Ministry of Energy

of Georgia

Norwegian Water

Resources and Energy

Directorate

COST BASE
FOR HYDROPOWER PLANTS IN GEORGIA
>13 MEGAWATT

(price level 1st January 2015)

2016

PREFACE

In 2013 the Norwegian Water Resources and Energy Directorate (NVE) entered into a cooperation with the Ministry of Energy of Georgia and the National Environmental Agency of Georgia, with the purpose of developing an inventory of all hydropower potential in Georgia, including development and construction costs. The cooperation necessitated a step-wise approach, where the following steps were necessary:

- Preparation and quality control of historical hydrometeorological data
- Land use mapping and preparation of a digital elevation model (DEM)
- Preparation of a national runoff map for Georgia
- Compilation of cost data for hydropower development
- Calculation of the hydropower potential and associated costs

This manual, which has been prepared by Georgian (Gross Energy Group) and Norwegian (Norconsult AS) consultants in cooperation with the Ministry of Energy of Georgia and NVE, contains relevant cost data for hydropower development in Georgia. Hopefully the manual may serve as a useful guide to potential investors in renewable energy in Georgia, as well as a tool for the government for assessment and prioritization of the hydropower development.

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1 GENERAL CHAPTER

1.1 GENERAL

1.1.1 INTRODUCTION

Up to now former Soviet Union standards, as well as the quarterly published manual issued by the Construction evaluation union has been used in Georgia.

Norconsult AS (Norway) has been assigned the task of preparation the *Cost Base for Hydropower Plants* for Georgia (price level 1 January 2015) by the Norwegian Water Resources and Energy Directorate (NVE) as a task in the agreement between NVE and Ministry of Energy (MOE) of Georgia. The final version is a result of joint review and corrections by NVE (also consulting Norconsult) and MOE (assisted by Georgian consultant Gross Energy Group).

Current manual represents very smart tool for the calculation of hydropower development in Georgia. Maintenance and upgrading of the Cost Base in future will be undertaken when judged necessary.

1.1.2 THE CONTENT OF THE REPORT

The report provides a basis for calculation of mean foreseeable contractor costs (construction and civil engineering works) and supplier costs (mechanical and electrical equipment). These costs will depend on a number of conditions and may vary from power plant to power plant.

The given tools (price curves, etc.) have been based on assumptions considered to be reasonable. Primary assumptions and comments are given in the figures and the associated texts.

Builder expenses have not been included in the price basis.

Furthermore, the report outlines estimated margins of error to be used in conjunction with the price curves and unit prices.

1.1.3 PURPOSE OF THE REPORT

In the early stages of a hydropower project it is important to weigh economic factors against conflicts with other stakeholders. This is where estimated construction costs play an important part. Furthermore, it is important that the cost calculations are performed in such a manner that the development price for the individual development objects/alternatives can be compared without undue imbalance caused by different approaches (included/non-included costs, etc.)

The cost curves, unit prices, etc. for the report’s various installation parts (dams, tunnels, power station, etc.) are meant as a tool for conducting the cost calculations, so that:

1. The cost calculations can be performed readily, and
2. The estimated costs can be compared with a reasonably degree of accuracy. In this respect, it is of greater importance to accurately evaluate the relative cost difference

between individual development objects and methods, rather than the accurately assess total construction costs.

1.1.4 REPORT STRUCTURE

The report consists of four sections:

1. General Chapter
2. Construction and Civil Works
3. Electro-technical Work
4. Mechanical Engineering Works

Each section has a subsection where the text and figures related to the various installation parts are presented together. When using the report, the text and the figures should be studied in conjunction.

1.1.5 USE OF THE REPORT

The report can be used to calculate the costs of installation parts at an early stage of the planning process.

The cost figures and price curves in the report provide an average foreseeable cost figure. Additional, and more rigorous, calculations must be performed in order to obtain a more accurate cost estimate that is less likely to overrun. Preliminary margins of uncertainty have been included for this purpose, but local conditions and other factors that can influence the project costs must be considered in each individual case.

A number of cost units have been excluded from the presented cost base. Consequently it is imperative to study the price curve assumptions and comments. Non-included costs must naturally be calculated separately if a more complete estimate is required.

The report is not meant as a design tool for optimisation or choice of construction type, for instance.

1.1.6 PRICE LEVEL

The prices in the report are as of 1 January 2015.

1.2 FINANCIAL ASPECTS OF U/E PROJECTS

1.2.1 OBSERVATIONS RELATING TO DIFFERENT CHOICES

1.2.1.1 REGARDING SHUTDOWNS

Shutdowns caused by U/E (upgrades/expansion) alterations will always be planned and thus defined as a planned shutdown rather than a breakdown, meaning that alterations can be undertaken to ensure minimal production losses.

It is important to note that turbines have a convex efficiency graph with an optimum capacity at approximately 75% of full load. The efficiency will also vary according to the head of water. Production outside the optimum capacity will result in poor energy utilisation, increased vibration and cavitation, thus increasing the need for maintenance.

If the power plant has a reservoir, alterations requiring short-term shutdowns will not cause water loss provided that the inflow can be stored in the reservoir. This means that the planned production must be staggered so that the reservoirs are drained as much as possible prior to the shutdown. The power plant will lose production when the reservoir is drained, due to the loss of head as well as reduced turbine efficiency. In a long-term shutdown the water level in the reservoir will rise above the top water level (TWL) which will result in flooding and diversion flow, and resulting production losses will be considerable

If the water level in the reservoir is higher than desired after the work has been completed, the power plant will operate on high load for a period of time until the level in the reservoir has sunk to the desired level. In such a case, the extra production will take place at a greater head. However, this benefit may be offset by poorer turbine efficiency at full load.

If the level in the reservoir must be kept low whilst work is ongoing, it is desirable to produce power with the heightened discharge. However, the power plant will then produce at a lower head and poorer efficiency. Alternatively, the inflow may be diverted which will result in greater loss of production. When the work has been completed, the water level in the reservoir will be lower than desirable. The power plant should therefore be left idle for a period of time until the water in the reservoir has reached the desired level.

When production is staggered, the consequence will normally be a loss of production revenues. However, advance production will provide revenues at an earlier stage yielding higher net present value. Power prices may develop differently than expected. It is therefore possible that in certain cases production revenues may increase when production is staggered.

Power plants with supply obligations will have to purchase power from other producers in the event of a shutdown. It was assumed that the cost of any power purchases will be higher than the costs of production in one's own power plant. If it is not possible to purchase power, the costs can easily be considerable.

In order to reduce losses in the event of a shutdown, it is also important that operating personnel have received thorough training and that preventive maintenance has been conducted.

1.2.1.2 CATCHMENT AREA

An extension of the catchment area will, in isolation, not cause loss of production. It may, however, entail that the capacity of the power plant has to be increased. Various alterations may have to be conducted regarding to the reservoir, intake, waterways and station. Most of these alterations will incur a production shutdown of varying duration.

1.2.1.3 INTAKE

When restructuring a stream inlet, the inflow must be directed past the inlet during the construction period. This will not cause production shutdown, only reduced production during the construction period. The production loss will vary according to the amount of water that has to be redirected during the period.

If inlets are to be reconstructed the reservoir must be drained in advance and be kept down for the duration of the work. In such a situation, the power station will run at full load and at poorer efficiency/head until the reservoir is empty. If the station fails to empty and/or keep the level in the reservoir low, the inflow must be diverted. After the work has been completed the station will remain idle until the reservoir has been refilled to the desired level.

Simple steps can be taken to reduce air entrainment and intake eddies without significant halts in production. The same applies to reconstruction of screens.

1.2.1.4 INCREASED CAPACITY OF WATERWAYS AND HEAD LOSS REDUCTION

<u>Smoothing of tunnels</u> - Smoothing of tunnels using various methods will require closing the station and draining the tunnel in question. If the work can be performed with a closed intake/inspection gate, it will be possible to use the reservoir during the shutdown.

<u>Expansion of cross-sections</u> - During back ripping of existing tunnels the power plant must cease operations for the duration of the work. If the breaking-in point for the back ripping is via existing cross cuts and the intake/inspection gate is closed, it will be possible to conduct the work whilst the reservoir is in use. As back ripping is a time-consuming process a shutdown will quickly result in loss of flow from the reservoir.

If a new tunnel is run parallel to an existing tunnel, the power plant must be shut down when the new and old tunnel are connected. It will usually be possible to schedule the connection to a time when there is no significant risk of loss of flow.

<u>Pipes</u> - The power plant must be shut down, or operations will be reduced during replacement of pipes or internal pipe maintenance. It will be possible to use the reservoir whilst work is ongoing. However, the reservoir must be drained before the work commences. The loss of production will depend on the length and number of pipes.

If new pipes are installed in parallel with existing pipes, shutdown will only be necessary when the old and new pipes are connected. The connection will usually be quick enough to avoid any risk of loss of flow. The same applies when old pipes are replaced by a shaft solution.

1.2.1.5 IMPROVING POWER UNIT EFFICIENCY

Upgrades of turbine wheels and the guide vane operating mechanism and reconstruction of a generator require shutdown of the power unit for 1-2 months. For a well-regulated system it should be possible to integrate the shutdown in the ordinary operations without significant loss, particularly if the power station has several units which can produce whilst one unit is out of operation. With a lower degree of regulation and fewer units it will be necessary to adjust the operations by draining the reservoir prior to the work and store water whilst work is ongoing. Unregulated plants with only a single unit must let the entire inflow pass whilst work is ongoing.

1.2.1.6 CHANGES IN MANOEUVRING REGULATIONS

Changes in the manoeuvring regulations will not require production shutdown. However, such an alteration may increase inflow to the power plant, which again may result in the power plant wishing to increase its capacity. The implementation of subsequent alterations will in most cases mean that production must cease for a period of time.

1.2.1.7 REDUCING TECHNICAL RESTRICTIONS

<u>Reservoir</u> - Most reservoir alterations will involve removing sills so that the reservoir can be fully drawn down to the lowest water level (LWL). Smaller sills may be removed by divers/underwater blasting and will not require significant shutdowns.

Removal of larger sills will require draining down the reservoir and keeping the water level low whilst work is ongoing. This means draining the reservoir prior to the work, unregulated production at low heads and thus poorer efficiency. In such a case it will be possible to interrupt the work and continue it the next season. It will therefore not be necessary to divert the flow, provided that the power station can be used to keep the water level low. Consequently, loss of production will be limited for this type of work.

<u>Waterways</u> - In waterways it is important to reduce large singular losses. Relevant alterations may include giving concrete culverts a better hydraulic shape and removing blockages in the waterway such as air pockets, etc.

The tunnel must be drained before this work can commence. It is possible to use the reservoir with a closed gate, thus minimising production losses.

1.2.1.8 ENLARGING THE INSTALLATION

If an older unit is to be replaced with a new one, production will shut down whilst the replacement work is ongoing. This work will last for a couple of months depending on the size of the unit. To minimise production losses, the work should be scheduled to periods of low water levels in the reservoir and low inflow. The relevant reservoir should be drained down before the work commences. It will be possible to use the reservoir whilst work is ongoing.

Some power plants have a designated space in the existing station for a new unit. If this is the case, the new unit can be installed without having to cease production with the original unit.

If a new station is being constructed in connection with existing one, it is likely necessary to shut down the existing units whilst work is ongoing. This has applied particularly to blasting work; however, improved blasting techniques have significantly reduced tremors. Consequently in some cases it will be possible to operate the existing units even during blasting work nearby. This means that only a short shutdown is necessary during connection of the old and new unit.

Upgrades and expansion of control systems are not likely to result in any significant shutdowns, particularly if existing measuring points are re-used. If new measuring points have to be established, it might be necessary to shut down production for a short period.

1.2.1.9 RESERVOIR

If upstream dam alterations are to be implemented, the reservoir must be fully drained before the work can commence and the level be kept down for the duration of the work, and in some instances water may have to be diverted in order to achieve this.

Implementation of alterations on the downstream side can usually take place without halts in production.

1.2.1.10 NEW SMALL-SCALE POWER PLANTS IN EXISTING CATCHMENT AREA

For existing power plants it may be of interest to construct small-scale power plants which utilise the fall from the transferred field down to the intake reservoir. It may also be relevant to construct small-scale power plants which make use of the mandatory release of water from the reservoir.

Small-scale power plants in transferred fields are often constructed as separate power plants, or in connection with existing transfer tunnels. It is possible to construct the power station itself without halting transmission excepting when the new power station is connected to the existing transfer tunnel. If the power station has a separate inlet and outlet it will not be necessary to interrupt the transfer. The loss of production related to the construction of small-scale power plants in an existing catchment area is therefore minimal, and it should be possible to adapt the shutdown to the ordinary power plant operations.

1.2.2 CONSIDERATIONS REGARDING THE VALUE OF RESERVOIR SIZE

Reservoirs are used to even out differences between natural flowrates in a river system and the energy demand. Georgian climate results in inflow and consumption in anti-phase, with greater demand in winter. Prior to today, when grid connections to Europe were poor, it was largely necessary to be self-sufficient, and as a consequence winter power was considerably more valuable than summer power. As a result large reservoirs were a natural part of power plant development. The improved grid has reduced this seasonal disparity to such an extent that diurnal variations are expected to be greater. Consequently it is less valuable to store the inflow for winter production. On the other hand, it generates greater interest in hydropeaking, and some occasions have proved the necessity of full reservoirs in the autumn.

Today, the reasons for investing in increased reservoir capacity are in summary:

- Reduced loss of flow
- Increased head
- Increased need for power regulation/hydropeaking
- Increased drought security

Reservoirs do not generate energy in their own right, but increase production by reducing the loss of flow and increasing the head of water. Moreover, reservoirs increase the possibility of producing at high turbine efficiency through so-called optimum capacity operation (intermittent duty). Reservoirs also provide greater freedom to produce when power values are high, by either transferring the inflow from the filling to the draw-off period, or by hydropeaking. Power plants usually distinguish between four different types of reservoirs:

1.2.2.1 DAILY/WEEKLY STORAGE RESERVOIR

Daily/weekly storage reservoirs equalise the rates of flow so that low flow can be collected and discharged at high efficiency, and reduce flood crests. Unit wear and tear as a result of producing at low water flow is reduced, but this is offset by increased wear and tear due to increased start/stop operation of the units. The reservoirs facilitate hydropeaking as the power station may shut down at night and produce in the daytime.

This type of reservoir is common for small-scale power plants and run-of-river power stations. For these power stations, the value of increasing the reservoirs is primarily to reduce loss of flow, increase head and facilitate hydropeaking.

1.2.2.2 ELEVATED STORAGE RESERVOIR

Elevated reservoirs are constructed exclusively to increase the water head. Elevated reservoirs usually have small reservoir volumes where the level in the reservoir increases quickly with the increasing dam volume. The dam height is determined by dam costs and production.

The level in the reservoirs is usually kept close to the top water level (TWL). The reservoirs are usually only drained down in a flood situation if the reduction in the loss of flow offsets the loss of head. The loss of head reduces the possibility of hydropeaking. It is generally not profitable to expand this type of reservoir as construction costs will outweigh value from increased production.

1.2.2.3 SEASONAL STORAGE RESERVOIR

A seasonal storage reservoir transfers the inflow from one season to another. These reservoirs have a storage capacity of approximately 150% of mean annual inflow. The reservoirs are usually drained during the draw-off period (winter) and refilled during the filling season (summer). In this way, the reservoirs transfer the inflow from seasons with low demand for electrical energy and high inflow, to seasons with high demand for energy and low inflow. The power station will usually have an installation with a service life of 3-4000 hours per year. This makes hydropeaking possible within the framework set by the reservoir and the installation.

This type of reservoir is common in medium sized power plants. The value of the increased reservoir capacity lies primarily in the reduced loss of flow. The value of increased head and better hydropeaking possibilities is somewhat limited for this type of reservoir.

1.2.2.4 MULTI-YEAR STORAGE RESERVOIR

A multi-year storage reservoir has a capacity to store more than 150% of the mean annual inflow. Such reservoirs are very rarely drained down to the lowest water level (LWL) and if so only during years of extremely low precipitation. As the water level in the reservoirs is generally high, the power station will utilise the inflow with high heads and good turbine efficiency. Multi-year storage reservoirs are well suited for hydropeaking.

For this type of reservoir the value of a reservoir expansion is limited to increased dry-year security. Whether dry-year security is profitable from a business point of view must be considered very carefully. Better hydropeaking possibilities may also be relevant. However, for multi-year storage reservoirs hydropeaking in combination with pumping is most interesting.

1.2.2.5 CONSIDERATIONS REGARDING THE VALUE OF POWER

In the power industry the term power is often divided into two types:

1. Sufficient output - produced in power plants
2. Peak output - produced in peak load power stations

Sufficient output means the power output necessary to run out a mean annual inflow with an operation time of about 3000-4000 hours/year. With peak power it is possible to run out the inflow in a significantly shorter operation time, usually in the region of 1-2,000 hours/year.

The demand for power in Georgia has been characterised by high ohmic load (caused by melting furnaces and electric heaters). In total this gives little power variation. The periods with highest peak output in Georgia have occurred on the coldest days of winter. The Georgian power system consists mainly of hydropower which has a short response time. This has resulted in non-stable power supply in the Georgian system. Consequently, there has been huge interest in investing in peak output. This is clearly highlighted by several older power developments connected with industrial developments. These power plants usually have an operating time of 6000-7000 hours.

In Georgia, peak output investments have been limited to power plants where head loss has been low, high head of water and the good regulating ability.

The peak output costs are primarily related to an increase in power unit costs. However, it could readily be considered expand the power station, increase the cross-section of the waterways and increase the reservoir capacity. Hydropeaking results in increased wear and tear on the unit, thus increasing operating costs. The wear and tear is caused by a higher number of starts/stops, as well as increased attrition caused by vibrations and cavitation. When operating on full load, the energy effect will also be reduced due to lower turbine efficiency.

Since 2010, there has been a decrease in investments in new power production in Georgia, particularly in peak output. However, demand for power increased steadily and after year 2015 there has been an increasing shortage of power in Georgia. This development has reversed. In the 2010 report, it was referred to higher power prices as a result of trading carbon credits, and expectations of even higher prices. This was not the case. Since 2015 power prices have fallen considerably as a consequence of little growth in demand, growing supply, and the low prices carbon credits.

Future prices are expected to remain low for several years, possibly increasing somewhat with improved grid connections to Europe and due to economic crisis overcome. The most important, and least certain, factor is the development of carbon credit prices. Another important factor will be future EU climate policies, and emission targets.

2 CONSTRUCTION AND CIVIL ENGINEERING WORKS

2.1 GENERAL

2.1.1 AVERAGE FORESEEABLE COSTS AND UNCERTAINTY

This chapter provides a basis for calculating an estimate of average contractor costs for building-related work. By “average” it is implied that there is 50% probability of real costs being higher, and 50% probability that they will be lower than estimated.

Uncertainty margins have also been estimated for the individual installation parts. The real costs are estimated to have 90% probability of being within the specified margins.

Generally speaking, all cost estimates should specify the probability of real costs being higher and possibly also specify the highest and lowest probable costs.

2.1.2 CONTRACTOR COSTS

INCLUDED/NON-INCLUDED COST ELEMENTS

The given price estimates includes all contractor costs with the exceptions specified in the sections for individual installation parts.

Generally, the following have been included/not been included:

- Temporary roads for construction purposes:
  Building and maintenance costs for a main road up to the construction site and for a road between, for instance, the soil extraction site and dam body have not been included. Some guidelines for how to calculate such costs are given in Item 2.13. Minor local roads are included in the cost base for each installation part.

- Transportation costs:
  All transportation costs have been included in the cost base for the individual installation parts in those cases where there is a road leading up to the construction site.

  Where there is no such road, no costs have been included relating to construction or operation of special transportation facilities. Thus, helicopter and aerial cableway transportation has not been included in the cost base for the individual installation parts. Some guidelines for how to calculate aerial transportation costs have been included in Item 2.13.

- Construction site power
  Construction and maintenance expenses for power lines and transformers have not been included. The contractor will usually be obliged to pay for the power he uses. Consequently, costs for power used at the installation have been incorporated in the unit prices. Some guidelines for how to calculate such costs have been included in Chapter 3, Electrotechnical work.
  Also prices for grid connection is not considered, which is regulated by the Georgian legislation and has standard tariff.

- Clearing of submerged areas and land purchase:
  Costs for this have not been included, and must be calculated separately. Expenses relating to land purchases or leases have not been included.

- Rigging and operation of construction site:
  Rigging and operation costs have *not* been included in the individual items, and instead the cost of rigging, site establishment and decommissioning, operation, and overheads should be *added to the total of all other works*. This additional cost is estimated to an average of +30%, but can vary significantly between different projects. The cost tends to increase for larger projects and decrease for smaller projects, and will depend on contractor pricing-strategies. It is common for contractors with high rigging- and operation fees to charge lower unit prices for civil works, and vice versa. Moreover overheads vary depending on location, availability of infrastructure, complexity of the work and

- Fees and taxes:
  The costs do not include value added tax or investments fees.

2.1.3 PRICE VARIANCE

The presented unit prices for individual construction parts are weighted averages based on collated prices from tendering documents and published index values. Consequently, each unit is assumed to be of "normal" accessibility and difficulty (unless where stated otherwise). In practice a range of factors influence actual unit prices, and price variations are to be expected, between projects and for different construction parts of the same project.

This is accounted for by the provided uncertainty ranges. Simply put, work under very favourable conditions may result in 20% lower unit prices, whereas work in adverse conditions may increase unit prices by 30%, for instance.

2.1.4 BUILDER'S COSTS

Builder's costs have not been included in the cost curves and must be calculated/estimated separately for each power plant.

Builder's costs may vary significantly, depending on the type of power plant, its location, construction time, level of interest rates, etc. It has been fairly common to calculate builder's costs as a percentage of the contractor expenses (and the supplier expenses). This is not a robust approach, as there is no regular connection between contractor expenses and the construction client's often significant and highly variable expenses relating to, for instance, location, local conditions and the power plant's composition of various installation parts, feasibility studies, compensations, valuation, land rehabilitation, etc.

Builder's costs should be broken down into individual components and be calculated separately. If actual calculations are not possible at the current stage, these expenses should be estimated roughly.

Separate calculations/estimates should be made of the following cost units relating to builder's costs:

- Surveying (mapping, contouring, staking out)
- Investigation of ground conditions (seismology, shafting, drilling, laboratory work)
- Planning, preliminary projects, etc.
- Preparation of tendering documents, construction drawings, follow-up, etc.
- Construction management and quality control (local administration)
- Administration (central)
- Land rehabilitation, alterations
- Land acquisition, valuation/compensation
- Interests in the construction period, financing costs
- Funds, payments to local authorities, etc.
- Construction of permanent dwellings, workshops
- Sills, special land rehabilitation alterations. (Normal clearing and preparation of the site including soil extraction site and tips have been included in the cost curves)
- Reservoir clearing (tree felling below the top water level (TWL)).

2.1.5 CONTRACTOR COSTS – PRICE LEVELS

The costs have been stated terms of January 2015 prices.

The price evaluation has aimed to provide a level which reflects a normal market situation. Where market conditions vary one may experience pronounced price changes over a short period of time. It has not been deemed appropriate to let such conditions influence the basic price levels. The report includes provisions for calculation the cost of the power plant. The construction of the plant, however, may take place at some point in the future, and it should be noted that market conditions may change before the commencement of this work.

2.1.6 CONSTRUCTION SITE LOCATION

The costs given in the report relate to the average foreseeable costs. It is critical to note that additional costs must be added for plants in remote locations with difficult communications or lengthy transportation.

It should be expected that plants in areas exposed to harsh weather and/or with a short construction season will be more expensive than average. This applies to dam work in particular.

Prices will typically in the range between +25% and -10% due to the plant location.

2.1.7 PLANNING AND CONSTRUCTION MANAGEMENT

Plant engineering costs are often calculated as a percentage of the construction costs. However, the percentage mark-up will be higher for small plants than for larger ones. Detailed engineering of plants where tunnels constitute a major part of the costs will give a lower mark-up compared to plants where concrete work and ordinary building work make up most of the cost.

Approximate engineering and construction management costs will be:

- Pre-engineering 1-2%
- Tendering documents 2-3%

- Detailed engineering, construction drawings 5-10%
- Construction management, local 5-10%

2.2 ROCK FILL DAM WITH MORAINE CORE

2.2.1 MAIN DAM DIMENSIONS

In addition to the provisions stipulated official codes and supporting guidelines, as well as any minimum requirements stipulated for contingency reasons, the main dimensions of the dam will be determined by the natural conditions of the dam foundation, the nature/quality and access to materials, flood increase (flood alleviation), reservoir surface and location (wave impact). Of these conditions it is often only the location and the minimum requirements of the Dam Safety Regulations that are known at an early stage in the planning phase. With regard to the other conditions, the initial estimated cost and volumetric calculations must therefore be based on assumptions.

If there are any special conditions that one is aware of and that will affect the dam's main dimensions, these should be specified separately.

2.2.1.1 NORMAL CROSS-SECTION

There are two normal cross-sections which can be used as a basis for mass calculations.

Normal cross-section A is shown in Fig. 2.1.1. this cross-section can be used in cases where the uncompacted materials are so small that the entire dam foundation is established on rock. The slope inclination is 1:1.5.

Normal cross-section B is shown in Fig. 2.1.2 this cross-section can be used in cases where the volumes of uncompacted material are so large that the support filling foundations are established on uncompacted material. The slope inclination is 1:1.7.

Volume curves for the two normal cross-sections have been prepared and presented in Figures 2.1.3, 2.1.4 and 2.1.5.

<u>The crest width, freeboard and width of the individual inner zones</u> have been chosen on the basis of a maximum dam height of approximately 50 m. For larger dams, these dimensions will also be somewhat larger. Consequently, for dams with other maximum heights, the presented volume curve correction factors are found in Fig. 2.1.6.

The correction factor is based on the following (in metres):

Max. dam height	Crest width	Width filter + transition zone	Freeboard
30	5.5	7.0	3.5
50	6.0	7.5	4.0
100	10.0	9.0	4.5
150	10.0	9.0	4.5

In this instance freeboard means the distance from the top of the dam to the design floodwater level. The average dam height is assumed to equal 80% of the maximum dam height.

The flood increase (Q_{1000}) has been set at 1.5 m, which will in many cases be a reasonable flood control reservoir. Deviations in flood increase may of course occur and in cases where this has been determined, the volumes can be corrected for this. If, for instance, the flood increase is 2.5 m, the volume is at a dam height equal to 20 m is read as H = 21 m.

The dam height has in this report been defined as the height from the top water level (TWL) down to the average height of the dam foundation in the individual zones.

The normal cross-section should only be considered as a basis for a cost calculation early in the planning phase. Depending on local conditions and the quality of and access to materials, it will be necessary to determine the increased cross-section for the construction of the dam.

2.2.2 DAM FOUNDATION

Costs associated with the dam foundation have been organised into three groups. The given cost figures include an average of foreseeable contractor costs.

2.2.2.1 STRIPPING/REMOVAL OF UNCOMPACTED MATERIAL

The extent of stripping/removal of uncompacted material must be estimated/calculated in each case. All accessible information should be taken into account.

The following guidelines are proposed:

If little stripping of uncompacted material is necessary such that it may be assumed that the entire dam can be established on rock, the average stripping can usually be estimated at 2 m.

If calculations/estimates give a higher value, this value should be used. Even in cases where the dam foundation contains a minimal amount of uncompacted material, a cost will be included corresponding to 0.5 m of stripping of the entire dam foundation as a minimum.

If there are large volumes of uncompacted materials, and it is assumed that the support fillings will be established on uncompacted material, one can generally assume the average stripping to be 1 m. In cases where mapping has been conducted of marsh areas and other types of masses that must be removed, this must be taken into account and the stripping volume increased accordingly.

It should be assumed that moraine and filter zones will be established on rock. The volume of stripped uncompacted material must be estimated/calculated separately for these areas.

The unit cost “stripping of uncompacted material” is set at the volume of uncompacted material x 1.4 USD/m^3.

2.2.2.2 *FOUNDATION AND DAM TOE TREATMENT*

The cost of all work that is normally required at the dam toe has been included in Fig. 2.1.7. The figure also indicates the outlines of the costs as a function of the dam height.

The main cost elements are as follows:

a) Removal of rock in the foundation
b) Scaling and cleaning of the foundation
c) Pouring of concrete, cement grouting of the foundation
d) Placement of the first moraine layer
e) Required slope protection of toe

The extent of this work varies significantly. However, according to previous experience, these costs can in total be estimated at 80 USD/rm (USD per meter run) dam toe plus 20 USD/m^2 for the moraine foundation.

2.2.2.3 *INJECTION WORK*

The extent and cost of required injection work has been assessed on the basis of experiences from Georgian rock-fill dams.

It has been assumed a normal injection system with surface injection at 6 m depths in 2 rows and a hole pitch of 5 m, and a one-row deep injection screen at a depth equal to half the water pressure, though at least 10 m. Furthermore it is assumed that deep injection holes will be drilled until an impermeability corresponding to 1 Lugeon has been achieved.

Normal costs can be set at 110 USD/rm dam, plus 4.2 USD/m^2 for injection screen areas deeper than 10 m.

The cost of the injection work as a function of the dam height is presented in Figure 2.1.7.

2.2.3 DAM BODY

Further cost units are the volumes of the five main zones of the rock-fill dam: Impervious zone, filter, transition zone, support filling and slope/crest protection.

The specified cost figures include all average, foreseeable contractor costs for dam construction (including costs relating to soil extraction at the site). The costs are for a dam size of 500,000 m^3. Experience indicates unit cost figures are often lower for large dams than for small ones. This is corrected by applying the correction factor given in Fig. 2.1.8. Additionally it should be noted that for large dams the least expensive zones constitute a larger share of the work.

2.2.3.1 *IMPERVIOUS ZONE*

Volume estimations can be conducted by applying the volume curves presented in Figure 2.1.3, part 1, 2 or 3.

The location of a prepared foundation should be considered on the basis of local conditions. In general, it is recommend assuming that the completed dam foundation will be 1 m lower than the original rock surface.

The average costs of the impervious zone are set at 4.5 USD/m^3. This is assuming that the moraine pit is within a transportation distance of 2 kilometres from the dam. If the transportation distance exceeds 2 kilometres, an additional cost of 0.15 USD/m^3/km should be added.

The price also includes moraine screening and rock separation in the moraine pit to a normal extent.

The costs of 4.5 USD/m^3 mainly comprise the following elements:

a) Moraine pit costs such as forest clearing, stripping and land adjustment after operations have ceased. Necessary trenching during operations and if necessary removal of unusable material.
b) Loosening of moraine
c) Loading and transportation (2 kilometres)
d) Placement and compaction

2.2.3.2 FILTER ZONE

Volume estimations can be conducted by applying the volume curves presented in Figure 2.1.4.

It is assumed that foundation for the filter zone is located on the original rock surface.

The average cost of the filter zone is set at 4.0 USD/m^3.

It is also assumed that natural gravel is available within a transportation distance of 4 kilometres. Some sort of gravel treatment will often be necessary to ensure satisfactory material grading. Costs of, for instance, screening or temporary storage are included within the range of the specified average costs.

In exceptional cases, the gravel pit is of such a good standard that satisfactory material grading is achieved directly during loading in the gravel pit over water. In such cases, the filter costs can be set at 2.5 USD/m^3.

If the distance to the gravel pit exceeds 4 kilometres, an additional cost of 0.15 USD/m^3/km should be added.

Should usable natural gravel not be available within an economical distance, it must be assumed that crushed material will be used. In such cases, the cost is set at 6.5 USD/m^3.

The normal price of 4.0 USD/m^3 mainly comprises the following elements:

a) Gravel pit costs such as forest clearing, stripping and land adjustment after operations have ceased, and if necessary removal of unusable material.
b) Loading and transportation (2 kilometres)
c) Screening and temporary storage
d) Placement and compaction

2.2.3.3 *TRANSITION ZONE*

Volume estimations can be conducted by utilising the volume curves presented in Figure 2.1.4.

It is assumed that the location of the foundation for the transition zone is the same as the rock surface.

Average costs for the transition zone are set to 4.0 USD/m^3. This price is based on the assumption that the transition zone is prepared by applying a simple crushing process using blasted rock, and that the transportation distance does not exceed 2 kilometres.

In some cases, tunnel rock is available in the vicinity of the dam. This rock can usually be used for the transition zone by applying a simpler screening process. The costs in such cases are set to 2.5 USD/m^3.

A more complex crushing process may be necessary in cases where the quality of the filter and rock material is poor. The costs in such cases are set to 3.7 USD/m^3.

The normal price of 4.0 USD/m^3 mainly comprises the following elements:

a) Proportion of stripping and restoration of the site after operations have ceased. Land adjustment expenses associated with the crushing rig area.
b) Rock blasting
c) Loading and transportation
d) Crushing
e) Transportation (2 kilometres).
f) Placement and compaction

2.2.3.4 *SUPPORT FILLING*

Volume estimations can be performed by applying the volume curves presented in Figure 2.1.5, part 1, 2 or 3.

It has been assumed that the location of the foundation for the support filling is at the rock surface, alternatively 1 m below the terrain.

Average costs for the support filling are set to 2.1 USD/m^3.

The price is conditional on the support filling being produced using quarry stone and on the condition that there is a suitable quarry area within 1 kilometre of the dam.

The extent of stripping work is usually modest. Additional costs must be expected in cases where it is necessary to remove large volumes of uncompacted material to get to suitable bedrock.

If tunnel rock is available in the vicinity of the dam, this will usually be used as support filling at a lower price. The costs in such cases can be set at 1.3 USD/m^3.

The normal price of 2.1 USD/m^3 will usually comprise the following elements:

a) Stripping and land adjustment of quarry area.
b) Blasting

c) Loading and transportation
d) Placement and compaction

2.2.3.5 SLOPE AND CREST PROTECTION

Volume estimations can be conducted by applying the volume curves presented in Figure 2.1.4.

It has been assumed that the location of the foundation for the slope protection is at the rock surface, alternatively 1 m below the terrain surface.

Average costs for the slope and crest protection are set to 4.0 USD/m^3.

This price assumes that the support filling is produced at the quarry and that the coarse rock material is generally produced as a product of this process. A certain extent of blasting conducted for the purpose of producing coarse rock material is expected and included in the price.

As the need for coarse rock material is generally largest during construction of the dam top, a certain degree of temporary storage is also considered normal and included in the price.

If the support filling is constructed using tunnel stone, a separate quarry must be established for production of coarse rock material. If this is the case, the price is set to 5.4 USD/m^3.

2.2.4 PRICE LEVEL

The stated prices represent the price level as of January 2015.

2.2.5 INCLUDED/NON-INCLUDED COSTS

Please see Chapters 1.2. The following applies specifically:

- Bottom outlet/by-pass/coffer dams:
  Bottom outlet/by-pass/coffer dam costs have not been included in the cost figures. These costs must be calculated separately.
- Flood gates and any emergency discharge devices:
  These costs have not been included in the cost figures and must be calculated separately.
- Instrumentation costs:
  Costs have not been included.
- Gates, gratings, screens:
  Costs have not been included. For gate costs, see Chapter 4.4.

2.2.6 COST CALCULATION UNCERTAINTY

It is estimated that the cost calculation uncertainty for dam foundations is +70% to -30%, and the cost calculation uncertainty of the dam body to be $\pm$25.

2.2.7 INCREASING THE HEIGHT OF EXISTING DAMS

It is difficult to give general guidelines for how much a dam should be extended. In most cases the extension will be limited to a few metres. The different zones have been designed according to material quality and water pressure, and slope at the top of the dam. An increase in the water level will increase the gradient through the moraine core, and it must be verified that the material quality and dimensions are able to sustain this.

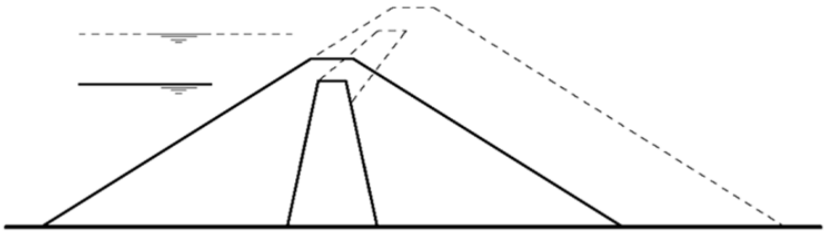
Such verification will also show how far down the sloping zones must be removed before the extension work can commence.

Special conditions such as the availability and volume of masses, transportation distances, etc. may have caused the zones of the dam to have a shape which are statically indeterminate. This may also impact the possibility of extending the dam height.

In most cases, the extension will take place on the downstream side and top of the dam. Thus no special regulation restrictions apply during the construction period.

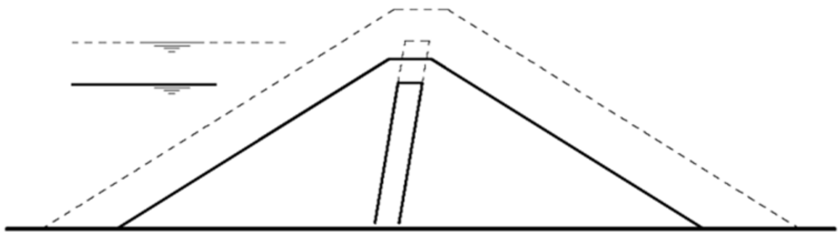
The costs can be calculated by using the unit prices given above, whereas volumes must be calculated separately in each case.

It is pointed out that in cases where the extension consists mainly of slope protection, it must be taken into account the proportion of large rocks in relation to the blasted volume. Hence, the price of the slope protection could increase by up to 100%. This must, however, be assessed in each individual case.



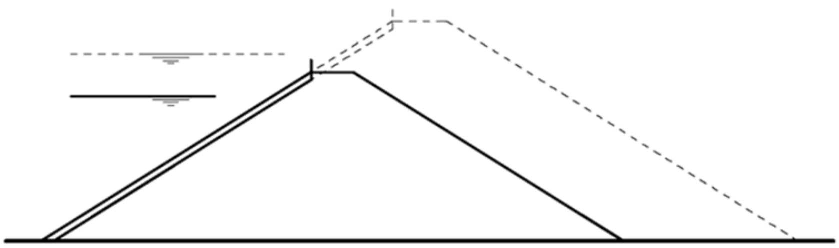
1. ROCKFILL DAM WITH MORAINE SEALING.

A height increace of a few meters is usually technically possible.



2. ROCKFILL DAM WITH CENTRAL ASPHALT SEALING.

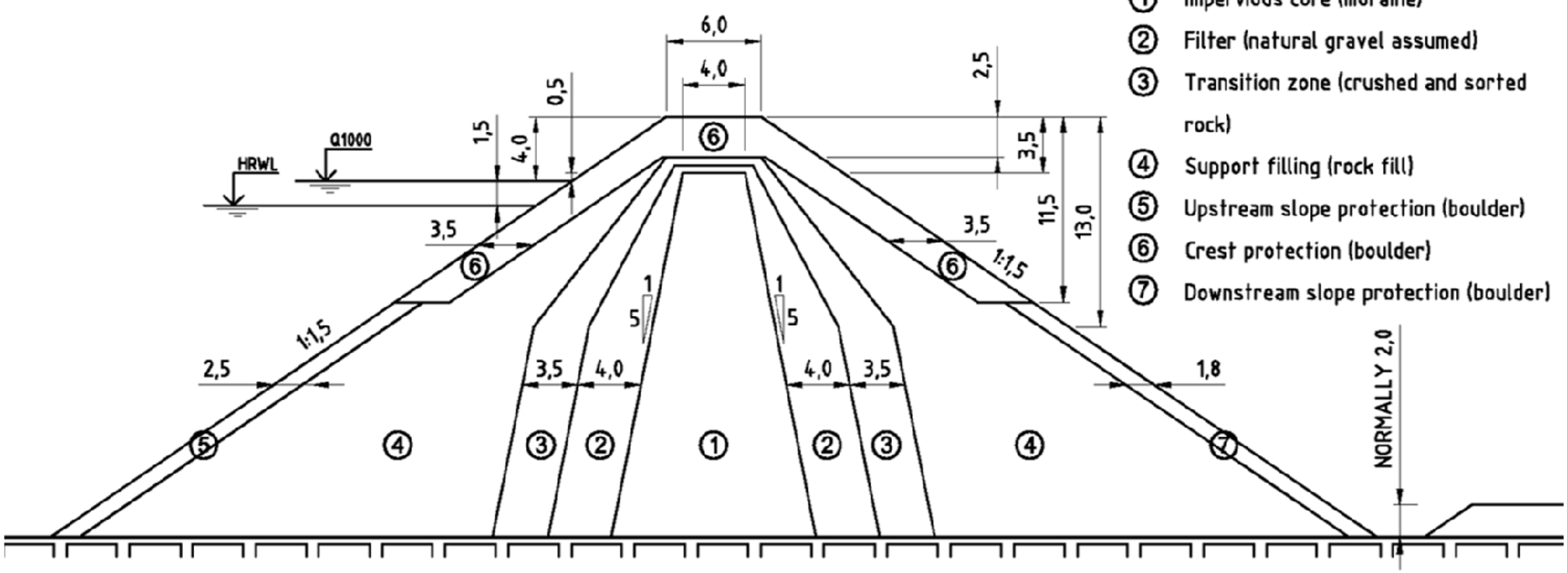
A height increase is usually technically possible. An increase which does not affect the upstream side of the dam will probably be limited to 2-3 metres.



3. ROCKFILL DAM WITH FRONT SEALING.

This type of dam allows for height increases without significant restriction in the construction period with regard to the water level in the reservoir.

Norwegian Water Resources and Energy Directorate NVE	EXAMPLES OF ROCKFILL DAM HEIGHT INCREASES	Fig. 2.1



COMMENTS:

1. The chosen height between the HRWL and the top moraine depends on the flood increase (Q1000 and PMF) as well as on the reservoir's flood control function.

2. 1% added to dam height as compensation for settling in the volume calculations.

3. The crest protection measurements may deviate from the given measurements.

4. Only valid as basis for volume calculations for cost estimates.

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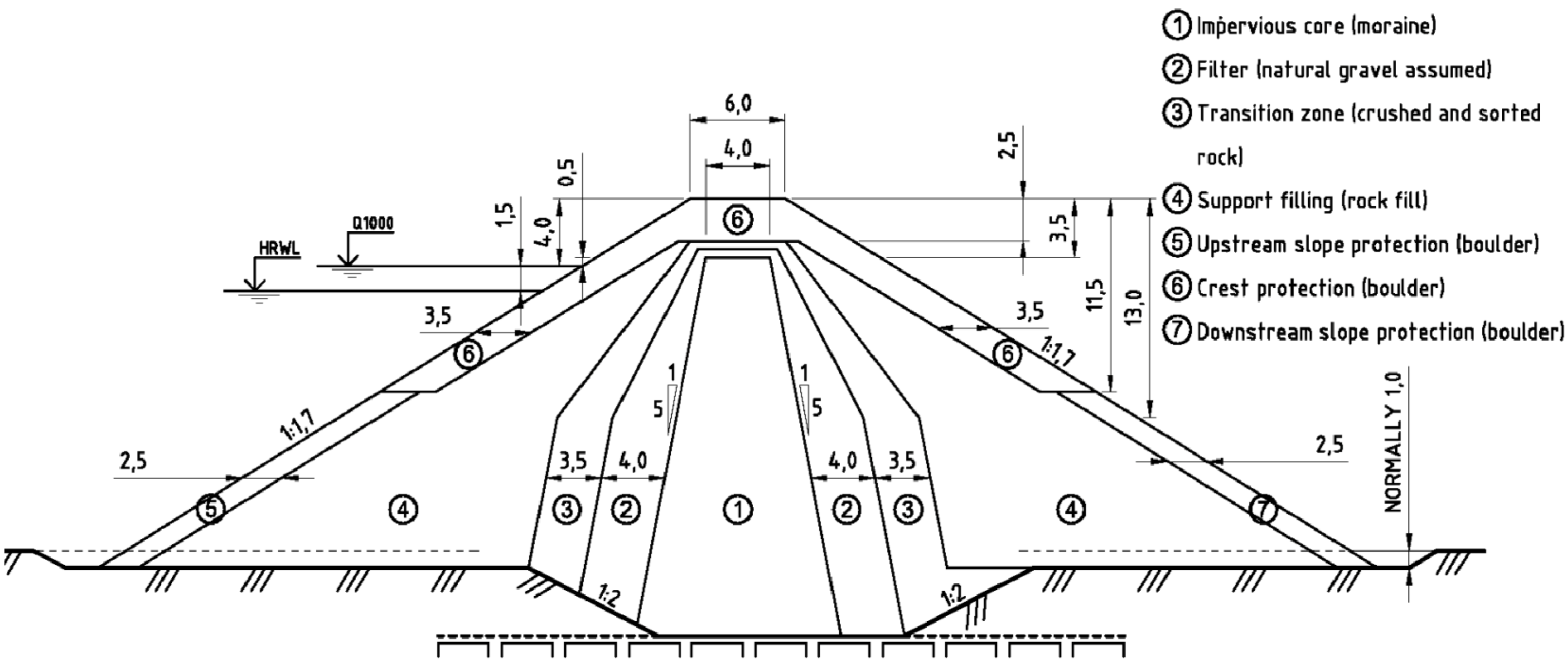
ROCKFILL DAM WITH CENTRAL MORAINE SEALING
DAM CROSS-SECTION ASSUMED FOR VOLUME AND COST CALCULATIONS.
SIDE SLOPE 1:1.5

Fig. 2.1.1



COMMENTS:

1. The chosen height between HRWL and the top moraine depends on the flood increase (Q1000 and PMF) as well as on the reservoir's flood control function.

2. 1% added to dam height as compensation for settling in the volume calculations.

3. The crest protection measurements may deviate from the given measurements.

4. Only valid as basis for volume calculations anc cost calculations.

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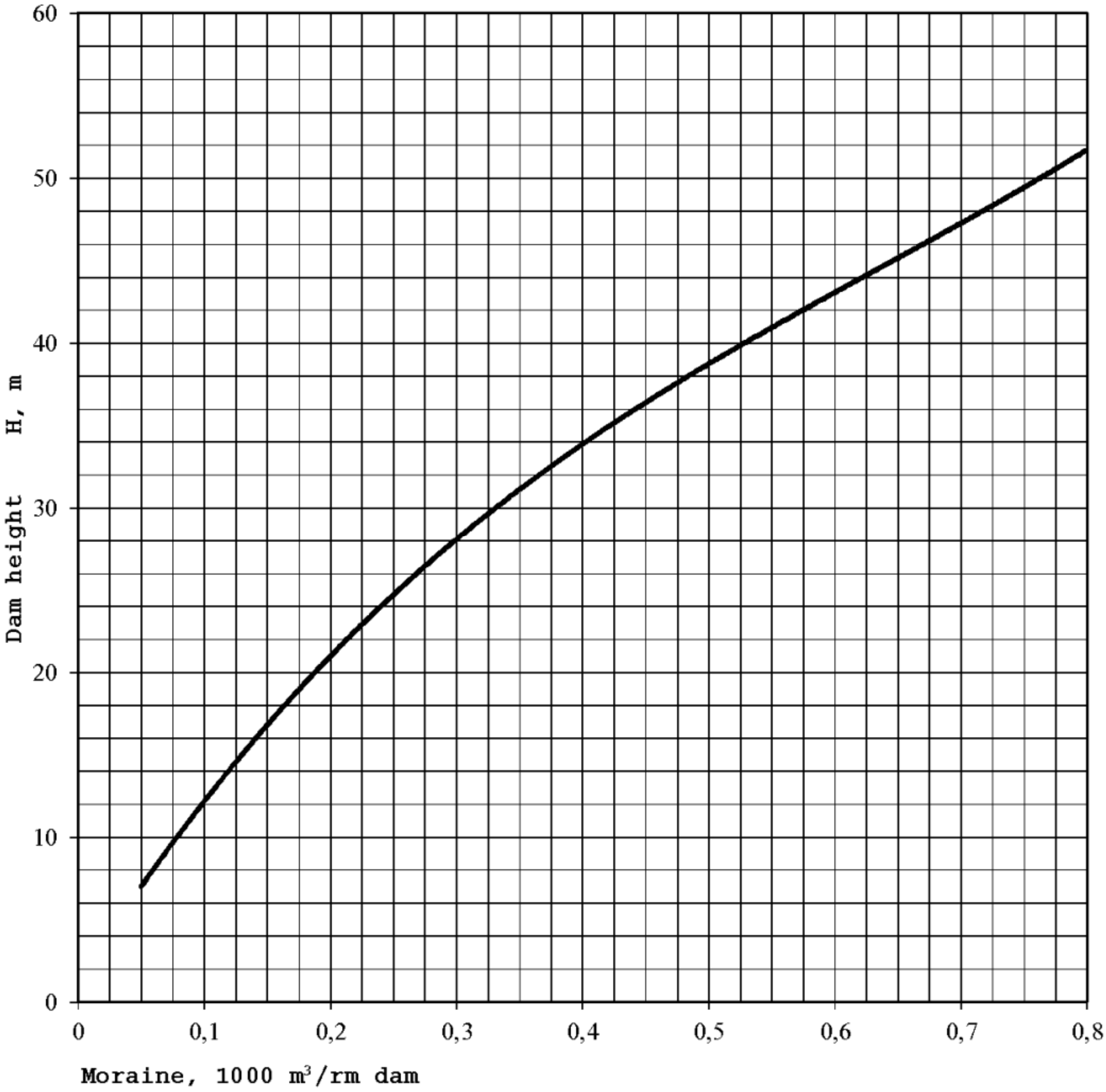
ROCKFILL DAM WITH CENTRAL MORAINE SEALING
DAM CROSS-SECTION ASSUMED FOR VOLUME AND COST CALCULATIONS.
SIDE SLOPE 1:1.7

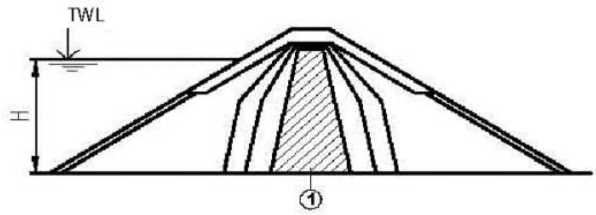
Fig. 2.1.2



COMMENTS:

1. Dam height H calculated from top water level.

2. Assumed dam cross -section, see Fig. 2.1.1 and 2.1.2.



Norwegian Water Resources and Energy Directorate
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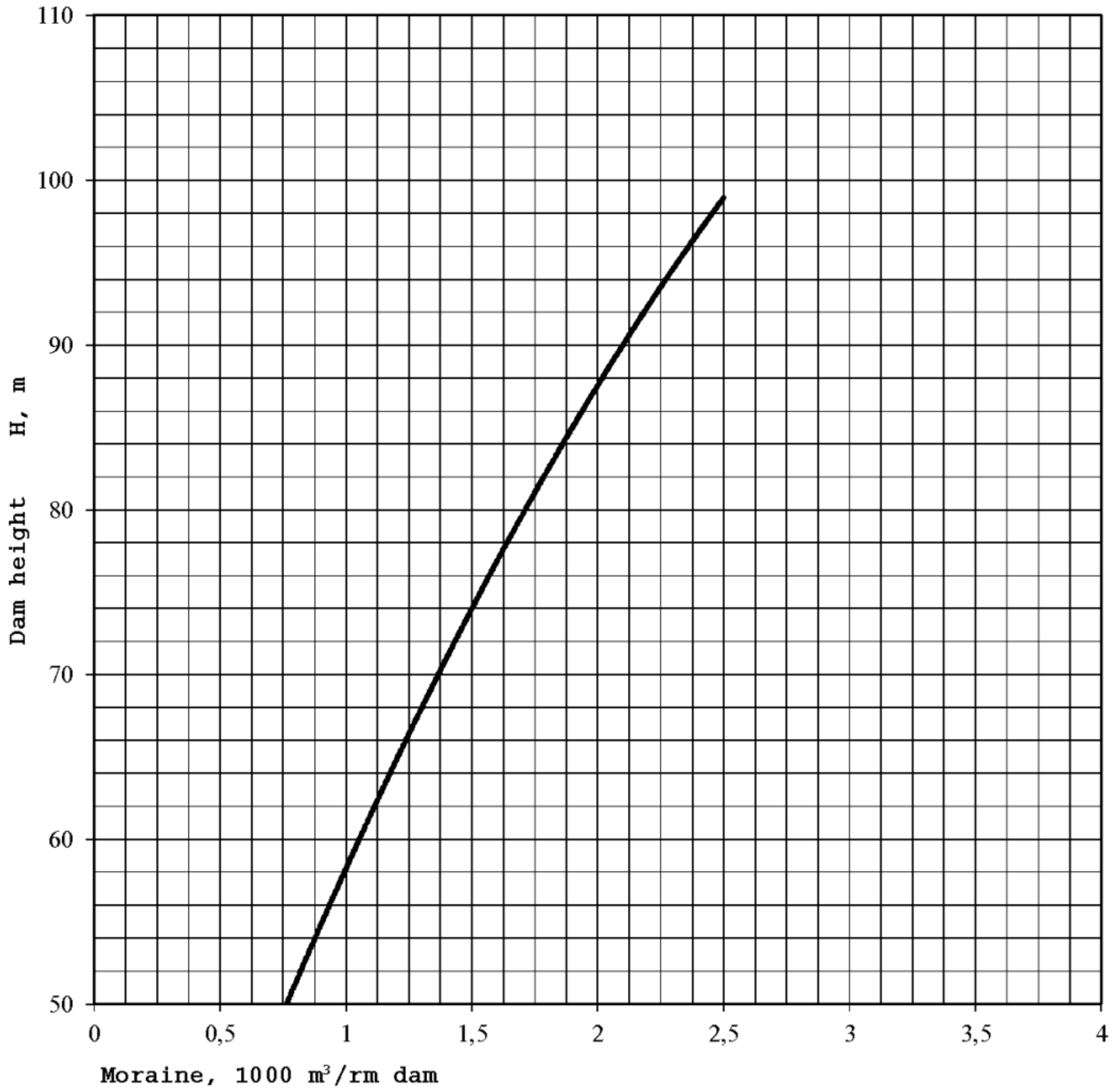
ROCKFILL DAM
WITH MORAINE CORE
VOLUME CURVE MORAINE

Fig. 2.1.3
Part 1

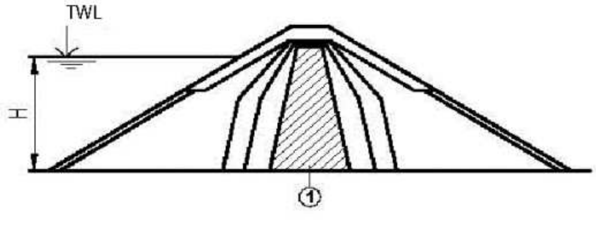
01.01.15



COMMENTS:

1. Dam height H calculated from top water level.

2. Assumed dam cross -section , see Fig. 2.1.1 and 2.1.2.



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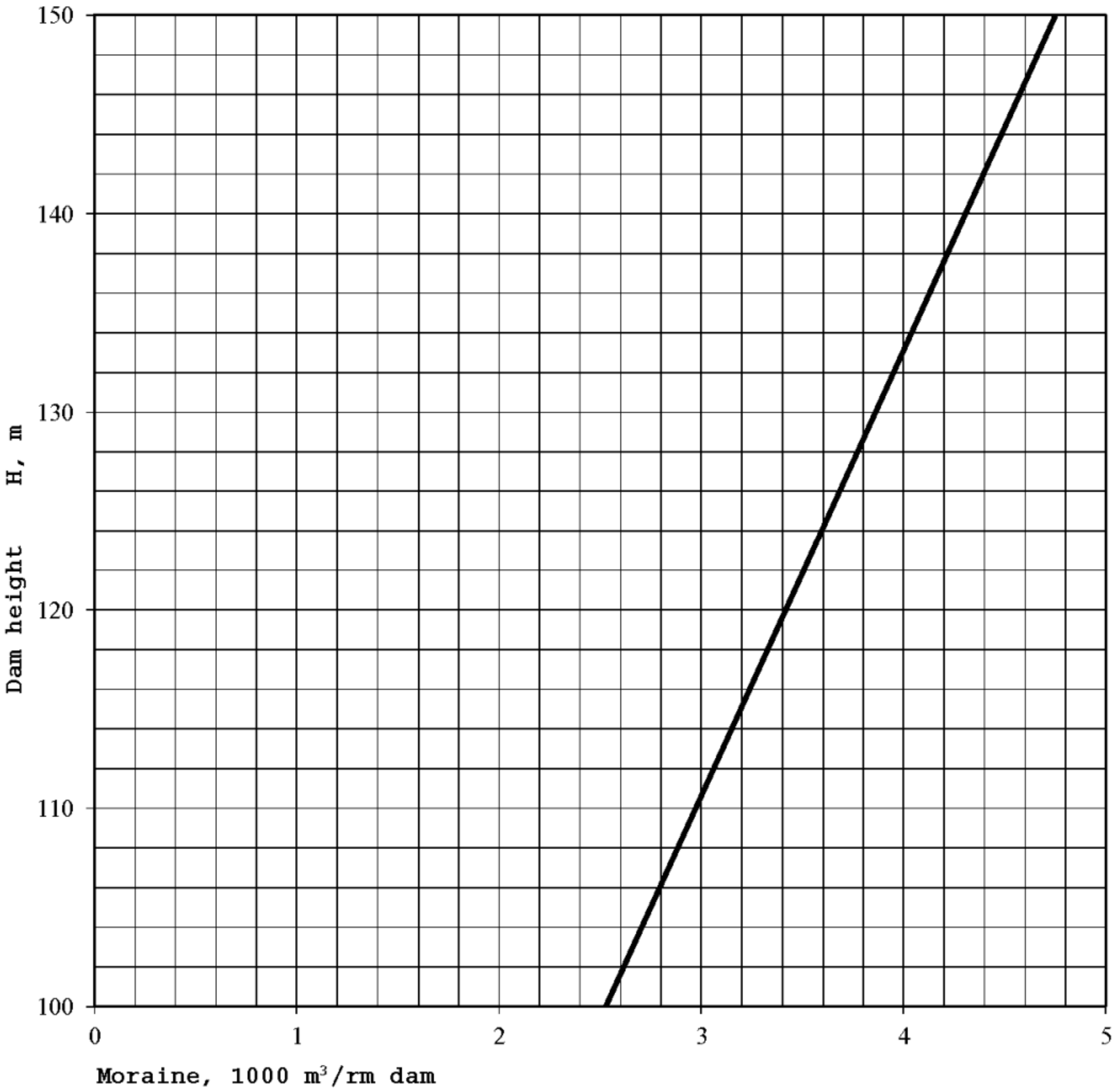
ROCKFILL DAM
WITH MORAINE CORE
VOLUME CURVE MORAINE

Fig. 2.1.3
Part 2

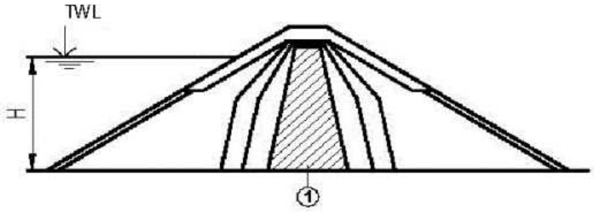
01.01.15



COMMENTS:

1. Dam height H calculated from top water level.

2. Assumed dam cross -section , see Fig. 2.1.1 and 2.1.2.



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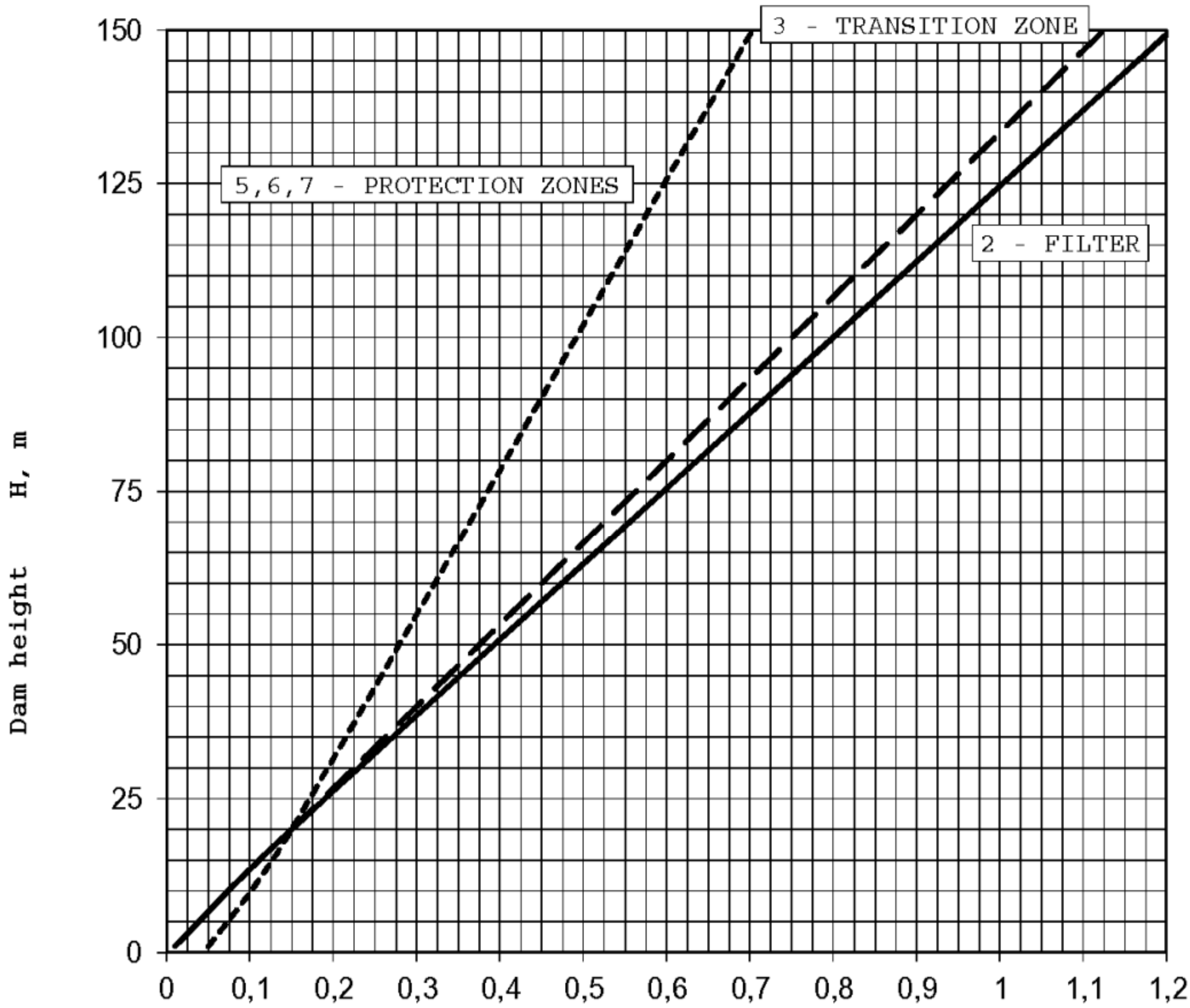
ROCKFILL DAM
WITH MORAINE CORE
VOLUME CURVE MORAINE

