Cost base for hydropower plants

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VEILEDER

COST BASE

FOR HYDROPOWER PLANTS

(With a generating capacity of more than 10 000 kW)

Price level 1 January 2010

Norwegian Water Resources and Energy Directorate (NVE)

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Cost base for hydropower plants

(over 10 000 kW)

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Abstract: This manual has been prepared as a tool for calculation of average foreseeable contractor costs (civil works) and supplier costs (mechanical and electrical equipment) for large hydroelectric power plants with an early phase generating capacity of more than 10 000 kW.
These costs will depend on a number of conditions which may vary from plant to plant, and this requires that the user to have a sound technical knowledge. This applies in particular to the civil works associated with the hydropower plant. The manual is a supplement to our cost base for smaller hydropower projects (Manual No. 2/2010).

Key terms: Average costs, hydropower plants, civil works, mechanical and electro-technical equipment

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F.1 GENERAL

F.1.1 Introduction

In 1982, the Norwegian Water Resources and Energy Directorate (NVE), Avdeling for vasskraftundersøkelser (VU) (*Department for water resources studies*), created a tool for preparation of foreseeable construction costs for hydroelectric power plants as part of its Master Plan for Hydropower Development. The work resulted in a two-part report dated July 1982.

A new revised version of the 1982 report was prepared in 1987. The new report included prices at a 1986 price level. The report also provided estimated price inflation from January 1986 to January 1987.

New revisions were made in 1990 with price levels as of 1 January 1990, in 1995 with price levels as of 1 January 1995, in 2000 with price levels as of 1 January 2000, in 2005 with price levels as of 1 January 2005, and finally in this 2010 report with price levels as of 1 January 2010.

The two-part report was originally prepared and subsequently revised by Ingeniør Chr. F. Grøner A.S. (Civil work), Nybro-Bjerck A.S. (mechanical equipment) and Ingeniør A.B. Berdal A/S (electrical equipment).

The 1995 updates were conducted by Statkraft Engineering A.S. (Mechanical and electrical equipment) and Berdal Strømme A/S (Civil work). Chapters B.3.4 Concrete arch dams and B.11 Surface power stations were taken from our "Cost base for small hydro power plants (with a generating capacity of up to 10 000 kW)", prepared by NVK A/S Norsk Vandbygningskontor. In 2000, the report was updated in its entirety by Norconsult AS and in 2005 by Sweco Grøner AS.

The current report is a revision of the 2005 report with prices adjusted to the price level as of 1 January 2010. The report has in its entirety been prepared by SWECO Norge AS.

F.1.2 The content of the report

The report provides a base for calculation of mean predictable contractor costs (Civil work) 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 normal. Primary assumptions and comments are given in the figures and their associated texts.

The developer expenses have not been included in the price basis.

Furthermore, the report specifies which margins of uncertainty should be considered in a cost estimate based on the tools in the report.

F.1.3 Purpose of the report

In an early phase of a hydropower project it will be important to weigh economic factors up against conflicts with other user interests. This is where foreseeable 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 too much 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 relatively quickly, and
2. The estimated costs can be compared with a reasonably degree of accuracy. (The correct relative difference between the calculated costs of the individual development objects is in this connection more important than great accuracy with regard to the real construction costs).

F.1.4 Report structure

The report consists of four sections:

F General chapter

B Civil work

M Mechanical equipment

E Electro-technical work

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 together.

Both parts of the report have been put into a folder. Thus, it is possible to revise certain chapters separately.

F.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.

The cost figures/curves in the report provide an average foreseeable cost figure. Additional calculations must be performed for a cost estimate with a high degree of certainty against overruns. Uncertainty margins have been included for this purpose.

A number of cost units have been excluded from the presented cost base. Thus, it is important 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 projecting tool for, for instance, optimisation or choice of construction types.

F.1.6 Price level

The prices in the report are as of 1 January 2010.

F.2 FINANCIAL ASPECTS OF U/E PROJECTS (UPGRADING/EXPANSION)

F.2.1 Observations relating to the choice of measures which require shutdown versus alternative measures where shutdown is avoided

F.2.1.1 General about shutdowns

Shutdowns caused by U/E measures will always be planned and thus defined as a planned shutdown rather than a breakdown. A planned shutdown means the shutdown can be planned in advance thus minimising loss of production.

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

If the power plant has a reservoir, measures 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 high enough so that the reservoirs are drained down as much as possible prior to the shutdown. The power plant may lose production when the reservoir is drained down, due to the loss of reduced head as well as reduced turbine efficiency. In a long-term shutdown the water level in the reservoir may rise above the highest regulated water level (HRV), which will result in flooding and diversion flow. The loss in production will in such a case 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 neutralised by poorer efficiency in the turbine at full load.

If the level in the reservoir must be kept down whilst work is ongoing, the power station will as far as possible be used to keep the water level low. However, the power plant will then produce at a lower head and poorer efficiency. Alternatively, the inflow must 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 different from to the planned production, the consequence will normally be a reduction in production revenues. However, advance production will provide revenues at an earlier stage and consequently increase interest earnings. Power prices may develop differently from what one might expect. 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. We assume 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 the event of a power production shutdown.

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

F.2.1.2 Catchment area

An extension of the catchment area will not in itself cause loss of production. However, it may entail that the capacity of the power plant has to be increased. Various measures may then be necessary with regard to the reservoir, intake, waterways and station. Most of these measures will entail production shutdown of varying duration.

F.2.1.3 Intake

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

If inlets are to be reconstructed, the reservoir must be drained down in advance and be kept down for the duration of the work. In such a situation, the power station will be run at full load and at a poorer efficiency/head until the reservoir is empty. While work is ongoing the station will at times be operated at low head and poor efficiency in order to keep the level in the reservoir low. If the station fails to empty and/to 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 reduction in production. The same applies to reconstruction of thrashracks.

F.2.1.4 Increased capacity in the waterways, head loss reduction

Smoothing of tunnels

Smoothing of tunnels using various methods will require closing of the station and draining of the tunnel. If the work can be performed with a closed intake/revision gate, it will be possible to use the capacity of the reservoir during the shutdown.

Expansion of cross-sections

During back ripping of existing tunnels the power plant must cease operations for the duration of the back ripping 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.

Pipes

The power plant will 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 down 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 increased risk of loss of flow. The same applies when old pipes are replaced by a shaft solution.

F.2.1.5 Improvement of 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 down the reservoir prior to the work and store water whilst work is ongoing. Unregulated plants with only one unit must let the entire inflow pass by whilst work is ongoing.

F.2.1.6 Changes in the manoeuvring regulations

Changes in the manoeuvring regulations will not require shutdown of production. However, such a measure may increase inflow to the power plant, which again may result in the power plant wishing to increase its capacity. The measures which will then be implemented will in most cases mean that production will be shut down for a period of time.

F.2.1.7 Reduced technical restrictions

Reservoir

Most reservoir measures will involve removing sills so that the reservoir can be used down to the lowest regulated water level (LRWL). 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 down 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.

Waterways

In the waterways it will be relevant to reduce large singular losses. Relevant measures may include giving concreted elements 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 will be possible to use the reservoir with a closed gate, thus minimising the total loss of production.

F.2.1.8 Increased installation

If an older unit is to be replaced by 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 loss, the work should be scheduled for periods with 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 shut down the power plant.

If a new station is being constructed in connection with the old one, it will most likely be necessary to shut down the existing units whilst work is conducted near by. This applies in particular to blasting work. However, improved blasting techniques have significantly reduced tremors so that in most cases it will be possible to operate the existing units even during blasting work near by. 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 the 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.

F.2.1.9 Reservoir

If dam measures are to be implemented on the waterside, the reservoir must be emptied before the work can commence and the level be kept down for as long as necessary. If necessary one must also divert the flow in order to keep the water level low.

Implementation of measures on the dam's airside can usually take place without halts in production.

F.2.1.10 New small-scale power water plants in an existing catchment area

For existing power plants it may be relevant to construct small-scale power plants which utilise the head in an existing transfer tunnel from the intake to the 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 fieldes are constructed as separate power plants, or in connection with existing transfer tunnels. It will be possible to construct the power station itself without halting transmission. However, the transfer must be interrupted 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 in connection with 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.

F.2.2. Considerations regarding the value of reservoir increase

Power plant reservoirs are used to even out differences between natural rates of flow in a river system and the need for electrical energy. Norway has a climate which means that inflow and consumption are in an anti-phase. Previously, when grid connections to Europe were poor and it was necessary to produce our own electricity to a greater extent, winter energy was considerably more valuable than summer energy. This resulted in reservoirs having a high priority in power plant developments.

Better grid connections to Europe have reduced the difference between summer and winter prices. However, prices are expected to vary more within a 24-hour period. This means that it is less valuable to store the inflow for winter production. On the other hand, it generates greater interest in hydro peaking. However, some situations have proved the need for full reservoirs in the autumn (particularly in the autumn of 2002 and winter 2003).

Today, the reasons for investments in increased reservoir capacity are commonly:

- Reduced loss of flow
- Increased head
- Increased need for power regulation/peaking (daily or weekly)
- Increased need for dry year security

In general, reservoirs do not generate energy, 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 operation). 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.

F.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 neutralised 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 plants. For these power stations, the value of increasing the reservoirs is primarily to reduce loss of flow, increase head and facilitate peaking.

F.2.2.2 Elevated storage reservoir

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

The level in the reservoirs is usually kept close to the highest regulated water level (HRWL). 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 peaking. It is generally not profitable to expand this type of reservoir as construction costs will increase more than the increase in the value of production.

F.2.2.3 Seasonal storage reservoir

A seasonal storage reservoir transfers the inflow from one season to another. The reservoirs have normally a storage capacity of approximately 30-50% 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 utilization time of 3-4000 hours per year. This makes peaking possible within the framework set by the reservoir and 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 peaking possibilities is somewhat limited for this type of reservoir.

F.2.2.4 Multi-year storage reservoir

A multi-year storage reservoir has a capacity to store more than 100% of the mean annual inflow. Such reservoirs are very rarely drained down to the lowest regulated water level (LRWL), 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 hydro peaking.

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 hydro peaking possibilities may also be relevant. However, for multi-year storage reservoirs hydro peaking in combination with pumping is most interesting.

F.2.3. Considerations regarding the value of power

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

1. Base load - produced in power plants (thermal or hydro)
2. Peak power - produced in peak load power plants

Base load means the power necessary to run out a mean annual inflow with an operation time of about 3-4000 hours/year. With peak power it is possible to run out the inflow in a significantly shorter operation time, usually in the region of 1-2000 hours/year.

The demand for power in Norway has been characterised by high ohmic load (caused by smelting plants). In total this gives little power variation. The periods with highest peak output in Norway have occurred on the coldest days of winter. The Norwegian power system consists mainly of hydropower which has a short response time. This has resulted in a stable power supply in the Norwegian system. Consequently, there has been little interest in investing in peak power. This is clearly highlighted by several older power developments connected with industrial developments. These power plants usually have a service life of 6-7000 hours.

In Norway, peak power investments have been limited to power plants where head loss has been low, heads high and the regulating ability good.

Since 1995, there has been a decrease in investments in new power production in Norway, particularly in peak output (except small hydro). However, demand for power has increased steadily and after 2000 there has been an increasing shortage of power in Norway. This has resulted in a higher price level enhanced by carbon trading (the Kyoto treaty) and which will be further forced by the introduction of green certificates. At the same time, the grid connections to Europe will be strengthened in the near future.

Consequently, there is reason to expect more stable power prices at a higher level in Norway and greater variations in price throughout a 24-hour period. Up till now the daily price variations have varied by approximately NOK 0.05/kWh between low and high load periods. This price difference has not been sufficient to prompt any major power developments.

The peak power costs are primarily related to an increase in power unit costs. However, it will soon be relevant to expand the power station, increase the cross-section of the waterways and increase the reservoir capacity.

Peaking will result 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.

F.2.4 Green certificates

There are plans to introduce a Swedish-Norwegian green certificate market by 2012. The certificates will be technology-neutral and will apply for the next 15 year after implementation. We interpret this to mean that hydropower will be comprised by the scheme. However, we do not know if there will be limitations with regard to the size and economy of the projects.

A green certificate means an (electronic) document which proves that a certain amount of electricity has been generated in accordance with special regulations. There has been much interest in this type of securities recently, as they are regarded as an appropriate tool for stimulating the development of electricity production based on renewable energy.

B CIVIL WORK

B.0 GENERAL

B.01 Average foreseeable costs and uncertainty

This chapter provides a basis for calculating the average foreseeable contractor costs for Civil work. “Average foreseeable” means that there is a 50% risk of real costs being higher and a 50% risk that they will be lower.

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

Generally speaking, all cost estimates should specify how much risk there is of real costs being higher and perhaps also specify the highest and lowest probable costs.

B.02 Contractor costs

Included/non-included cost elements

The given cost estimate 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 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 B.12. Minor local roads (travelling 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 such costs have been included in Item B.12.

- 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 construction/installation have been incorporated in the unit prices and rigging costs. Some guidelines for how to calculate such costs have been included in Chapter E, Electro-technical work.

- Clearing of submerged areas:
  Costs for this have not been included and must be calculated separately.

- Rigging and operation of construction site:

The costs have been included in the cost curves for the individual installation parts. Where unit prices have been specified for, for instance, blasting, mass haulage, concrete, etc. these have been given excluding rigging and operation. Expenses relating to land purchases or leases have not been included. If the water supply or drainage conditions are particularly difficult, these should be taken into account through roughly estimated lump sum additions.

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

B.0.3 Developer's costs

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

Developer'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 contractors expenses (and the supplier expenses). This is not a good 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, preliminary 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 of the engineering phase, these expenses should be estimated.

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 tender documents, construction drawings, follow-up, etc.
- Construction management and quality control (local administration)
- Administration (central)
- Land rehabilitation, measures
- 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 measures. (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 highest regulated water level (HRWL)).

B.0.4 Contractor costs – price level

The costs have been stated in January 2010 prices.

In our determination of the price level we have aimed to provide a price level which reflects the normal market situation. Where market conditions vary, one may experience pronounced price changes over a short period of time. We have not found it appropriate to let such conditions influence our choice of basic prices. The cost base will be used to calculate costs of power plants whose actual construction may take place at some point in the future, and the relative market conditions may change quickly.

B.0.5 Location of the construction site

The costs given in the report relate to the average foreseeable cost level in Norway. Additional costs must be estimated for plants in remote locations with long distances and/or difficult communications.

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

Rough estimates should be prepared for adjustment to such conditions.

We would estimate price variations in the range of +25% and -10%, due to the plant location, to be within the normal range.

B.0.6 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 than 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%
- Tender documents 2-3%
- Detailed engineering, construction drawings 5-10%
- Construction management, local 5-10%

B.1 ROCK FILL DAM WITH MORAINE CORE

B.1.1 Main dam dimensions

In addition to the provisions stipulated in the *Regulations governing the safety and supervision of watercourse structures (Dam Safety Regulations*) 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 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.

B.1.1.1 Normal cross-section

We have chosen two normal cross-sections which can be used as a basis for mass calculations.

Normal cross-section A is shown in Fig. B.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. Inclination is 1:1.5.

Normal cross-section B is shown in Fig. B.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. Inclination is 1:1.7.

Volume curves for the two normal cross-sections have been prepared and presented in Figures B.1.3, B.1.4 and B.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 we have presented volume curve correction factors in Fig. B.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 connection 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 highest regulated water level (HRWL) 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.

B.1.2 Dam foundation

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

B.1.2.1 Excavation of uncompacted material

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

We propose the following guidelines:

If so 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 moraine and filter 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 54 NOK/m^3.

B.1.2.2 Foundation and dam toe treatment

The cost of all work that is normally required at the dam toe, has been included in Fig. B.1.7. 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) 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 3,500 NOK/lm dam toe plus 870 NOK/m^2 for the moraine foundation.

B.1.2.3 Injection work

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

It is 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. We have further assumed that deep injection holes will be drilled until a permeability corresponding to 1 Lugeon has been achieved.

Normal costs can be set at 4,260 NOK/lm dam, plus 170 NOK/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 B.1.7.

B.1.3 Dam body

As the other cost units for the dam it is chosen 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 rigging, operation and soil extraction at the site). The costs are for a dam size of 500,000 m^3. In our experience, unit cost figures are often lower for large dams than for small ones. This is corrected by applying a correction factor given in Fig. B.1.8. In addition comes the effect that for large dams the least expensive zones constitute a larger share.

B.1.3.1 Impervious zone

Volume estimations can be conducted by applying the volume curves presented in Figure B.1.3, part 1, 2 or 3.

The location of a ready prepared foundation should be considered on the basis of local conditions. In general, we 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 166 NOK/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 6.00 NOK/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 166 NOK/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

B.1.3.2 Filter zone

Volume estimations can be conducted by applying the volume curves presented in Figure B.1.4.

We assume that foundation for the filter zone is located on the original rock surface.

The average cost of the filter zone is set at 159 NOK/$m^{3.}$

We assume 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 for, for instance, screening or temporary storage are included within the scope 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 101 NOK/m^3.

If the distance to the gravel pit exceeds 4 kilometres, an additional cost of 6.00 NOK/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 280 NOK/m^3.

The normal price of 159 NOK/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

B.1.3.3 Transition zone

Volume estimations can be conducted by applying the volume curves presented in Figure B.1.4.

We assume 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 at 166 NOK/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 costs in such cases are set at 109 NOK/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 at 185 NOK/m^3.

The normal price of 166 NOK/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

B. 1.3.4 Support filling

Volume estimations can be conducted by applying the volume curves presented in Figure B.1.5, part 1, 2 or 3.

We assume 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 at 88 NOK/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 54 NOK/m^3.

The normal price of 88 NOK/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

B.1.3.5 Slope and crest protection

Volume estimations can be conducted by applying the volume curves presented in Figure B.1.4.

We assume 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 at 169 NOK/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 at 227 NOK/m^3.

B. 1.4 Price level

A few rock-fill dams have been constructed in the 2000s. However, most of the dam work that has been conducted has related to upgrades of large existing dams.

Since the 2005 update, the NVE has issued new *Guidelines for rock-fill dams*. The filter criteria have changed from the ones established in the previous guidelines. The new requirements are stricter and more difficult to comply with. This has resulted in an increase in the price level for filters and the transition zone which is somewhat larger than the normal price increase. “Byggekostnadsindeks for veganlegg” (*Construction cost index for road construction*) from Statistics Norway has been used as a basis for the price index adjustments. This index shows a price increase of approximately 19% from 2005 to 2010. The general price increase for the period was 12.6%.

The stated prices represent the price level in January 2010.

B.1.5 Included/non-included costs

Please see Chapters B.02 and B.03. 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, thrashracks:
  Costs have not been included. For gate costs, see Chapter M.3.

B.1.6 Cost calculation uncertainty

The estimation of the cost calculation uncertainty for the dam <u>foundation</u> is +70% to -30%.

The estimation of the cost calculation uncertainty for the dam <u>body</u> is +25% to - 25%.

B.1.7 Increasing the height of existing dams

It is difficult to give any general guidelines for how much the cost of dam extension 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.

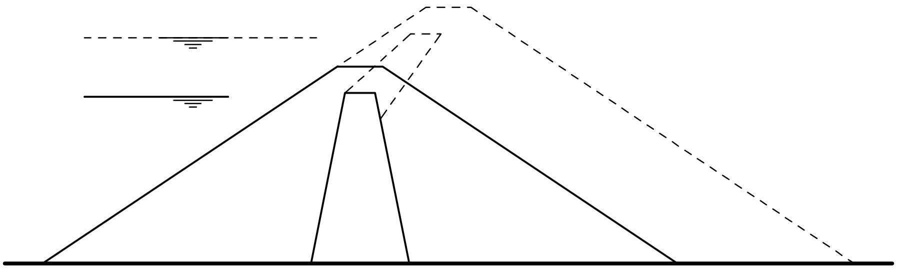
Such verification will also show how far down the sloping zones must be removed before the extension work can commence.

Special conditions such as availability and volume of masses, transportation distances, etc. may have caused the zones of the dam to have a shape which is not statically determined. 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.

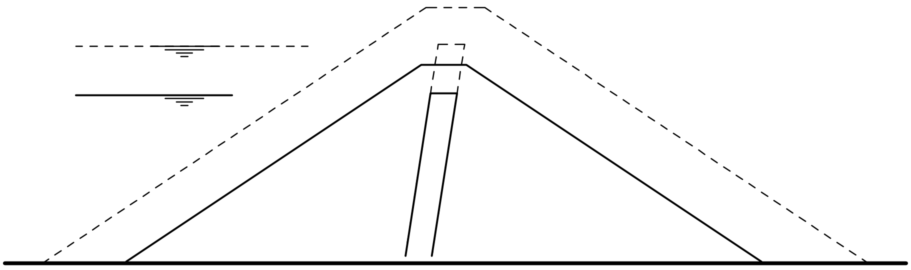
The costs can be calculated by using the unit prices given in Item B.1.2.6 above, whereas volumes must be calculated separately in each case.

We would like to point out that in cases where the extension consists mainly of slope protection, on must take into account the proportion of large rocks in relation to the blasted volume. Thus, the price of the slope protection could increase by up to 100%. However, this must be assessed in each case.



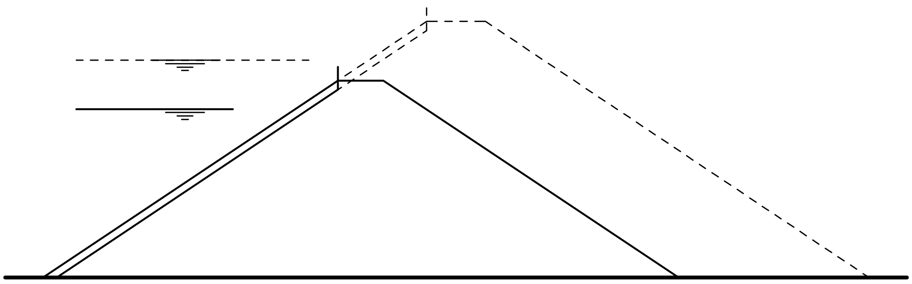
1. ROCKFILL DAM WITH MORAINE SEALING.

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.

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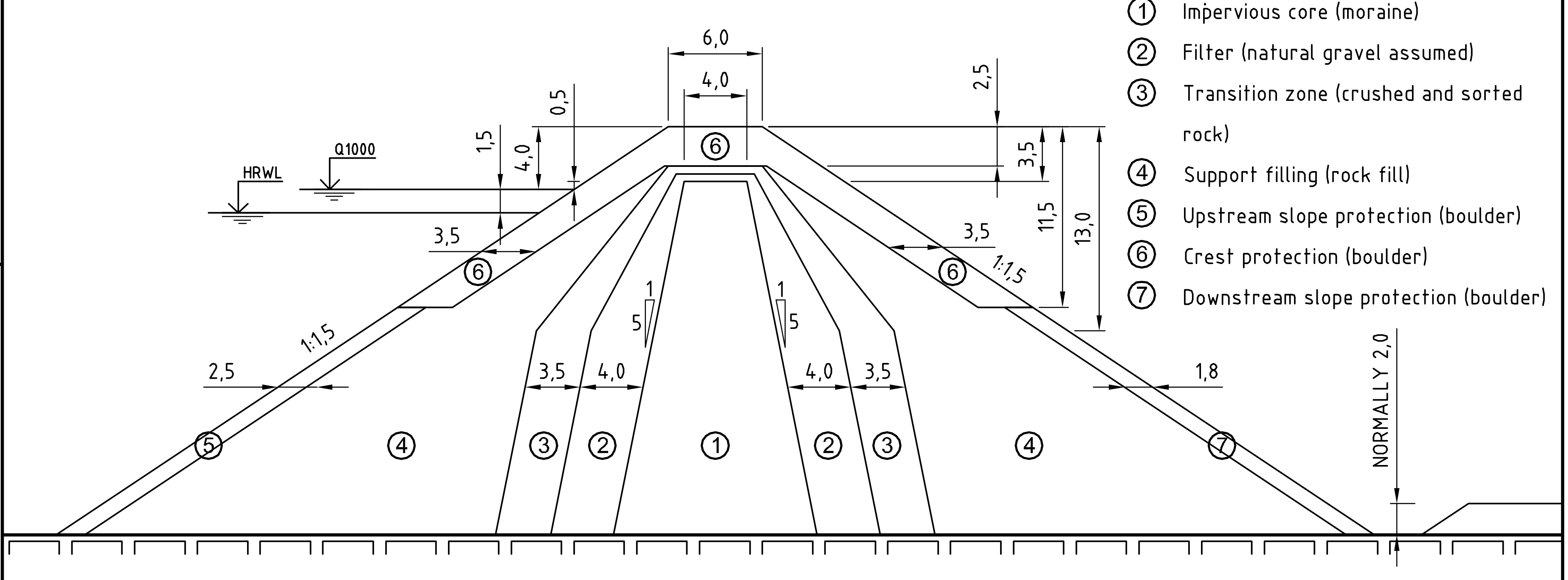
EXAMPLES OF ROCKFILL DAM HEIGHT INCREASES



① Impervious core (moraine)
② Filter (natural gravel assumed)
③ Transition zone (crushed and sorted rock)
④ Support filling (rock fill)
⑤ Upstream slope protection (boulder)
⑥ Crest protection (boulder)
⑦ Downstream slope protection (boulder)

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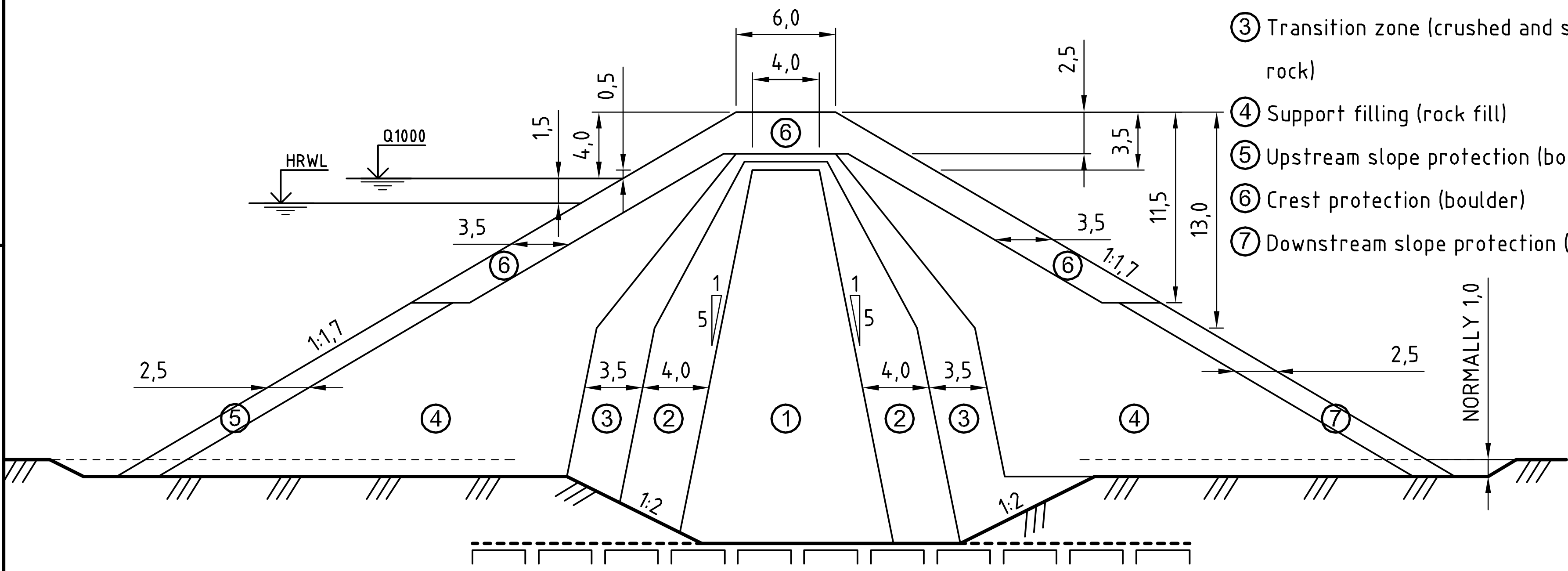
ROCKFILL DAM WITH CENTRAL MORAINE SEALING.
DAM CROSS-SECTION ASSUMED FOR VOLUME AND COST CALCULATIONS.
SIDE SLOPE 1:1.5

FIG. B.1.1



1 Impervious core (moraine)
2 Filter (natural gravel assumed)
3 Transition zone (crushed and sorted rock)
4 Support filling (rock fill)
5 Upstream slope protection (boulder)
6 Crest protection (boulder)
7 Downstream slope protection (boulder)

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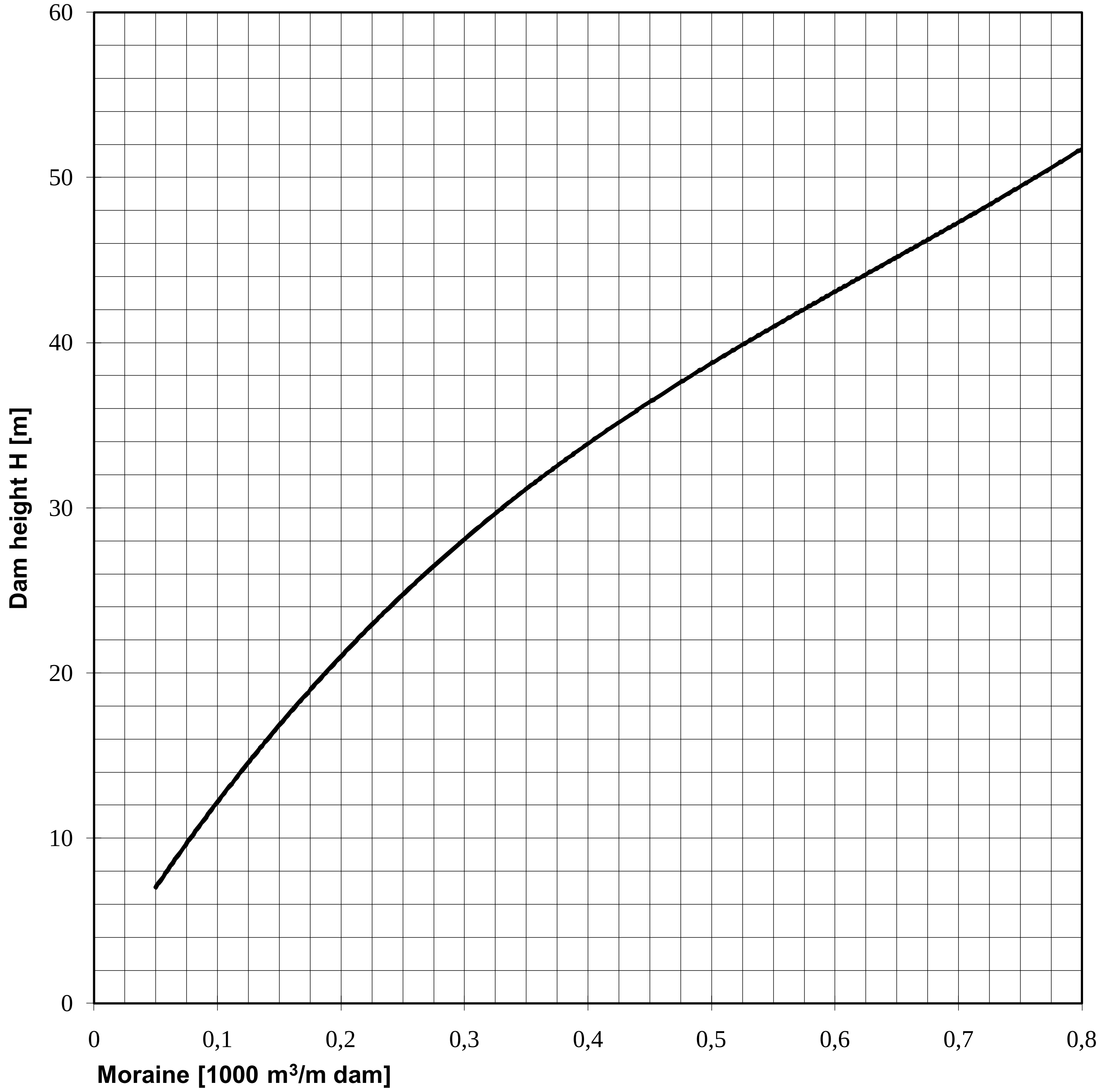
ROCKFILL DAM WITH CENTRAL MORAINE SEALING
DAM CROSS-SECTION ASSUMED FOR VOLUME AND COST CALCULATIONS.
SIDE SLOPE 1:1.7

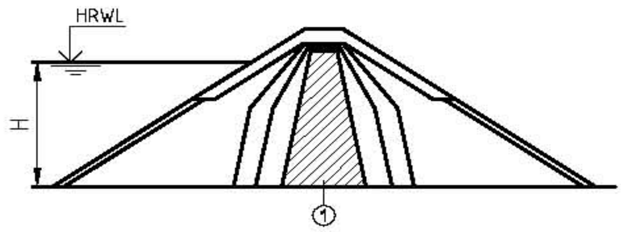
FIG. B.1.2



COMMENTS:

1. Dam height H calculated from HRWL.

2. Assumed dam cross section, see Fig. B.1.1 and B.1.2.



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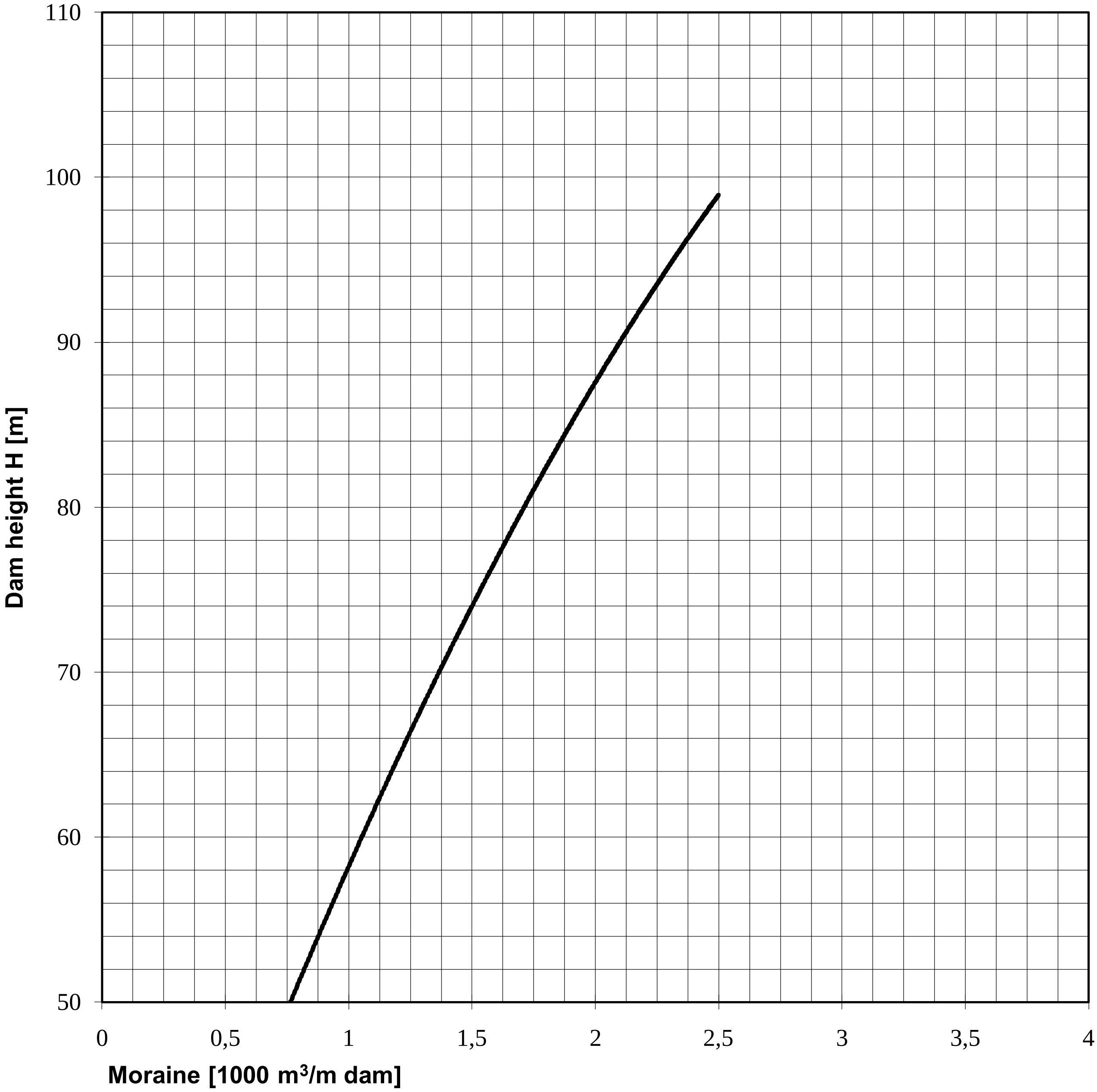
ROCKFILL DAM WITH MORAINE CORE VOLUME CURVE MORAINE

Fig. B.1.3 Part 1

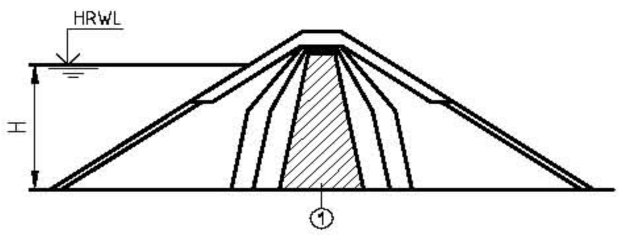
1 January 2010



COMMENTS:

