13.0
Transmission System	5.567	6.5
Engineering and Administration	4.566	5.3
Other Costs	3.033	3.5

It is obvious, that the costs for civil works are more than half of the project costs. Therefore the evaluation of civil work costs has an important impact on the total costs of the project.

1.3 ALTERNATE COST ESTIMATION

The presented order of cost estimation in the above paragraph is one possibility to carry out the estimation for high head hydropower developments. Therefore another example for a high head hydropower development is enclosed in the appendix. The basic principle of the cost estimation is the same, total costs are divided into local and foreign distribution.

The materials and quantities required are computed using the engineering drawings consisting of plans and sections of all components of the project. In the example presented, the 106 MW Golen Gol Hydropower Project in Chitral Valley, North Pakistan, cost estimation was carried out for a feasibility study. Drawings in the scale of 1:200 and 1:500 were used. A more detailed cost estimation is supposed to be carried out at tender stage after detailed engineering design. Since the complete cost estimation is enclosed in the appendix of this chapter, here only the order of the cost estimation should be presented.

1.3.1 COST ESTIMATION

Environmental impact mitigation cost:

Major basis of mitigation cost are measures taken at pre-construction and construction stages. The main components are already discussed in the chapter of "Data Processing and Data Collection".

Colony

Comprises normally the cost of construction for two colonies, mostly two small colonies in a high head hydropower development, one at the diversion and one at the powerhouse.

Preliminary works

This includes access roads, realignments of roads and construction of bridges

Civil works

All civil components are covered under this item

Electrical and Mechanical Equipment

All electrical and mechanical equipment is covered under this item

Transportation and Shipment

In case of Pakistan, all electro-mechanical equipments including turbines and generators are to be imported. These materials are to be shipped from the country of its manufacturers and special arrangements for its inland transportation are to be made. The cost of freight, shipment and insurance etc. from the country of manufacture can be taken as 7% of the F.O.B. cost and 8% for its inland transportation to the project site. Transportation costs of locally manufactured electro-mechanical equipment can be taken as 8% of its cost.

Erection, Commission, and Testing Charges

For erection, commission and testing purposes, 14% of FOB of mechanical equipment and 7% of FOB of electrical equipment can be assumed.

Transmission System Cost

As already mentioned, the cost for the transmission line is dependent on the site location and the boundary conditions of the grid.

Contingencies

There are many unforeseeable events that may occur over the period of construction. This amount of costs can be assumed to be 5% for local and foreign capital costs of civil works as well as of electrical and mechanical equipment.

1.3.2 INDIRECT COSTS

Beneath the main components of cost estimation mentioned above, other costs are estimated on basis of a percentage of the previous costs. This approach differs in this respect to the procedure presented in the previous paragraph. Whether these indirect costs are considered separately or as a percentage of main costs, makes no big difference. The main aspect is, that these costs have to be considered in one or the other way, because the amount is considerable and cannot be neglected. In the following the different cost items are briefly explained:

Site Installation

Following items have to be mentioned:

- Mobilisation and demobilisation
- Accommodation for consultants and contractors personnel and other facilities
- Workshop warehouse sheds and yards
- Providing necessary equipment and furnishing of consultants and contractors administration and field offices
- Providing and maintaining vehicles for engineers and consultants personnel
- Providing personnel transport between camp and construction site
- Maintenance of colonies and camps including securities and all other facilities

To fulfil this item of work, 10% cost of civil works can be assumed.

Engineering and Supervision

For a high head development at feasibility stage, this item represents the cost of preparation of detailed construction drawings at tendering stage, prequalification of bidders, evaluation of tenders/bids review of contractors submittals, administration of the construction contract, measuring of work.

The cost of engineering and supervision can be taken as 4% on civil works and 2.5% on electro-mechanical equipment.

Administration, Audit and Accounts

For this item approximately 4% of the total project costs can be estimated with the assumption, that 3% will be sufficient for administration expenses and other 1% for audit and accounts.

Import Duties

Based on the aforementioned Import Policy of the Government of Pakistan, each imported equipment and material has to be charged with 12% of the imported goods. This item is dependent on the policy of the concerned country and therefore a general statement cannot be given.

Interest During Construction

In the case of the Golen Gol Hydropower Project, the interest during construction is estimated at a rate of 16% per annum for 3.5 years of the construction period on local cost component and 12% on foreign cost component. This item can also be considered as site specific

The estimation of the total project costs is the sum of all above mentioned items, which are included in the main costs and in the indirect costs, which are estimated by percentages.

It should be mentioned again in this context, that there might be some more approaches, how to estimate the total costs of the project and in which way indirect costs and unit prices have to be taken into account. Either these costs are already included in the main costs of civil work or electro-mechanical equipment or they are taken as a percentage of a subtotal cost. It is not important, as long as they are included.

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