Fig. 2.1.3
Part 3

01.01.15



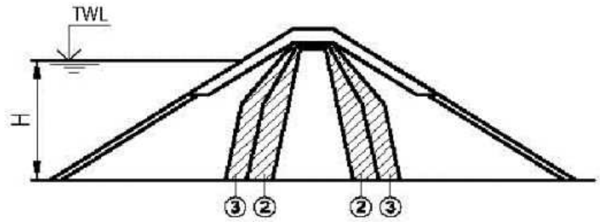
FILTER	1000 m^3/rm dam
TRANSITION ZONE	1000 m^3/rm dam
PROTECTION ZONES	1000 m^3/rm dam

COMMENTS:

1. Dam height H calculated from top water level.

2. Assumed dam cross section , see Fig. 2.1.1 and 2.1.2

3. Volume of transition zone and filter is corrected according to Figure 2.1.6 .



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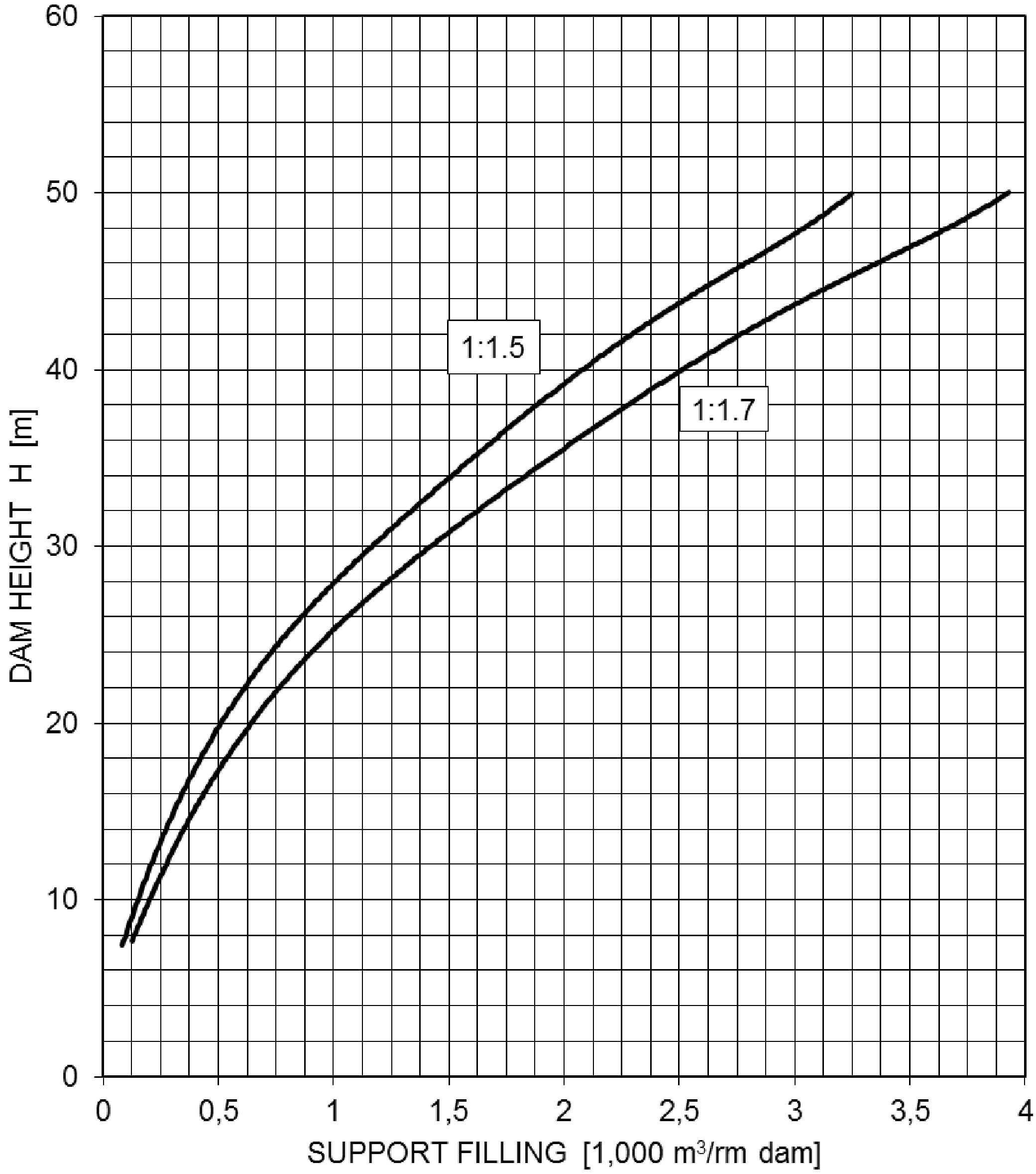
ROCKFILL DAM WITH MORAINE CORE
VOLUME CURVE FILTER
TRANSITION ZONE AND
PROTECTION ZONES

Fig. 2.1.4

01.01.15

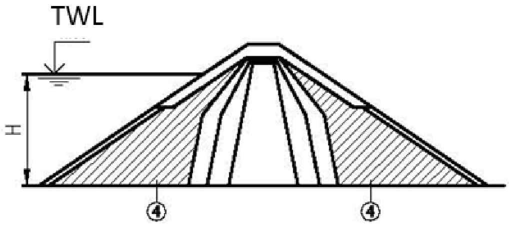


COMMENTS:

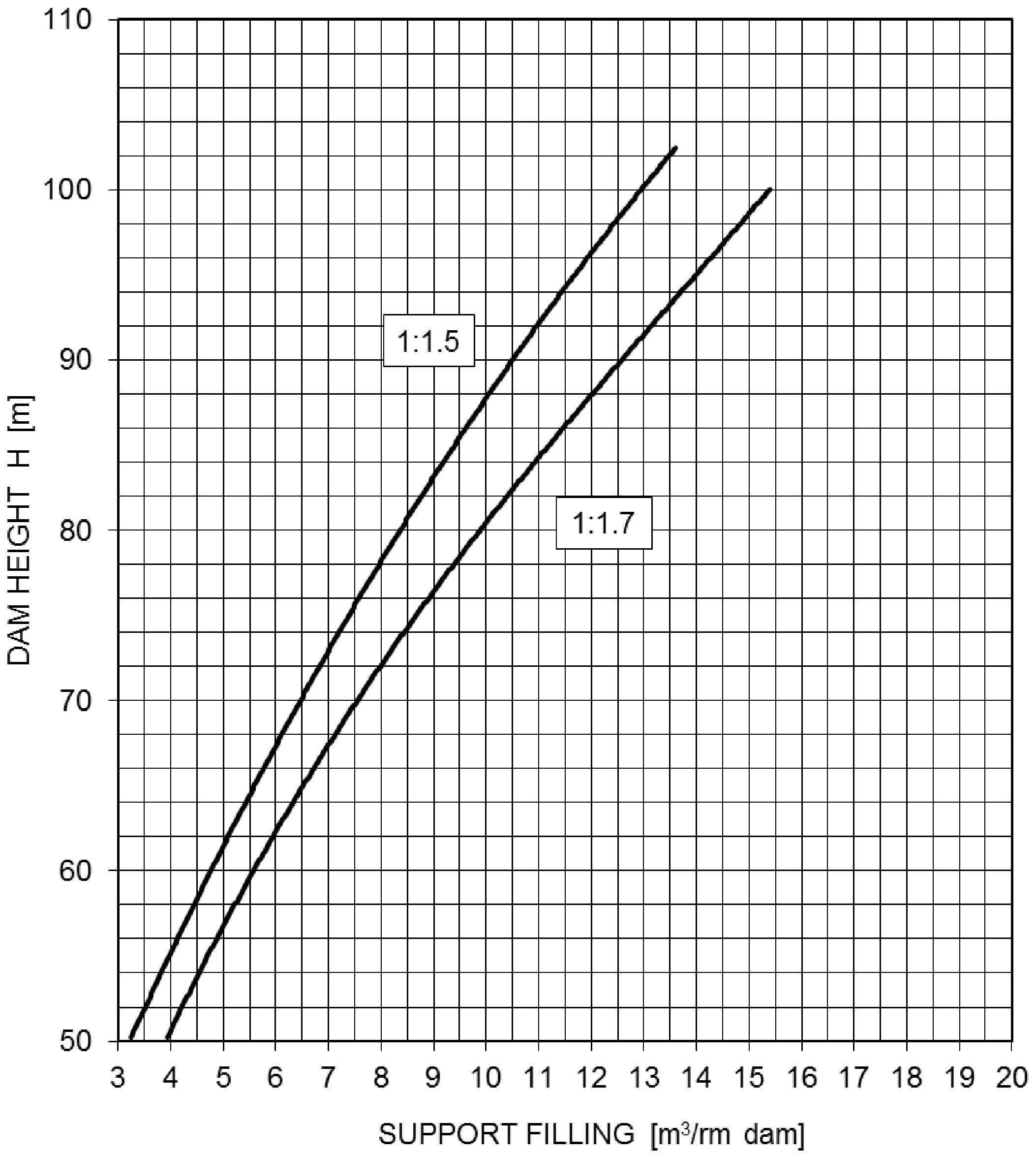
1. Dam height H calculated from top water level.

2. Assumed dam cross section, see Fig. 2.1.1 and 2.1.2

3. Volume of support filling corrected according to Figure 2.1.6.

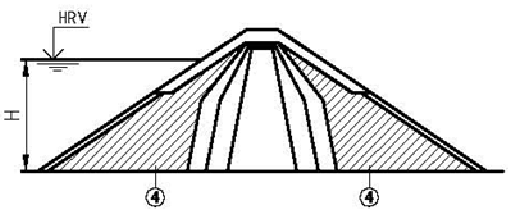


Norwegian Water Resources and Energy Directorate NVE	**ROCKFILL DAM WITH MORAINE CORE VOLUME CURVE FOR SUPPORT FILLING 1:1.5 AND 1:1.7**	Fig. 2.1.5 Part 1 01.01.15



COMMENTS:

1. Dam height H calculated from top water level.
2. Assumed dam cross section, see Fig. 2.1.1 and 2.1.2
3. Volume of support filling corrected according to Figure 2.1.6



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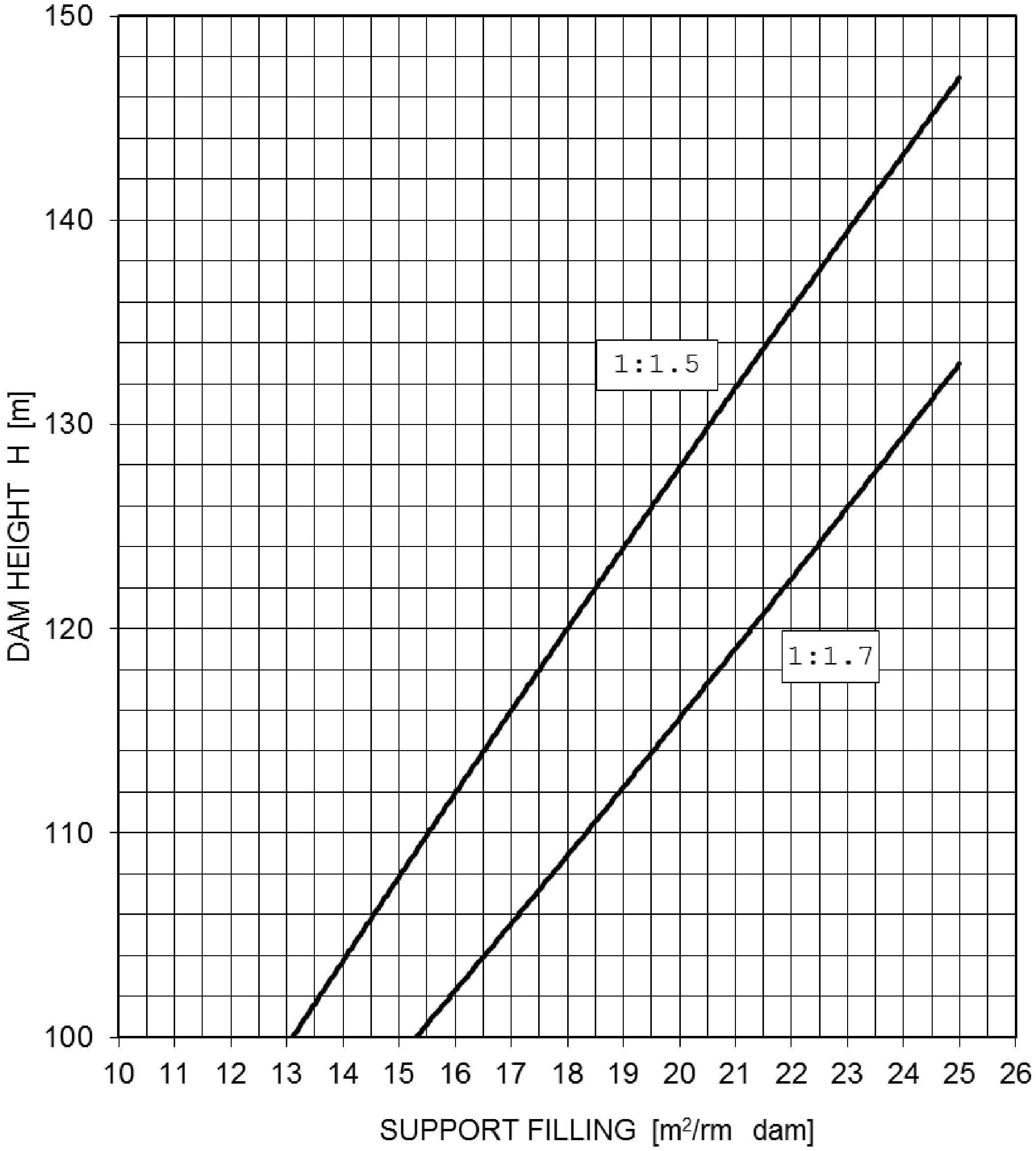
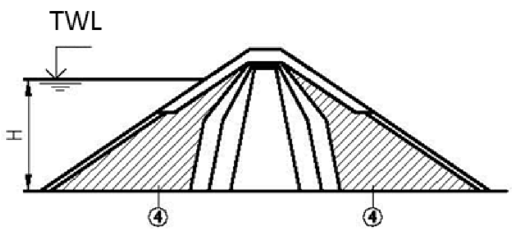
ROCKFILL DAM WITH MORAINE CORE VOLUME CURVE FOR SUPPORT FILLING 1:1.5 AND 1:1.7

Fig. 2.1.5
Part 2
01.01.15



COMMENTS:

1. Dam height H calculated from top water level.
2. Assumed dam cross section, see Fig. 2.1.1 and 2.1.2
3. Volume of support filling corrected according to Figure 2.1.6



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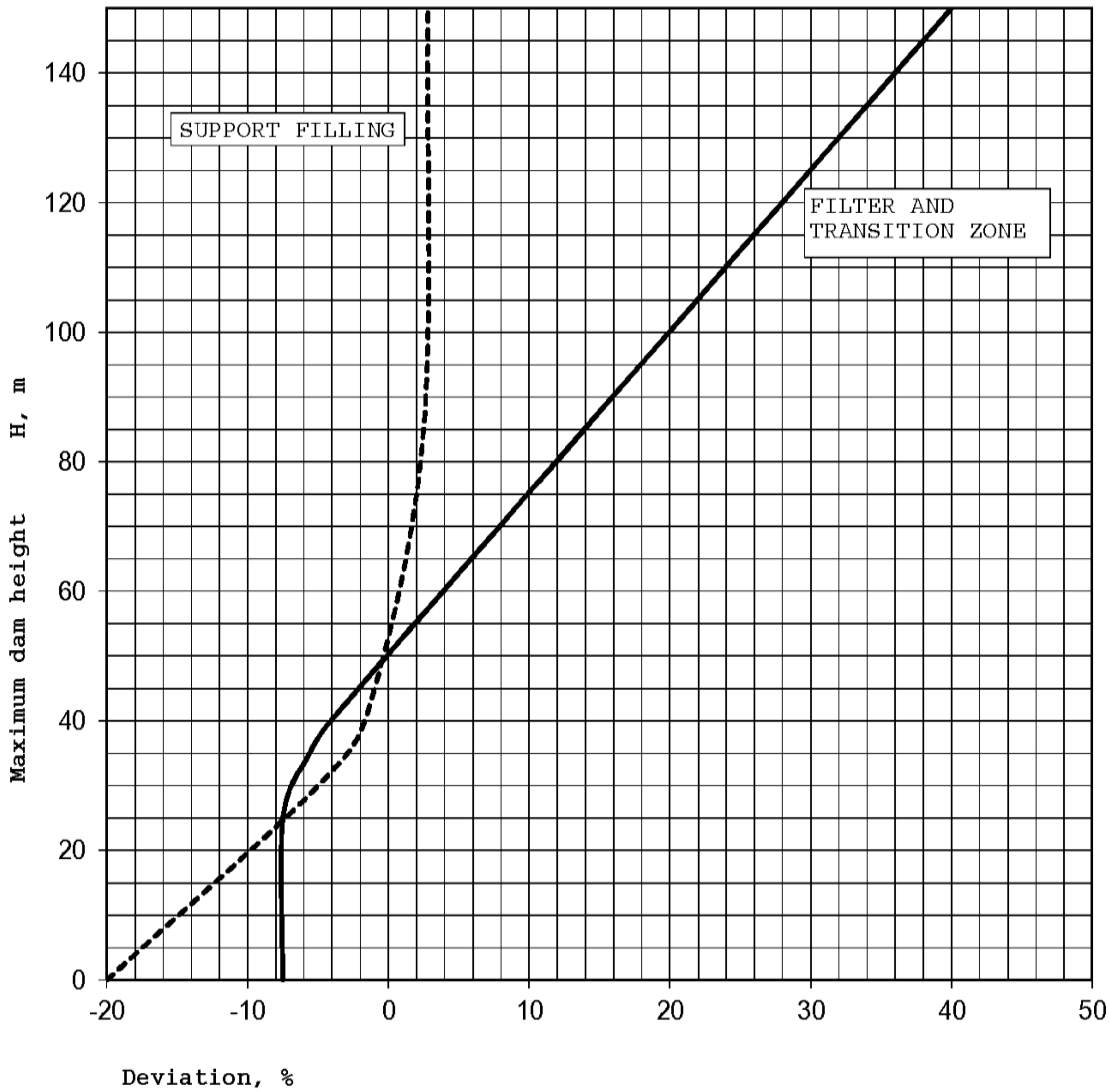
ROCKFILL DAM WITH MORAINE CORE VOLUME CURVE FOR SUPPORT FILLING 1:1.5 AND 1:1.7

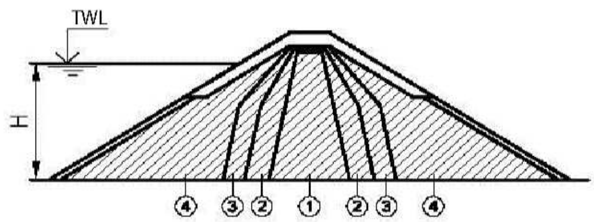
Fig. 2.1.5
Part 3
01.01.15



COMMENTS:

1. The figure shows the correction factor for the total volume of the transition zone and support filling as a function of maximum dam height.

2. Cf. chapter 2.1.1.1



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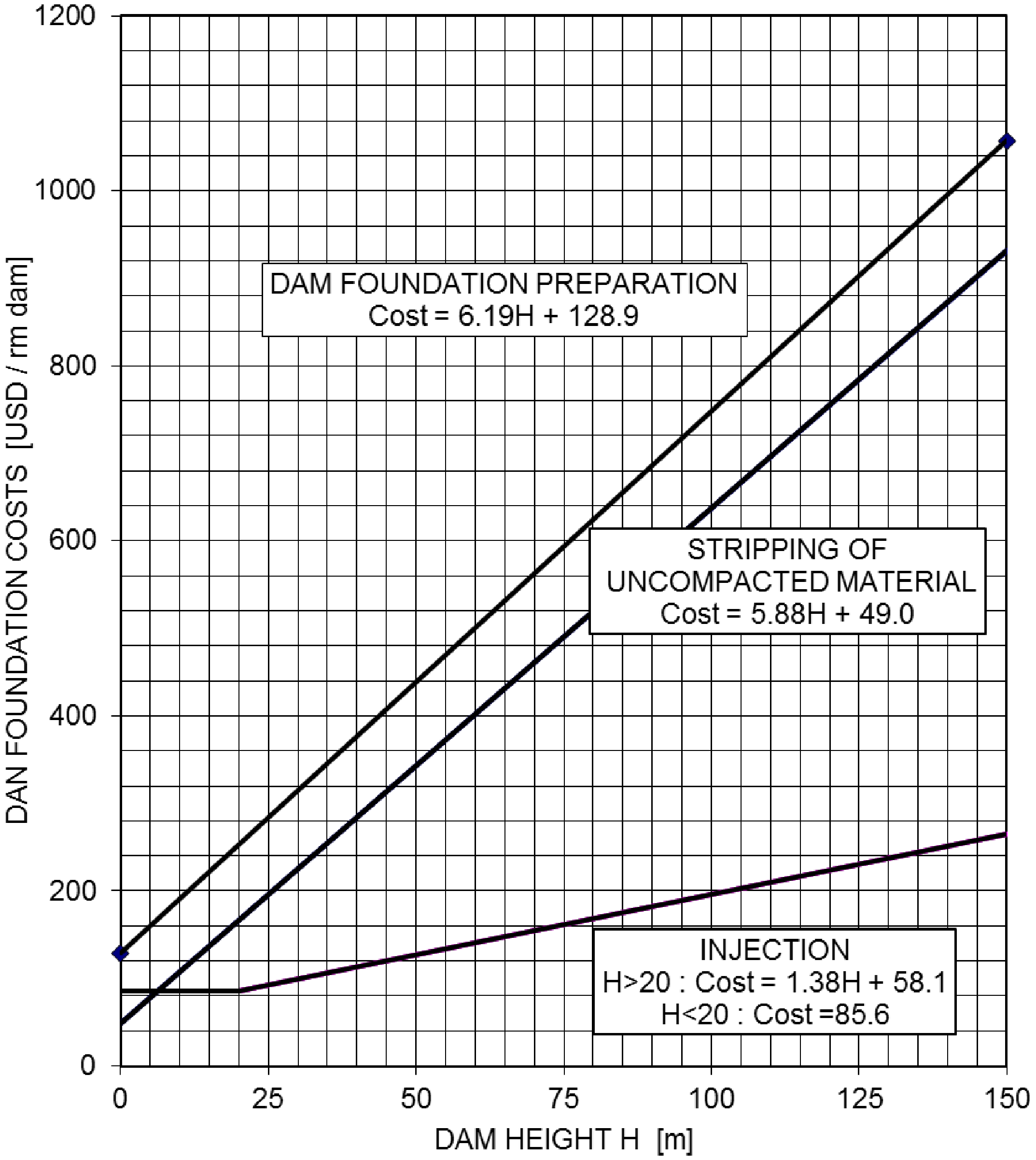
ROCKFILL DAM
WITH MORAINE CORE,
SUPPORT FILLING,
FILTER, AND TRANSITION ZONE

Fig. 2.1.6

01.01.15

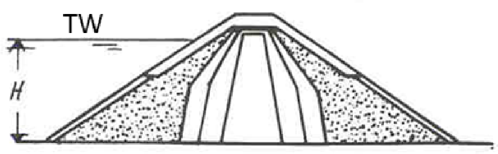


COMMENTS:

1. Price level January 2015.

2. The cost of stripping uncompacted material is shown for an uncompacted material depth of 2 m.

3. Costs are stated for dam cross section in Fig. 2.1.1.



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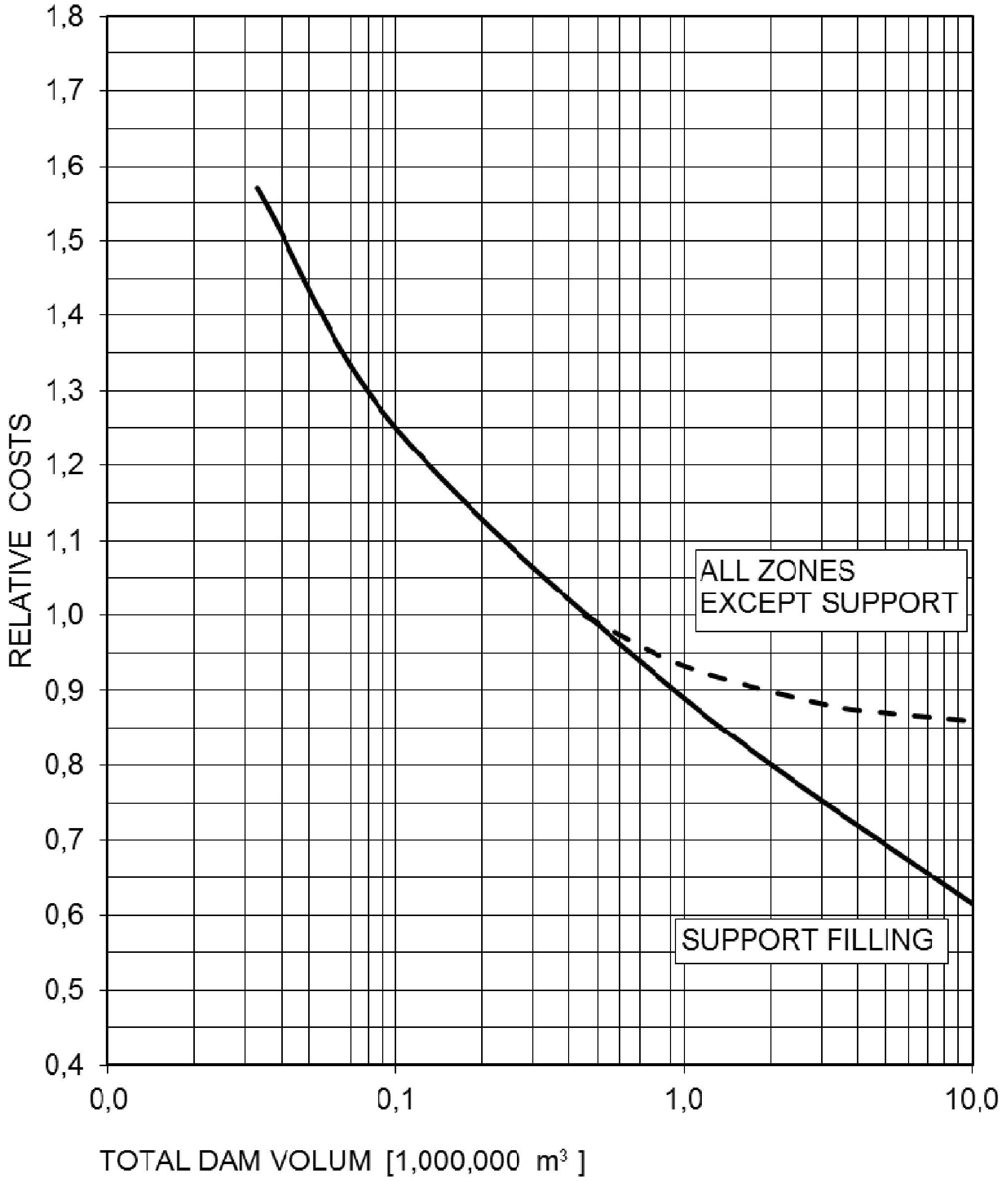
ROCKFILL DAM WITH MORAINE CORE DAM FOUNDATION COSTS

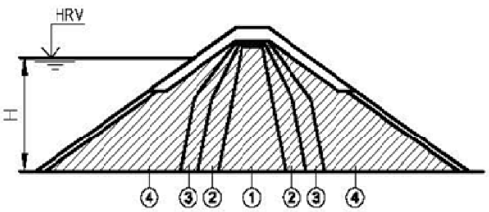
Fig 2.1.7
01.01.15



COMMENTS:

1. The figure shows the correction factor for the dam zone costs depending on the total dam volume .

2. Cf. Chapter 2.1.3



	ROCKFILL DAM WITH MORAINE CORE COST CORRECTION FACTOR IN PROPORTION TO TOTAL VOLUME	Fig 2.1.8 01.01.15

2.3 ROCK-FILL DAM WITH ASPHALT CONCRETE

2.3.1 MAIN DAM DIMENSIONS

In addition to the provisions stipulated in official codes and supporting guidelines, as well as any minimum requirements stipulated for contingency reasons, the main dimensions of the dam will be determined by the natural conditions of the dam foundation, the nature/quality and access to materials, flood increase (flood alleviation), reservoir surface and location (wave impact). With regard to the other conditions, the initial estimated cost and volume calculations must therefore be based on assumptions.

If there are any special conditions that one is aware of and that will have a negative impact on the dam's main dimensions these should be specified separately.

2.3.1.1 NORMAL CROSS-SECTION

There are two normal cross-sections which can be used as a basis for mass calculations.

Normal cross-section A is shown in Fig. 2.2.1. this cross-section can be used in cases where the uncompacted materials are so small that the entire dam foundation is established on rock. Inclination is 1:1.5.

Normal cross-section B is shown in Fig. 2.2.2. this cross-section can be used in cases where the volumes of uncompacted materials are so large that the support filling foundations are established on uncompacted material. Inclination is 1:1.7.

Volume curves for the two normal cross-sections have been prepared and presented in Figures 2.2.3 and 2.2.4.

The crest width, freeboard and width of the individual inner zones have been chosen on the basis of a maximum dam height of approximately 50 m. For larger dams, these dimensions will also be somewhat larger. Consequently, for dams with other maximum heights the presented volume curve correction factors are found in Fig. 2.2.5.

The correction factor is based on the following (in metres):

Max. dam height	Crest width	Width filter + transition zone	Freeboard
30	5.5	4.5	3.5
50	6.0	4.5	4.0
100	10.0	6.0	4.5
150	10.0	6.0	4.5

In this instance, freeboard means the distance from the top of the dam to the design floodwater level. The average dam height is assumed to equal 80% of the maximum dam height.

The flood increase (Q_{1000}) has been set at 1.5 m, which will in many cases be a reasonable flood control reservoir. Deviations in flood increase may of course occur and in cases where this has been clarified, the volumes can be corrected for this. If, for instance, the flood increase is 2.5 m the volume is at a dam height equal to 20 m is read as H = 21 m.

The dam height has in this report been defined as the height from the top water level (TWL) down to the average height of the dam foundation in the individual zones.

The normal cross-section should only be considered as a basis for a cost calculation early in the planning phase. Depending on local conditions and the quality of and access to materials, it will be necessary to determine the increased cross-section which will be used for the construction of the dam.

2.3.2 DAM FOUNDATION

Costs associated with the dam foundation have been organised into three groups. The given cost figures include all average, foreseeable contractor costs.

2.3.2.1 STRIPPING OF UNCOMPACTED MATERIAL

The extent of stripping of uncompacted material must be estimated/calculated in each case. All available information should be taken into account.

The following guidelines are proposed:

If sufficiently little stripping of uncompacted material is necessary that it is assumed that the entire dam can be established on rock, the average stripping can usually be estimated at 2 m.

If calculations/estimates give a higher value, this should be used. Even in cases where the dam foundation contains a minimal amount of uncompacted material, a cost will be included corresponding to 0.5 m of stripping of the entire dam foundation as a minimum.

If there are large volumes of uncompacted materials and it is assumed that the support fillings will be established on uncompacted material, one can generally assume average stripping to be 1 m. In cases where mapping has been conducted of marsh areas and other types of masses that must be removed, this must be taken into account and the stripping volume increased.

It should be assumed that the impervious, filter and transition zones will be established on rock. The volume of stripped uncompacted material must be estimated/calculated separately for these areas.

The cost unit “stripping of uncompacted material” is set at the volume of uncompacted material x 1.4 USD/m^3.

2.3.2.2 FOUNDATION AND DAM TOE TREATMENT

The cost of all work that is normally required at the dam toe has been included in Fig. 2.2.6. The figure also indicates the size of the costs as a function of the dam height.

The main cost elements are as follows:

a) Removal of rock in the foundation
b) Scaling and cleaning of the foundation
c) Concreting of concrete base as toe for the impervious and filter zones
d) Required slope protection of toe

The extent of this work varies significantly. However, according to previous experience material, these costs can in total be estimated at 680 USD/rm dam toe for heights up to 50 m and 730 USD/rm for heights up to 100 m. For dam heights up to 150 m the costs can be set at 780 USD/rm.

2.3.2.3 INJECTION WORK

The extent and cost of required injection work have been assessed on the basis of experiences from Georgian rock-fill dams.

It has been assumed a normal injection system with surface injection at 6 m depths in 2 rows and a hole pitch of 5 m, and a one-row deep injection screen at a depth equal to half the water pressure, though at least 10 m. It has further been assumed that deep injection holes will be drilled until an impermeability corresponding to 1 Lugeon has been achieved.

The cost of the injection work as a function of the dam height is presented in Figure 2.2.6.

2.3.3 DAM BODY

Further cost units are the volumes of the five main zones of the rock-fill dam: Impervious zone, filter, transition zone, support filling and slope/crest protection.

The specified cost figures include all average, foreseeable contractor costs for dam construction (including costs related to soil extraction at the site).

The costs are for a dam size of 1,000,000 m^3. Experience indicates that unit cost figures are often lower for large dams and higher for small ones. This is corrected by applying a correction factor given in Fig. 2.2.7. Additionally it should be noted that for large dams the least expensive zones constitute a larger share of the work.

2.3.3.1 THE IMPERVIOUS ZONE

Volume estimations can be conducted by applying the volume curves presented in Figure 2.2.3, part 1, 2 or 3.

The location of a ready prepared foundation should be considered on the basis of local conditions. In general, it is recommended to assume that the completed dam foundation (top of the concrete plinth) will be 1 m lower than the original rock surface.

The average costs of the impervious zone are set at 88 USD/m^3.

2.3.3.2 THE FILTER ZONE

Volume estimations can be conducted by applying the volume curves presented in Figures 2.2.3, part 1, 2 or 3.

It has been assumed that the location of the foundation for the filter zone is 1 m below the original rock surface.

The average cost of the filter zone is set at 6.7 USD/m$^{3.}$ The filter is installed in the same operation as the impervious zone, and these costs must be seen in relation to each other.

It has been assumed that crushed stone is used for the filter. This will normally be necessary due to strict quality requirements. The transportation distance remains 2 kilometres.

The main elements of the normal price of 6.7 USD/m^3 are as follows:

a) Proportion of stripping and restoration of the quarry site after operations have ceased. Land adjustment expenses associated with the crush rig area.
b) Rock blasting
c) Loading and transportation
d) Crushing
e) Transportation (2 kilometres).
f) Placement and compaction

2.3.3.3 TRANSITION ZONE

Volume estimations can be conducted by applying the volume curves presented in Figure 2.2.3, part 1, 2 or 3.

It has been assumed that the location of the foundation for the transition zone is 1 m below the rock surface.

Average costs for the transition zone are set at 4.0 USD/m^3. This price is based on the assumption that the transition zone is prepared by applying a simple crushing process using blasted rock, and that the transportation distance does not exceed 2 kilometres. In some cases, tunnel rock is available in the vicinity of the dam. This can then usually be used as a transition zone by applying a simpler screening process.

The normal price of 4.0 USD/m^3 mainly comprises the following elements:

a) Proportion of stripping and restoration of the quarry site after operations have ceased. Land adjustment expenses associated with the crush rig area.
b) Rock blasting
c) Loading and transportation
d) Crushing
e) Transportation (2 kilometres).
f) Placement and compaction

2.3.3.4 SUPPORT FILLING

Volume estimations can be conducted by applying the volume curves presented in Figure 2.2.5, part 1, 2 or 3.

It has been assumed that the location of the foundation for the support filling is at the rock surface, alternatively 1 m below the terrain.

Average costs for the support filling are set to 2.0 USD/m^3.

The price is conditional on the support filling being produced using quarry stone and on the condition that there is a suitable quarry area within 1 kilometre of the dam.

The extent of stripping work is usually modest. Additional costs must be expected in cases where it is necessary to remove large volumes of uncompacted material to get to the bedrock.

If tunnel rock is available in the vicinity of the dam, this will usually be used as support filling at a lower price. The costs in such cases can be set at 1.3 USD/m^3.

The normal price of 2.0 USD/m^3 will usually comprise the following elements:

a) Stripping and land adjustment of the quarry area.
b) Blasting
c) Loading and transportation
d) Placement and compaction

2.3.3.5 SLOPE AND CREST PROTECTION

Volume estimations can be conducted by applying the volume curves presented in Figure 2.2.3, part 1, 2 or 3.

It has been assumed that the location of the foundation for the slope and crest protection is at the rock surface, alternatively 1 m below the terrain surface. Average costs for the slope and crest protection are set at 4.1 USD/m^3.

This price assumes that the support filling is produced at the quarry and that the coarse rock material is generally produced as a product of this process. A certain extent of blasting conducted for the purpose of producing coarse rock material is expected and is included in the price.

As the need for coarse rock material is generally greatest during construction of the dam top, a certain degree of temporary storage is also considered normal and is included in the price.

If the support filling is constructed using tunnel stone, a separate quarry must be established for production of coarse rock material. If this is the case, the price is set at 5.4 USD/m^3.

2.3.4 PRICE LEVEL

The stated prices represent the price level in January 2015.

2.3.5 INCLUDED/NON-INCLUDED COSTS

Please see Chapters 2.1. The following applies specifically:

- Bottom outlet/by-pass/coffer dams:
  Bottom outlet/by-pass/coffer dam costs have not been included in the cost figures. These costs must be calculated separately.
- Flood gates and any emergency discharge devices:

These costs have not been included in the cost figures and must be calculated separately.

- Instrumentation costs:
  Costs have not been included.
- Gates, gratings, screens:
  Costs have not been included. For gate costs, see Chapter 4.4.

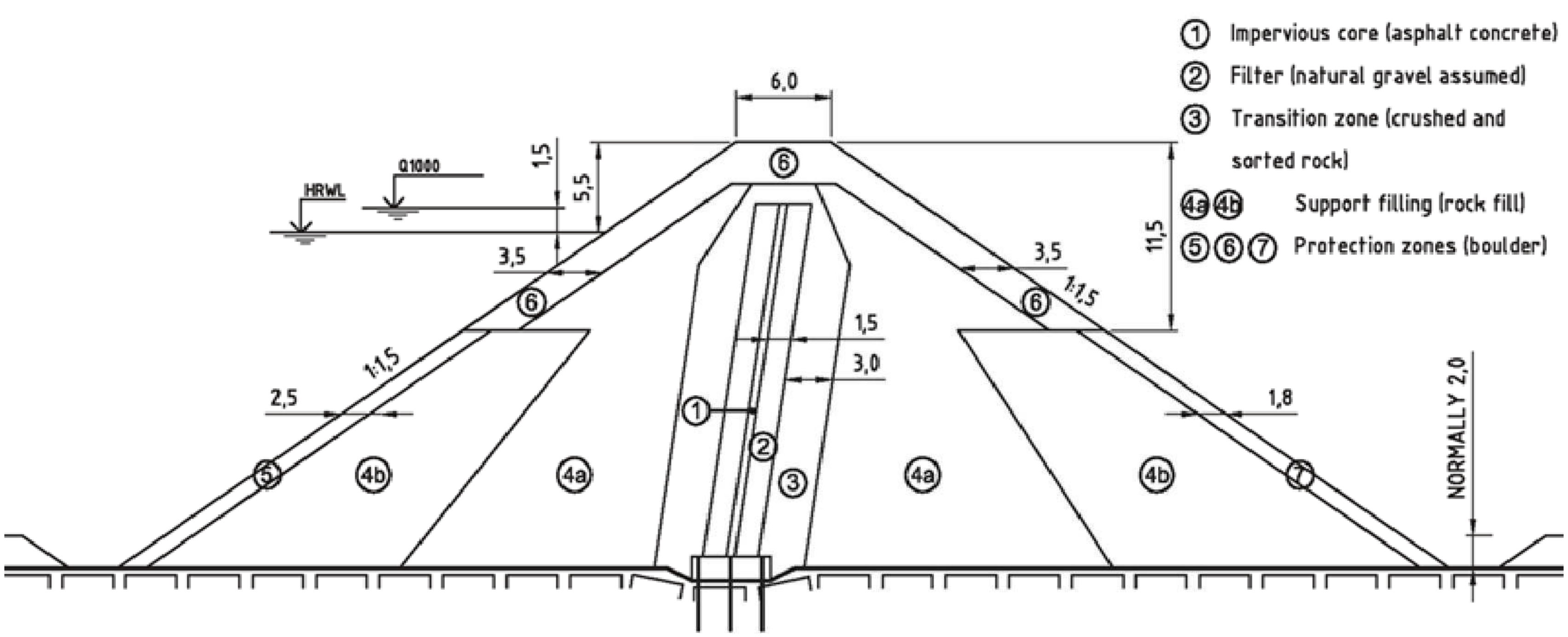
2.3.6 COST CALCULATION UNCERTAINTY

It is estimated that the cost calculation uncertainty for dam foundations is +70% to -30%, and the cost calculation uncertainty of the dam body to be ±25.

2.3.7 INCREASING HEIGHT OF EXISTING DAMS

It is difficult to give any general guidelines for how much a dam should be extended. The existing dam has been designed according to the current water pressure, and the extension of the dam will be contingent on whether the parts of the dam that cannot be reinforced are able to stand the increased load. The depth of the injection screen depends on the dam height, and if the dam height increases, this ratio will change. Leaks will increase in line with the increase in water pressure, and it will be necessary to evaluate whether the system for leak measuring and the dam as a whole will be able to handle this in an appropriate manner. It is recommended that the thickness of the impervious core is at least 1% of the height, and no less than 50 cm. According to this, an increase in the height will mean that the recommended minimum thickness is exceeded for dam heights over 50 m. It should be carefully considered whether the design in question will allow this.

The costs can be calculated by using the unit prices given above, whereas volumes must be calculated separately in each case.



COMMENTS:

1. The height between HRWL and the top sealing (2m) depends on the flood increase, cf. Chapter B.2.1.1.

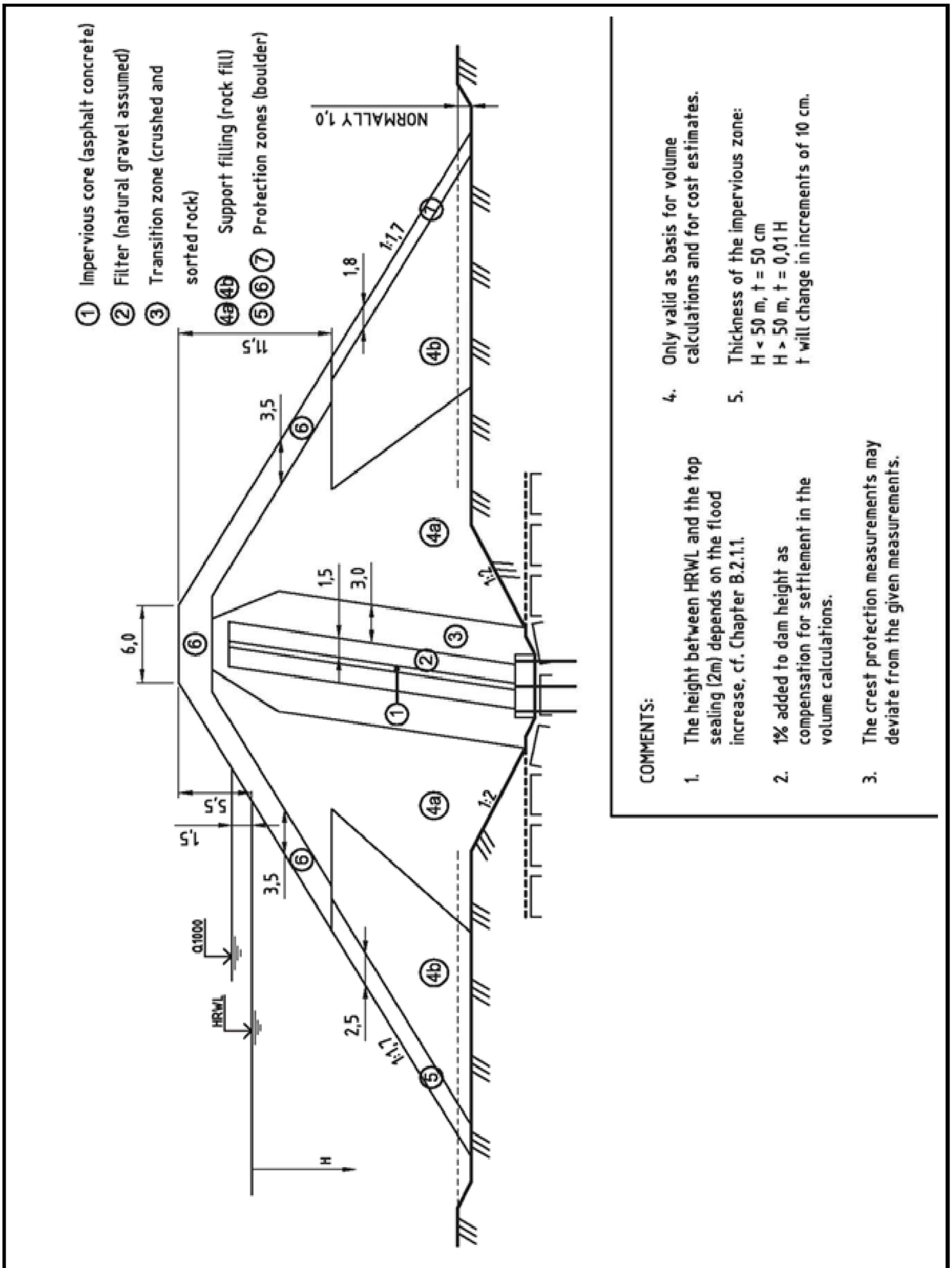
2. 1% added to dam height as compensation for settling in the volume calculations.

3. The crest protection measurements may deviate from the given measurements.

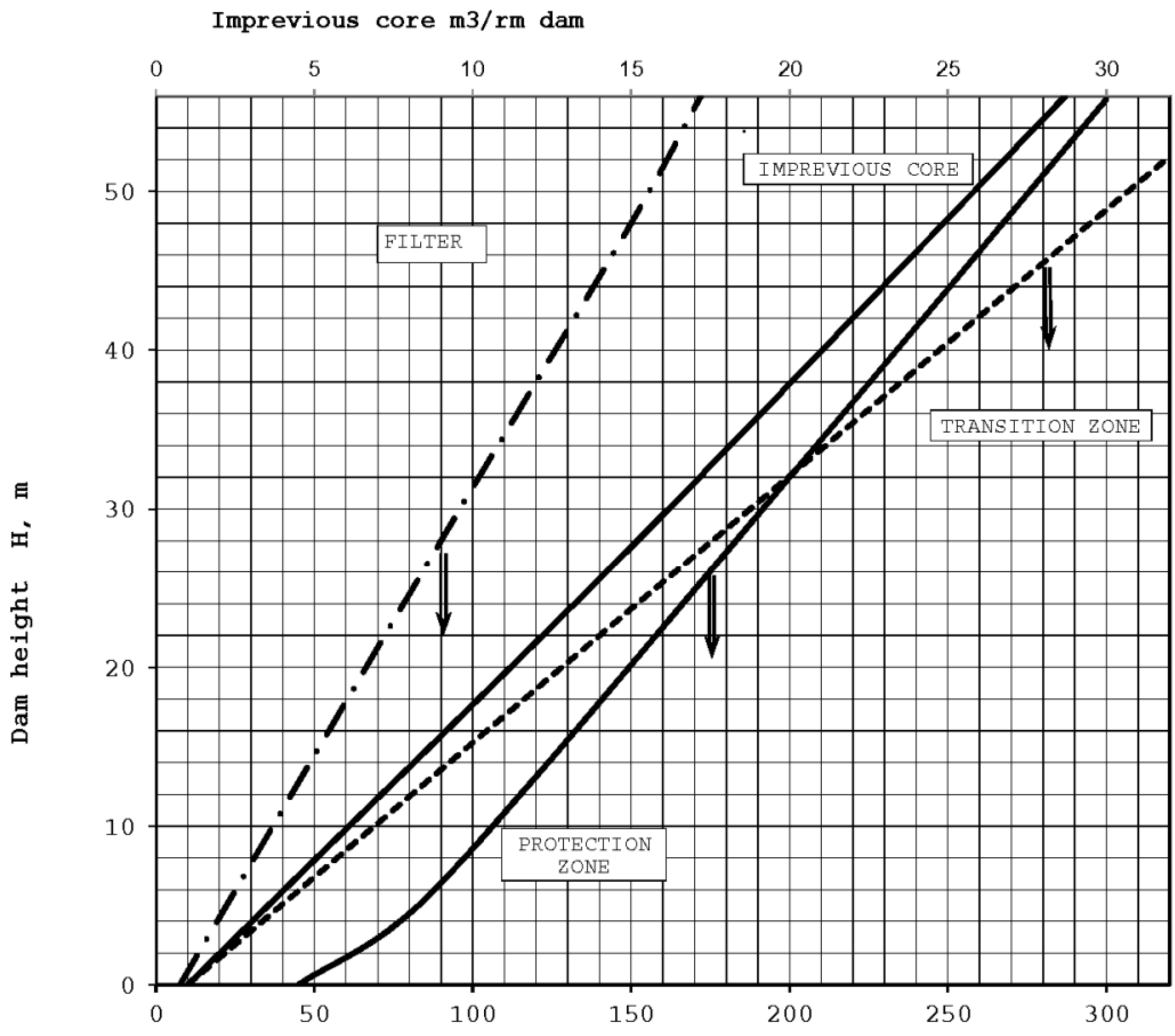
4. Only valid as basis for volume calculations and for cost estimates.

5. Thickness of the impervious zone:
   H < 50 m, t = 50 cm
   H > 50 m, t = 0,01 H
   t will change in increments of 10 cm.

Norwegian Water Resources and Energy Directorate NVE	ROCKFILL DAM WITH ASPHALT CONCRETE CORE. DAM CROSS-SECTION ASSUMED FOR VOLUME AND COST CALCULATIONS. SIDE SLOPE 1:1.5	Fig. 2.2.1



Norwegian Water Resources and Energy Directorate NVE	ROCKFILL DAM WITH ASPHALT CONCRETE CORE. DAM CROSS-SECTION ASSUMED FOR VOLUME AND COST CALCULATIONS. SIDE SLOPE 1:1.7	Fig. 2.2.2



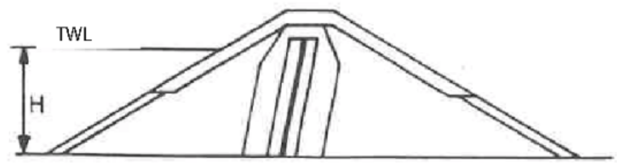
Filter [m³/rm dam]
Transition zone [m³/rm dam]
Protection zone [m³/rm dam]

COMMENTS:

1. Dam height H calculated from TWL.

2. Assumed dam cross-section, see Fig. 2.2.1 and 2.2.2.

3. Volume of transition zone and support filling is corrected according to Figure 2.2.5.



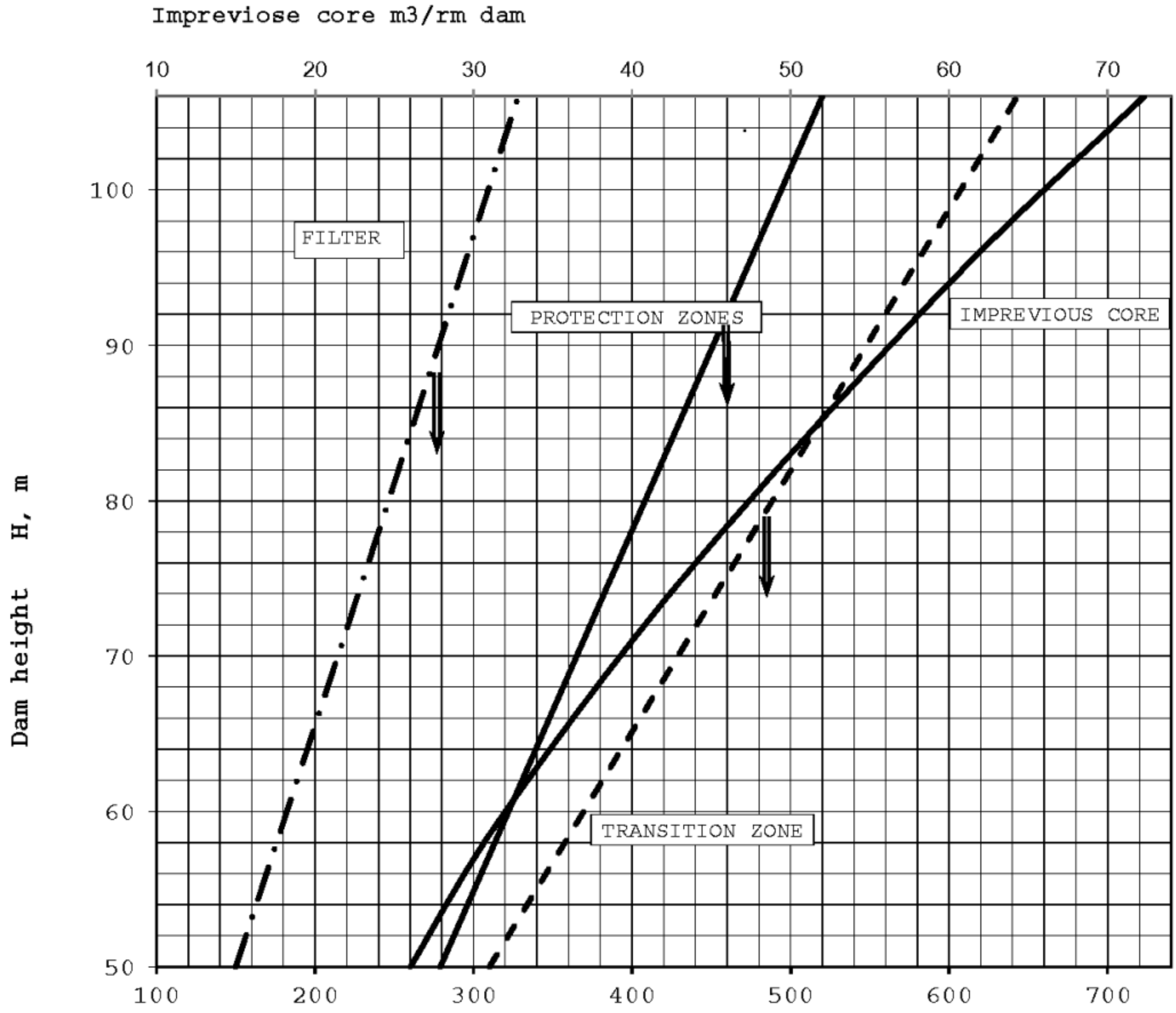
Norwegian Water Resources and Energy Directorate

NVE

ROCKFILL DAM
WITH ASPHALT CONCRETE CORE
VOLUME CURVES FOR CORE , FILTER,
TRANSITION - AND PROTECTION ZONES

Fig. 2.2.3
Part 1

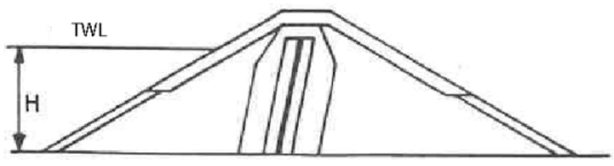
01.01.15



Filter [m³/rm dam]
Transition zone [m³/rm dam]
Protection zone [m³/rm dam]

COMMENTS:

1. Dam height H calculated from TWL.
2. Assumed dam cross-section, see Fig. 2.2.1 and 2.2.2.
3. Volume of transition zone and support filling is corrected according to Figure 2.2.5.