1. Dam height H calculated from HRWL.

2. Assumed dam cross-section, see Fig. B.1.1 and B.1.2.



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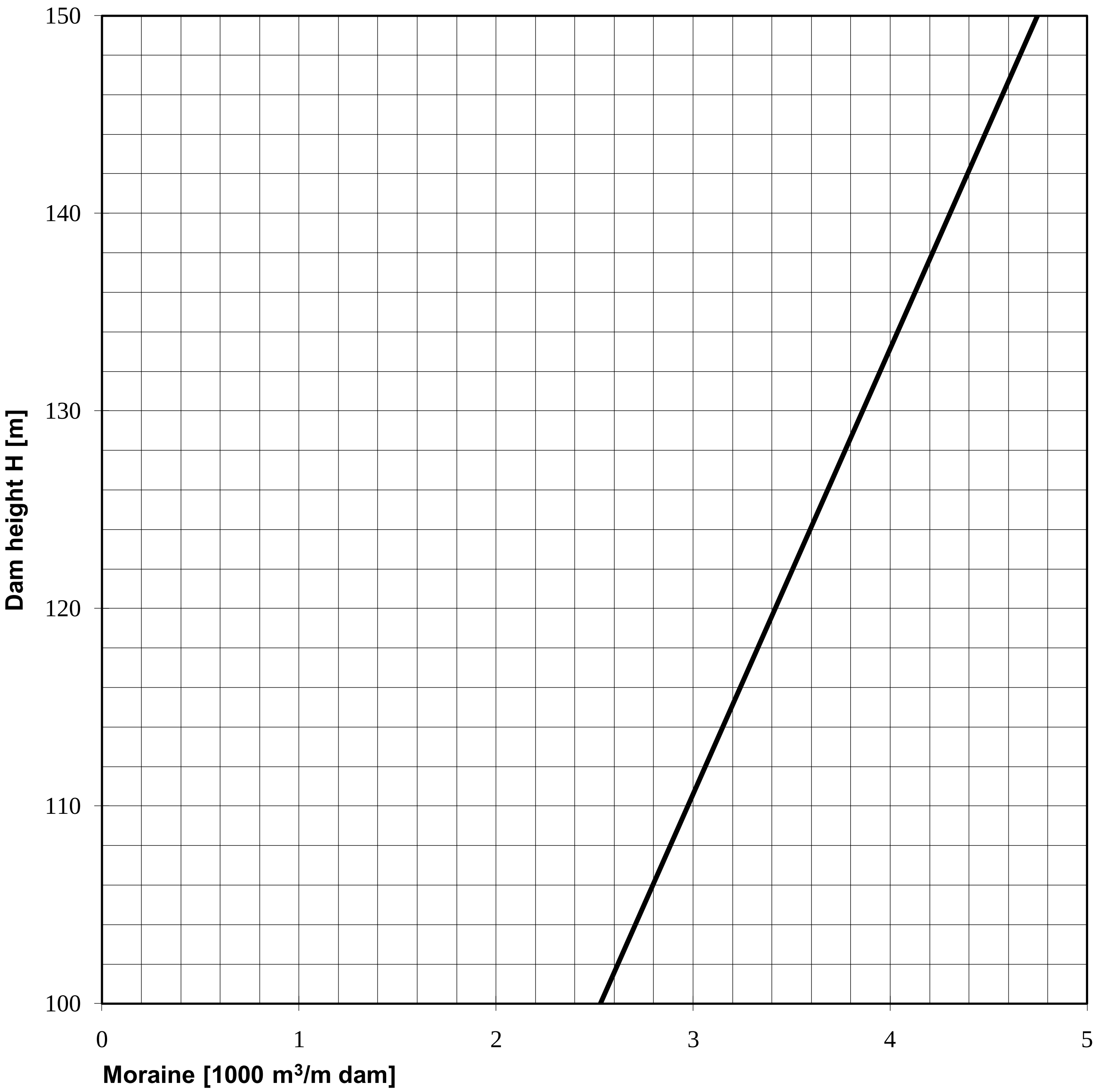
ROCKFILL DAM WITH MORAINE CORE VOLUME CURVE MORAINE

Fig. B.1.3 Part 2

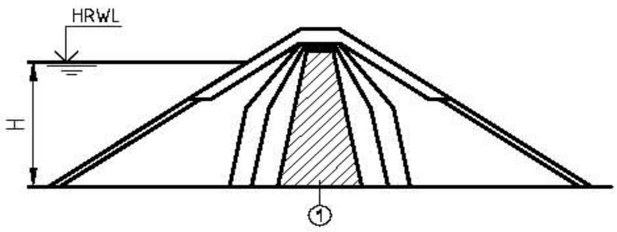
1 January 2010



COMMENTS:

1. Dam height H calculated from HRWL.

2. Assumed dam cross-section, see Fig. B.1.1 and B.1.2.



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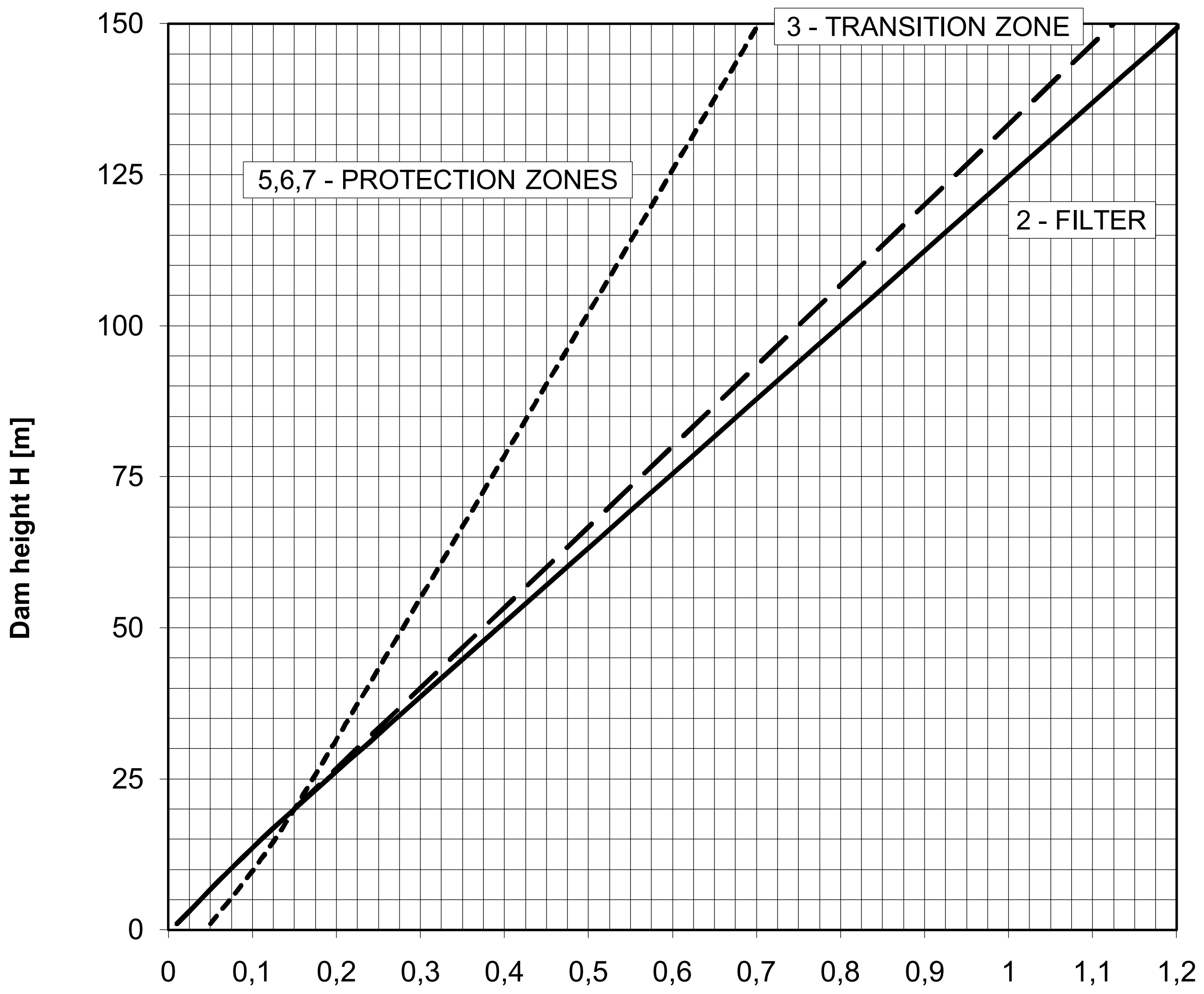
ROCKFILL DAM WITH MORAINE CORE VOLUME CURVE MORAINE

Fig. B.1.3 Part 3

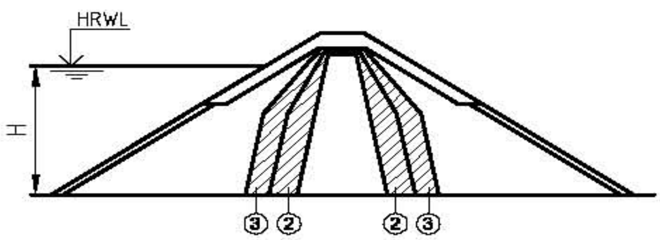
1 January 2010



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

COMMENTS:

1. Dam height H calculated from HRWL.
2. Assumed dam cross section, see Fig. B.1.1 and B.1.2.
3. Volume of transition zone and filter is corrected according to Figure B.1.6.



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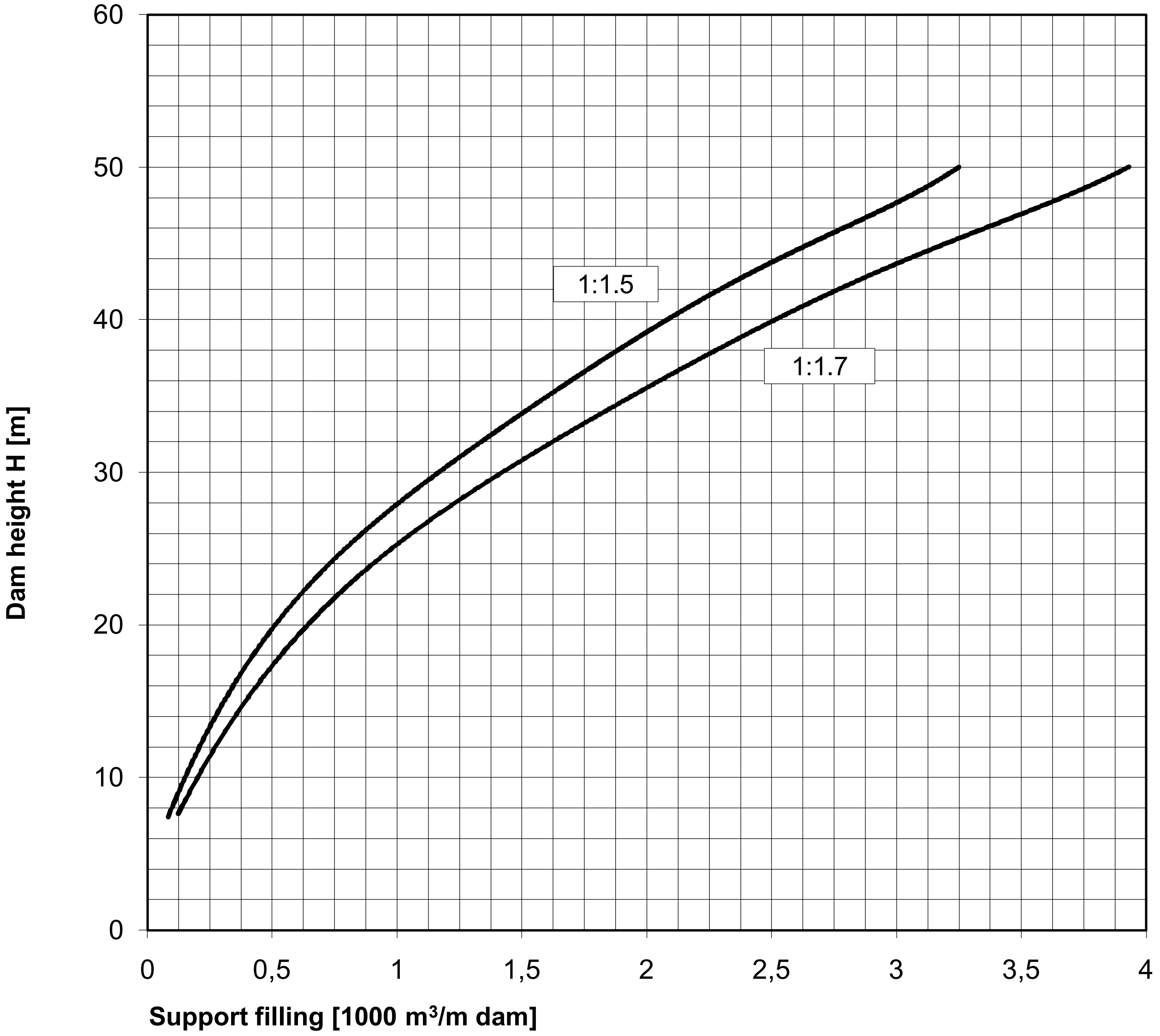
ROCKFILL DAM WITH MORAINE CORE VOLUME CURVE FILTER, TRANSITION ZONE AND PROTECTION ZONES

Fig. B.1.4

1 January 2010

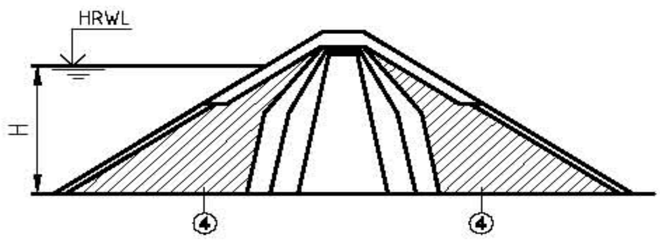


COMMENTS:

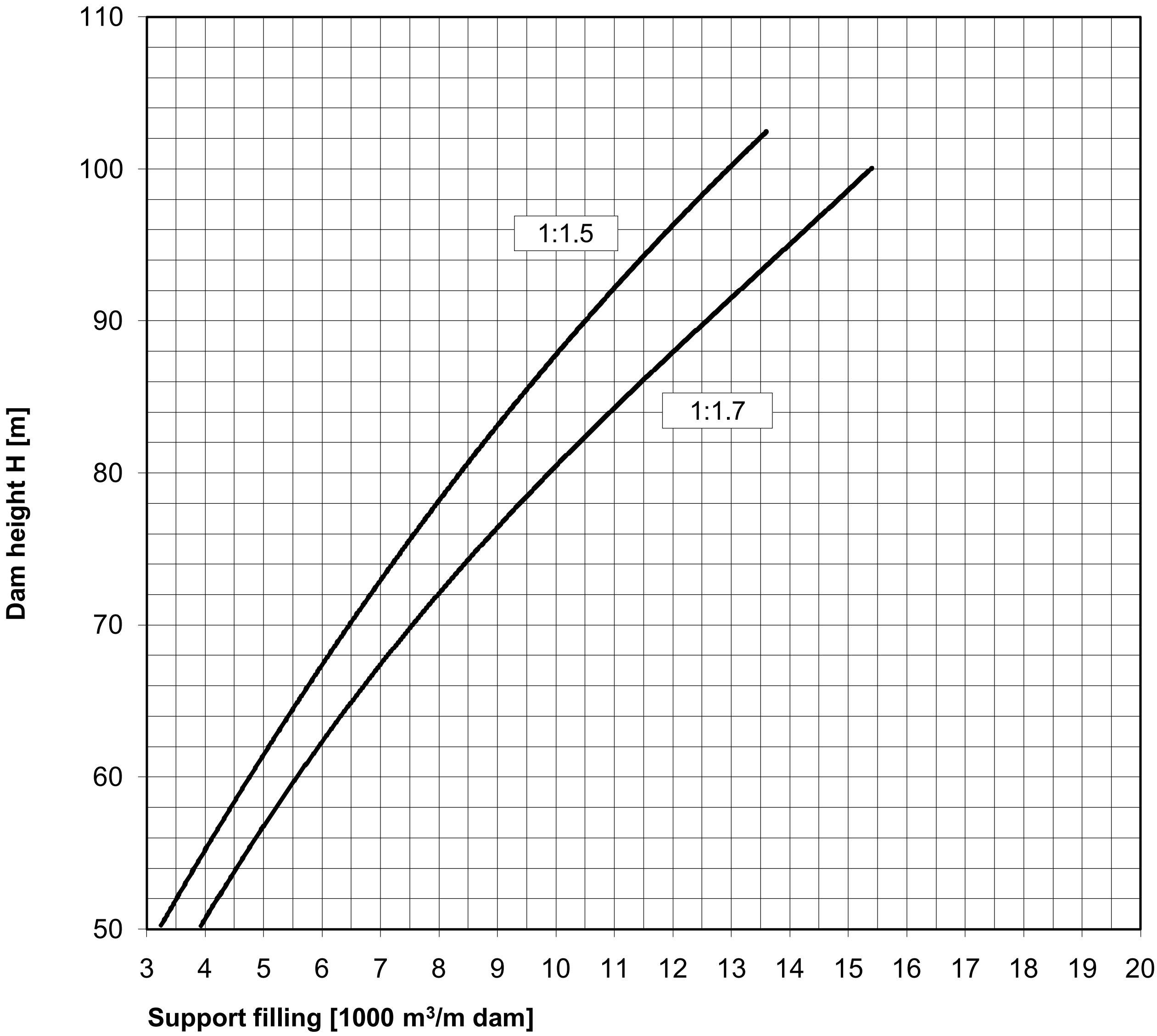
1. Dam height H calculated from HRWL.

2. Assumed dam cross-section, see Fig. B.1.1 and B.1.2.

3. Volume of support filling corrected according to Figure B.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. B.1.5 Part 1 1 January 2010

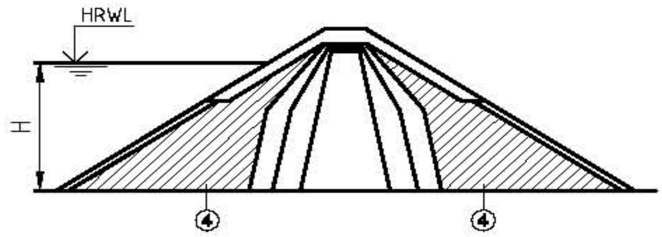


COMMENTS:

1. Dam height H calculated from HRWL.

2. Assumed dam cross-section, see Fig. B.1.1 and B.1.2.

3. Volume of support filling corrected according to Figure B.1.6.



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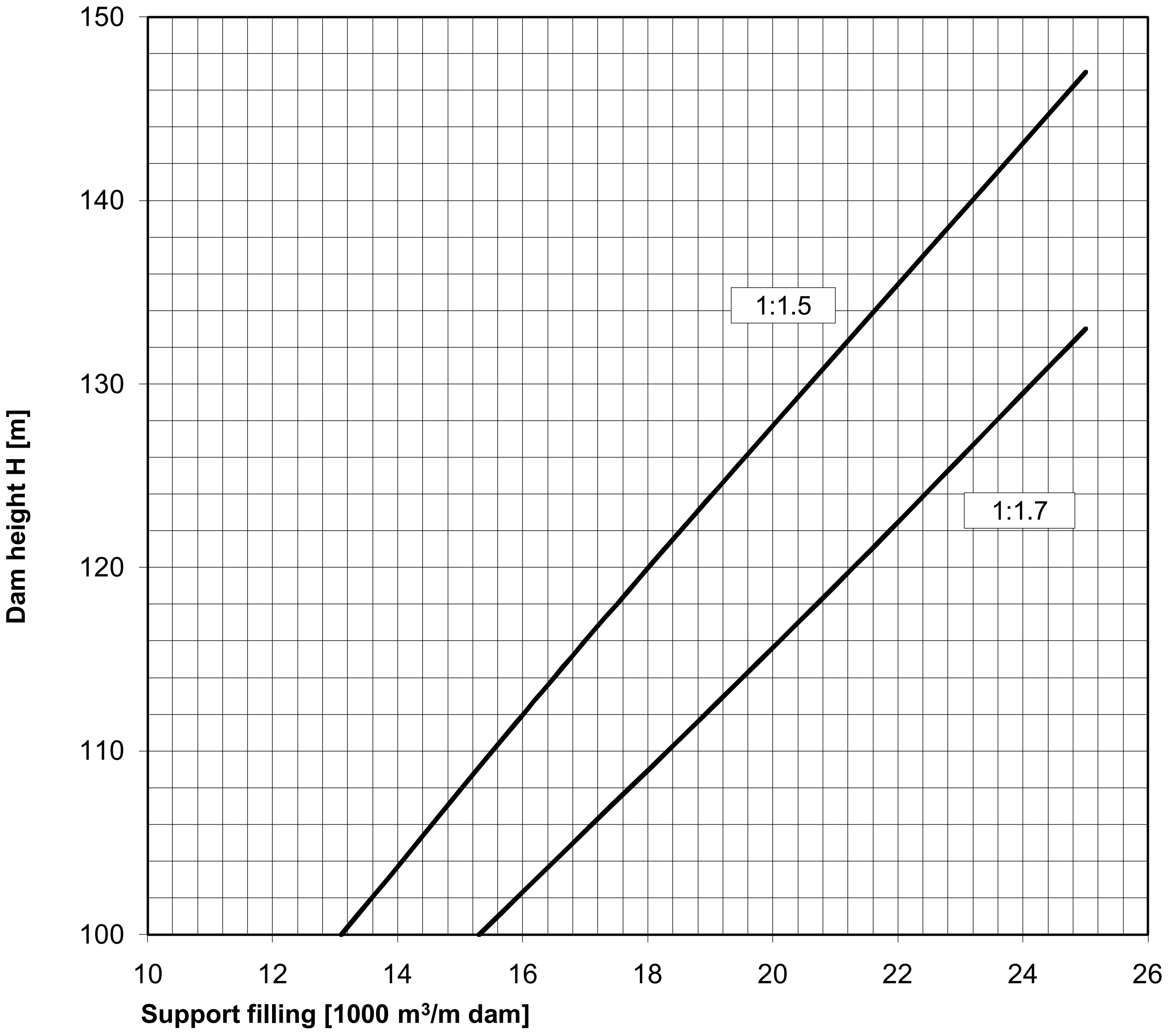
ROCKFILL DAM
WITH MORAINE CORE
VOLUME CURVE FOR
SUPPORT FILLING 1:1.5 AND 1:1.7

Fig. B.1.5
Part 2

1 January 2010

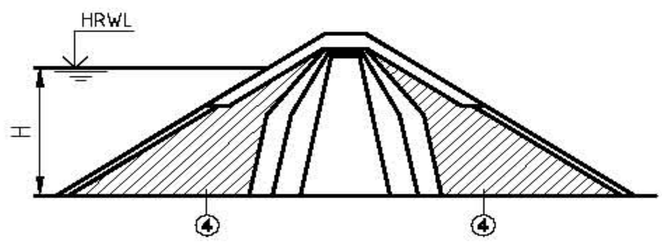


COMMENTS:

1. Dam height H calculated from HRWL.

2. Assumed dam cross-section, see Fig. B.1.1 and B.1.2.

3. Volume of support filling corrected according to Figure B.1.6.



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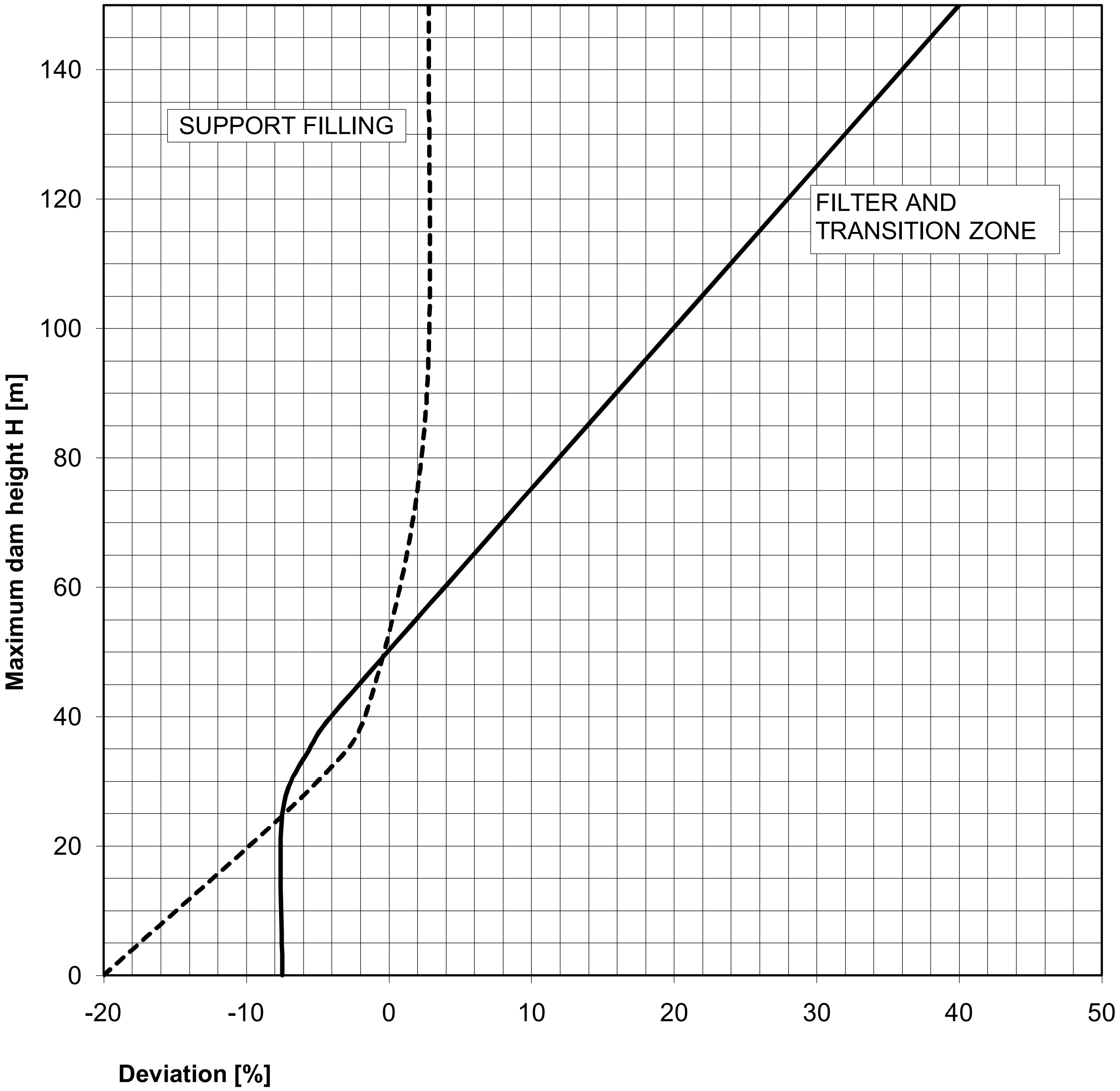
ROCKFILL DAM
WITH MORAINE CORE
VOLUME CURVE FOR
SUPPORT FILLING 1:1.5 AND 1:1.7

Fig. B.1.5
Part 3

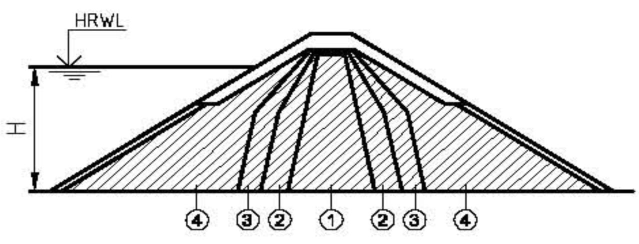
1 January 2010



COMMENTS:

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

2. Cf. Chapter B.1.1.1.



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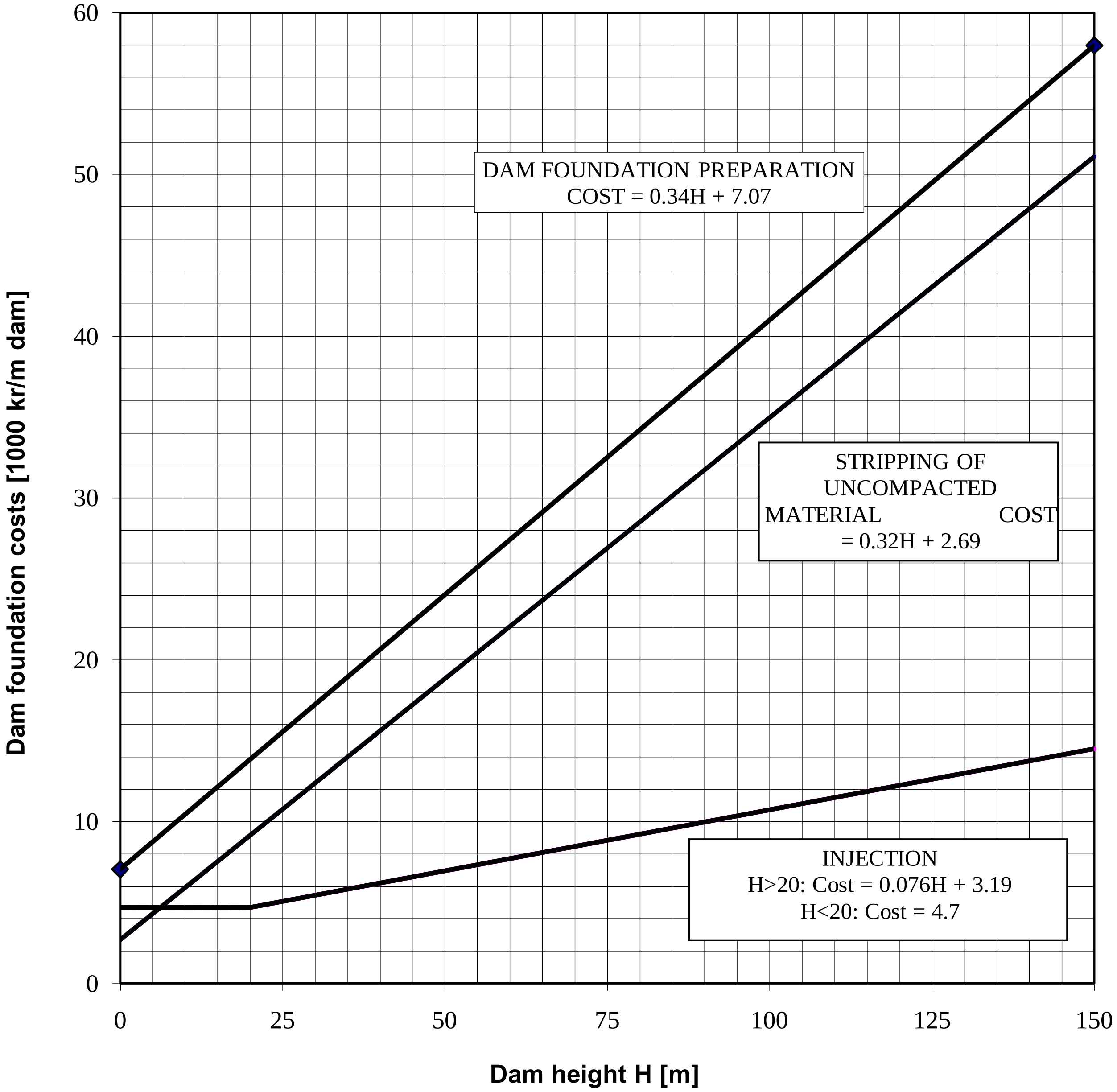
ROCKFILL DAM
WITH MORAINE CORE,
SUPPORT FILLING,
FILTER AND TRANSITION ZONE.

Fig. B.1.6

1 January 2010



COMMENTS:

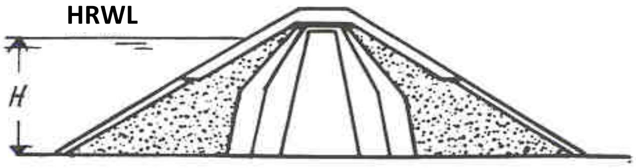
1. Price level January 2010.

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 B.1.1. 1.

4. Contractor's rigging and operating costs are included.

5. Dam height calculated from HRWL.



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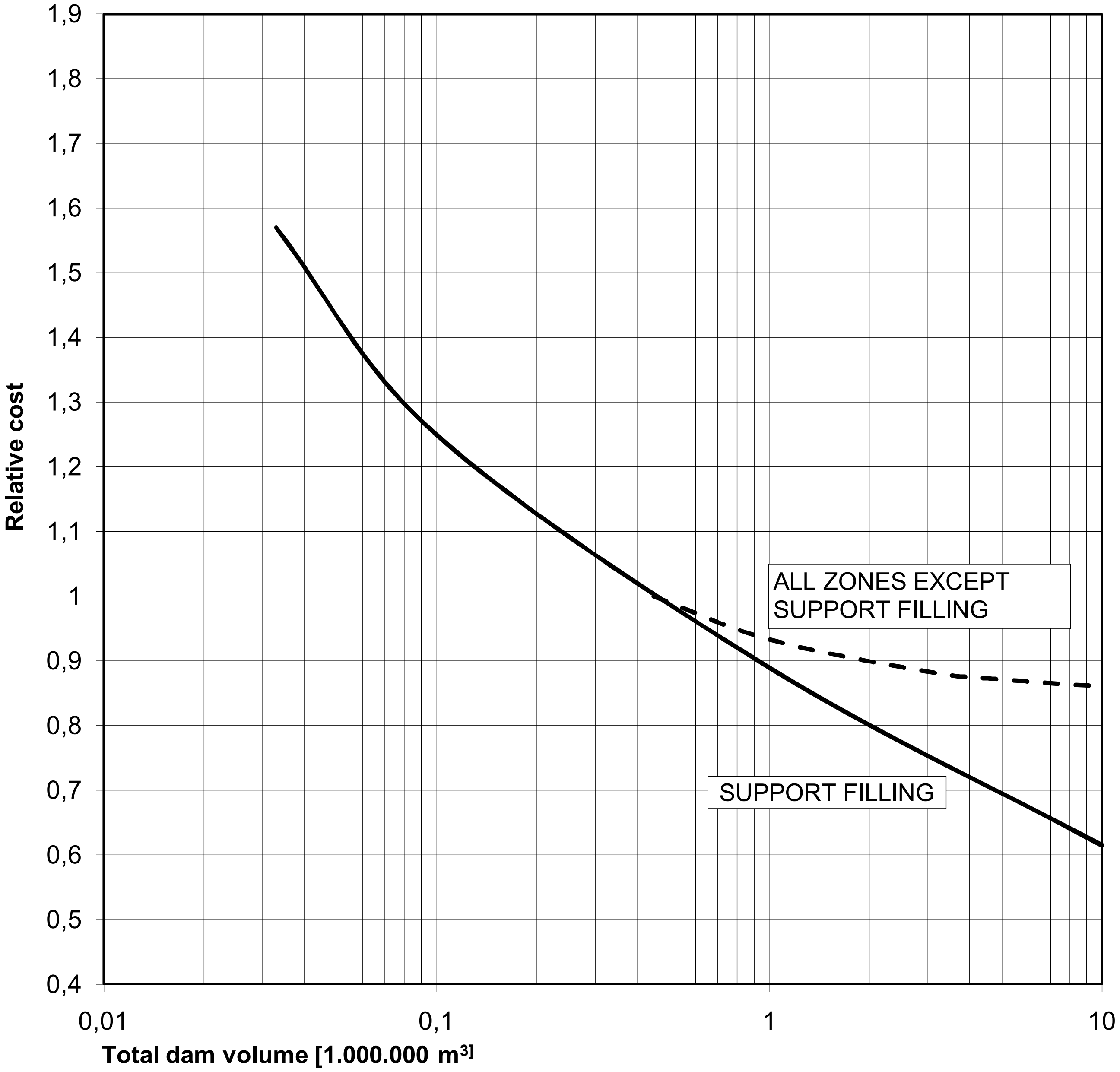
ROCKFILL DAM
WITH MORAINE CORE
DAM FOUNDATION COSTS

Fig. B.1.7

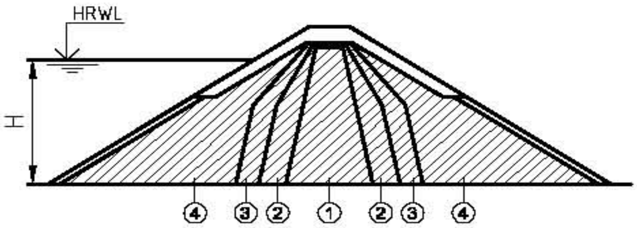
1 January 2010



COMMENTS:

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

2. Cf. Chapter B.1.3



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ROCKFILL DAM WITH MORAINE CORE COST CORRECTION FACTOR IN PROPORTION TO

Fig. B.1.8

1 January 2010

B.2 ROCK-FILL DAM WITH ASPHALT CONCRETE CORE

B.2.1 Main dam dimensions

In addition to the provisions stipulated in the *Regulations governing the safety and supervision of watercourse structures (Dam Safety Regulations*) 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 minimum requirements of the Dam Safety Regulations that are known early in the planning phase. 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.

B.2.1.1. Normal cross-section

We have chosen two normal cross-sections which can be used as a basis for mass calculations.

Normal cross-section A is shown in Fig. B.2.1. The 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. B.2.2 The 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 B.2.3 and B.2.4.

<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 we have presented volume curve correction factors in Fig. B.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 connection 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 highest regulated water level (HRV) 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.

B.2.2 Dam foundation

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

B.2.2.1 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.

We propose the following guidelines:

If so 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 54 NOK/m^3.

B.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. B.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 28,700 NOK/lm dam toe for heights up to 50m and 30,800 NOK/lm for heights up to 100 m. For dam heights up to 150 m the costs can be set at 32,800 NOK/lm.

B.2.2.3 Injection work
The extent and cost of required injection work have been assessed on the basis of experiences from Norwegian rock-fill dams.

We assume 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. We have further assumed that deep injection holes will be drilled until an impermeability corresponding to 1 Lugeon has been achieved.

Normal costs can be set at 4,660 NOK/lm dam, plus 170 NOK/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 B.2.6.

B.2.3 Dam body
As the other cost units for the dam, we have chosen 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 rigging, operation and soil extraction at the site).

The costs are for a dam size of 1,000,000 m^3. In our experience, 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. B.2.7. In addition comes the effect that for large dams the least expensive zones constitute a larger share.

B.2.3.1 The impervious zone
Volume estimations can be conducted by applying the volume curves presented in Figure B.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, we recommend assuming 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 3,690 NOK/m^3.

B.2.3.2 The filter zone

Volume estimations can be conducted by applying the volume curves presented in Figures B.2.3, part 1, 2 or 3.

We assume 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 282 NOK/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.

We assume 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 282 NOK/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

B.2.3.3 Transition zone

Volume estimations can be conducted by applying the volume curves presented in Figure B.2.3, part 1, 2 or 3.

We assume 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 166 NOK/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 costs in such cases are set at 109 NOK/m^3.

The normal price of 166 NOK/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

B.2.3.4 Support filling

Volume estimations can be conducted by applying the volume curves presented in Figure B.2.5, part 1, 2 or 3.

We assume 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 at 86 NOK/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 54 NOK/m^3.

The normal price of 86 NOK/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

B.2.3.5 Slope and crest protection

Volume estimations can be conducted by applying the volume curves presented in Figure B.2.3, part 1, 2 or 3.

We assume 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 174 NOK/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 227 NOK/m^3.

B.2.4 Price level

Only a few rock-fill dams with asphalt concrete cores have been constructed in the 2000s. All of these are relatively small dams (<20m).

Since the 2005 update, the NVE has issued new *Guidelines for rock-fill dams*. The filter criteria have changed from the ones established in the previous guidelines. The new requirements are stricter and more difficult to comply with. This has resulted in an increase in the price level for filters and the transition zone which is somewhat larger than the normal price increase. “Byggekostnadsindeks for veganlegg” (*Construction cost index for road construction*) from Statistics Norway has been used as a basis for the price index adjustments. This index shows a price increase of approximately 19% from 2005 to 2010. The general price increase for the period was 12.6%.

The stated prices represent the price level in January 2010.

B.2.5 Included/non-included costs

Please see Chapters B.02 and B.03. 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, thrashracks:
  Costs have not been included. For gate costs, see Chapter M.3.

B.2.6 Cost calculation uncertainty

The estimation of the cost calculation uncertainty for dam <u>foundation</u> is +70% to -30%.