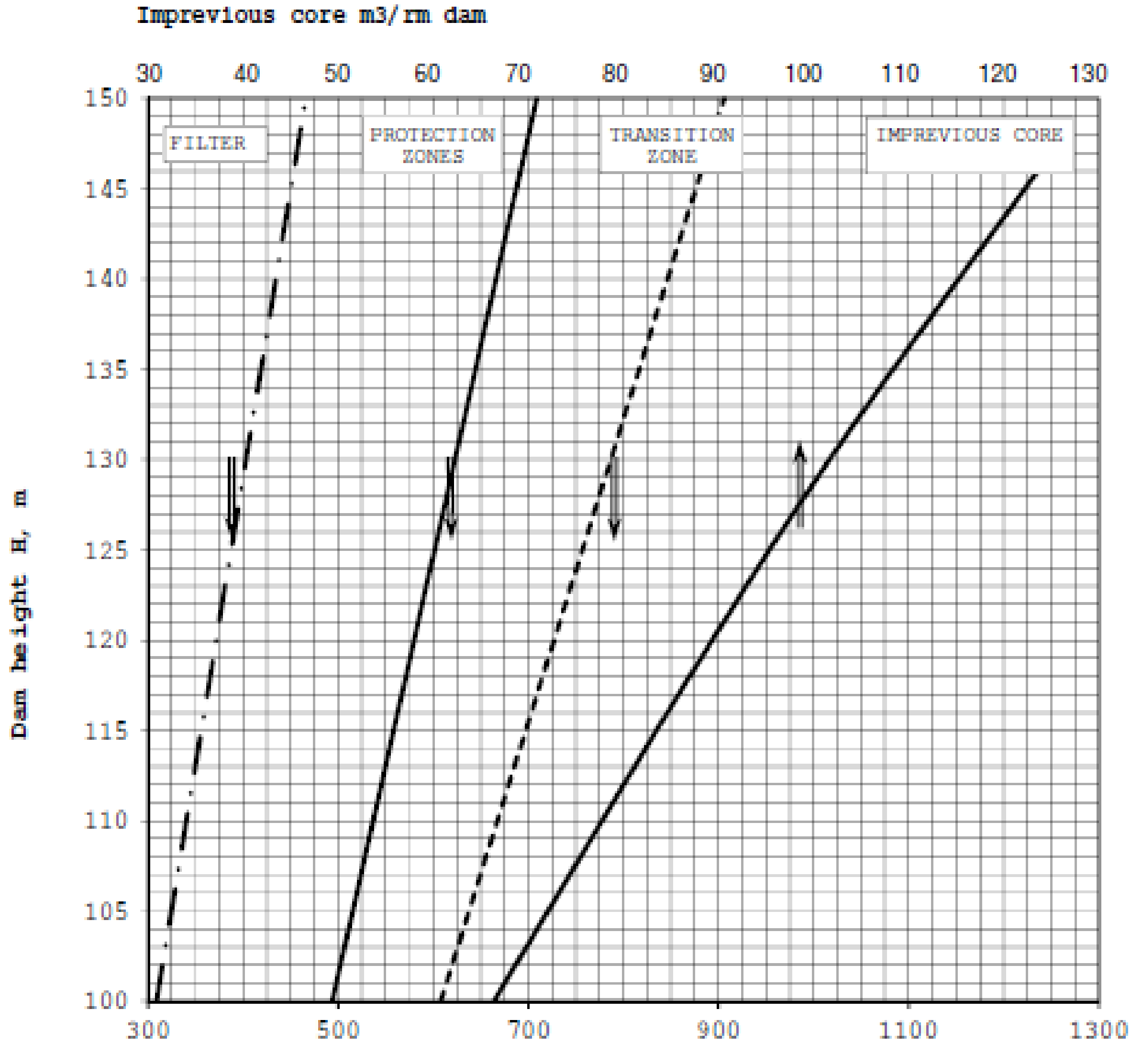


Norwegian Water Resources and Energy Directorate
NVE

ROCKFILL DAM
WITH ASPHALT CONCRETE CORE
VOLUME CURVES FOR CORE , FILTER,
TRANSITION - AND PROTECTION ZONES

Fig. 2.2.3
Part 2

01.01.15



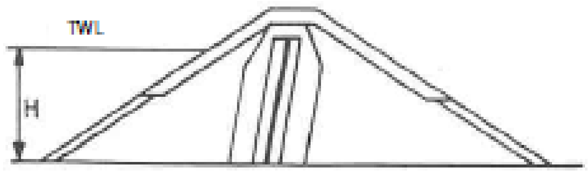
Filter [m³/rm dam]
Transition zone [m³/rm dam]
Protection zone [m³/rm dam]

COMMENTS:

1. Dam height H calculated from TWL.

2. Assumed dam cross-section, see Fig. 2.2.1 and 2.2.2

3. Volume of transition zone and support filling is corrected according to Figure 2.2.5.

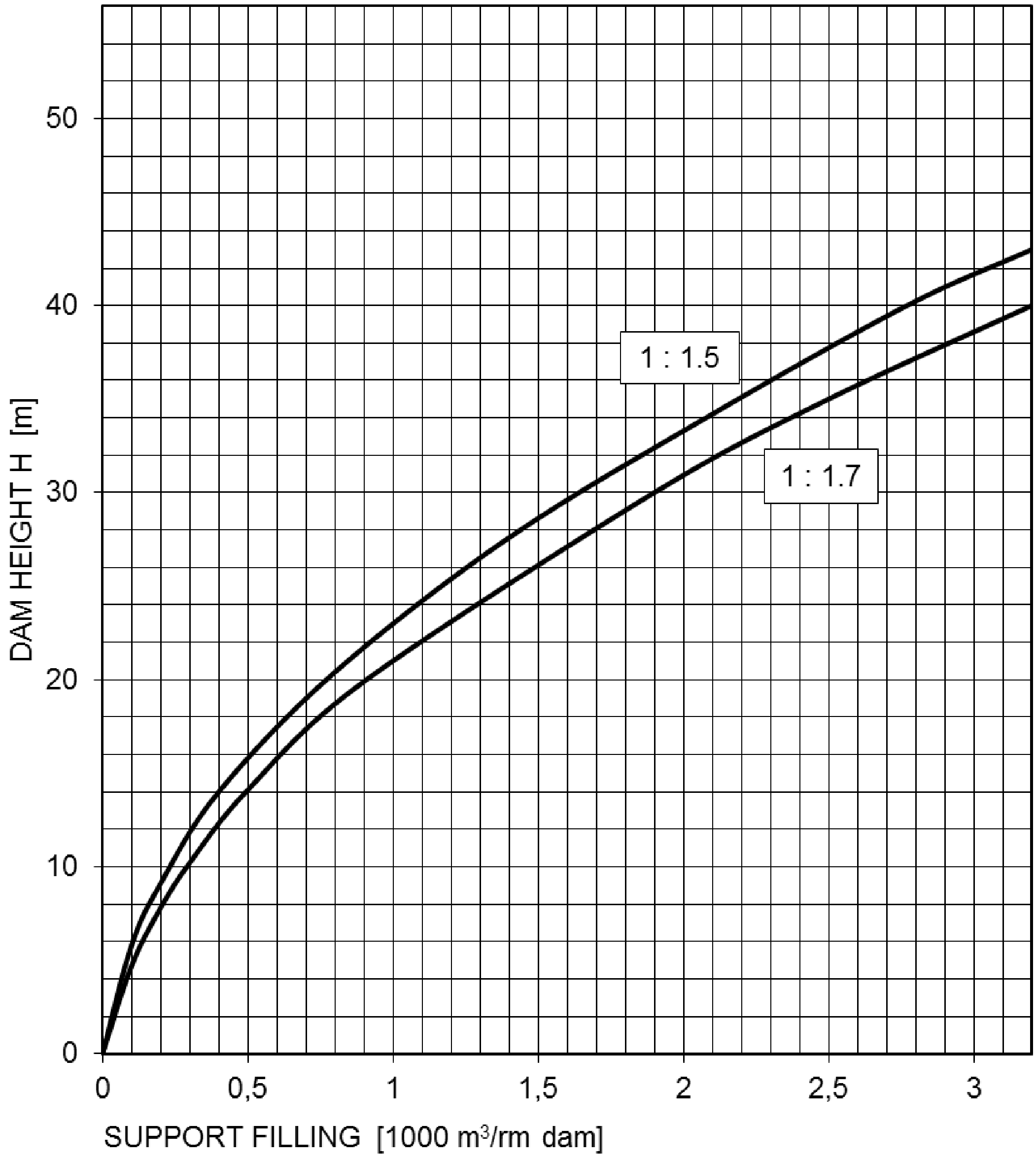


Norwegian Water Resources and Energy Directorate
NVE

ROCKFILL DAM
WITH ASPHALT CONCRETE CORE
VOLUME CURVES FOR CORE , FILTER, TRANSITION - AND PROTECTION ZONES

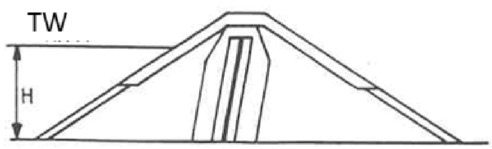
Fig. 2.2.3
Part 3

01.01.15



COMMENTS:

1. Dam height H calculated from TWL.
2. Assumed dam cross section, see Fig. 2.2.1 and 2.2.2.
3. Volume of support filling is corrected according to Figure 2.2.5.



Norwegian
Water Resources and
Energy Directorate
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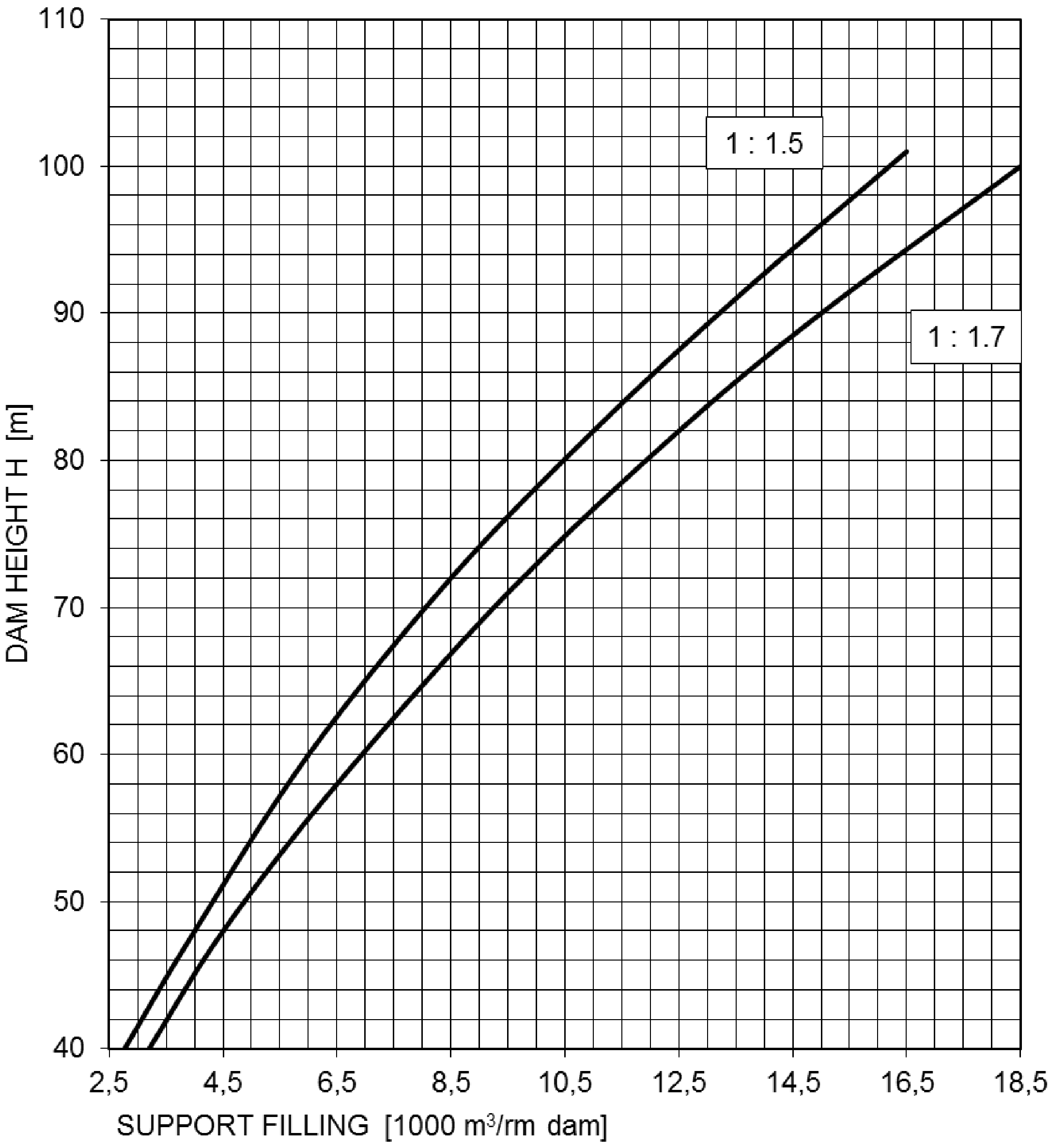
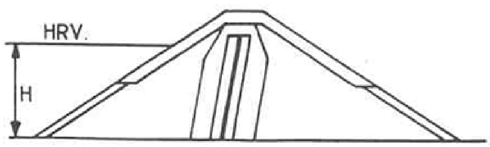
ROCKFILL DAM WITH ASPHALT CONCRETE CORE
VOLUM CURVES FOR SUPPORT FILLING

Fig. 2.2.4
Part 1
01.01.15



COMMENTS:

1. Dam height H calculated from TWL.
2. Assumed dam cross section, see Fig. 2.2.1 and 2.2.2.
3. Volume of support filling is corrected according to Figure 2.2.5.



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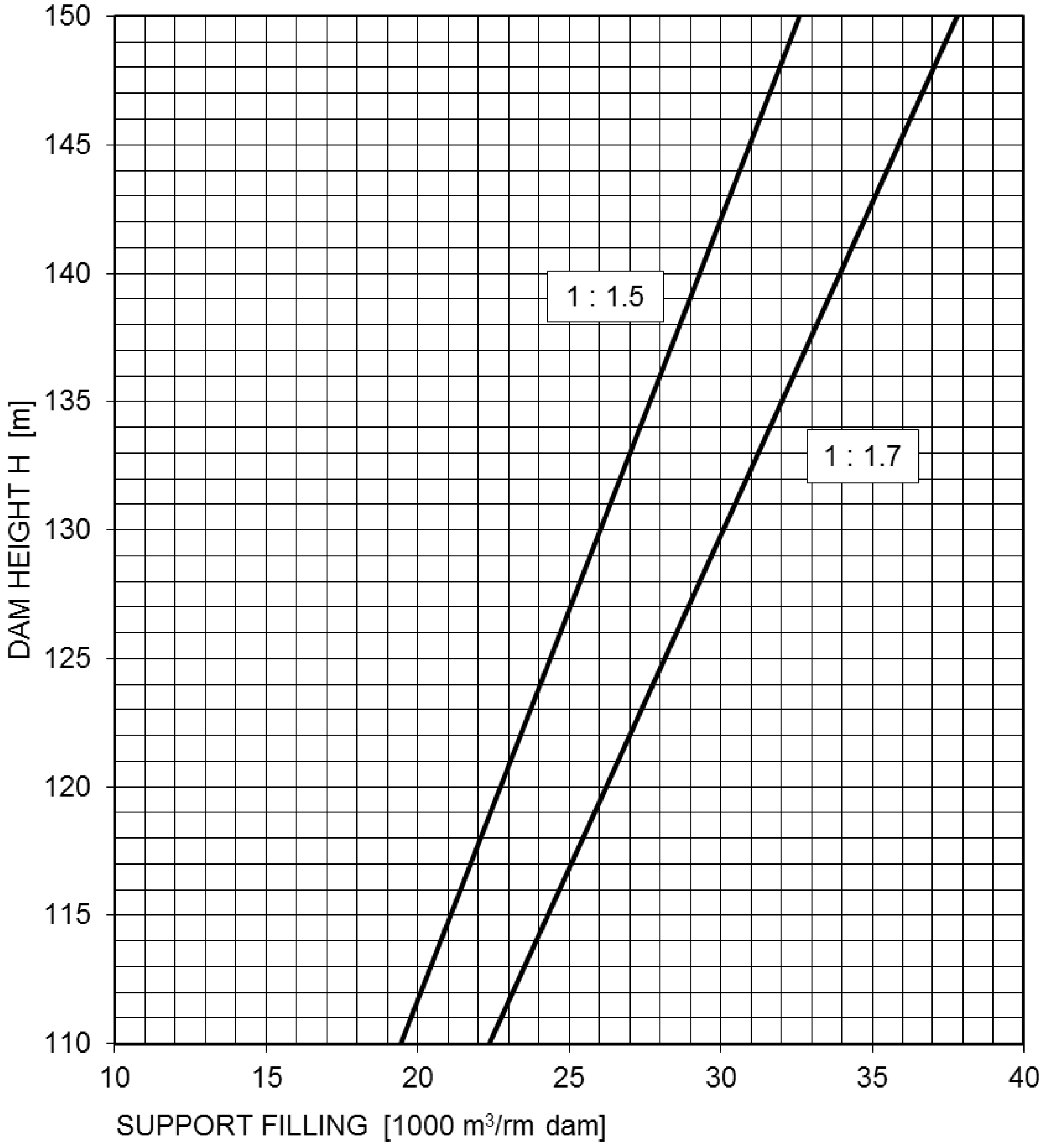
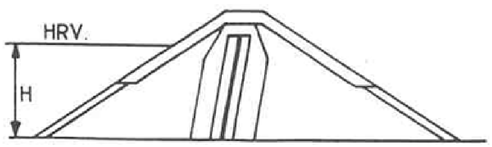
ROCKFILL DAM WITH ASPHALT CONCRETE CORE
VOLUM CURVES FOR SUPPORT FILLING

Fig. 2.2.4
Part 2
01.01.15

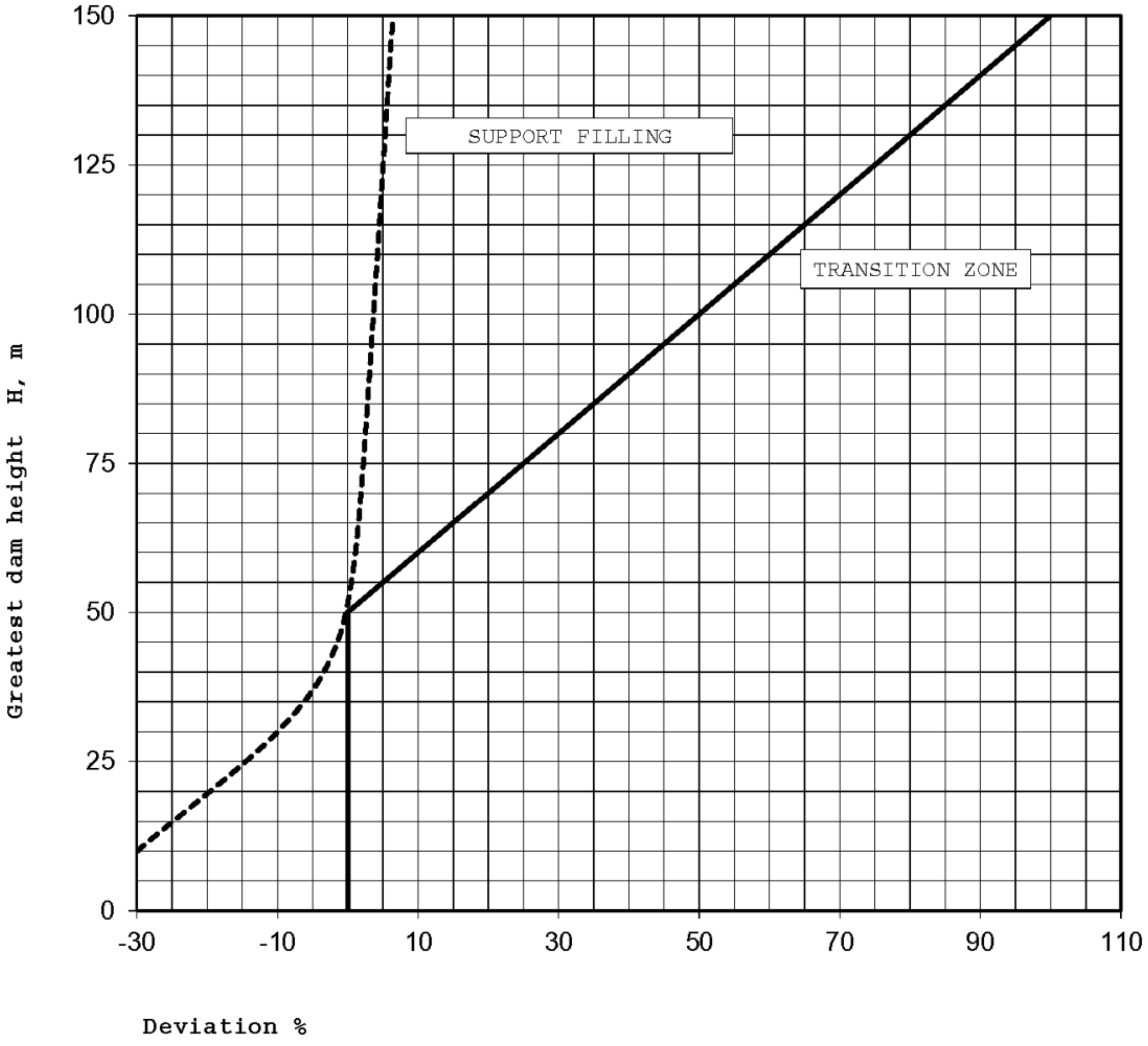


COMMENTS:

1. Dam height H calculated from TWL.
2. Assumed dam cross section, see Fig. 2.2.1 and 2.2.2.
3. Volume of support filling is corrected according to Figure 2.2.5.

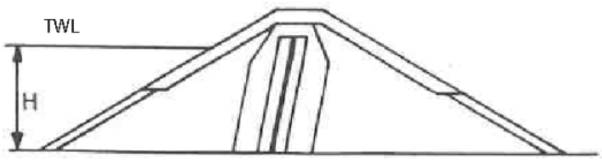


Norwegian Water Resources and Energy Directorate NVE	**ROCKFILL DAM WITH ASPHALT CONCRETE CORE VOLUM CURVES FOR SUPPORT FILLING**	Fig. 2.2.4 Part 3 01.01.15



COMMENTS:

1. The figure specifies the correction factor for the total volume of the transition zone and support filling as a function of the greatest dam height.
2. Cf. Chapter 2.2.1.1.



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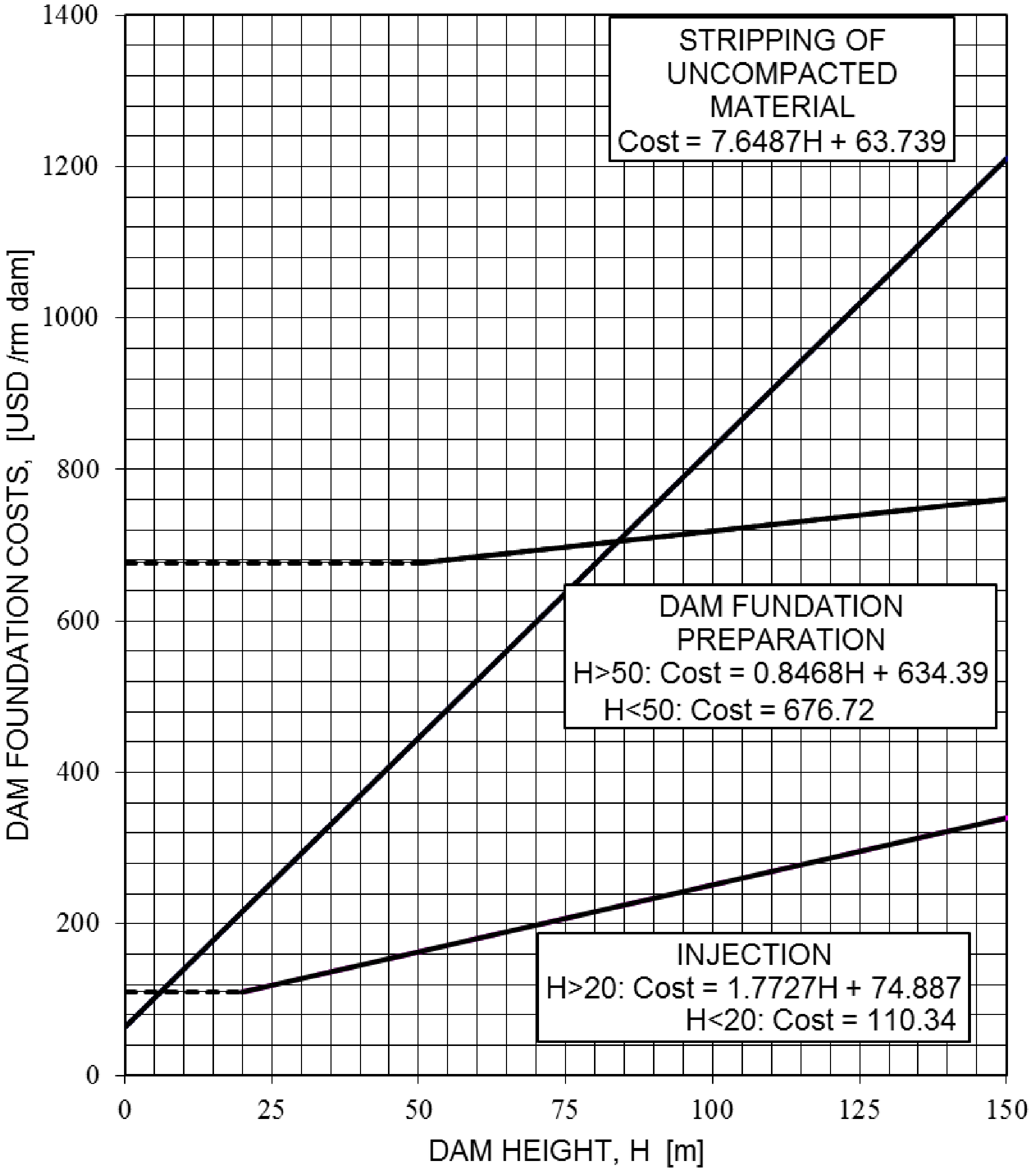
ROCKFILL DAM
WITH ASPHALT CONCRETE CORE
SUPPORT FILLING AND TRANSITION ZONE
CORRECTION FACTOR FOR VOLUM

Fig. 2.2.5

01.01.15

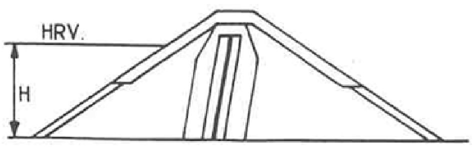


COMMENTS:

1. Price level January 2015.

2. Cost of stripping of uncompacted material depth of 2 m.

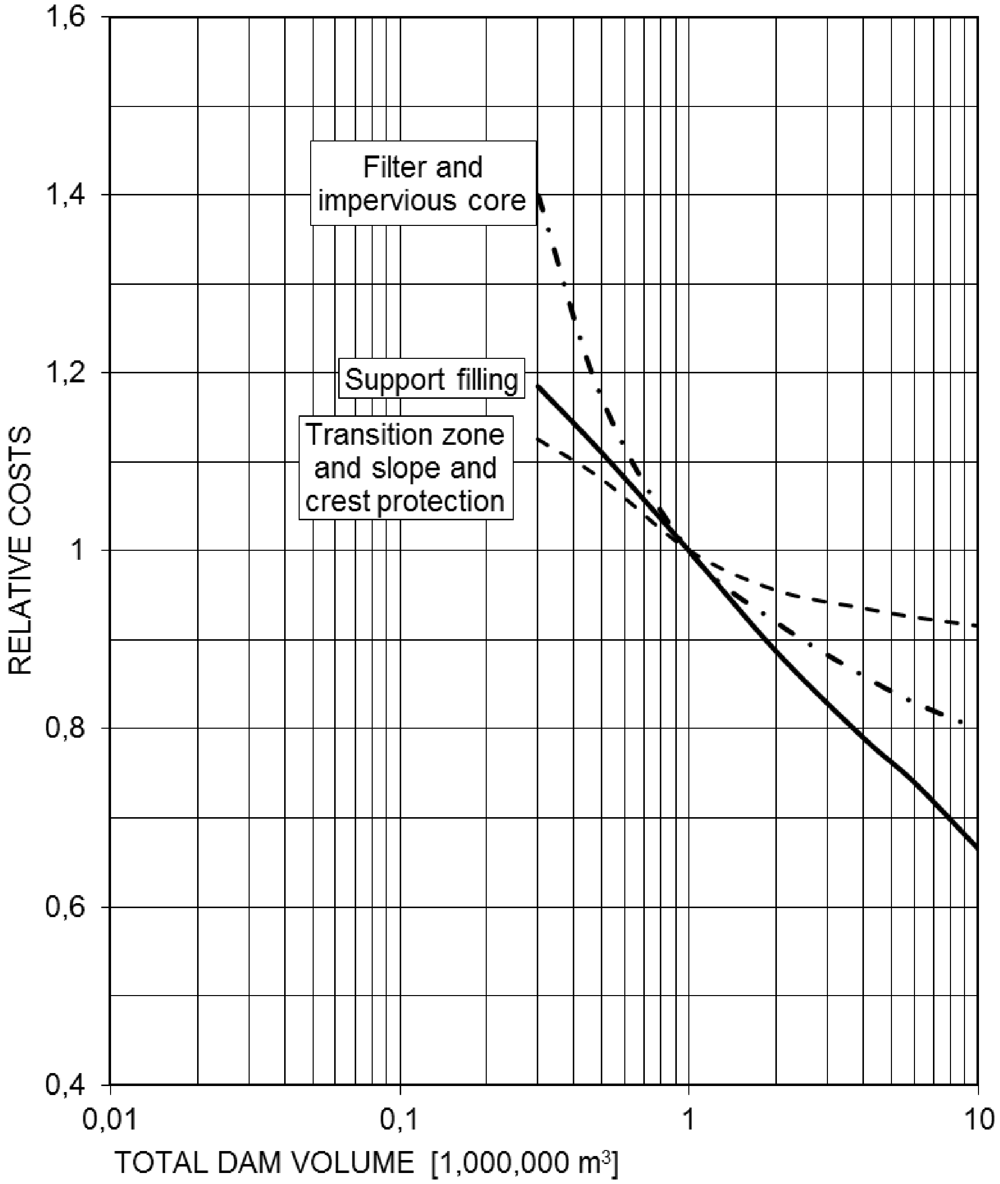
3. Costs started for dam cross section is shown in Fig. 2.2.1.



Norwegian Water Resources and Energy Directorate
NVE

ROCKFILL DAM WITH ASPHALT CONCRETE CORE DAM FOUNDATION COSTS

Fig. 2.2.6
01.01.15



COMMENTS:

1. The figure shows the cost correction
factor for the dam zone costs depending
on the total volume.

2. Cf. Chapter. 2.2.3

Norwegian Water Resources and Energy Directorate NVE	**ROCKFILL DAM WITH ASPHALT CONCRETE CORE COST CORRECTION FACTOR IN RELATIVE TO TOTAL DAM VOLUME**	Fig. 2.2.7 01.01.15

2.4 CONCRETE DAMS

2.4.1 GENERAL

2.4.1.1 ASSESSMENTS

Several types of concrete dams may be of relevance. The different dam types overlap.

The costs of the different dam types also overlap. Consequently, for simple dam sites with dams of moderate height it is, from a cost perspective, not vital to make a final decision on the choice of dam type during evaluation of the project opportunities. In the following sections curves for four different dam types are presented: gravity dams, slab concrete dams, arch dams in normal concrete and RCC gravity dams. Sluice gate dams may also be an option. However, such dams are not very suitable for schematic cost calculations and should be calculated separately for each individual case. An RCC dam is a special type of concrete gravity dam which may be relevant for larger dams. From a cost perspective, RCC dams can compete with rock-fill dams.

When comparing rock-fill dams with concrete dams it should be noted that there will be no floodgate costs for concrete dams if the flood water can be diverted to permanent overflows over the dam. It is further pointed out that bypass costs for concrete dams will be significantly lower during the construction period than rock-fill dams. This is because bypass tunnels will not be required as the water can run along the riverbed during the initial phase and in the next phase be directed through a bottom sluice in the dam by means of coffer dams. Finally it should be noted that concrete dams often have the least expensive temporary roads.

For the above reasons concrete dams are in many cases less expensive than rock-fill dams, for dam heights up to 18-20 m. This is particularly true if the dam is classified as important from a national safety point of view.

2.4.1.2 MAIN ASSUMPTIONS

- Price level as of January 2015

- The price curves and unit prices provide an overview of foreseeable contractor costs (building-related work), excluding value added tax/investment fees, with the exceptions specified below. The price curves for the specified total dam volume apply to RCC dams. RCC dams are not likely to be competitive for volumes below 30,000 m3.

- Assumptions concerning local conditions appear from the schematic diagrams of the cross-section as shown in the graphs, as well as from the text in the price/cost material.

- The main plan for the dam installation should provide a basis for cost calculations of temporary roads, bottom outlets/bypasses and loss of flow.

- <u>The dam height</u> has for all concrete dams been defined as the height from the top water level (TWL) down to the average height of the dam foundation in the individual zones. This gives the relevant dam height for sections in the overflow part of dams with a free overflow. The dam cross-section is usually the same in overflow and non-overflow sections. For non-overflow sections there will only be an extension of the dam crest. This will be the width of a footpath/road or have a parapet. The costs, as indicated by the cost curves and with the accuracy that it is normally possible to achieve, will be approximately the same for an overflow and non-overflow section. For large flood increases a flood increase beyond 0.5 – 1 m should be added to the dam height for both overflow and non-overflow sections.

2.4.1.3 INCLUDED/NON-INCLUDED COSTS

It refer to Chapter 2.1. The following applies specifically:

General costs such as rigging, overheads, and operational expenses (henceforth referred to as "overheads" or "rigging") are excluded in all building-related cost components and must be added to the total project cost. Generally, the additional rigging cost that should be added is 30% of the total cost of all other works.

However, it is imperative to note that the rigging cost addition may vary considerably. The addition is usually in the region of 20-60%, and in special cases even higher. This must be evaluated from project to project, and depending on contract, infrastructure, project size and choice of contractor. Greater distance to villages/towns results in higher overheads due to increased transport, travel and accommodation costs. Deviations from overhead costs of 30% must be corrected. However, rigging costs also vary from contractor to contractor. Major contractors often have more expensive/ larger rigs, but are not necessarily more expensive in total.

<u>Included costs:</u>

- Only costs relating to the construction of the concrete dam body itself and dam foundation work, including 2 m of stripping, have been included in the cost curves.
- The cost curves include 150 kilometres transportation of concrete.
- Dam foundation work has been included in the costs in Figures 2.3.1, 2.3.3, 2.3.4, 2.3.5 and 2.3.6. Costs relating to stripping of uncompacted material and the location of the future completed uncompacted material stripping, as well as the location of the future completed dam foundation should be clarified through an assessment of the local conditions. It is recommended that costs corresponding to 1 m of stripping should be included, even for the most favourable conditions. Furthermore, the ready—prepared dam foundation is assumed to be located 1 m below the terrain.
- The total costs presented in the figures usually include costs for 2 m of stripping.

<u>Non-included costs:</u>

- Bottom outlet/by-pass/coffer dams: Bottom outlet/by-pass/coffer dam costs have not been included in the cost figures. These costs must be calculated separately.
- Flood gates and any emergency discharge devices: All costs are included for dams with direct dam overflows. For other overflow arrangements these must be calculated separately.

- Costs relating to a potential bridge along the dam crest have not been included.
- Instrumentation costs have not been included.
- Gates, gratings, screens: Costs have not been included. For gate costs, see Item 4.4.

2.4.1.4 USE OF THE COST CURVES

Estimated contractor costs per 1 m run of dam for gravity dams and slab concrete dams are indicated in Figures 2.3.1 and 2.3.3. Based on the length profile of the dam axis of the assumed completed dam foundation, the dam is divided into appropriate sections and the costs are estimated for each section.

For arch dams the area of the dam is calculated and then multiplied by a cost per m^2 as indicated by the cost curve. The shape of the dam, the ratio between the width at the top and bottom of the dam, and the dam's height in relation to the width determine the concrete volume and thus the price per m^2.

The total costs for each section provide foreseeable contractor costs for the dam. Costs not included in the cost curves are calculated/estimated separately and then added to the costs found by means of the cost curves.

2.4.1.5 COST UNITS

The cost curves in the figures are based on the following main cost units:

-	Stripping, clearing and grubbing and removal of material:	1.4 USD/m^3
-	Foundation preparation:	16 USD/m^2
-	Foundation preparation, arch dam, incl. concrete toe:	58 USD/m^3
-	Formwork:	10.4 USD/m^2
-	Formwork, arch dam system formwork for hatches:	11.2 USD/m^2
-	Formwork, arch dam curved slab formwork:	12.8 USD/m^2
-	Shaping of the RCC dam's outer surfaces:	22 USD/m^2
-	Reinforcement:	633 USD/tonne
-	Concrete:	48 USD/m^3
-	Concrete for RCC dam:	
	Aggregate: preparation transportation, storage, mixing, placement and compaction in the dam, (depending on the total volume of the dam)	4.0-6.5 USD/m^3
	purchase of concrete	75 USD/m^3
	purchase of pozzolan	9 USD/m^3
-	Miscellaneous and unforeseen:	10%

The prices have been stated within a normal variation range.

2.4.1.6 COST CALCULATION UNCERTAINTY

The uncertainty of the cost calculation is estimated to ±25.

2.4.2 CONCRETE GRAVITY DAM

Contractor costs relating to the construction of concrete gravity dams are shown in Figure 2.3.1. Volume curves for the key cost units are presented in Figure. 2.3.2. The choice of concrete quality will be vital to reduce crazing in the early hardening phase. The concrete must be durable and the quality selected on the basis of current standards for engineering and execution of concrete constructions (Norwegian Standard (NS) 3473/Eurocode 2 and NS3465). The extent of crazing will also be determined by the sectioning of a gravity dam. Recently, sections have become smaller and today a section width of approximately 6 metres is recommended. Other potential measures to reduce crazing, such as cooling tubes in the dam body, have not been included in the cost estimates.

2.4.3 SLAB CONCRETE DAM

Contractor costs relating to the construction of slab concrete dams are shown in Figure 2.3.3. Volume curves for the central cost units are presented in Figure. 2.3.4. A slab concrete dam will be adjusted to the abutments by a transition consisting of a concrete gravity dam. The costs of this can be established by using the cost curve for concrete gravity dams. The cost figures presented here assume a pillar distance of 6 metres, whereas in practice the distance between pillars varies between 4.5 and 6.5 metres. The design of pillars and sectioning by means of pillar distance are primarily determined by the static system one chooses to use during the engineering of the front slab. Furthermore, it is assumed that an isolation wall will be constructed between the pillars. Any other measures to prevent icing have not been included in the cost curve in Figure 2.3.3.

2.4.4 CONCRETE ARCH DAMS

An arch dam might be the best solution for narrow locations. A concrete arch dam is characterised by a low mass volume compared to its height. Arch dams are therefore very practical at suitable dam locations.

In the cost curve the minimum thickness of an arch dam has been set at 0.6 m. The dam is uninsulated and functions as a flood route. Other associated costs have not been included, such as for discharge gates, pedestrian paths, larger abutments, etc. Rock that has been removed from the toe of the dam is replaced by concrete. As the dam location and general design of arch dams vary greatly, with regard to, for instance, type of arch, curvature radius and slimness, it is difficult to prepare simple curves for dams over a certain size. As such it is recommended that separate dimensioning is conducted for larger dams that are taller than 15 metres.

2.4.5 ROLLER COMPACTED CONCRETE DAMS (RCC)

2.4.5.1 GENERAL

Roller compacted concrete dams (RCC) have become more common on the international market for concrete gravity dams and rock-fill dams. Since the first compacted concrete dam was constructed around 1980, roller compacted concrete dams have developed into fully acceptable dam constructions. The construction is primarily based on one of two different principles; using either very dry lean concrete in the dam body and an upstream sealing membrane, or richer concrete so that the whole dam body functions as a sealing medium.

The roller compacted concrete is characterised by a normal to low cement content (35 – 200 kg/m^3). The concrete's water content is adjusted (80 – 130 l/m^3) so that the fresh concrete has a firm consistency ensuring that it can be transported with, and being driven on, by heavy construction vehicles. The concrete is laid down in horizontal layers up to 30 cm and compacted. Aggregates of different types and material grading are used. There is a multitude of variations with regard to dam types and qualities.

The dam's water side is practically vertical. Cement enriched RCC is normally used and construction concrete against formwork and concrete elements or panels as finishing. The same is used for the downstream side, which has an inclination of 1.0: 0.7-0.9, or it is finished off by leaving an untreated slope. The downstream side usually consists of steps. Dam parts such as flood gates/overflows, dam crest and inspection galleries are often made of reinforced concrete.

Today dams can be constructed in accordance with case to case requirements with regard to stability, water impermeability, temperature, crazing development, concrete proportioning, construction joints and available construction equipment.

- Concrete quality B25 – B35, assumed composition:

- Water/concrete ratio = 0.45 (water/cement and pozzolan)

Cement	150 kg/m^3 concrete
Pozzolan	80 kg/m^3 concrete

2.4.6 INCREASING HEIGHT OF EXISTING DAMS

2.4.6.1 GENERAL

It is difficult to give general guidelines for the price of increasing the height of an existing concrete dam. The increase must be adapted to the existing dam type, and the need for reinforcement of existing constructions will vary from dam to dam. It is therefore recommended that the dams are planned and the costs calculated separately in each case.

2.4.6.2 CONCRETE GRAVITY DAMS

Concrete gravity dams are probably the type of dam which is easiest to extend. An adequate connection must be established between the new and existing concrete, and the dam can be extended without the reservoir efficiency being affected. See Figure 2.3.7.

Figure 2.3.1 can be used to estimate the costs by deducting the costs of the dam with the "old" height from the costs of the dam with the "new" height.

The design of the existing dam is likely to deviate significantly from that used as a basis for drawing up the cost curve. The recommendation is therefore that the dam costs are estimated by mass calculation, and then applying the unit prices.The cost of preparing the dam for extension must also be included. The costs must comprise demolition of the parapet and railings, establishment of connection and treatment of the old concrete surface. For approximate calculations, the costs can be set to 54 USD/rm + 7.0 USD/m^2 of concrete surface that is to be treated (contact surface against new concrete).

2.4.6.3 SLAB CONCRETE DAM

In general, slab concrete dams are not well suited for extensions, and it must be checked in each individual case whether the dam will be able to sustain the increased load.

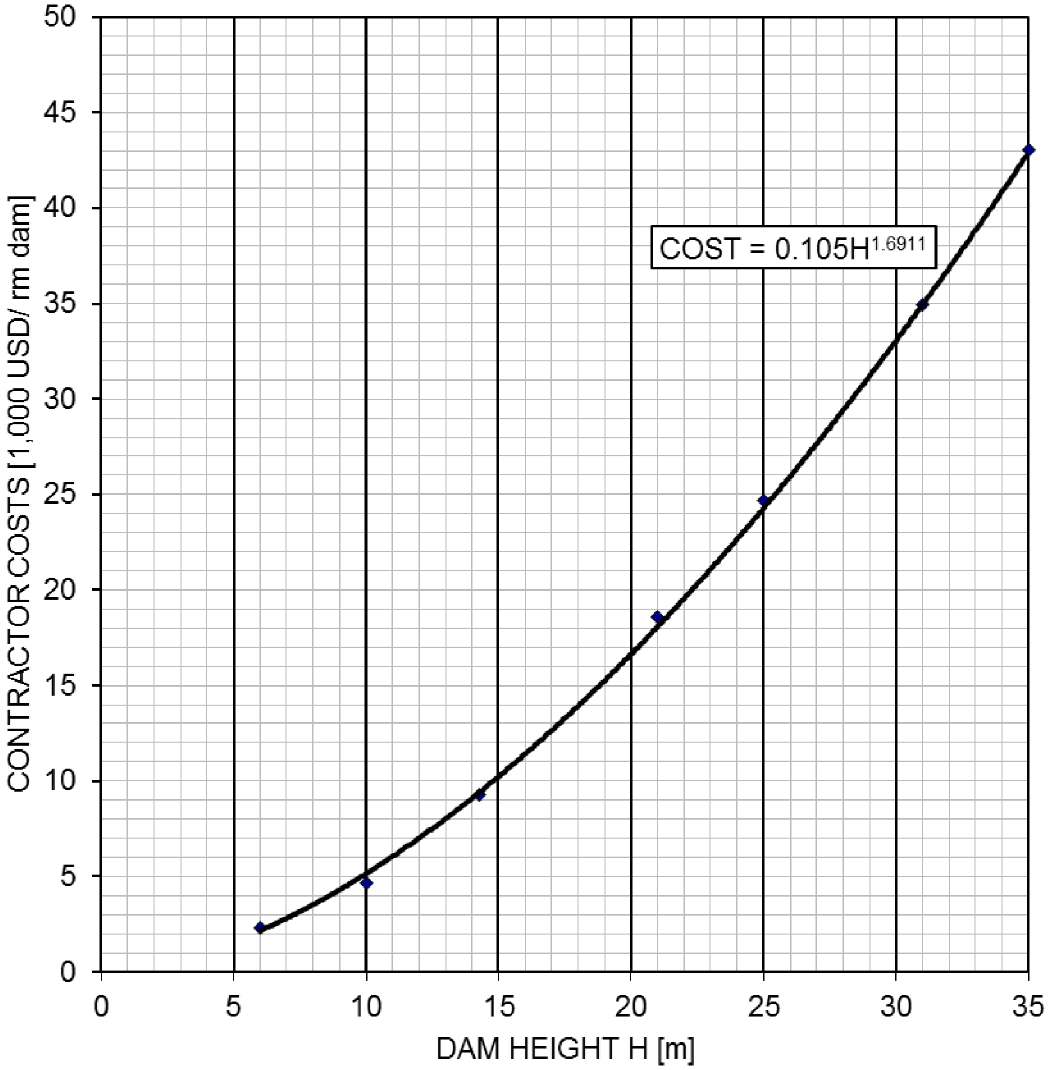
The execution must be planned and cost estimates prepared for each case.

2.4.6.4 CONCRETE ARCH DAM

In general, arch dams are not well suited for extensions, and the execution must be planned and cost estimates prepared for each case.

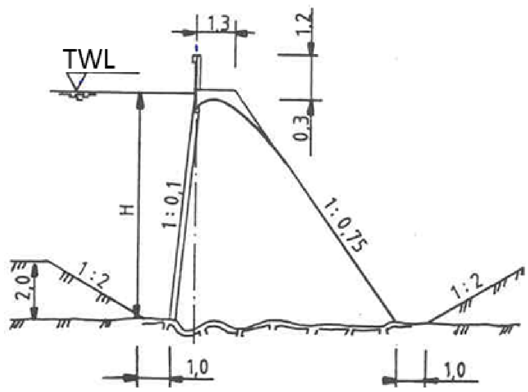
2.4.6.5 OTHER DAM TYPES

The execution must be planned and cost estimates prepared for each case.



COMMENTS:

1. Price level January 2015. For lower dams, see cost base for small hydropower plants.
2. The cost curve comprises all contractor costs for building- related work on the dam body and dam foundation.
3. Removal costs for 2 meters of uncompacted material over rock have been included.
4. Expenses relating to bottom outlets, redirection of water in the construction period, flood gates/overflows and construction elements relating to contingency requirements (such as blastable field) have not been included.
5. The dam height H is calculated from the top water level (TWL).



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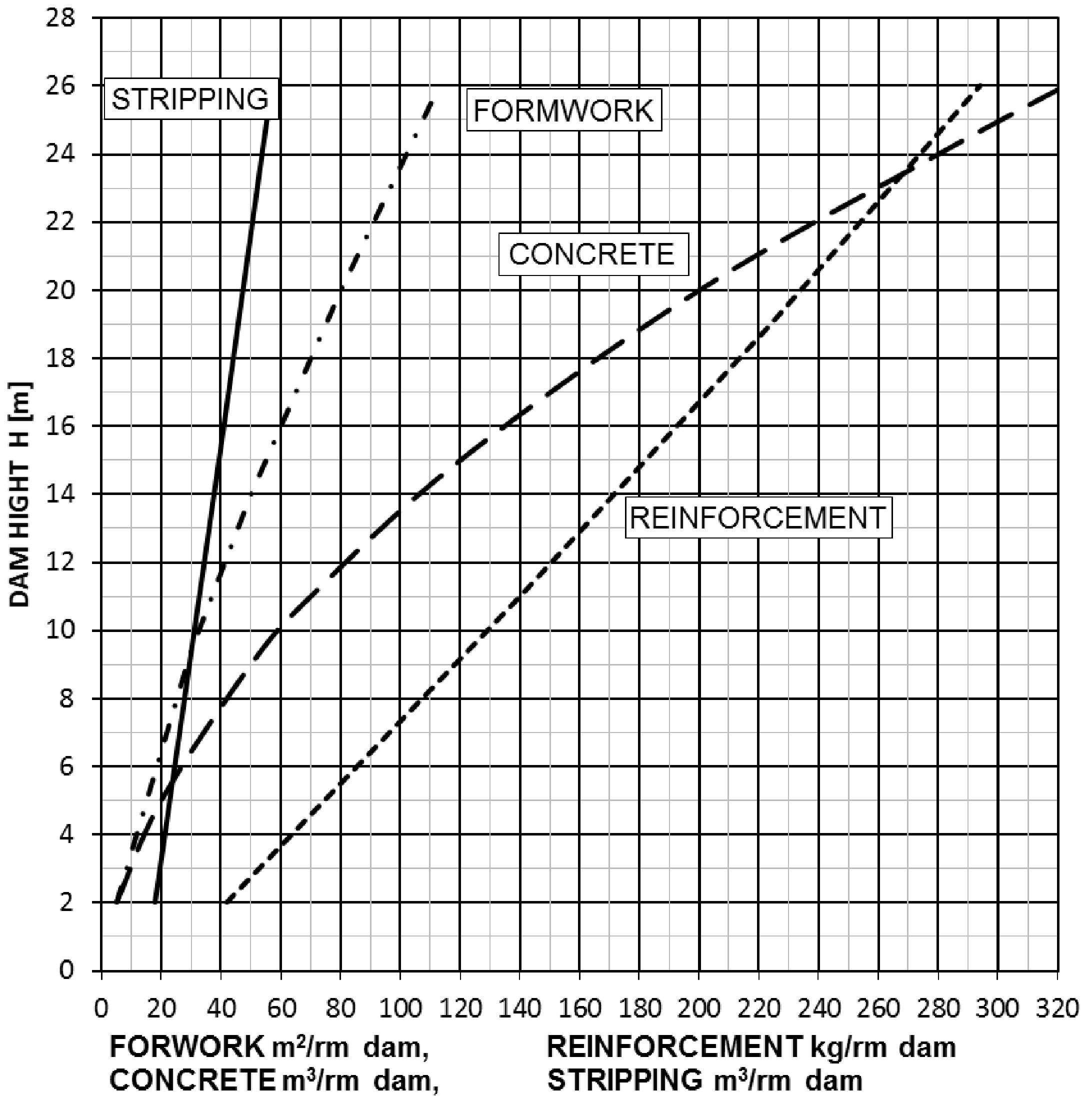
GRAVITY DAM CONTRACTOR COSTS FOR LARGE DAMS , H=6-35 M

Fig 2.3.1
01.01.15

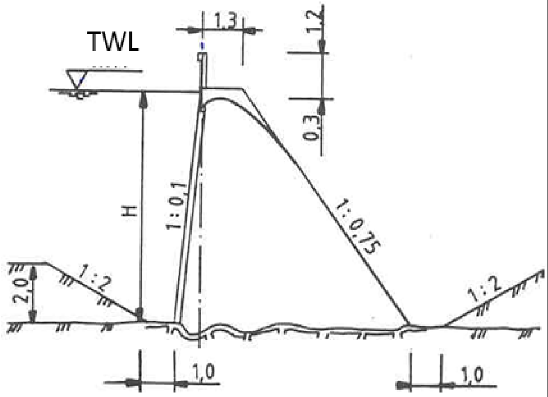


COMMENTS:

Volumes are given as pr rm dam. The section lenght is assumed to be 6.1 m.

Addition for parapet:
Formwork 2.55 m^2/rm dam.
Reinforcement 20 kg/rm dam.
Concrete 0.273 m^3/rm dam.

Aditional for spillway:
No addition until the overflow height is greater than 1.5 m.



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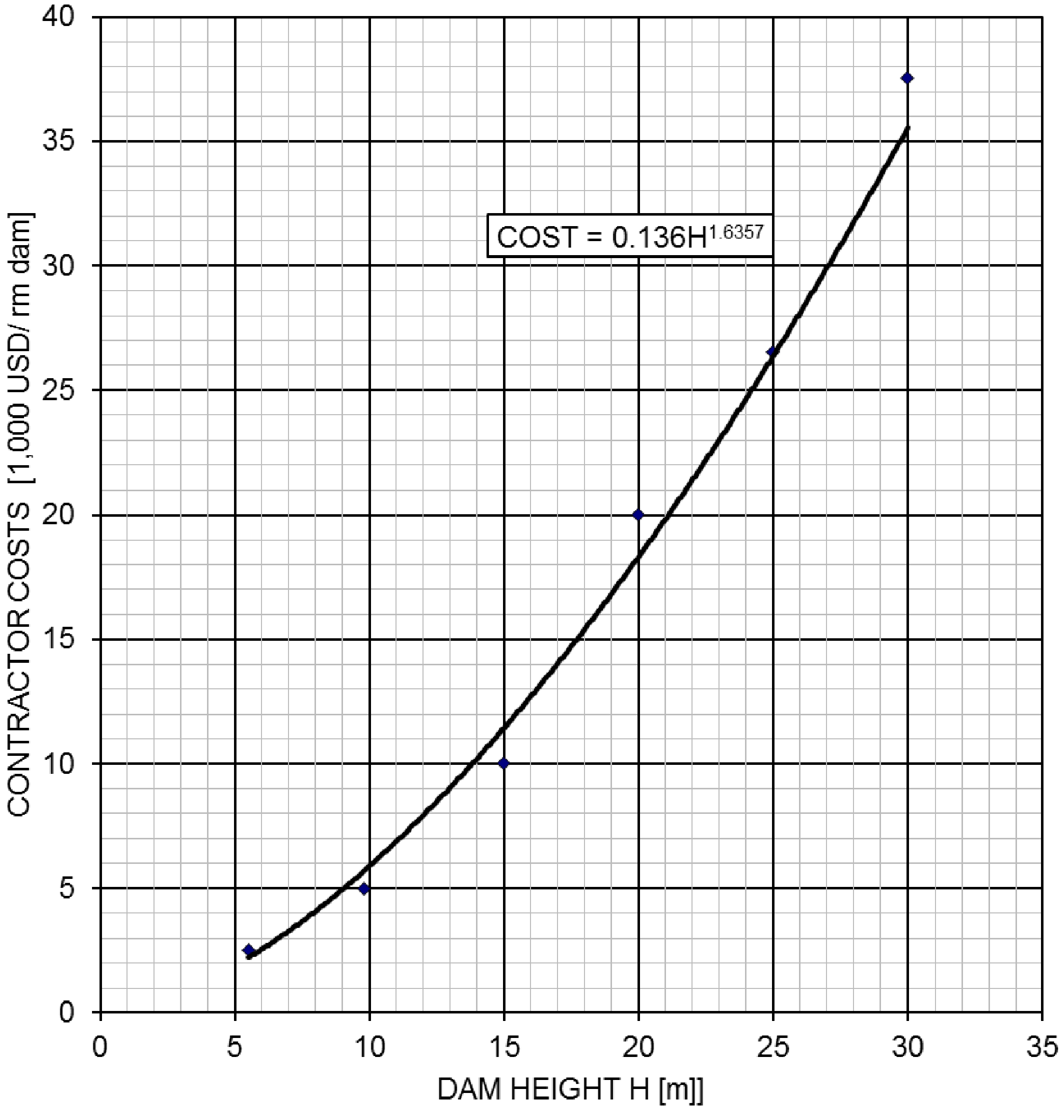
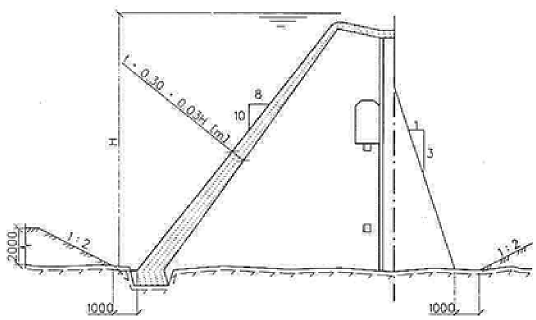
GRAVITY DAM (CONCRETE) VOLUME CURVES

Fig 2.3.2
01.01.15



COMMENTS:

1. Price level: January 2015.
2. The cost curve includes all contractor costs for building - related work relating to the dam body and dam foundation.
3. Costs for removal of 2 meters of uncompacted material over rock have been included.
4. Expenses relating to bottom outlets and redirection of water in the construction period have not been included.
5. Dam height is calculated from the top water level (TWL)



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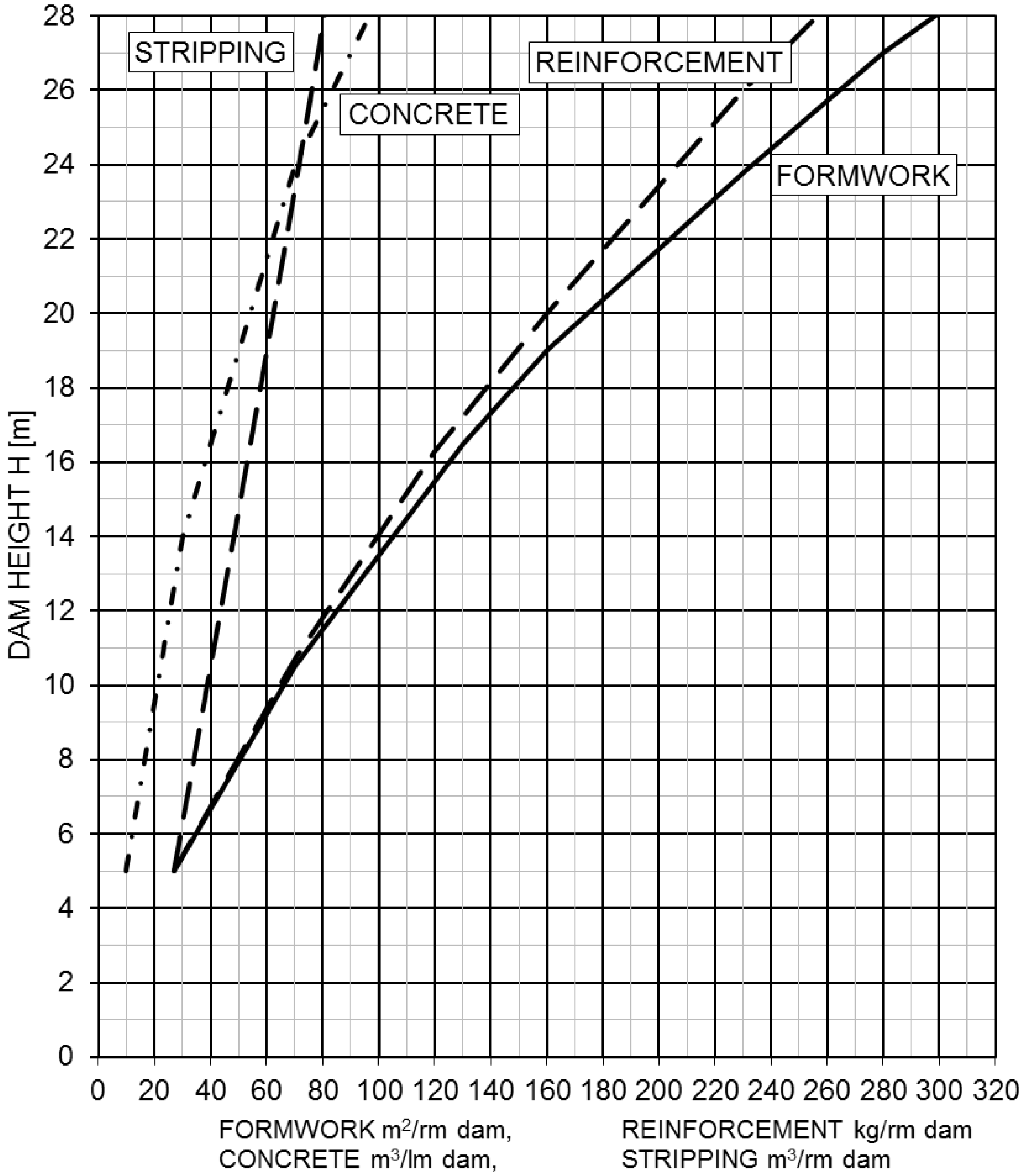
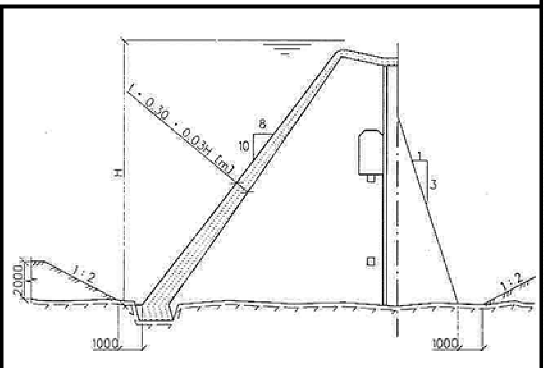
FLAT SLAB DECK DAM CONTRACTOR COSTS

Fig 2.3.3
01.01.15



COMMENTS:

1. Volume are given as per rm dam. The section lenght/ pillar distance assumed to be 6 m.
2. The pillars are assumed to be 0.3 m wide at the top, increasing by 0.03 m per vertical metre.
3. Dam height H is calculated from the top water level (TWL).