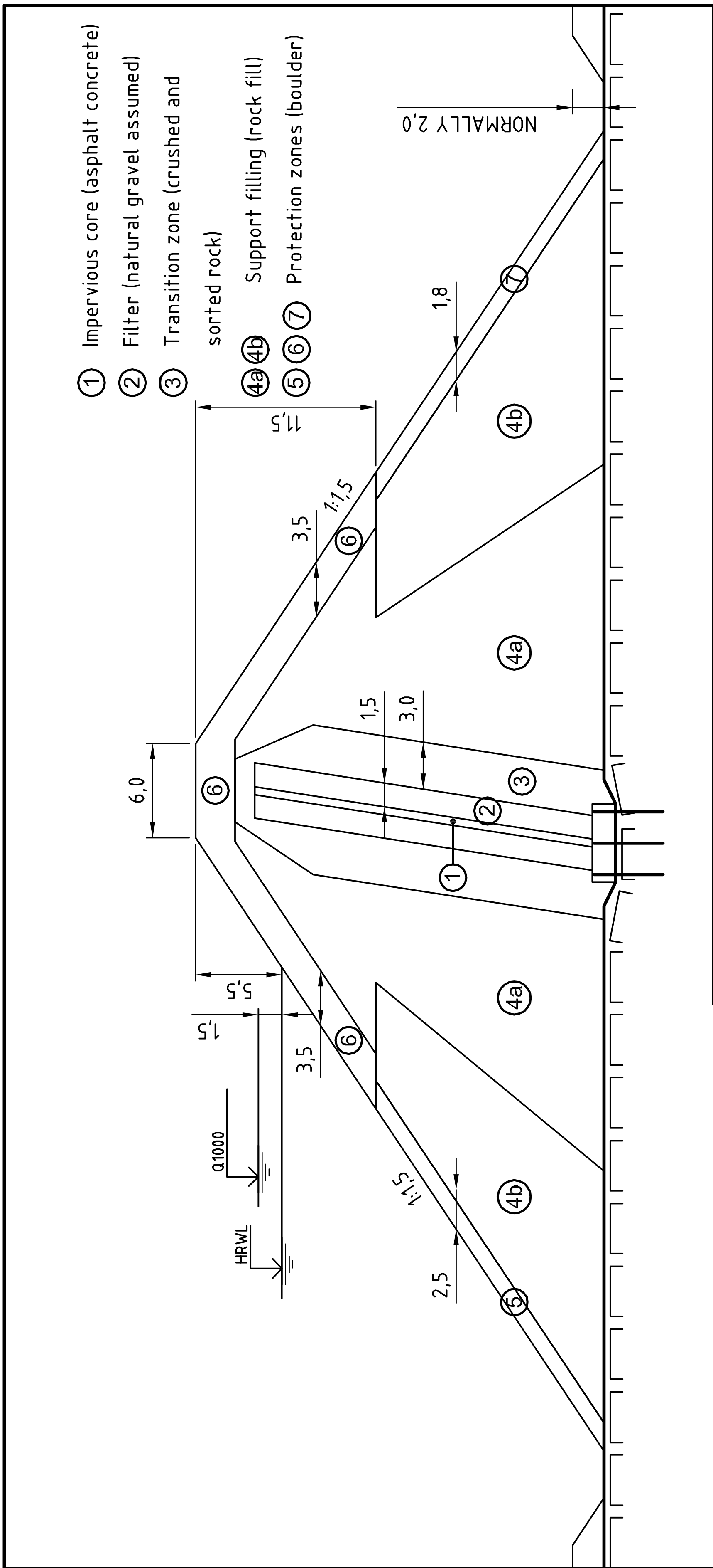
The estimation of the cost calculation uncertainty for the dam <u>body</u> is +25% to -25%.

B.2.7 Increasing the 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 in Item B.2.2.6 above, whereas volumes must be calculated separately in each case.

Cf. comments on slope protection in Item B.1.7.



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.

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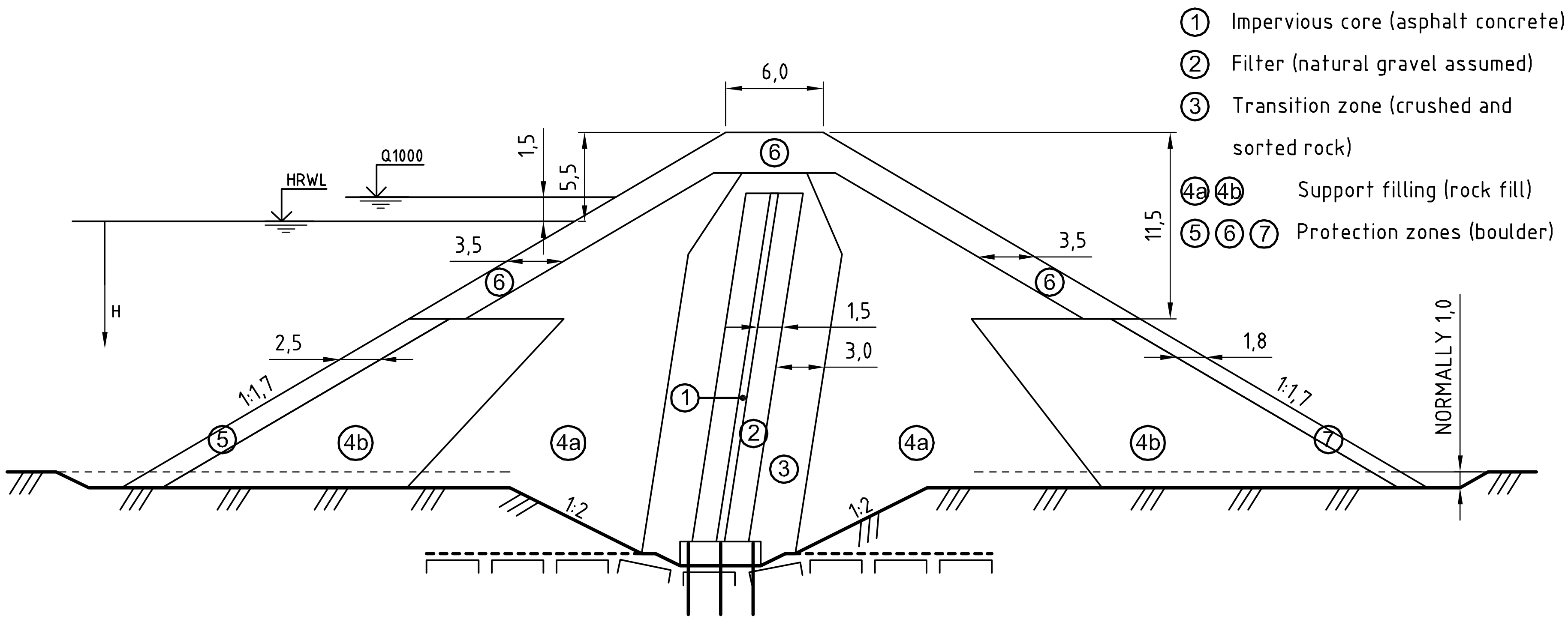
ROCKFILL DAM WITH ASPHALT CONCRETE CORE.
DAM CROSS-SECTION ASSUMED FOR VOLUME AND COST CALCULATIONS.
SIDE SLOPE 1:1.5

FIG. B.2.1



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 settlement 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.

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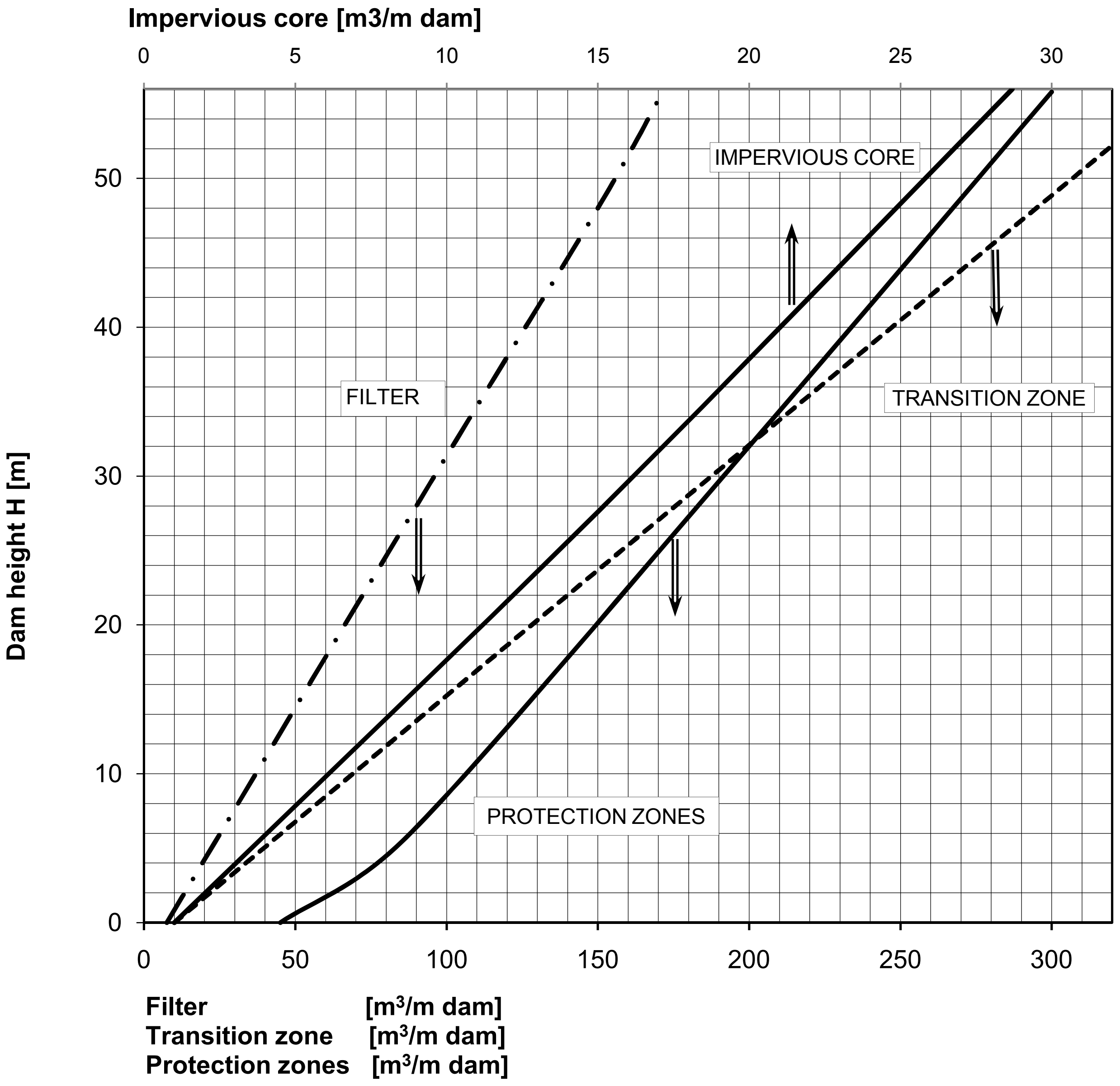
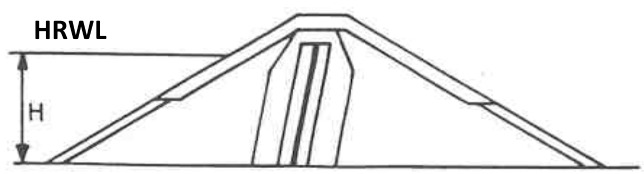
ROCKFILL DAM WITH ASPHALT CONCRETE CORE.
DAM CROSS-SECTION ASSUMED FOR VOLUME AND COST ESTIMATES.
SIDE SLOPE 1:1.7

FIG. B.2.2



COMMENTS:

1. Dam height H calculated from HRWL.
2. Assumed dam cross-section, see Fig. B.2.1 and B.2.2.
3. Volume of transition zone and support filling is corrected according to Figure B.2.5.



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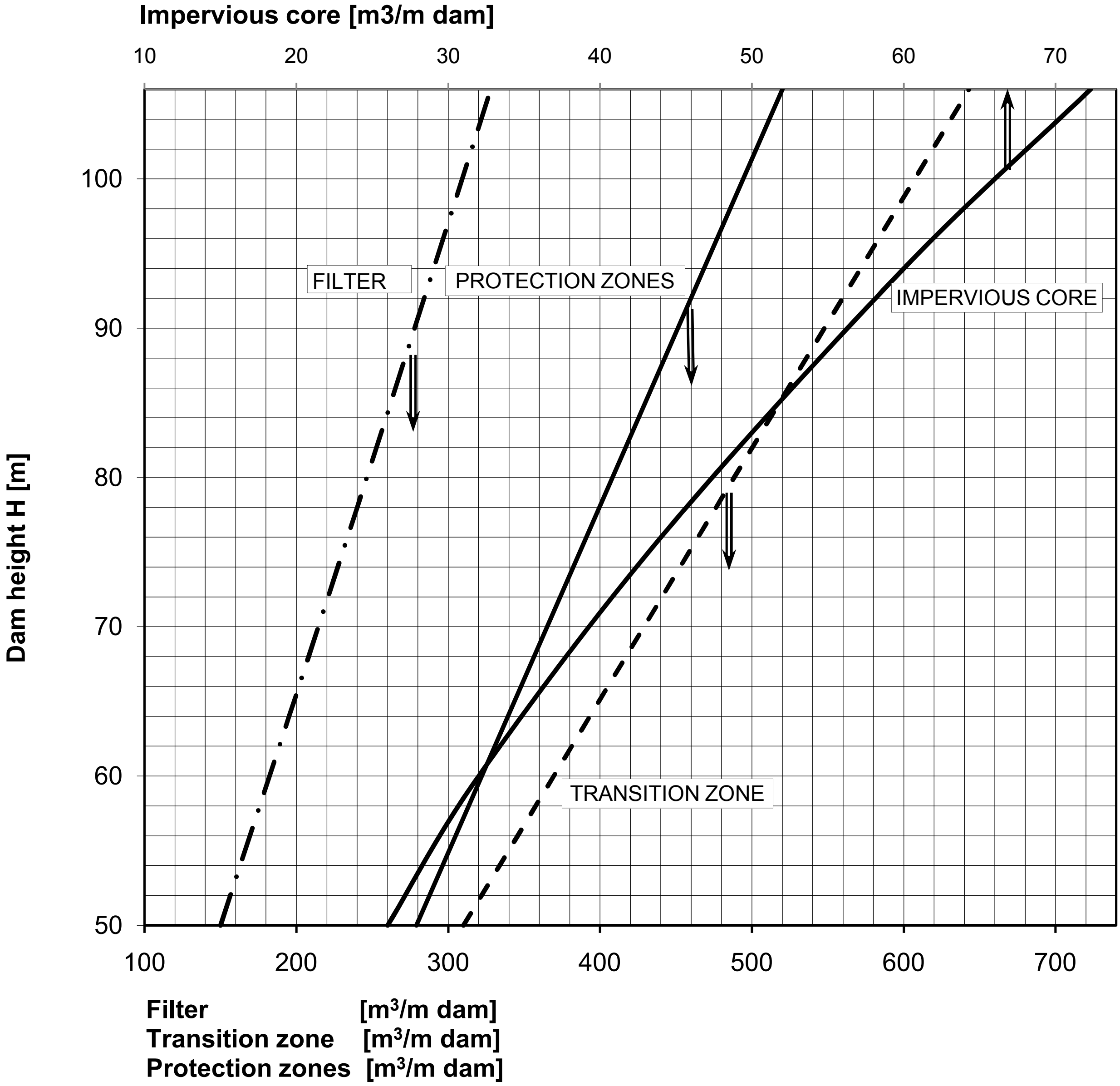
ROCKFILL DAM
WITH ASPHALT CONCRETE CORE
VOLUME CURVES FOR CORE, FILTER, TRANSITION- AND PROTECTION ZONES

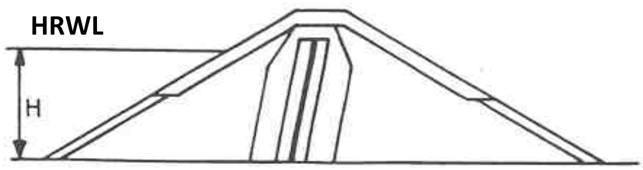
Fig. B.2.3
Part 1

1 January 2010



COMMENTS:

1. **Dam height H calculated from HRWL.**
2. **Assumed dam cross-section, see Fig. B.2.1 and B.2.2.**
3. **Volume of transition zone and support filling is corrected according to Figure B.2.5.**



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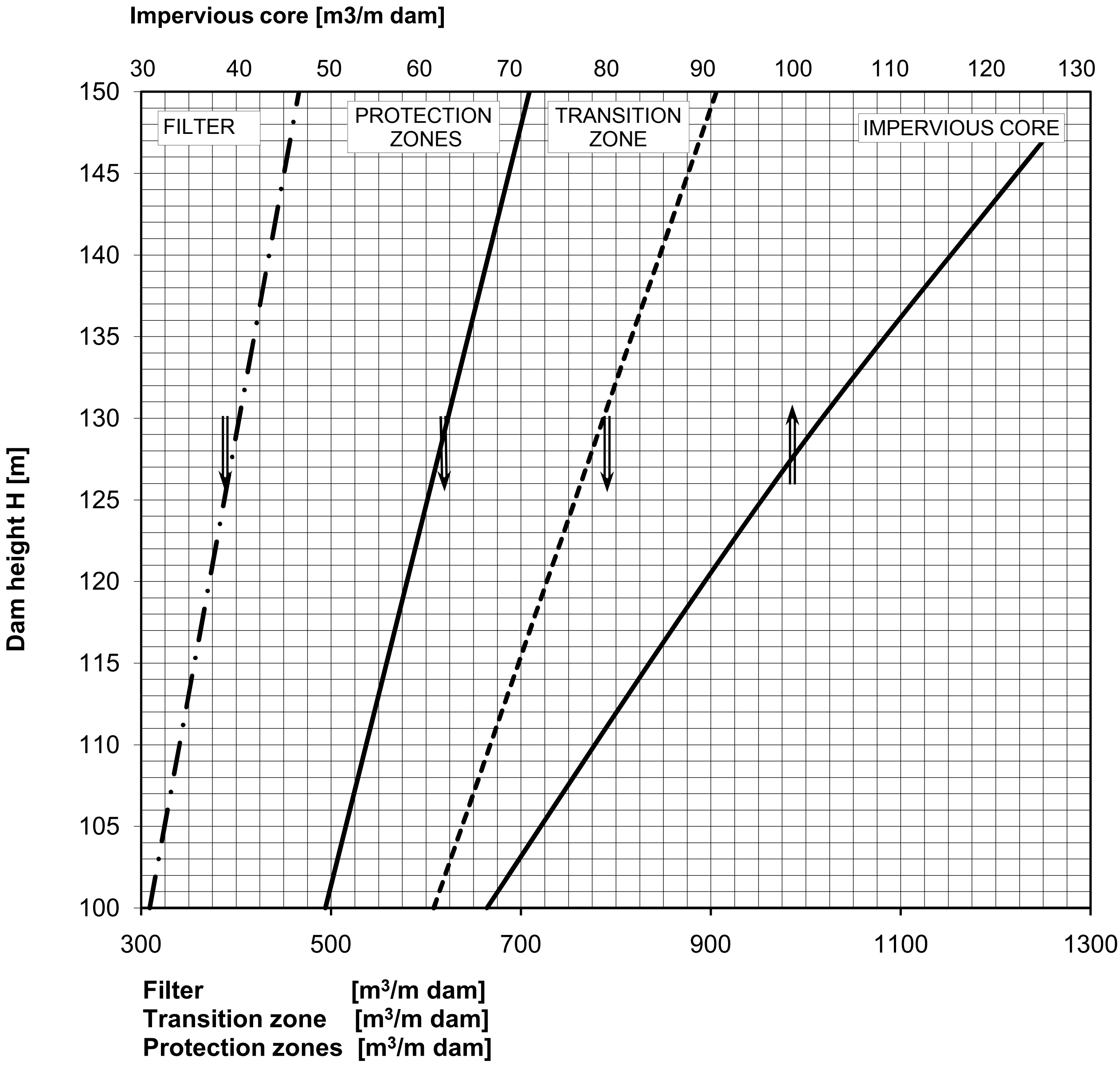
ROCKFILL DAM WITH ASPHALT CONCRETE CORE VOLUME CURVES FOR CORE, FILTER, TRANSITION- AND PROTECTION ZONES

Fig. B.2.3 Part 2

1 January 2010

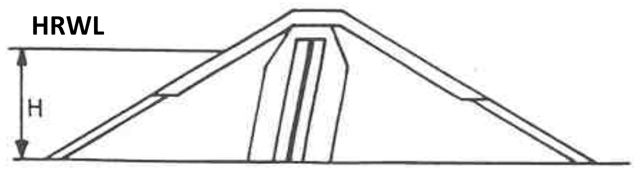


COMMENTS:

1. Dam height H calculated from HRWL.

2. Assumed dam cross-section, see Fig. B.2.1 and B.2.2.

3. Volume of transition zone and support filling is corrected according to Figure B.2.5.



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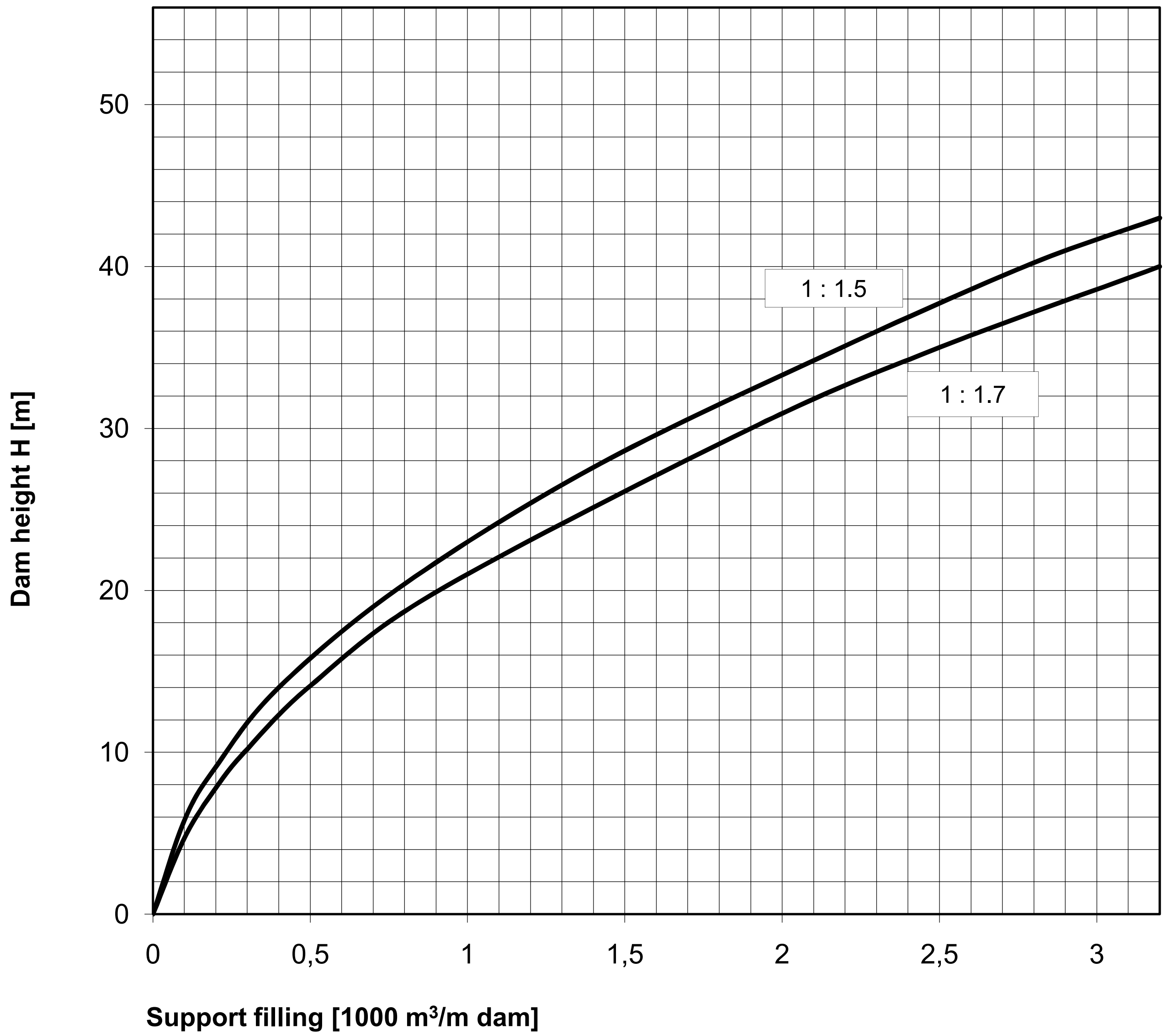
ROCKFILL DAM WITH ASPHALT CONCRETE CORE VOLUME CURVES FOR CORE, FILTER, TRANSITION- AND PROTECTION ZONES

Fig. B.2.3 Part 3

1 January 2010

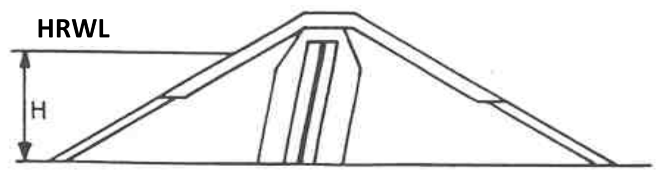


COMMENTS:

1. Dam height H calculated from HRWL.

2. Assumed dam cross-section, see Fig. B.2.1 and B.2.2.

3. Volume of support filling is corrected according to Figure B.2.5.



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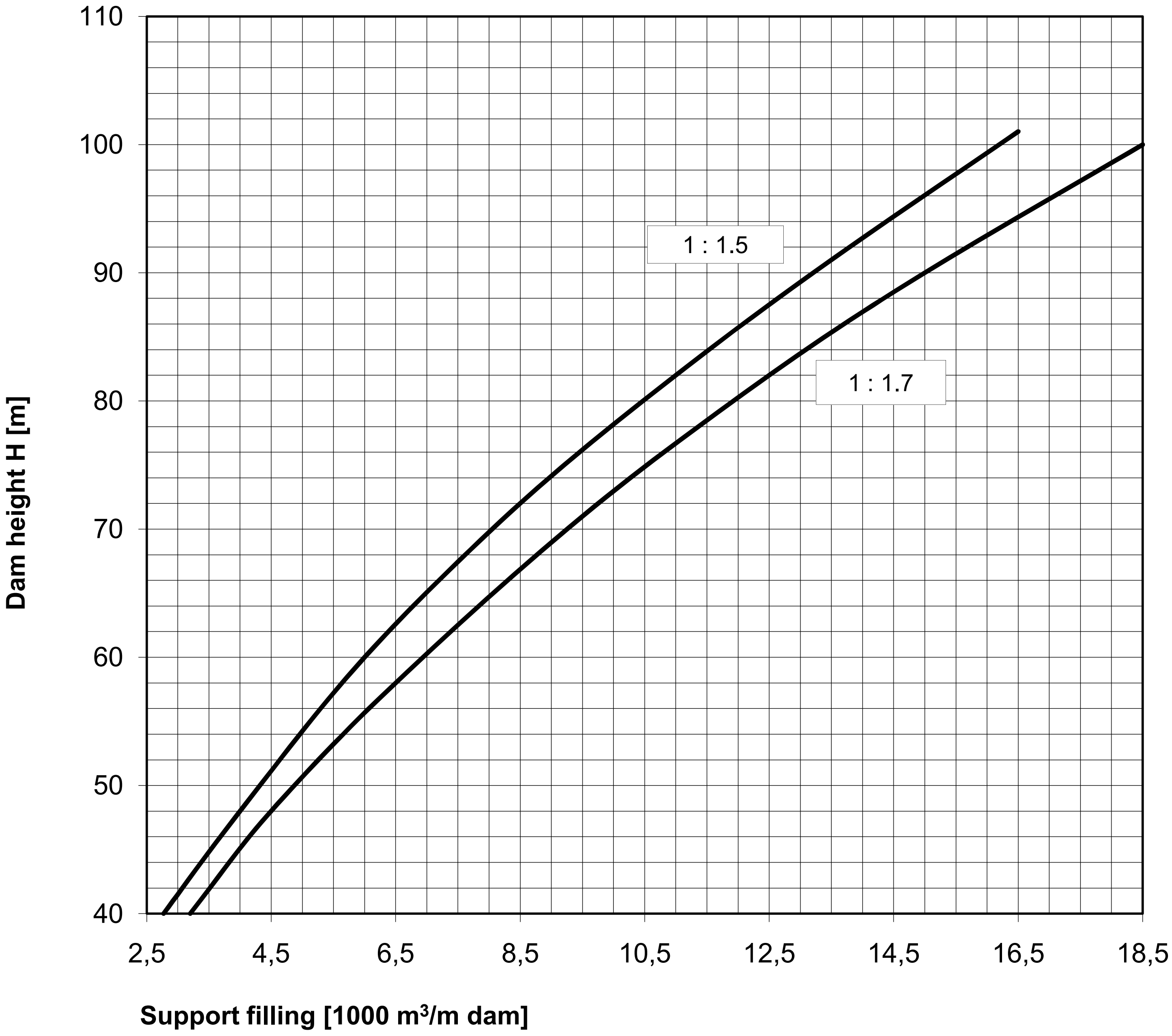
ROCKFILL DAM
WITH ASPHALT CONCRETE CORE
VOLUME CURVES FOR SUPPORT FILLING

Fig. B.2.4
Part 1

1 January 2010

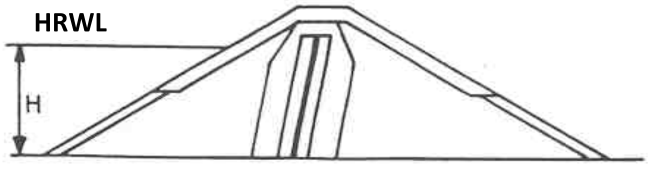


COMMENTS:

1. Dam height H calculated from HRWL.

2. Assumed dam cross-section, see Fig. B.2.1 and B.2.2.

3. Volume of support filling is corrected according to Figure B.2.5.



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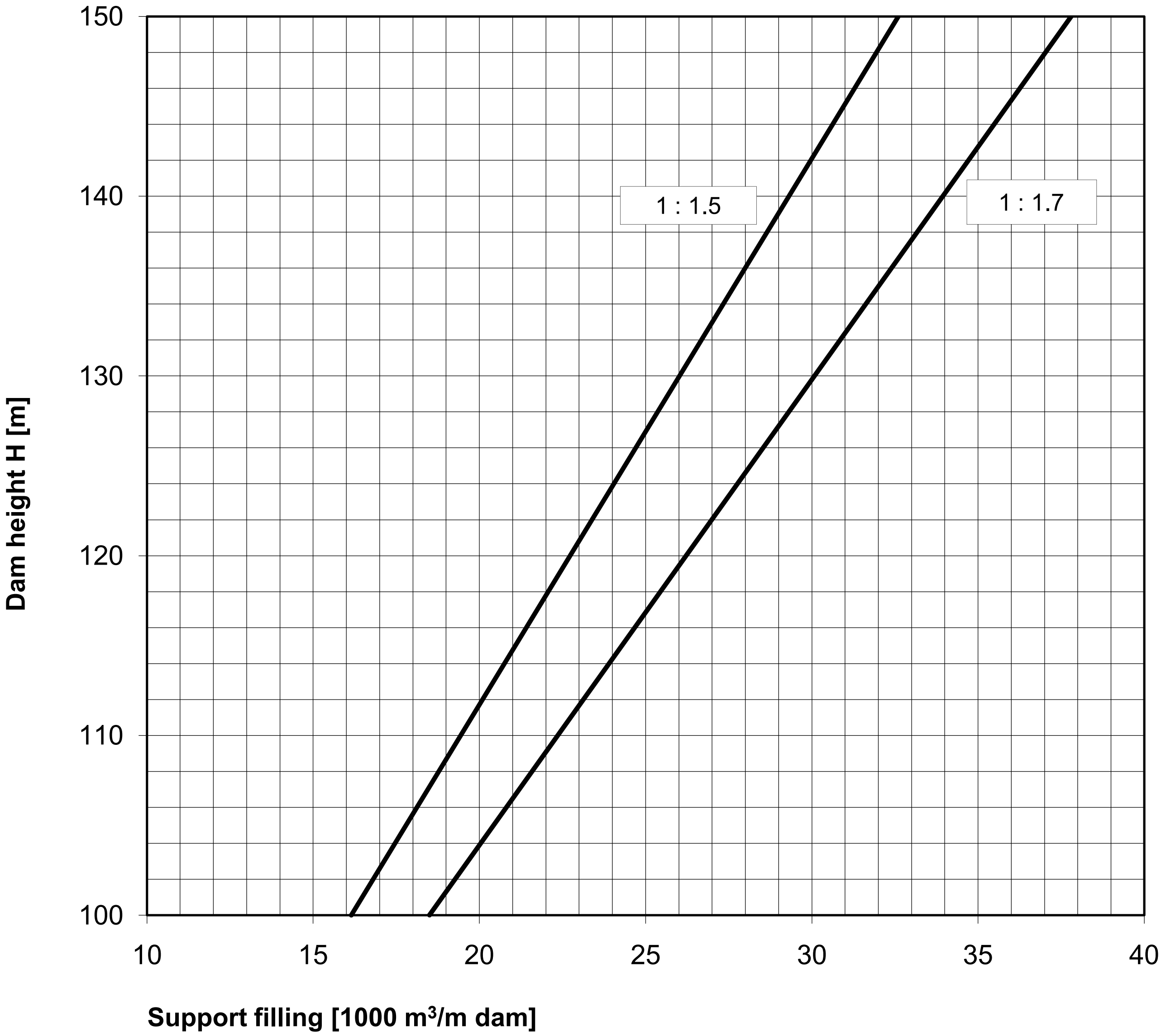
ROCKFILL DAM
WITH ASPHALT CONCRETE CORE
VOLUME CURVES FOR SUPPORT FILLING

Fig. B.2.4
Part 2

1 January 2010

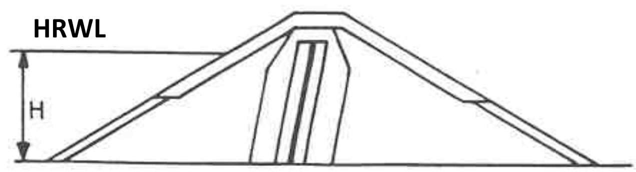


COMMENTS:

1. Dam height H calculated from HRWL.

2. Assumed dam cross-section, see Fig. B.2.1 and B.2.2.

3. Volume of support filling is corrected according to Figure B.2.5.



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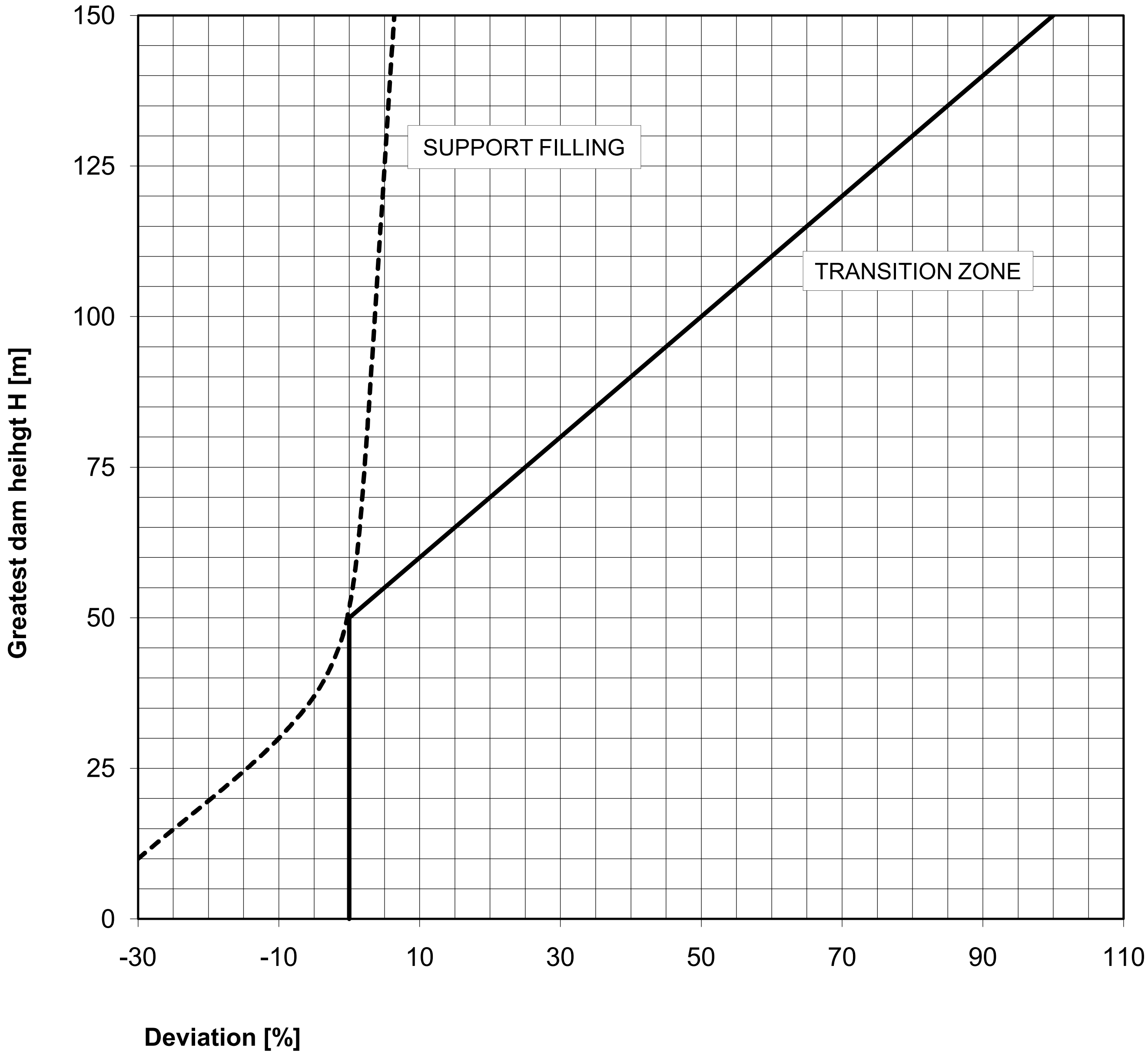
ROCKFILL DAM
WITH ASPHALT CONCRETE CORE
VOLUME CURVES FOR SUPPORT FILLING

Fig. B.2.4
Part 3

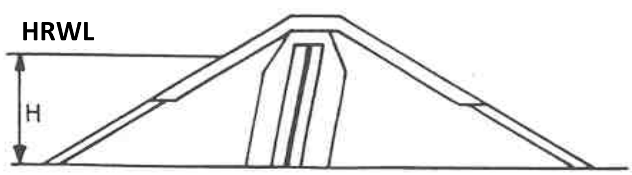
1 January 2010



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 B.2.1.1.