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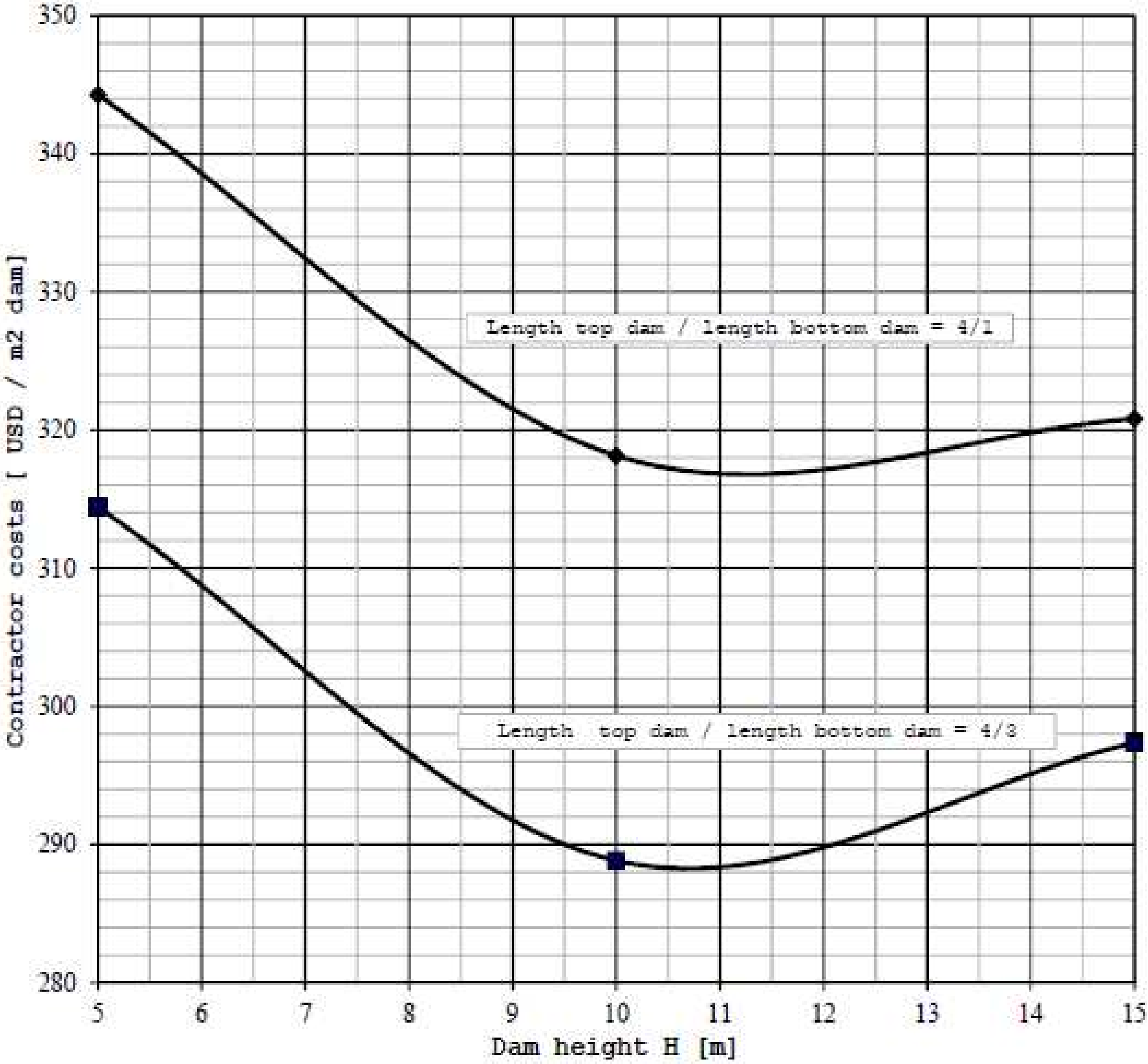
FLAT SLAB DECK DAM
VOLUME CURVES

Fig 2.3.4
01.01.15



COMMENTS:

1. Price level 2015.

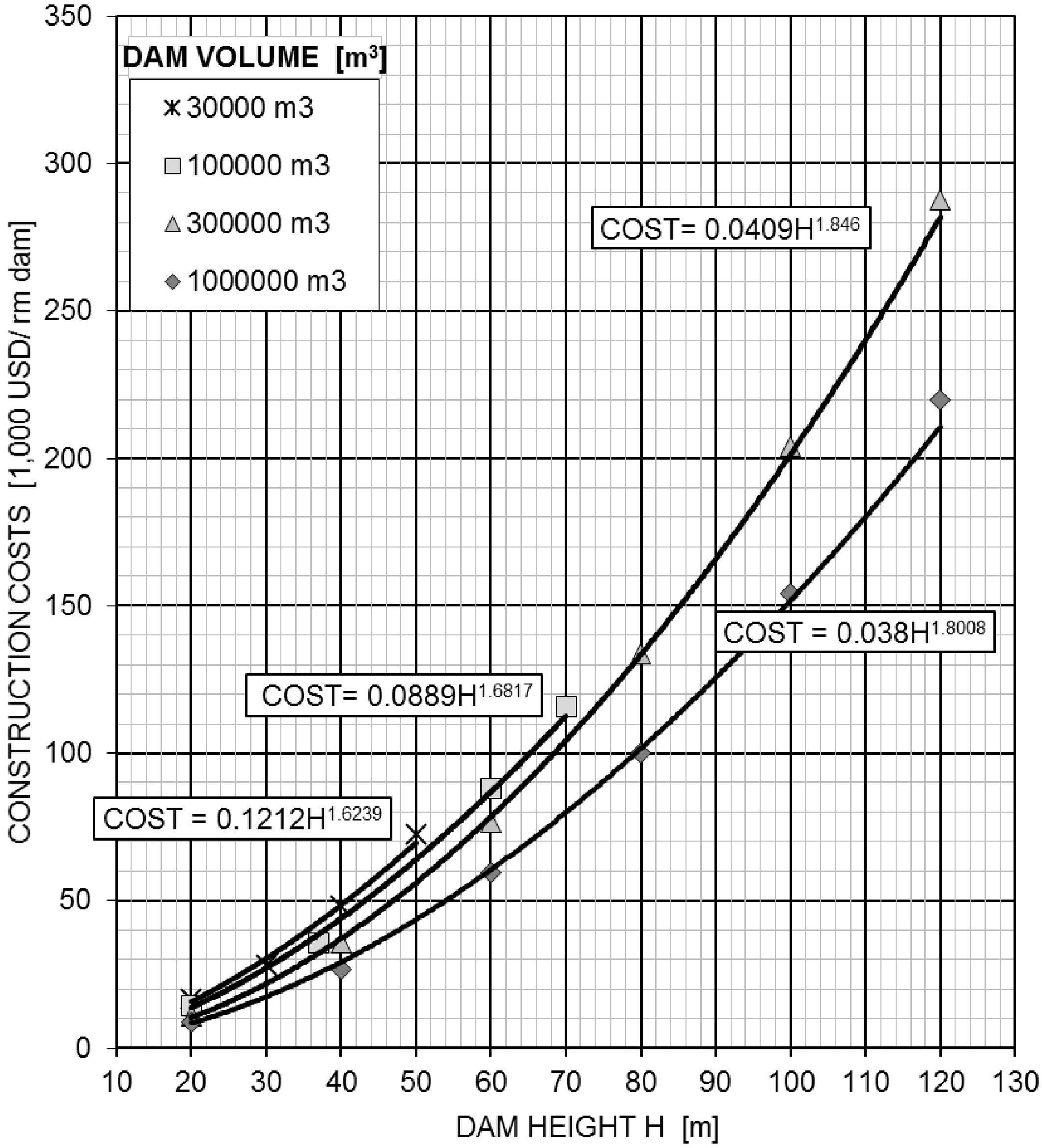
2. The cost curves includes all contractor costs for building-related work relating to the dam body and dam foundation.

3. Minimum thickness 60 cm. The thickness increases with the distance from the crest dam body and dam foundation.

4. The area between the curves covers the most relevant dam cross-sections.

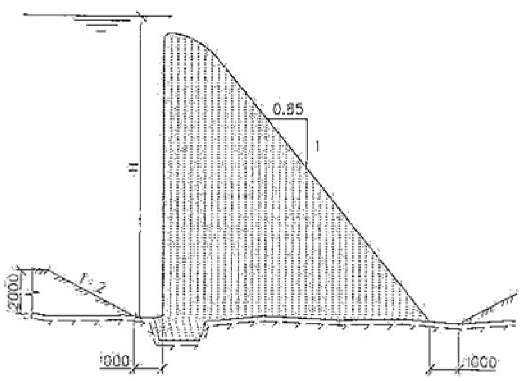
5. The dam height H is calculated from the top water level (TWL) .

Norwegian Water Resources and Energy Directorate	CONCRETE ARCH DAM CONTRACTOR COSTS	Fig. 2.3.5 01.01.15



COMMENTS:

1. Price level 2015.
2. The cost curve includes all contractor costs for building- related work relating to the dam body and dam foundation. A 2 m uncompacted material is assumed.
3. The dam height H is calculated from the top water level (TWL).



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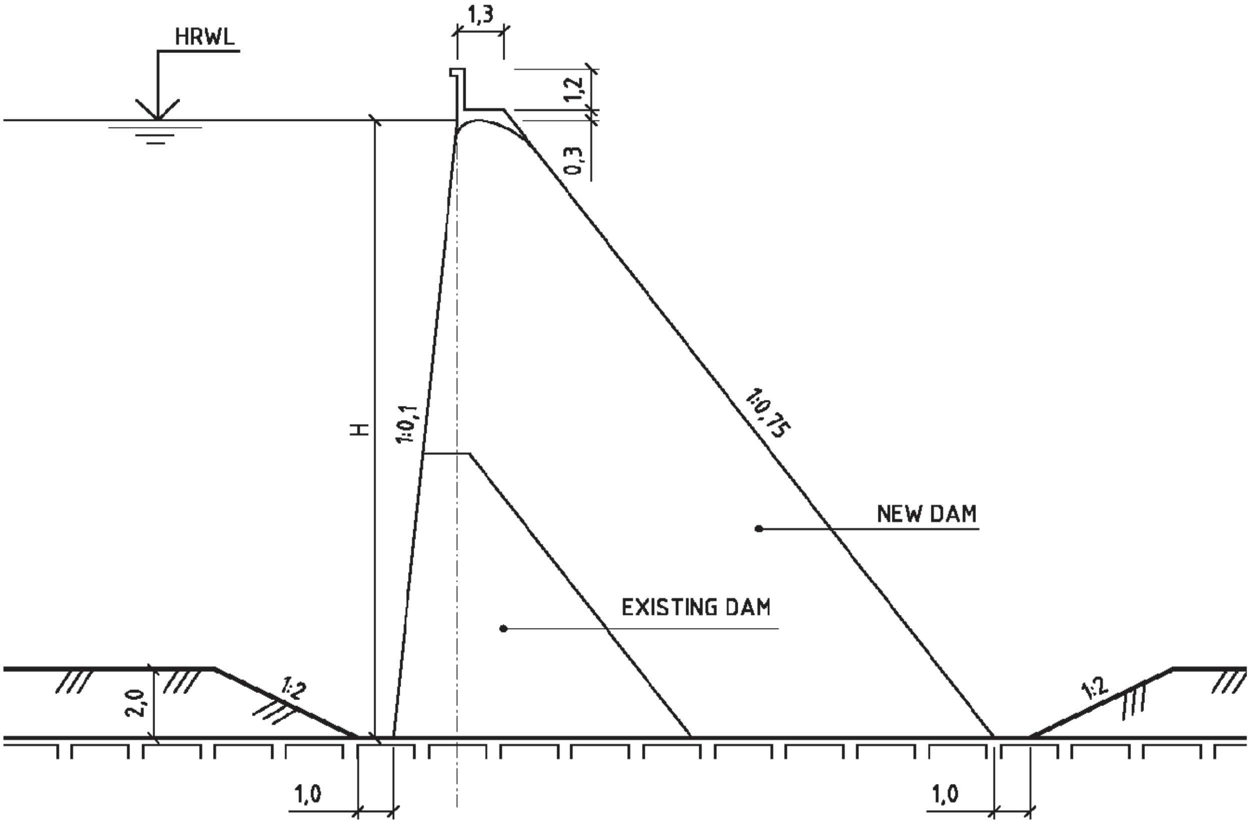
RCC - DAM CONTRACTOR COSTS

Fig 2.3.6
01.01.15



Connection must be established with reinforcement in the existing dam by chipping off old concrete, or by using anchor bolts.
New sealing tape must be connected to the old sealing tape.

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GRAVITY DAM (CONCRETE)
HEIGHT INCREASE PRINCIPLE

Fig. 2.3.7

2.5 BLASTED TUNNELS

2.5.1 GENERAL

The contractor costs for a tunnel will cover the cost of the following operations:

- Cutting:
  The costs must be calculated separately. The cost calculation basis is given in Item 2.6.1.
- Collaring/portaling:
  The costs must be calculated separately. The cost calculation basis is given in Item 2.6.1.
- Tunnel driving:
  Has been included in the cost calculations in this chapter on tunnels.
- Tunnel securing and injection:
  Have been included in the cost calculations in this chapter on tunnels.
- Cross cuts:
  The costs must be calculated separately. The cost calculation basis is given in Item 2.6.2
- Piercing
  The costs must be calculated separately. The cost calculation basis is given in Item 2.6.4.
- Plugs, gates, hatches, stop log:
  The costs must be calculated separately. The cost calculation basis for plugs is given in Item 2.6.2.2. The cost calculation basis for gates is presented in Item 2.6.1, whereas the basis for hatches can be found in Item 2.6.3 (building-related) and in Chapter 4.8 Stop log costs must be calculated separately.

Of these operations it is really only the work on the tunnel itself and the cross sections that are suitable for schematic cost calculations. However, even these operations are impacted by several parameters which vary according to natural conditions and which one often has only limited knowledge of when the first estimations are prepared.

The single factor which may have the greatest impact on costs is tunnel safety; particularly grouting or injection in the event of water seepage problems. Ensuring the structural safety of tunnels is often underestimated in cost calculations. Tunnel safety work will affect not only contractor costs (such as extra bills and acceleration costs) but also builder costs (if, for instance, interest expenses are determining for the construction time). It is important to adopt a conservative approach to determining the need for tunnel securing work. Furthermore, when using the cost curves it is important to bear in mind that in terms of securing work the curve applies to normal and favourable conditions. A relevant engineering-geological survey will always be useful.

The price per consecutive metre (rm) of tunnel driving will under otherwise equal conditions depend on the cross-section of the tunnel. An increasing cross-section will make it possible to adopt more efficient operations by using more efficient equipment and other driving methods.

It is expected to be cheaper to drive minimum cross-sections with wheel drive than to drive small cross-sections with rail drive.

In practice there is a tendency for tunnels to be driven with larger cross-sections than specified in the tender documents or the contract. The situation can be described using the following example:

The tender documents request a price of, for instance, a 20 m^2 tunnel. The contractor offers a price for a 25 m^2 tunnel which is so favourable that the contract is based on a 25 m^2 tunnel cross-section. However, other costs might occur if he enters into this agreement such as higher tunnel securing and tipping area costs, etc.

The price per consecutive metre is determined by many factors not discussed in this report. It is pointed out, however, that the price curve will underestimate the price for short tunnels, and that tenders provide large price variations for shorter tunnels (of a few hundred metres). One reason for this is that there is seldom a rhythm in the work at the outset and that it may or may not be possible to alternate operations on two working faces. This can be roughly allowed for in the cost calculations by correcting for the length in accordance with the correction curves.

The basic price, here USD/m run excluding tunnel safety work, rigging and operation as well as miscellaneous and unforeseen costs, can be found in Figure 2.4.1. The same values are also presented in the table below:

Cross-section m^2	Basic price USD/rm (approx.)	Comments	
18	222	18-35 m^2	Wheeled loaders are used
35	258	35-70 m^2	Larger transporting equipment might be necessary
70	232	70 m^2 and >	Larger dumper trucks, bogie
85	364	85 m^2 and >	Piling will be necessary when the height of the tunnel exceeds 7.5 m.

The table shows the price per consecutive metre of tunnel and comments for relevant equipment replacements.

The basic price must be adjusted for conditions that deviate from the assumptions. In cases where little is known about local conditions, the adjustments must in many cases be made based on a rough estimate.

Figure 2.4.1 shows the cost curves for the basic price and the total price. It has been assumed that the tunnel is driven on an upward gradient. The following assumptions are included in the cost curve:

1. *Basic price*

   a) Tunnel length 3 km (correction for deviations according to a separate figure)
   b) Contour blasting, distance between holes 0.7 m.
   c) Total transport length assumed to be 600 m (300 + 300 m)
   d) Medium blastability and drillability (DRI = 49). Correction for rock that it is difficult to blast/drill, maximum 5% for smaller cross-sections, 10% for larger cross-sections.
   e) The tunnel is driven at a moderate upward gradient (3-$6^{0}/_{00}$) and with moderate water penetration (<500 l/min).
   Water penetration >500 l/m will typically result in additional costs of 13 USD/rm. For downward gradients 5% should be added assuming that water penetration is <500 l/min. If the tunnel is driven at an upward gradient, but the cross cut is descending, the basic price of the tunnel should be increased by 1%.
   f) Typical location.

2. *Tunnel safety*

   Tunnel safety should be divided between securing of the working face and face back-up. This will comprise extra rock removal/scaling, bolting, sprayed concrete, pouring and to a certain extent injection. Supplementary costs for tunnel securing have been estimated as 20% of the basic price for smaller tunnel cross-sections and as 30% of the basic price for larger tunnel cross-sections. This reflects normal to good conditions. In recent years the use of sprayed concrete has increasingly tended to replace extra rock removal/scaling to secure the worksite. Moreover, the increasing focus on HSE and safe workplace requirements has increased safety at the worksite.

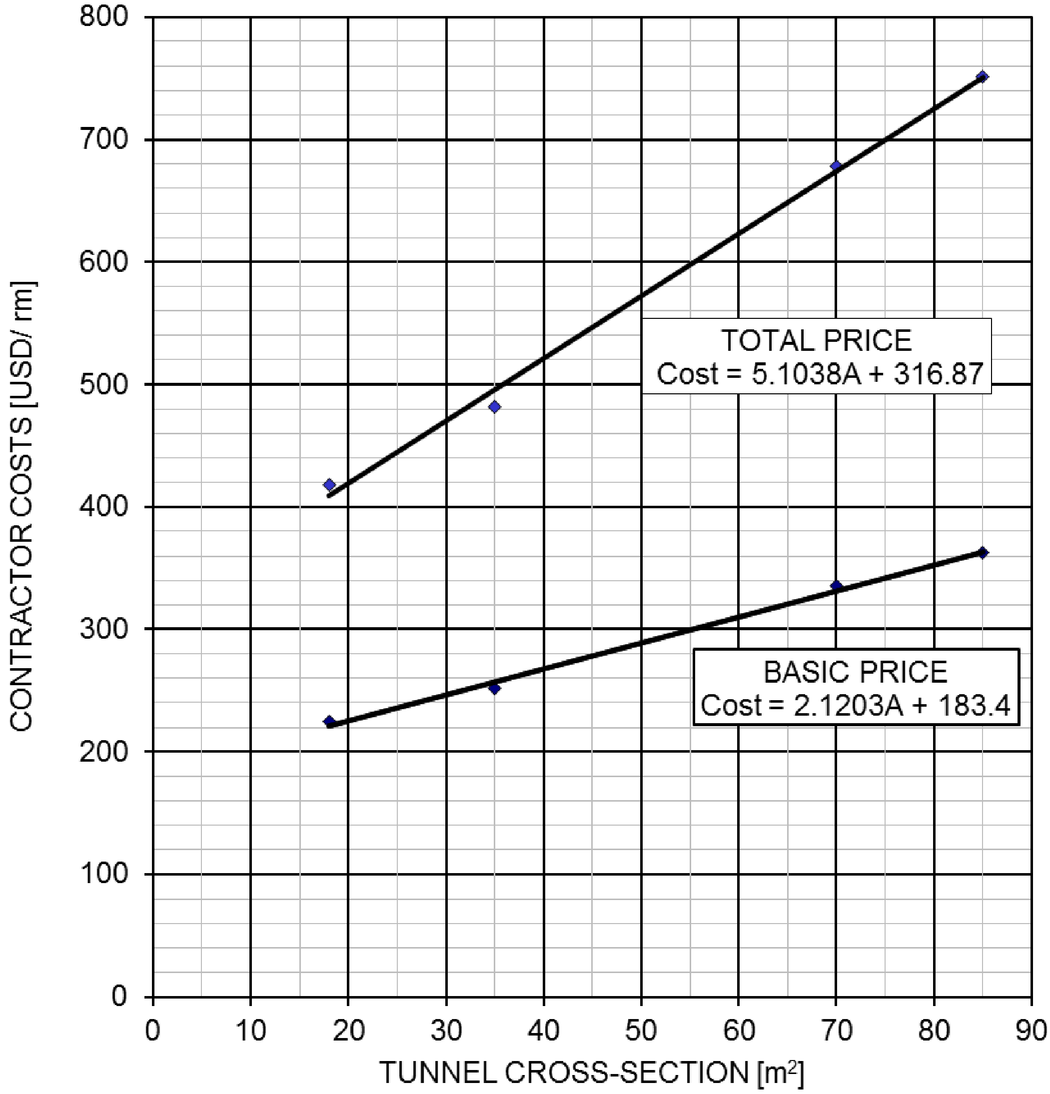
3. *Miscellaneous, unforeseen*

   Included in the curves with 10% of the total price + securing work (1+2)

2.5.2 PRICE LEVEL AND PRICE ESTIMATE UNCERTAINTY

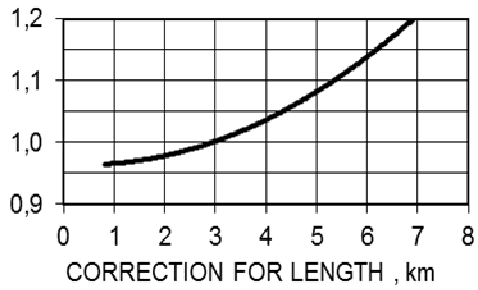
The prices are as of January 2015.

It has been estimated that the uncertainty of the calculations given in this chapter to be +30% to -20%.



COMMENTS:

1. Price level January 2015.
2. Assumed rock medium quality and blastability.
3. Tunnel length (working face length) 3 km, excluding cross cut. Correction for deviating length as in figure.
4. Cross cut of length 300 m not included.
5. Distance collaring/portaling - cross cut tip 300 m.
6. Protection work included in the total price curve as 30% of the basic price for small cross - sections and 45% for large cross-sections.
7. Miscellaneous and unforeseen costs are included as 10% of the basic price and securing.
8. Correction for driving at moderate downward gradients: 5%



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BLASTED TUNNELS CONTRACTOR COSTS

Fig. 2.4.1
01.01.15

2.6 MISCELLANEOUS ON BLASTED TUNNELS

All prices are as of January 2015.

2.6.1 CUTTING

Cutting with collaring/portaling and wall with gate are included in the cross cut item (if the tunnel has a cross cut) or directly in the tunnel item.

Cutting costs, etc. are largely dependent of local conditions. The cutting costs should be based on volume estimates based on surveys/maps/profiles. The following total unit prices (all contractor costs included) can be applied:

Blasting, loading and transportation to tip: 7.0 USD/m^3

Removal of material: 1.5 USD/m^3

For information purposes it is pointed out that the cost calculations have been conducted on the assumption that the terrain is ascending 1:1 at the collaring/portaling location, that the rock has 2 m of uncompacted material cover and that collaring/portaling is achieved by 4 m of rock cover.

It is further assumed that there are two screens with bolts over the collaring/portaling and one bolt per consecutive metre in the walls. Moreover, it has been assumed that 10 cm of sprayed concrete has been used on the surface over the collaring/portaling.

Finally, it has been assumed that there is a 20 cm concrete wall with a gate of 2.5 x 2.5 m and a fixed louvre in the cutting. Costs for extra contingency measures have not been included (extra concrete wall with lattice gate). Such costs can be estimated as the costs of the wall including the gate.

Cutting costs are indicated in Figure 2.5.1. Separate cost curves have been presented for cutting and for the wall incl. the gate as a function of the tunnel cross-section.

The curves show normal foreseeable contractor costs for cutting.

Costs relating to roads, construction site power and general builder expenses have not been included.

2.6.2 CROSS CUT

2.6.2.1 TUNNEL

The cross-section of the cross cut may vary according to both the cross-section of the main tunnel and its length. Furthermore, the size of the cross cut may be determined by the transportation of gates and gate parts. The costs per consecutive metre may vary according to the length of the cross cut (higher price per consecutive metre for short cross cuts).

In the initial planning face it has been assumed that it would be appropriate to simplify the dimensioning and cost calculation of cross cuts as follows:

1. For tunnel cross-sections of up to approx. 25 m^2 the cross cut is considered part of the main tunnel, i.e. the length of the cross cut will be included in the tunnel length.
2. For tunnel cross-sections over approx. 25 m^2 the cross cut cross-section should be kept at approx. 25 m^2 and cost calculations are made according to the following unit prices, including securing, unforeseen/miscellaneous:

   Cost: 480 USD/rm

3. Cutting, etc. See Item 2.6.1.

2.6.2.2 CROSS CUT PLUG

Contractor costs for cross cut plugs have been calculated on the following assumptions:

1. Plug length 1/20 of the water pressure, but 4 metres as a minimum.
2. Steel gate 2.5 x 3 m (gate not included in the curve).
3. Length of steel lining 4 m, which may be a bit short for high pressures (lining not included in the curve).
4. Concrete thickness against rock upstream of the steel lining 1.0 m (which may be insufficient for high pressures if it is possible to drain the tunnel quickly).

Building-related costs are shown in Figure 2.5.2.

Costs of gate with steel lining are in addition. These costs are presented in curves in chapter 4.8.

2.6.3 GATE SHAFTS, STREAM INLET, GATEHOUSE

2.6.3.1 SHAFTS

Whereas gate shafts are vertical shafts, stream inlet shafts are almost always inclined for ventilation purposes. Stream intake shafts usually have a short adit between the tunnel and the shaft so that the tunnel work can be conducted with minimum disturbance from the shaft work (and the stream inlet). Raw shaft costs can be calculated by using the price curve for blasted or drilled shafts (Chapters 2.8 and 2.9).

The price curve for blasted tunnels can be used to calculate horizontal adit costs (Chapter 2.5).

2.6.3.2 GATE SEALING

Gate sealing costs can be calculated by applying the price curve for cross cut plugs, unless more accurate calculations are made based on volume calculations. For volume calculations the following total prices can be used:

Working face	8.4 USD/m^3
Cleaning/scaling	8.0 USD/m^2
Bolts	14 USD/each
Formwork	10.4 USD/m^2

Reinforcement	630 USD/tonne
Concrete	48 USD/m^3

Injection prices are highly variable, but an addition of 2,000 to 10,000 USD

depending on conditions may be assumed.

The cost of the gate including sheet covering is calculated separately (Chapter 4).

2.6.3.3 BUILDING-RELATED WORK IN THE GATE SHAFT

The cost of building-related work in the gate shaft (support bearings for the retraction rod, ladder attachments, landings, etc.) will depend on the chosen design (stuffing box or retraction rod for the gatehouses above the highest recommended water level (TWL). Consequently, the costs of the work should be calculated separately according to volume and unit prices. A rough cost estimate can be found by calculating 355 USD/rm shaft (from top gate flow to TWL + 2m).

2.6.3.4 GATEHOUSE, GATE CHAMBER

Gatehouse costs vary significantly depending on the terrain, transport conditions and sometimes requirements relating to defence reinforcement. Consequently, the costs should be based on volume estimates and unit prices. Unit prices, as specified in the next section for stream inlets, can be used for gatehouses.

Costs relating to blasting and securing of gate chambers can be calculated as follows:

-	Blasting, loading and transport to tip	7.0 USD/m^3
-	Securing mark-up on the price above	30%

2.6.3.5 STREAM INLETS

The curve in Figure 2.5.3 shows simplified normal stream inlet costs for Georgian hydropower plants.

The figure is based on a concrete intake construction located above the shaft/stream course where an intake screen has been installed as well as an air vent if there is a risk of air discharge. Furthermore, it has been assumed that it is possible to drain the intake by installing a closing component which would make it possible to divert the stream around the intake.

Local conditions have a great impact on the costs. Consequently, average estimates for conditions such as rigging opportunities, climate and topography, ground conditions, terrain slope, the nature of the stream, sediment transportation, uncompacted materials or rock, etc. have been conducted.

The costs are presented as a function of the annual mean flow. However, distinction is made between whether helicopter transport is required or not.

The contractor costs include ground and concrete work, including installation of closing component and screens.

For larger intakes where the Q_{mean} is above 3 m^3/s, local conditions will be of such great significance that the uncertainty will be considerable. The curves have been prepared for up to 5 m^3/s.

Intake shaft costs have not been included.

As mentioned above, the costs are to a large extent determined by the rate of flow and local conditions, and the curves are based on average estimates. Below is a presentation of the basis for unit prices which can be used if it is possible to calculate the foreseeable costs on the basis of volume estimations.

As transport and ground conditions are often difficult, higher unit prices should be applied. This applies particularly to concrete, but other unit prices might need to be increased by up to 30%. Below are suggested unit prices:

Blasting, loading and transport to tip:	7 USD/m^3
Foundation preparation:	11 USD/m
Rock bolts:	18 USD/each
Formwork:	10.4 USD/m^2
Reinforcement:	633 USD/tonne
Concrete:	70 USD/m^3

The prices above are based on the assumption that it is possible to drive up to the construction site. If helicopter transport is necessary the prices will increase considerably.

2.6.4 TUNNEL MOUTH, UNDERWATER TUNNEL PIERCING

2.6.4.1 TUNNEL MOUTH

Water-carrying tunnels will, of course, always have a mouth, almost always a closing device (stop log for simpler constructions) and usually screens. The costs depend on several conditions such as design flow and pressure, whether the work can be conducted above ground with or without coffer dams or via the tunnel, etc.

The tunnel mouth costs will often vary between transfer tunnels and operating tunnels (inlet tunnel or outlet tunnel) and depend on whether the breakthrough is to air or under water (such as underwater piercing). The tunnel mouth costs must be seen in conjunction with the gate shaft and its associated arrangements.

Tunnel mouth costs will constitute a minor part of the total costs, particularly for longer tunnels. Any major errors in the mouth cost calculations will therefore usually have little impact on the total costs.

Tunnel mouth costs are not very suitable for schematic cost calculations. The costs should be calculated on the basis of the volume and unit prices in each case after the main design principles have been determined.

2.6.4.2 *UNDERWATER TUNNEL PIERCING*

Underwater tunnel piercing costs (in addition to normal tunnel costs) will depend on a number of factors such as water pressure, tunnel cross-section, rock conditions, coverage of uncompacted materials above the rock, etc. Underwater tunnel piercing is not suitable for schematic cost calculations.

The costs should be estimated in each case based on water pressure, cross-section, inlet tunnel or transfer tunnel, as well as an assessment of the natural conditions. As for the mouth of the tunnel, piercing will constitute a small part of the total costs of longer tunnels.

As a very rough estimate underwater tunnel piercing costs can be calculated as follows: (USD):

Small tunnels, modest water pressure	30 000
Medium tunnels (15-20 m2) 40-70 m pressure	60 000
Large tunnels (70 m2) 40-70 m pressure	120 000

For large tunnels in particular, probe drilling in the final section of the tunnel near the piercing, and the extent of injection required in front of the working face, will have a significant impact on the time, and thus costs, not only directly, but indirectly, as commissioning may be delayed if the inlet tunnel is determining for the construction period.

2.6.5 DISTRIBUTION RESERVOIR

2.6.5.1 *GENERAL*

Both conventional shaft reservoirs with admission and dispersion chambers and compressed air reservoirs may be relevant. Surge shafts (with any chambers) in the tailwater are also considered distribution reservoirs.

The choice between a shaft reservoir and a compressed air reservoir will be determined by the installation's topographic conditions and whether the rock is suitable for the compressed air option. A relevant engineering-geological study should be conducted before deciding on a compressed air reservoir solution.

For both solutions, the costs are dependent on a number of variable parameters such as head, rate of flow, tunnel dimensions, location of the plant in the grid, inlet tunnel shafts, distance between water surface in the distribution reservoir and intake (including any stream inlet shafts).

Consequently, a schematic presentation of cost calculations for distribution reservoirs would require simplifications or comprehensive and detailed calculation work. It is doubtful whether the efforts that are put in will be reasonably proportionate to what is achieved. Estimated cost calculations for distribution reservoirs should be conducted on the basis of prior dimensioning and unit prices.

2.6.5.2 SHAFT RESERVOIRS

The shaft cross-section (F) can be set at:

1.3 x Thoma cross-section

F = 1.3 x 12.3 x $^{5/3}$/H

f = tunnel cross-section

H = minimum net head

Unit price according to the shaft price curve. Costs relating to any upper chambers and lower chamber working faces should be calculated by using a unit price of 8.4 USD/m^3.

2.6.5.3 AIR CUSHION RESERVOIRS

The required air volume can be estimated at roughly V_{air} = 1.2 x 17.2 x $f^{5/3}$ and the rock volume at V_{rock} = 1.35 x V_{air}.

The cost of the chamber can be calculated by using the price per consecutive metre in accordance with the price curve for tunnels (V = cross-section x length) or by applying a total unit price of 8.4 USD/m^3 (assuming the chamber cross-section to be approximately 80 m^2).

Injection, air filling and operating costs have not been included. These costs may be considerable. Generally speaking, an air cushion project should have a very sound financial footing if chosen instead of a more conventional surge shaft which usually requires no maintenance.

2.6.6 TUNNEL BACK RIPPING

2.6.6.1 GENERAL

The flow capacity in a power plant can be increased by either:

- Enlarging the cross-section of existing tunnels
- Constructing a parallel tunnel

The choice of method will depend on a number of different factors. First and foremost, scheduling will be important. Any shutdown will represent a risk of loss of production, and, at worst, loss of water in the overflows. Local conditions will determine whether to choose back ripping or a new parallel tunnel, as construction of a new tunnel will mean that one is freer with regard to the existing power production. The back ripping work could be spread over many seasons. However, this alternative should always be compared to that of a parallel tunnel.

In most cases, tunnels will be enlarged by conventional blasting. Engineering solutions for other enlargement methods such as mechanical back ripping (milling) or smoothing of the surface (without enlarging it) are either not good enough, or they cannot compete financially with conventional back ripping.

The tunnel should be drained and inspected during the engineering phase. To avoid any delays in the short construction period, it is important to check the condition of the existing tunnel securing and locate any landslides or major rock falls.

There are some engineering factors which should be considered when choosing to enlarge a tunnel:

2.6.6.2 RIGGING AND PENETRATION RATES

Rigging up for conventional back ripping is easy provided there is an access road to the cross cut. Blasting work in the tunnel can commence as soon as access to the cross cut has been established. Rigging down times are also short.

Provided that the conditions are advantageous, penetration rates are usually good during expansion of existing tunnels, perhaps as much as double the production compared to normal tunnel operations.

2.6.6.3 CROSS CUTS

The size of the cross cut and cross cut gate must be assessed with modern construction machinery in mind for the back ripping operation. One solution is to blast the existing gate, expanding the cross cut correspondingly and inserting a new cross cut gate. For cost reasons it is important that there is a road connection to the cross cut and that there is access to a tip.

2.6.6.4 BACK RIPPING METHODS

Side back ripping is most relevant for large and medium cross-sections, to achieve optimal use of the drilling rig capacity. Side back ripping is necessary for large cross-sections (height of approx. 10 m) as a result of the reach of the drilling rig.

Side back ripping may be necessary due to geological conditions. For tunnels with anisotropic stress ("slope stress") and substantial tunnel securing in parts of the cross-section, side back ripping is most practical.

Round back ripping is suitable for all cross-section sizes except extra-large ones, where limitations will be set by the drilling rig. This operation sets strict requirements to execution because so much of the cross-section is renewed, and thus needs to be cleared and secured.

Bottom back ripping is best suited for large and medium cross-sections. The bench can either be horizontal or vertical. The vertical bench has few limitations, whereas the vertical bench sets requirements to the bench height and tunnel height to function operationally. The recommended bench height is minimum 3 m, and for the drilling to function well, the existing tunnel height should be 1.5 – 2 m higher than the height of the bench. To achieve an efficient vertical bench it is best to have two accesses; one for drilling and charging and one for loading and transport.

2.6.6.5 EXISTING TUNNEL SECURING

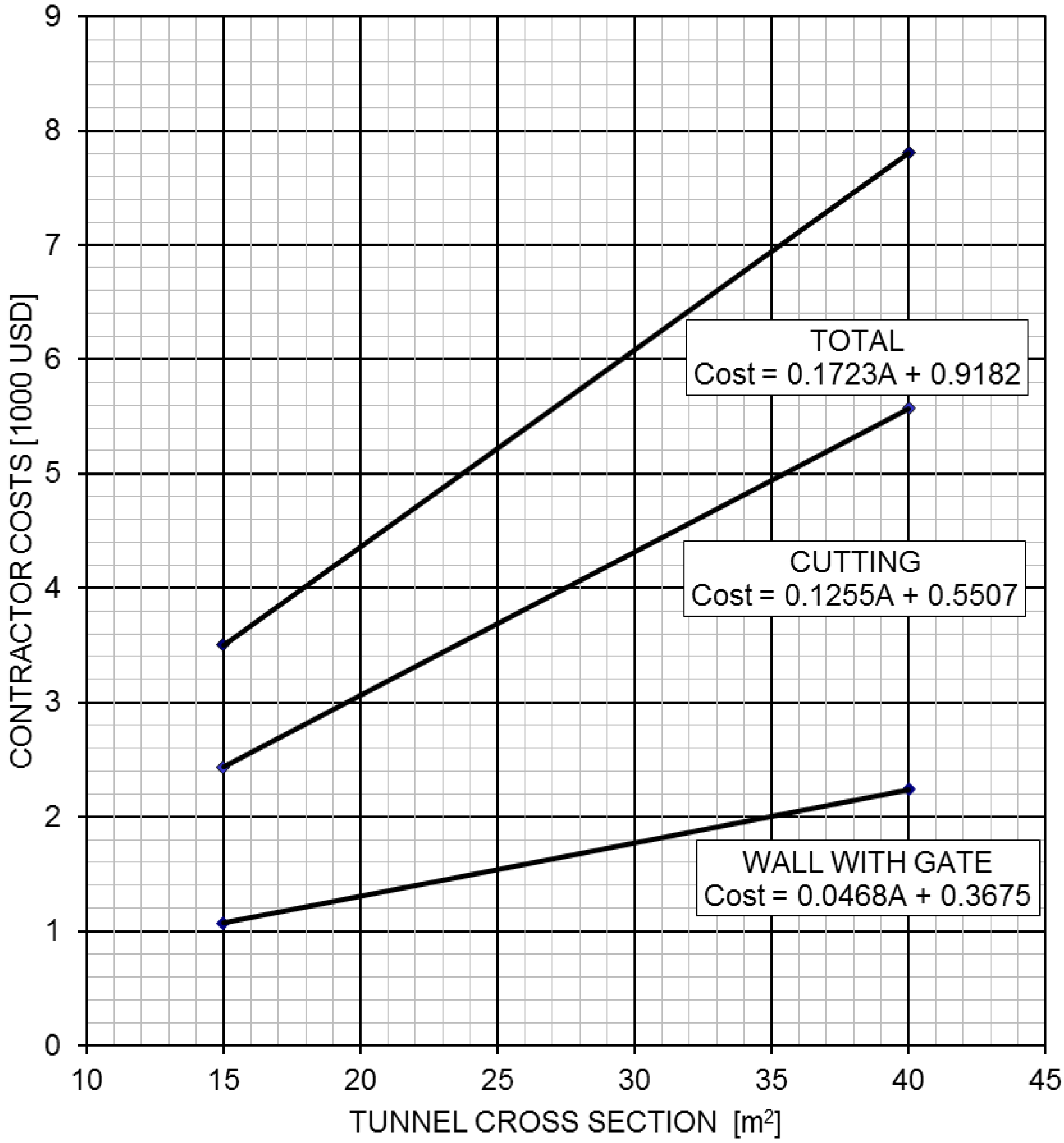
Existing tunnel securing is a challenge for the back ripping as there may be problems with drilling into bolts, removal of casts and grid reinforced sprayed concrete. For operational purposes a bottom bench is most suitable in such cases. In tunnels where there is not much existing tunnel securing and thus little need for tunnel securing, there is a choice of back ripping method.

2.6.6.6 FUNCTION REQUIREMENTS

Experience indicates that current blasting techniques result in higher rugosity than previously. The reason for this is usually related to the construction and the contract. The cost of a desired head loss improvement by more accurate blasting should always be weighed up against the costs of a somewhat larger cross-section. The chances of achieving smoother tunnel walls through back ripping are, however, very good. The existing tunnel can be regarded as a large cut, and more careful blasting can take place than if a new tunnel were to be constructed.

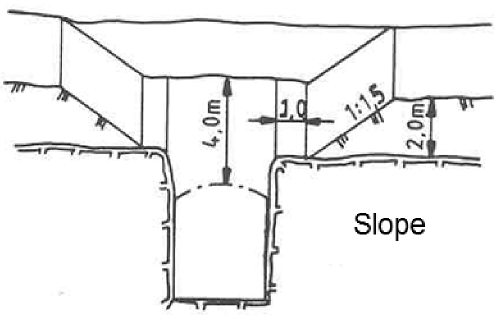
2.6.6.7 COSTS

The extent of back ripping work has not been sufficient to be able to document enough experience and results in general cost curves. The costs will vary according to back ripping area, rock conditions, tunnel length, local conditions, etc. As an indication driving costs (blasting, transportation, excluding rig and operation) will vary between 9.2 USD/fm^3 for small enlargements (approx. 10m^2) and approx. 4.6 USD/fm^3 for larger enlargements (>30 m^3).



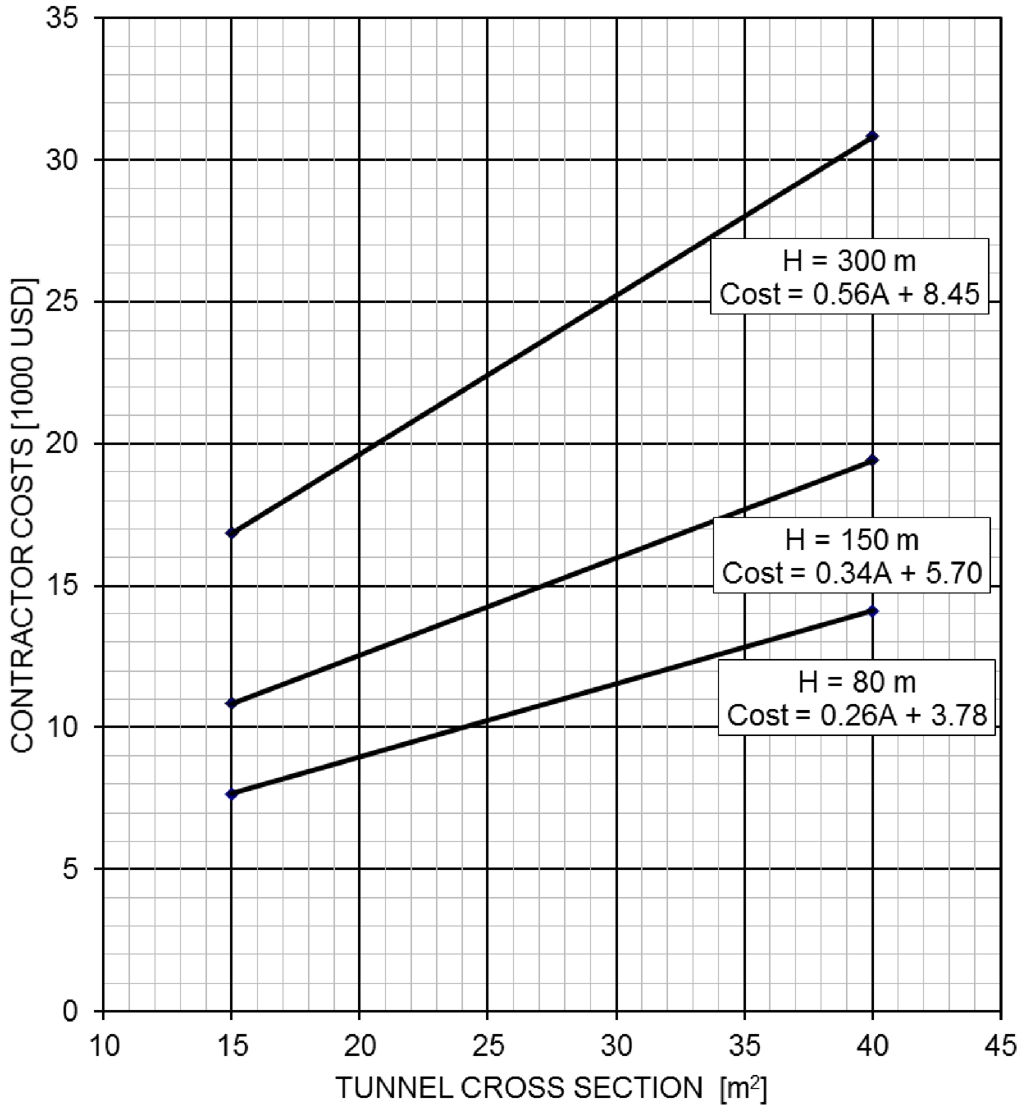
COMMENTS:

1. Price level January 2015.
2. Assumed rock of medium drillability and blastability.
3. The curve comprises cutting with wall with two- bladed gate 2,5 x 2,5 m + door ready installed.
4. Extra lattice gate if necessary has not been included. The cost can be set as for a wall with a normal gate.



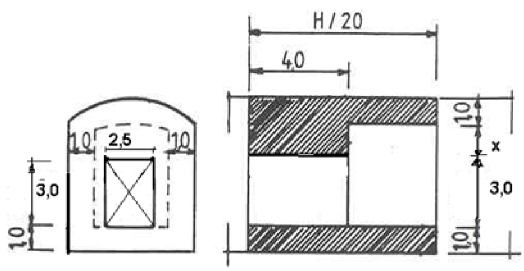
Vertical cross

Norwegian Water Resources and Energy Directorate NVE	**CUTTING WITH GATE CONTRACTOR COSTS**	Fig. 2.5.1 01.01.15



COMMENTS:

1. Price level January 2015.
2. H gives the water pressure in meters.
3. The curve comprises all contractor costs for building - related work.
4. The price for injection is included with 8,000 USD. Injection prices are highly variable and can for high water pressure end up to 2,000 - 3,000 USD.
5. Cross cut gate with steel lining has not been included. The cost of this is given in the table and must be added. See Fig. 4.4.7.



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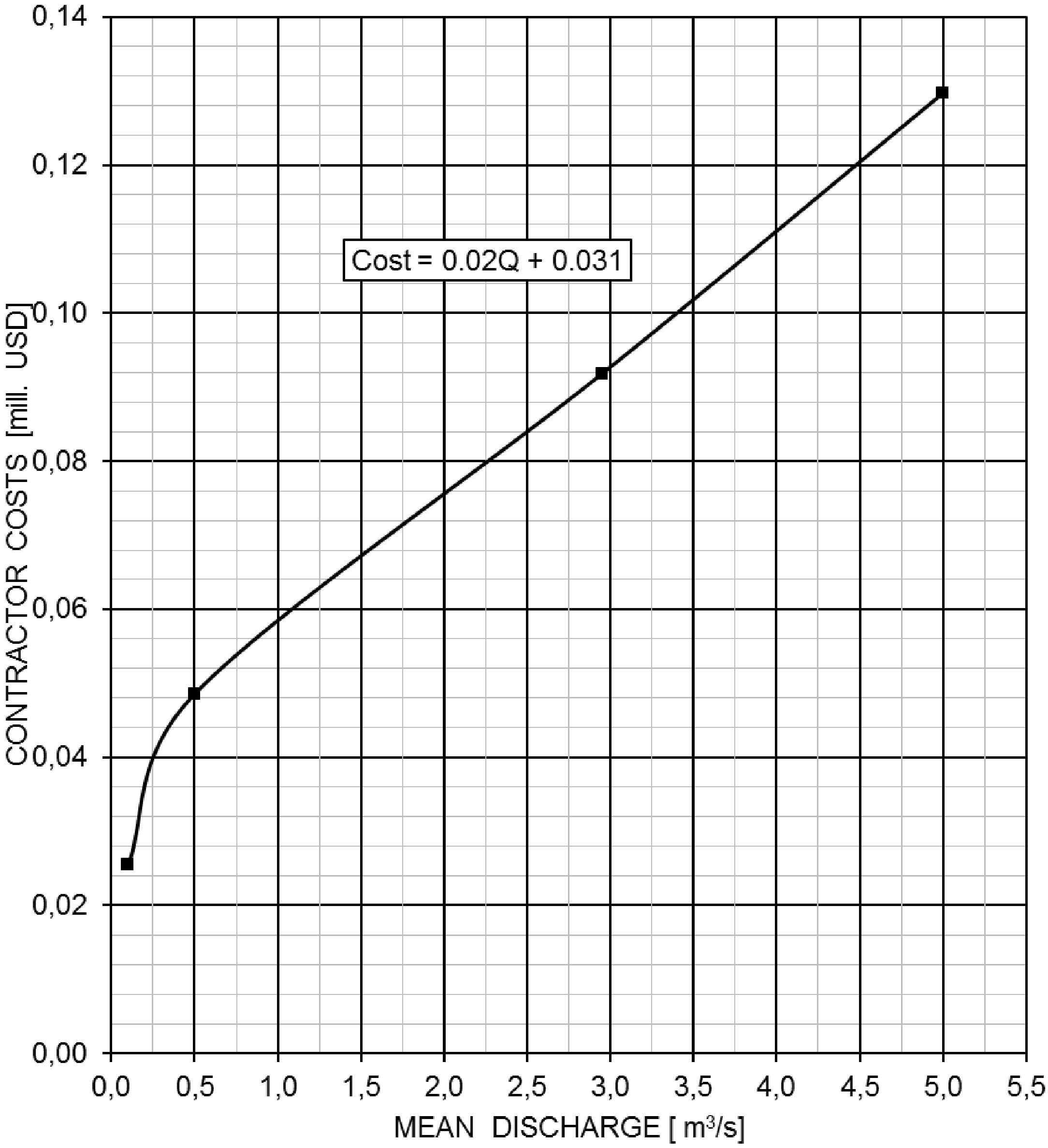
CROSS CUT PLUGS CONTRACTOR EXPENSES BUILDING - RELATED WORK

Fig. 2.5.2
01.01.15



COMMENTS:

1. Price level January 2015.

2. The curve indicates cost for brook intakes. Shaft or tunnel, as well as any dam installation must be calculated separately.

3. Helicopter transport: For small intakes where man-hours make up a significant cost factor, cost will increase by 30-50% if helicopter is used.

4. For installations where material costs are dominant, helicopter transport will increase costs by 100-300%.

Norwegian Water Resources and Energy Directorate NVE	**BROOK INTAKE FOR HYDROPOWER PLANTS**	Fig. 2.5.3 01.01.15

2.7 DRILLED TUNNELS

2.7.1 FULL-FACE DRILLING

2.7.1.1 GENERAL

Full-face drilling is a form of rotating, crushing drilling. The drillhead is pressed against the working face with great force whilst rotating. For each rotation the drillhead penetrates a little into the working face, from 1 to 15 mm. The result is a circular tunnel profile with even walls.

There are advantages and disadvantages to full-face drilling. The heavy tunnel boring machinery (TBM) may seem slow and impractical, but has its advantages in the working environment, and when the rock and geometrical conditions are favourable, full-face drilling will also be advantageous from a financial point of view.

Cost estimates for tunnel installations where full-face drilled tunnels are planned, must be based on a plan which reflects the advantages and disadvantages of full-face drilling. Attention is drawn to the fact that the optimal working face length for full-face drilling will be longer than for conventional operations, and that the cross-section for water tunnels may be smaller, as the head loss is smaller in a full-face drilled tunnel due to smoother walls. A rule of thumb is that the area can be reduced by approximately 40%, which also means that less stone tipping is required for full-face drilling.

Whenever considering full-face drilling a relevant engineering-geological survey is always required to estimate time and costs. Some rock engineering parameters are more relevant for full-face operation than for conventional operations. The penetration rate will be greatest in systematically jointed rock. This applies to all types of fractures.

The drillability of the rock is expressed by the drilling rate index DRI and is a contributing factor for penetration. The same applies to the abrasion qualities of the rock, which will affect the feeding force and the running time of the cutters. Pausing to replace cutters means a halt in operations and thus a reduction in the effective operating time. The rock pressure and porosity of the rock are important parameters when deciding on the type of drilling machine. The drilling machine ought to be “tailored” to the task.

Due to the favourable shape of a circular cross-section, the need for tunnel securing will be less.

Miscalculations relating to drillability, the degree of fracturing, or abrasion value can lead to great deviations from the penetration and cost prognosis. Cost estimates for full-face drilled tunnels must therefore be based on a much more rigorous engineering-geological survey than for conventionally blasted tunnels.

When deciding whether to choose conventional or full-face drilled tunnels, it is important to conduct comparative stability assessments and vibration calculations for the power plant. The smoother tunnel walls achieved through full-face drilling operations will give other results in terms of vibration limits than conventional operations.

TBM costs will differ between new and used machines. If a new machine is purchased for a project it will depreciate by 85 -90% due to strict repurchase agreements with the supplier. A contractor who owns a machine will write it off by approximately 40% for one job. The price of a TBM with a diameter of 3.5 m is around 5.5 million USD, giving a depreciation difference of 2.5 million USD between a new and second-hand machine. If the length of the tunnel is 10 km, this would entail a difference of 250 USD per metre. The difference will be bigger for shorter tunnels. For a TBM with a diameter of 7 m, the same calculation would give a difference of 460 USD per metre of tunnel longer than 10 kilometres.

2.8 BLASTED SHAFTS

2.8.1 GENERAL

Below follows what is intended as a rough overview of foreseeable contractor and supplier costs for shafts, both raw blasted and steel-lined. The prices are meant to be used for both 1:1 shafts and vertical shafts. The prices are contingent on the shafts being operated using a lift running on a rail installed on the hanging wall (Alimak), and do not apply to short shafts. For steel-lined shafts it was assumed that there are tracks on the floor. However, pipe installation may also take place by using the shaft guide for the raised shaft lift.

By use of an Alimak it will normally be possible to drive a shaft cross-section of up to 16 m^2. Shaft cross-sections of up to 20 m^2 may be operated with one rig if conditions are good. Driving larger cross-sections will require two rig-up. Furthermore, ensuring the safety of all working personnel is particularly important during such operations. By having, for instance, two rig-ups it will be possible to drive shaft cross-sections of up to 40 m^2. For shafts larger than 40 m^2 back ripping will be required. For larger shaft cross-sections, considerable securing costs must be expected.

As for tunnels, shaft costs are impacted by local conditions such as drillability and blastability, shaft cross-section and length, transport length and, not least, the need for securing. Thus, in the interest of making the cost curves readily useable, schematic cost calculations for shafts are simplified and based on broad assumptions.

The main assumptions are specified as comments in Figure 2.7.1. Please note that securing costs of 20% of the basic price have been included in the cost curves for shafts with small cross-sections (4-8 m^2) and 35% for large cross-sections (30 m^2).

It is also worth noting that working environment surveys have been conducted for Alimak operations. The survey values have been higher than recommended according to current HSE requirements. This may result in shafts being driven with more use of raise drilling in the future, unless working environment conditions do not improve for the use of Alimak.

2.8.2 RAW BLASTED SHAFT

The price curve (B.7.1) shows estimated contractor expenses including assumed securing work (20-35%), miscellaneous and unforeseen work (10%).

In addition to the costs indicated in the cost curve, there will be additional costs for pressure shafts for the extended, unlined upstream section of the steel-lined section, as well as for the plug with cross cut gate.

The raw blasted section can be included in the costs by including the extra expansion costs in the total shaft length, or by estimating the volume (m^3) and applying a unit price of 15 USD/m^3.

The cost of a plug with a gate is indicated in the cost curve for cross cut plugs for tunnels.

The cost of the concrete cone at the upstream end of the steel-lined section is calculated in together with the steel-lined section of the shaft.

2.8.3 STEEL-LINED PRESSURE SHAFTS

Steel-lined pressure shafts comprise, in addition to lined 1:1 shafts, the steel-lined section of the waterway on the upstream side of the power station for stations with a raw blasted tunnel or pressure tunnel.

The costs of a steel-lined pressure shaft comprise of the costs for building-related work (contractor costs), and steel pipe costs (supplier costs). These costs are calculated on price per meter run basis, additional costs are the inlet cone, and including screen as well as branch tunnels (if there are two units or more).

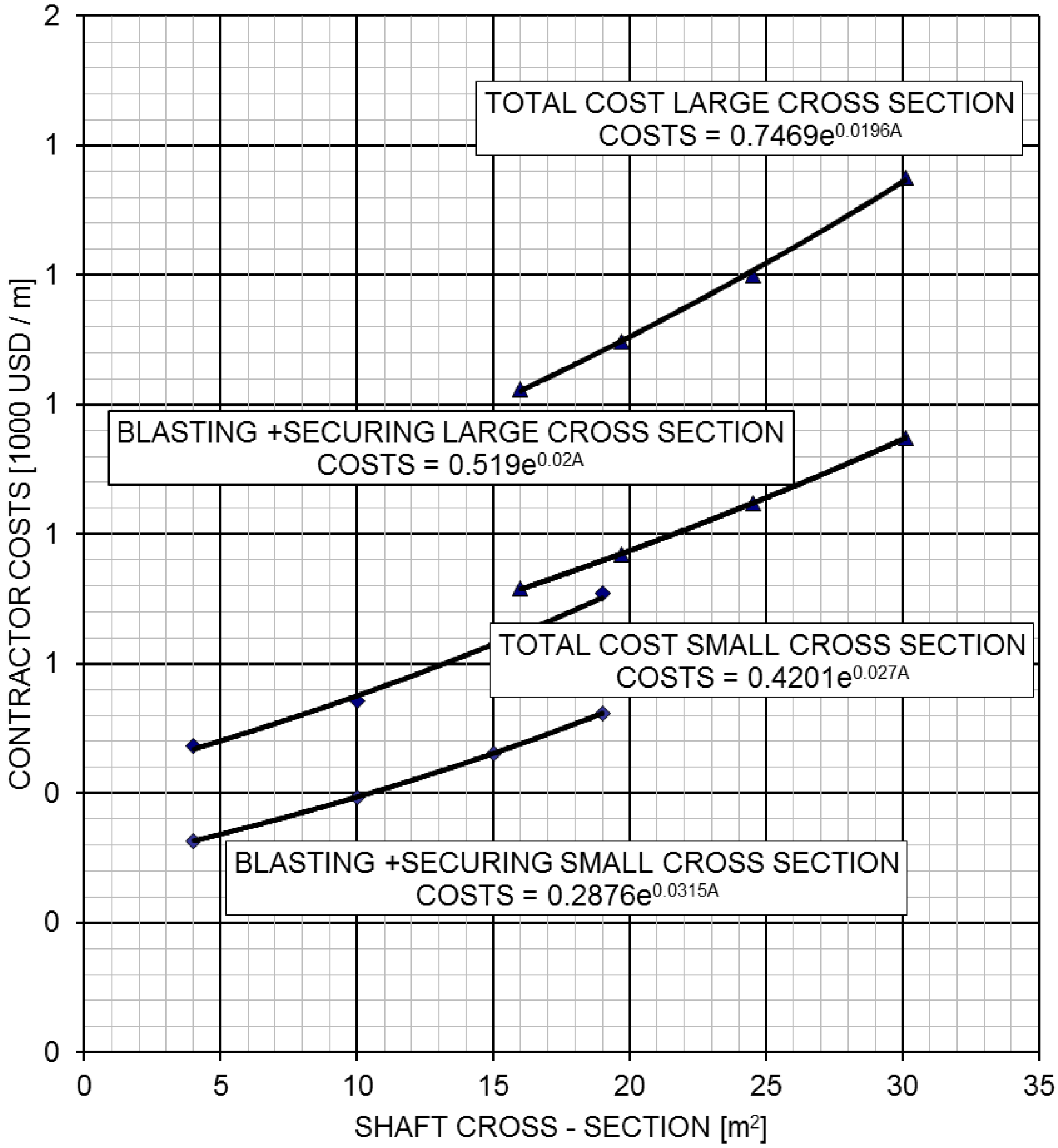
Costs for building-related work are indicated in:

1. Cost curve 2.7.2 which gives the price per rm of shaft depending on the pipe diameter.
2. Cost curve 2.7.3 which gives the inlet cone price depending on the tunnel cross-section and pressure head. The curve can be used for cones for both embedded pipes and open pipes downstream of the cone.
   The pressure head is a parameter for the plug length only in the latter case. For embedded pipes the cone costs can be read from the cost curve which gives the lowest costs, including the dotted line. Please note that for modest heads the length of the cone will be determined by geometric conditions (flow conditions). This has been incorporated in the cost curve.

Supplier costs are presented in Chapter 4, Mechanical Engineering.

2.8.4 UNCERTAINTY

It has been estimated that the cost calculation uncertainty for shafts to be ±25.



COMMENTS:

1. Price level January 2015.

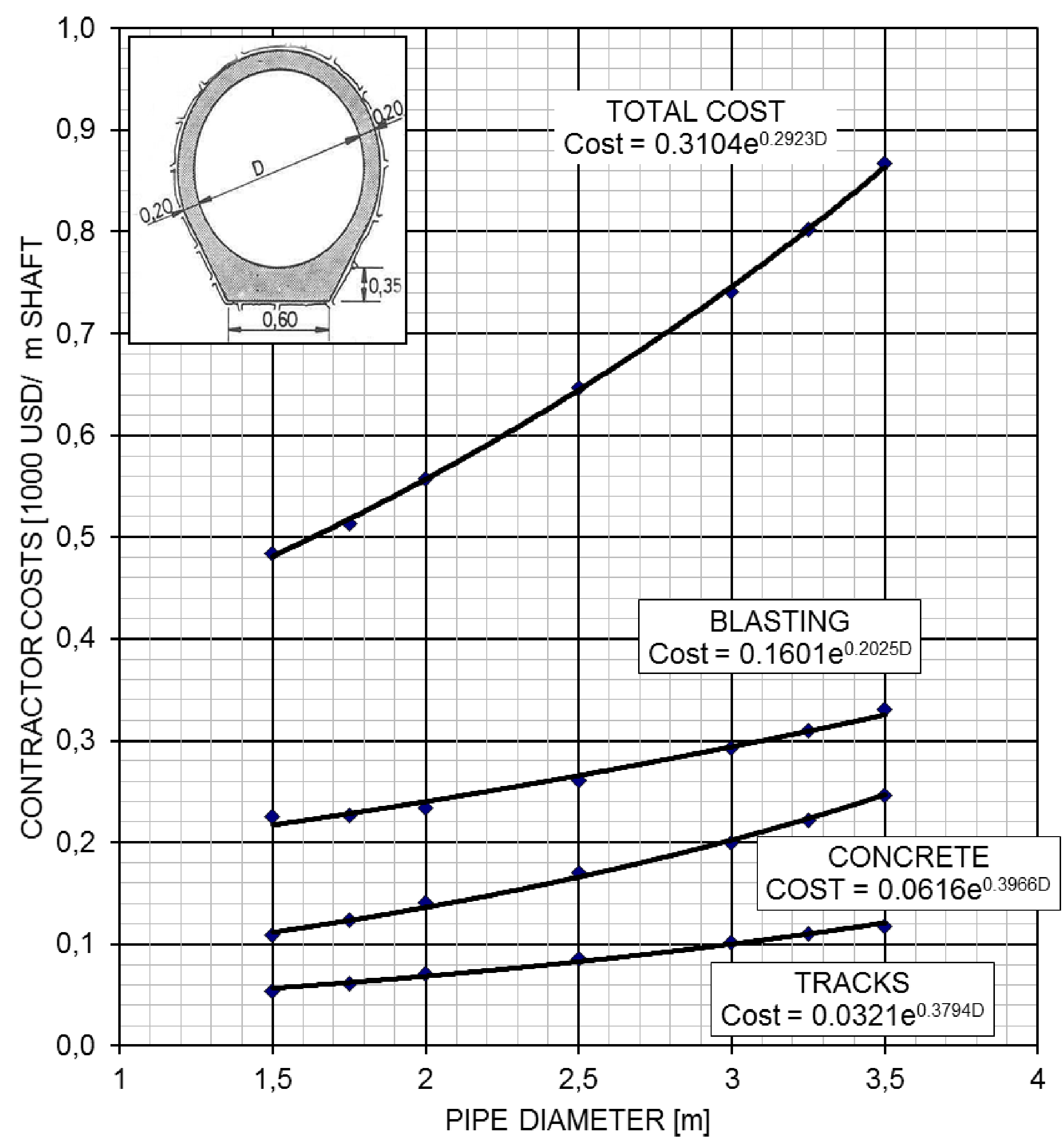
2. Assumed rock of medium drillability and blastability.