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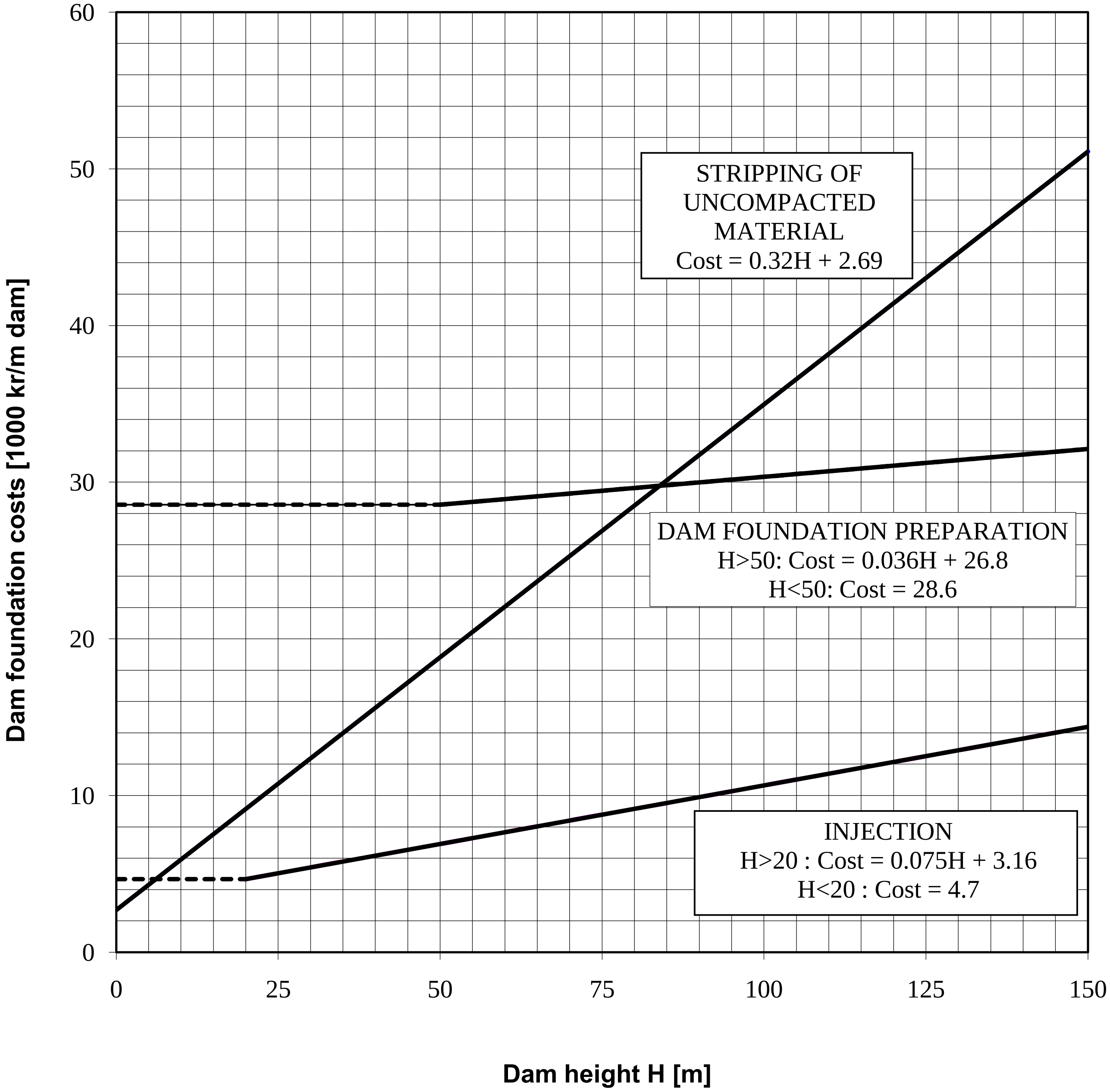
ROCKFILL DAM
WITH ASPHALT CONCRETE CORE
SUPPORT FILLING AND TRANSITION ZONE
CORRECTION FACTOR FOR VOLUME

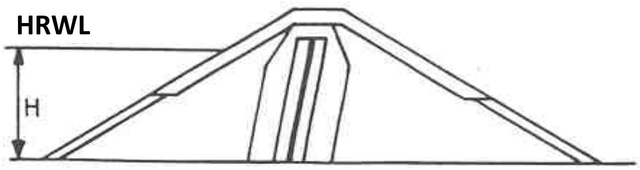
Fig. B.2.5

1 January 2010



COMMENTS:

1. Price level January 2010.
2. Cost of stripping of uncompacted material is shown for an uncompacted material depth of 2 m.
3. Costs stated for dam cross section is shown in Fig. B.2.1.
4. Contractor's rigging and operating costs are included.
5. Dam height H is calculated according to HRWL.



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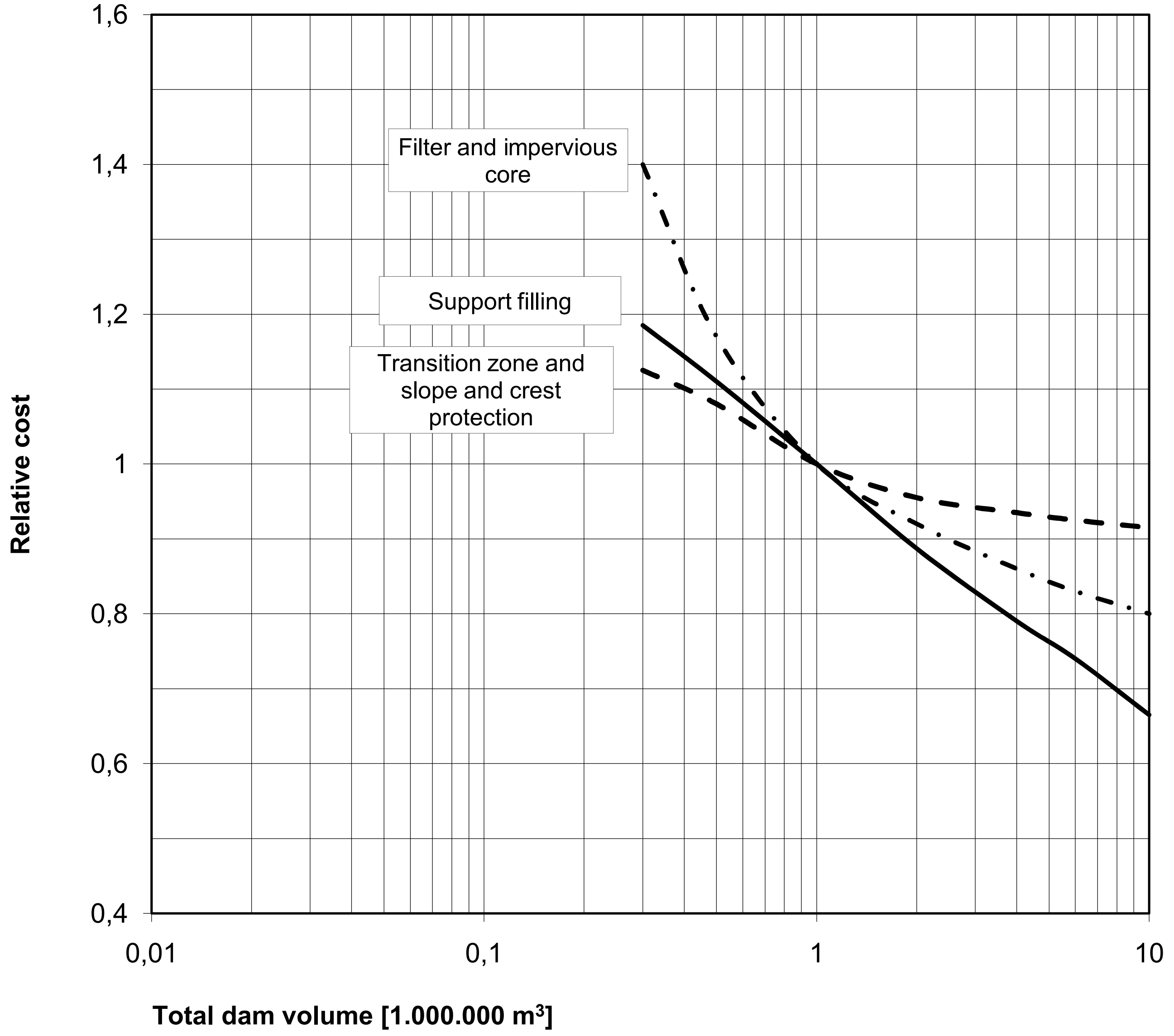
ROCKFILL DAM WITH ASPHALT CONCRETE CORE DAM FOUNDATION COSTS

Fig. B.2.6

1 January 2010



COMMENTS:

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

2. Cf. Chapter B.2.3

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ROCKFILL DAM
WITH ASPHALT CONCRETE CORE
COST CORRECTION FACTOR
IN RELATION TO THE

Fig. B.2.7

1 January 2010

B.3 CONCRETE DAMS

B.3.1 General

B.3.1.1 Assessments

Several types of concrete dams may be relevant. 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 not vital from a cost point of view to make a final decision on the choice of dam during evaluation of the project opportunities. In the following we present curves for four different dam types: Gravity dams, flat slab deck concrete dam, 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 for each 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 gate costs for concrete dams if a free spillway is used. 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 river bed during the initial phase and in the next phase be directed through a bottom sluice in the dam by means of coffer dams. We would finally like to point out 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 can be classified as important from a national defence point of view.

B.3.1.2 Main assumptions

- Price level January 2010
- When price curves were prepared for RCC dams in 1995, prices from international tenders were used along with information from Norwegian contractors. Subsequently, only the unit prices have been updated which have been used to prepare the price curves.
- The price curves and unit prices provide an overview of foreseeable contractor costs (Civil 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.

- The dam height has for all concrete dams been defined as the height from the highest regulated water level (HRWL) down to the average height of the dam foundation in the individual zones. This gives the relevant dam height for sections in the dam with free spillways. 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.

B.3.1.3 Included/non-included costs

Please see Chapters B.02 and B.03. The following applies specifically:

Included costs:

- 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 B.3.1, B.3.3, B.3.4, B.3.5 and B.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. We recommend 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.

Non-included costs:

- 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, thrashrack s: Costs have not been included. For gate costs, see Chapter M.3.

B. 3.1.4 Use of the cost curves

Foreseeable contractor costs per 1 m dam for gravity dams and slab concrete dams are indicated directly in Figures B.3.1 and B.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 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.

B.3.1.5 Cost units

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

-	Stripping, clearing and grubbing and removal of material	80 NOK/m^3
-	Foundation preparation	700 NOK/m^2
-	Foundation preparation, arch dam (incl. concrete toe)	2,600 NOK/m^3
-	Formwork:	1,100 NOK/m^2
-	Formwork, arch dam system formwork for hatches	1,100 NOK/m^2
	(Formwork, arch dam curved slab formwork)	1,200 NOK/m^2
-	Shaping of the RCC dam's outer surfaces	900 NOK/m^2
-	Reinforcement:	16,000 NOK/tonne
-	Concrete	2,000 NOK/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)	150-550 NOK/m^3
	purchase of concrete	700 NOK/m^3
	purchase of pozzolan	400 NOK/m^3
-	Miscellaneous and unforeseen:	10 %
-	Rigging and operation of construction site:	30 %

The prices have been stated within a normal variation range.

B. 3.1.6 Cost calculation uncertainty

The estimation of the cost calculation uncertainty is $\pm$25%.

B. 3.2 Concrete gravity dam

Contractor costs relating to the construction of concrete gravity dams are shown in Figure B.3.1. Volume curves for the key cost units are presented in Figure. B.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 (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.

B.3.3 Flat slab deck dam

Contractor costs relating to the construction of flat slab concrete dams are shown in Figure B.3.3. Volume curves for the central cost units are presented in Figure. B.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, we assume 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 B.3.3.

According to the document “Prosjektering av betongkonstruksjoner” (*Engineering of concrete constructions*) and NS 4365, concrete dams must be dimensioned in accordance with certain given durability and exposure categories. This will be particularly important with regard to the choice of concrete.

B.3.4 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. 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. We therefore recommend that separate dimensioning is conducted for larger dams that are higher than 15 metres.

B.3.5 Roller compacted concrete dams (RCC)

B.3.5.1 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 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. Here cement enriched RCC can be used, 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 most often 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

B.3.5.2 Roller compacted concrete dams (RCC) in a Norwegian climate

It is a prerequisite for the costs below that high-quality concrete is produced and used for the entire dam body. This concrete will be resistant to most environmental impact and loads. Frost resistance will normally be ensured by using frost resistant concrete with the appropriate air pore volume.

Successful placement of roller compacted concrete is contingent on it not freezing the first 24 hours after it has been laid. This limits the construction period to a few months a year most places in Norway.

Placement will be impossible in heavy rain. However, a rainfall intensity of 2 to 4 mm/hour will not normally constitute a problem; higher intensities have been allowed for existing dams in exceptional cases.

B.3.6 Increasing the height of existing dams

B.3.6.1 General

It is difficult to give any general guidelines for how much it will cost to increase 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. We therefore recommend that the dams are planned and the costs calculated separately in each case.

B.3.6.2 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 B.3.7.

Figure B.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 quite a bit from that used as a basis for drawing up the cost curve. We therefore recommend that the dam costs are estimated by mass calculation, and then applying the unit prices given in Chapter 3.1.5. The cost of preparing the dam for extension must also be included. The costs must comprise demolition of the parapet and railings, establishment of adhesion and treatment of the old concrete surface. For estimate calculations, the costs can be set at 2,300 NOK/lm + 290 NOK/m2 of concrete surface that is to be treated (contact surface against new concrete).

B.3.6.3 Slab concrete dam

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

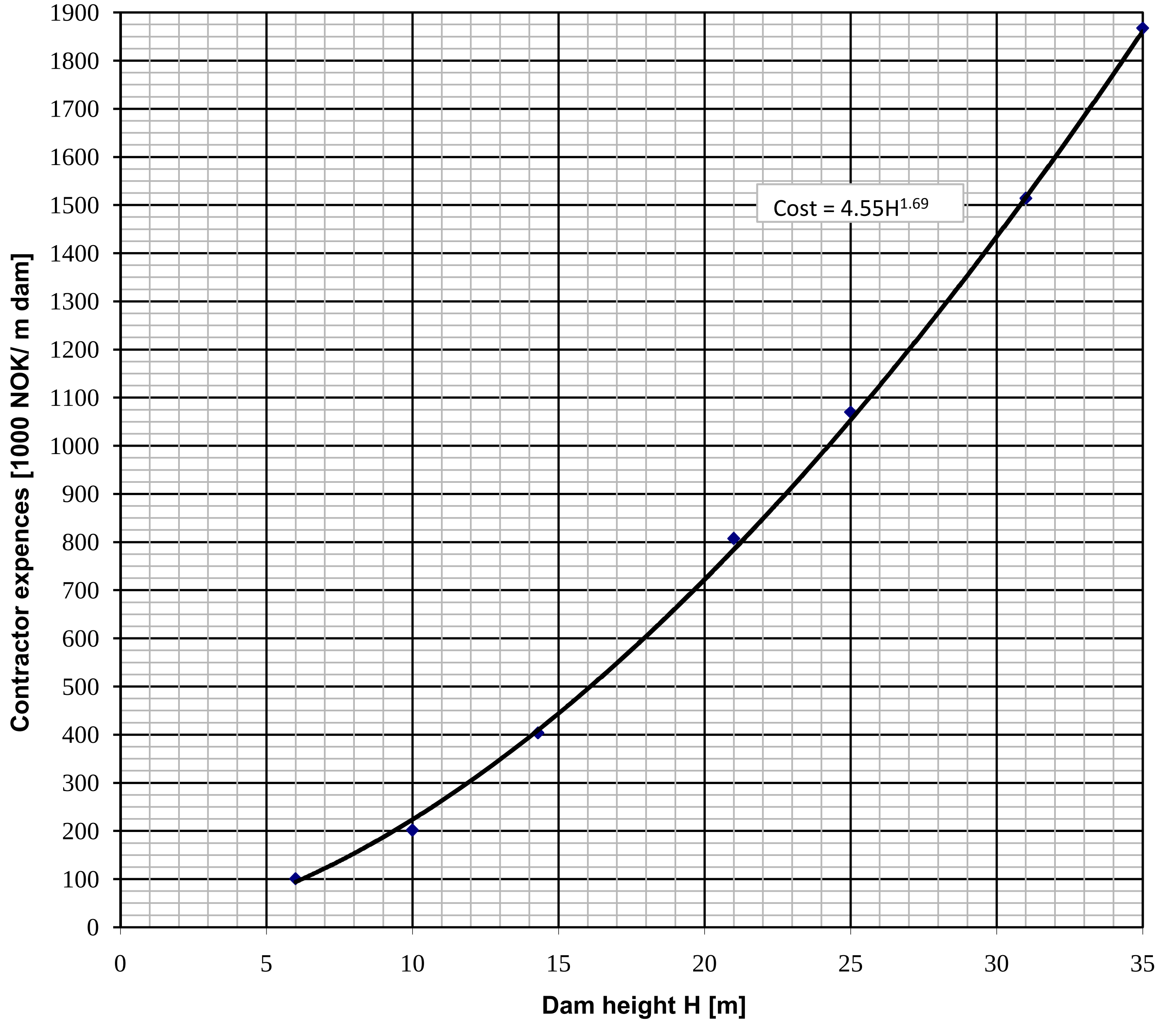
The execution must be planned and cost estimates prepared for each case.

B.3.6.4 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.

B. 3.6.5 Other dam types

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



COMMENTS:

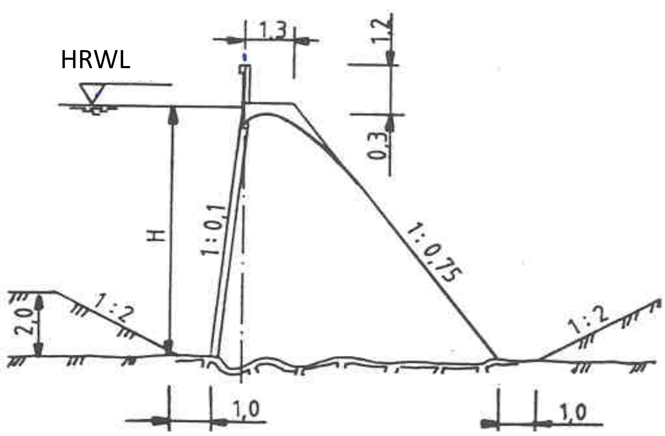
1. Price level January 2010. For lower dams, see cost base for small hydropower plants.

2. The cost curve comprises all contractor costs for building- related work on the dam body and dam foundation.

3. Removal costs for 2 metres of uncompacted material over rock have been included.

4. Expences 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 highest regulated water level /HRWL.



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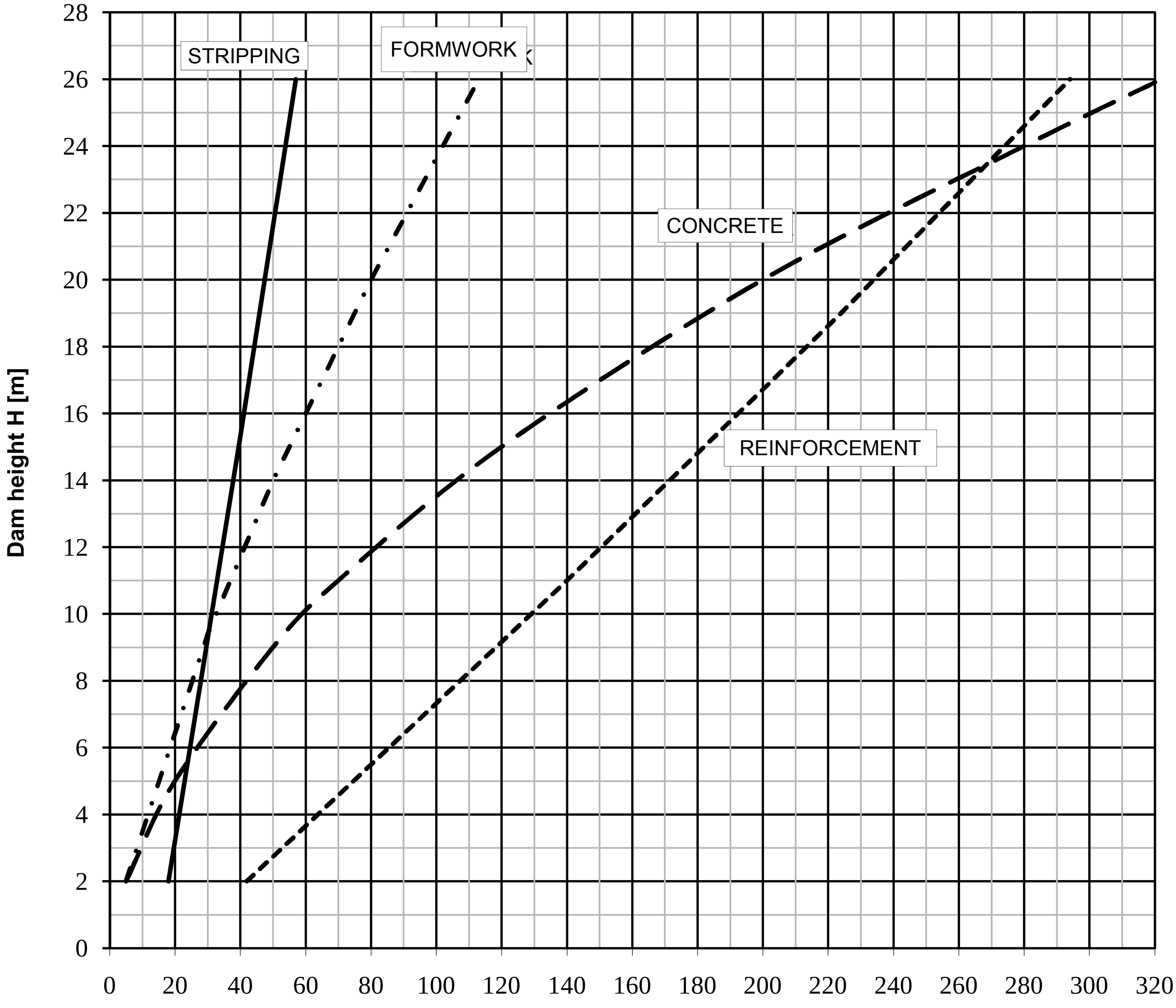
GRAVITY DAM
CONTRACTOR EXPENCES FOR LARGE DAMS, H = 6-35 M

Fig. B.3.1 a

1 January 2010

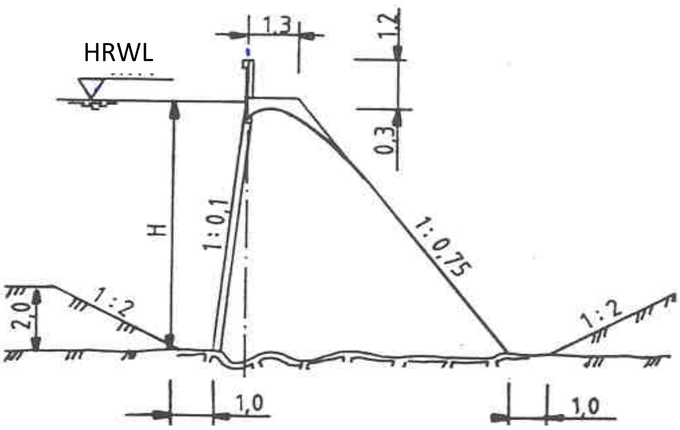


COMMENTS:

Volumes are given as pr m dam. The sectuion length is assumed to be 6.1 m. Reinforcement B500C c300 on the water side.

Addition for parapet:
Formwork 2,55 m2/lm dam
Reinforcement 20 kg/lm dam
Concrete 0,273 m3/lm dam.

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



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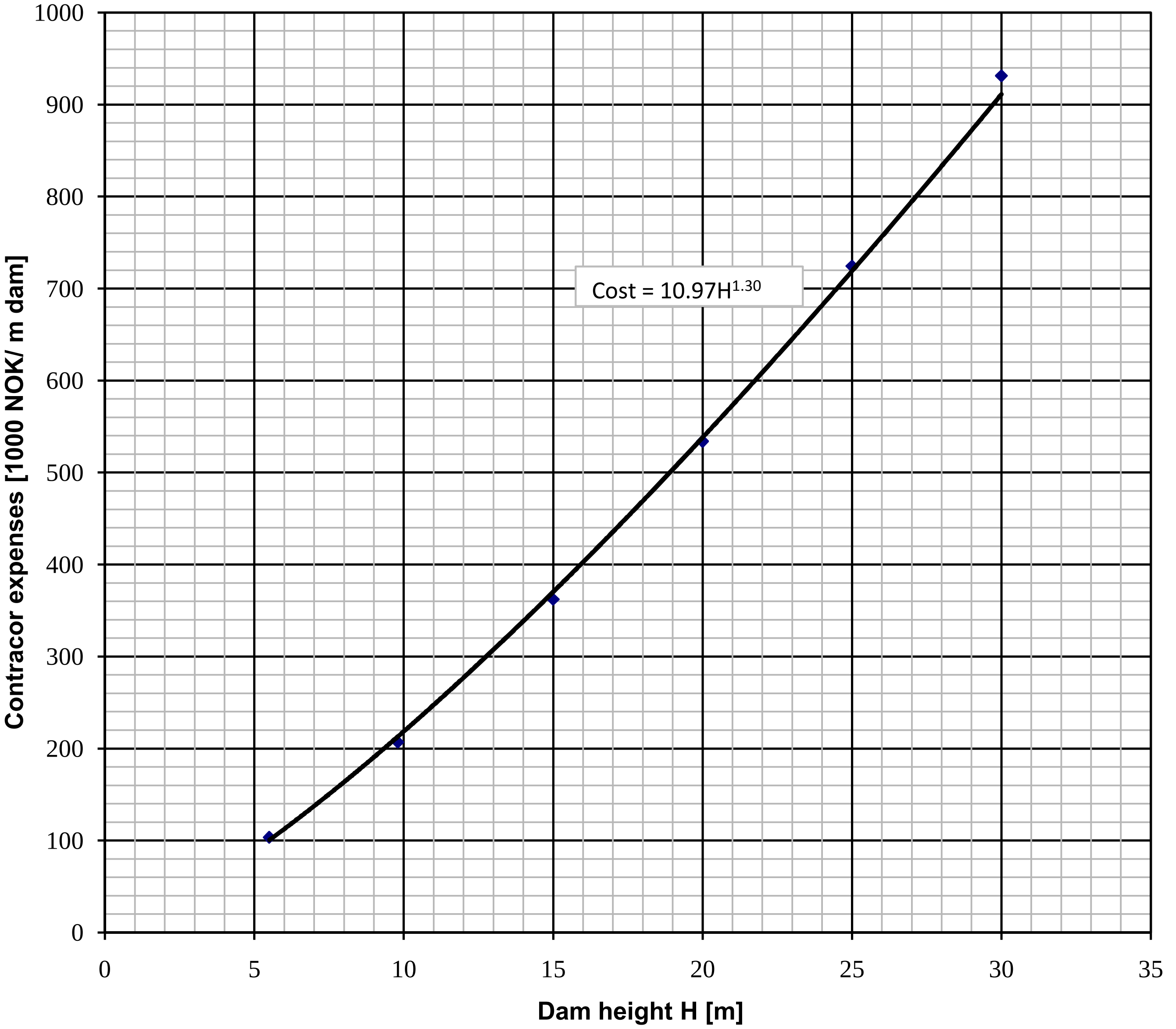
GRAVITY DAM (CONTRETE)

VOLUME CURVES

Fig. B.3.2

1 January 2010



COMMENTS:

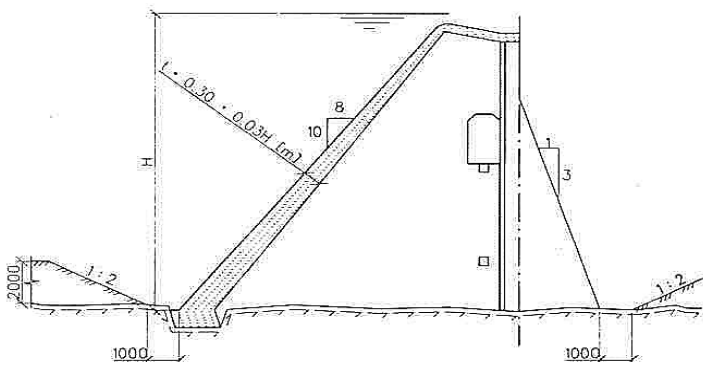
1. Price level January 2010

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 metres of uncompacted material over rock have been included.

4. Expences relating to bottom outlest and redirection of water in the construction period have not been included.

5. Dam height is calculated from the highest regulated water level (HRWL).



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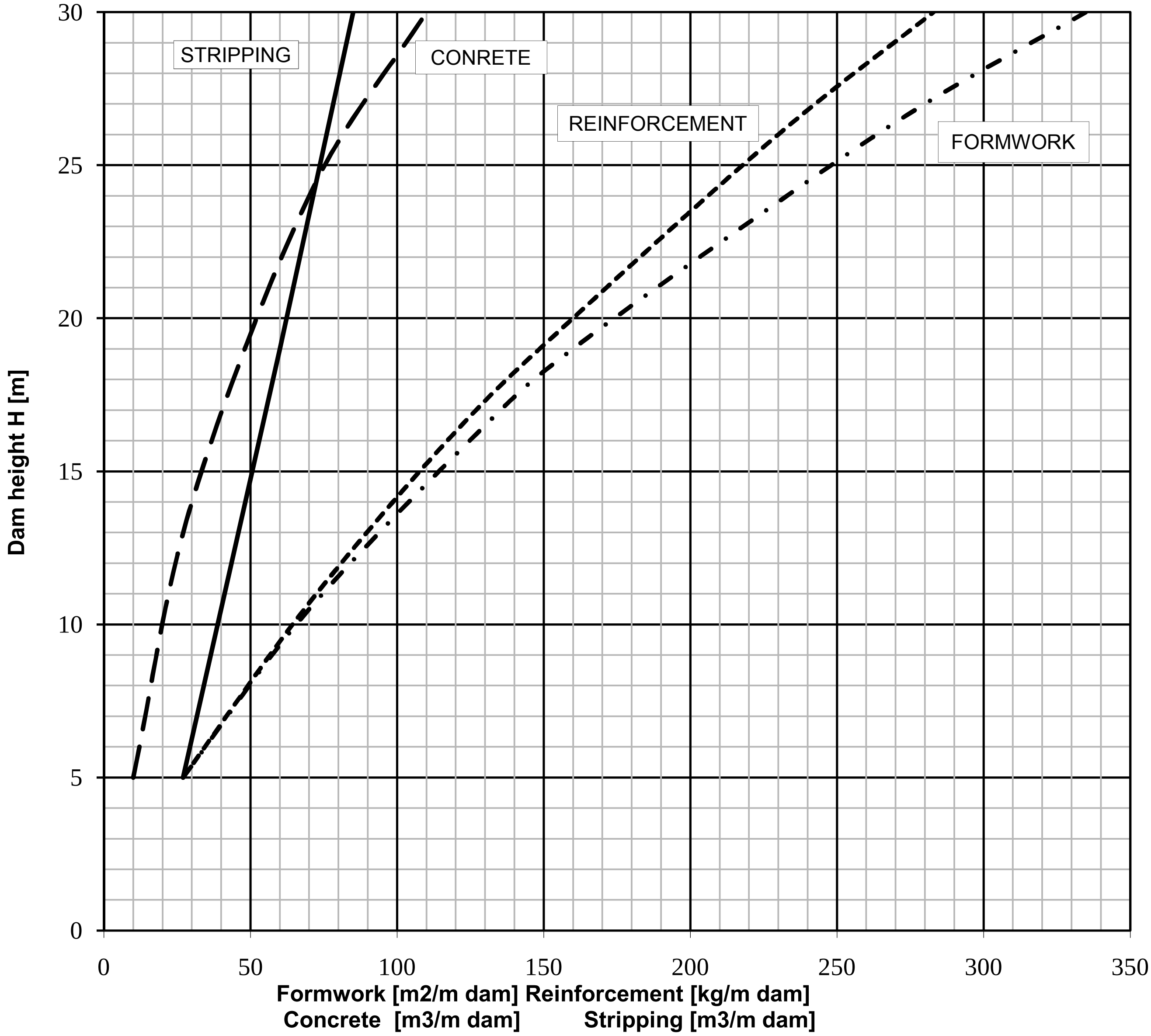
FLAT SLAB DECK DAM
CONTRACTOR EXPENSES

Fig. B.3.3

1 January 2010

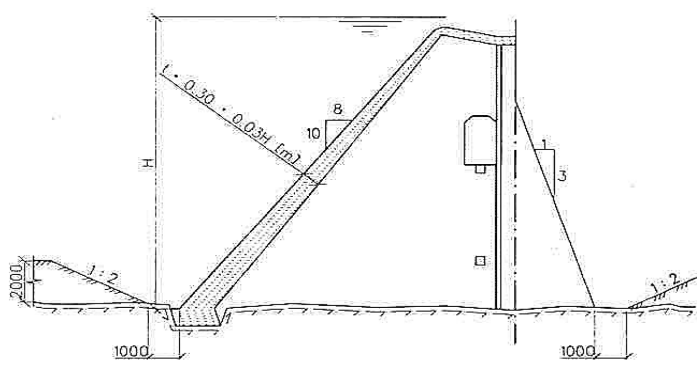


COMMENTS:

1. Volume are given as per m dam. The section length/ pillar distance is 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 highest regulated water level (HRWL).



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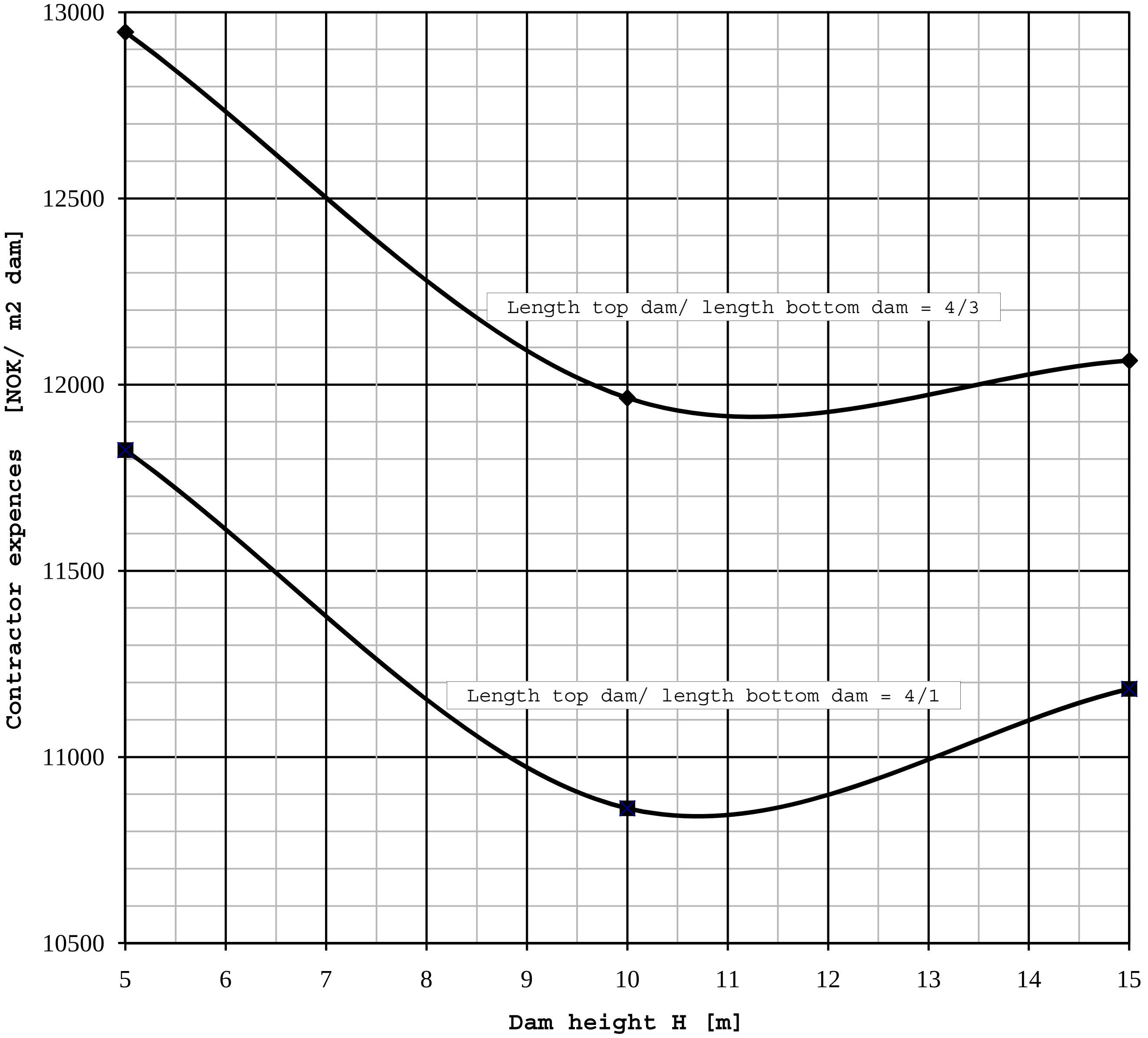
FLAT SLAB DECK DAM

VOLUME CURVES

Fig. B.3.4

1 January 2010



COMMENTS:

1. Price level January 2010.
2. The cost curve 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.
4. The area between the curves covers the most relevant dam cross-sections.
5. The dam height H is calculated from the highest regulated water level (HRWL).

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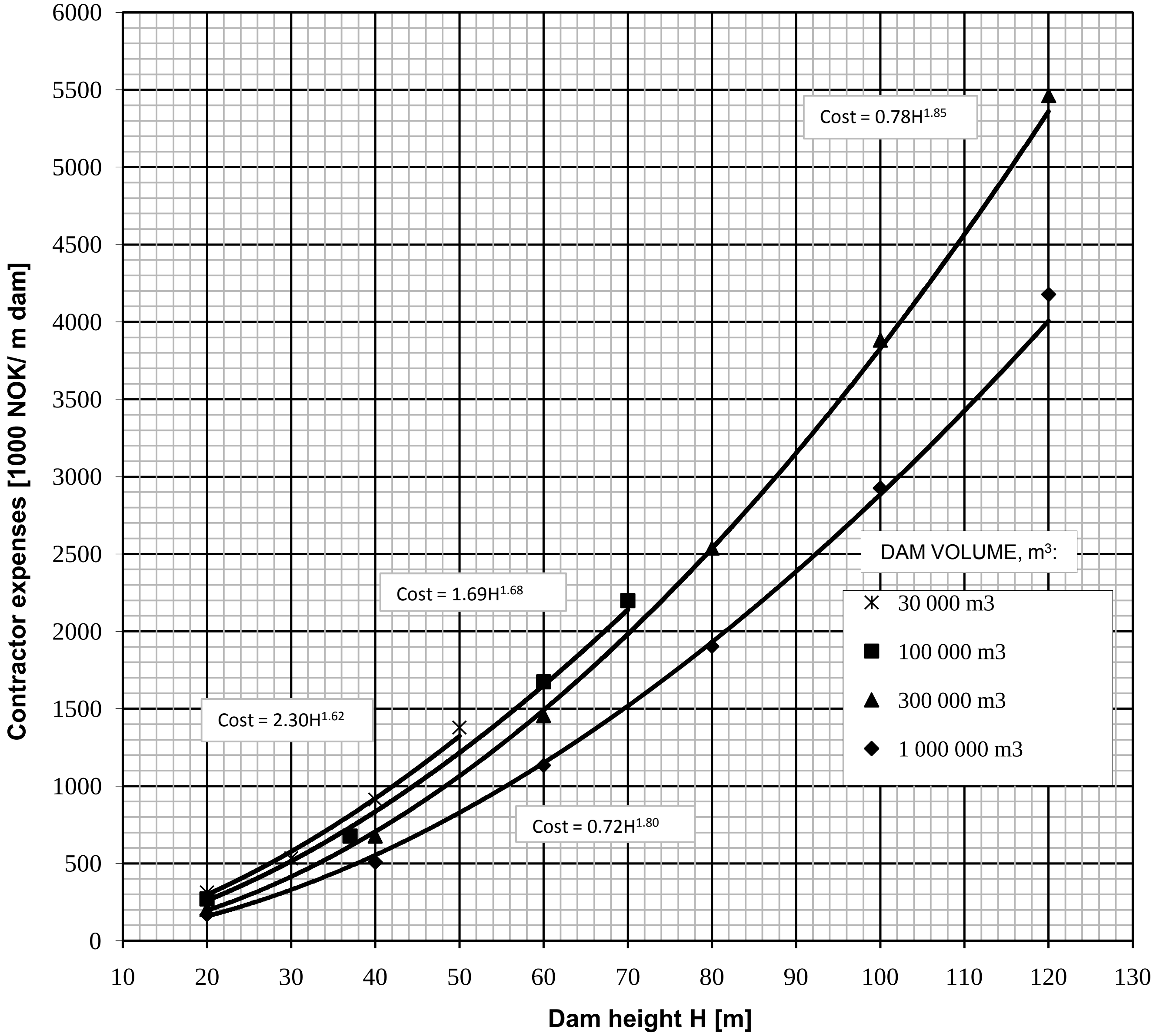
CONCRETE ARCH DAM
CONTRACTOR EXPENSES

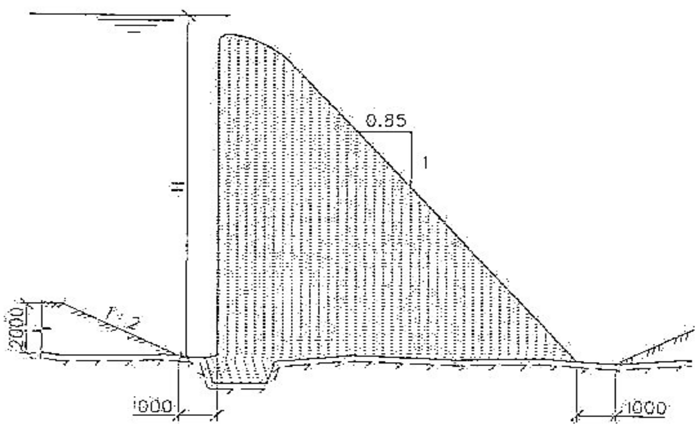
Fig. B.3.5

1 January 2010



COMMENTS:

1. Price level January 2010
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. Contractor rigging and operating costs have been included.
4. The dam height H is calculated from the highest regulated water level (HRWL).