3. Assumed shaft length L=400 m Approximately 5% higher rm price if L = 150 or 700 m.

4. Rock protection work is incl. as 20% for smaller cross-sections to 35% for larger cross-sections.

5. Misc. and contingency costs of 10% have been included.

Norwegian Water Resources and Energy Directorate NVE	**BLASTED SHAFT CONTRACTOR COSTS**	Fig. 2.7.1 01.01.15



COMMENTS:

1. Price level January 2015.
2. The cost curve comprises all contractor costs for building related work. Blasting, concret and track costs are specified without their share of joint expenses and misc. and contingency costs.
3. Assumed rock of medium drillability and blastability.
4. Assumed shaft length = 400m. Approximately 5% higher m-price if L=150 m or 700 m.
5. Rock protection work included as 15% of costs.
6. The costs curve do not comprise cone costs; available in separate figure. Other elements must be cost calculated on an individual basis.
7. Misc. and contingency costs of 10% have been included.

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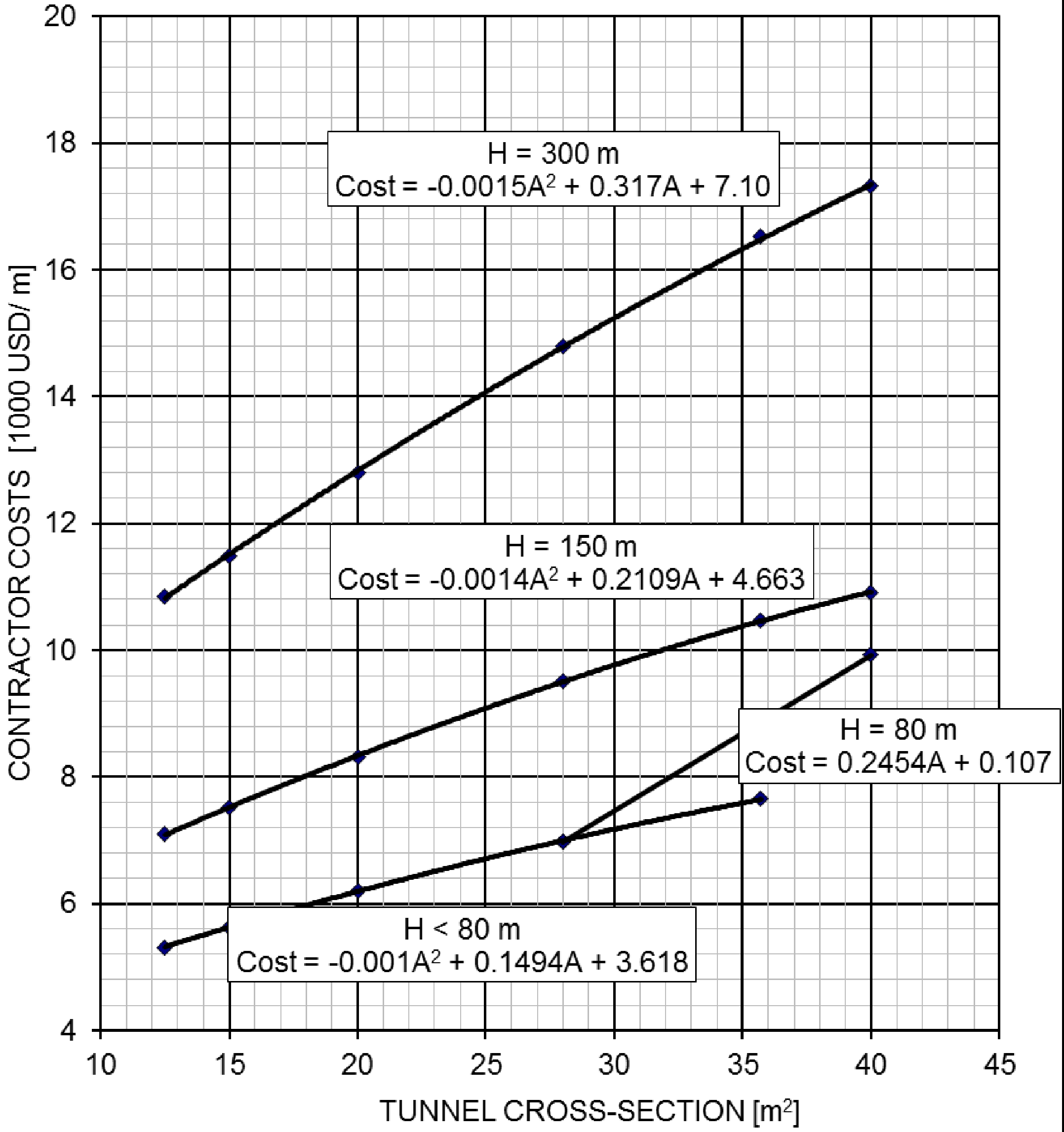
STEEL - LINED PRESSURE SHAFT CONTRACTOR COSTS

Fig. 2.7.2
01.01.15



COMMENTS :

1. Price level January 2015
2. The cost curve includes all contractor costs for building related work to pressure shaft intake cones
3. The cost curves do not include blasting work in the cone area.
4. The costs do not include any branching/ branch pipes.
5. The curve for H=80 m is broken due to a set max. cross-section change in the cone.
6. H indicates the water pressure in meters.

Pipe cross section estimated as approximately 1/4 of the tunnel cross - section. Cone assumed to be made of concrete, but can also be made of steel. The cost curve applies even if the pipe downstream the cone is in the open. The curve may also be applied to gate sealing in the tunnels unless more detailed calculations are conducted. Also compare with Fig. 2.5.2

Norwegian Water Resources and Energy Directorate (NVE)	**INLET CONES CONTRACTOR COSTS**	Fig. 2.7.3 01.01.15

2.9 DRILLED SHAFTS

2.9.1 GENERAL

Contractor costs for a shaft drilled using a pilot hole and reaming comprise of:

- Transport of equipment
- Rigging up and taking down necessary equipment as well as rig operations (including accommodation for personnel and workshop)
- Drilling costs
- Loading and transport of cuttings
- Joint expenses (central administration, profit, etc.)

As for full-face tunnel drilling costs, costs relating to drilling of shafts with pilot holes and reaming are highly dependent on rock conditions. For the pilot hole/reaming the main factor is the drillability of the rock, but the degree of fracturing is also important. To ensure that the cost calculations are as accurate as possible, it is important to be familiar with the rock conditions at the site where the drilling is to take place, or conduct relevant engineering-geological surveys.

In addition to the rock conditions, the cost of a shaft drilled by using a pilot hole and reaming depends on the cross-section of the shaft and its length and inclination (if inclination is less than 45º), as well as the location of the worksite. In principle, the method is intended for smaller cross-sections, in practice up to a diameter of 3.1 m, and the length should not exceed 500-600 metres.

If more accuracy is required, it may be necessary to steer the pilot hole, though this is more expensive. One method is to drill the hole first and then log it to find the exact location. The driving of the connecting tunnel is then directed towards the hole.

2.9.2 COST CURVE

The cost curve for the pilot hole/reaming is presented as a function of the shaft's cross-section and the drillability of the rock. It was further assumed a shaft length of minimum 150 m, and that the shaft has an inclination of between 45º and 90º. Corrections for the shaft length have been given in a separate figure. For shafts with an inclination of from

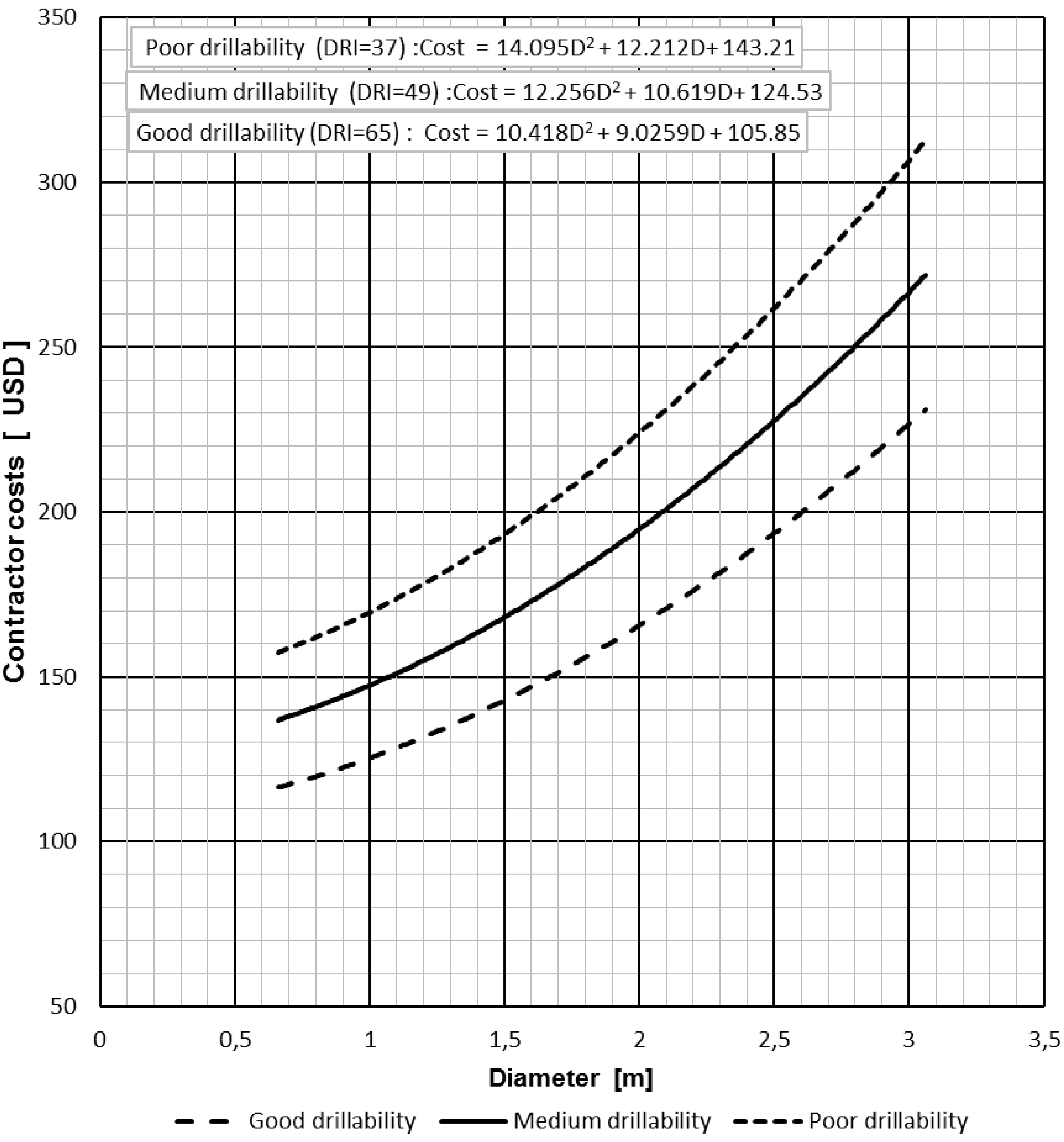
45º down to 0º, one can expect a steady cost increase of up to 30%.

Unforeseen costs have not been included. However, one should expect these to be substantial as there is a tendency for quite a few unforeseen costs will occur both with the drilling operation itself and as a result of the worksites often being difficult to access and exposed in inclement weather.

Potential road construction or helicopter transport costs that may occur relating to shaft drilling have not been included. If the worksite is particularly difficult to access thus incurring high rigging and transportation costs, these costs should be increased somewhat.

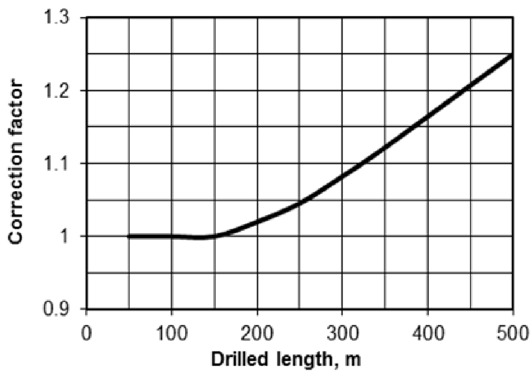
2.9.3 UNCERTAINTY

Uncertainty in the cost estimate based on this material will depend on how well one knows the rock conditions at the site in question. The cost estimate should normally be within $\pm$ 30%.



COMMENTS:

1. Price level January 2015
2. Assumed shaft length: min 150 m and shaft inclination: 45°-90°. Correction for shafts with an inclination of < 5°: gradually increasing to +30% for an inclination of 0°
3. Transport (road) is included. For drilling operations without road access, the price may increase by up to 100%.
4. The cost of large holes includes the price for both pilot hole and reaming.



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DRILLED SHAFT (PILOT HOLE / REAMING) CONTRACTOR COSTS

Fig. 2.8.1
01.01.15

2.10 PENSTOCKS

2.10.1 GENERAL

Penstocks are installed either on the surface or underground. Penstocks in tunnels can be laid in the same way as surface penstocks, or be buried/embedded. Surface penstocks are installed on support cradles/sliding saddles, with concrete anchor blocks at the penstock bends (traditional penstock). Underground penstocks are installed with the necessary surrounding filling material and concrete anchor blocks at the bends. When installing a penstock in/on rock, parts of the anchoring can be done using penstock rings.

The most commonly used pipe types are steel pipes, glass-fibre reinforced, unsaturated polyester pipes (GRP pipes), polyethylene pipes (PE pipes) and ductile cast-iron pipes. The cost of these pipe types are specified in Chapter 4.7. Wooden pipes and concrete pipes are also used in some cases. GRP pipes and ductile cast-iron pipes in particular can be installed underground, if the local conditions are favourable. An interesting alternative to penstocks may be shafts drilled into the rocks with open pipes in tunnels for the last section upstream of the power station, cf. Chapter 2.9 for drilled shafts.

The costs of building-related work in relating to penstocks are largely dependent on the ground conditions (hilly or flat terrain, rock or uncompacted material foundations, and, if relevant, the load capacity of the uncompacted material), and on whether a road is constructed to both the bottom and top of the penstock. As such it is pointed out that the costs obtained by using this method are purely indicative, and that the costs are contingent on favourable local conditions.

The penstock costs can be divided into three main groups:

1. Supplier costs

   Available in Chapter 4.7.

2. Contractor costs (building-related work)

   Clearance, removal of material, blasting in pipe route and trolley ways. If necessary, use of trolley way with windlass and trolley, windlass operator. Anchor blocks and foundations for support cradles/sliding saddles, scaffolding. Assistance in connection with loading/unloading and pipe handling during pipe installation. Local transport at the site.

   Approximate contractor expenses for surface penstocks are available in Figure 2.9.1.

   Approximate contractor expenses for penstocks in a tunnel are available in Figure 2.9.2.

   Costs relating to trenches for embedded pipes are available in Chapter 2.10.

3. Builder costs

   Estimated separately.

2.10.1.1 TRADITIONAL PENSTOCKS

Rough cost estimates have been prepared for the building-related penstock work. These have been based on the following simplified assumptions:

1. Route clearance: 1.1 USD/rm for a small/large pipe.

2. Removal of material: 0.5 m depth as an average in the route section.

3. Blasting: 0.5 m depth as an average in the route section (may not be sufficient if the terrain is hilly).

4. Distance between support cradles/sliding saddles: 12 m

5. Distance between anchor blocks: average of 90 m (which is far if the terrain is hilly).

6. Anchor blocks: 40 m^3/each for a small pipe and 80 m^3/each for a large pipe as average size.

7. Unit prices

- Removal of material	1.5 USD/m^3
- Blasting	4.4 USD/m^3
- Formwork	10.4 USD/m^2
- Reinforcement	633 USD/tonne
- Concrete	70 USD/m^3

The following will be additional:

- Transport in the route:

  For adverse terrain conditions a 50% higher rm price should be expected

- Miscellaneous and unforeseen: 15%

Costs for <u>building-related work</u> (contractor costs) are stated in the cost curve for average pipe diameters in USD/m run.

The price per meter run multiplied with pipe length give the estimated expenses including miscellaneous, unforeseen costs for a pipe route with relatively favourable ground conditions. For very hilly terrain, or if much of the route runs through uncompacted material, an estimate of an additional 50% should be added to the costs found by using the cost curves.
The prices are as of January 2015.

Cost calculation uncertainty is + 60% to - 40%.

2.10.2 TRENCHES

Cost tables for earth trenches, rock trenches and combined earth/rock trenches are prepared for cost calculations of embedded pipes. The tables apply to pipe trenches in a relatively easy terrain.

GRP pipes and ductile cast-iron pipes are most suitable for embedding. Polyethylene and concrete pipes may also be embedded, but only at low pressures and in easy terrain.

An illustration of a typical trench cross-section is included below:

(text in illustration – clockwise: Backfill of local material, surrounding filling material depending on the type of pipe, foundation material, pipe)

The inclination of the trench slope has been set at 1:1 for earth trenches and 5:1 for rock trenches. The trench's bottom width has been set as the pipe diameter plus 1.0 m.

For cost calculations of embedded pipes, the cost figures for earth and rock trenches, as well as combined earth/rock trenches are provided.

The costs in the tables comprise all contractor costs relating to digging, blasting and backfilling from 30 cm above the pipe. Costs relating to reinforcement/shore up of the trenches and anchor blocks have not been included.

Filling material surrounding the pipes has been included in the prices, based on the use of local material. If it is not possible to use local materials, approximately 3 USD/m^3 must be added for delivery of the surrounding filling material.

The costs of any temporary roads which must be built for the digging of trenches and installation of pipes, have not been included in the price, but must be calculated separately. Such costs might be considerable, especially if the terrain is steeper than 1:5.

Costs for combined earth/rock trenches are set as equal to the cost of rock trenches.

A terrain profile and a thorough assessment of the local conditions will be necessary in order to calculate the cost of pipe trenches. Rugged or steep terrain, as well as difficult access, will greatly influence the total costs. If the terrain is particularly difficult, the costs could easily rise by 50%.

Uncertainty in the cost indications for relatively easy terrains can be estimated at $\pm$ 30%.

The following unit prices have been applied:

- Removal of vegetation	1.1 USD/m^2
- Digging	1.1 USD/m^3
- Rock removal/scaling	2.0 USD/m^2
- Blasting	12,0 USD/m^3
- Surrounding filling material	3.6 USD/m^3
- Backfilling	2.8 USD/m^3

Table Trench costs (USD/rm). Trench width is 1.5 m at the bottom.

Total trench depth	1.5 m	2.0 m	3.0 m	4.0 m
Earth trench	30	40	70	110
Rock trench or combined earth/rock trench	40	55	85	120

Table Trench costs (USD/rm). Trench width is 2.5 m at the bottom.

Total trench depth	1.5 m	2.0 m	3.0 m	4.0 m
Earth trench	35	50	85	130
Rock trench or combined earth/rock trench	60	80	120	170

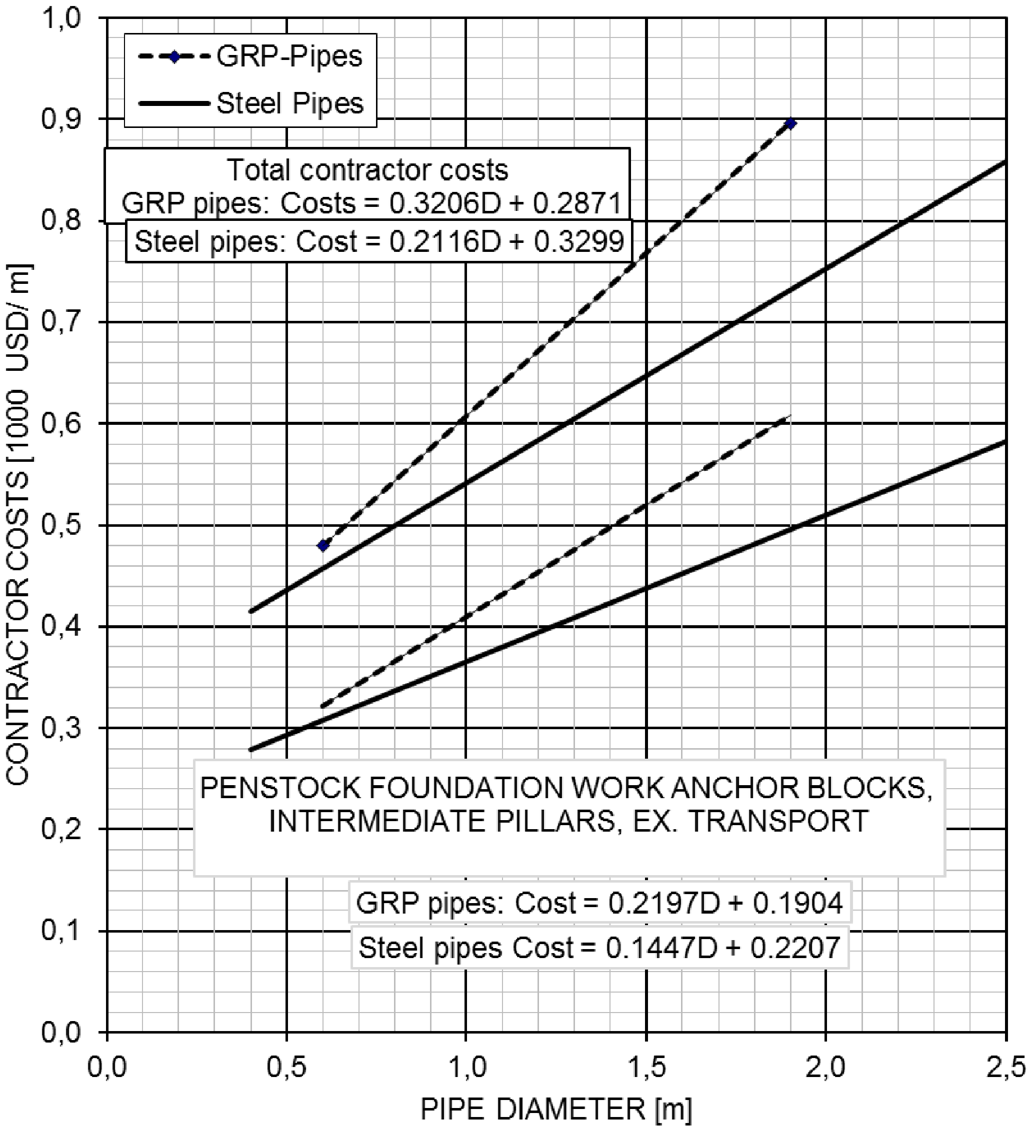
2.10.3 PENSTOCKS IN TUNNELS

Building engineering costs for pipes in tunnels have been included in Figure 2.9.2.

In the figure the same price basis has been used as in 2.9.2; traditional penstocks.

For GRP pipes supports have been included at every 6 m, whereas for steel pipes supports have been included every 6 to 12 m depending of the pipe diameter. Simple scaling of the bottom of the tunnel has been included, as well as construction of a path/roadway on one side of the pipe. A simple drainage trench has also been included for one of the tunnel sides. The tunnel itself and tunnel securing have not been included, nor has a plug in the tunnel where the pipe starts. See Figure 2.5.2, cross cut plugs.

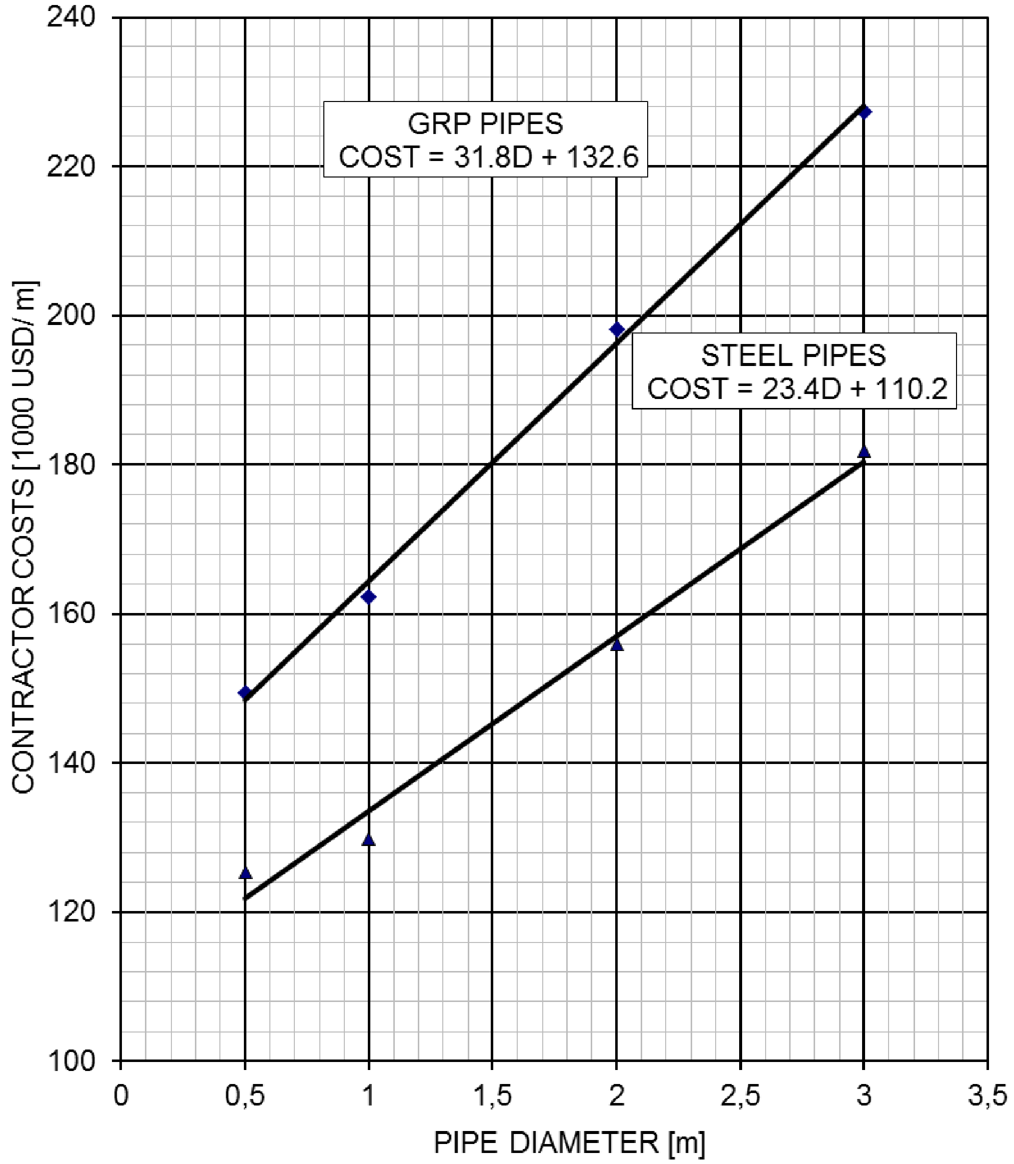
It was assumed that the pipe is installed tangentially in the tunnel. For small diameter pipes it will be possible to arrange bend force support without a significant increase in costs. For large pipes an addition should be added for directional changes.



COMMENTS:

1. Price level January 2015
2. Digging and blasting estimated at 0.5 m average. The distance between sliding saddles/ intermediate saddles 6->12 m (GRP->steel) and anchor blocks 90 m. Local conditions may cause considerable deviations.
3. Transport costs in the route estimated at 50% of unit costs. Local conditions may cause considerable deviations. The cost curve for total expenses includes transport costs.
4. The cost curve for foundation work anchor blocks and intermediate pillars includes miscellaneous, unforeseen and the contractor's joint expenses.
5. Anchor blocks amount to approximately 112 USD/m.
6. GRP pipes must only be used for low pressures. See limitations in Fig. 4.7.2

Norwegian Water Resources and Energy Directorate NVE	**SURFACE PENSTOCK CONTRACTOR COSTS CIVIL WORK**	Fig. 2.9.1 01.01.15



COMMENTS:

1. Price level January 2015.

2. The cost curve shows the contractor costs for pipes laid open in a tunnel. Blocks, crushed stone on the floor and walkway incl.

3. For GPR pipes a 6 m c/c support has been calculated.

4. For steel pipes a 6-12 m c/c support has been calculated depending of the diameter of the pipe.

5. The cost curve does not include the tunnel, tunnel protection or floor scaling.

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PENSTOCK IN TUNNEL CONTRACTORS COSTS CIVIL WORK

Fig. 2.9.2
01.01.15

2.11 UNDERGROUND POWER STATIONS. POWER STATION AREA

2.11.1 GENERAL

Building related construction costs in the power station area for underground installations comprise:

- Access tunnel with roadway and if necessary a cable channel, as well as any portal buildings.
- Tailrace tunnel (U tunnel) with any surge chambers
- Transformer chamber, if any
- Cable shaft/cable tunnel, if any
- Any auxiliary tunnels for blasting of station hall and tailrace tunnel. (Auxiliary tunnel for driving of pressure shaft/pressure tunnel has been included in the cost calculations for the pressure shaft).
- Power station
- Switching station/switchgear (outdoor area)
- Any separate buildings for control system/workshop/operations centre/administration

This chapter provides a basis for calculating the costs of the power station itself and the access tunnel.

Other cost elements such as the tailrace tunnel and auxiliary tunnels for the blasting must be calculated separately. Auxiliary tunnels and ramps, which are mainly located in the station hall, have been included in the costs specified in this chapter.

For electro/mechanical equipment please see separate sections in Chapters 3 and 4.

2.11.2 POWER STATION

The purpose of this chapter is to provide a simple method for quick estimates of foreseeable construction costs relating to underground power stations.

The method that has been used has been briefly explained below. It is based on simplified assumptions which again are based on a relatively rough analysis of a number of high pressure underground power stations that have been built.

It is emphasised that the results are rough estimates only, and that the costs of a completed installation might vary considerably from the cost estimate made at the preliminary stage by applying this tool. There are several reasons for this. However, this will not be discussed in any more detail in this report.

2.11.2.1 BASIS, ASSUMPTIONS FOR NEW POWER PLANTS

In principle, it has been chosen to link the construction costs (building-related work) to the blasted volume in the power stations. Based on a more detailed review of a limited number of power stations, simplified cost calculations based on the following assessed assumptions and prices has been conducted.

- Blasting: average unit price: 4.4 USD/m^3
- Concrete volume = 20% of the blasted volume: 52 USD/m^3
- Reinforcement: 60 kg/m^3 concrete: 633 USD/tonne
- Formwork: 2.1 m^2/m^3 concrete: 10.4 USD/m^2
- Securing work (rock): 15% of blasting costs.
- Masonry and plastering work: 5% of the blasting and concreting costs.
- Interior work (flooring, painting, steel, glass, etc.): 15% of the blasting and concreting costs.
- Unforeseen: 10% of the above costs.
- Electrical installations, lighting, heating, etc.: USD 20000 – 100000 for a medium-sized plant.

2.11.2.2 Heating, Ventilation and Air Conditioning

Introduction

HVAC implies: Heating, Ventilation and Air Conditioning. Sanitary installations includes interior sanitary installations. VA implies Water and Wastewater (exterior installations).

Conditions that influence ventilation costs are listed below.

1. Size / Volume

Airflow for ventilation are proportional to the floor area and/or volume of the power station.

2. Heat Dissipation from Electrical. Components

Removal of excess heat from electrical and mechanical equipment are design parameters for airflow and consequently the size of the ventilation system. If heat load in the room is large enough that air cooling requires disproportionately large airflows, local cooling by additional cooling equipment (fan coils), must be installed. Local cooling is based mostly on chillers that obtain water from the main cooling system of the power plant. This installation generates extra costs, but also makes it possible to reduce the extent of the ventilation system. The ventilation system can then be designed for normal ventilation volume, and all components, batteries, fans etc., will need lower capacity.

4. Fire Sectioning

To prevent the spread of fire, it is sufficient to fire insulate ducts on both sides of the fire partition. This is beneficial in terms of cost. Smoke dampers should be installed if preventing the spread of smoke is deemed important. This also requires electrical connection to the fire alarm panel.

5. Length of access tunnel

Installation of the main air intake duct through the access tunnel gives the following benefits:

- Supply of fresh air to the plant without pollution from traffic in the access tunnel

- Better control of temperature and humidity of the supply air (due to water ingress in the tunnel)

- Possibility for venting the access tunnel during evacuation.

Length of the access tunnel is decisive for the cost of such a duct.

6. Venting of transformer cells

Transformer compartment must be shockproof, and normally requires shock dampers in the ventilation openings. By oil-filled transformers, which are water cooled, transformer temperature is independent of ambient temperature. If one allows high temperature in the transformer room, the required ventilation cooling airflow is reduced. As such one can avoid having to install shock dampers, resulting in reduced costs associated with ventilation / cooling.

7. Automation of the plant

Experience indicates that automation cost of HVAC plants have become significantly more expensive in recent years. Control of the ventilation and cooling systems have become more and more complicated in order to meet the requirements for ambient temperature and humidity for electrical components. Many electrical components emit more and more heat, yet set strict limits to the ambient temperature. Exceeding this temperature limit makes the warranty void.

8. Cost Estimate construction

Normal ventilation rate in a power plant pr. hour is $4m^3$ / m^2.

• For hydroelectric power stations above ground, the typical cost for the ventilation system will be 20 USD / m^3/h treated ventilation air.

• For underground hydroelectric power stations the typical cost for the ventilation system will be 25 USD / m^3/h treated ventilation air.

At large heat dissipation from equipment in power station, costs will increase due to the need for local cooling.

The cost will typically be:

• For hydroelectric power stations above ground, typical cost for the ventilation system will be 25 USD / m^3 treated ventilation air.

• For underground hydroelectric power stations, typical cost for the ventilation system will be 35 USD / m^3 treated ventilation air

For hydroelectric power stations with Francis turbines ventilation duct in the access tunnel for fresh air supply to the power plant are used.

For hydroelectric power stations with Pelton turbines, fresh air via the outlet tunnel above the water without separate ventilation duct are used.

Cost for supply air duct is approximately 200 USD /meter run of tunnel, depending on size

The length of the access tunnel will therefore increase the cost to the ventilation system accordingly.

Typical total cost for ventilation and cooling systems in power plants are:

• Hydroelectric power stations above ground (smaller power plants); 0.1 – 0.4 MUSD

• Hydroelectric power stations under ground and larger power plants in the day; 0.4 – 1.0 MUSD

2.11.2.3 BASIS, ASSUMPTIONS FOR POWER PLANT EXPANSIONS

In relation to power plant capacity increases it may become relevant to expand the

power plant itself. It must for each individual case be assessed whether the operation of the existing plant can be shut down for a prolonged period of time.

Only a few power plants have been constructed with a provisions for future expansion and if so there is usually a ready blasted volume for allow for the increased number of turbines. Moreover, there will be very strict requirements for such expansions.

An extension of a power plant in operation without prior preparations will not be acceptable due to the tremors caused by the blasting operations, the dust and other inconveniences that will arise throughout the plant during the construction period. What should be considered in such a case is whether it is possible to construct a new plant via a new access tunnel, which could for instance be a branch of an existing access tunnel. Furthermore, it must be assessed whether mechanical equipment at existing plants would be able to sustain the tremors caused by the blasting operations, and the blasting work must be planned in accordance with the tremor requirements. The costs are calculated as for a new plant with the exception of blasting work, which is calculated using an average blasting price of 6.0 – 7.5 USD/m^3.

2.11.2.4 VOLUME AND BLASTING REQUIREMENTS

The required volume in a power station depends on a number of parameters which are partly objective (based on technical issues) and partly subjective (based on the builder’s wishes, opinions of the planner, etc.). The volume requirement will probably also have changed over time.

In order to try and illustrate the connection between the number of power units and their size on the one hand, and the blasted volume in the power station for various types of turbines on the other hand, a correlation has been plotted for existing power stations in Figures 2.10.1, 2.10.2 and 2.10.3.

As can be seen in the diagrams, there are significant variations in the volume compared to the installation.

Despite the significant variations in volume it was ventured to express the space requirements in a simple formula using the net head, total maximum rate of flow for the plant and the number of power units as parameters.

An estimate of the blasted volume for underground power stations can be obtained by applying the following formula:

Blasted volume $V = 78 \times H^{0.5} \times Q^{0.7} \times n^{0.1}$

V = blasted volume, m^3

H = net head, m

Q = total maximum rate of flow, m^3/s

n = number of power units

Estimates obtained by applying this formula will be highly approximate. Therefore it is recommended that an arrangement is drawn up for each plant and used as a basis to calculate the blasted volume.

2.11.2.5 FORESEEABLE CONSTRUCTION COSTS

A rough estimate of foreseeable construction costs (building contractor) excluding builder's expenses for an underground power station can be obtained by following the points below in the proper order:

1. Calculate the station's installation [N = 8.5 x Q x Hn (kW)] and choose the type and number of power units.
2. Pre-dimension the power station through a preliminary study in order to calculate the blasted volume. For an approximate estimate the blasted volume can be found by using the formula above.
3. The total unit price for the total building-related contractor costs can be set at 50 USD/m^3 for small power stations and 45 USD/m^3 for larger stations.

2.11.2.6 COST CALCULATION UNCERTAINTY

Cost estimate based on individual pre-project dimensioning and total unit price: -30% to +70%.

Cost estimate based on the given curves for volume and cost: -50% to +100%.

2.11.3 ACCESS TUNNELS

Access tunnels mainly consist of the tunnel itself with a continuous secured hanging wall, drivable cover, drainage, lighting, cable trench and any building-related installations for, for instance, ventilation.

The cross-section of the access tunnel will vary considerably. The absolute minimum cross-section can be assumed to be 18 m^2, but normally the cross-section will be in the region of 30-40 m^2. It will be the size of the mechanical equipment that is to be installed in the power station which will govern the tunnel cross-section. For Francis turbines it is normally the transformer which will determine the height of the tunnel. Likewise, the turbine drum will determine the permanent width of the access tunnel.

The portal or entry to the power station will vary both in size and general design. The portal could, for instance, be constructed together with other building-related functions such as offices, meeting rooms, changing rooms, showers, cleaning system, etc. The portal has not been included in the cost curves in Figure 2.10.4.

Ventilation for the power station can be planned either through a potential escape shaft/cable shaft or in together with the access tunnel. For the latter solution there are several options. A combined solution together with, for instance, cables routing is one relevant option. Another alternative is a simple installation of ventilation pipes on the hanging wall. Ventilation costs vary considerably, depending on the choice of (requirement for) solution, and have thus not been included in the cost curves.

There is often a protected walkable cable culvert. An approximately 3 m high and 1.5 – 2 m wide culvert can roughly be estimated at approx. 300 USD/m run. The walkable culvert will not only ensure that there are two separate accesses to the plant, but can also be used for ventilation.

Cables are often laid in cable culverts as a pavement in the access tunnel. This is a simpler and cheaper solution which can be estimated at roughly 80 USD/m run. The power cables and other conductive cables are laid in the channel, whereas signal cables are laid on a cable bridge on the hanging wall or along a wall. In addition, communication cables for the escape room and any other emergency communication systems will normally be laid in a separate cable conduit.

Figure 2.10.4 shows a rough schematic cost curve for access tunnels. It is important to note the curve is approximate, and largely dependent on the finishing of the access tunnel. There is one curve for the price in total and tunnel driving for moderate upward gradients and one curve showing the total price of tunnel driving for moderate downward gradients (incline less than 1:10). An additional cost of 4.2% of the basic price has been added to the cost curve for downward gradients. The following assumptions apply to the cost curves:

1. *Basic price*

a) Tunnel length 3 km (correction for deviations from figure)
b) Contour blasting, distance between holes 0.7 m.
c) Transport length total 600 m from the mouth of the tunnel to the tip.
d) Medium blastability and drillability (DRI = 49). Correction for rock which is difficult to blast or drill in, maximum 5% for smaller cross-sections, 10% for larger cross-sections.

e) The tunnel is driven at a moderate upward gradient ($3 – 6^0/_{00}$). Correction for driving at moderate downward gradients and minor water breakthrough has been set at 5%.

2. Tunnel securing

Tunnel securing will be divided between working face securing and face backup securing and will consist of extra scaling, bolting, sprayed concrete and pouring of concrete. Additional securing costs have been estimated as 35% of the basic price for smaller tunnel cross-sections and 50% of the basic price for larger tunnel cross-sections as these tunnels will be secured using sprayed concrete all the way. This reflects normal to favourable conditions.

3. Lighting

The cost of lighting fixtures and other installations has been estimated at 4.8 USD/rm tunnel. This provides a very simple but fully acceptable solution.

4. Driving surface

A fully built-up drivable asphalted surface has been included in the costs curves with 14 USD/rm.

5. Drainage

A double-sided drainage trench with drain pipe has been included in the cost curves with 13 USD/rm for both sides.

6. Miscellaneous, unforeseen

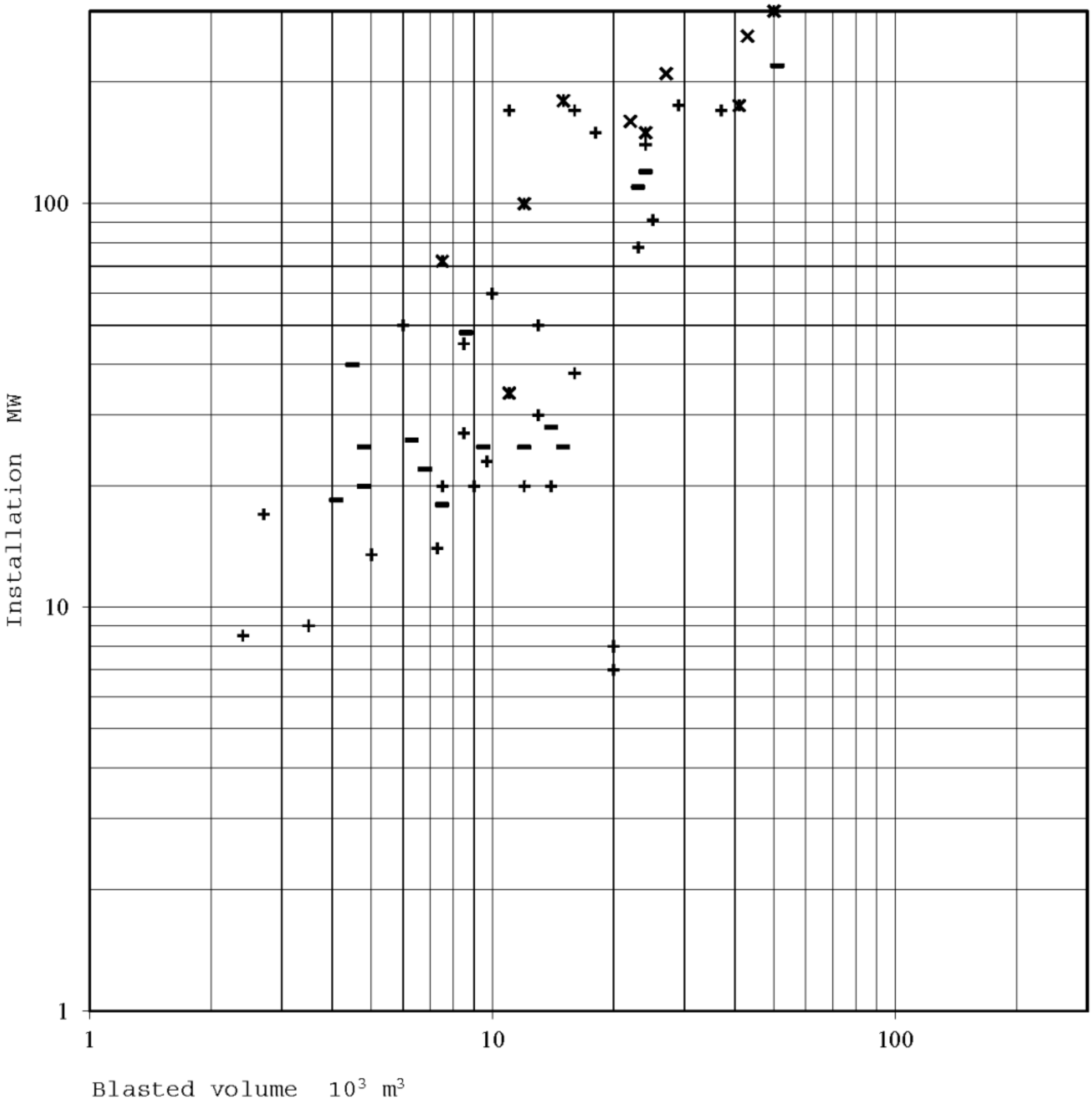
Included in the cost curves with 10% of the basic price + securing work (1 + 2).

7. Uncertainty

Cost uncertainty has been set as ± 30%.

8. Price level

The costs have been given as of January 2015.



COMMENTS:
- 1 power unit
+ 2 power units
* 3 power units
x 4 power units

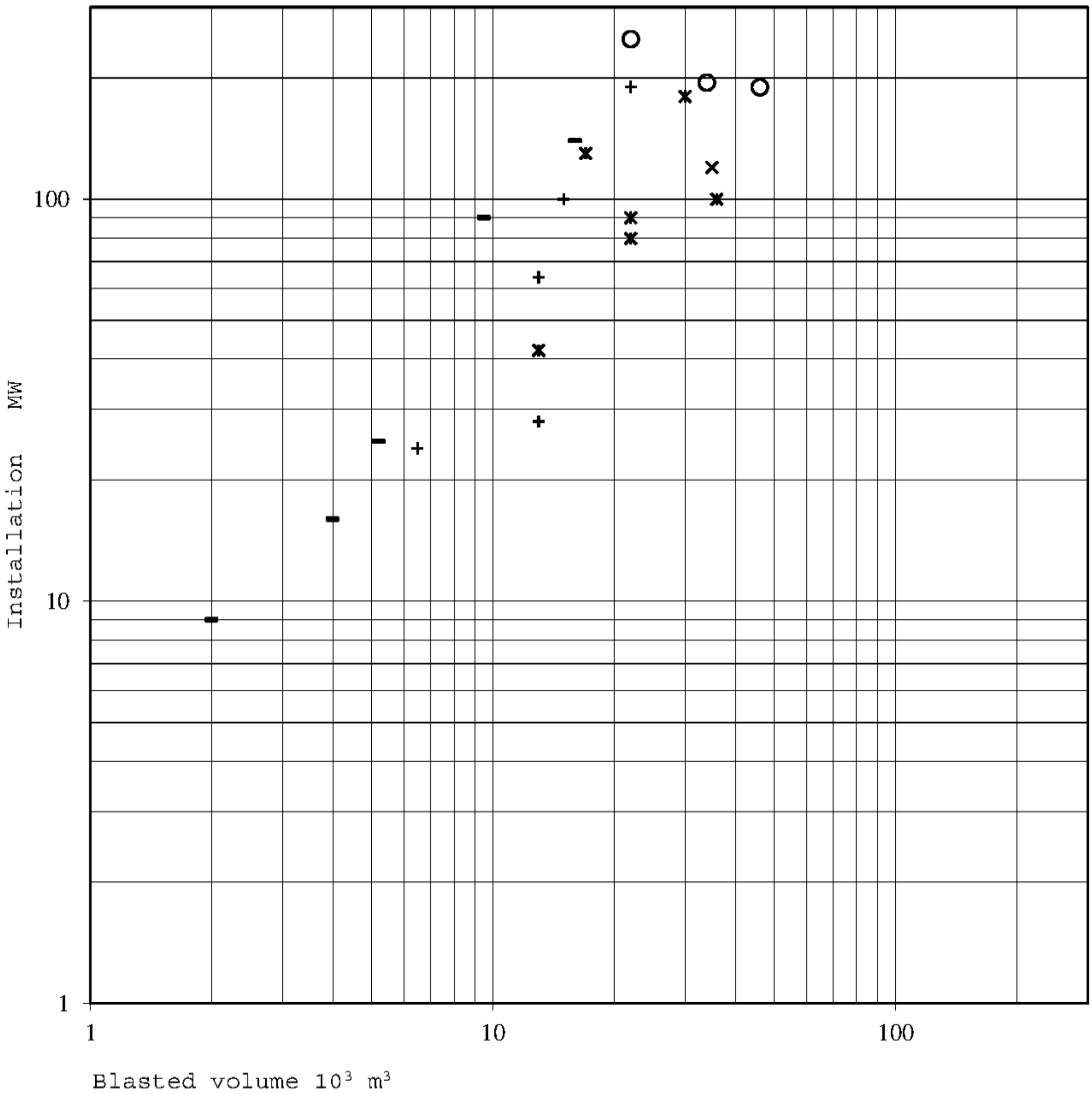
1. Underground power station

FRANCIS POWER

UNIT BLASTED VOLUME VERSUS PERFORMANCE

Fig. 2.10.1

01.01.15



COMMENTS:
- 1 power unit
+ 2 power units
* 3 power units
x 4 power units
o over 4 power units

1. Underground power station

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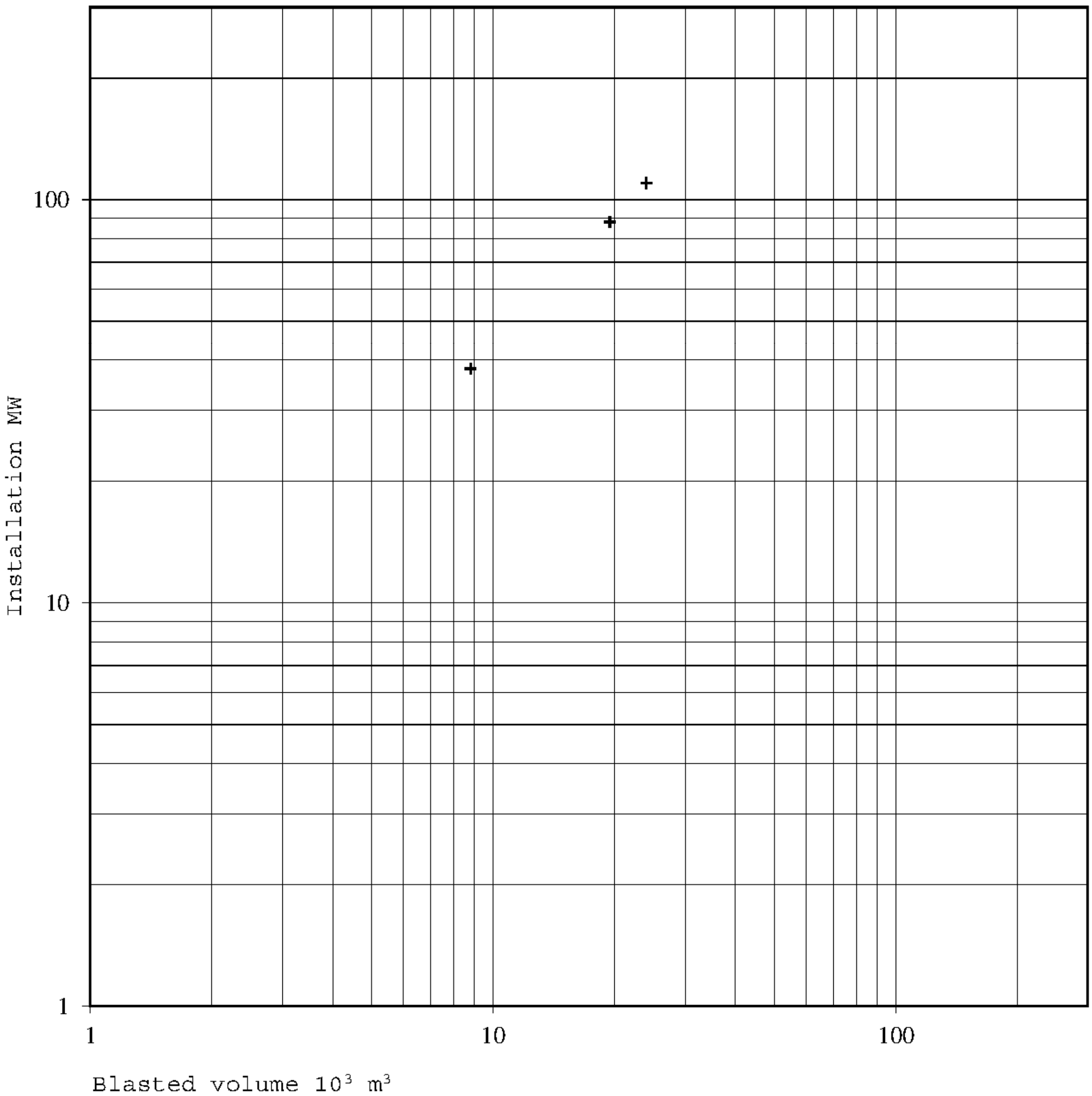
PELTON POWER UNIT

BLASTED VOLUME
VERSUS PERFORMANCE

Fig. 2.10.2

01.01.15



COMMENTS:

+ 2 power units

1. Underground power station

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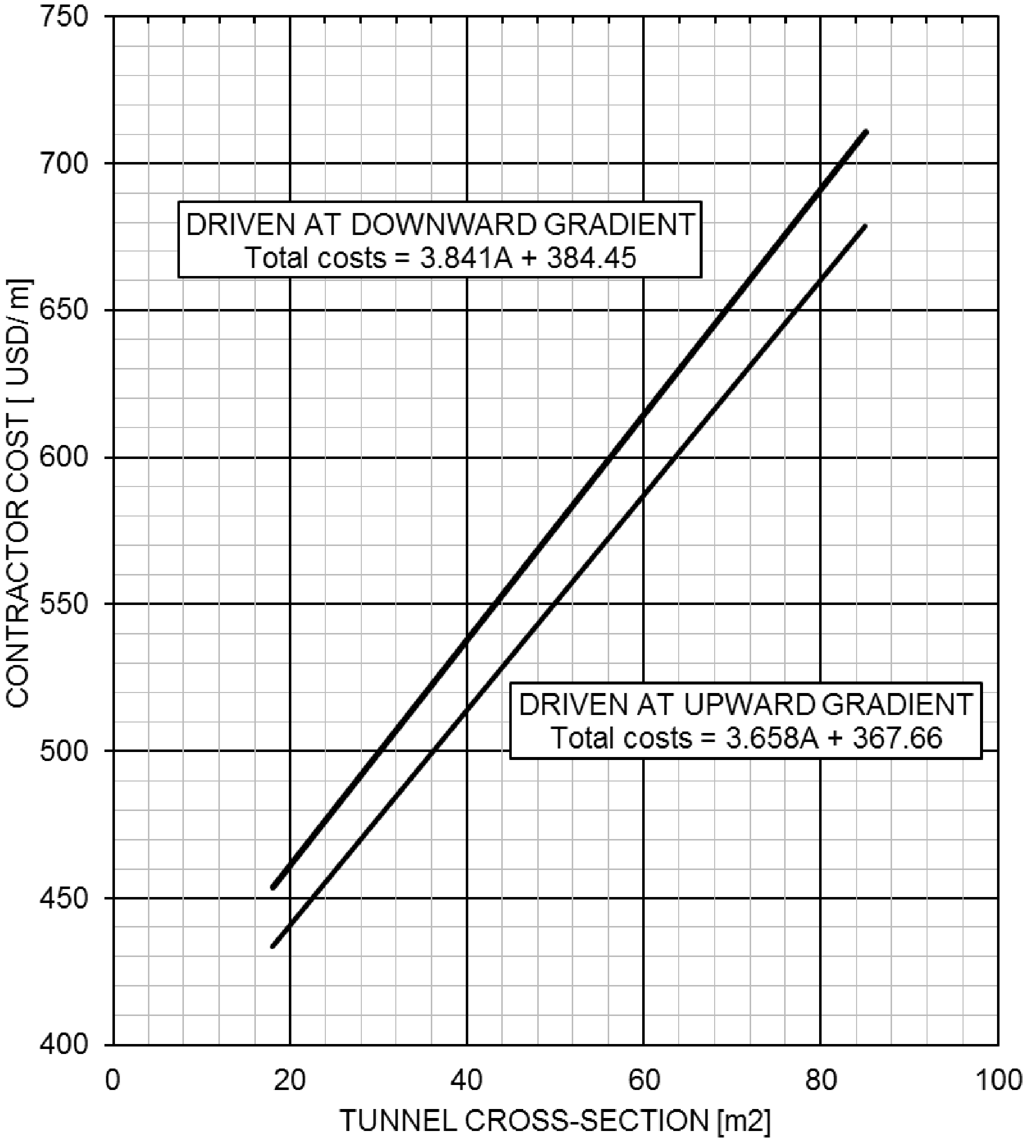
KAPLAN POWER UNIT
BLASTED VOLUME
VERSUS PERFORMANCE

Fig. 2.10.3

01.01.15



COMMENTS:

1. Price level January 2015
2. Assumed rock of medium drillability.
3. Distance to portal tip: 600 m
4. Protection work included (shortcrete all along).
5. Miscellaneous and unforeseen costs are included as 10% of the basic price and securing.
6. Concrete cable channel laid as pavement has been included with 70 USD/rm.
7. Any additions for walkable protected cable and ventilation culvert will cost roughly 240 USD/rm.

Norwegian Water Resources and Energy Directorate NVE	**ACCESS TUNNEL AND CABLE CULVERT CONTRACTOR COSTS**	Fig. 2.10.4 01.01.15

2.12 SURFACE POWER STATIONS

2.12.1 AVERAGE FORESEEABLE COSTS AND UNCERTAINTY

This chapter provides a basis for calculating the average foreseeable costs for the building work for surface power stations.

Costs for surface power stations are mainly based on empirical data, but it must be pointed out that these data vary a greatly. This is because there are major differences between power stations, due to their location, size and the general quality of the buildings.

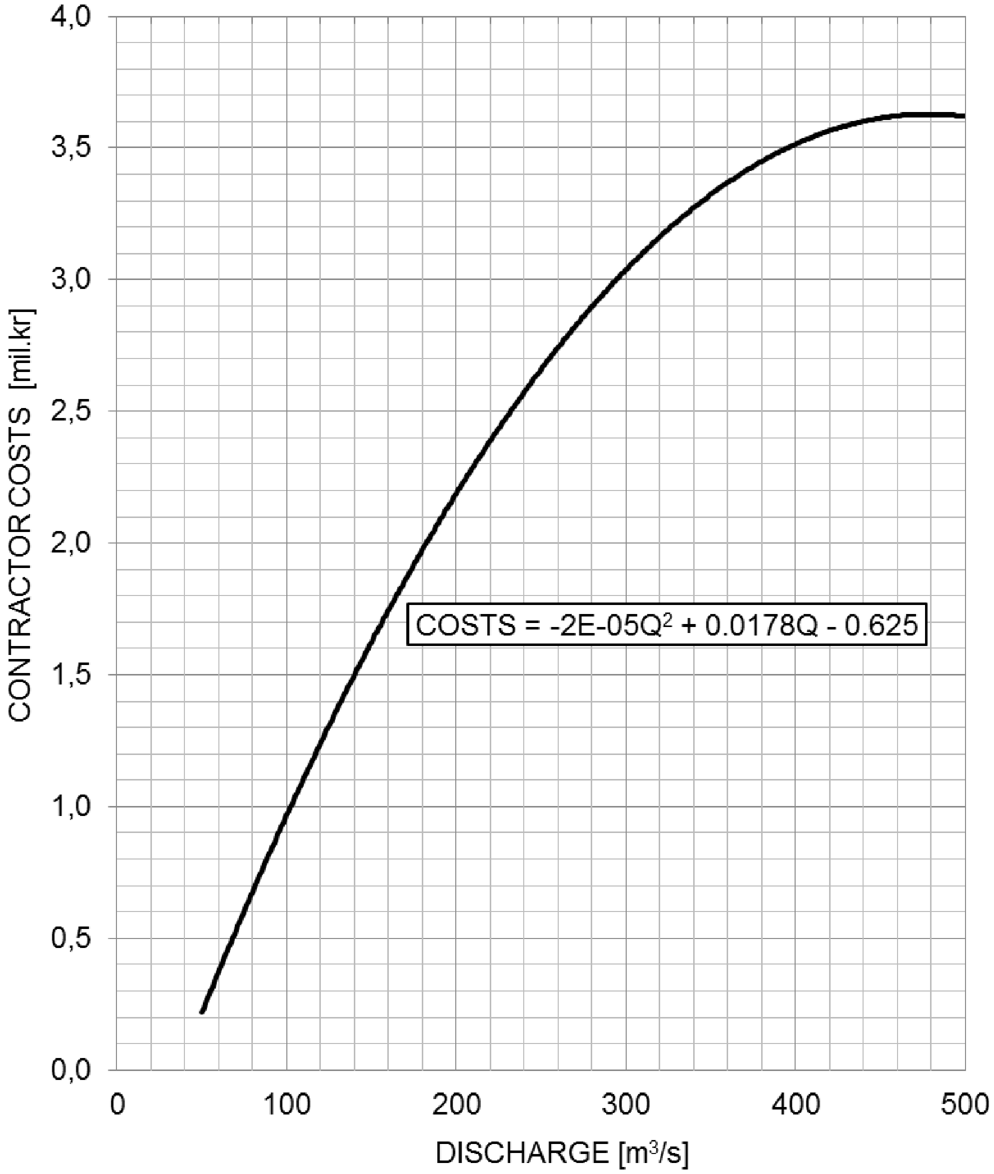
The cost curve in Fig. 2.11.1 is based on power stations with one Kaplan unit. The head will be between 10 and 30 m. The absorption capacity will be much more important for the costs than the output in MW, as the pressure does not matter much for the construction of the buildings. A short inlet and outlet channel has been included. Potential extra costs for coffer dams, dam constructions, etc. have not been included.