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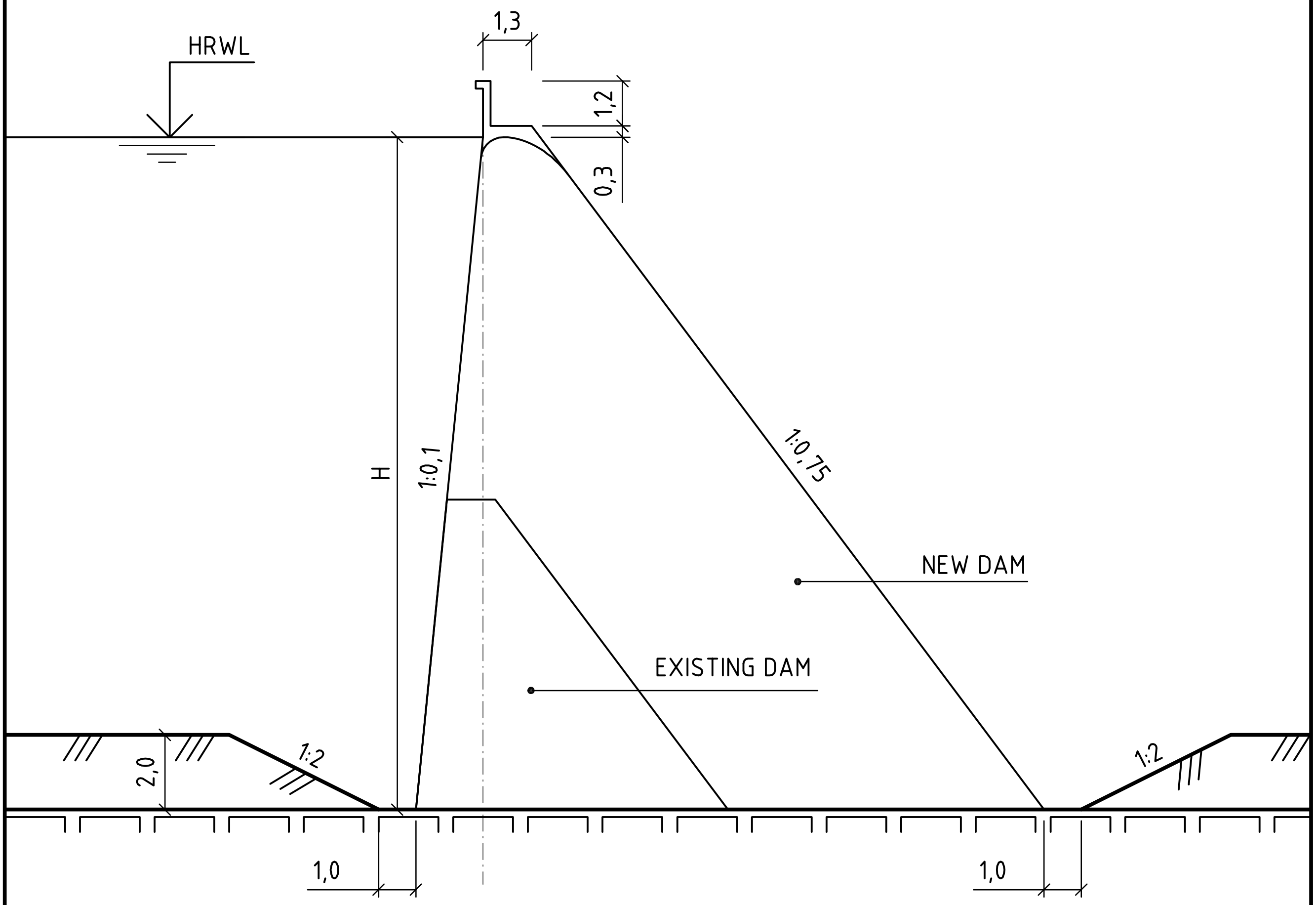
RCC DAM
CONTRACTOR EXPENCES

Fig. B.3.6

1 January 2010



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. B.3.7

B. 4 BLASTED TUNNELS

B.4.1 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 Chapter B.5.1.
- Collaring/portaling:
  The costs must be calculated separately. The cost calculation basis is given in Chapter B.5.1.
- Tunnel excavation:
  This is included in the cost calculations in this chapter on tunnels.
- Tunnel support and injection:
  This is 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 Chapter B.5.2.
- Piercing
  The costs must be calculated separately. The cost calculation basis is given in Chapter B.5.4.2.
- Plugs, gates, hatches, stop log:
  The costs must be calculated separately. The cost calculation basis for plugs is given in Chapter B.5.2.2. The cost calculation basis for gates is presented in Chapter B.5.1, whereas the basis for hatches can be found in Chapter B.5.3 (building-related) and in Chapter M. Stop log costs must be calculated separately.
- Rigging and general operation:
  Have been included in the cost calculations in this chapter on tunnels

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 support; particularly grouting or injection in the event of water seepage problems. The need for tunnel securing is often underestimated in cost calculations. Tunnel securing work will affect not only contractor costs (such as extra bills and acceleration costs) but also developer costs (if, for instance, interest expenses are determining for the construction time). It is important not to be too optimistic when 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 be useful in any case.

The price per consecutive metre (lm) 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.

Previous editions of the cost base have included prices for rail-driven tunnels. This is not considered a relevant mode of operation today, as there is no equipment for this in Norway. 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, often also in the contract. The situation can be described using the following example:

The tender documents request a price of, for instance, a 20m^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 other conditions than we have touched on in this report, and that we could have discussed. We would like to point out, however, that the price curve will give a price that is too low 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 NOK/m excluding tunnel securing, rigging and operation as well as miscellaneous and unforeseen costs, can be read from Figure B.4.1. The same values are also presented in the table below:

Cross-section m^2	Basic price NOK/lm (approx.)	Comments	
18	7 950	18-35 m2	Wheeled loaders are used
35	8 900	35-70 m2	Larger transporting equipment might be necessary
70	11 850	70 m2 and >	Larger dumper trucks, bogie
85	12 800	85 m2 and >	Bench blasting 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 B.4.1 shows the cost curves for the basic price and the total price. We have 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 excavated 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 550 NOK/lm. For downward gradients 5% should be added assuming that water penetration is <500 l/min. If the tunnel is excavated at an upward gradient, but the adit is descending, the basic price of the tunnel should be increased by 1%.
f) Normal, representative location.

2. *Tunnel support*

Tunnel securing should be divided between securing of the working face and face back-up. This will comprise extra rock removal/scaling, bolting, shotcrete, 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 shotcrete 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)

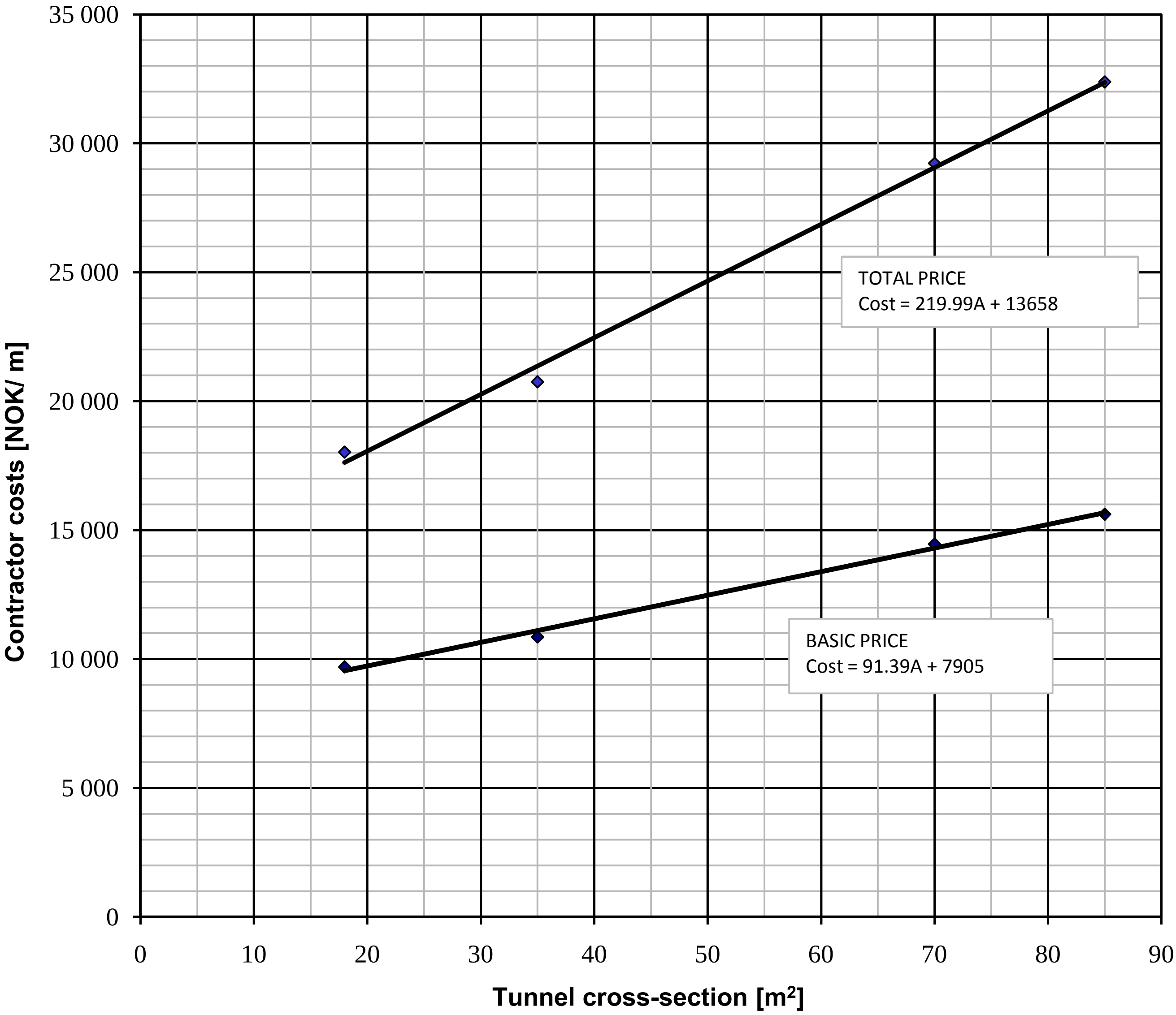
4. *Rigging and operation*

Contractor costs for rigging and operation of the worksite have been included as 30% of the basic price + securing work (1+2). Even though these costs have been increased compared to previous editions they may still be a bit too low for smaller installations and for installations in a difficult location, such as in the high mountains or where transport would be difficult. If this is the case, the rigging percentage may reach 45% or more.

B.4.2 Price level and price estimate uncertainty

The prices are as of January 2010.

We estimate the uncertainty for calculations given in this chapter to be +30% to -20%.



COMMENTS:

1. Price level January 2010

2. Assumed rock of 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.

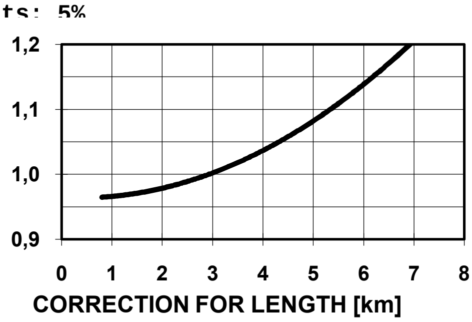
5. Distance collaring - cross cut tip 300 m.

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. Rigging and operating costs are included as 30% of the basic price and securing.

8. Miscellaneous and unforseen costs are included as 10% of the basic price and securing.

9. Correction for driving at moderate downward gradients: 5%



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BLASTED TUNNELS
CONTRACTOR COSTS

Fig. B.4.1

1 January 2010

B.5 MISCELLANEOUS ON BLASTED TUNNELS

All prices are as of January 2010.

B.5.1 Cutting

Cutting with portaling and wall with gate are included in the adit 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, also rigging and operation) can be applied:

Blasting, loading and transportation to tip:	240 NOK/m3
Removal of material:	110 NOK/m3

For information purposes we would like to point out that the cost calculations have been conducted on the assumption that the terrain is ascending 1:1 at the portaling location, that the rock has 2 m of uncompacted material cover and that portaling is achieved by 4 m of rock cover.

We further assume that there are two screens with bolts over the collaring/portaling and one bolt per consecutive metre in the walls. Moreover, we assume that 10 cm of shotcrete concrete has been used on the surface over the portaling.

Finally, we assume 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 B.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 estimated contractor costs (incl. rigging and operation) for cutting.

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

B.5.2 Adit

B.5.2.1 Tunnel

The cross-section of the adit 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 we assume 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 m2 and cost calculations are made according to the following unit prices, including support, unforeseen/miscellaneous and rigging and operation:

   Cost: 20 000 NOK/lm

3. Costs of NOK 210 000 have been included for achieving collaring/portaling.
   Cutting, etc: See section B.5.1.

B.5.2.2 Plug

Contractor costs for plugs in the adit 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 B.5.2.

Costs of gate with steel lining are in addition. These costs are presented in curve figure M.3.E.

B.5.3 Gate shafts, stream inlet, gatehouse

B.5.3.1 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 B.7 and B.8).

The price curve for blasted tunnels can be used to calculate horizontal adit costs (Chapter B.4).

B.5.3.2 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	360 NOK/m^3
Cleaning/scaling	370 NOK/m^2
Bolts	600 NOK/each
Formwork	1 000 NOK/m^2
Reinforcement	16 000 NOK/tonne
Concrete	2 500 NOK/^{m3}
Injection/grouting	70 000 NOK for small cross cuts
“	170 000 NOK for large cross cuts

Rigging and operation of construction site 30% addition.
The cost of the gate including sheet covering is calculated separately (Section M).

B.5.3.3. Civil work in the gate shaft

The cost of Civil 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 (HRV). 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 15 000 NOK/m shaft (from top gate flow to HRWL + 2m).

B.5.3.4 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		240 NOK/m^3
-	Rock support mark-up on the price above		30%
-	Rigging and operation of the work site	mark-up	30%

B. 5.3.5 Stream inlets

The curve in Figure B.5.3 shows simplified normal stream inlet costs for Norwegian hydropower plants.

The figure is based on a concrete intake construction located above the shaft/stream course where an intake thrashrack has been installed as well as an air intake. Furthermore, we have assumed that it should be possible to drain the intake by installing a closing component.

Local conditions have a great impact on the costs. Consequently, we have conducted 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.

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

The contractor costs include rigging costs, ground and concrete work including installation of closing component and thrash racks.

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 3.2 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 we have presented a 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, high unit prices should be applied, for example:

Blasting, loading and transport to tip:	450 NOK/m^3
Foundation preparation:	500 NOK/m
Rock bolts:	900 NOK/each
Formwork:	1 200 NOK/m^2
Reinforcement:	19 000 NOK
Concrete:	3 000 NOK/m^3
Rigging and operation of the work site	30% extra

Thrash racks, gates, stop logs: 85 000 NOK + 40 000 NOK per m^3/s design flow. This is a very rough estimate.

The prices in the 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. This is particularly the case for concrete where transport will have a great impact on the price. The price of concrete could easily rise to 6000 – 9000 NOK/m3. The price of work where man-hours make up a significant factor will increase considerably if both manpower and materials must be transported to the worksite by helicopter.

B.5.4 Tunnel mouth, underwater tunnel piercing

B.5.4.1 Tunnel mouth

Water-carrying tunnels will, of course, always have a mouth, almost always a closing device (stop log for simpler constructions) and most often thrashracks. 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 headrace tunnels and tailrace tunnels depend on whether the breakthrough is to air or under water (such as underwater piercing). The tunnel mouth costs must be seen in connection 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.

B.5.4.2 Under water tunnel piercing

Under water 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 and cross-section, 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: (NOK):

Small tunnels, modest water pressure	1 100 000 Mill.NOK
Medium tunnels (15-20 m2) 40-70 m pressure	2 400 000 Mill.NOK
Large tunnels (70 m2) 40-70 m pressure	4 800 000 Mill.NOK

For large tunnels in grouting, probe drilling in the final section of the tunnel near the piercing, and the extent of grouting 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 headrace tunnel is determining for the construction period.

B.5.5 Distribution reservoir (surge chamber)

B.5.5.1 General

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

The choice between a shaft reservoir/surge chamber 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 basin 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, shafts in the headrace tunnel, distance between water surface in the distribution reservoir and intake (including any stream inlet shafts).

Consequently, a schematic presentation of cost calculations for distribution reservoir 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.

B.5.5.2 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 360 NOK/m^3.

B.5.5.3 Air cushion chamber

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 360 NOK/m^3 (assuming the chamber cross-section to be approximately 80 m^2).

Grouting, 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.

B.5.6 Tunnel enlargement

B.5.6.1 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 spillways. Local conditions will determine whether to choose back ripping or a new parallel tunnel. Construction of a new tunnel will mean that one is more free 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 really 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 rock support and locate any landslides or major rock falls.

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

Rigging and progress rates

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

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

Adits

The size of the adit and adit 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 adit correspondingly and inserting a new adit gate. For cost reasons it is important that there is a road connection to the adit and that there is access to a tip.

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 rock support 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 supported.

Bottom back ripping or bench blasting 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.

Existing rock support

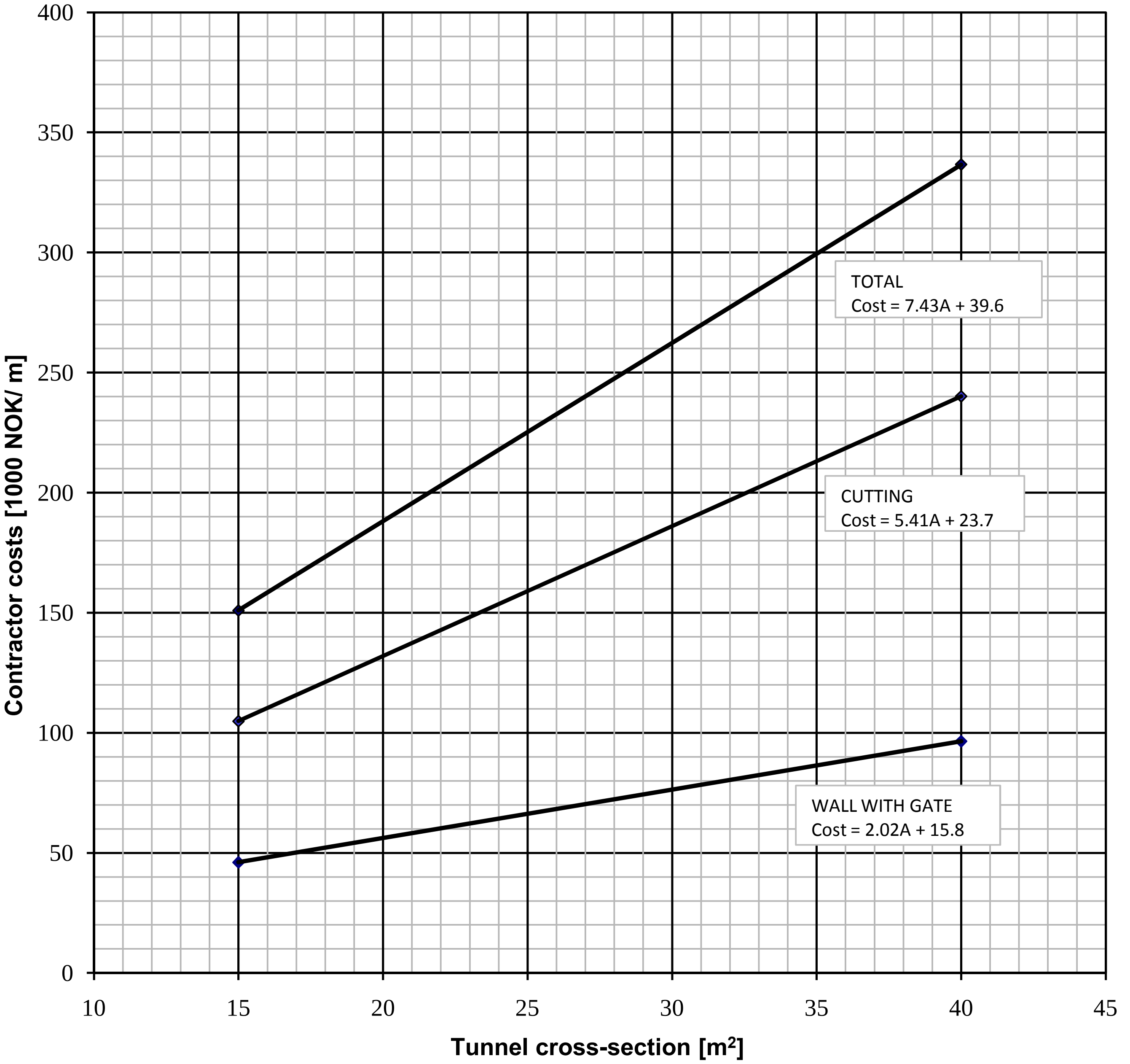
Existing rock support is a challenge for the back ripping as there may be problems with drilling into bolts, removal of casts and grid reinforced shotcrete. For operational purposes a bottom bench is most suitable in such cases. In tunnels where there is not much existing tunnel support and thus little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

Function requirements

In our experience, current blasting techniques result in higher roughness than previously. The reason for this is usually to do with 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.

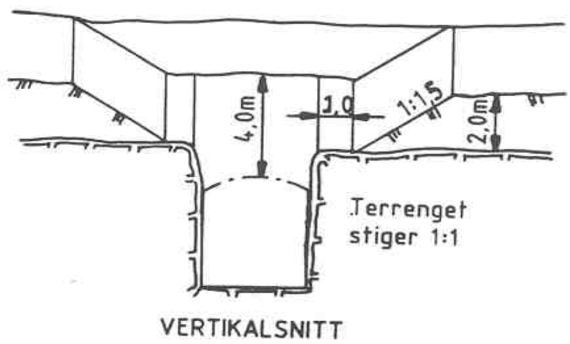
B.5.6.2 Costs

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 tunnel costs (blasting, transportation, excluding rig and operation) will vary between 400 NOK/m^3 for small enlargements (approx. 10m^2) and approx. 200 NOK/fm^3 for larger enlargements (>30 m^2).



COMMENTS:

1. Price level January 2010
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.
5. Contractor rigging and operatinghe costs have been included as 30%



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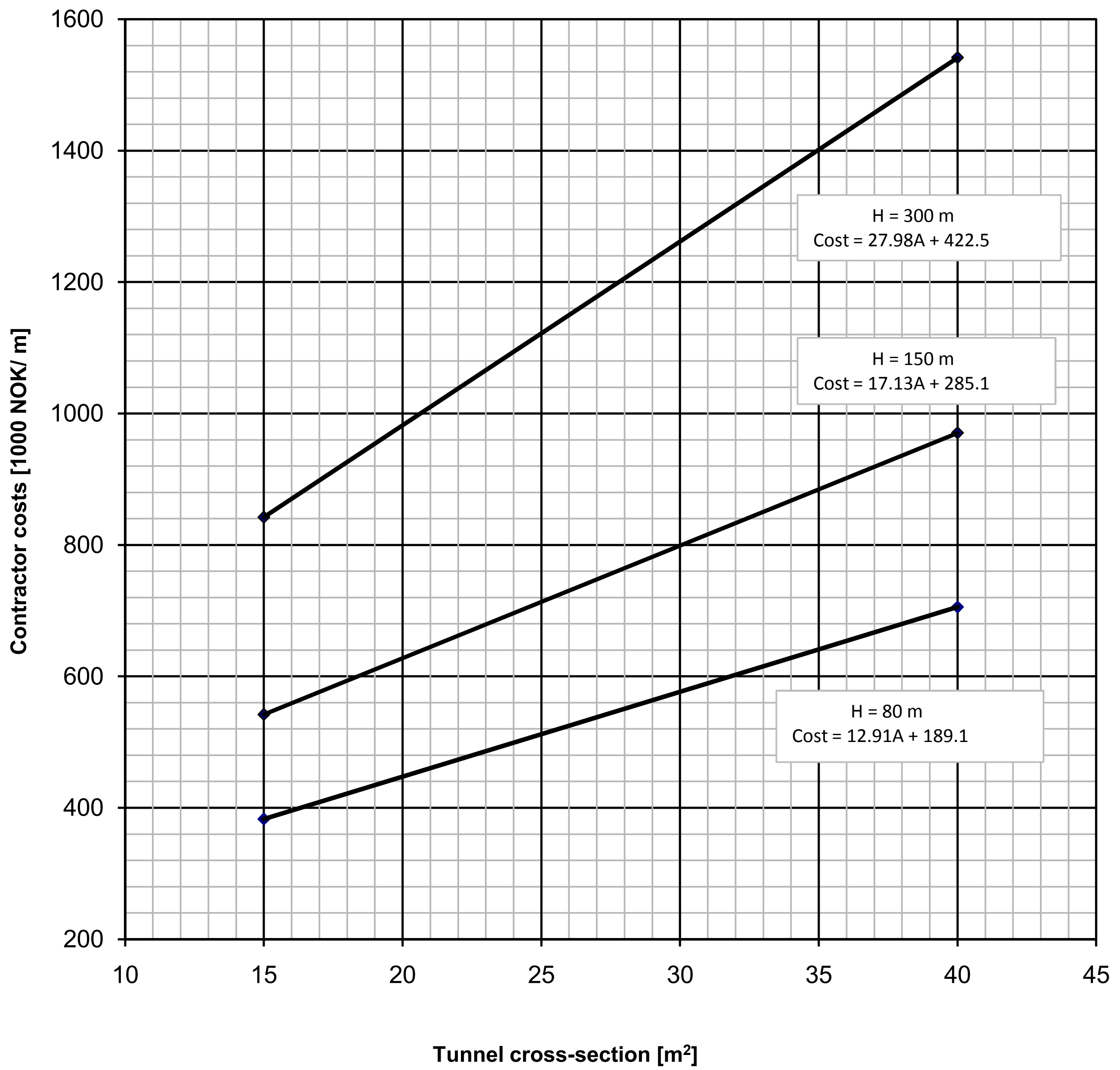
CUTTING WITH GATE CONTRACTOR COSTS

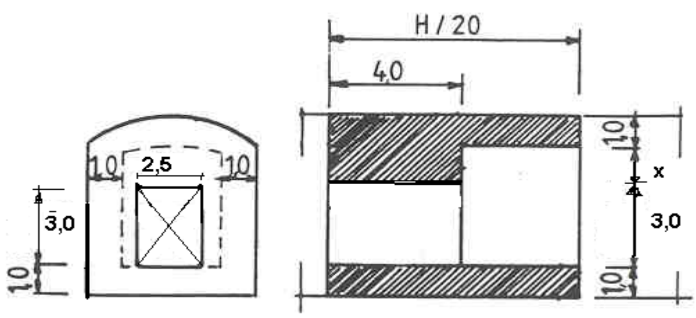
Fig. B.5.1

1 January 2010



COMMENTS:

1. Price level January 2010
2. H gives the water pressure in metres.
3. The curve comprises all contractor costs for building-related work.
4. NOK 38 000 - 53 000 of injection costs have been included for small cross-sections (H=80-300m) and NOK 53 000-78 000 for large cross sections (H=80-300m).
5. Cross cut gate with steel lining has not been included. The cost of this is given in the table and must be added.



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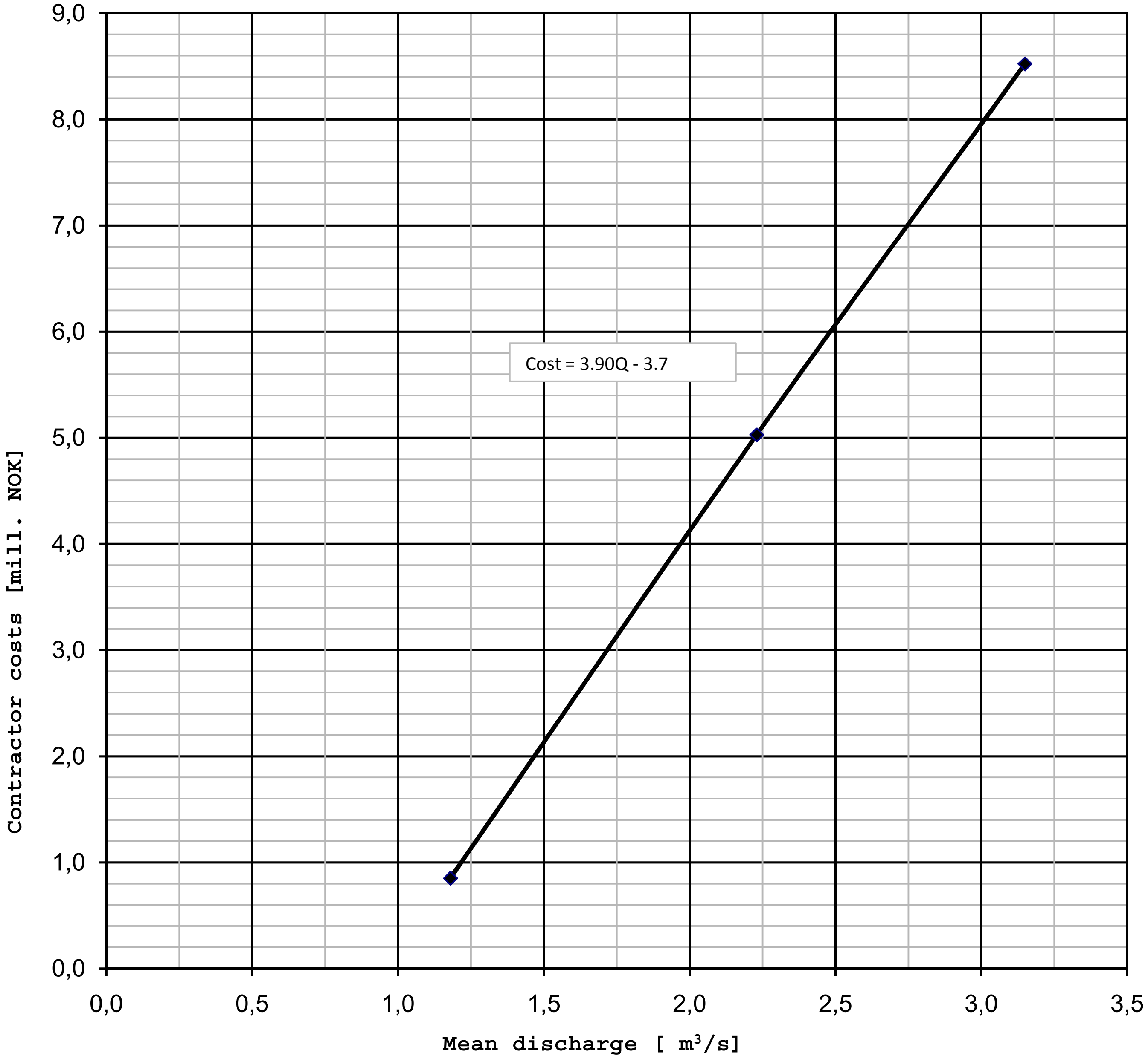
CROSS CUT PLUGS CONTRACTOR EXPENSES BUILDING-RELATED WORK

Fig. B.5.2

1 January 2010



COMMENTS:

1. Price level January 2010

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

3. Rigging and operating costs have been included.

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

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

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BROOK INTAKE FOR HYDROPOWER PLANTS

Fig. B.5.3

1 January 2010

B.6 DRILLED TUNNELS

B.6.1 Full-face drilling (TBM)

B.6.1.1 General

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

There are many reasons why full-face drilling may be chosen instead of conventional drill and blast.

There are advantages and disadvantages with 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. We would like to draw attention 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. The rule of thumb is that the cross section can be reduced by approximately 40%, which also means that land fill is less for full-face drilling.

In connection with full-face drilling, a relevant engineering-geological survey is 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. A replacement of the cutters means a halt in operations and thus a reduction in the effective operating time. The rock pressure and porosity of the rock are parameters that will be significant for the type of drilling machine. Usually the drilling machine is “tailored” for the task.

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

Miscalculations relating to drillability, degree of fracturing and abrasion value can lead to great deviations from the penetration and cost prognoses. Cost estimates for full-face drilled tunnels must therefore be based on a much more thorough 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. As of 2010 there are no second-hand machines in Norway. 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 NOK 40 million, giving a depreciation difference of NOK 18 million between a new and second-hand machine. If the length of the tunnel is 10 km, this would entail a difference of NOK 1 800 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 NOK 3 400 per metre of tunnel longer than 10 kilometres.

B.6.1.2.4 Basis and uncertainty

A basis for revision of cost curves for tunnels run with tunnel boring machines in Norway is virtually non-existent. The last time tunnel boring machines were used in the construction of a hydropower plant in Norway, was when Meråker power plant was constructed in 1994. If long hydropower tunnels are to be constructed, the use of tunnel boring machines should be considered.

As sufficient empirical figures are not available we have chosen to remove the cost curves for tunnel boring machines from this revision.

B.7 BLASTED SHAFTS

B.7.1 General

Below follows what is intended as a rough overview of foreseeable contractor and supplier costs for shafts, both 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 we have 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 make 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. For larger cross-sections two rig-ups will be necessary. Furthermore, ensuring the safety of personnel is particularly important during such operations. By having, for instance, two rig-ups it will be possible to have shaft cross-sections of up to 40m^2. For shafts larger than 40 m^2 back ripping will be required. For larger shaft cross-sections, considerable rock support 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 rock support. Thus, schematic cost calculations for shafts must be based on simplified assumptions. Otherwise, the “form” will be too difficult to use.

The main assumptions are specified as comments in Figure B.7.1. Please note that rock support 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 with more use of raise drilling in the future, unless working environment conditions do not improve for the use of Alimak.

B.7.2 Blasted shaft

The price curve (B.7.1) shows foreseeable contractor expenses including assumed securing work (20-35%), miscellaneous and unforeseen (10%) and contractor rigging and operation (30%).

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

The blasted section can be included in the costs by including the extra expansion costs in the total shaft length, or by estimating the volume (m3) and applying a unit price of 720 NOK/m3, including rigging and operation.

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

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

B.7.3 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 plants with a pressure tunnel.

The costs of a steel-lined pressure shaft comprise the costs for Civil work (contractor costs) and steel pipe costs (supplier costs). In addition to the costs that can be calculated using the m price come inlet cone costs including thrashrack as well as branch tunnels (if there are two units or more).

Costs for Civil work are indicated in:

1. Cost curve B.7.2 which gives the price per m of shaft depending on the pipe diameter.
2. Cost curve B.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.

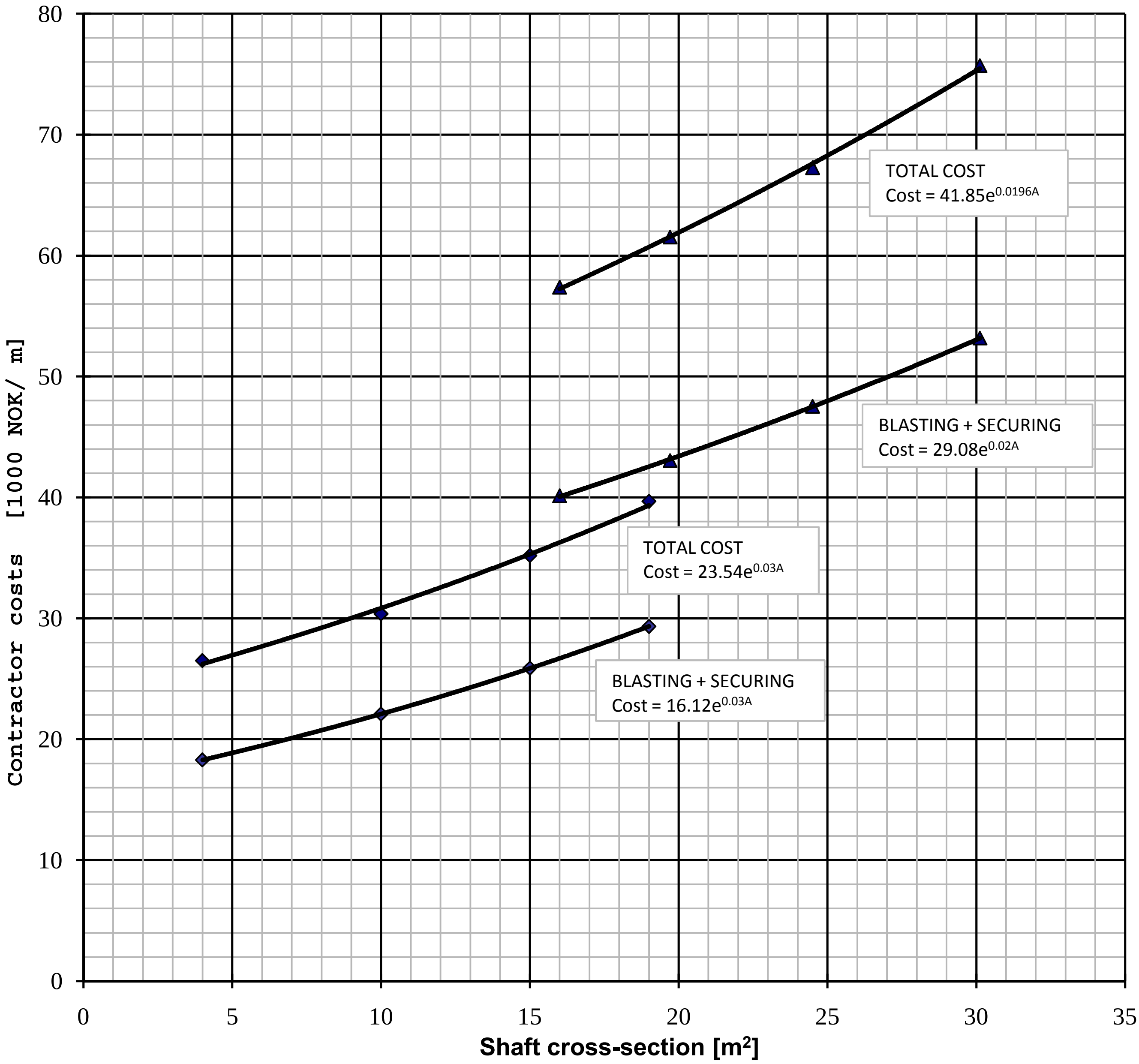
   The pressure head is a parameter for the plug length only in the latter case. For embedded pipes the cone costs can be read from the cost curve which gives the lowest costs, including the dotted line. Please note that for modest heads the length of the cone will be determined by geometric conditions (flow conditions). This has been incorporated in the cost curve.