2.12.2 COST ELEMENTS

The price estimate covers the contractor's expenses for the building work.

In general, the following unit prices have been used in the calculation:

-	Transport of material	2.2 USD /m^3
-	Blasting, loading and transport	7.0 USD /m^3
-	Formwork	10.4 USD /m^2
-	Reinforcement	633 USD /m^3
-	Concrete	48 USD /m^3
-	Fixtures and fittings (of the above items)	20%



COMMENTS

1. Price level January 2015

2. Includes intake and concrete drum for vertical Kaplan turbine.

3. Presupposes::
   - Head of 15 - 40 m
   - 1 power unit
   - surface station
   - dam construction costs excl.

Norwegian Water Resources and Energy Directorate NVE	**SURFACE LOW PRESSURE PLANT CIVIL WORK**	Fig. 2.11.1 01.01.15

2.13 TRANSPORT FACILITIES

2.13.1 TEMPORARY ROADS

The costs of building temporary roads for construction purposes will vary greatly depending on the terrain.

As a guideline in estimating such costs, the following total costs for temporary roads (USD/m run) are included here:

	High standard	Low standard
Easy terrain	20	10
Normal terrain	30	20
Difficult terrain	60	30

Bridges are not included in these costs. The cost of a normal, small bridge (span up to 6 m) may be set at 500 USD m^2 roadway (decking).

Annual maintenance costs for temporary roads during operation of the plant can be set as 10% of the building costs.

The uncertainty in this cost estimate should be set to -50% to +100%.

2.13.2 ROAD TRANSPORT OF CONCRETE

The normal building costs include transport from the mixing plant to the pouring site, within a distance of 5 km.

2.13.3 HELIKOPTER TRANSPORT

2.13.3.1 General

Expenses for helicopter transport will vary with a number of different factors.

In the following both average costs and some key data are given, so that the calculation can take both into account where the construction situation is known in more detail.

The stated costs are total extra costs that incur because of the helicopter transport.

Table 2.13.1.A Helicopter transport of concrete. Average transport capacity

Distance in km (one way)	Transport volume m^3 concrete/hour	
	Helicopter with a load capacity of approx. 3 tonnes	Helicopter with a load capacity of approx. 1 tonne
1	12	6.5
5	7.5	3.1
10	4.0	1.7
15	3.0	1.3

Table 2.13.1.B Helicopter flight times

Round trip under normal transport conditions

Distance in km (one way)	Normal load (min.)	Concrete transport (min.)	Transport of barrack(s) (min.)
1	3	4	6
5	7	8	10

For longer distances, the flight time should be increased by 1 min/km.

An elevation difference of up to 15% of the distance is included in the table. For greater elevation differences the flight time can be estimated by adding 0.5 km to the distance per extra 100 m elevation.

2.13.3.2 Helicopter transport prices

Helicopters are used to transport materials as well as personnel. The price of using a helicopter is found by adding up the price for the return flight between the helicopter base and the starting point of the assignment, plus flights within the construction area. The speed of long-distance flights without any cargo can be set at 200 km/h. For transport of concrete the speed should be set at 60 km/h.

The price is stated in NOK per hour of effective flight time and is in principle the same for flights to the construction area and flights within this area. One might often be able to get a discount on the flight to the area.

A helicopter with a load capacity of 1 to 3 tonnes is normally used. The various companies offer different aircraft from different bases. Several helicopters are also offered that have a load capacity between those indicated here. The price per tonne is generally more or less the same regardless of which helicopter is chosen.

Work conducted with the use of a helicopter will normally be considerably more expensive. A distant location where both personnel and materials are transported by helicopter leads to high unit prices. The prices normally increase significantly more than the transport price quoted by the helicopter company.

We suggest that the following unit prices are used for such work:

- Formwork 16 USD/m^3
- Reinforcement 1,000 USD/tonne
- Concrete 180 USD/m^3
- Rigging and operation 30% in addition on the quantity items

Prices for just the helicopter transport as quoted by the helicopter company without the contractor's mark-up are given in the table below (for Norway).

Table 2.13.2.C Costs of helicopter hire

Type	Hire cost USD/hour of operation	Load capacity
Small helicopter	1,800	Approx. 1.0 tonne
Large helicopter	6,400	Approx. 3.0 tonnes

2.14 CHANNELS

2.14.1 GENERAL

Where tunnel operation is not practical, channels are normally used. Channels are rarely used to a large extent in Georgian power plants. Channels are used in rock, uncompacted materials and in combinations of rock and uncompacted materials.

The question of whether a channel might be a viable option will be decided by the channel's total depth from the terrain surface to the bottom. For channels in uncompacted materials where a conservative estimate for the channel slope would be an inclination of 1:2, the channel width would quickly become considerable if the channel is deep. In rocks where the sides will be steep (5:1), the depth will have little impact on the width. For channels in uncompacted materials the side slope may be tightened up, but this may increase the need for pitching.

For channels in uncompacted materials, the velocity of the water and need for pitching will affect the work. It was assumed a 0.5 m thick pitching of the entire channel, i.e. both the bottom and side slopes.

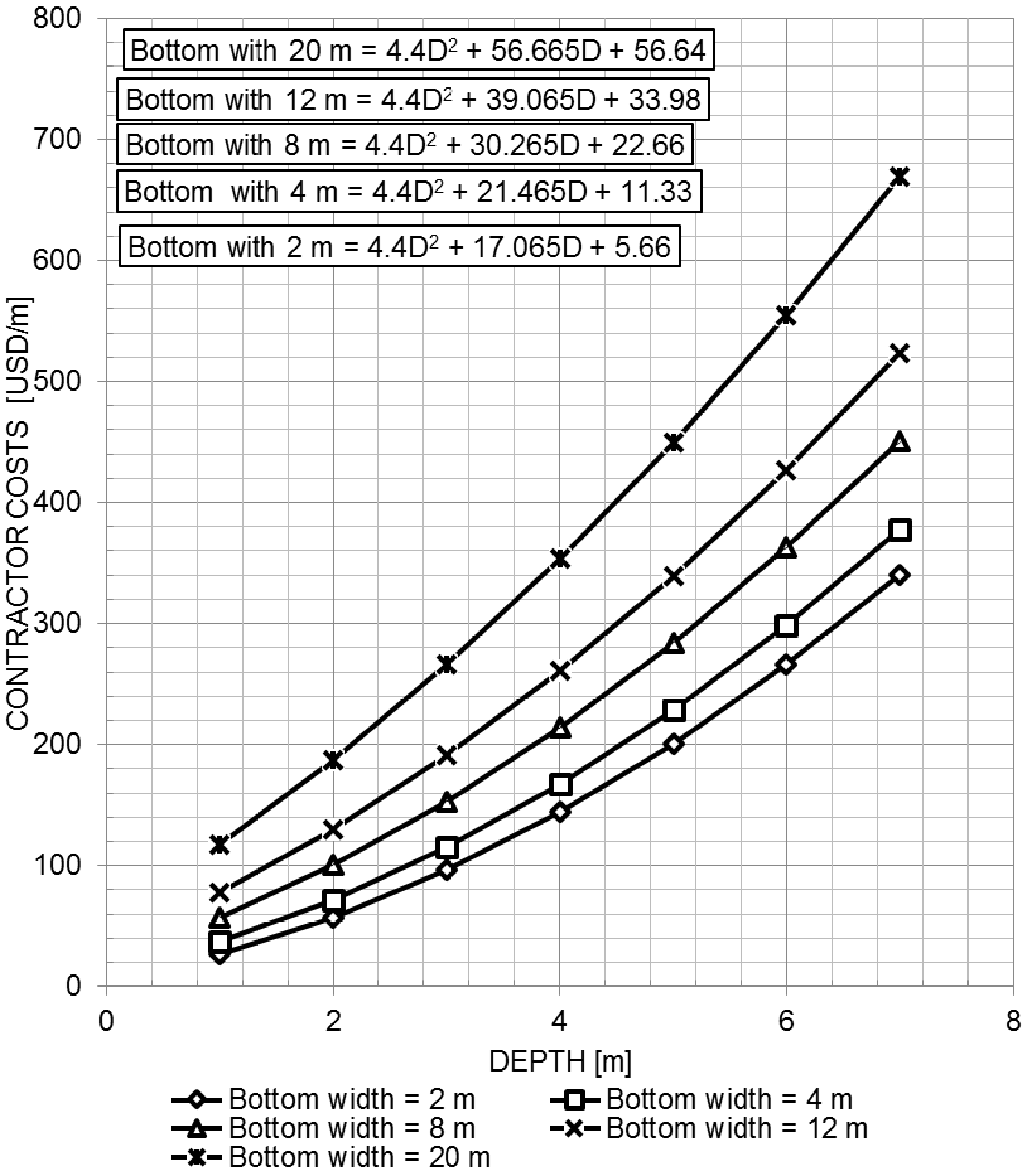
For channels in rock there is in practice no limitation regarding the velocity. On account of the head loss when the channel forms part of the waterway to a power plant, however, the channel should be dimensioned for a velocity in the range of 1.5-1.0 m/s.

The price of channels will largely depend on the size of the channel and whether the contractor is able to produce it efficiently with their equipment. The following prices are calculated for constructing a major channel system with a tip within reasonable proximity.

The following prices have been used:

- Transport of mass 2.2 USD/m^3
- Blasting, loading and transport 7.0 USD/m^3
- Pitching 3.2 USD/m^2

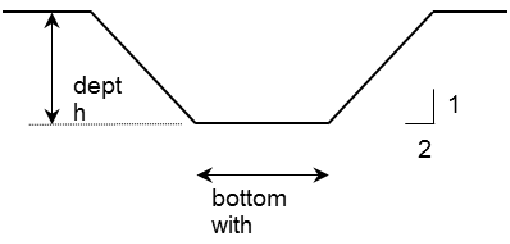
Figures 2.13.1 and 2.13.2 show channel prices per metre for channels with different bottom width and depth measured from the terrain surface. For channels in rock it was assumed side slopes of 5:1 and for uncompacted material channels, side slopes of 1:2.



COMMENTS:

1. Price level January 2015.
2. Includes simple pitching of bottom and side slope with a 0.5 m thick layer of pitching stone.
3. Presupposes:
   - Side slopes 1:2

Cross section, $A = BD + 2D^2$



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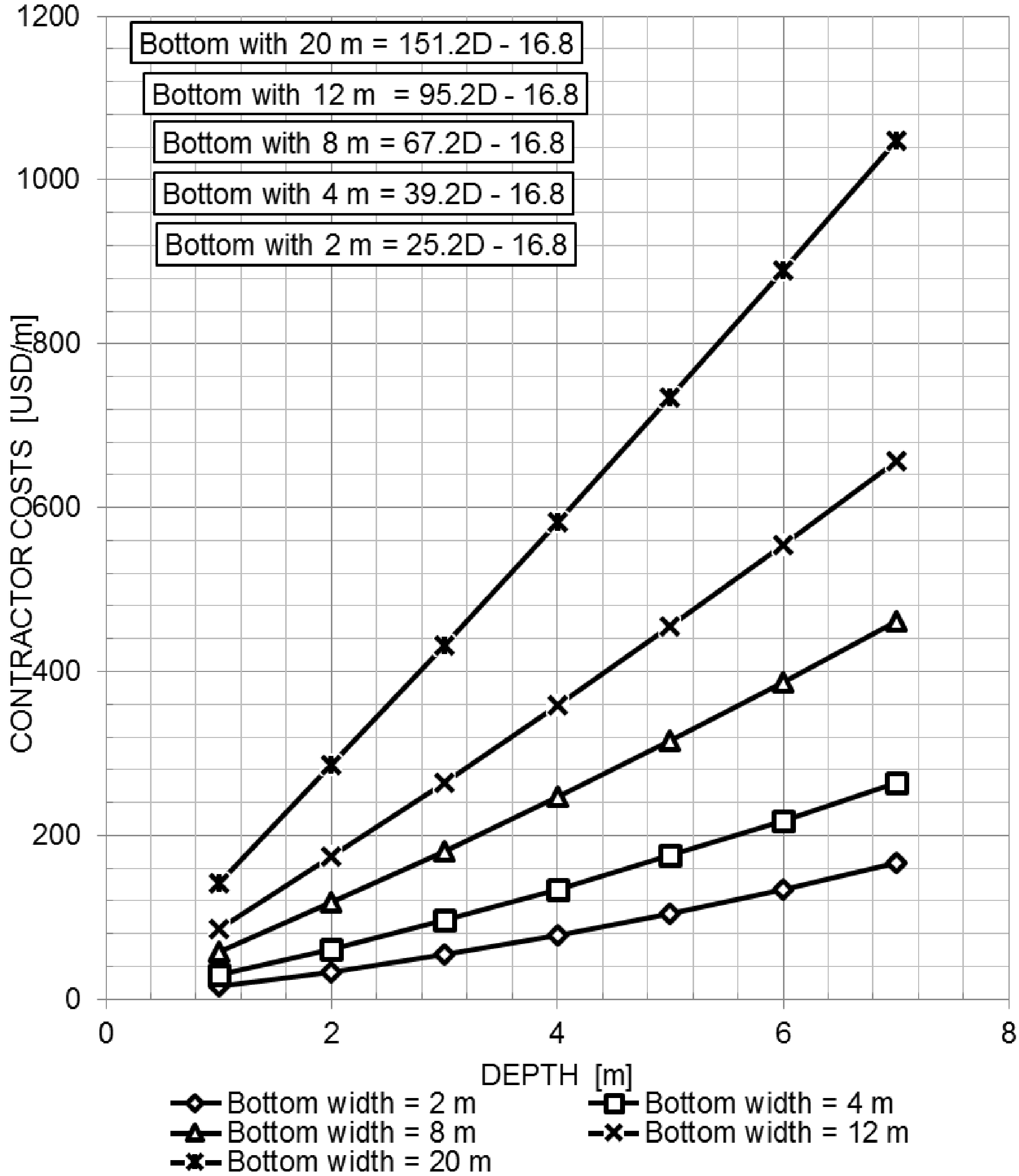
CHANNEL IN UNCOMPACTED MATERIALS CONTRACTOR COSTS

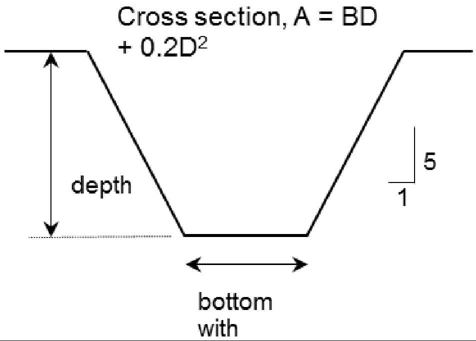
Fig. 2.13.1
01.01.15



COMMENTS:

1. Price level January 2015

2. Presupposes :
   - Side slopes 5:1



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CHANNEL IN ROCK

CONTRACTOR COSTS

Fig. 2.13.2
01.01.15

3 ELECTROTECHNICAL WORKS

3.1 GENERAL

3.1.1 Average Foreseeable Costs and Uncertainty

Chapter 3 provides a basis for calculating the average foreseeable costs for electrotechnical installations in power stations and transformer stations.

By “average” it is meant that the real costs might deviate from the estimate by ±10-20%.

When obtaining quotes for components such as generators, transformers, appliances and control systems plus high voltage appliances, prices from the different suppliers may vary by 0-15% at any given time. The prices may also vary over time due to market conditions and changes in wages, raw materials and currency exchange rates. Consequently, this creates a complex picture. Tender prices and prices for obtained contracts in the period 2010-2015 have been used to establish the correct cost, i.e. the most competitive market prices. In some cases the costs are provided directly by a supplier have been used.

3.1.2 Assumptions for the use of this Price Estimate

The stated prices are intended to aid the early planning phases, in order to make a rough estimate of the profitability, and assess different technical solutions.

This price estimate should be treated as indicative rather than exact, as each plant will have its special features that may not be covered by a general estimate. Before any decision is made regarding development, a more accurate cost assessment must be carried out for the project in question, where updated prices shall be obtained depending on the existed market conditions.

3.1.3 Cost Elements

In general, this price estimate covers the supplier’s price of materials delivered from the factory, including engineering work and routine acceptance tests.

The following costs are also included:

- Costs for transport and insurance to a random construction site
- Costs of installing the equipment
- Costs for commissioning the plant and start-up

In the following chapters, costs will be presented for the following plant components:

- Generators
- Transformers
- High voltage switching stations
- Control systems
- Auxiliary systems
- Cables
- Power lines

Each chapter will comprehensibly outline relevant assumptions upon which the cost estimates are based.

Chapter 3.9 contains a presentation of the total costs for the electrotechnical system as a function of the generator output, based on simplified assumptions for the plant construction.

3.1.4 Costs not included

The following costs have not been included in this cost base, but must be included in the total estimate:

- Value-added tax
- Interest during the construction period. This item will depend on the interest rate, how long the construction period is and the disbursement dates. Interest during the construction period may be a considerable cost element, representing 10-15% of the total development costs.
- Planning and administration
- Installation follow-up and quality control.

Nor have the following more modest builder's expenses been included:

- Free power for the installation work
- Temporary material storage
- Extra labour and hire of a mobile crane, etc. during installation

We have sought to express the extras as a percentage of the component price. If it is desirable to include the above extras in the estimate, the prices found in the following chapters should be increased by approximately 12%, consisting of:

- Interest during the construction period 9% (an interest rate of 5-6%, even disbursement over 3 years)
- Planning, administration and follow-up of the plant: 3-5%, depending on the size of the plant. Use 3% for large plants and 5% for small ones.
- Various minor builder expenses: approx. 2%.

3.1.5 Price level

The costs are given according to the price level as of January 2015. The revision of January 2010 price level is based on tender prices and obtained contract prices in the same period, plus price indexation. The cost of electrotechnical components have risen evenly, albeit modestly, since 2010.

3.1.6 Effect factor (cosΦ)

The output of electrotechnical components such as generators, transformers and appliances, is given in MVA. In the chapters on construction and mechanical installations, MW is used as a measure of output. For the sake of consistency, MW is also used for electrotechnical material. We have assumed a fixed effect factor (cosΦ) of 0.85. This means that the electrical output in MVA is approximately 18% higher than the one given in MW.

3.1.7 Definition of terms

English	Definition
Power unit	Electrical energy production unit. Comprises turbines and generators.
Switchgear and control	Comprises high-voltage switching station, cables, local control, direct current system, low-voltage system, station supply, fire alarm and extinguishing system.
Switching panel	Part of the switching station. Allows connection/disconnection of the line, transformer or power unit to a bus bar.
Auxiliary system	Parts of the appliance system; e.g. direct current system, low-voltage system, station supply, firefighting system, plus lighting and heating, ventilation, pumps and other support functions in the power station.
High-voltage switching station	The system for electrical connection/disconnection of generators, transformers and/or wires. Bus bars and switching panels are key elements in a switching station.
Maximum station output	The output (effect) a station (unit) can provide during a certain period without any detectable damage in the longer term. The maximum station output may be limited by turbines, generators and/or waterways.
Rated output	The output (effect) stamped on the name plate. Generally coincides with full-load output.
Average annual production	The estimated average annual production over a number of years.
Grid loss	The energy loss in the transmission and distribution grid.
Nominal effect	The effect stated in the data stamped on the turbine, generator or transformer. The nominal effect may be exceeded under certain conditions.
Transmission capacity	Transmission capacity – concerning transmission of power, the permitted load, given the heat development (temperature), stability and voltage drop.
Bus bar	Part of the switching station. Often termed A, B or C, depending on whether one has one, two or three bus bars. Connects different switching panels. The electricity may for instance enter the bus bar from the transformer switching panel and go via the bus bar into the power cable. See also the schematic diagram for power stations.

3.2 GENERATORS

3.2.1 Generators with an output below 10 MW

For smaller generators, the technical requirements and the requirements for additional equipment will have a much greater impact on the overall price than for larger generators. An example is asynchronous design and integrated stator design. Consequently, the uncertainty limits will be correspondingly higher.

Depending on the output and rotational speed, smaller generators might be supplied with a standardised design based on motor production. There is strong competition in this market segment due to an abundance of suppliers, and the cost level might be up to 1/3 lower. The quality level will also be lower, but it may still be adequate in most cases.

Such generators are often part of a delivery package, and the price is not necessarily representative even if it has been specified separately.

3.2.2 Generators with an output above 10 MW

Most generators above 10 MW will be of a vertical design. The smallest and fastest can be supplied with a horizontal axle, and the price level for these generators is about 15% lower.

Prices are generally based on normal technical criteria and requirements. Special values for flywheel effect or voltage will have marginal impact.

Prices are based on a normal scope of delivery, i.e. delivery to plant site, mounting, testing and start-up. Excitation equipment, spare parts and accessories such as monitoring equipment is also included.

3.2.3 Price level

The stated prices are representative as of January 2015. Even though the prices follow inflation trends to some degree, the market situation will have a much greater impact. Based on experience, uncertainty limit is set to ±15%.

The cost of the generator usually constitutes the largest component in the overall cost related to the electrotechnical installation. Since 2010 the cost of generators has increased by 10-15%.

3.2.4 Costs for improving efficiency

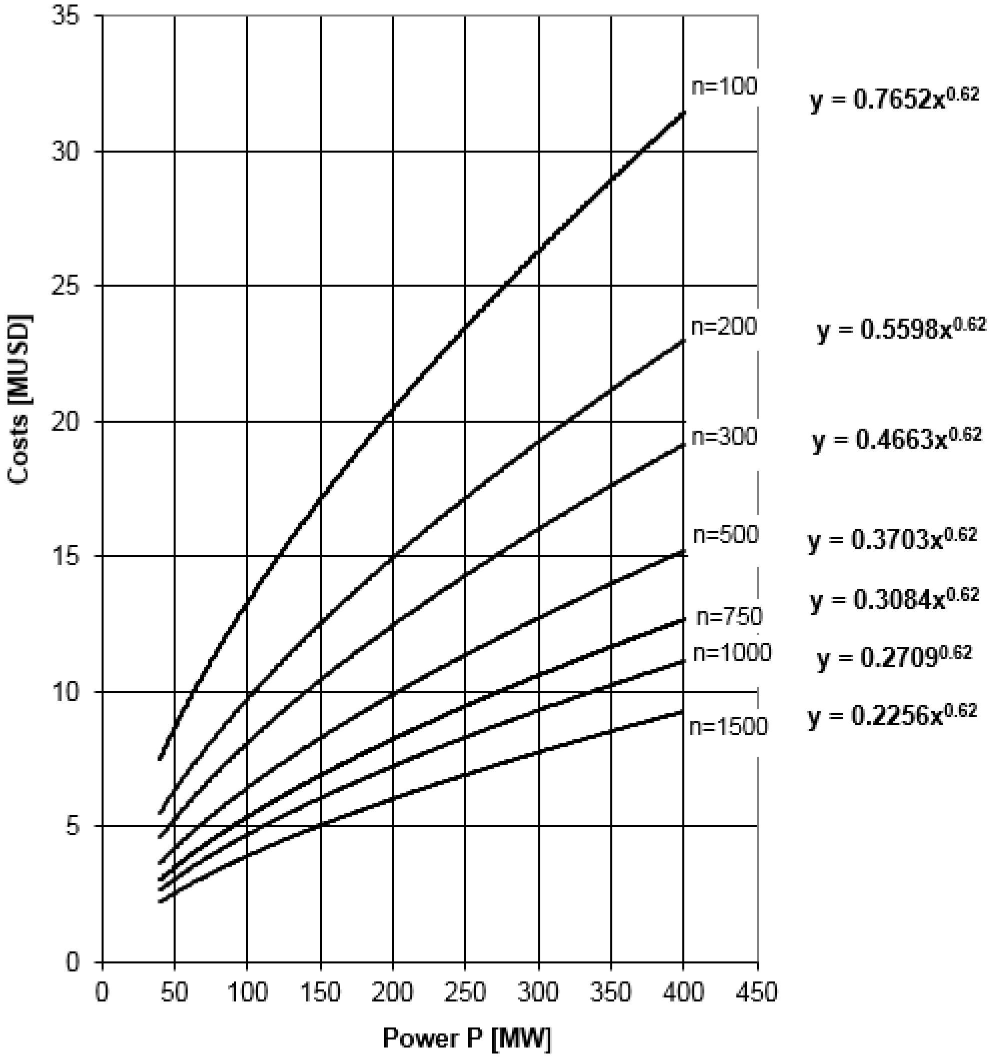
The generator efficiency can mainly be improved in the following two ways:

- Rewinding
- Rehabilitation / new cooling system

The costs of rewinding a generator are about 10% of the price of a new generator. These days there is little gain in rewinding a generator. The efficiency improvement is marginal and the costs due to production shutdown and rewinding far exceed savings due to efficiency gain.

Rewinding is nowadays generally performed only in the case of a breakdown, or when the winding no longer satisfies electrical requirements due to ageing.

Improving the cooling system (new coolers, etc.) will be a marginal cost compared to a new generator, but the improvement in efficiency are largely negligible and is unlikely to be very profitable.



NOTES:

1. Price level January 2015
2. Prices for complete generator with mounting and commissioning
3. Tolerances +/- 15%
4. Cos(φ) = 0.85

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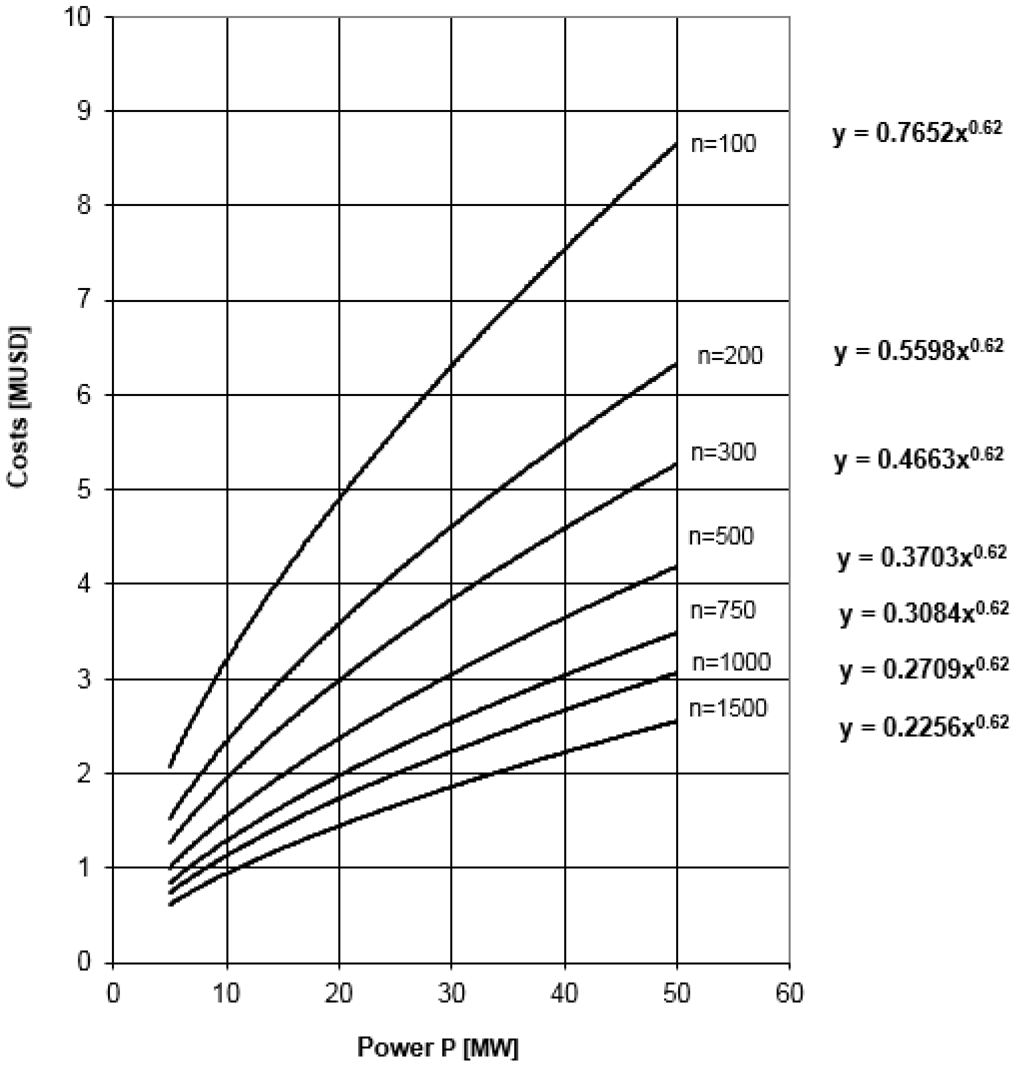
GENERATOR COSTS
Power > 50 MW

Fig: 3.2.1a
01.01.2015



NOTES:

1. Price level January 2015

2. Prices for complete generator with mounting and commissioning

3. Tolerances +/- 15%

4. Cos(φ) = 0.85

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GENERATOR COSTS
Power < 50 MW

Fig: 3.2.1b
01.01.2015

3.3 TRANSFORMERS

3.3.1 Scope

Prices concern power transformers / generator transformers of all values for the high-voltage outlet, since this value is not always known. Experience shows that it more or less follows the unit output and makes up less than the rest of the tolerance, which is due to market conditions.

Accessories are included to a reasonable extent, such as the on-load tap changer. For larger units the accessories will in any case make up less than the rest of the tolerance, which is due to market conditions.

3.3.2 Price level

The considerations for generator prices are also valid for transformer prices, with exception of the following:

To a greater extent than for generators, prices for power transformers depend on the choice of supplier, because the suppliers are more specialised. Additionally there tends to be greater disparity in quality between suppliers, and as quality is a critical selection criteria, one should allow for a slightly greater price tolerance here than for generators (±20%).

3.3.3 Costs for improving efficiency

Transformer efficiency can mainly be improved by rewinding.

The cost of rewinding a transformer is around 60-80% of the cost of a new transformer. There is currently little gain in rewinding a transformer to improve its efficiency, as the transformer efficiency is already very high, and any improvement made would be marginal. The costs of a production shutdown and rewinding would be much greater than the small gain in efficiency.

Today rewinding is generally only performed in the case of a breakdown, or when the winding no longer satisfies electrical requirements due to ageing.

Basic prices for electro-technical works

#	Name	Cost in USD
1	3	4
	Average costs for installation works for high voltage hydropower plants	
	I. Transformers:	
1	Transformer 50 MW 2X25000 kVA 35kV	185,000
2	Transformer 100 MW 2X63000 kVA 110/10 kV	310,000
3	Transformer 150 MW 2X80000 kVA 110/35 kV	360,000
4	Transformer 200 MW 2X100000 kVA 220 kV	465,000
5	Transformer 250 MW 2X125000 kVA 220/110 kV	550,000
6	Transformer 300 m MW 2X200000 kVA 330/220 kV	1,250,000

7	Transformer 350 MW2X200000 kVA 330/110 kV	1,150,000
8	Transformer 400 MW 2X250000 kVA 500/220 kV	1,700,000

3.4 HIGH-VOLTAGE SWITCHING STATION

3.4.1 Scope

It is impossible to indicate the scope and thus the costs of the high-voltage switching station in a power plant without knowledge of the number of outgoing lines and power units. The voltage level and type of switching station will also affect the price.

A switching station can be supplied in different versions adapted to the customer's needs and the nature of the power plant. This report contains prices for the main types within each voltage level.

3.4.2 Price level

The stated prices are representative as of January 2015.

The prices are based on updated contracts during the 2010-2015 period, and obtained budget prices from suppliers. The prices are also based on the armament in accordance with the table 3.4.1 and on the basis of a schematic diagram for small and medium size power stations Figure 3.4.2.

An exact comparison between prices is difficult, as the delivery scope varies from plant to plant. There might be one or two circuit breakers per field, separate connection switching panels, a varying number of isolators, surge arrestors and instrument transformers. Building and area costs are not included.

Prices for conventional switchgear have been adjusted upwards by 9-11%. For SF_6 plants the prices have been adjusted upwards by 10% from the 2010-level.

3.4.3 Cost included / not included

The price tables apply for one complete field with circuit breaker, isolator, instrument transformer and surge arrestors, installed, tested and started up at the power plant. Voltage transformers and bus bar earthing have been included, as have ground investments for the buildings and electrotechnical system.

3.4.4 Choosing a switching station

Indoor/outdoor conventional switching system

For voltage levels from 35 kV up to 110 kV, it will be practical and economical to use standardised high-voltage cells for indoor installation.

For 220 kV and up it is normal to build the switching station as a conventional open air plant.

Single/double bus bar

A double bus bar will cost a little more, but will allow more flexible operation. When conducting repairs one can move the operation to the other bus bar and then carry out repairs and maintenance on the voltage-free bus bar.

Circuit breakers

One can choose between one or two circuit breakers per field.

A system with two circuit breakers is often used for higher voltage levels. This is an expensive solution which for instance allows for instantaneous backup if one bus bar breaks down. This solution is illustrated in the schematic diagram for large stations. See Figure 3.4.2.

If there are more than three or four fields in the switching system, a double bus bar with one circuit breaker per field plus a box switch will be a cheaper solution and also allows for some flexibility in operation.

Circuit breakers have become more reliable in recent years, with longer service intervals. Nowadays it is often found that sufficient availability can be obtained with one circuit breaker per field and a double bus bar.

SF_6 stations

If there is no room for an open air station, or if atmospheric pollution will affect operations, one can choose an SF_6-isolated switching station. These are now very reliable. Though component costs for an SF_6 station are higher than for conventional switchgear, these costs can often be recovered by reducing the required area of the switching station.

Costs

Switchgear		
1	35kVsingle bus bar	$ 65,000.00
2	35kV double bus bar	$ 130,000.00
3	110kV single bus bar	$ 150,000.00
4	110kV double bus bar	$ 300,000.00
5	220kV single bus bar	$ 290,000.00
6	220kV double bus bar	$ 580,000.00
7	330kV single bus bar	$ 615,000.00
8	330kV double bus bar	$ 1,125,000.00
9	500kV single bus bar	$ 880,000.00
10	500kV double bus bar	$ 1,350,000.00

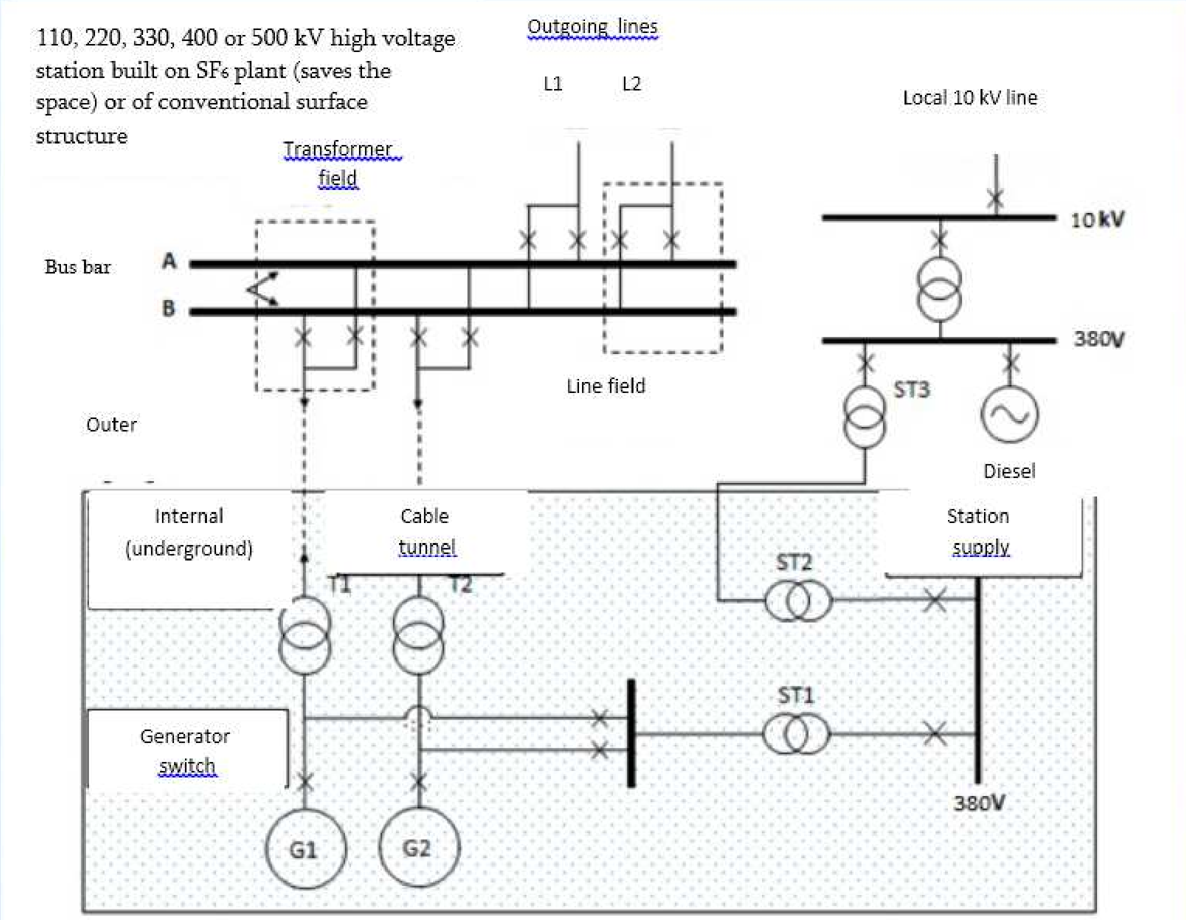
OPY (outdoor switchgear)		
1	35kV	$ 390,000.00
2	110kV	$ 625,000.00
3	220kV	$ 1,100,000.00

Gas power circuit breaker 1 set (outdoor switchgear)		
1	35kV	$ 15,000.00
2	110kV	$ 95,000.00
3	220kV	$ 155,000.00

Gas power circuit breaker 1 set (Switchgear)		
1	35kV	$ 25,000.00
2	110kV	$ 100,000.00
3	220kV	$ 310,000.00

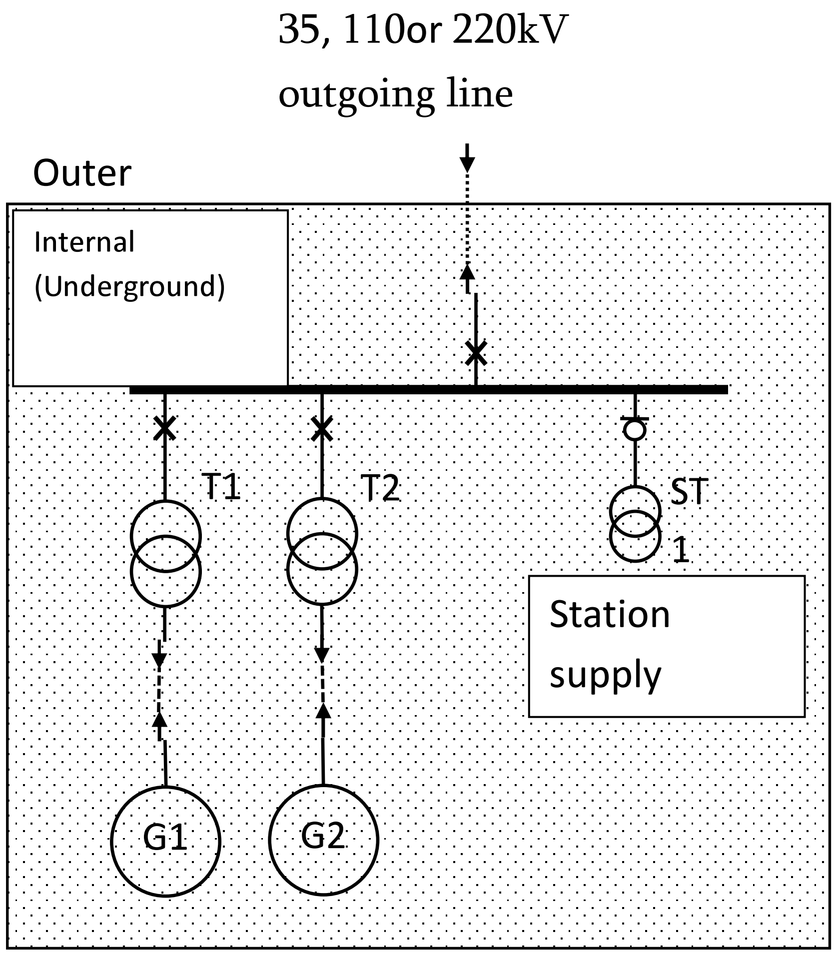
Schematic diagrams

Schematic diagrams are shown in Figure 3.4.2 and Figure 3.4.3.



Schematic diagram for medium and large power stations with two plants and two outgoing lines

Figure 3.4.2



Schematic diagram for small and medium size stations with underground switching station and
35, 110 or 220 kV outgoing line

Figure 3.4.3

3.5 CONTROL SYSTEMS

3.5.1 The scope of the analysis

The cost curves for control systems includes local systems, pumps and pump aggregate, as well as shared system, object computer, screen system and remote control. Local control for the switching panel has been included under switching panel. Local control for fields in the auxiliary systems is included under auxiliary systems.

Please be aware that power stations differ greatly, due to varying age, size, technical solution and general quality standards. Therefore, stated costs for control systems will be of a general nature only.

3.5.2 The price curves

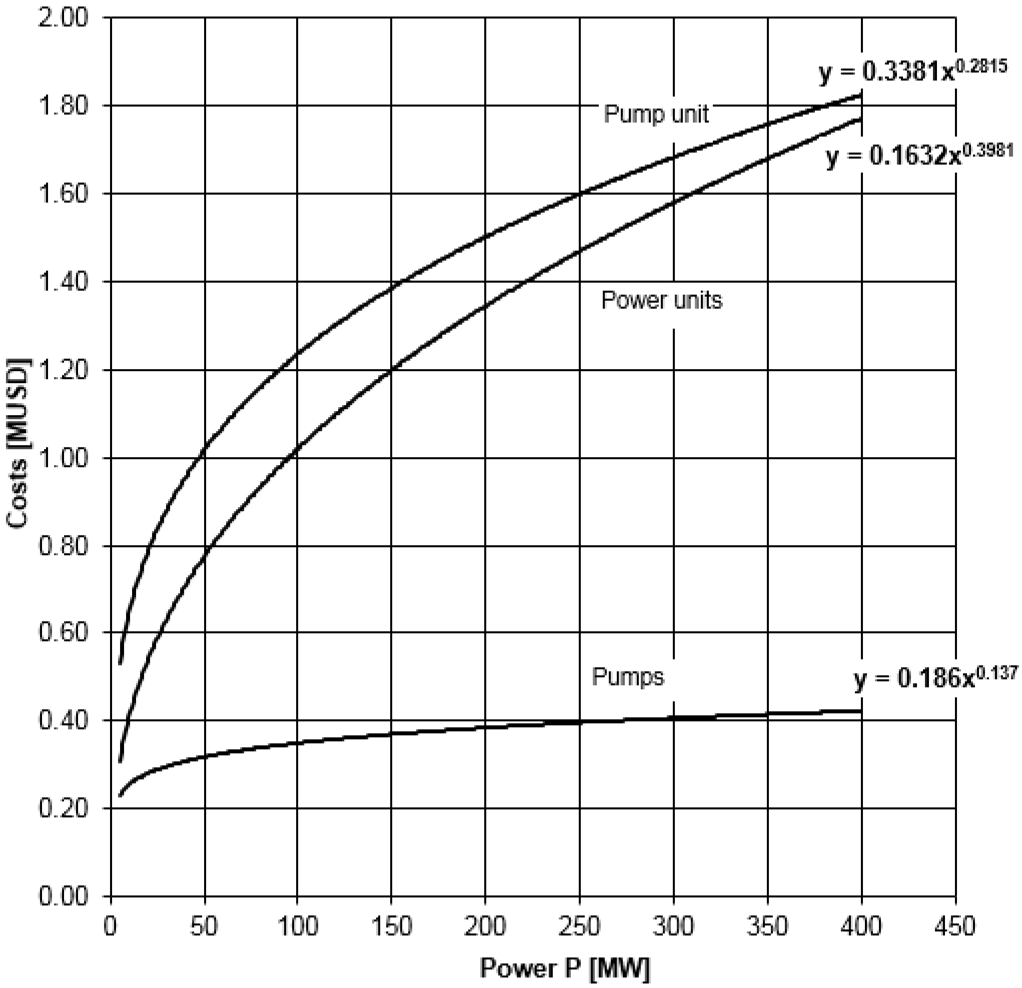
The price curves indicate the price for a complete control system once the unit output is given. Prices include installation and testing/start-up.

3.5.3 Price levels

The stated prices are representative as of January 2015. Since 2010 prices have increased by approximately 10%.

3.5.4 Power plants with more than two units

If output is split between more than two power units, 50% of the control system per unit cost can be estimated for each power unit above two units.



NOTES:

1. Price level January 2015

2. Correction of the costs from the curves shall be done by adding the following numbers (1,000 USD):

For each hatch control with remote control:	40
For eah water level regulation with remote control:	53
For each 100 meter (signal cable trench) between hydropower plant and switchyard installations:	13

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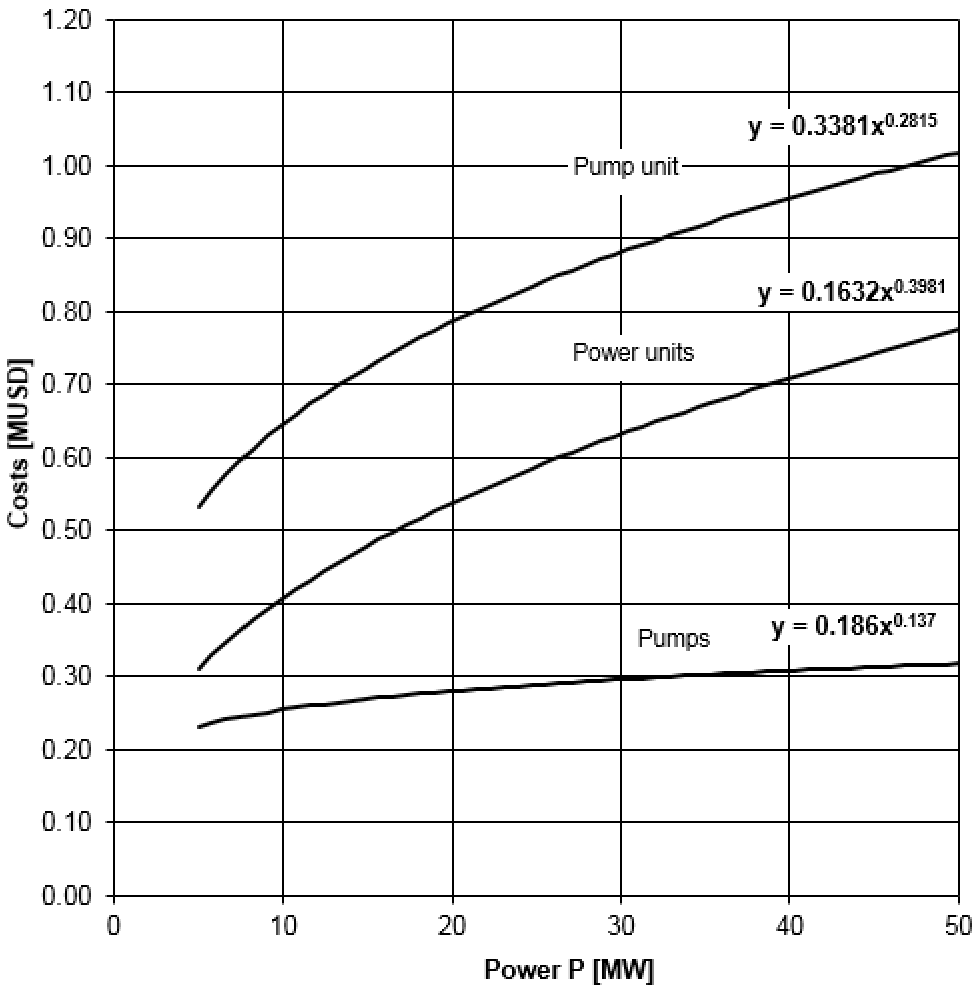
CONTROL SYSTEM COSTS

Fig. 3.5.1a
01.01.2015



NOTES:

1. Price level January 2015

2. Correction of the costs from the curves shall be done by adding the following numbers (1,000 USD):

For each hatch control with remote control:	40
For eah water level regulation with remote control:	53
For each 100 meter (signal cable trench) between hydropower plant and switchyard installations:	13

NVE Norwegian Water Resources and Energy Directorate	CONTROL SYSTEM COSTS P < 50 MW	Fig. 3.5.1b 01.01.2015

3.6 AUXILIARY SYSTEMS

3.6.1 The scope of the analysis

The prices in Table 3.6.1 for auxiliary systems include:

- Fire alarm and fire extinguishing system
- Fire marking and sealing
- Telecommunication system.

As for high voltage and low voltage stations, transformers, high voltage and low voltage cables, diesel operated devices, an accumulator system with DC supply, the earthing, etc., are included in the transformer costs.

Please note that power stations differ greatly, due to their different ages, size, technical solution and general quality level. Therefore, the costs stated for control systems will be of a general nature only.

3.6.2 The price curves

The price tables indicate the price for the entire control system once the unit output is given. Prices include installation and testing/start-up.

3.6.3 Price levels

The prices stated represent the price level in January 2015.

3.6.4 Power plants with more than two units

In cases where the output is split between more than two power units, add 50% of the auxiliary system cost for one unit, per unit installed above two units.

Telemechanic and fire alarm system protection		
1	110 kV substation automated control system	$ 110,000
2	220 kV substation automated control system	$ 140,000
3	Fire alarm system 110 kV	$ 30,000
4	Fire alarm system 220 kV	$ 35,000

Emergency control automatics		
1	220 kV	$ 12,000
2	330 kV	$ 20,000

Fiber optic cables		
1	High voltage 35 kV fiber optic one cable on existing pole	$ 12,000
2	High voltage 110 kV fiber optic one cable on existing pole	$ 17,000
3	High voltage 110 kV fiber optic two cables on existing pole	$ 30,000
4	High voltage 220 kV ASLH-D(S)bb 1X24SMF (AA/ACS 52/30-12.2) on existing pole	$ 35,000

Table 3.6.1

3.7 CABLE SYSTEMS

3.7.1 The scope of the analysis

This analysis covers cable systems that transmit output from a generator to a switching station in power and transformer stations. Cable systems that transmit power through underground cables between stations have not been included.

3.7.2 The price curves

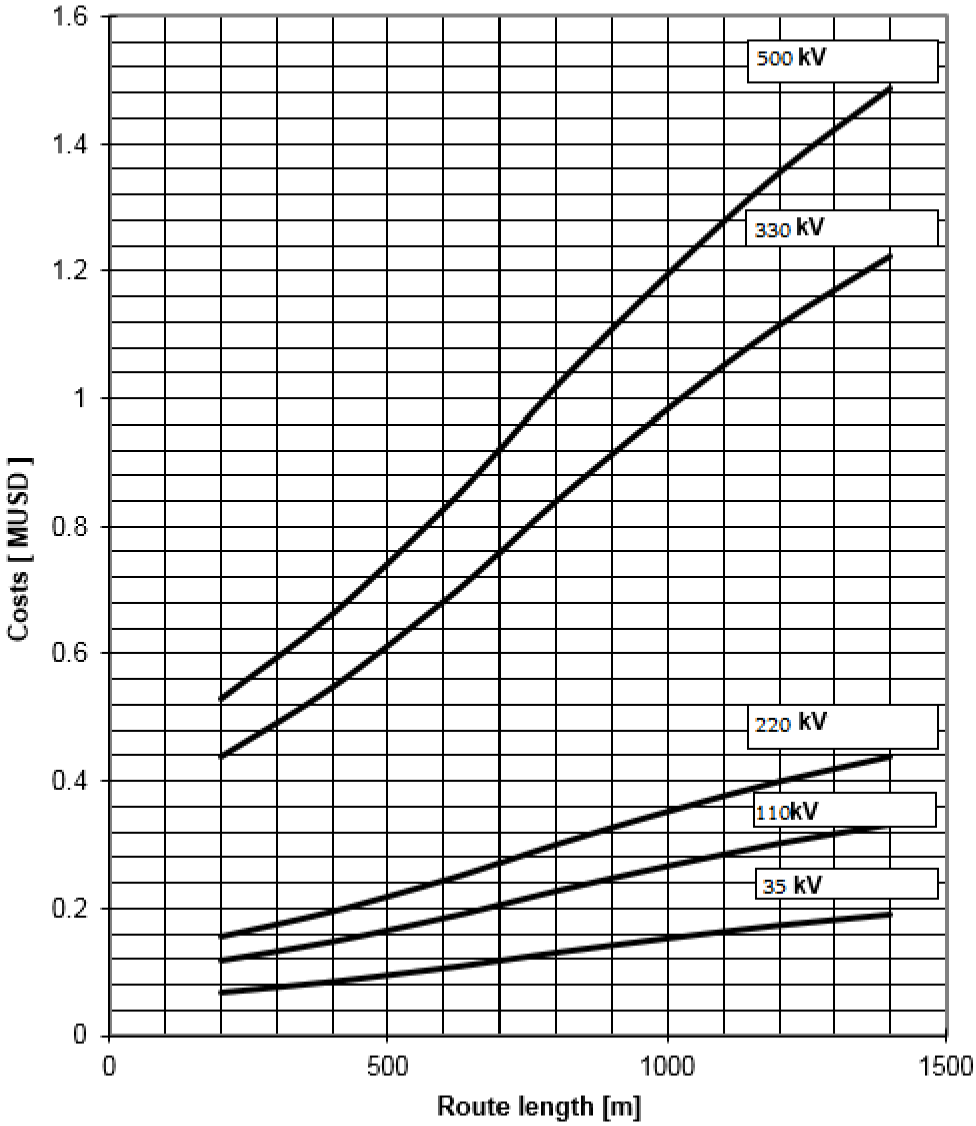
The price curves indicate the price for a complete cable system when the voltage level and the length of the cable run are given. Prices include installation and testing/start-up. We have for the various voltage levels indicated the rough MW effect that the cable is able to transmit, if the cable has a cross-section of 800 mm^2. We are then assuming a voltage of 750 A for the 330 kV and 500 kV PEX cables, and 1000-1100 A for the PEX cables of 35 kV, 110 kV and 220 kV.

3.7.3 Price level

The prices stated represent the price level in January 2015. For all cable systems, the price is for a PEX-insulated cable.

3.7.4 Costs included / not included

The price does not include spare cables or other spare parts.



NOTES:

1. Price level January 2015
2. Tolerances +/- 20%
3. Prices are valid for complete cable systems fully assembled and tested Cross section 800 mm2
4. Prices are valid for PEX cables
5. Approximate load capacity in MW is specified assuming cos(φ) = 0.9
6. For short or very long cable routes prices should be tendered. This also applies for 300 and 420 kV systems

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CABLE SYSTEM COST
Cross section 800 mm2 Al

Fig. 3.7.1
01.01.2015

3.8 POWER LINES

3.8.1 The scope of the analysis

This analysis covers lines for system voltages of 35, 110, 220, 330 and 500 kV. For these voltage levels one can find the costs for lines with timber or steel pylons.

The Table 2 shows the total costs that should be expected when an electric company builds power lines on its own, so that material costs as well as labor costs have been included.

3.8.2 Cost variations

The Table 2 shows the total price for 1 km installed and operational line. If the length of the route is significantly shorter or longer, the cost estimate may be extrapolated, assuming that 90% of the price varies proportionally with the length of the line, and 10% is fixed. The cost estimate involves averagely difficult terrain.

3.8.3 Price level

Prices for overhead lines with voltage level spanning from 35 kV to 110 kV have increased markedly from 2010 to 2015, which is likely due to increased personnel costs and material costs. The price increase for 330 kV and 500 kV lines has been moderate. One reason for this might be more international competition for work on the highest voltage levels. The stated prices reflect the price levels as of January 2015.

3.8.4 Costs included / not included

Costs for a necessary switching station at the far end of the line have not been included.

Land compensation has not been included.

3.8.5 Financial load

The financial load has been estimated by calculating the reduction in capitalised loss by increasing the cross-section of the line, and comparing this with the correspondingly increased construction costs.

The result depends on how long the line will be used and the interest rate used in the calculation. We have chosen to use EFI-TR 1975 "Kostnader av elektriske tap i overførings- og fordelingsnett" (*Costs of electrical losses in the transmission and distribution grid*). The increase in construction costs has been taken from Fig. 3.8.1-3.8.4 on the assumption that only the line cross-section will vary. This approach leads to significant uncertainty margins, but one may nevertheless conclude that the financial electricity load as a rough estimate may be set as 40-60% of the thermal limit load, i.e. current densities in the region of 1.0-1.5 A/mm^2 calculated in proportion to the total cross-section. The lowest figures are used for the smallest cross-sections and vice versa.

3.8.6 Choice of voltage and line cross-section

Today practically all lines are made of steel and aluminium (FeAl). The cross-section is indicated by a figure that describes the copper (Cu) cross-section in mm^2 of the same resistance. For example: FeAl no. 95 has the same resistance per metre as a Cu wire with a 95 mm^2 cross-section.

Figure 3.8.5 shows the approximate transmission capacity as a function of the transmission length for various voltages and line cross-sections, with a voltage drop of about 5%. If a higher voltage drop is acceptable, the transmission length will increase correspondingly. When new lines are being dimensioned, the financially correct load will be lower than what is indicated in the figure.

Most commonly one is not free to choose the optimal transmission voltage for the effect in question, as it is dependent on the existing transmission grid in the area.

3.8.7 Transmission capacity for 330-500 kV power lines

<u>In general on dimensioning criteria for longer lines:</u>

When planning power lines over longer distances, several aspects must be considered. The starting point is always the fact that a certain effect (MW) must be transmitted.

Firstly, one must choose the voltage level for the transmission. The higher voltage one chooses, the lower current will be transmitted at the same effect, and consequently the loss will also be reduced. The effect loss in the line is proportional to the current squared, and it is therefore important to keep the current as low as possible.

At higher voltages, (particularly 330 kV and 500 kV) there will be problems with corona noise if the line diameter is too small. This means that 500 kV lines must be built as duplex or triplex lines to achieve sufficient equivalent conductor cross-section and thus avoid corona.

The maximum current intensity for a power line depends on the conductor cross-section given in the FeAl number. This indicates the equivalent copper cross-section for the conductor. The maximum current intensity for a given cross-section also depends on what temperature one can permit on the conductor. It is common to dimension new lines today on the basis of +80 ˚C in the conductor and ambient temperatures of +20 ˚C in summer and +5 in the winter.

The cross-section may be adjusted through varying conductor cross-sections, or by using a duplex line (two conductors per phase) or a triplex line (three conductors per phase). The disadvantage of large conductor cross-sections and duplex/triplex is that the lines become heavy. The pylons must be constructed to withstand the stresses that arise due to the weight of the line and additional stress caused by wind, and ice settling on the line.

<u>Transmission capacity, thermal limit load:</u>

The stated maximum transmission capacities of the power lines are based on the highest permitted currents without the temperature in the phase lines exceeding 80 ˚C.

	Thermal limit load (MVA)			
Voltage	**300 kV**		**420 kV**	
Ambient temperature	**5 ˚C**	**20 ˚C**	**5 ˚C**	**20 ˚C**
Simplex Parrot	915	820	----	----
Duplex Parrot	1830	1640	2440	2190
Duplex Curlev	1435	1280	1900	1710
Duplex Grackle	1560	1400	2080	1870
Triplex Grackle	2340	2100	3120	2800

Table 1. Thermal limit load for various line cross-sections depending on the voltage level and ambient temperature at a line temperature of 80 ˚C. Assumptions: 0.6 m/sec wind, thermal absorption and emission coefficient equals 0.5 blank line and no sun on the line. Source: Statnett (Norway)

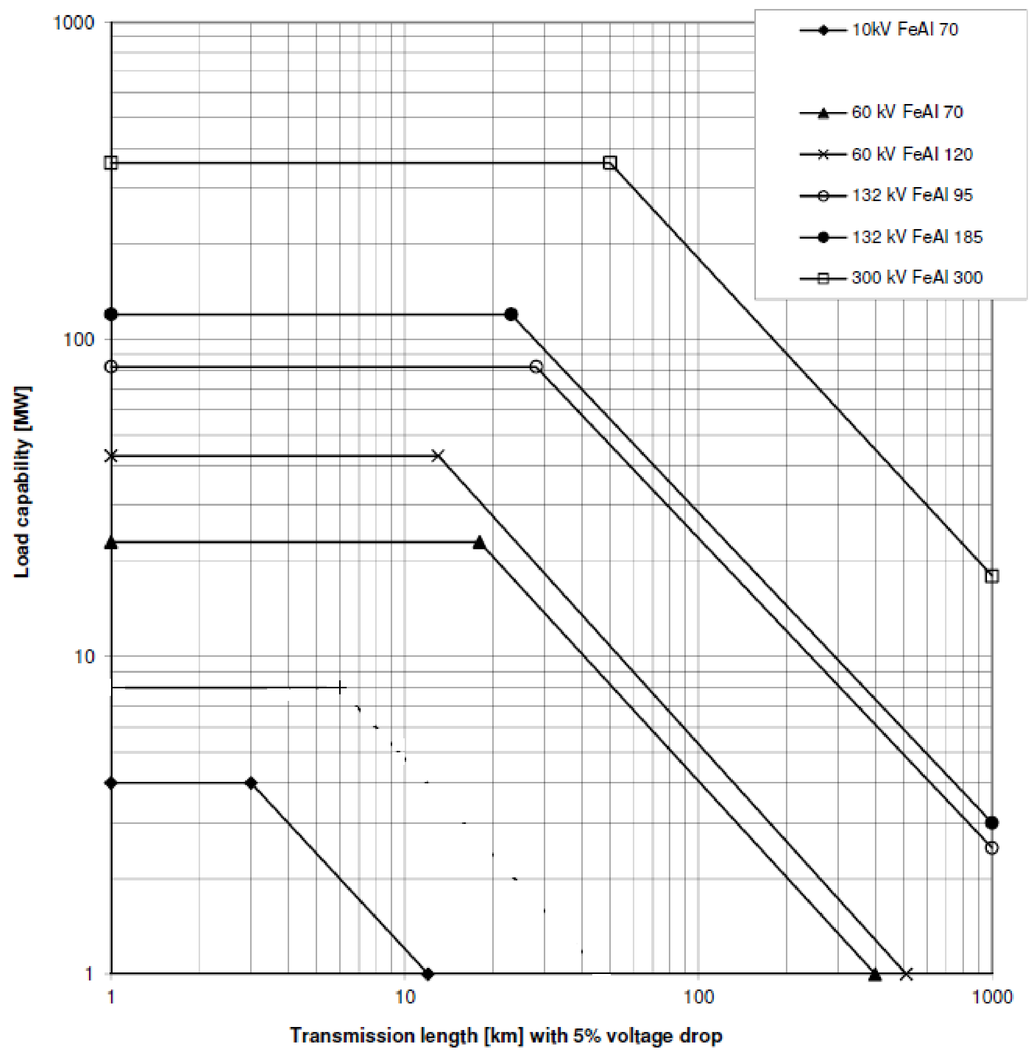
<u>Limited transmission capacity due to voltage drop:</u>

Power lines have serial impedance, and this is the main cause of voltage drop along the line. This voltage drop is the most important factor that limits the line's transmission capacity.