Supplier costs are presented in Chapter M, Mechanical engineering.

B.7.4 Uncertainty

The estimation of the cost calculation uncertainty for shafts is $\pm$25%.

The general price increase for rock work since 2005 is approximately 20%. We would also like to point out that the basis for the revision of this chapter is somewhat insufficient as few raw blasted shafts are driven in Norway today.



COMMENTS:

1. Price level January 2010

2. Assumed rock of medium drillability and blastability.

3. Assumed shaft length L=400 m Approximately 5% higher lm 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. Miscellaneous and unforeseen costs of 10% have been included.

6. Contractor rigging and operating costs are included as 30%.

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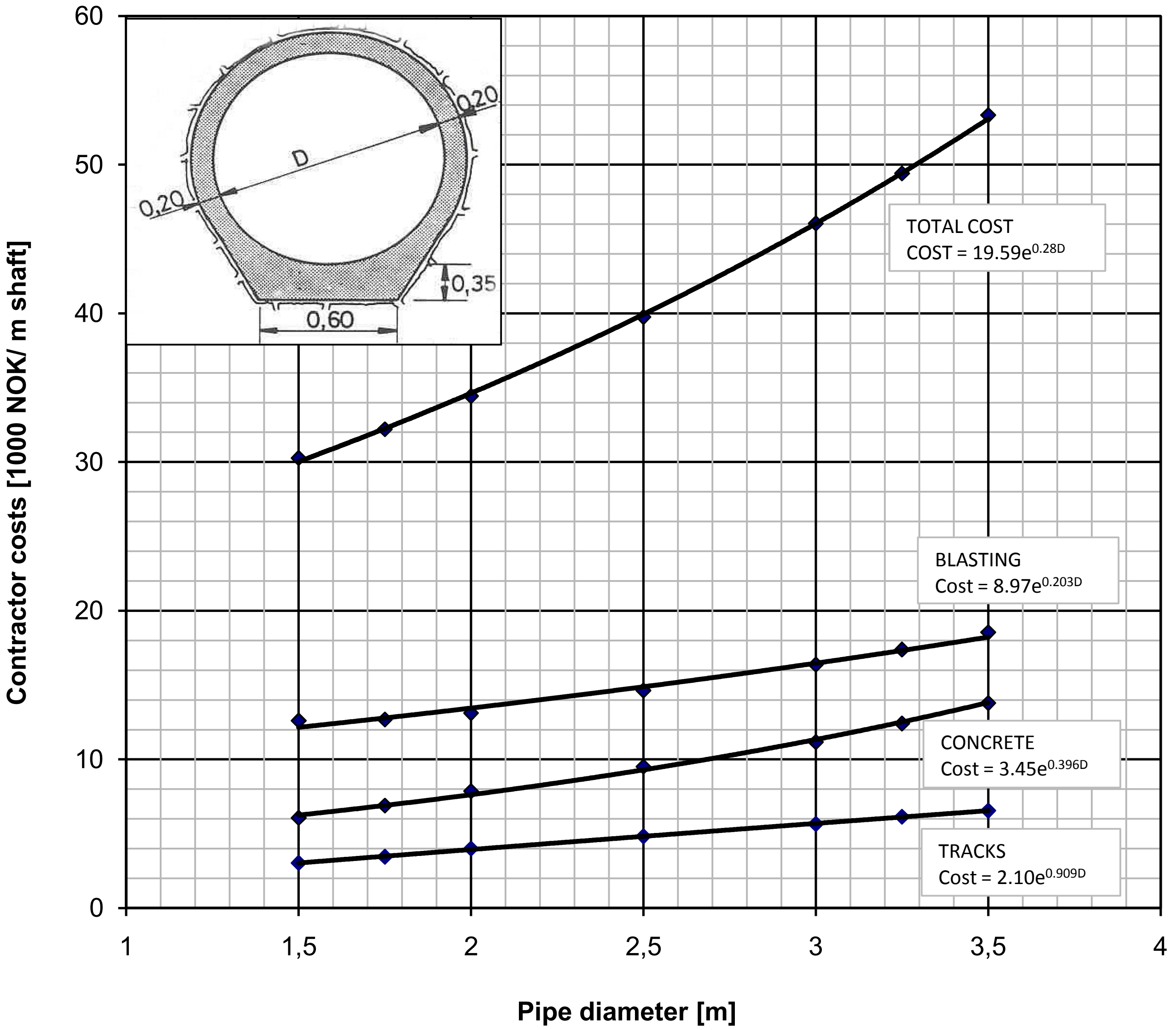
BLASTED SHAFT CONTRACTOR COSTS

Fig. B.7.1

1 January 2010



COMMENTS:

1. Price level January 2010

2. The cost curve comprises all contractor costs for building related work. Blasting, concrete and track costs are specified without their share of joint expenses and miscellaneous and unforeseen costs.

3. Assumed rock of meduim drillability and blastability.

4. Assumed shaft length L=400 m. Approximetaly 5% higher lm price if L=150 or 700 m.

5. Rock protection work included as 15% of costs.

6. The cost curve do not comprise cone costs; available in separate figure. Other elements must be cost calculated on an individual basis.

7. Miscellaneous and unforeseen costs of 10% have been included.

8. Contractor rigging and operating costs are included as 30%.

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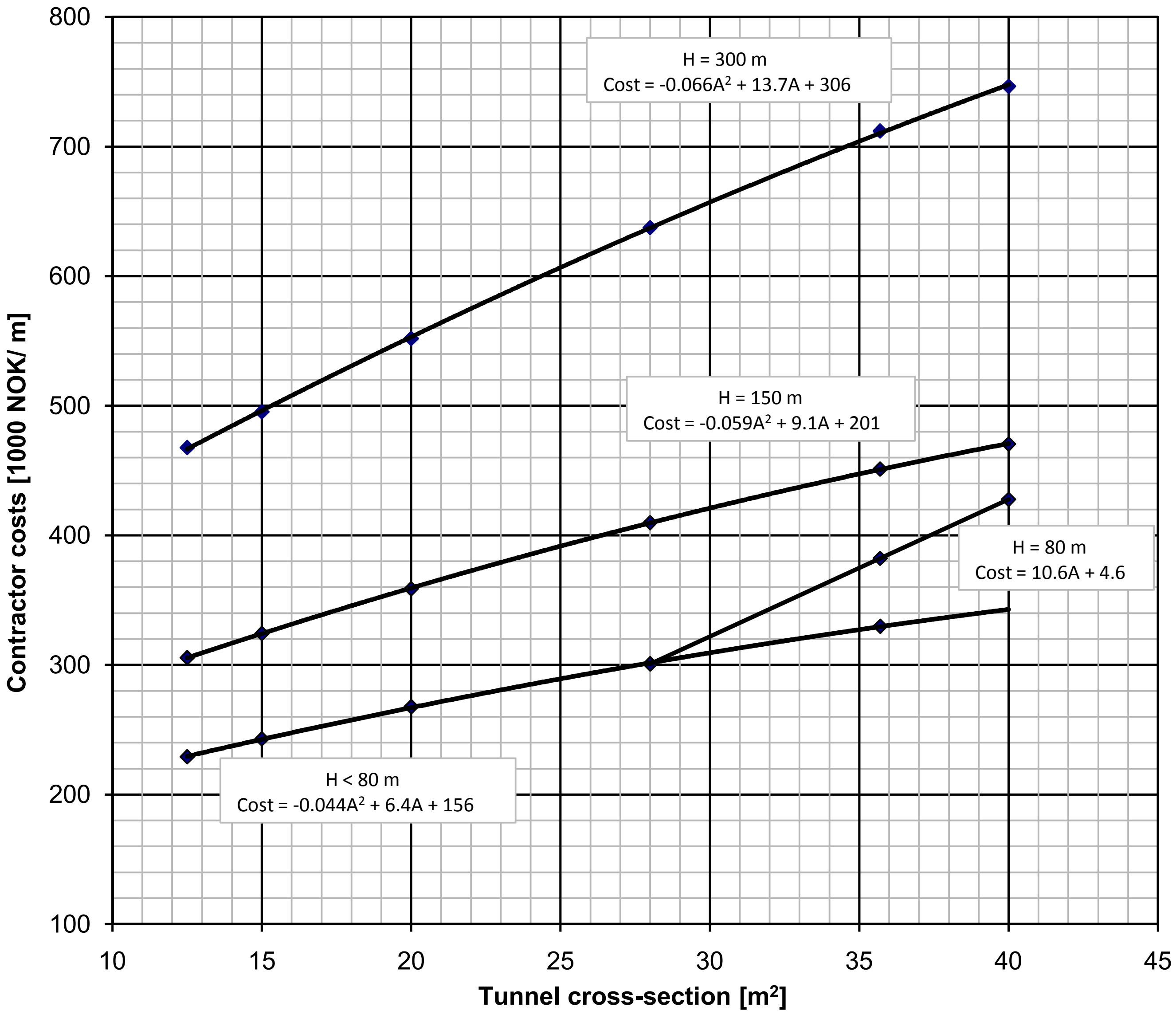
STEEL-LINED PRESSURE SHAFT
CONTRACTOR COSTS

Fig. B.7.2

1 January 2010



COMMENTS:

1. Price level January 2010

2. The cost curve comprises all contractor costs for building-related work relating 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 metres.

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 tunnels unless more detailed calculations are conducted. Also compare with Fig. B.5.2.

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INLET CONES
CONTRACTOR COSTS

Fig. B.7.3

1 January 2010

B. 8 DRILLED SHAFTS

B.8.1 General

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

- 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 spoil
- Joint expenses (central administration, profit, etc.)

As for full-face tunnel drilling costs, costs relating raise drilling are highly dependent on rock conditions. For the pilot hole/reaming the main factor is drillability of the rock, but the degree of fracturing is also quite 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 raise drilling 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 pilot hole first and then log it to find the exact location. The excavating of the connecting tunnel is then directed towards the hole.

B.8.2 Cost curve

The cost curve for the raise drilling is presented as a function of the shaft's cross-section and the drillability of the rock. We further assume 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%.

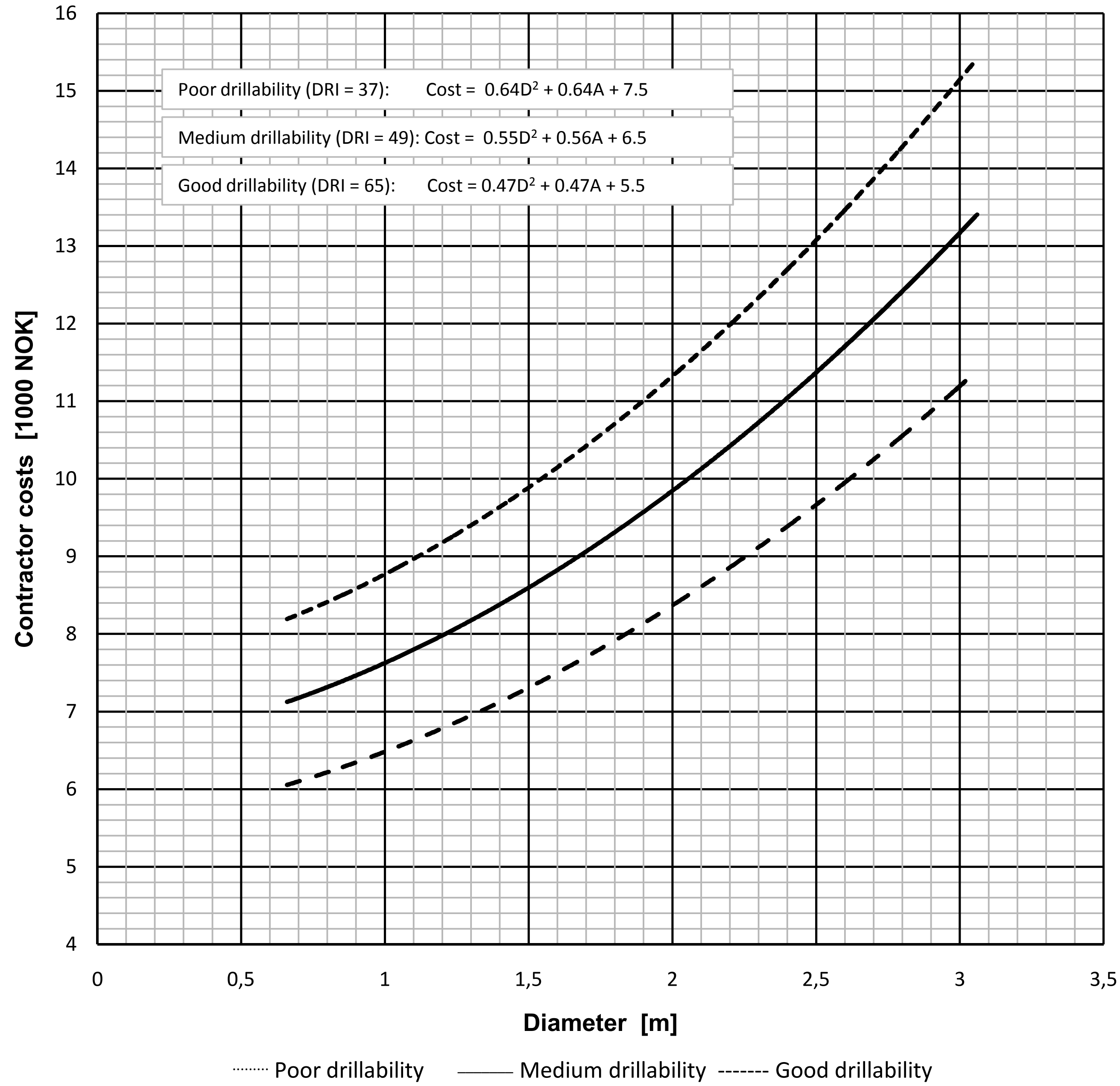
A 20% addition for rigging and operation has been included in the cost calculations for diameters below 2.1 m. A 15% addition has been estimated for diameters from 2.1 m and above. Unforeseen costs have not been included. However, one should expect these to be substantial as, in our experience, quite a few unforeseen costs will occur both in connection 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 in connection with shaft drilling have not been included. If the worksite is particularly difficult to access thus incurring extra high rigging and transportation costs, these costs should be increased somewhat.

B.8.3 Uncertainty

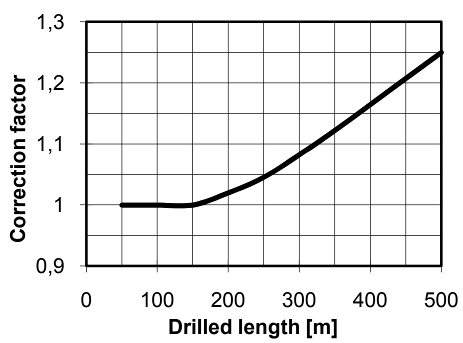
Uncertainty in the cost estimate based on this material will depend on how well one knows the rock conditions at the site in question. The cost estimate should normally be within $\pm$ 30%.

Due to method and equipment developments prices for drilling of shafts are generally at the same level. However, these are expected to rise in future. Diameter and length limitations are being exceeded, and it is now possible to drill shafts with a diameter of 3.5 to 4.0 m. Internationally there is currently equipment for drilling shafts that are up to 1 300 m long with a diameter of up to 6 m.



COMMENTS:

1. Price level January 2010
2. Assumed shaft length: min 150 m and shaft inclination: 45°-90°. Correction for shafts with an inclination of < 45°: gradually increasing to +30% for an inclination of 0°
3. Transport (road), rigging and operating cost are 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. B.8.1

1 January 2010

B.9 PENSTOCKS

B.9.1 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 M.6. 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. See Chapter B.8 for drilled shafts.

The costs of Civil work in connection with 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. We would therefore like to point out that the costs obtained by using this tool are purely informative, 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 M.6.

2. Contractor costs (Civil work)

   Clearance and 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 installation of pipe. Local transport at the site. Rigging and operation of construction site.

   Approximate contractor expenses for surface penstocks are available in Figure B.9.1.

   Approximate contractor expenses for penstocks in a tunnel are available in Figure B.9.2.

   Costs relating to trenches for embedded pipes are available in Chapter B.9.3.

3. Builder costs

   Estimated separately.

B. 9.2 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: 130-140 NOK/m 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	80 NOK/m^3
- Blasting	200 NOK/m^3
- Formwork	1 100 NOK/m^2
- Reinforcement	16 000 NOK/tonne
- Concrete	2 500 NOK/m^3

The following will be additional:

- Transport in the route:
  For difficult terrain a 50% higher lm price should be expected
- Miscellaneous and unforeseen: 15%
- Rigging and operation of the construction site: 30%

Costs for Civil work (contractor costs) are stated in the cost curve for average pipe diameters in NOK/m.

The m price x pipe length gives the foreseeable expenses including miscellaneous, unforeseen and contractor rigging and operating costs for a pipe route with relatively simple easy ground conditions. For very hilly terrains, or if much of the route runs through a terrain of uncompacted material, a rough addition should be added to the costs found by applying the cost curves. As an estimate this should be about 50%.

The prices are as of January 2010.

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

B.9.3 Trenches

For cost calculations of embedded pipes, we have prepared costs tables for earth trenches, rock trenches and combined earth/rock trenches. 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.

Below we have included an illustration of a typical trench cross-section:

(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, we have provided cost figures for earth and rock trenches, as well as combined earth/rock trenches.

The costs in the tables comprise all contractor costs (including rigging and operation of the construction site) 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 150 NOK/m^3 must be added for delivery of the surrounding filling material.

Rigging and operation costs of 30% have been included in the prices.

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 to be able to calculate the cost of pipe trenches. A 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%. For steep terrains the price might be two or three times that for a relatively easy terrain.

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 40 NOK/m^2
- Digging 50 NOK/m^3
- Rock removal/scaling 60 NOK/m^2
- Blasting 500 NOK/m^3
- Surrounding filling material 150 NOK/m^3
- Backfilling 110 NOK/m^3

Table B. 9.3.A Trench costs (NOK/lm). 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	1470	1940	2200	2820
Rock trench or combined earth/rock trench	2170	2830	4080	5660

The prices included 30% mark-up for rigging and operation of the construction site.

Table B. 9.3.B Trench costs (NOK/lm). 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	2050	2730	3170	3800
Rock trench or combined earth/rock trench	3160	4210	6290	8910

The prices included 30% mark-up for rigging and operation of the construction site.

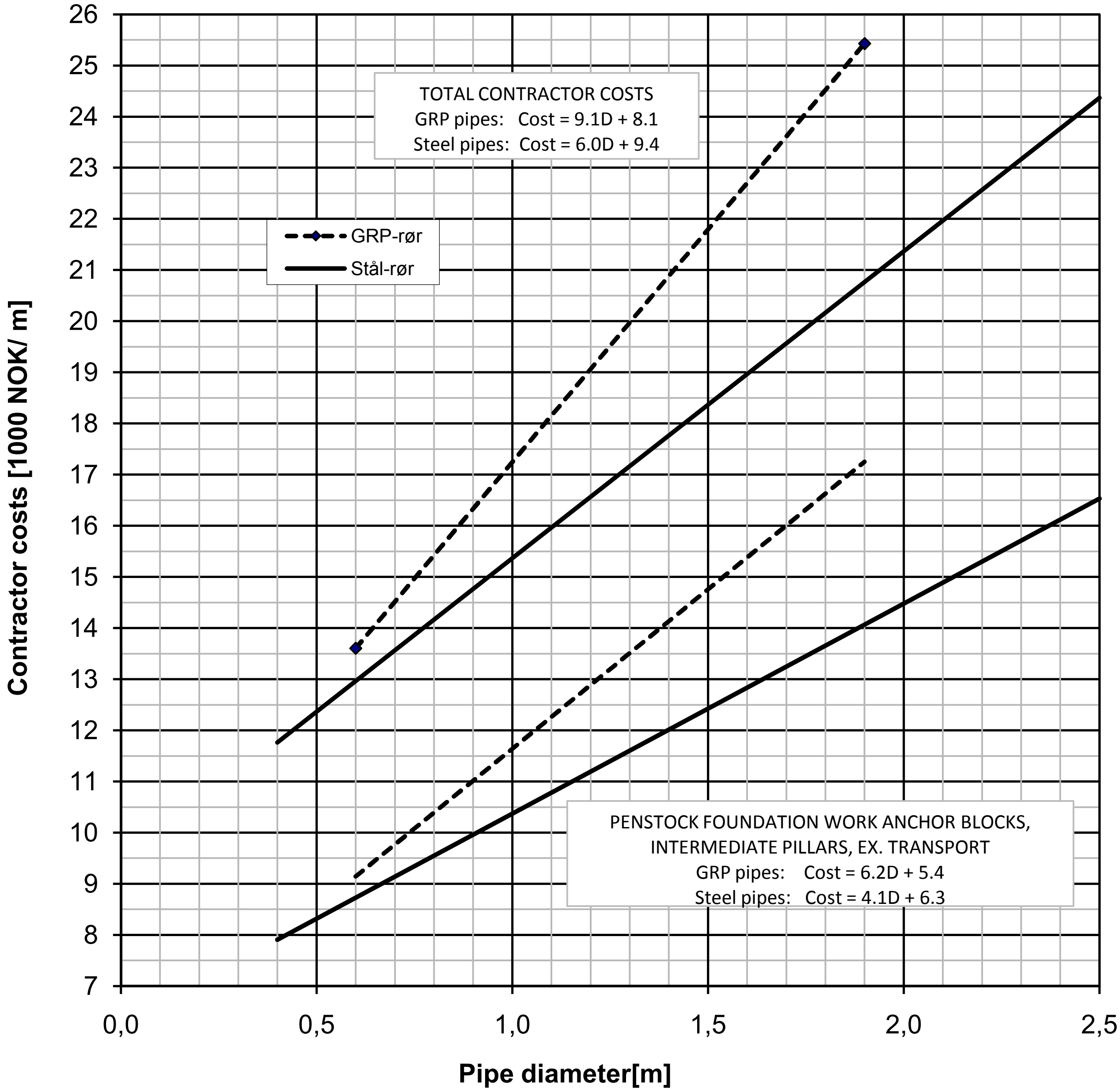
B.9.4 Penstocks in tunnels

Civil engineering costs for pipes in tunnels have been included in Figure B.9.2.

In the figure the same price basis has been used as in B.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 rock support have not been included, see B. 4, nor has a plug in the tunnel where the pipe starts. See Figure B.5.2, cross cut plugs.

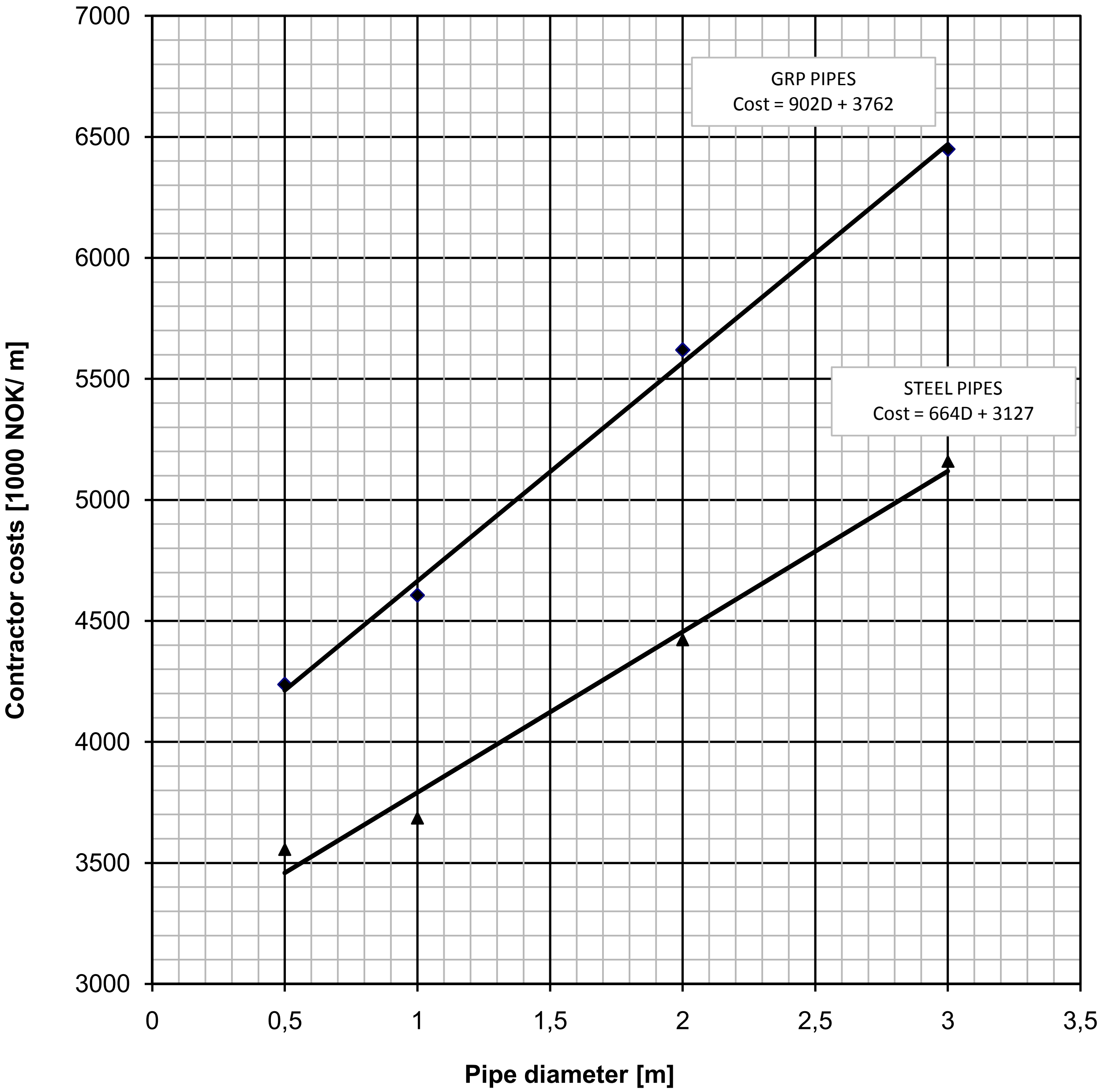
We have assumed that the pipe is installed tangentially in the tunnel. For small-diameter pipes it will be possible to arrange bend force support without a significant increase in costs. For large pipes a addition should be added for directional changes.



COMMENTS:

1. Price level January 2010
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 expences includes transport costs.
4. The cost curve for foundation work anchor blocks and intermediate pillars includes miscellaneous, unforeseen and the contractor's joint expences.
5. Anchor blocks amount to approximately 5 600 NOK/m.
6. GRP pipes must only be used for low pressures. See limitations in Fig. M.6.A.

NVE Norwegian Water Resources and Energy Directorate	**SURFACE PENSTOCK CONTRACTOR COSTS CIVIL WORK**	**Fig. B.9.1** **1 January 2010**



COMMENTS:

1. Price level January 2010.

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 benn 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
CONTRACTOR COSTS
CIVIL WORK

Fig. B.9.2

1 January 2010

B.10 UNDERGROUND POWER STATIONS. POWER STATION AREA

B.10.1 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 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
- Switchgear/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 E and M.

B.10.2 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.

We would like to emphasise that the results that we have achieved 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, we will not discuss this in any more detail in this report.

B.10.2.1 Basis, assumptions for new power plants

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

- Blasting: average unit price: 230 NOK/m^3
- Concrete volume = 20% of the blasted volume: 2 500 NOK/m^3
- Reinforcement: 60 kg/m^3 concrete: 16 000 NOK/tonne
- Formwork: 2.1 m^2/m^3 concrete: 1 000 NOK/m^2
- Supporting 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.
- Rigging and operation of the construction site: 25-30% of the above work.
- HVAC (ventilation, water supply and sewer): NOK 2-6 million for a medium-sized plant.
- Electrical installations, lighting, heating, etc.: NOK 1.0 – 2.5 million for a medium-sized plant.

B.10.2.2 Basis, assumptions for power plant expansions

In connection with power plant capacity increases it may become relevant to expand the power plant itself. It must in each 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 view to expansion, and if so there is usually a ready blasted volume for the number of turbines which the expansion is to represent. 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 340 – 420 NOK/m^3.

B.10.2.3 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, we have plotted this for existing power stations in Figures B.10.1, B.10.2 and B. 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 we have 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. We therefore recommend that an arrangement is drawn up for each plant and used as a basis to calculate the blasted volume.

B.10.2.4 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 [$N = 8.5 \times Q \times Hn$ (kW)] and choosing the number of power units and type.
2. Pre-dimension the power station through a preliminary project 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 2 250 NOK/m^3 for small power stations and 2 000 NOK/m^3 for larger stations. Price level January 2010.

B.10.2.5 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%.

B.10.3 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 estimated at 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 be dimensioning for 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, wardrobe, showers, restrooms, cleaning system, etc. The portal has not been included in the cost curves in Figure B.10.4.

Ventilation for the power station can be planned either through a potential escape shaft/cable shaft or in connection with the access tunnel. For the latter solution there are several options. A combined solution together with, for instance, cable 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. 12 000 NOK/m. 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 3 500 NOK/m. The power cables and other conductive cables are laid in the culvert, 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 B.10.4 shows a rough schematic cost curve for access tunnels. There is one curve for the price in total and tunnel excavating for moderate upward gradients and one curve showing the total price of tunnel excavating 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 our own 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. *Rock support*

Tunnel securing will be divided between working face securing and face backup support and will consist of extra scaling, bolting, shotcrete and pouring of concrete. Additional support 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 200 NOK/lm tunnel. This provides a very simple but fully acceptable solution.

4. *Road surface*

A fully built-up drivable asphalted surface has been included in the costs curves with 600 NOK/m.

5. *Drainage*

A double-sided drainage trench with drain pipe has been included in the cost curves with 550 NOK/m for both sides.

6. *Miscellaneous, unforeseen*

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

7. *Rigging and operation of the construction site*

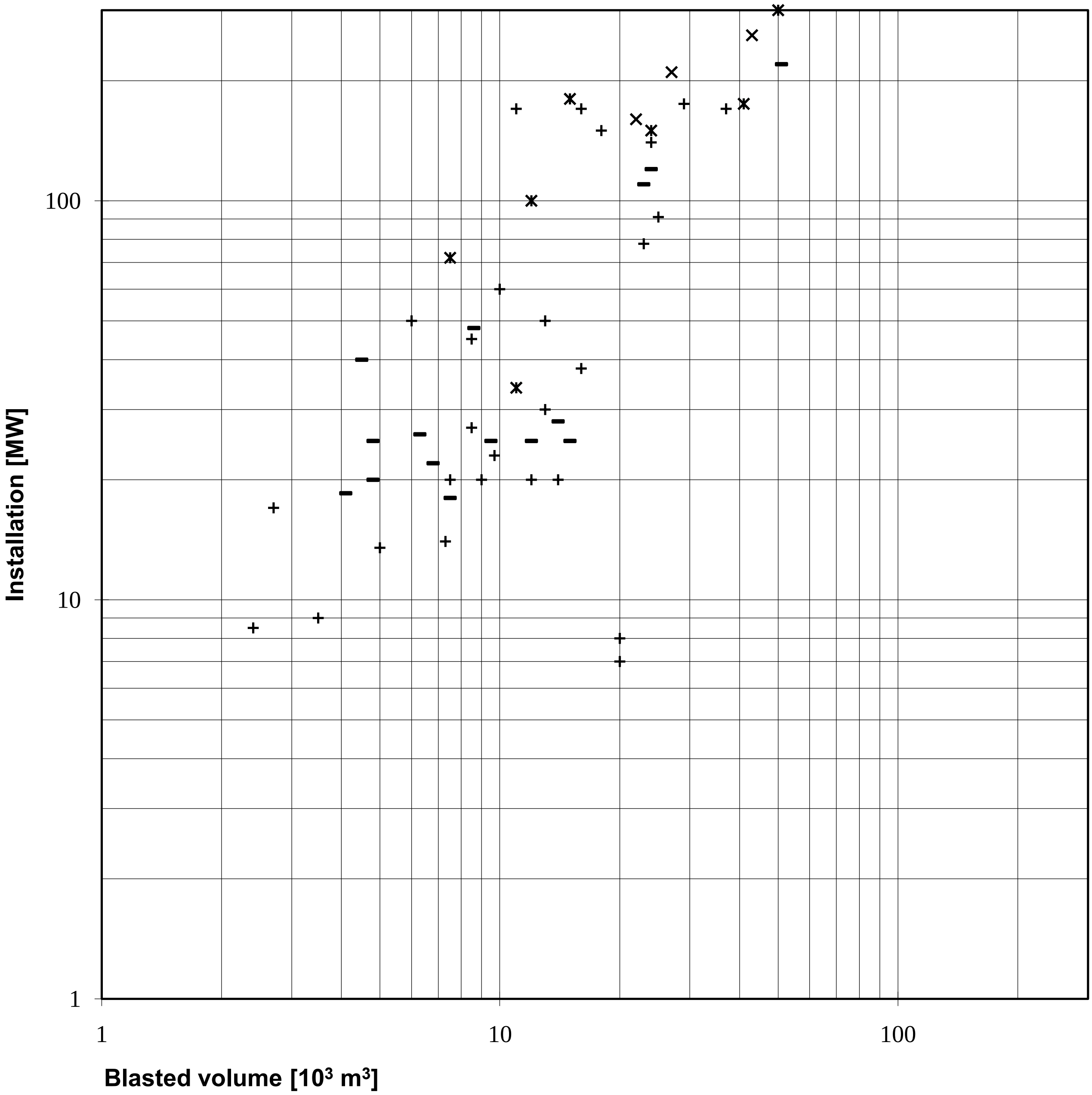
Rigging and operation of the construction site have been included with 30% of (1 + 2 + 3).

8. *Price level*

The costs have been given as of January 2010.

9. *Uncertainty*

Cost uncertainty has been set as $\pm$ 30%.



COMMENTS:

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

1. Underground power station

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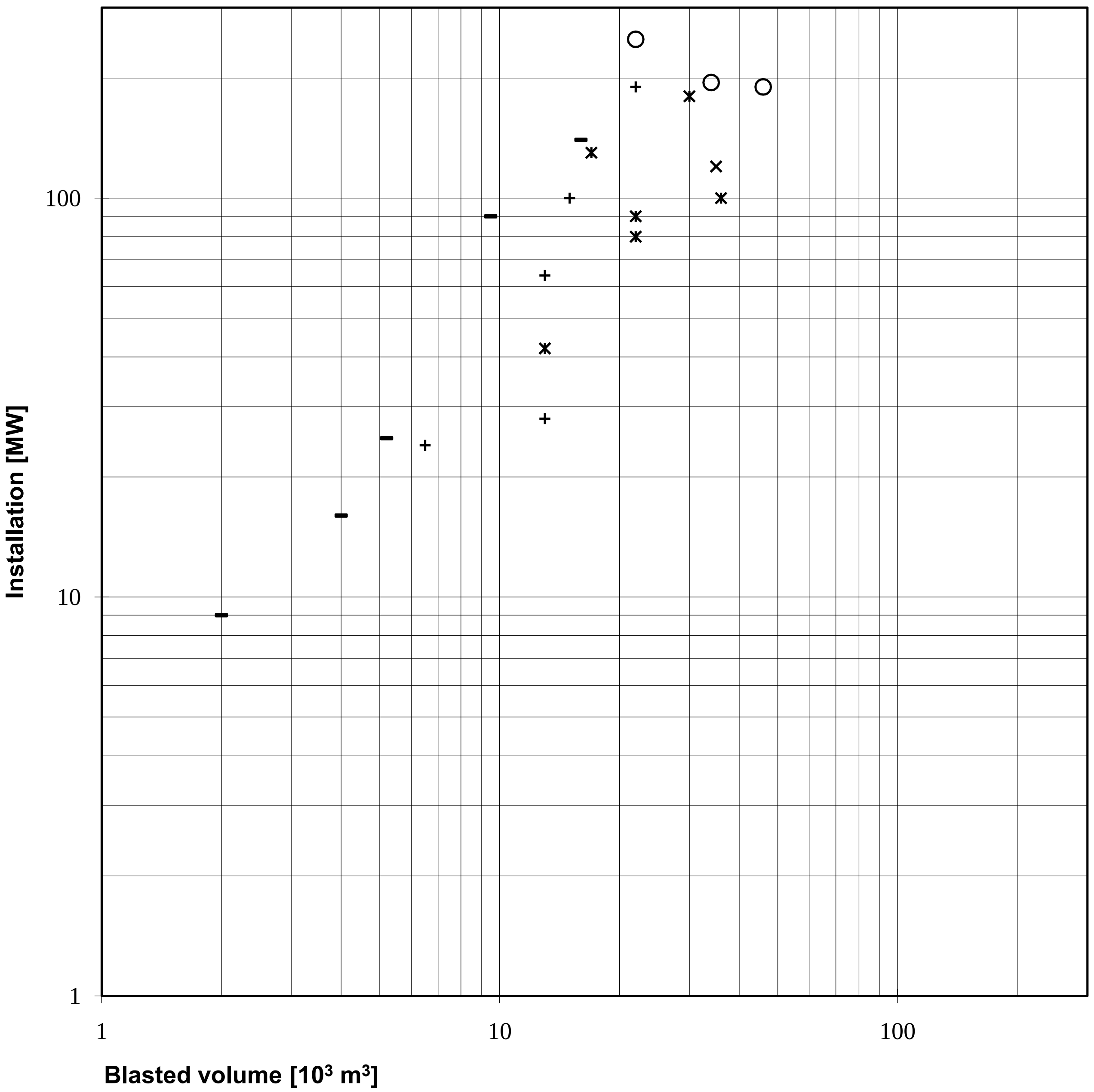
FRANCIS POWER UNIT
BLASTED VOLUME
VERSUS PERFORMANCE

Fig. B.10.1

1 January 2010



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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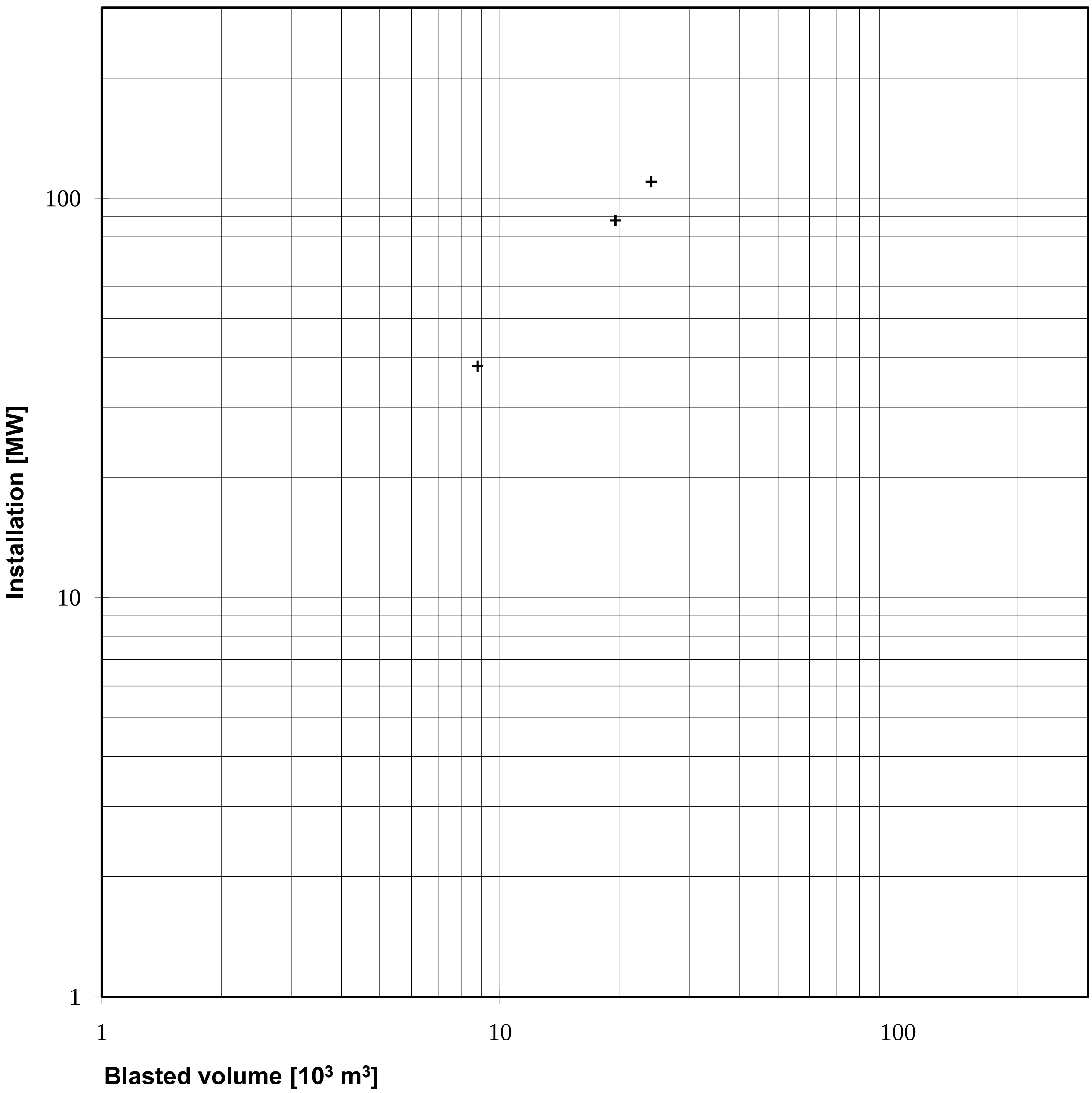
PELTON POWER UNIT

BLASTED VOLUME VERSUS PERFORMANCE

Fig. B.10.2

1 January 2010



COMMENTS:

+ 2 power units

1. Underground power station

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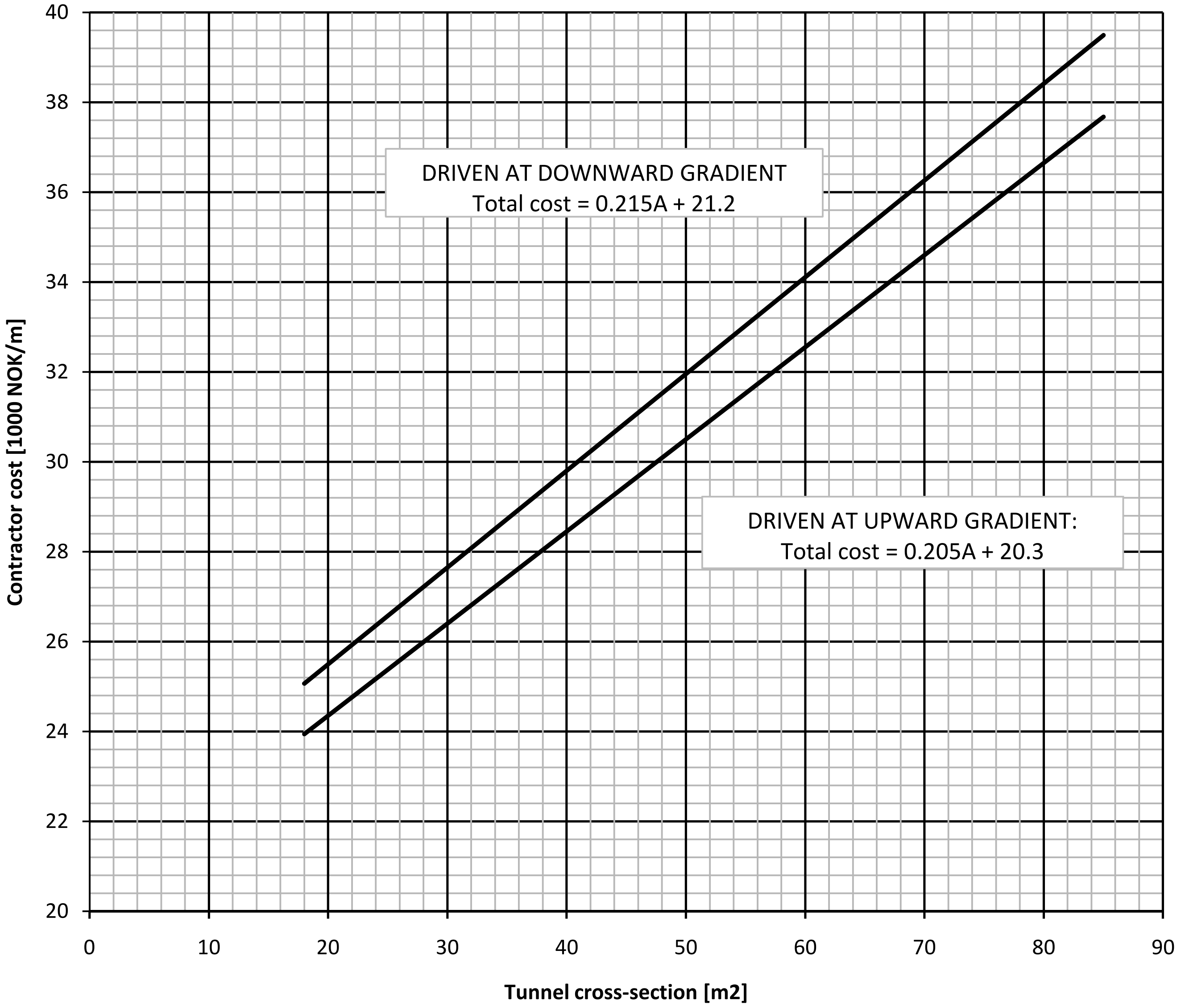
KAPLAN POWER UNIT

BLASTE VOLUME VERSUS PERFORMANCE

Fig. B.10.3

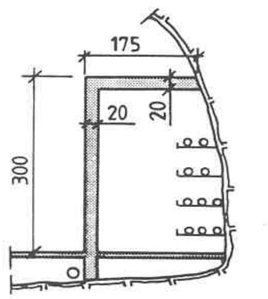
1 January 2010



COMMENTS:

1. Price level January 2010
2. Assumed rock of medium drillability
3. Distance to portal-tip: 600 m
4. Protection work included (shotcrete all along).
5. Rigging and operation costs are included as 30% of the basic price and securing.
6. Miscellaneous and unforeseen costs are included as 10% of the basic price and securing.
7. Concrete cable channel laid as pavement has been included with 3500 NOK/lm.
8. Any additions for walkable protected cable and ventilation culvert will cost roughly 12 000 NOK/ lm.

Walkable protected cable and ventilation-culvert.



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ACCESS TUNNEL AND CABLE CURLVERT CONTRACTOR COSTS

Fig. B.10.4

1 January 2010

B.11 SURFACE POWER STATIONS

B.11.1 Average foreseeable costs and uncertainty

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

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

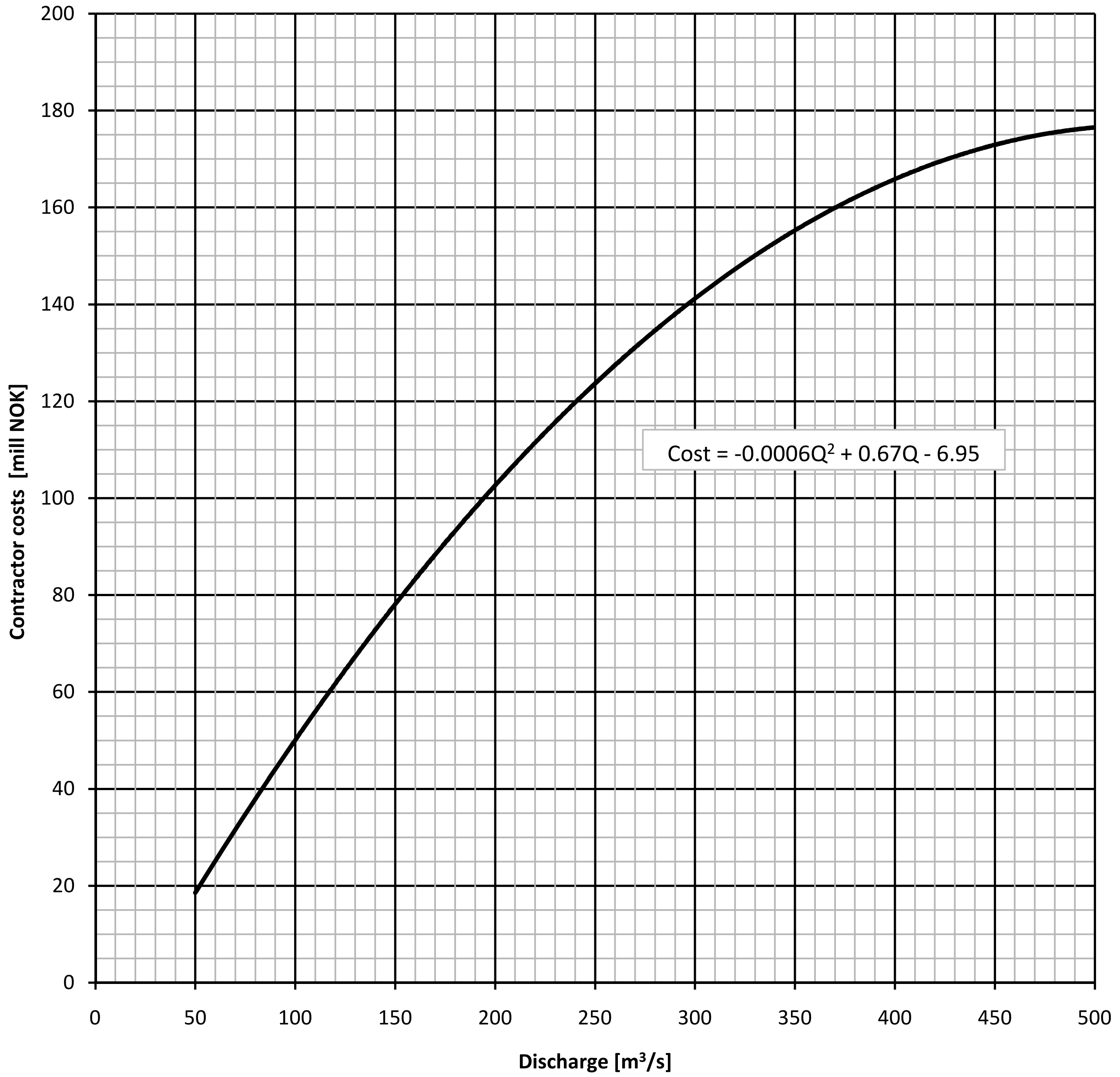
The cost curve in Fig. B.11.1 is based on power stations with one Kaplan unit. The head will be between 10 and 30 m. The absorption capacity will be much more important for the costs than the output in MW, as the pressure does not matter much for the construction of the buildings. A short inlet and outlet canal has been included. Potential extra costs for coffer dams, dam constructions, etc. have not been included.

B.11.2 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 80 NOK /m^3
- Blasting, loading and transport 150 NOK /m^3
- Formwork 1 100 NOK /m^2
- Reinforcement 16 000 NOK /m^3
- Concrete 2000 NOK /m^3
- Fixtures and fittings (of the above items) 20%
- Rigging and operation of the building site 30%



COMMENTS

1. Price level January 2010

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

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

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SURFACE LOW-PRESSURE PLANT
CIVIL WORK

Fig. B.11.1

1 January 2010

B.12 TRANSPORT FACILITIES

B.12.1 Temporary roads

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

As a guideline in estimating such costs, we are here indicating the following total costs for temporary roads (NOK/m):

	High standard	Low standard
Easy terrain	1000	500
Normal terrain	1500	1000
Difficult terrain	2000	1500

Bridges are not included in these costs. The cost of a normal, small bridge (span up to 6 m) may be set at 20 000 NOK 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 as -50% to +100%.

B.12.2 Road transport of concrete

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

If the distance is greater than 5 km, costs will increase by 8 NOK/km/m^3 of concrete.

B.12.3 Helicopter transport

B.12.3.1 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 B.12.3.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 12.3.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.

B.12.3.2 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 — 2 000 NOK/m^3
- Reinforcement — 20 000 NOK/tonne
- Concrete — 8000-10 000 NOK/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.

Table B.12.3.C Costs of helicopter hire

Type	Hire cost NOK/hour of operation	Load capacity
Small helicopter	13 000	Approx. 1.0 hour
Large helicopter	48 000	Approx. 3.0 hours

B.13 CHANNELS

B.13.1 General

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

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

For canals in uncompacted materials, the speed of the water and need for pitching will affect the work. Here we have presumed a 0.5 m thick pitching of the entire canal, i.e. both the bottom and side slopes.

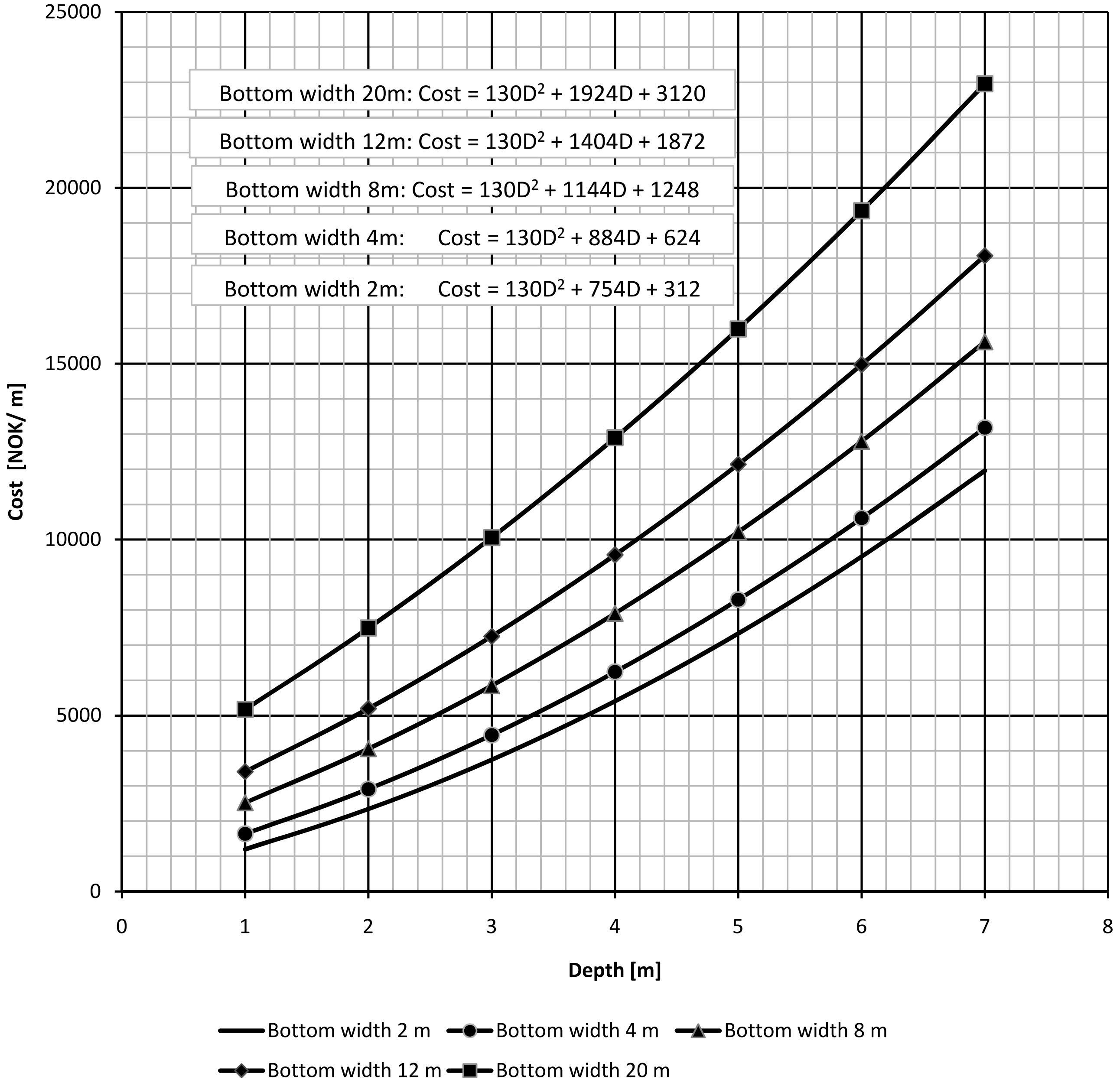
For canals in rock there is in practice no limitation regarding the speed. On account of the head loss when the canal forms part of the waterway to a power plant, however, the canal should be dimensioned for a speed in the range of 1.5-1.0 m/s.

The price of canals will largely depend on the size of the canal and whether the contractor is able to produce it efficiently with his equipment. We have here calculated prices for constructing a major canal system with a tip within reasonable proximity.

The following prices have been used:

- Transport of mass	50 NOK/m^3
- Blasting, loading and transport	240 NOK/m^3
- Pitching	120 NOK/m^2
- Rigging and operation	30%

Figures B.13.1 and B.13.2 show canal prices per metre for canals with different bottom width and depth measured from the terrain surface. For canals in rock we have assumed side slopes of 5:1 and for uncompacted material canals, side slopes of 1:2.



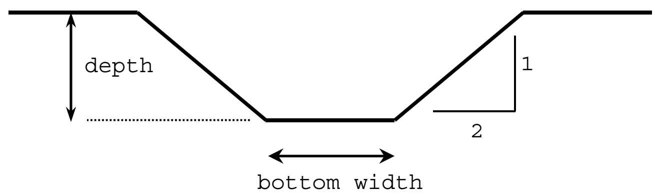
COMMENTS:

1. Price level January 2010

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
   - Rigging and operation costs included.

Cross section, $A = Bd+2d^2$



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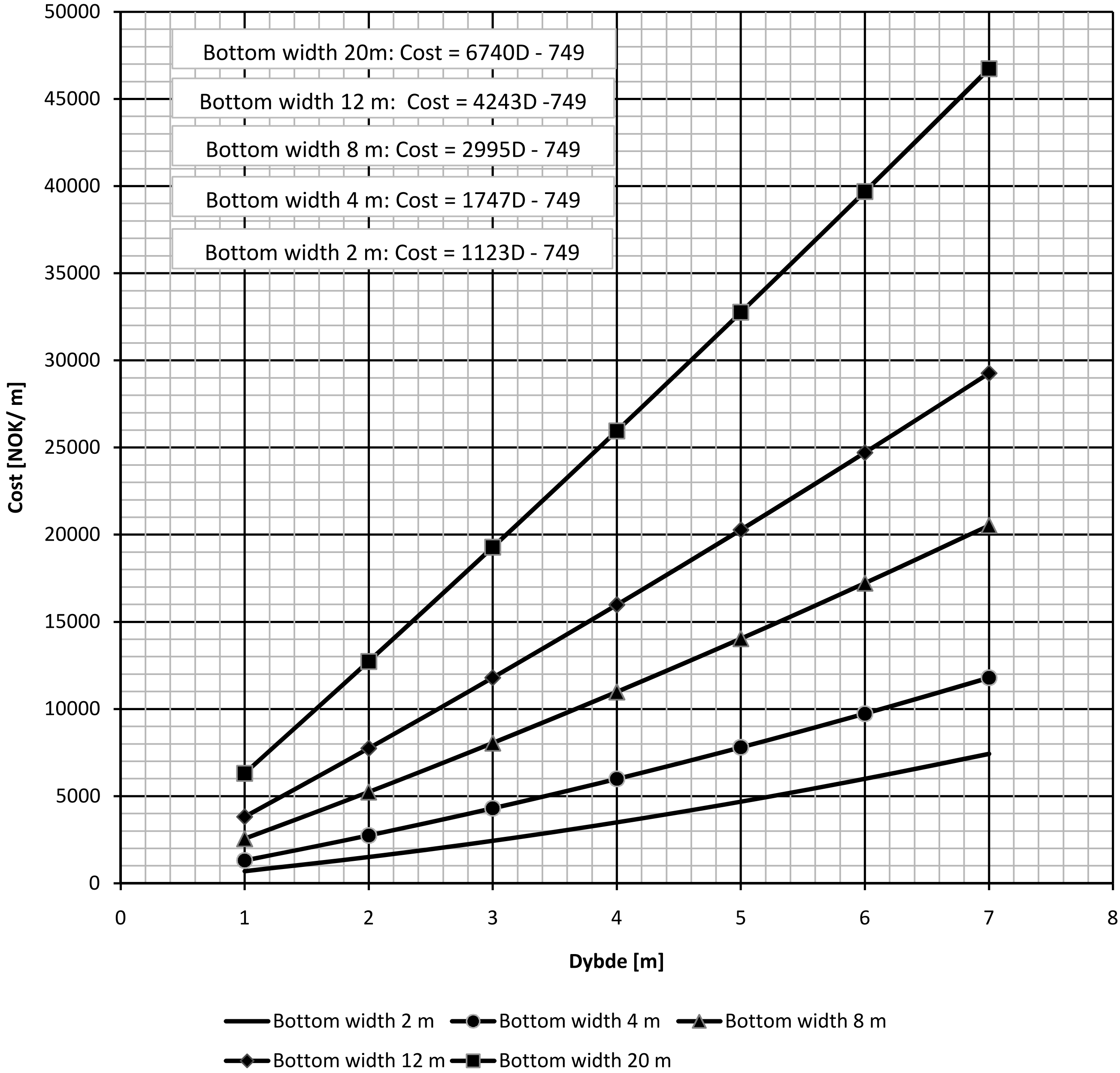
CHANNEL IN UNCOMPACTED MATERIALS CONTRACTOR COSTS

Fig. B.13.1

1 January 2010

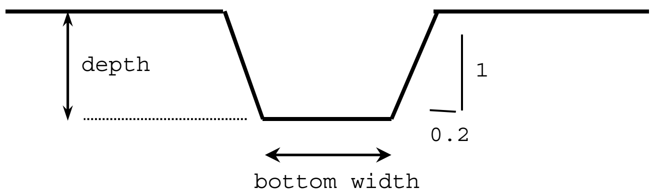


COMMENTS:

1. Price level January 2010

2. Presupposes:
   - Side slopes 5:1
   - Rigging and operation costs included.

Cross-section, $A = Bd+0,2d^2$



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CHANNEL IN ROCK

CONTRACTOR COSTS

Fig. B.13.2

1 January 2010

E ELECTROTECHNICAL EQUIPMENT

E.0 GENERAL

E.0.1 Average foreseeable costs and uncertainty

This chapter provides a basis for calculating the average foreseeable costs for electro-technical installations in power stations and transformer stations.

By “average” we mean 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 one time. The prices may also vary over time due to market conditions and changes in wages, raw materials and exchange rates. Altogether, this creates a rather complex picture. We have used budget prices and prices for obtained contracts in the period 2005-2010, i.e. the most competitive prices in the market.

E.02. Assumptions for the use of this price estimate

The stated prices are intended to support the planners in the early project phase, as they make a rough estimate of the profitability and assess various technical solutions.

This price estimate must not been seen as a definite answer, as each plant will have its special features that might 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 are obtained in the market. Market prices have until 2010 been affected by the general uncertainty in the world economy. However, incoming bids show that the prices of electro-technical components are rising.

E.0.3 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 is also included:

- Costs for transport and insurance to a random construction site in Norway
- 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
- Switchgear
- Control systems
- Auxiliary systems
- Cables
- Power lines

Each chapter will describe more fully what the cost estimates are based on.

Chapter 8 contains a presentation of the total costs for the electro-technical system as a function of the generator output, based on simplified assumptions for the plant construction.

E.0.4 Costs not included

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

- Value-added tax (24%)
- 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 factor, 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
- Somewhere to store materials temporarily
- Extra labour and hire of a mobile crane, etc. during installation

In case anyone would like to include the above extras in their estimate, we have sought to express the extras as a percentage of the component price. The prices found in the following chapters should be multiplied by a factor of approximately 1.12, which consists 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%.

E.0.5 Price level

The costs are given according to the price level as of January 2010. The updating of prices from the January 2005 level is based on budget prices and obtained contract prices in the same period, plus indexation.

In this issue we have chosen to index-regulate obtained contract sums up to January 2010.

E.0.6 Effect factor (cos Φ)

The output of electro-technical 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 electro-technical material. We have assumed a fixed effect factor (cos Φ) of 0.85. This means that the electrical output in MVA is 18% higher than the one given in MW.

E.1 GENERATORS

E.1.1 Generators with an output below 10 MW

For smaller generators, the technical requirements and the amount of and requirements for additional equipment will have a much greater impact on the price than they will for larger generators. As an example we might mention asynchronous design and integrated stator design. Thus the tolerance will be correspondingly higher.

Depending on the output and rotational speed, smaller generators might be supplied with a standardised design based on motor production. The competition in this part of the market is very stiff because there are many suppliers, and the cost level might be as much as 1/3 lower. The quality level will also be lower, but it might still be adequate in many cases.

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

E.1.2 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 will be about 15% lower.

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

The prices are based on a normal scope of delivery, i.e. delivered at the plant, installation completed, tested and started up, including excitation equipment, spare parts and accessories such as monitoring equipment.

E.1.3. Price level

The stated prices represent the price level in January 2010. Even though the prices follow inflation trends to some degree, the market situation will have a much greater impact. Based on experience, tolerance is set to ±15%.

A low price level in 2005 entails a relatively steep price increase for generators over the last 5 years. For generators with an output between 10 MW and 50 MW, the price has risen about 45%, and for generators above 50 MW, the price increase is about 55%.

E.1.4. Costs to improve efficiency

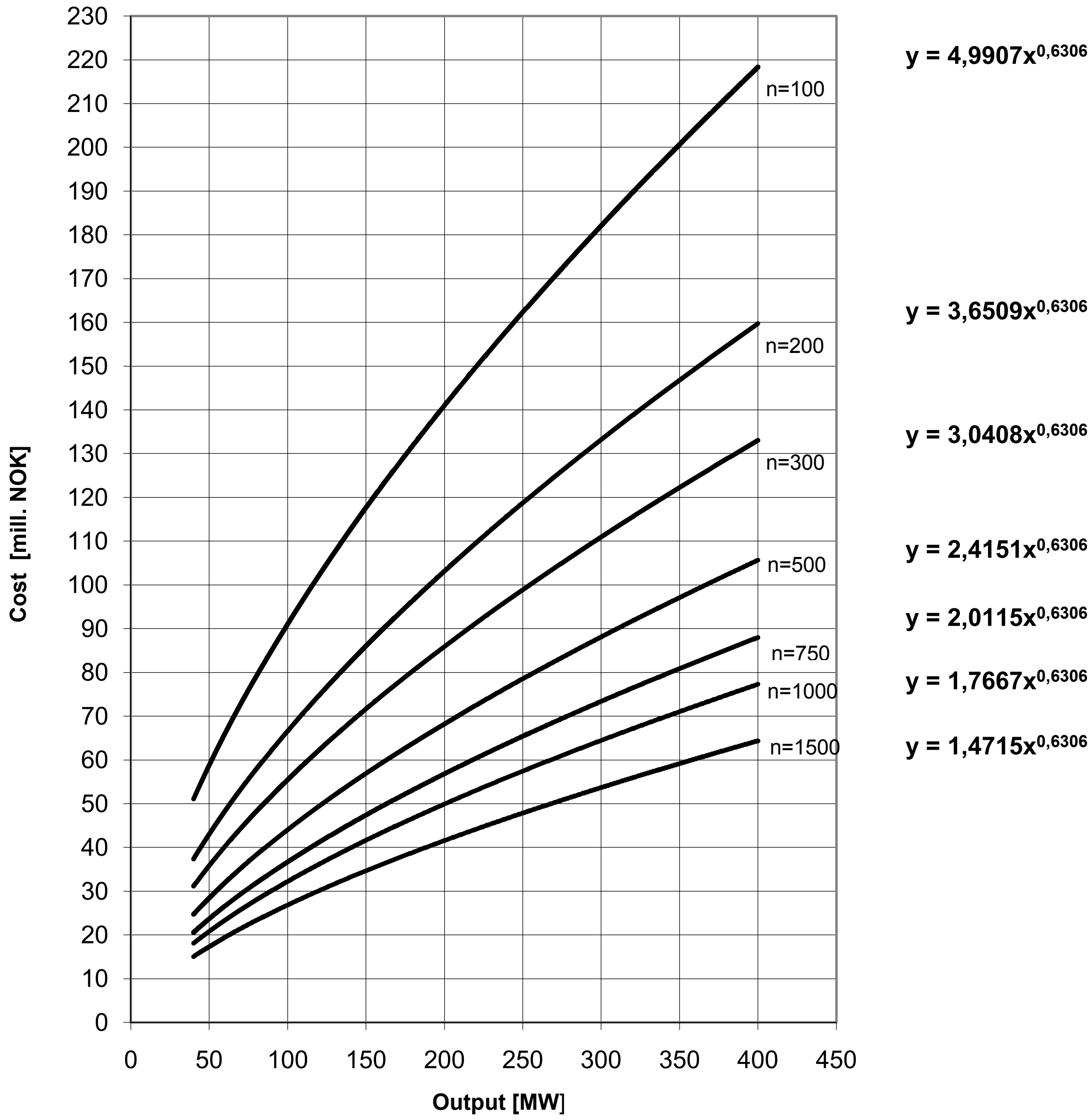
The generator efficiency can mainly be improved in the following two ways:

1. Rewinding
2. Rehabilitation / new cooling system

The costs of rewinding a generator are about 10% of the price of a new generator. These days there is not much point in rewinding a generator, since the improvement is only marginal and the costs of a production shutdown and rewinding are much greater than the small gain in efficiency.

Today rewinding is generally performed only in 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 will be counted in tenths of one percent and will therefore not be very profitable.



COMMENTS:

1. Price level January 2010

2. The costs apply for a generator installed and started up at the plant.

3. Tolerances ±15%.

4. Cos(j) = 0,85

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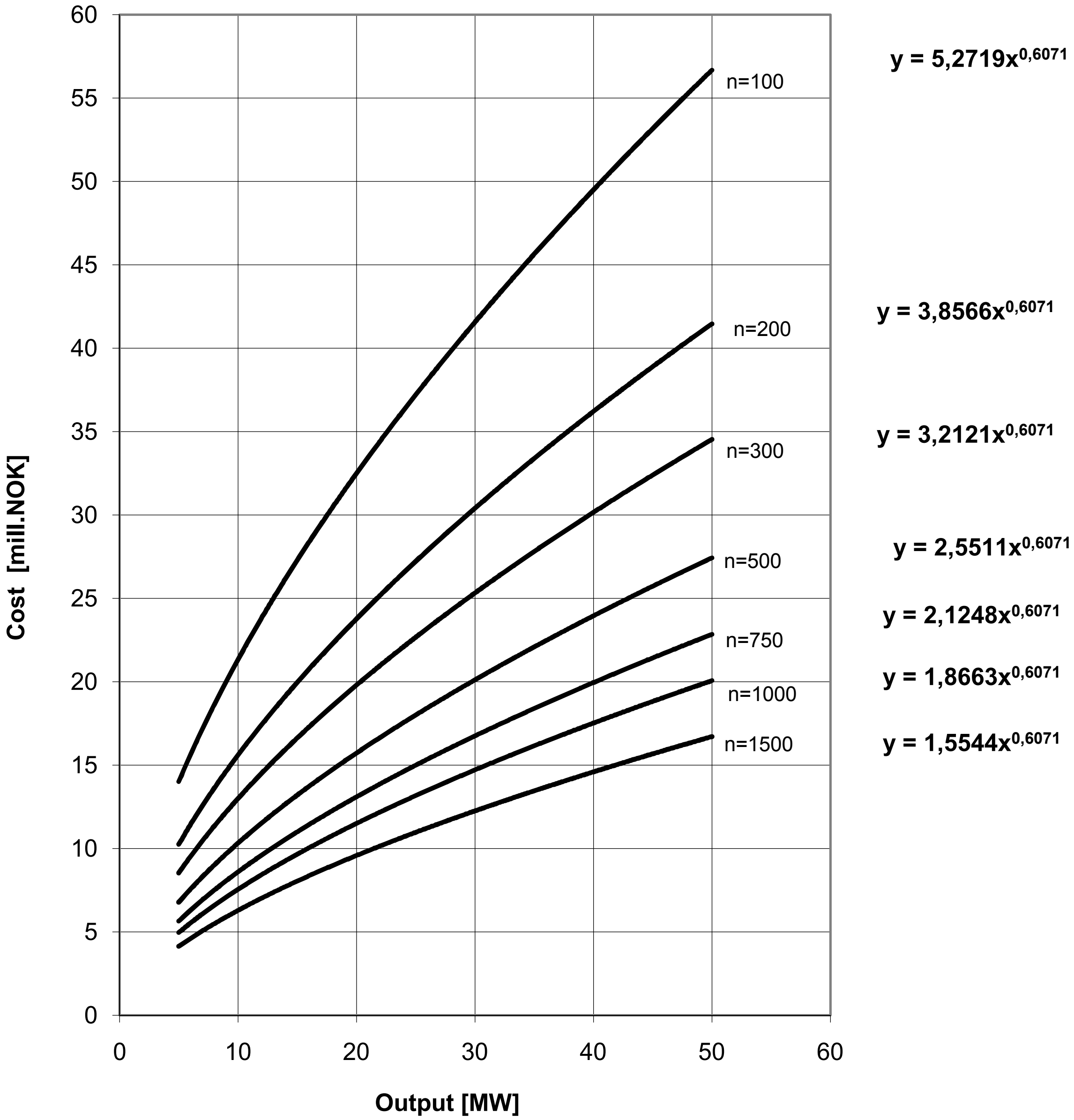
GENERATOR COST

Fig: E.1.1a
1 January 2010



COMMENTS:

1. Price level January 2010

2. The costs apply for a generator installed and started up at the plant

3. Tolerances ±15%.

4. Cos(j) = 0,85

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GENERATOR COST

Fig:E.1.1b
1 January 2010

E.2 TRANSFORMERS

E.2.1 Scope

Prices concern power transformers / generator transformers for 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.

E.2.2. Price level

The same is true for transformer prices as for generator prices, except for the following:

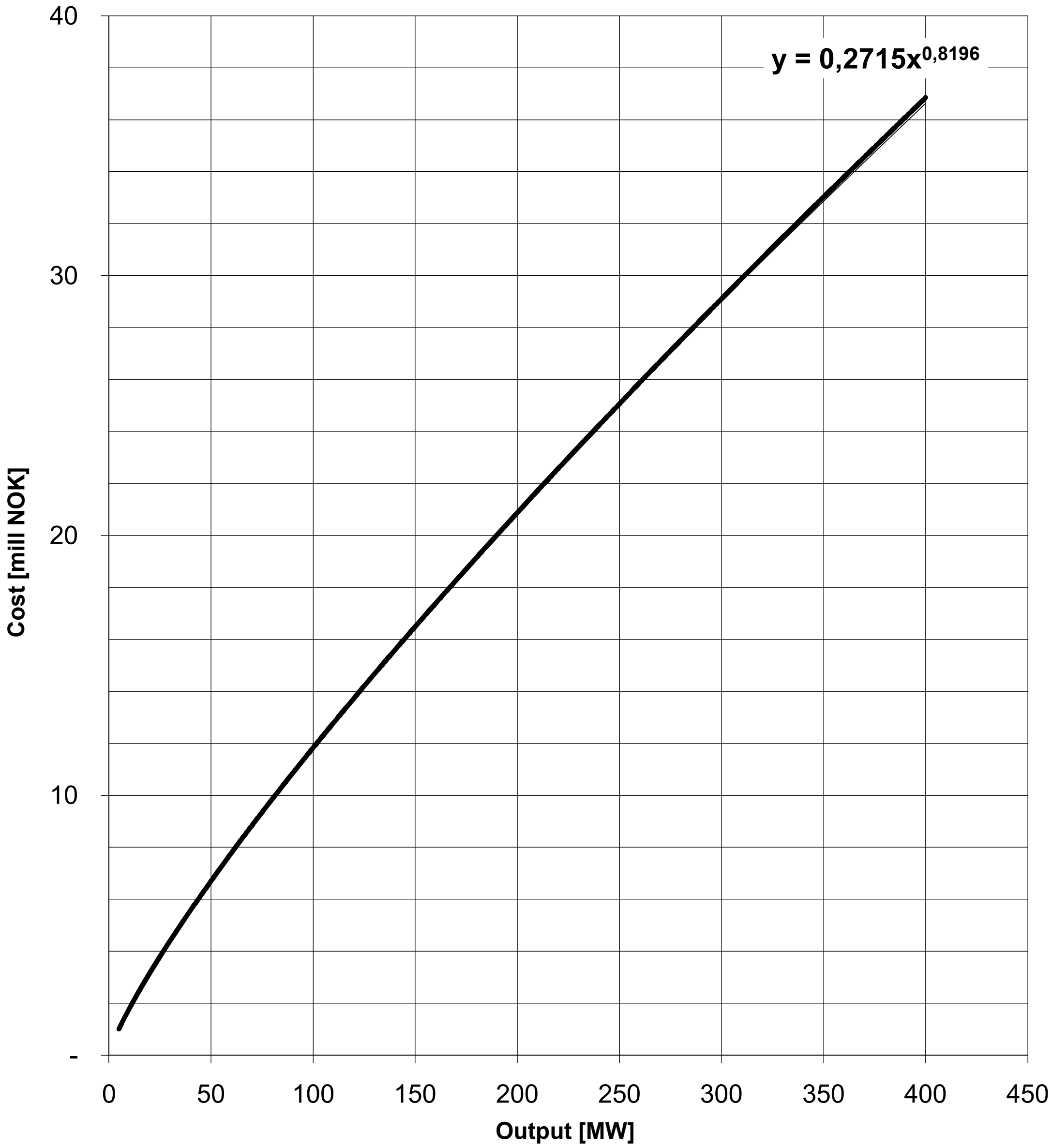
To a slightly greater extent than for generators, prices for power transformers depend on the choice of supplier, because the suppliers have specialised somewhat more. As the suppliers vary more when it comes to quality, and that might well be a selection criteria, one should allow for a slightly greater price tolerance here than for generators (±20%).