Serial compensation reduces the line's serial impedance and ensures that the voltage drop may be reduced to a minimum of a few percent. The need for compensation is largely dependent on the load conditions in the grid. With no-load lines, the voltage might rise at the receiving end on account of the line's capacitive discharge, while the voltage drops when the load increases. SVC (Static VAR Compensator) systems will adjust the supply of reactive effect according to the need.

When planning longer power lines it is necessary to conduct load flow analysis, where the entire surrounding grid assessed in a computer model. It will then be possible to predict how active and reactive effect will flow in a planned line with light load (summer) and heavy load (winter). Additionally, voltage drops and the need for compensation can be surveyed in the planning stage.

The transmission capacity based on thermal limit loads (Table 1) must be reduced if voltage drops occur due to a lack of compensation.



NOTES:

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LOAD CAPABILITY OF
OVERHEAD LINES

Fig. 3.8.5

Cost of 1 km transmission line		
35 kV transmission line		
1	Aluminum-steel -95 single circuit	$ 86,000
2	Aluminum-steel -150 double circuit	$ 135,000
110 kV transmission line		
1	Aluminum-steel single circuit up to 150mm^2	$ 110,000
2	Aluminum-steel single circuit up to 185-240mm^2	$ 125,000
3	Aluminum-steel double circuit up to 150mm^2	$ 180,000
4	Aluminum-steel double circuit up to 185-240 mm^2	$ 185,000
220 kV transmission line		
1	Aluminum-steel 300mm^2 single circuit	$ 135,000
2	Aluminum-steel 400mm^2 single circuit	$ 185,000
3	Aluminum-steel 300mm^2 double circuit	$ 215,000
4	Aluminum-steel 400mm^2 double circuit	$ 235,000
5	Aluminum-steel 500mm^2 double circuit	$ 410,000
330 kV transmission line		
1	Aluminum-steel 300mm^2 double circuit	$ 300,000
500 kV transmission line		
1	Aluminum-steel 300mm^2 double circuit	$ 525,000

Table 2

3.9 TOTAL COSTS

3.9.1 General

This chapter describes the total costs for electrotechnical systems in power plants, based on the assumptions given below. The total price is found by adding up the costs for the individual components described above.

3.9.2 Plants from 5 MVA and up

As a basis for this estimate, a power plant with the following main features has been chosen:

- Underground plant with 800 m cable run.
- Plant output divided between one or two power units in a block connection*
- Outgoing lines from the plant
- Switching station of a conventional type with a single bus bar and one circuit breaker. If an SF_6 station is required, extra costs must be added for this.
- For stations above approximately 150 MW we have assumed the use of enclosed bus bars and a generator circuit breaker.

*Block connection means that there is one transformer for each power unit, as shown in the schematic diagram in Fig. 3.4.2. In other cases, two power units might for example share one transformer that covers the overall generator output.

3.9.3 Variations in plant design

Besides plant outputs (MW), the factors of greatest importance for costs are:

- The number of power units
- The rotational speed of the units
- The number of line fields
- The type of switching station
- The length, type and number of cables

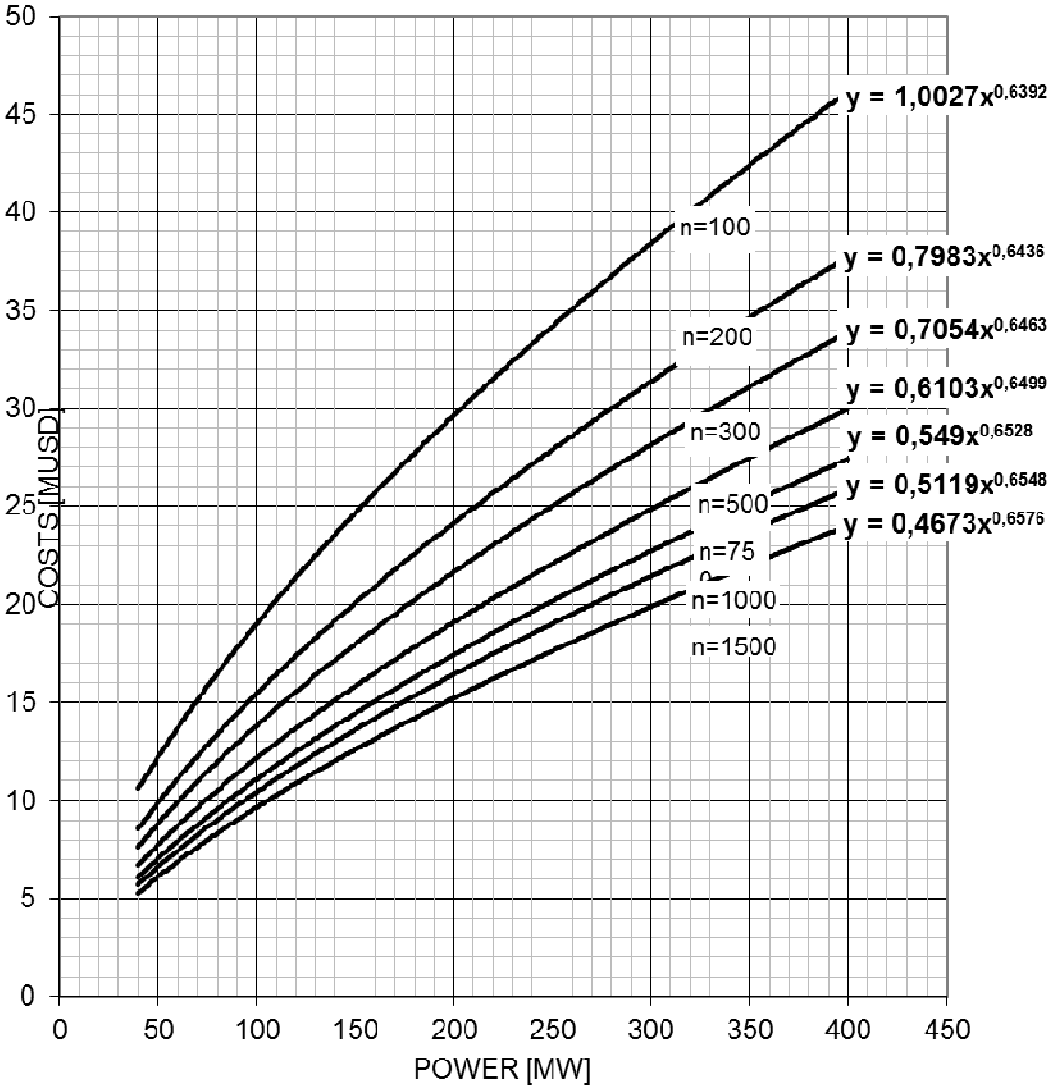
In principle, the scope of, and hence the price of electrotechnical equipment for a power plant will be the same whether the station is built above ground or underground. For a surface plant, however, it will often be possible to locate the high-voltage system so near the transformers that one avoids the long cable connection that has been assumed for underground plants. If the station is built above ground, one should deduct cable costs; cf. the price curve in Fig. 3.7.1.

3.9.4 Plant parts not included in the estimate

Costs for power lines and telecommunication have not been included. Power lines may amount to a considerable sum, cf. Chapter 3.8. For stations with large regulated areas, power supply and communication in these areas may be costly.

3.9.5 Power plants with more than two power units

Fig. 3.9.1a, 3.9.1b, 3.9.2a and 3.9.2b show the costs of electrotechnical equipment in a power station where the output is divided between one and two power units. In cases where the output is split between more than two power units, add 50% of the control system and auxiliary system costs for one unit, per unit installed over and above two units. For the rest, use the unit costs given in the figures.



NOTES:

1. Price level January 2015
2. Valid for total electrotechnical system incl. control/auxiliary system for medium size hydropower plant in tunnel site
3. Tolerances +/- 20%
4. Calculations incl. 800 m of cable voltage level varies with installed power
5. Telecom and power lines are not included
6. If SF6-switchgear is chosen one must add the difference between SF6 and conventional switchgear

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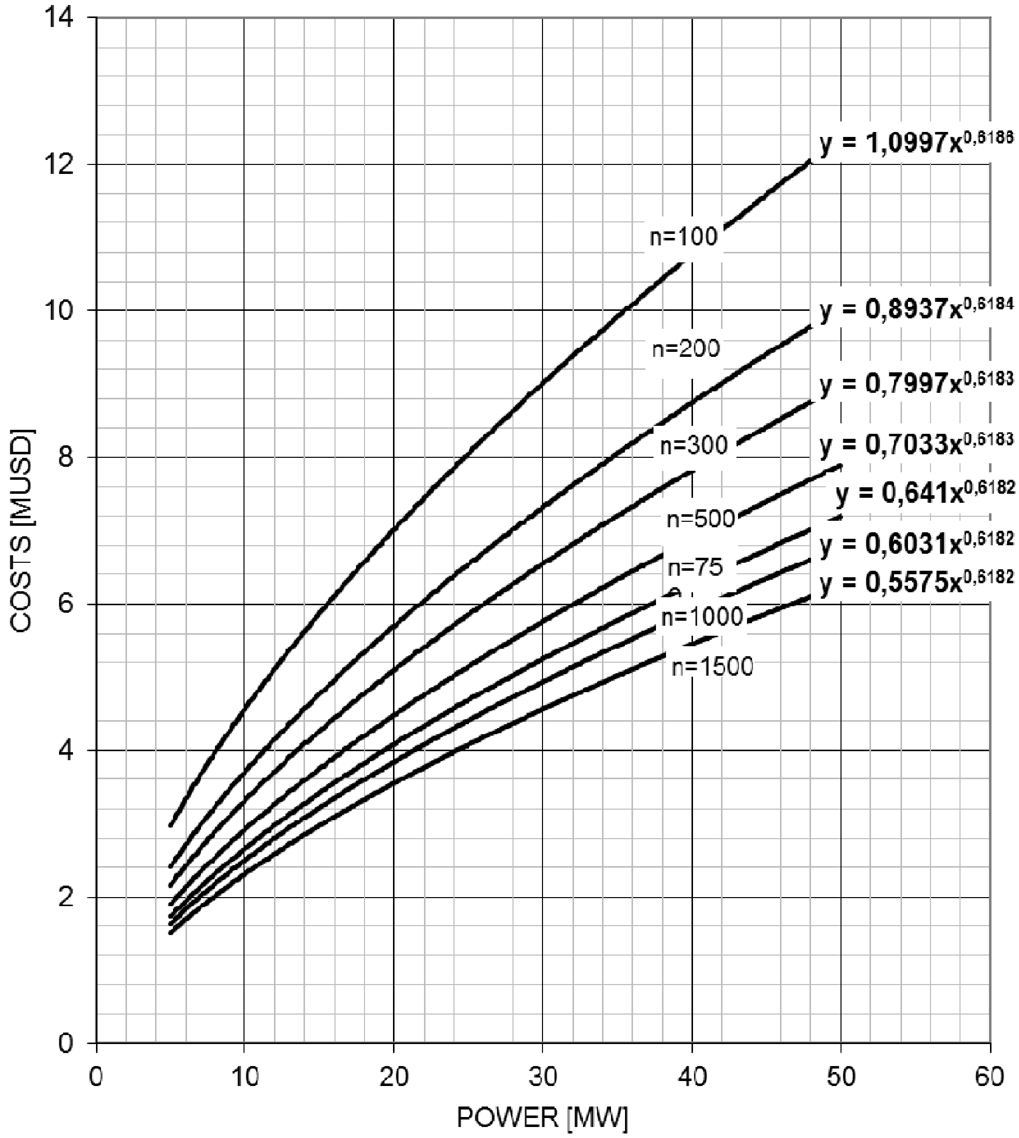
TOTAL COST OF ELECTROTECHNICAL EQUIPMENT IN HYDROPOWER PLANTS FOR ONE GENERATING UNIT.

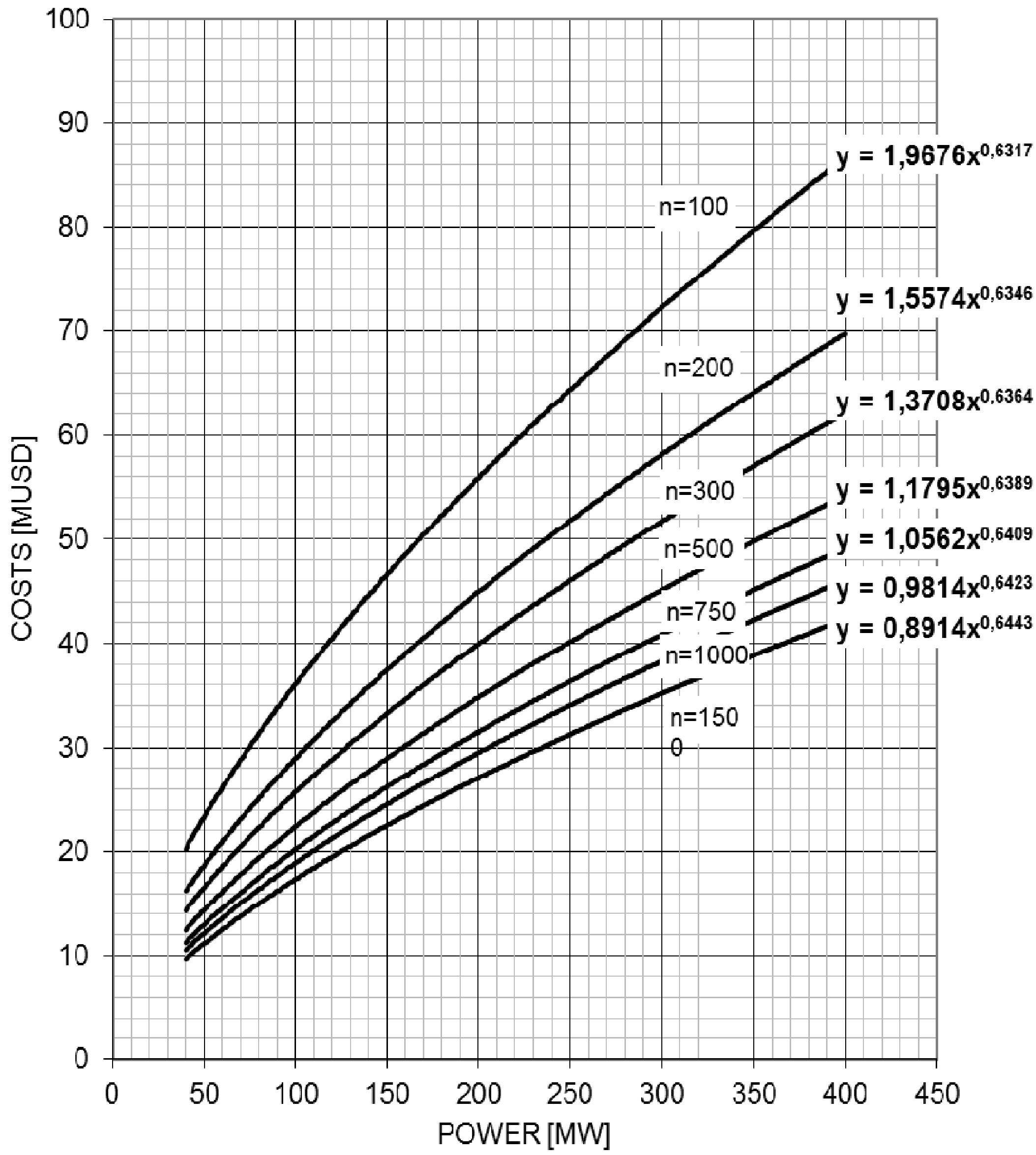
Fig. 3.9.1a
01.01.15



NOTES:

1. Price level January 2015
2. Valid for total electrotechnical system incl. control/auxiliary system for medium size hydropower plant in tunnel site
3. Tolerances +/- 20%
4. Calculations incl. 800 m of cable Voltage level varies with installed power
5. Telecom and power lines are not included
6. If SF6-switchgear is chosen one must add the difference between SF6 and conventional switchgear

Norwegian Water Resources and Energy Directorate NVE	**TOTAL COST OF ELECTROTECHNICAL EQUIPMENT IN HYDROPOWER PLANTS FOR ONE GENERATING UNIT [5-50 MW]**	Fig. 3.9.1b 01.01.15



NOTES:

1. Price level January 2015
2. Valid for total electrotechnical system incl. control/auxiliary system for medium size hydropower plant in tunnel site
3. Tolerances + /- 20%
4. Calculations incl. 800 m of cable. Voltage level varies with installed power
5. Telecom and power lines are not included
6. If SF6-switchgear is chosen one must add the difference between SF6 and conventional switchgear.

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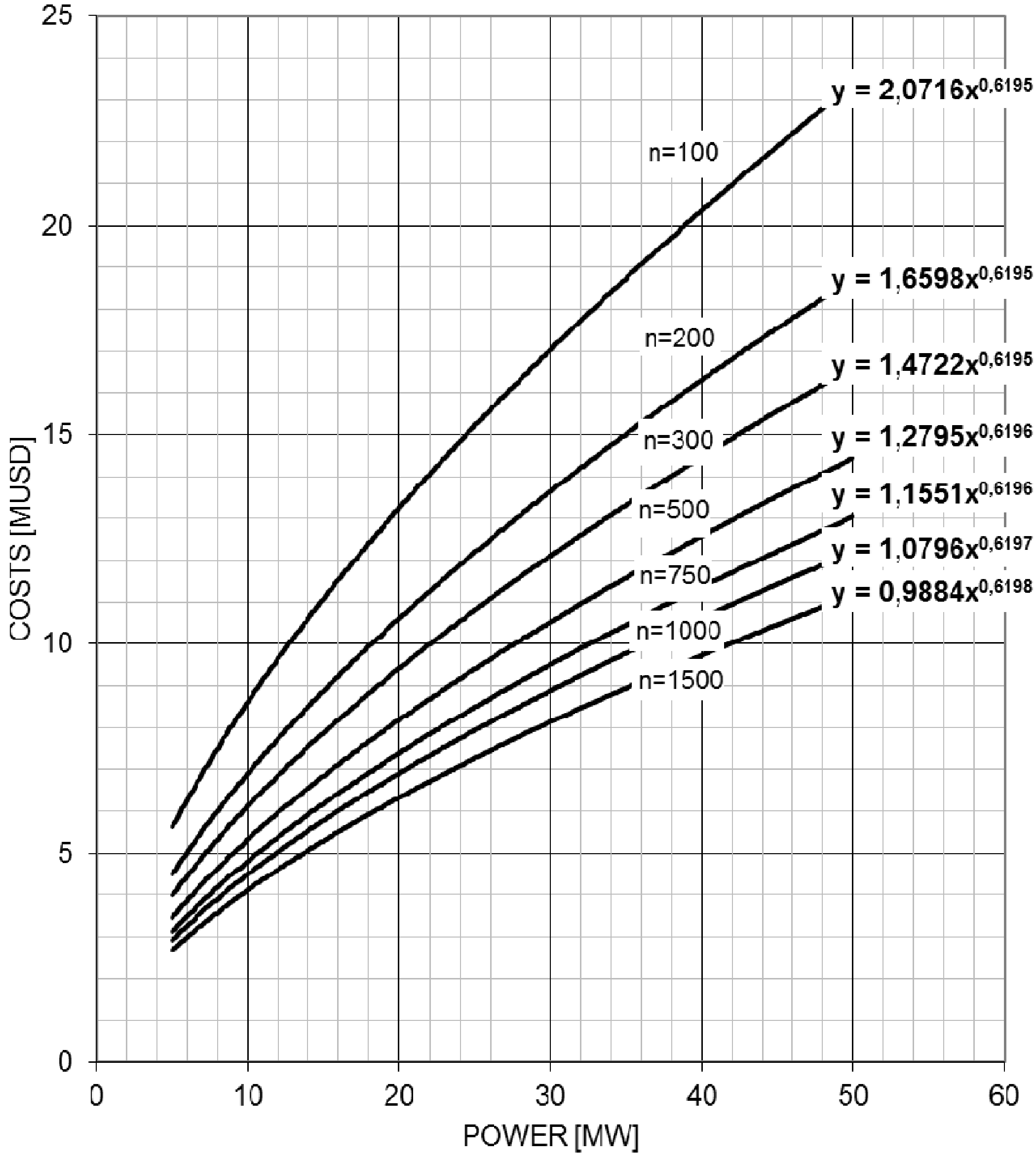
TOTAL COST OF ELECTROTECHNICAL EQUIPMENT IN HYDROPOWER PLANTS FOR TWO GENERATING UNITS

Fig. 3.9.2a
01.01.15



NOTES:

1. Price level January 2015
2. Valid for total electrotechnical system incl. control/auxiliary system for medium size hydropower plant in tunnel site
3. Tolerances + /- 20%
4. Calculations incl. 800 m of cable. Voltage level varies with installed power
5. Telecom and power lines are not included
6. If SF6-switchgear is chosen one must add the difference between SF6 and conventional switchgear.

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TOTAL COST OF ELECTROTECHNICAL EQUIPMENT IN HYDROPOWER PLANTS FOR TWO GENERATING UNITS [5-50 MW]

Fig. 3.9.2b
01.01.15

3.10 CONSTRUCTION POWER

3.10.1 General

Power supply for construction work varies a greatly and depends on how much power is consumed and the complexity of the plant. It has therefore not been prepared any graphs or tables for an accurate cost estimate.

It is often the builder's duty to provide construction power according to the contractor's needs. If so, the costs should be considered as builder's expenses and thus remains outside the scope of this report. Indicated prices for individual components that form part of the construction power supply is presented in the chapters below.

3.10.2 High-voltage line

Please see Chapter 3.8.

3.10.3 Cable system

We assume that 3 x 50 mm^2 Al is used. Ready installed, one can assume approx. USD 33.3 per metre. If a cable with a suspension line is used, add approx. USD 10 per metre.

3.10.4 Kiosks

A high-voltage feeder of a transportable type may be obtained for USD 20,000-26,500 exclusive of transformer. The price varies according to how easy it must be to move it.

One or several distribution kiosks with low-voltage outlets are also needed. These might cost from USD 10,000 to USD 17,000 exclusive of transformer.

3.10.5 Price level

The prices stated represent the price levels as of January 2015.

4 MECHANICAL ENGINEERING

4.1 GENERAL

4.1.1 Average foreseeable costs and uncertainty

This chapter provides a basis for calculating the average foreseeable costs for mechanical deliveries. The prices are for construction, production, and delivery of commissioned equipment.

The stated costs have an estimated accuracy of ±30%. The real costs are just as likely to be higher as lower.

4.1.2 Costs included / not included

The stated prices include the following in addition to construction, production and delivery of a complete, commissioned plant:

- Transport to the plant, including transport insurance
- Spare parts (large variation in scope)
- Installation and painting, board and lodging for the installer
- Casual labour assistance (5% of overall costs)
- The supplier's technical service during installation and start-up
- Provisions during the warranty period

The stated prices do not include the following:

- Local transport at the plant
- Building costs and electro-technical costs associated with the installation
- Value added tax
- Builder's expenses

4.1.3 Builder's expenses

Builder's expenses have not been included in the stated prices. The most important builder's expenses for mechanical engineering deliveries usually are:

- Planning and administration, including consultancy fees
- Financing, interest during the building period
- Value added tax
- Local transport at the plant
- Follow-up during installation and start-up
- "Miscellaneous" and "Unforeseen"

4.1.4 Price level

The stated prices refer to January 2015. The prices are mainly based on signed contracts, budget prices and discussions with suppliers. It must be stated that for some mechanical components the data basis is somewhat limited, hence the price estimates are somewhat uncertain. There is also a significant variation in the cost development for the different components.

Main contractors of mechanical components often use subcontractors across a number of countries. Local price developments are therefore often not very relevant, as the prices are driven by international trends. It can be mentioned that stainless steel has had a price increase of about 15-20% over the last five years.

Turbines have a general price increase of around 30%, although the increase has been somewhat higher for Kaplan turbines. The price increase is in the same region as for small power plants.

Please note that extensive use of subcontractors might lead to problems with obtaining the desired quality in the components ordered. In such cases the developer should spend more effort/money on quality control of the equipment purchased. This factor has not been included in the cost estimate.

4.2 TURBINES

4.2.1 General

Turbine prices are given as USD/kW maximum output and as a function of the maximum flow Q, the mean effective head H and rotational speed n. The prices apply mainly in the 5-300 MW output range.

Between two rotational speeds in the diagrams, the lower one must be used.

For a chosen rotational speed, the marginal costs for minor variations in maximum flow capacity or head will be smaller than what the curves might seem to show.

Please be aware that if one compares the curves for smaller turbines and large turbines, there might seem to be a contradiction in prices in the transition between large and small turbines. These are natural price jumps, caused by several different factors. Size and pressure contribute to different construction solutions, enabling simpler, softer, more standardized and cheaper solutions for small units. In addition, regulating capacity requirements will influence the costs of the units. There regulation capacity requirements are defined nationally, and vary quite significantly. Units that have such requirements (active frequency regulation, isolated grid ability, damper windings etc.) will be more costly.

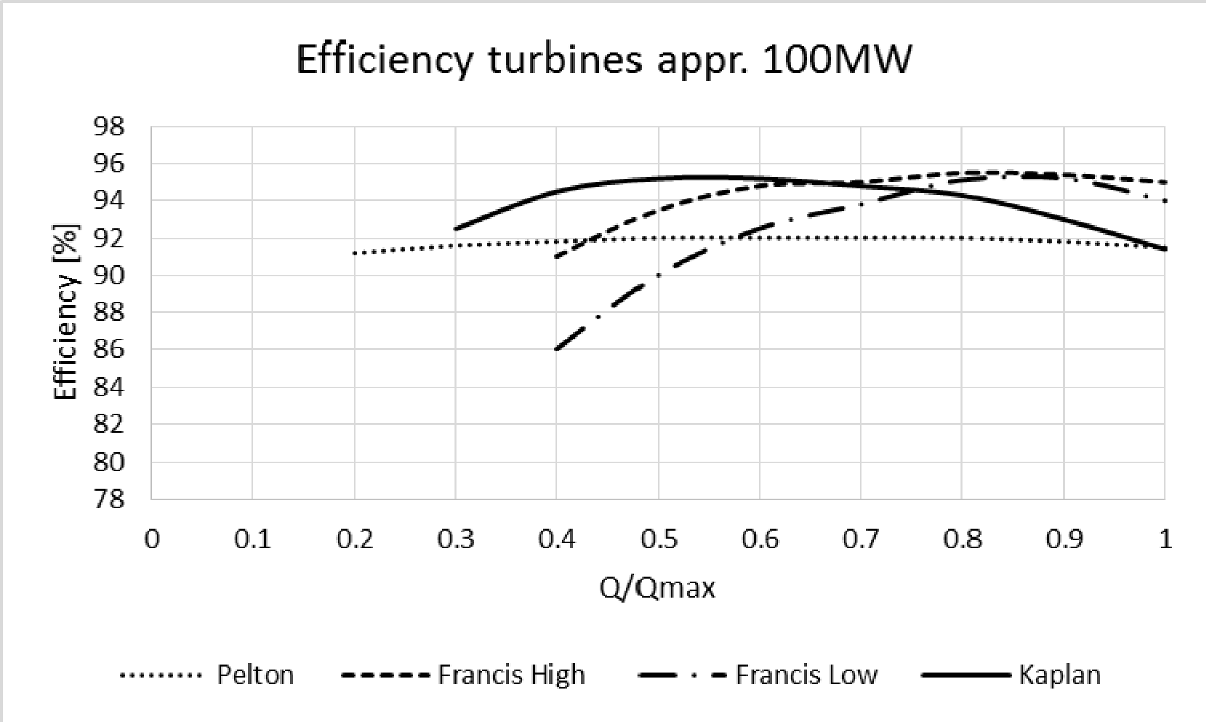
If two or more identical turbines are required in the same plant, turbine no. 2, no. 3 etc., will cost about 90% of turbine no. 1, if they are installed in a natural sequence.

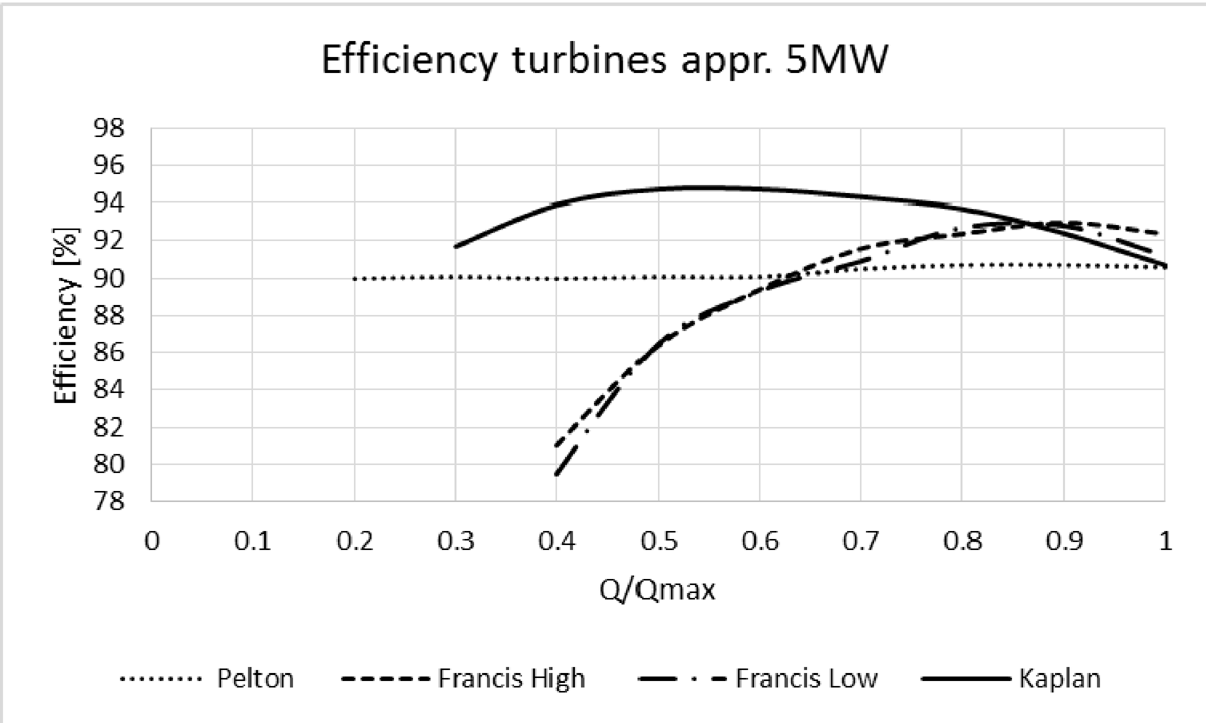
A spare turbine runner has not been included in the prices.

For all vertical machines, the turbine guide bearing is included. The thrust bearing is usually included in the generator delivery. For horizontal machines, both the radial bearings and the thrust bearing are usually included in the generator delivery.

4.2.2 Efficiencies

Some typical efficiency curves for various turbine types with an output of about 100 MW and about 5 MW are given below. The delivered output is estimated to be roughly 3-4% below the turbine output due to loss in the generator and transformer.





For actions to improve efficiency, see Chapter 4.2.7.

4.2.3 Pelton turbines with an output above approx. 10 MW

See Figure 4.2.1.

The price curves apply for turbines with a distributor ring, main inlet valve and frequency governor.

The curves are divided into two main areas: 2 jet horizontal turbines (horizontal axle) and 5-6 jet vertical turbines. Their range will in practice overlap, depending on variations in operation water flow, whether the station is on the surface or underground, etc. Sometimes 4-jet turbines might also be a good choice.

The Pelton runner must always remain above the highest tail water level. The turbines in the diagram must remain around one to four meters above the tail water level, depending on their size and shaft orientation.

For heads less than around 650 metres and large flows, a Francis turbine might be an option due to higher efficiency.

Prices are generally higher for Pelton turbines.

4.2.4 Francis turbines with an output above approx. 10 MW

See Figure 4.2.2.

The price curves apply for vertical units with a steel spiral casing, main inlet valve and frequency governor.

The prices apply for turbines with the runner center moderately submerged below lowest tail water level. If it is necessary for the turbine not to be submerged, the price will normally increase somewhat, but this depends to some extent on how close one is to the rotational speed limits.

For lower heads, high flow rates and great variations in flow, the Kaplan turbine might be an option. For greater heads, low flow rates and great variations in flow, the Pelton turbine might be an option.

4.2.5 Kaplan turbines with an output above approx. 10 MW

See Figures 4.2.3 and 4.2.4.

The price curves apply for double regulated vertical units with a frequency governor.

Two different price estimates have been given; one for Kaplan with a steel spiral casing, a head range of about 35-50 m, and one for Kaplan with a concrete spiral casing and a head range of about 5-30 m.

In the upper head range it may be an option to use a Francis turbine instead, particularly for small flow capacities and little variation in the water flow. In the lower head range it might also be possible to use bulb turbines, if sufficient stability is achieved. This will not alter the prices significantly, but the rotational speed will be 10-20% higher than shown in the diagram.

For Kaplan turbines equipped with a steel spiral casing and flow capacity below approx. 80-100 m^3/s, a butterfly valve might be used in front of the turbine instead of an intake gate. The valve cost may amount to 20-30% of the turbine price.

The price curves are generally higher for the Kaplan turbines.

4.2.6 Pump turbines

Pump turbine prices can be calculated by taking the price for a Francis turbine with the same operating flow and adding a percentage for the extra costs of a pump turbine. The ratio between Francis turbines and the corresponding pump turbines varies somewhat, but can on average be assumed to be about 1.25.

4.2.7 Measures to improve turbine efficiency

<u>Pelton turbines:</u>

Measures that can be taken to increase turbine efficiency are:

- New runner with improved hydraulic design, or to restore hydraulic profile after damages and frequent repairs
- New needles and nozzle assembly
- Modifying the turbine casing to reduce ventilation loss

The potential improvement in efficiency would be up to 3% for older turbines and 1% for newer ones (from about the 1970s). These improvements are valid for refurbished turbines. If there has been much wear and tear, the improvement will of course be even greater.

The cost of the runner comprises about 15-30% of a new turbine. The price will be affected by the technical choices made. The other components mentioned might make up about 10% of the costs of a new turbine. If the operating flow is increased, the turbine's mechanical regulation system might also have to be replaced (increased needle stroke).

The operating flow can normally be increased by 5-10%, but the increase is limited by the requirements for ventilation loss, back water level in the outlet channel and the generator's maximum output.

<u>Francis turbines:</u>

Measures that can be taken to increase turbine efficiency:

- New runner with altered geometry and optimum capacity
- New labyrinth seals
- New guide vanes and possibly guide vane end seals
- Adjusting the stay vanes with regard to inlet and outlet angles.

The potential improvement in efficiency would be up to 3% for older turbines and 1.5% for newer ones (from about the 1960s). This improvement is valid for refurbished turbines. If there has been much wear and tear, the improvement will of course be even greater.

The flow rate can normally be increased by 5-10%, but is limited by the requirements for submersion, permitted pressure rise during load rejections and the generator's maximum output.

The cost of the runner comprises about 15-30% of a new turbine. The price will be affected by the technical choices made. The other components that have been mentioned might make up about 10% of the cost of a new turbine. If the flow rate is increased, the turbine's mechanical regulation system might also have to be replaced (increased servo stroke).

Kaplan turbines:

Measures that can be taken to increase turbine efficiency:

- New runner with improved hydraulic design
- New guide vanes for increased flow capacity and reduced friction
- Adjusting the stay vanes with regard to inlet and outlet angles

The potential improvement in efficiency is up to 2% for older turbines and 1% for newer ones (from about the 1960s). If there has been much wear and tear, the improvement will of course be even greater.

The maximum flow rate can normally be increased by 5-10%, but is limited by the requirements for submersion and the generator's maximum output.

To perform prototype measurements to verify the hydraulic performance of Kaplan turbines is usually quite difficult and demanding. The resulting uncertainty is also quite high. Carrying out model tests may therefore be the cheapest and best method for verifying the efficiency.

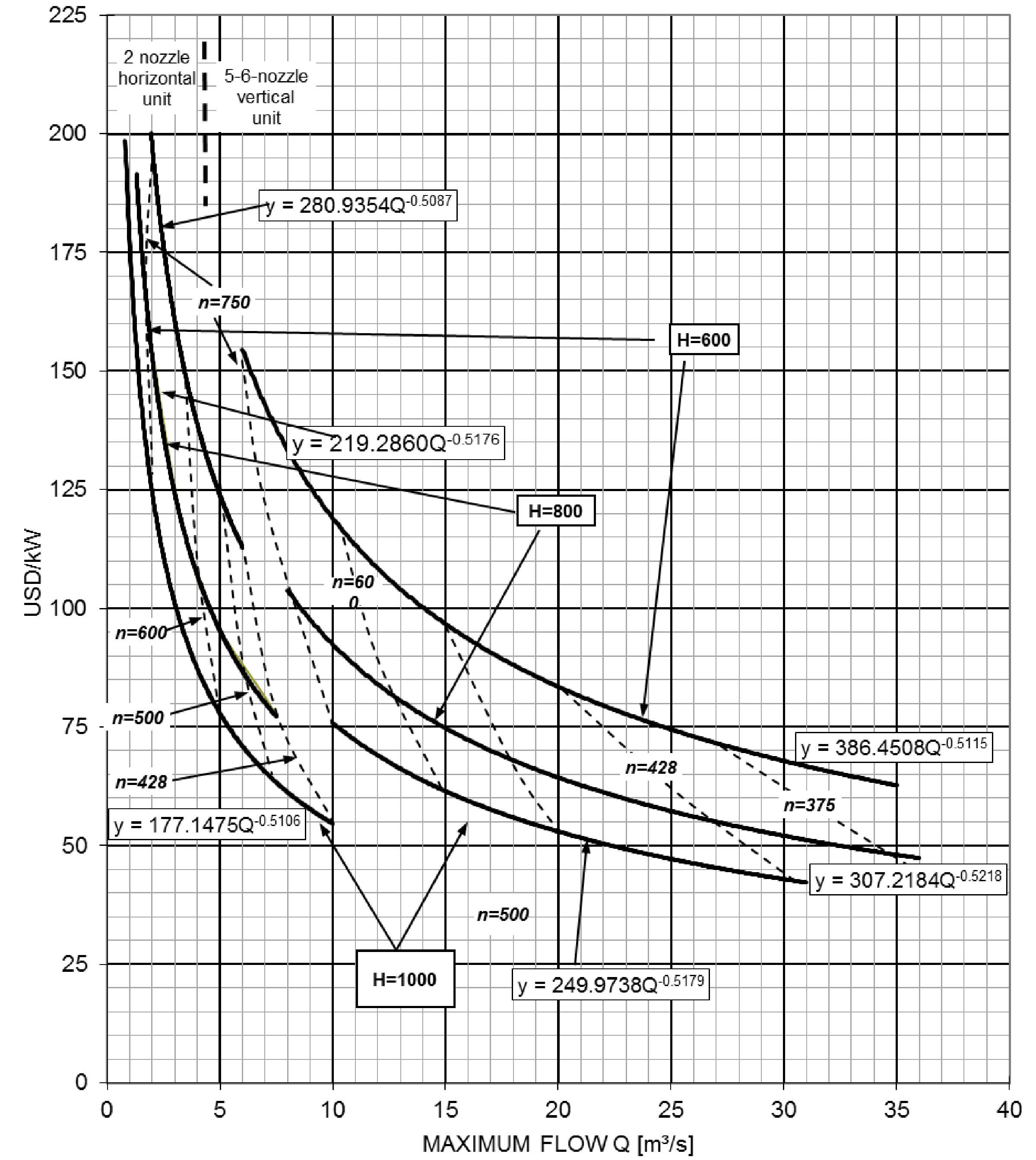
The cost of the runner comprises about 15-30% of a new turbine. The price will be affected by the technical choices made. The other components that have been mentioned might make up about 10% of the cost of a new turbine. If the flow rate is increased, the turbine's mechanical regulation system might also have to be replaced.

Improvements generally:

Improving the turbines through upgrades and modernization can generally give a 1-5% improvement in efficiency. In some cases, older power plants with Pelton turbines may be rebuilt into Francis turbines. If so, the gain might be up to 7% (at best efficiency point). This, of course, requires a major reconstruction of the power station, and such a measure is most appropriate if one is building a new power station next to the old one. In such a cases the flow rate may also be increased significantly.

If the turbine efficiency is improved by 1-5%, i.e. an output increase of 1-5%, equipment like the generator, transformer and other high-voltage equipment will in most cases already be dimensioned for this output level. Transformers and generators in particular are normally dimensioned to allow an increase of up to 10%. It is important to bear in mind that such a measure might, depending on how the components have been dimensioned, lead to a temperature increase that again might reduce the effective life of the equipment.

Bus bars, cables, power transformers, circuit breakers and isolators in particular must be checked to ensure that they have sufficient dimensions for an output upgrade.



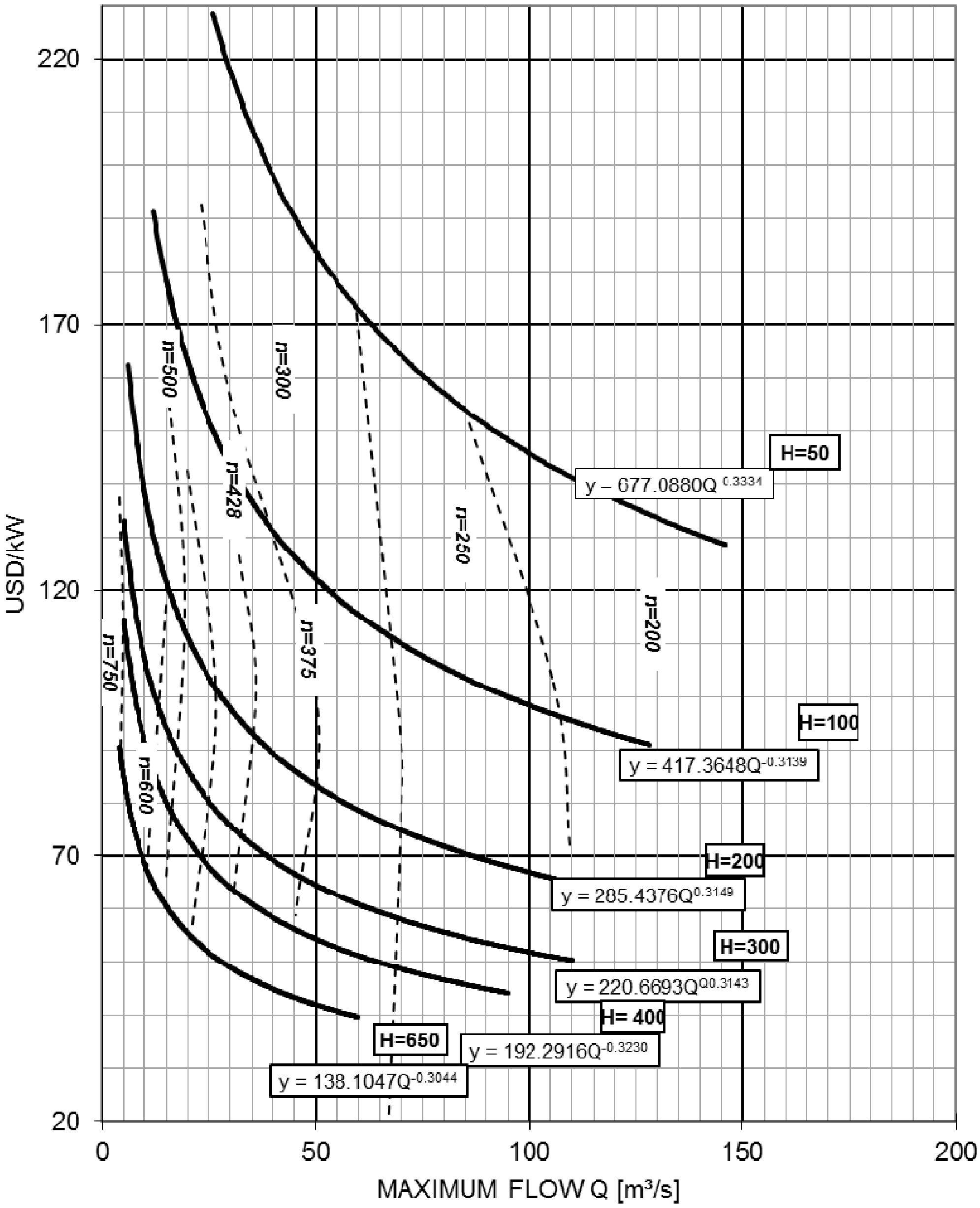
NOTES:

1. Price level January 2015

Norwegian Water Resources and Energy Directorate
NVE

PELTON TURBINE

Fig. 4.2.1
01.01.15



NOTES:

1. Price level January 2015

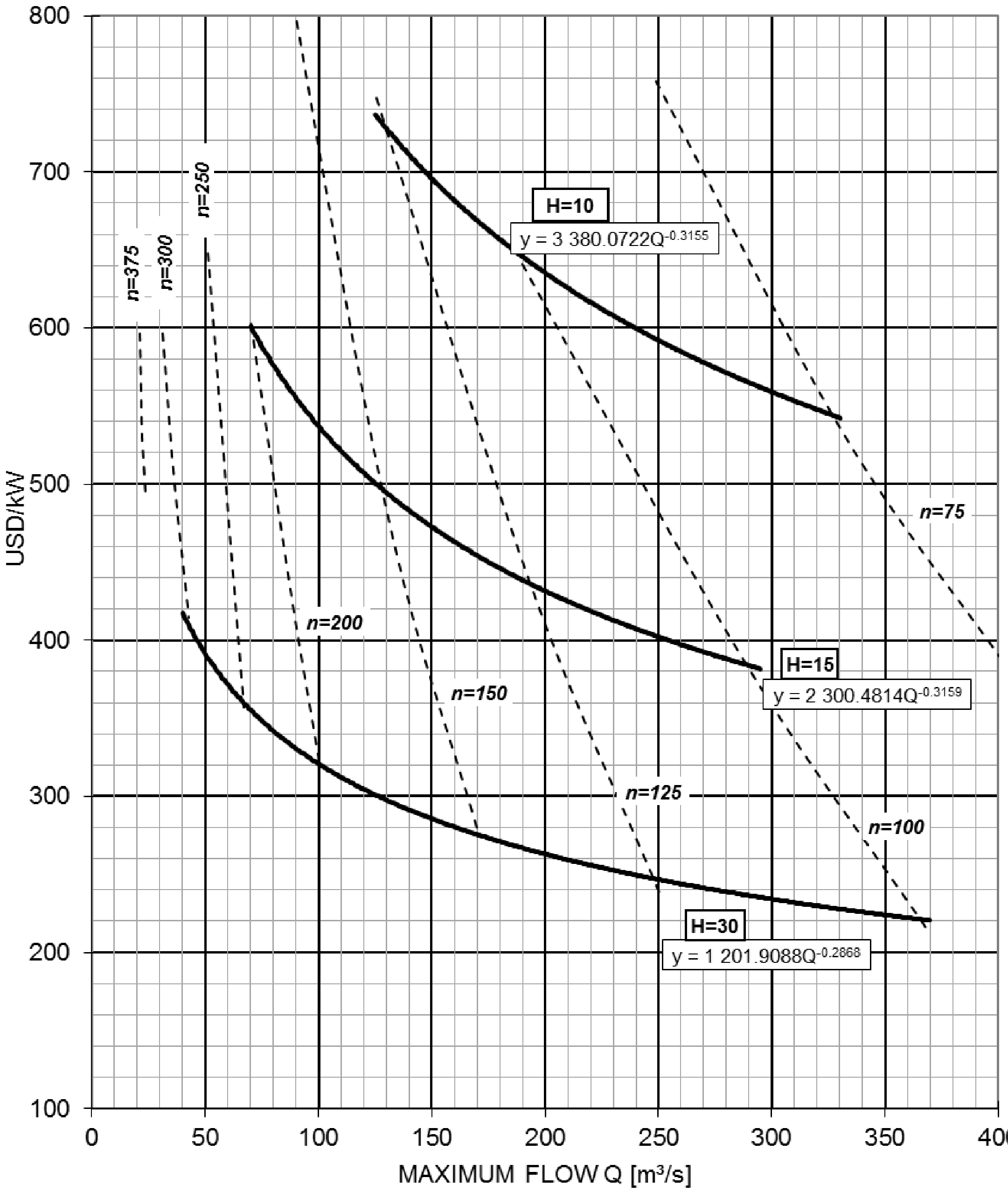
2. Turbine centre app. 3 m below lowest tailwater level

Norwegian Water Resources and Energy Directorate

NVE

FRANCIS TURBINE

Fig. 4.2.2
01.01.15



NOTES:

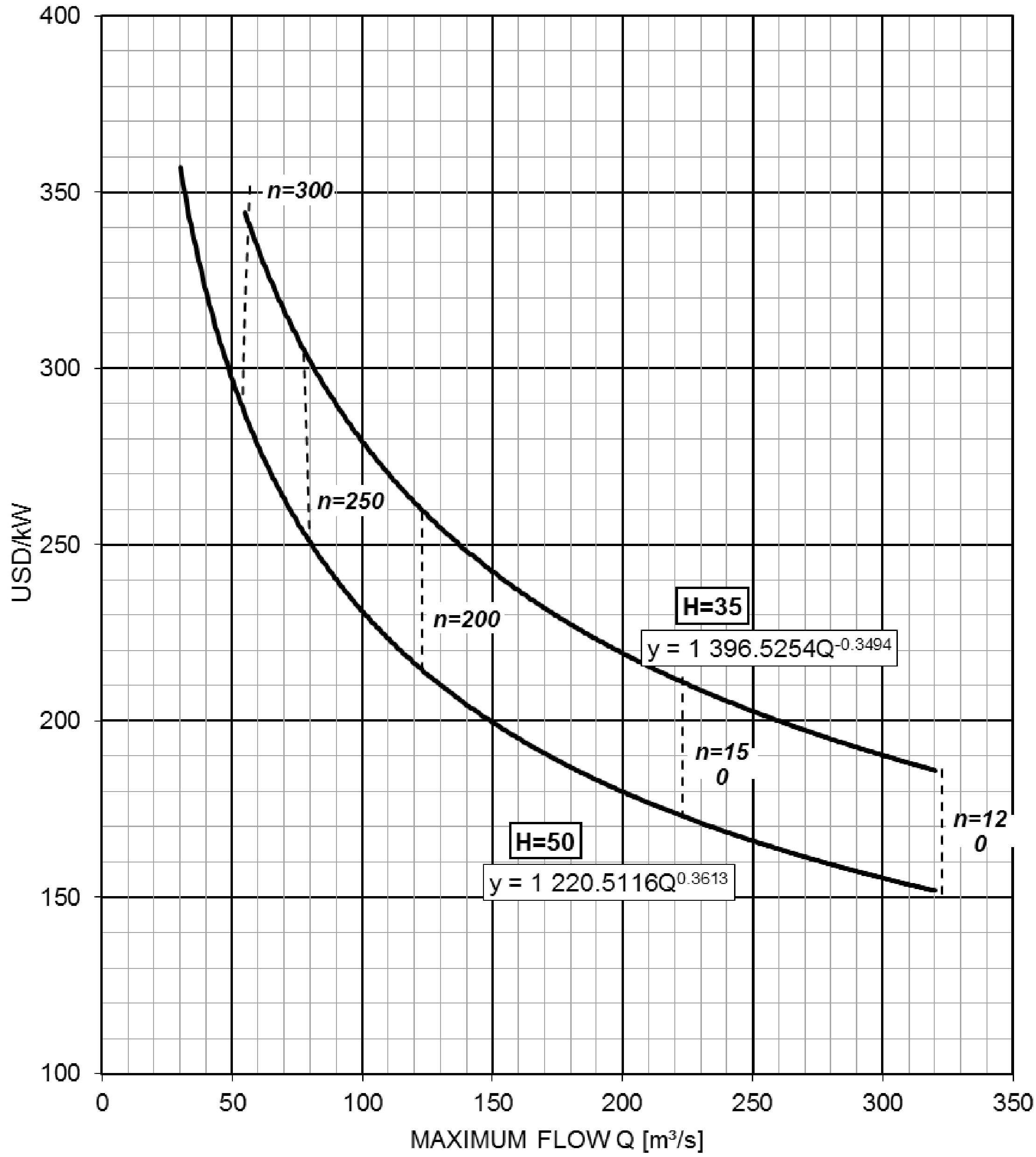
1. Price level january 2015
2. Curves for vertical units with concrete spiral casing

Norwegian Water Resources and Energy Directorate

NVE

KAPLAN TURBINE WITH CONCRETE SPIRAL CASING

Fig. 4.2.3
01.01.15



NOTES:

1. Price level January 2015

Norwegian
Water Resources and
Energy Directorate

NVE

KAPLAN TURBINE WITH STEEL SPIRAL CASING

Fig. 4.2.4
01.01.15

4.3 PUMPS

See Figure 4.3.1.

Prices on pumps have been stated as USD/kW stamped motor size, and as a function of the maximum flow Q and pump head H. The prices apply for the range above 100 l/s. The cost curves have been brought as far to the right as the standard programs for most of the relevant pump suppliers will go.

The efficiency increases with increasing water flow from approx. 75% at 0.1 m^3/s to 90% above 2 m^3/s.

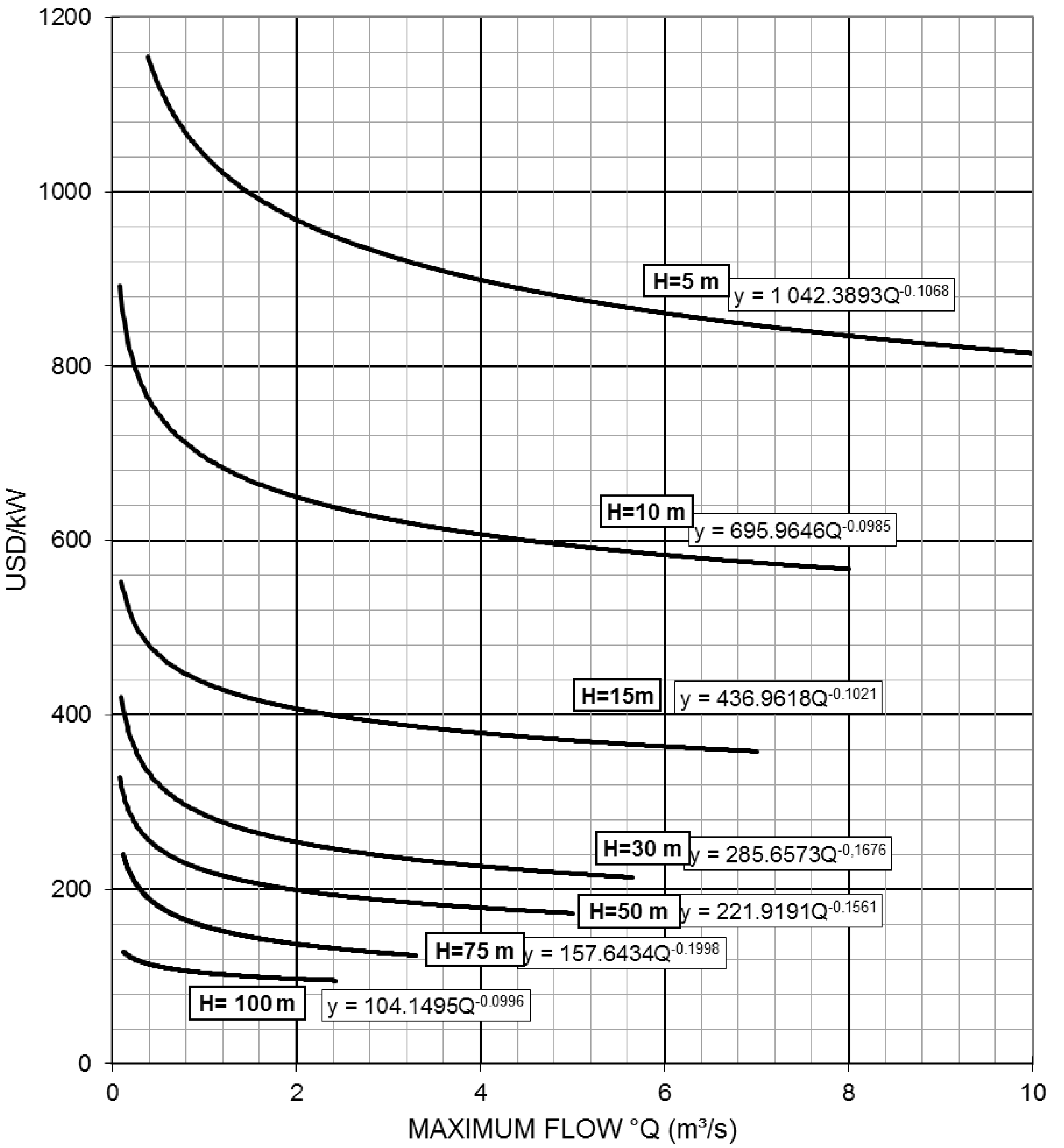
The rotational speed given is only indicative, and may in practice turn out to be one or even two steps different in either direction, depending on the submersion, design of the pump runner and the number of pump stages.

Unless one is buying more than three pumps for the same station, no quantity discount should be expected.

Pumps and electro-technical equipment will often be part of the same delivery.

The cost curves assume suction pumps with the inlet and outlet perpendicular to each other, or alternatively suction pumps with the inlet and outlet along the same axis.

For pressure heights above 100 m, prices for centrifugal pumps should be obtained from the supplier.



NOTES:

1. Price level January 2015

2. Prices are included motor and electrical cabinet

3. Horizontal pumps

Norwegian Water Resources and Energy Directorate

NVE

PUMPS

Fig. 4.3.1
01.01.15

4.4 GATES

4.4.1 General

Gate prices have been provided in USD in relation to the gate area A in m^2 and the design pressure H in mWc. The prices are for gates installed. For inlet gates and discharge gates in a tunnel, the price estimate for concrete plugs in a tunnel and blasted shafts may be used to estimate the construction costs.

4.4.2 Segment gates

See Figure 4.4.1.

Segment gates are most often used as dam gates, without top seal, designed for flood diversion or as regulating gates in rivers. Still, segment gates can also be used as intake gates and as discharge gates in dams and bypasses.

Opening forces are small compared to sliding gates.

4.4.3 Flap gates

See Figure 4.4.2.

The flap gate is a dam/surface gate used for flood diversion and control of water level in reservoirs and rivers. The gate is suitable when transport of timber, ice etc. in the river of concern.

The gate can be made long compared to its height and still have unilateral lifting machinery. The disadvantage of this type of gate is relevant where the temperature may fall below zero during winter. Even small seal leakages can result in ice build-up on downstream sill and sidewall. This may prevent the gate from opening.

4.4.4 Rubber gates

See Figure 4.4.3.

In some cases, rubber gates will be used instead of flap gates, segment gates or sector gates. The range of use will primarily will be where its small reservoirs, and consequences of a gate failure is small.

The advantages of rubber gates are:

- Favorable price at large gate lengths
- Simple civil works
- Easily maintained
- Low operational costs
- Not very visible in the terrain.

- Can be made in very long lengths
- Good seals

The disadvantages are:

- Control of reservoir level by partially opening the gate is not recommended.
- Over-topping may result in vibration problems (20-30% overtopping for air filled and 30-40% overtopping for water filled)
- Can only be used as surface gates.
- Limitations in possible gate heights

Previously, a cost curve for rubber gates was not included. Based on recent replies from suppliers compared with previous work with small hydro projects, we now include a cost curve for rubber gates. The prices are somewhat uncertain for large gate areas (i.e. long gates). The prices include gate with compressor, piping, governor, steel supports etc, fully commissioned. Prices does not include civil costs.

4.4.5 Roller gates

See Figure 4.4.4.

Roller gates are mainly used as intake gates, where self-closing capabilities at full water flow is necessary. Roller gates should be considered where closing at one-sided pressure is required, and where:

Pressure (m) * gate area (m^2) > 500

Roller gates are advantageous mainly at large gate apertures (free openings) due to the reduced lifting forces compared to sliding gates. This will result in less costly lifting mechanism and lifting rod.

Roller gates are not suitable as discharge gates.

Roller gates often have a revision gate just upstream of the main gate, with lifting rod in the same shaft. This will greatly ease maintenance of the main gate. Revision gate is not included in the price curves.

The price addition for a revision gate will be approximately 50%.

4.4.6 Sliding gates

See Figure 4.4.5.

The sliding gate is most commonly used as discharge gate in dams and transfer tunnels, but can also be used as closing gates in tunnels, draft tubes and intakes.

Due to friction between gate and gate guide, sliding gates are often not self-closing unless in still water. If used as discharge gate, the gate therefore must have a lifting mechanism also capable of pushing the gate downwards. This may result in a significant increase of the forces in the lifting mechanism.

Also for sliding gates, it is common with revision gates in the same manner as for roller gates. The price addition is approximately 70%.

4.4.7 Draft tube gates

See Figure 4.4.6.

For Francis and Kaplan units that are submerged, gates are installed to be able to empty the turbine of water for inspections and maintenance. The draft tube gate is often a sliding gate, without revision gate.

In stations with two or more identical units, the arrangement can be such that the units share one draft tube gate. If more than one identical draft tube gate is purchased, a price reduction of approximately 30% can be expected for the following gates.

4.4.8 Adit gates

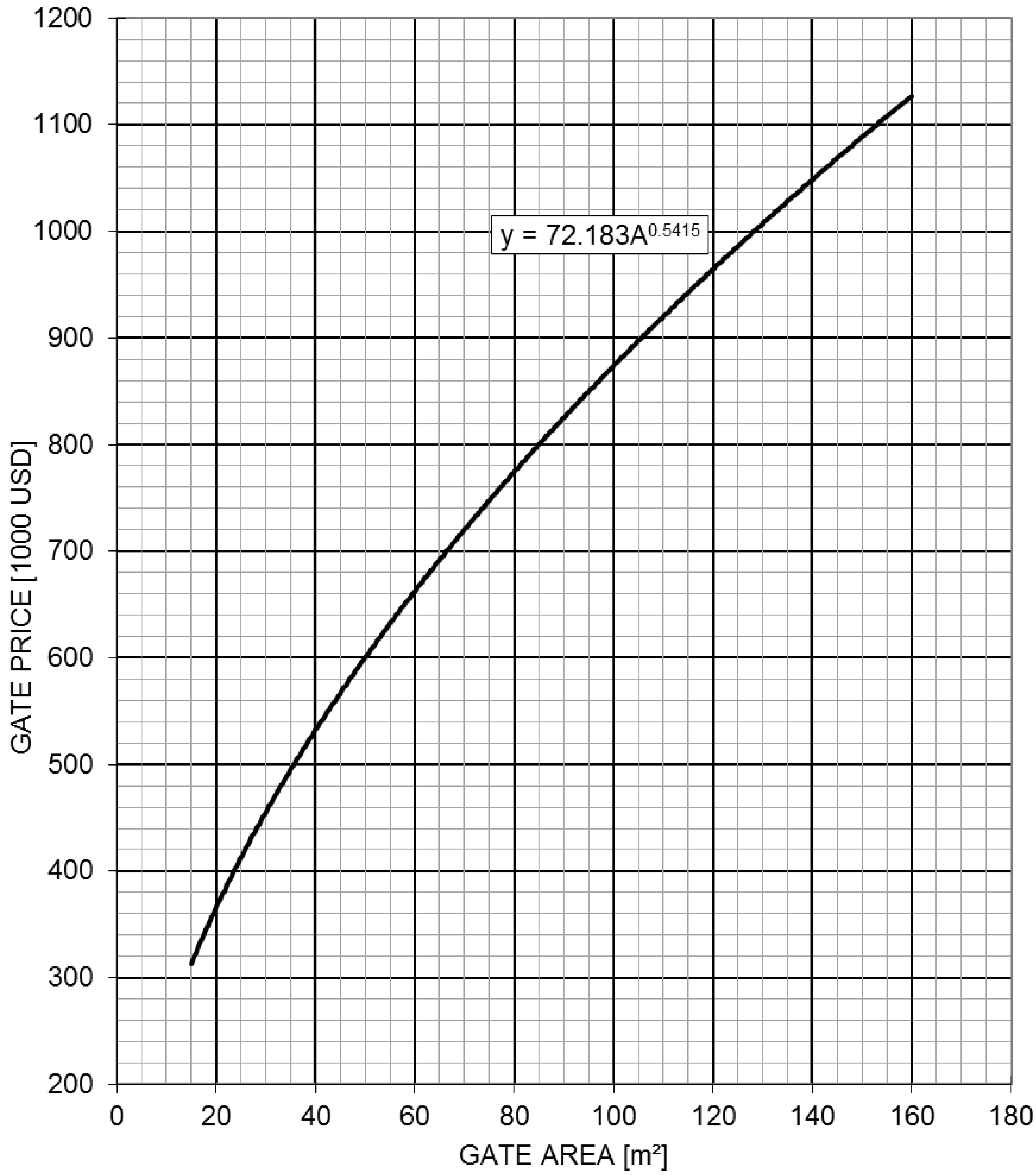
See Figure 4.4.7

Adit gates are used to close the access or service openings of the waterways.

Adit gates are made in very varying size and pressure classes, from man holes to gates large enough to drive large trucks through. The gate is often installed in a steel enforced concrete plug.

The price curve do not distinguish between circular or square-shaped adit gates.

To ensure long term stability of the structure, one may require that the steel lining is on the high pressure side of the adit gate. This may increase the use of steel and hence the price, but is a more robust solution. In addition, some actors now use stricter requirements for anchoring of the steel lining. This will also increase the installation cost.



NOTES:

1. Price level January 2015

2. Prices for dam gates without top seal

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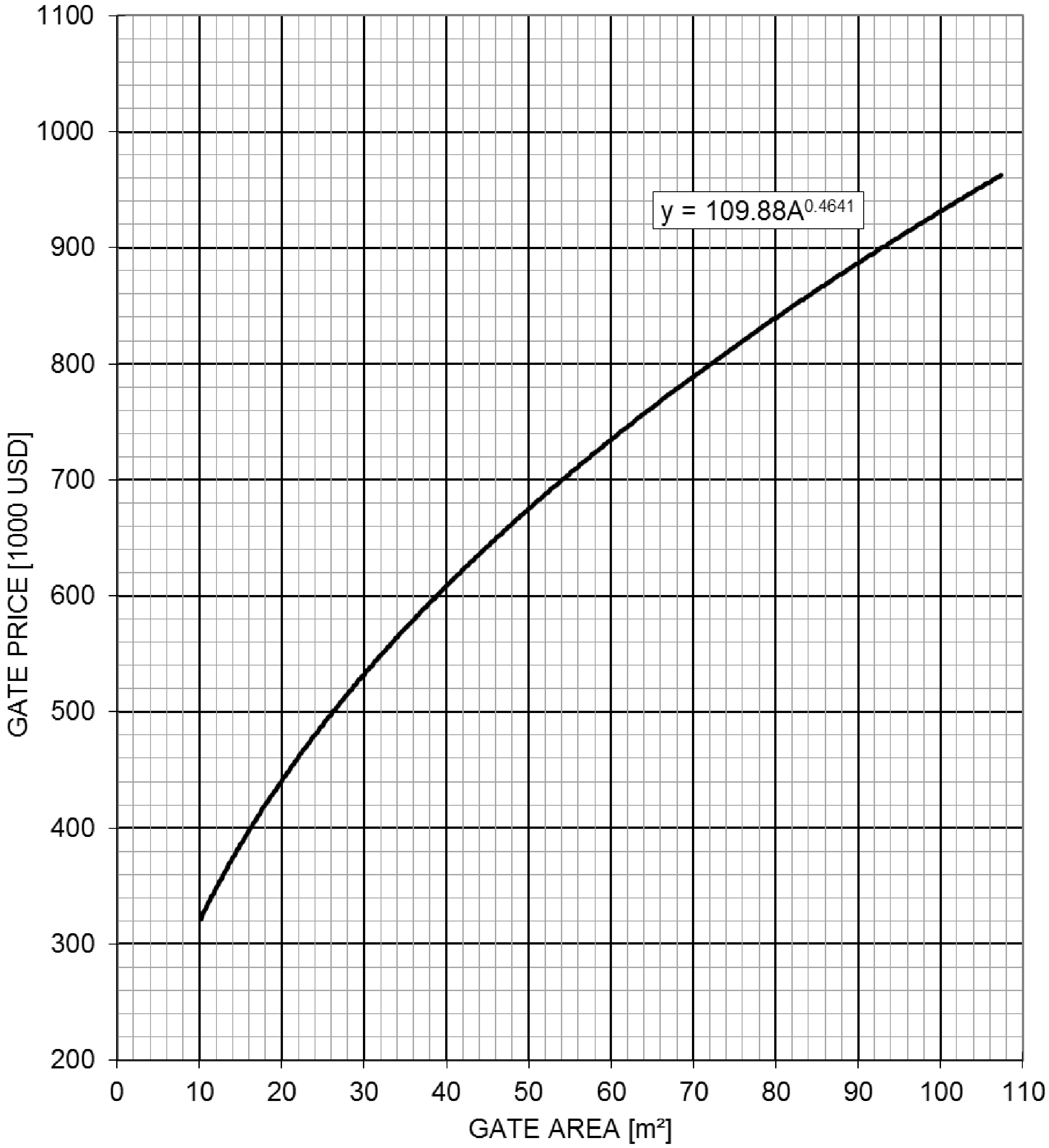
SEGMENT GATES

Fig. 4.4.1
01.01.15



NOTES:

1. Price level January 2015

2. Sill pressure < 5 m

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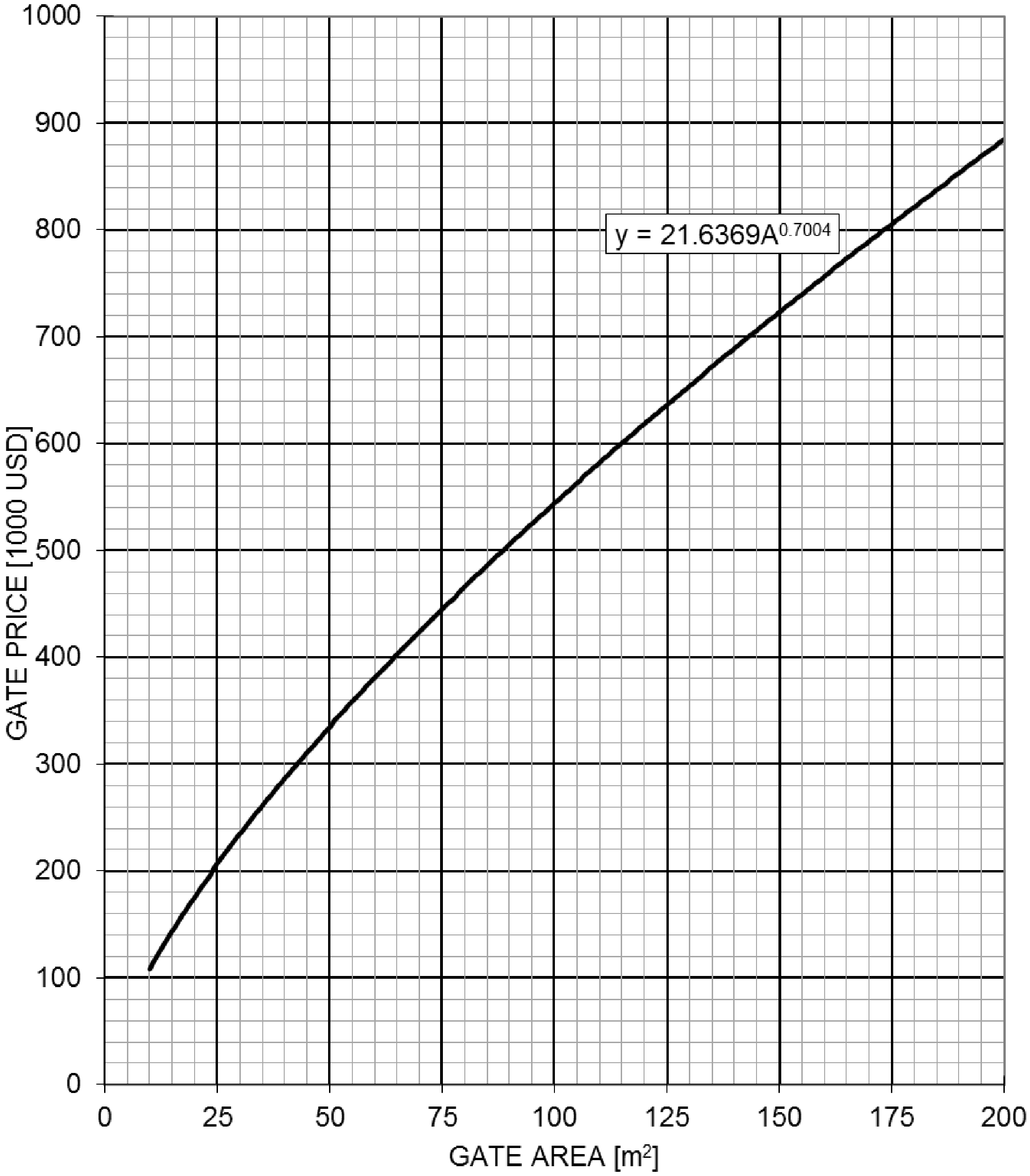
FLAP GATES

Fig. 4.4.2
01.01.15



NOTES:

1. Price level January 2015

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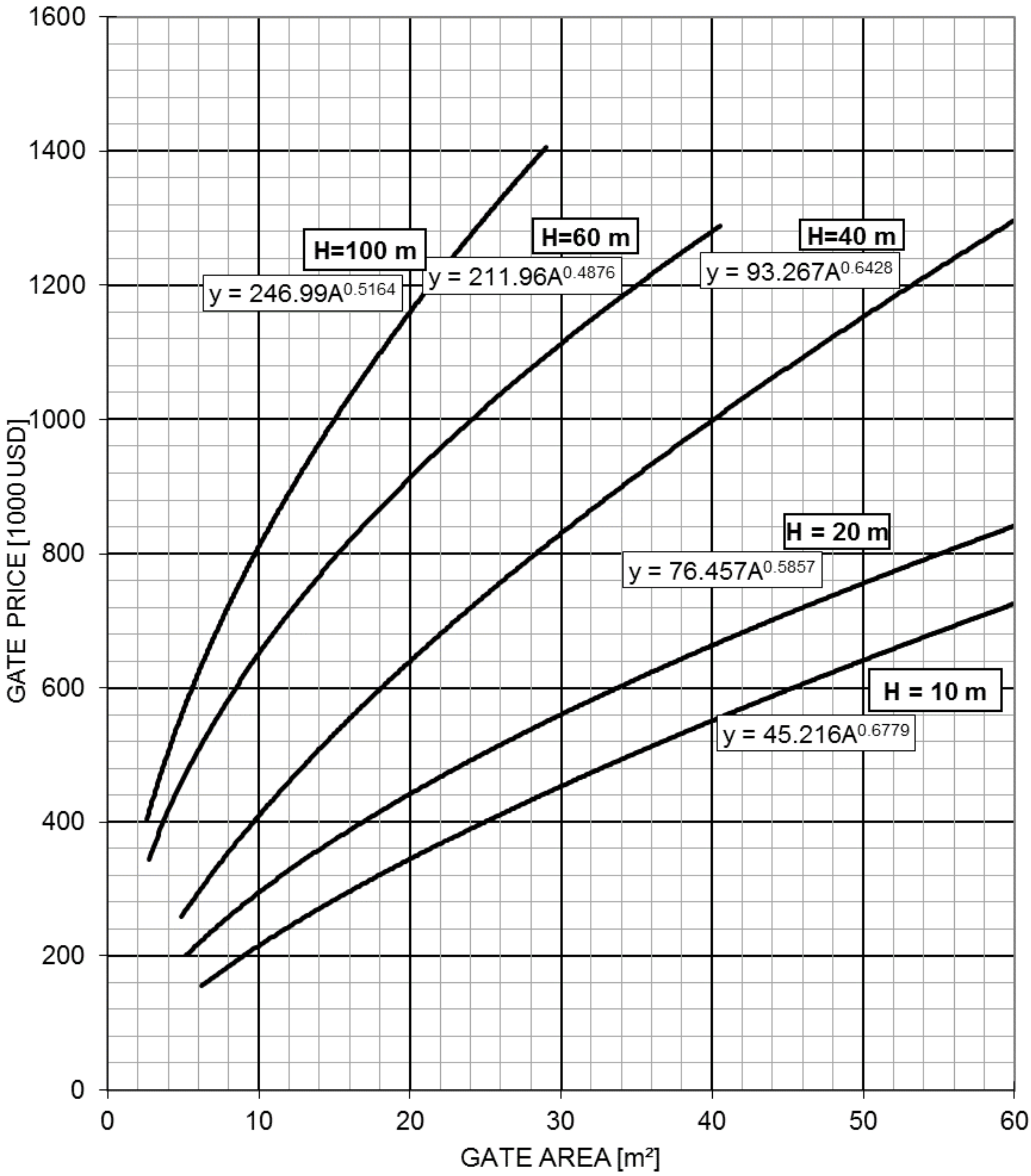
RUBBER GATES

Fig. 4.4.3
01.01.15



NOTES:

1. Price level January 2015

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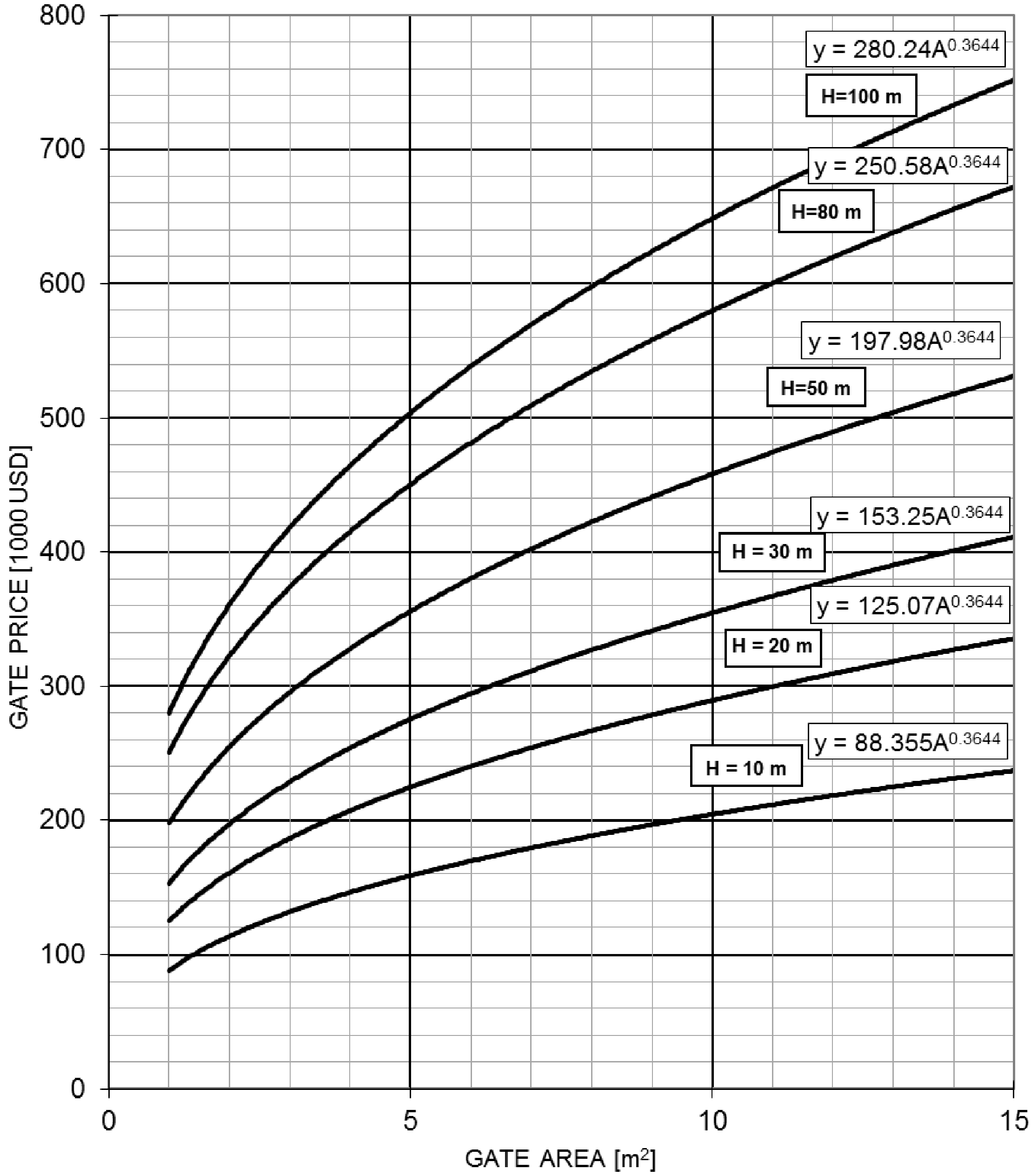
NVE

ROLLER GATES

Fig. 4.4.4
01.01.15



NOTES:

1. Price level January 2015
2. Length of pull rod equal to construction pressure
3. For construction pressure lower than 10 mWc, standard gates are assumed

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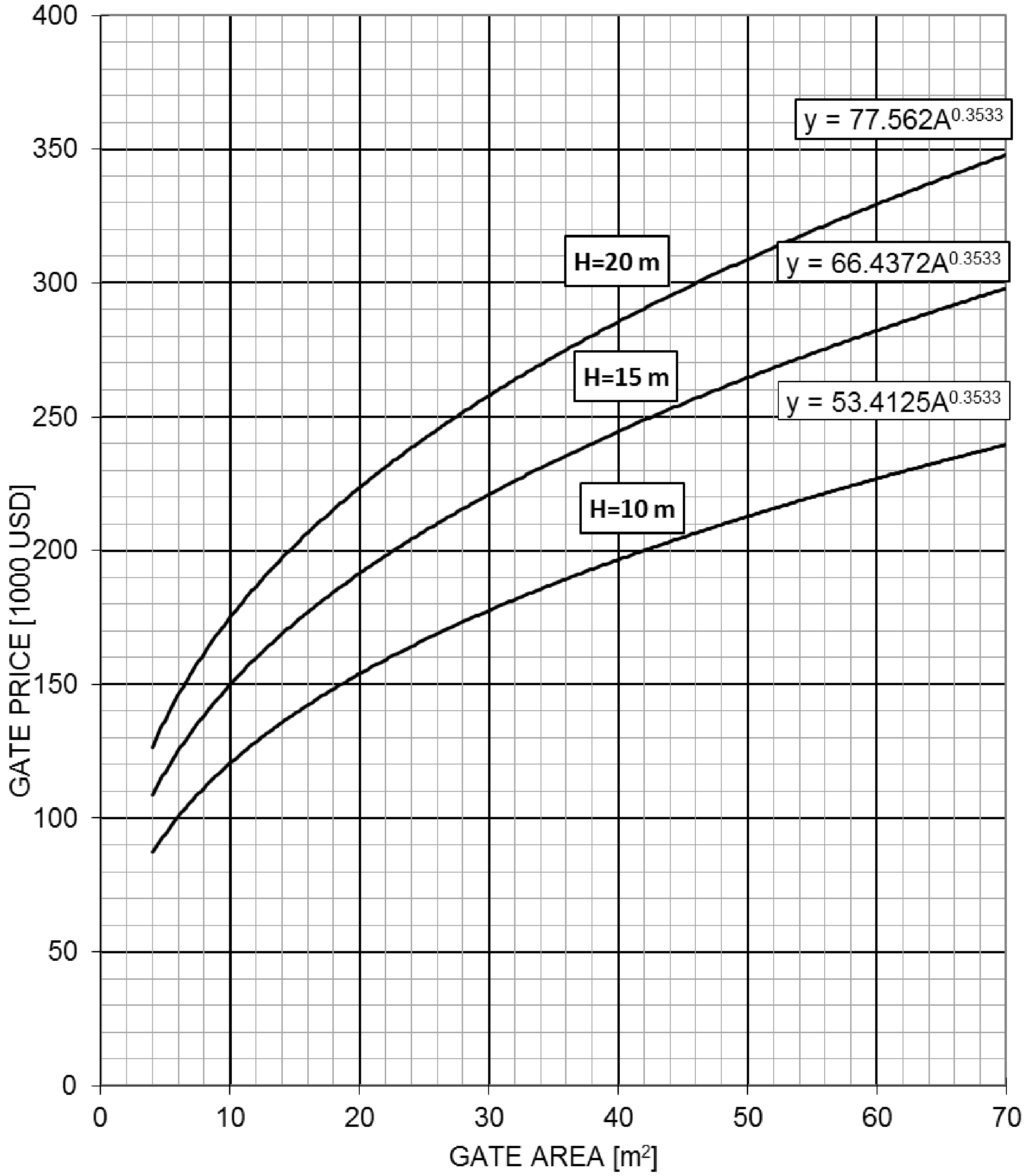
SLIDING GATES

Fig. 4.4.5
01.01.15

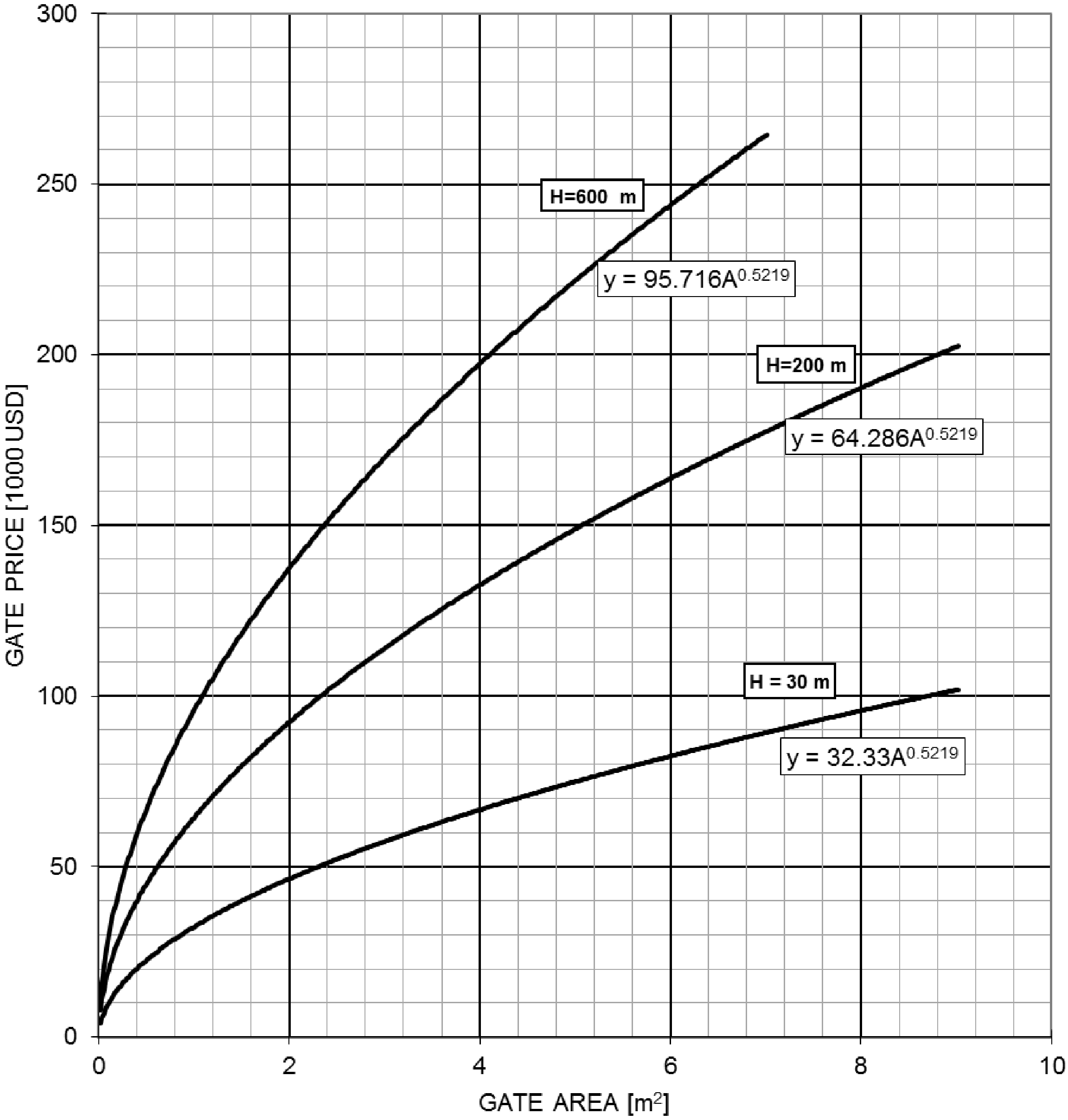


NOTES:

1. Price level January 2015

2. Price excl. lifting equipment

Norwegian Water Resources and Energy Directorate	**DRAFT TUBE GATES**	Fig. 4.4.6 01.01.15



NOTES:

1. Price level January 2015

Norwegian Water Resources and Energy Directorate

NVE

ADIT GATES

Fig. 4.4.7
01.01.2015

4.5 MISCELLANEOUS EQUIPMENT

4.5.1 General

Previously, the following equipment was included in a lump sum called “Miscellaneous equipment”:

- Intake screen
- Main crane
- Cooling and drainage plant
- Draft tube gate

In this edition, this category is split up, and prices given separately for each of the bullets above.

4.5.2 Intake screen

See Figure 4.5.1.

The price for intake screens is given as a function of the screen area. The price assumes that the screen is dimensioned for 10 meters one-sided water pressure (when screen is used with planks as a revision gate), water velocity of 1 m/s through the screen and free opening between the rods between 20 and 100mm (often 50-60mm). The screen is made in steel. Heating, screen rake, civil works etc. is not included.

4.5.3 Main crane

See Figure 4.5.2.

Price for main traveler crane is given as a function of the lifting capacity. The curves are valid for travelling cranes with capacity above 40 tonnes. The span is assumed to be 12 meters. The capacity of an auxiliary crane is assumed to be 10 tonnes.

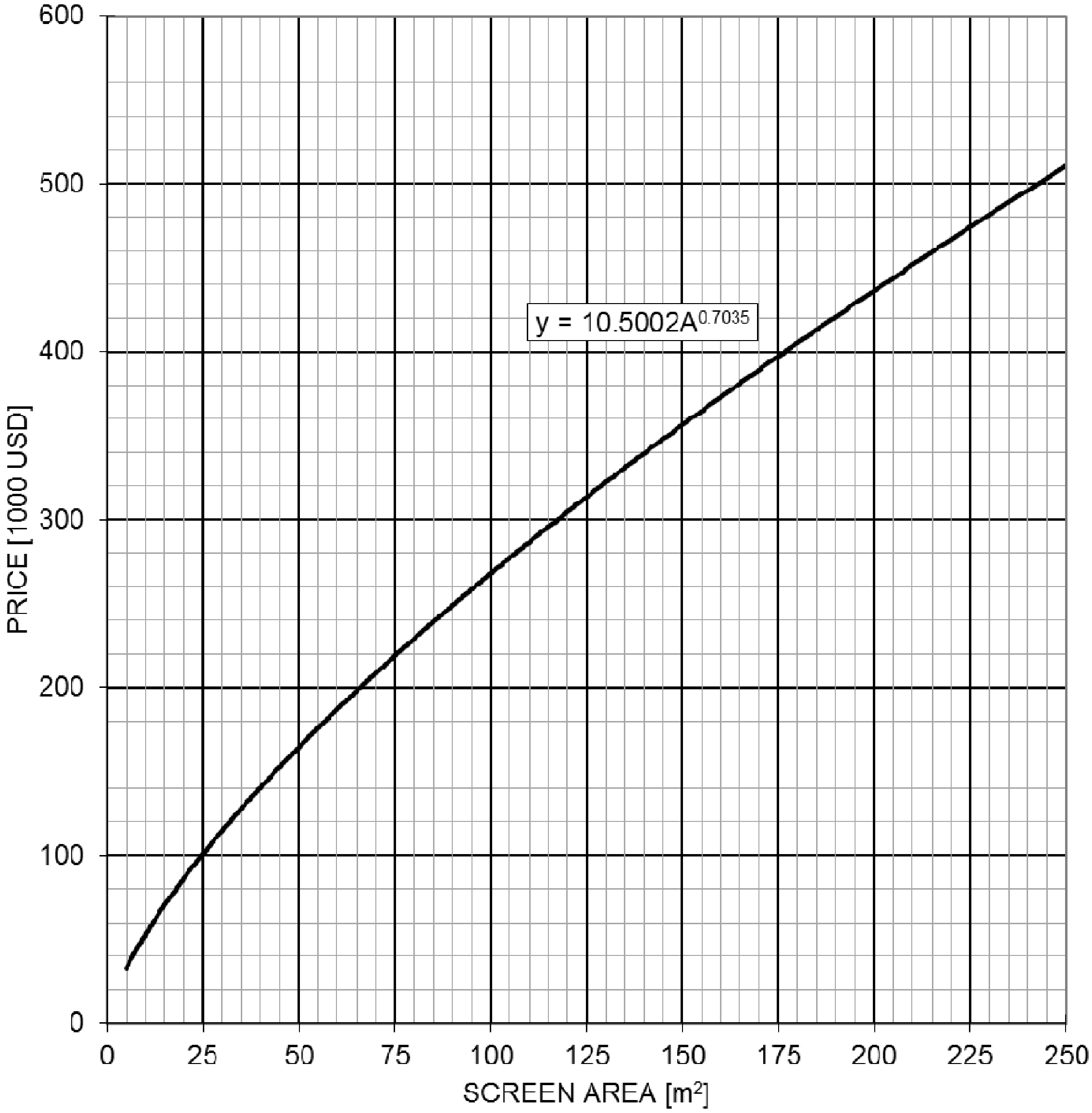
4.5.4 Cooling and drainage plant

Each cooling and drainage system is custom designed for each power plant, and every system is therefore unique. Construction, technical solutions and choice of components will vary from power plant to power plant. The construction will be dependent on turbine type, size and orientation, available space, and the complexity of the system will increase with number of turbine units.

We will not present price curves here. However, 6-7 USD per kW turbine output can be used as a rule of thumb to obtain a typical value.

4.5.5 Draft tube gates

See Chapter 4.4.7.



NOTES:

1. Price level January 2015

2. Prices assume 10 mWc differential pressure

3. Thrash rack made in steel

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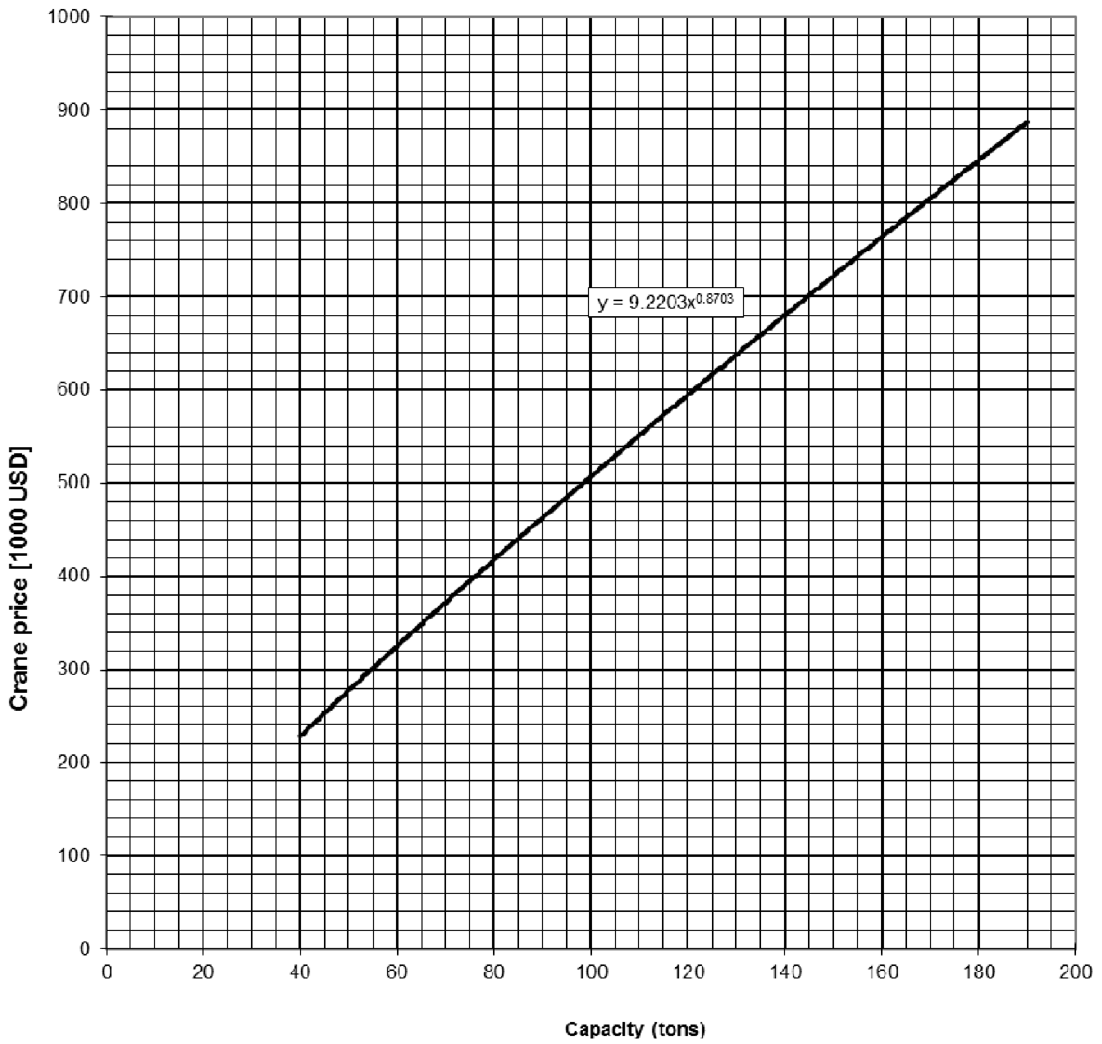
Energy Directorate

NVE

INTAKE SCREEN

Fig. 4.5.1
01.01.15



Notes:

1. Price level January 2015
2. Span assumed 12 m
3. Secondary crane weight assumed 10 tons

Norwegian Water Resources and Energy Directorate

NVE

MAIN TRAVELLER CRANE

Fig. 4.5.2

01.01.2015

4.6 VALVES

As spherical valves are common in larger power plants, a separate curve is presented in this issue of the Cost Base.

4.6.1 Sperical valves

See Figure 4.6.1.

Sperical valves are mainly used as main inlet valve placed as close to the turbine as possible. On larger turbine with pressure above 200m, spherical valves are almost exclusively used. They are relatively expensive, but have virtually no head loss.

The main inlet valve is often included in the turbine delivery. For estimates of separate valve prices, see Figure 4.6.1.

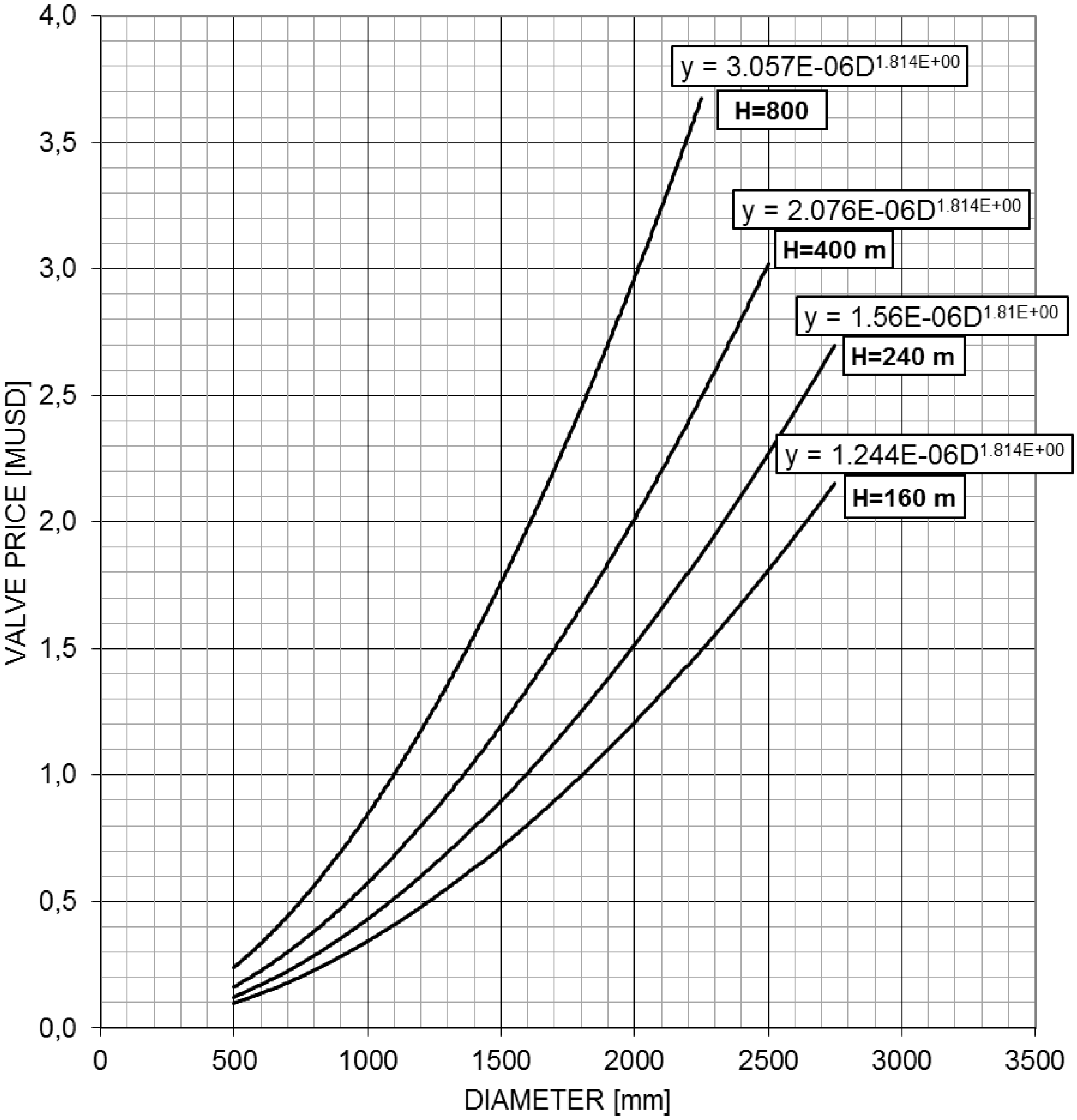
The valve price is given as a function of the valve inner diameter and the maximum design pressure. The price includes governor and hydraulic unit. If two or more identical valves are purchased, a price reduction of 25% can be expected for the following valves after the first.

4.6.2 Butterfly valves (pipe rupture valves)

See Figure 4.6.2.

As main inlet valves, butterfly valves are used for lower heads and when inner dimensions are large (Ø > 1200mm).

Butterfly valves are also used as pipe rupture valves. Expected valve price is given in Figure 4.6.2. The price is given as a function of the valve inner diameter and pressure class (PN). Prices include pipe rupture trigger and expansion joint. Price reduction when ordering more than one valve is assumed to be 25% following the first valve.

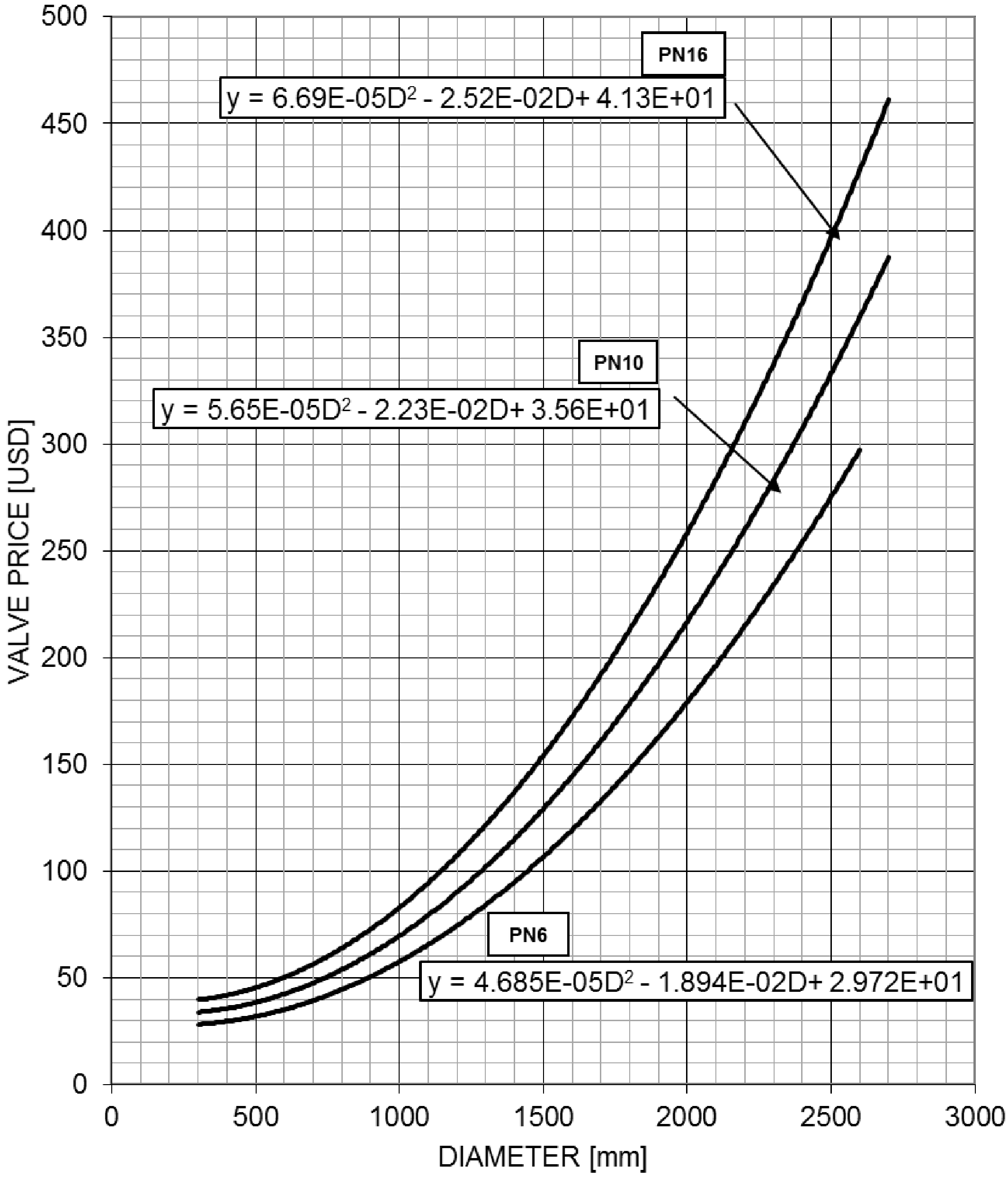


NOTES:

1. Price level January 2015

2. Incl. hydraulic unit and valve governor

Norwegian Water Resources and Energy Directorate NVE	**SPHERICAL VALVES**	Fig. 4.6.1 01.01.15



NOTES:

1. Price level January 2015

Norwegian Water Resources and Energy Directorate NVE	**BUTTERFLY VALVES (PIPE RUPTURE VALVES)**	Fig. 4.6.2 01.01.15

4.7 PIPES

4.7.1 Pipes on saddles or embedded pipes

See Figures 4.7.1 and 4.7.2.

The price curves show supplier costs for pipes on saddles, including installation but excluding building costs. Prices are given per meter pipe as a function of inner diameter and pressure.

The curves are basically based on two types of pipes: steel pipes and glass-fibre reinforced unsaturated polyester pipes (GRP).

The cost curves are shown in Figures 4.7.1 and 4.7.2. The basis for evaluating steel pipe price is somewhat limited.

The curves include necessary connecting parts (cones, bends, diffusors etc.) at both the upstream and the downstream end of the pipe. The curves are valid for "longer" pipes, i.e. longer than approximately 150 m, equipped with one bend each 150 m. For shorter pipes, or more bends etc., costs will rise. GRP pipes need twice as many foundation blocks (saddles) as steel pipes, and the foundation blocks will be more expensive, while the fixed points become cheaper. The price curves for GRP pipes are based on a total pipe length of minimum 300 m.

Steel pipes are divided into three groups:

a) Less than 700 mm.
The price depends to some extent on how important future internal corrosion protection is found. Below approximately 500 mm and 500 m pressure, ductile cast-iron pipes might be an option.

b) Dimension approx. 700 mm < D < approx. 2000 mm
Internal corrosion protection is no problem for this size, and there is quite a lot of price competition. Delivery is often based on spiral-welded pipes.

c) Large pipes
The price competition is limited.

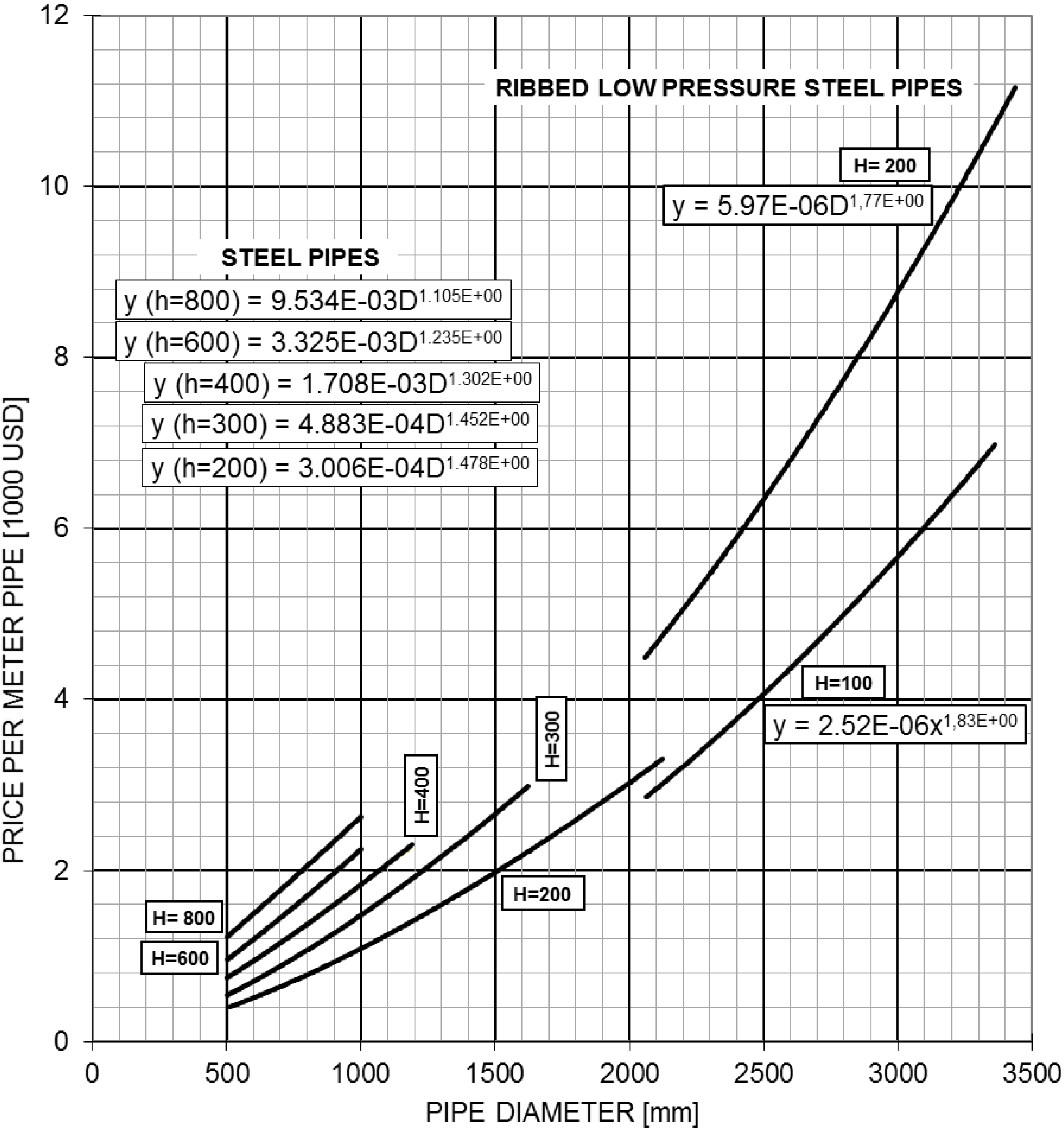
The same prices can be used for buried pipes as for pipes on saddles.

4.7.2 Steel-lined pressure shafts

See Figure 4.7.3.

The price curves give supplier costs for installed steel linings. The price assumes an overall length of approximately 100 m, rock cover (in m) approximately 20% of the design pressure and with only internal water pressure as dimensioning pressure. If external water pressure is relevant or the rock cover is thin, prices will change.

The price curve includes necessary transition in the upstream and downstream end. Prices are stated as USD per meter pipe as a function of inner pipe diameter and pressure.



NOTES:

1. Price level January 2015

2. H is largest pipe pressure in mWc

3. Price for installed pipe, excl. civil costs

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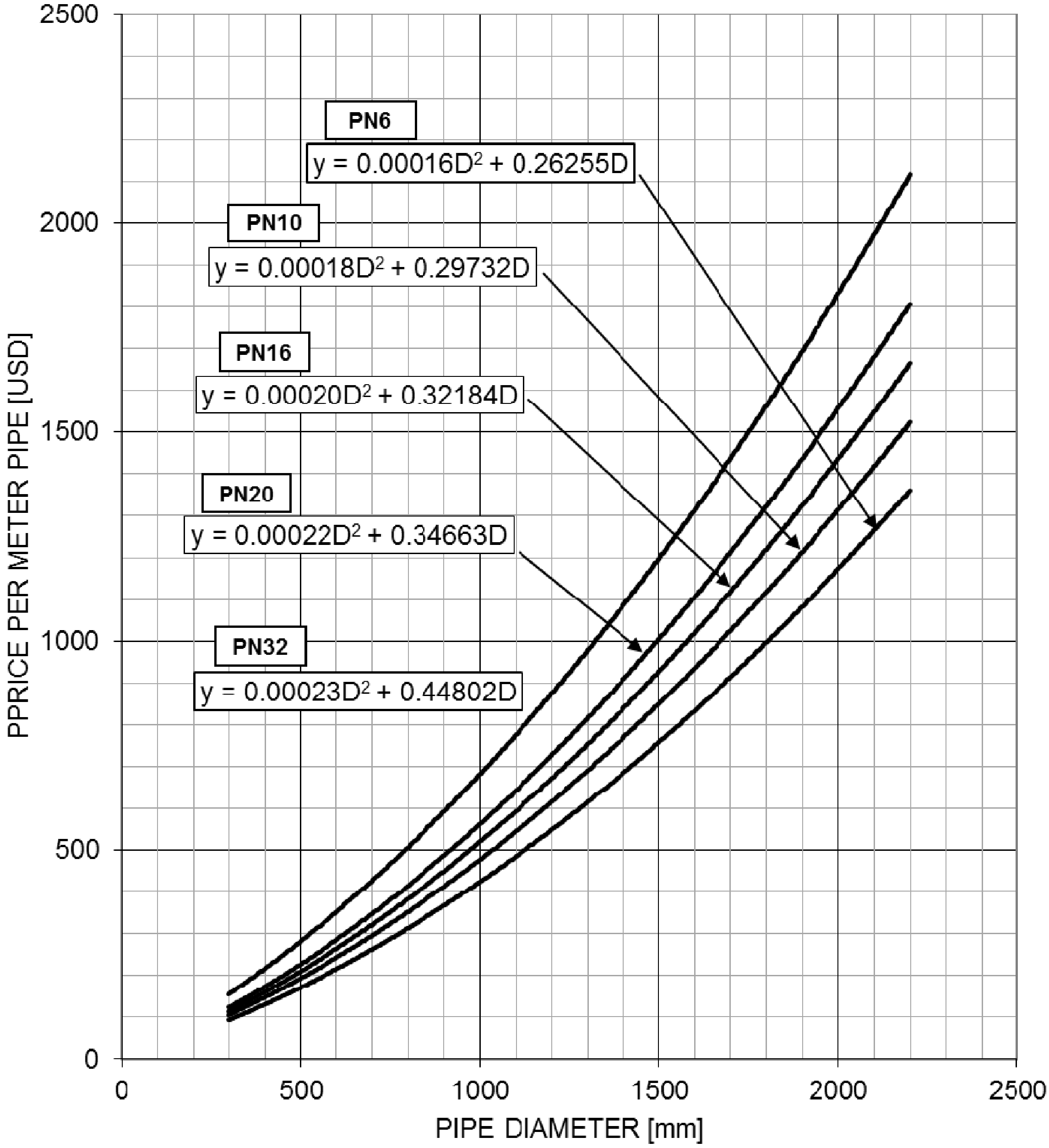
STEEL PENSTOCK ON SADDLES

Fig. 4.7.1
01.01.15



NOTES:

1. Price level January 2015

2. Prices for installed pipe, excl. civil costs

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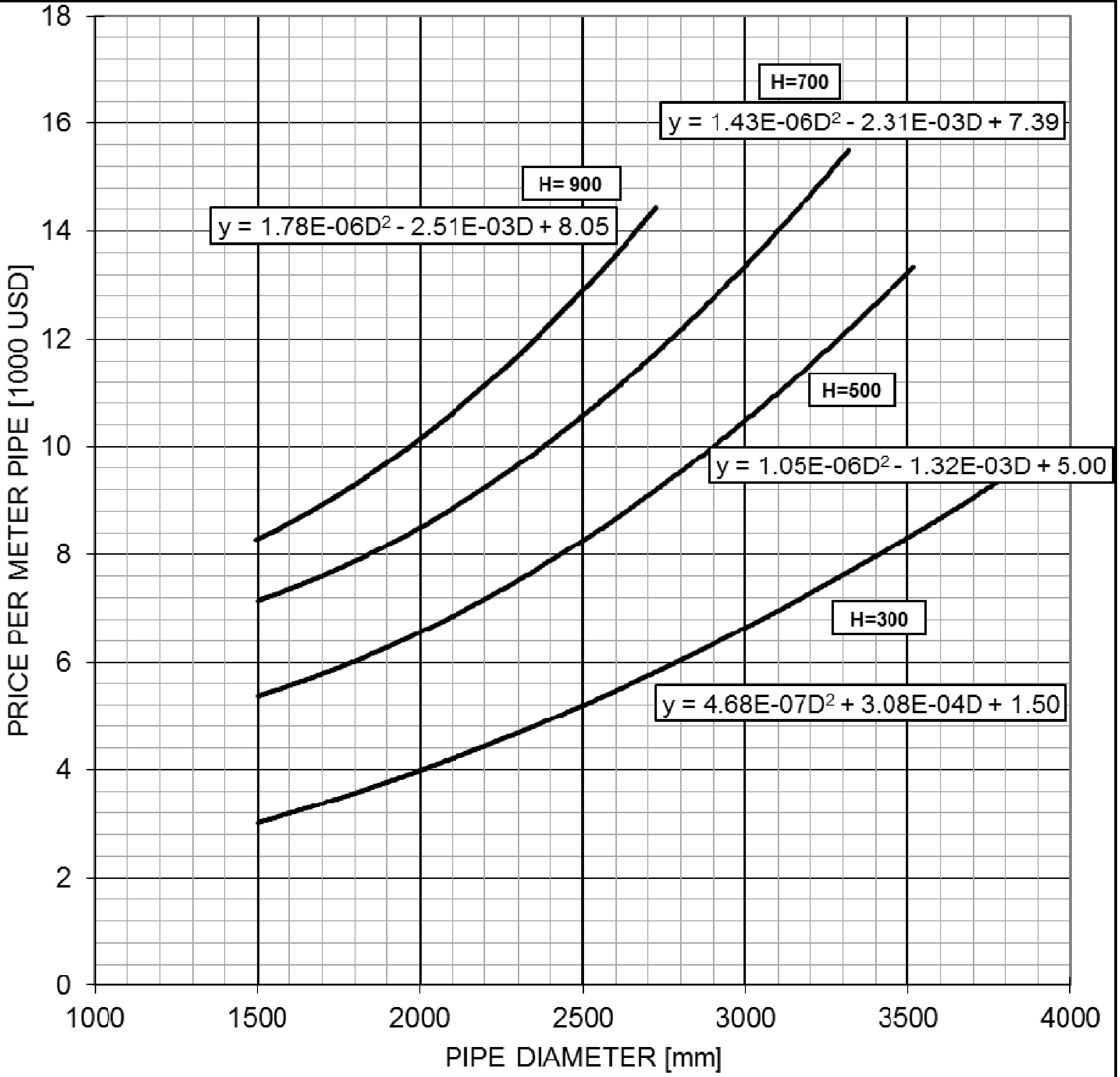
GRP PIPES ON SADDLES

Fig. 4.7.2
01.01.15



NOTES:

1. Price level January 2015
2. H is average pressure in mWc
3. Price for pipe length of appr. 100m.
   Other lengths, adjust price by:

Pipe length	Price factor
40 m	1.1
600 m	0.9

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STEEL LINED PRESSURE SHAFTS

Fig. 4.7.3
01.01.15