E.2.3 Costs to improve efficiency

Transformer efficiency can mainly be improved by rewinding.

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

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



COMMENTS:

1. Price level January 2010

2. The costs apply for a transformer installed, tested and started up at the plant.

3. Tolerances ±20 %.

4. For three one-phase transformers, a 20% addition has been calculated.

5. Cos(j) = 0,85

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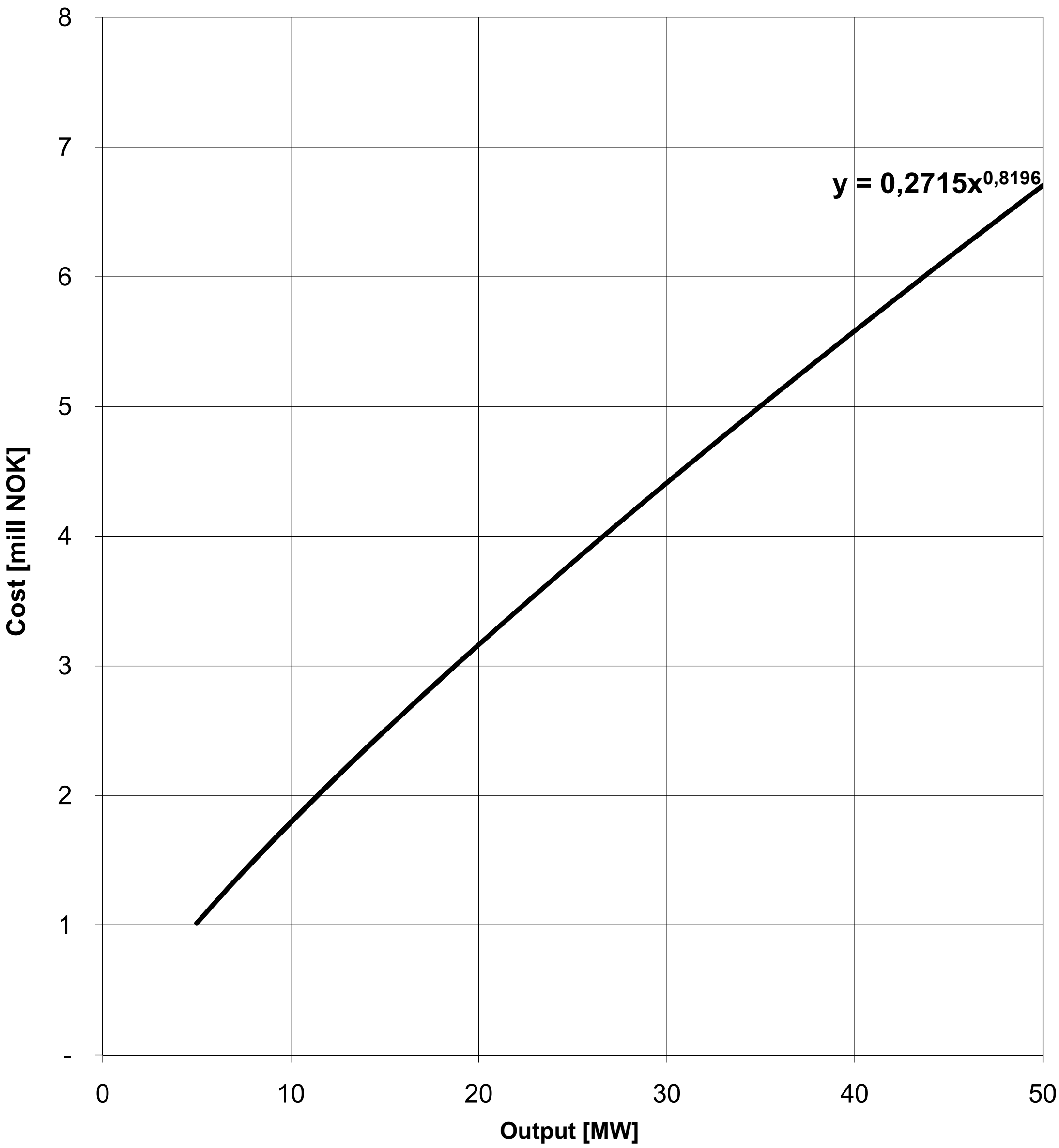
TRANSFORMER COST

Fig. E.2.1.1a
1 January 2010



COMMENTS:

1. Price level January 2010

2. The costs apply for a transformer installed, tested and started up at the plant.

3. Tolerances ±20 %.

4. For three one-phase transformers, a 20% addition has been calculated

5. Cos(j) = 0,85

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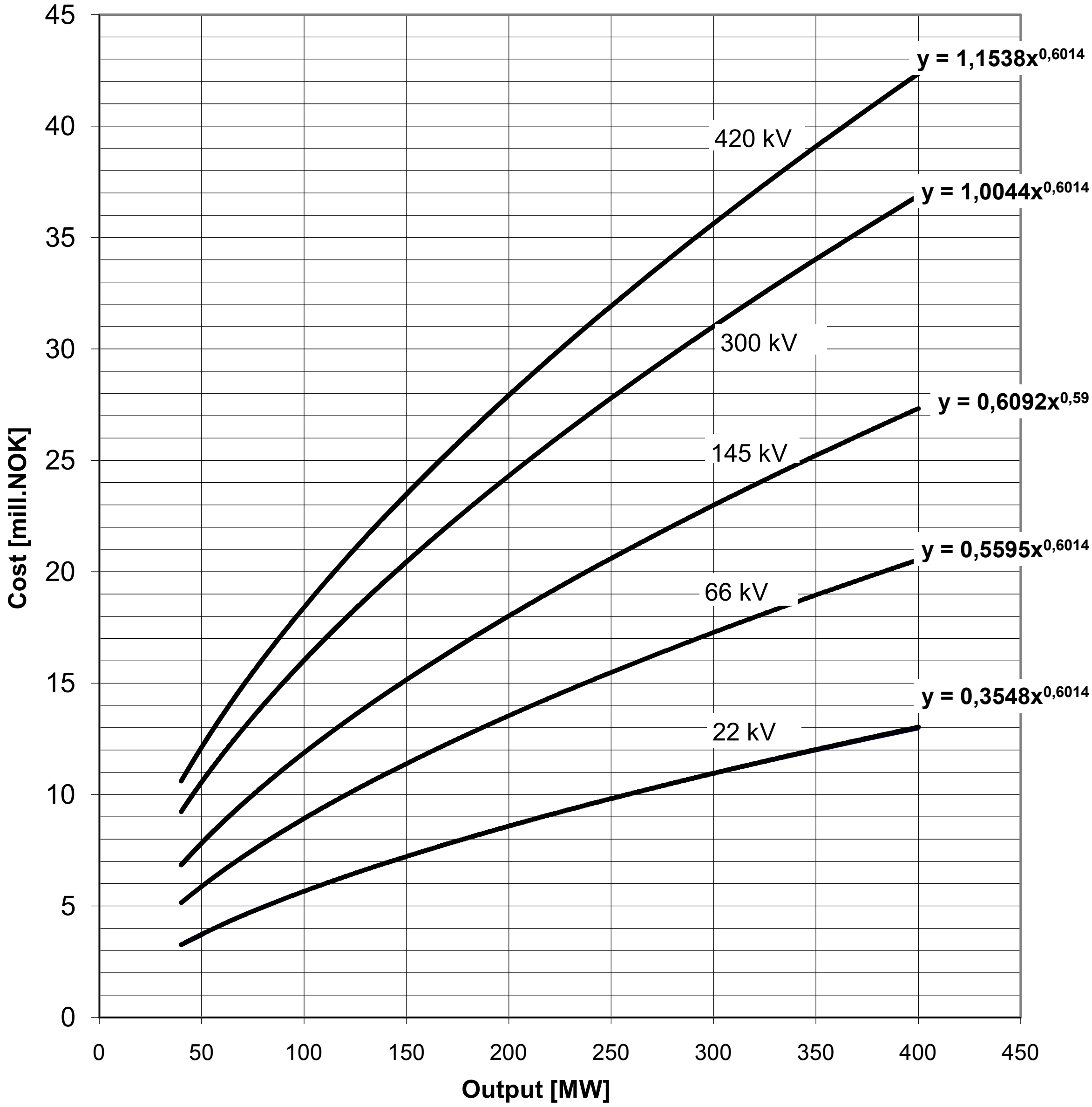
TRANSFORMER COST

Fig. E.2.1.1b
1 January 2010



COMMENTS:

1. Price level January 2010

2. The costs apply for a transformer installed, tested and started up at the plant

3. Tolerances ±20 %.

4. For three one-phase transformers, a 10% addition has been calculated

5. Cos(j) = 0,85

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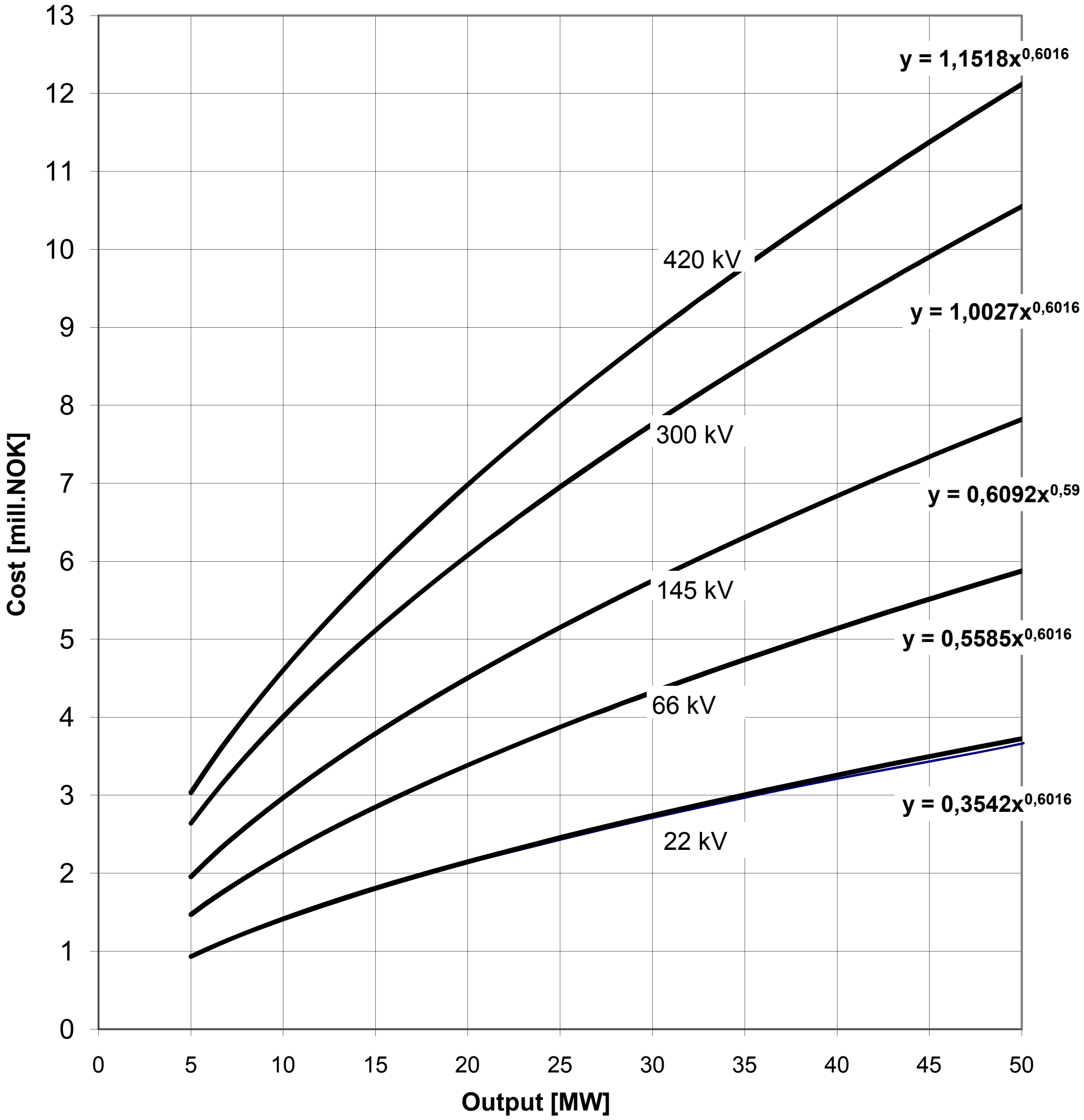
TRANSFORMER COST

Fig. E.2.1.2a
1 January 2010



COMMENTS:

1. Price level January 2010
2. The costs apply for a transformer installed, tested and started up at the plant
3. Tolerances ±20 %.
4. For three one-phase transformers, a 10% addition had been calculated
5. Cos(j) = 0,85

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TRANSFORMER COST

Fig. E.2.1.2b
1 January 2010

E.3 HIGH-VOLTAGE SWITCHGEAR

E.3.1 Scope

It is impossible to indicate the scope and thus the costs of the high-voltage Switchgear in a power plant without knowing how many outgoing lines will be needed and the number of power units. The voltage level and type of Switchgear will also affect the price.

A Switchgear 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.

E.3.2 Price level

The prices stated represent the price level in January 2010.

These prices are based on updated contracts during the 2005-2010 period, and obtained budget prices from suppliers. The prices are also based on the armament in accordance with the schematic diagram for small to medium-sized power plants shown in Fig. E3.1.

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 disconnectors, diverters and instrument transformers. Differences in ground and terrain might also affect the groundwork carried out for the buildings, and this is included in the field prices.

Prices for conventional power plants have been adjusted upwards except for the 66 kV plant, where no change in prices has been registered. For SF6 plants, the price for 132 kV has been reduced and for 300/400 kV remains unchanged from the 2005 price level.

E.3.3 Cost included / not included

The price tables apply for one complete field with circuit breaker, disconnector, instrument transformer and high-voltage diverters, 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 electro-technical system.

E.3.4 Choosing a Switchgear

<u>Indoor/outdoor conventional switching system</u>
For voltage levels from 11 kV up to 66 kV, it will be practical and economical to use standardised high-voltage cells for indoor installation.
For 132 kV and up it is normal to build the Switchgear as a conventional open air plant.

<u>Single/double bus bar</u>
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.

<u>Circuit breakers</u>
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 e.g. allows for instantaneous backup if one bus bar breaks down. This solution is illustrated in the schematic diagram for large stations, Fig. E 3.2.

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 it will also allow for flexible operation.

Circuit breakers have become more reliable in recent years, and their service intervals are longer, and it is now thought that one circuit breaker per field and a double bus bar provide high availability.

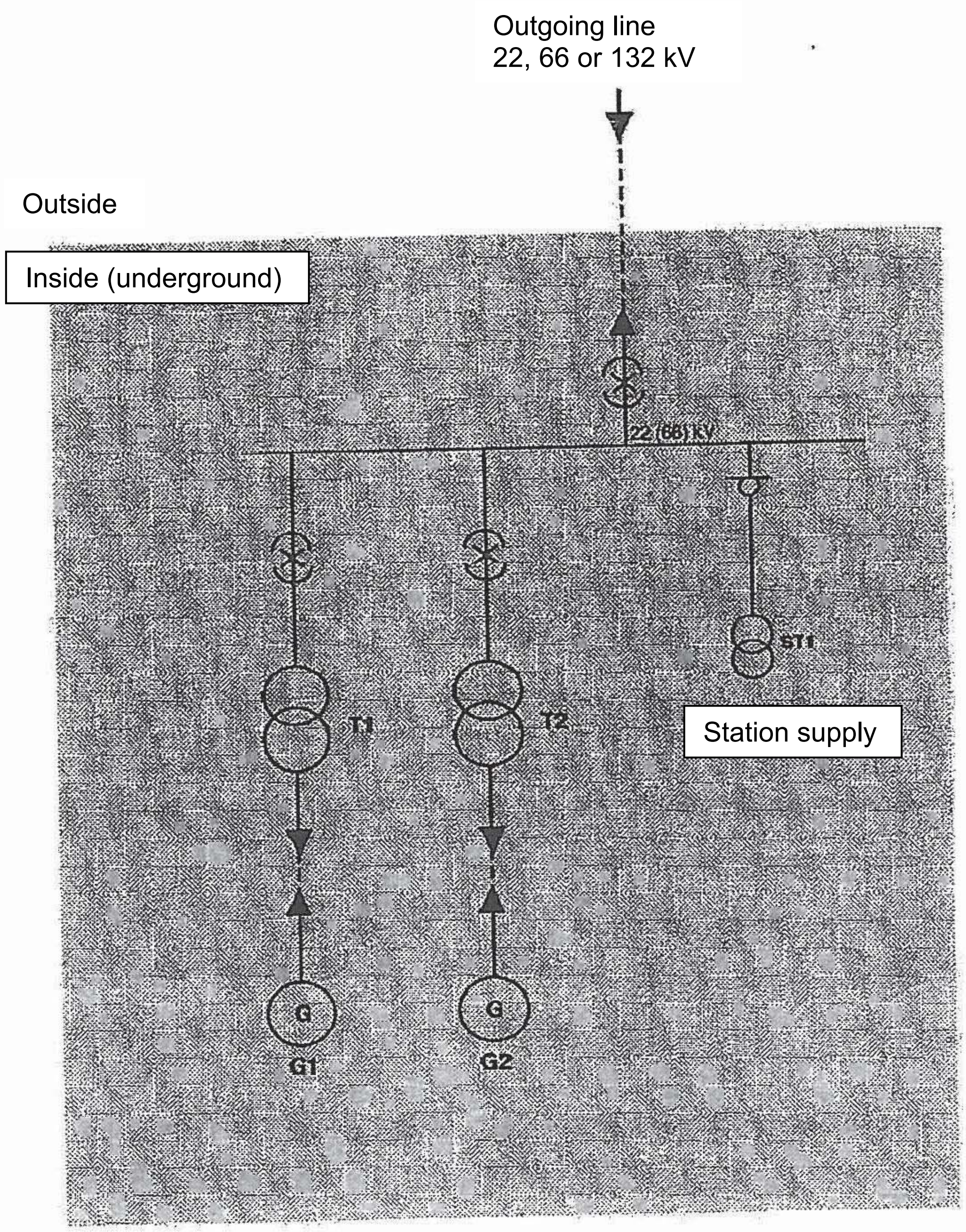
SF_6 stations

If there is no room for an open air station, or if atmospheric pollution will affect operations, one can choose an SF_6-isolated Switchgear. These are now very reliable, but the costs of an SF_6 station are higher than for a conventional station.

E.3.5 Definition of terms

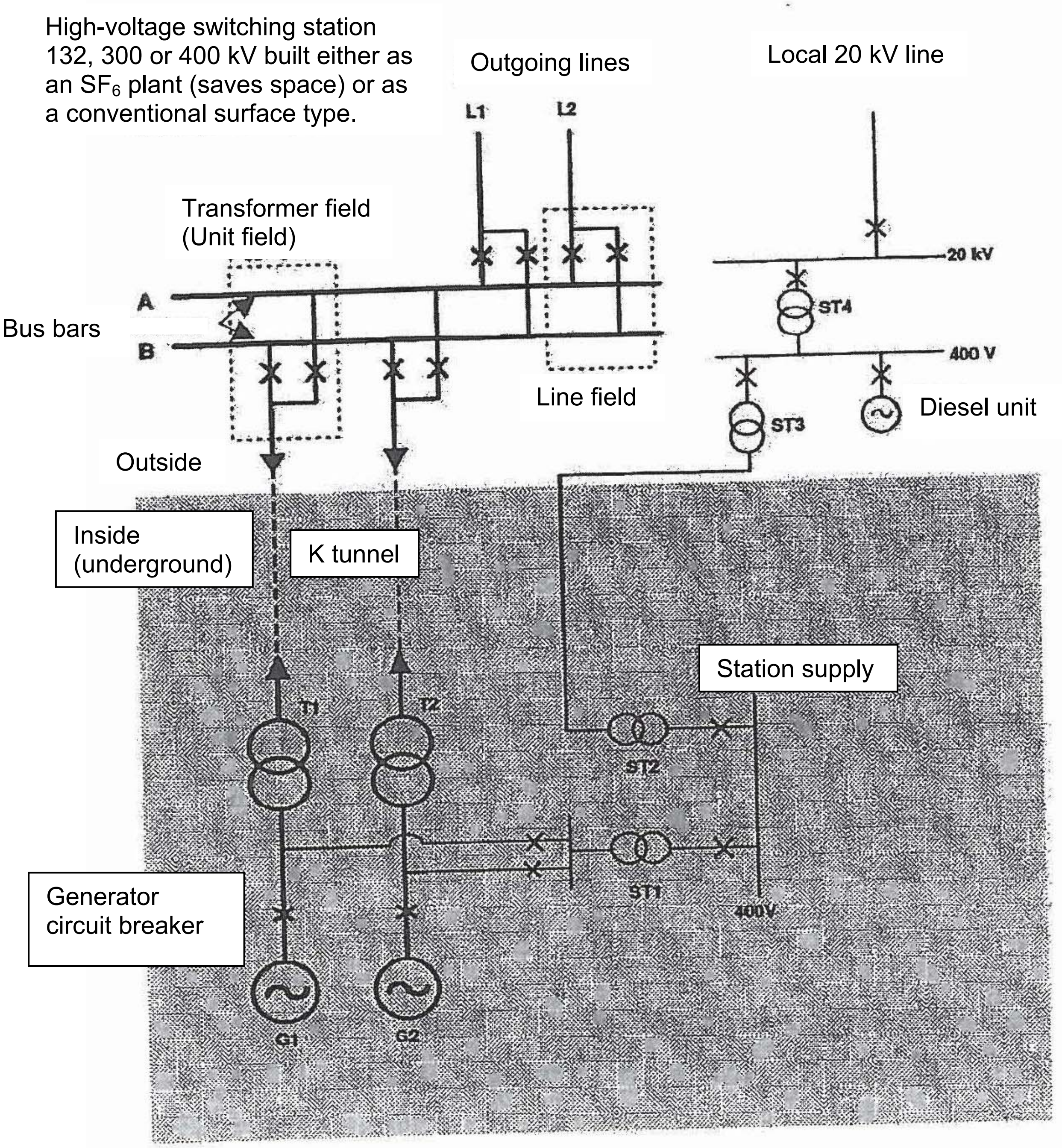
Norwegian definitions of terms marked * were taken from the Statkraft booklet "Kraftuttrykk".

Norwegian	English	Definition
Aggregat*	Power unit	Electrical energy production unit. Comprises turbines and generators.
Apparat og kontrollanlegg	Switchgear and control gear	Comprises high-voltage Switchgear, cables, local control, direct current system, low-voltage system, station supply, fire alarm and extinguishing system.
Bryterfelt	Switching panel	Part of the Switchgear. Allows connection/disconnection of the line, transformer or power unit to a bus bar.
Hjelpeanlegg	Auxiliary system	Parts of the appliance system; e.g. direct current system, low-voltage system, station supply, fire fighting system, plus lighting and heating, ventilation, pumps and other support functions in the power station.
Høyspent koplingsanlegg*	High-voltage Switchgear	The system for electrical connection/disconnection of generators, transformers and/or wires. Bus bars and switching panels are key elements in a Switchgear.
Maksimal stasjonsytelse*	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.
Merkeytelse*	Rated output	The output (effect) stamped on the name plate. Generally coincides with full-load output.
Midlere årsproduksjon*	Average annual production	The estimated average annual production over a number of years.
Nett-tap*	Grid loss	The energy loss in the transmission and distribution grid.
Nominell effekt*	Nominal effect	The effect stated in the data stamped on the turbine, generator or transformer. The nominal effect may be exceeded under certain conditions.
Overførings-kapasitet*	Transmission capacity	Transmission capacity – concerning transmission of power, the permitted load, given the heat development (temperature), stability and voltage drop.
Samleskinne	Bus bar	Part of the Switchgear. 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.



SCHEMATIC DIAGRAM FOR SMALL TO MEDIUM SIZED STATION
UNDERGROUND SWITCHING STATION AND OUTGOING LINE OF 22, 66 OR 132 kV

Fig. E.3.1



SCHEMATIC DIAGRAM FOR MEDIUM/ LARGE POWER STATION UNDERGROUND WITH TWO UNITS AND TWO OUTGOING LINES

Fig E.3.2

HIGH-VOLTAGE SWITCHGEAR

TOTAL PRICES PER FIELD (1000 NOK):

	CONVENTIONAL STATIONS Indoors:	CONVENTIONAL STATIONS Outdoors:	SF_6 stations
22 kV			
Single bus bar:	350		---
Double bus bar:	700		---
66 kV			
Single bus bar:	1 100	1 300	---
Double bus bar:	2 200	2 400	---
132 kV			
Single bus bar:		2 520	2 880
Double bus bar:		5 040	3 840
300 kV			
Single bus bar:		4 800	9 000
Double bus bar:		8 400	12 000
420 kV			
Single bus bar:		8 400	10 500
Double bus bar:		10 800	14 000

Price level January 2010

Tolerances ±20%

Prices are for one field, installed and started up at the power plant.

Double bus bar means a double bus bar and two circuit breakers per field.

Prices include control systems.
Assuming that the costs for a single bus bar is about 75% of a double bus bar.
The costs for a 22 kV field will vary more with the capacity of the field than in the case for other voltage levels.

Norwegian Water Resources and Energy Directorate NVE	**HIGH-VOLTAGE SWITCHGEAR**	**Fig. E.3.3** 1 January 2010

E.4 CONTROL SYSTEMS

E.4.1 The scope of the analysis

The cost curve for control systems includes local systems, pumps and pump-units, 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 has been included under auxiliary systems.

Please be aware that power stations differ greatly, due to their different ages, size, technical solution and how much has been spent on them. Therefore, the costs stated for control systems will be of a general nature only.

E.4.2 The price curves

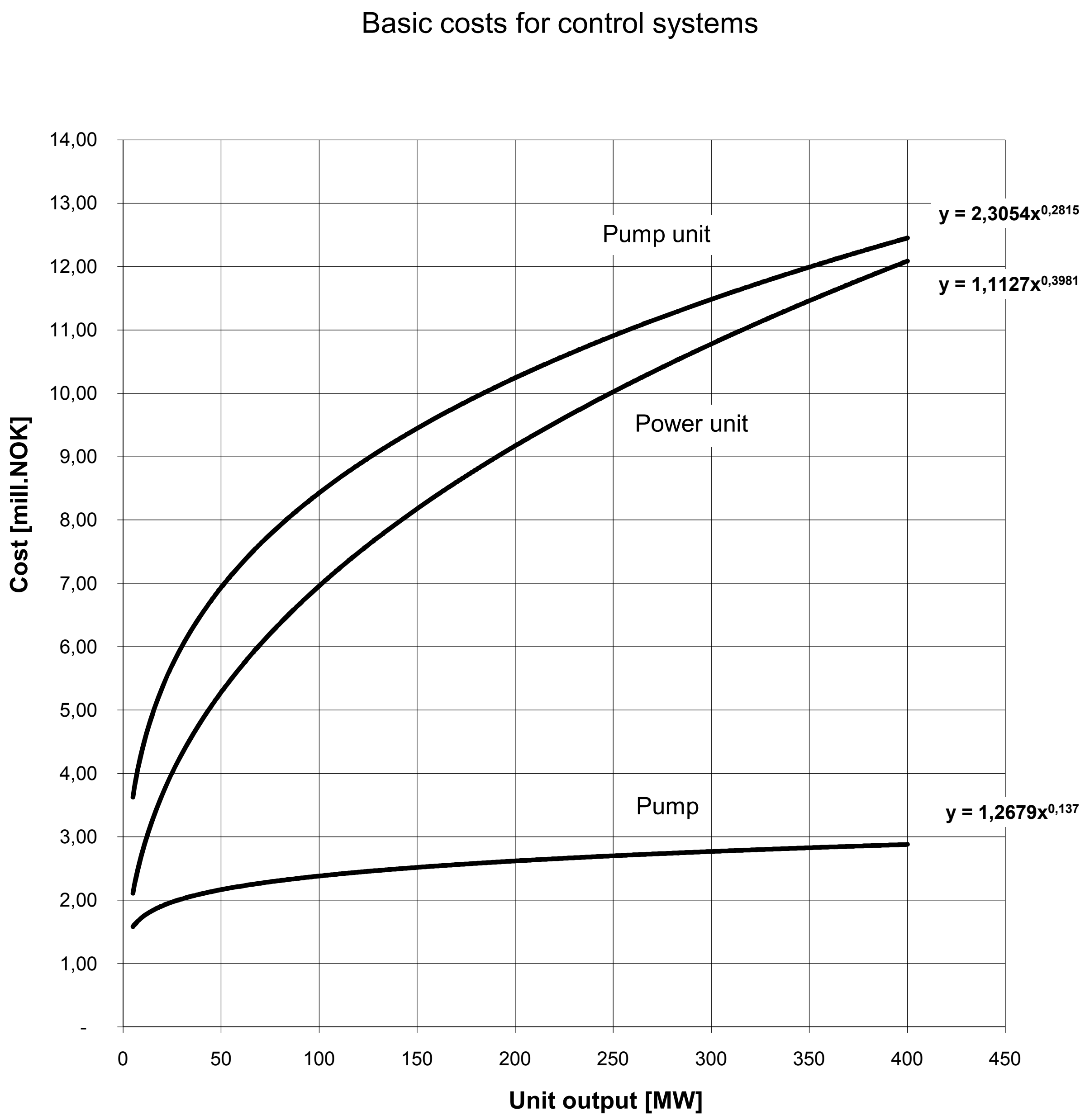
The price curves indicate the price for a complete control system once the unit output is given. Prices include installation and testing/commissioning.

E.4.3 Price levels

The prices stated represent the price level in January 2010.

E.4.4 Power plants with more than two units

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



COMMENTS:

1. Price level January 2010

2. Adjust the costs in the curve by adding the followinig (figures in 1000 NOK):

For each gate control with remote transmission:	**:250**
For each water level control with remote transmission	**:350**
For each 100 metre signal cable run between the underground plant and the surface plant:	**:100**

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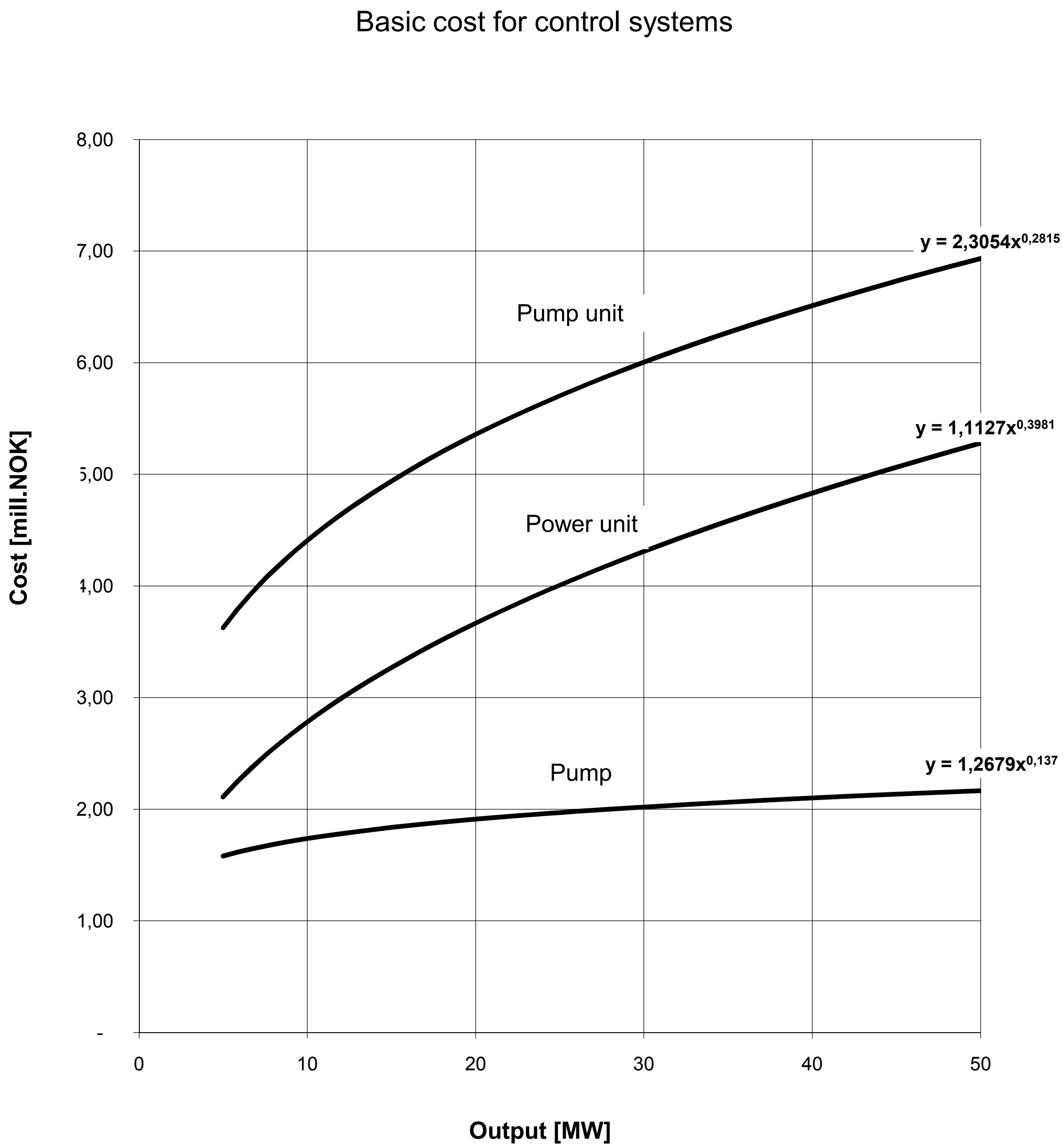
CONTROL SYSTEMS

Fig. E.4.1a
1 January 2010



COMMENTS:

1. Price level January 2010

2. Adjust the curve by adding the following (figures in 1000 NOK):

For each gate control with remote transmission:	**:250**
For each water level control with remote transmission:	**:350**
For each 100 metre signal cable run between the underground plant and the surface plant:	**:100**

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CONTROL SYSTEMS

5 - 50MW

Fig. E.4.1b
1 January 2010

E.5 AUXILIARY SYSTEMS

E.5.1 The scope of the analysis

The cost curve for auxiliary systems includes high-voltage and low-voltage station supply, station transformer, high-voltage and low-voltage cable, diesel unit, battery system with DC supply, earthing, fire alarm and fire extinguishing system, fire marking and sealing, plus a telephone system.

Please be aware that power stations arrangement differ greatly, due to their different ages, size, technical solution and how much has been spent on them. Therefore, the costs stated for auxiliary systems will be of a general nature only.

E.5.2 The price curves

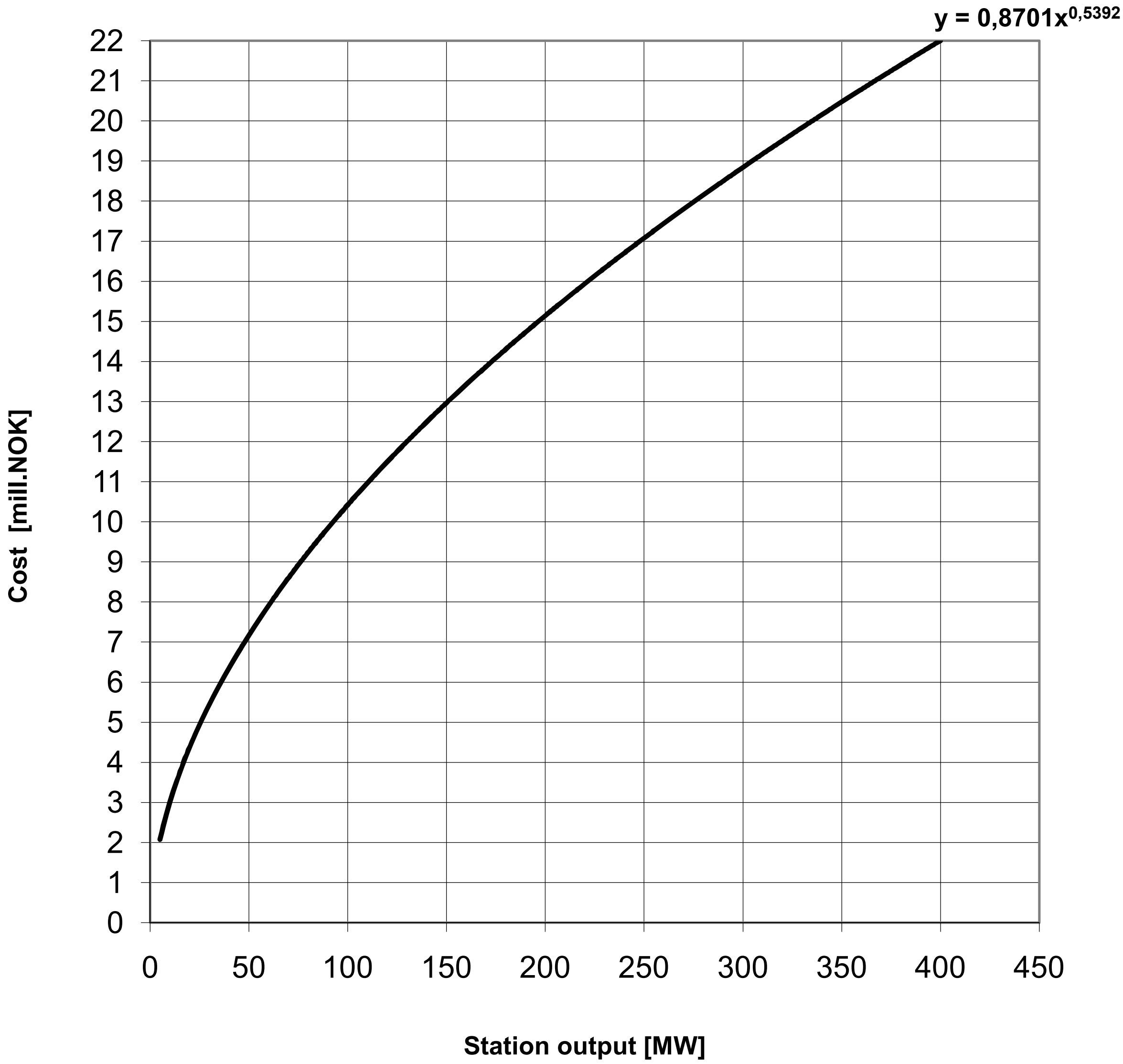
The price curves indicate the price for a complete auxiliary system once the unit output is given. Prices include installation and testing/commissioning.

E.5.3 Price levels

The prices stated represent the price level in January 2010. 2005 prices have not been adjusted.

E.5.4 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 over and above two units.



COMMENTS:

1. Price level January 2010

2. Adjust the costs in the curve by adding the following (figures in 1000 NOK):

For each 100 metre access and cable tunnel	**:150**
For each 230/ 400 V field incl. local control	**:150**
For each 12/ 24 kV field incl. local control	**:300**
For each radio line connection (both ends)	**:1000**
For each fibre-optic connection (botn ends)	**:300**

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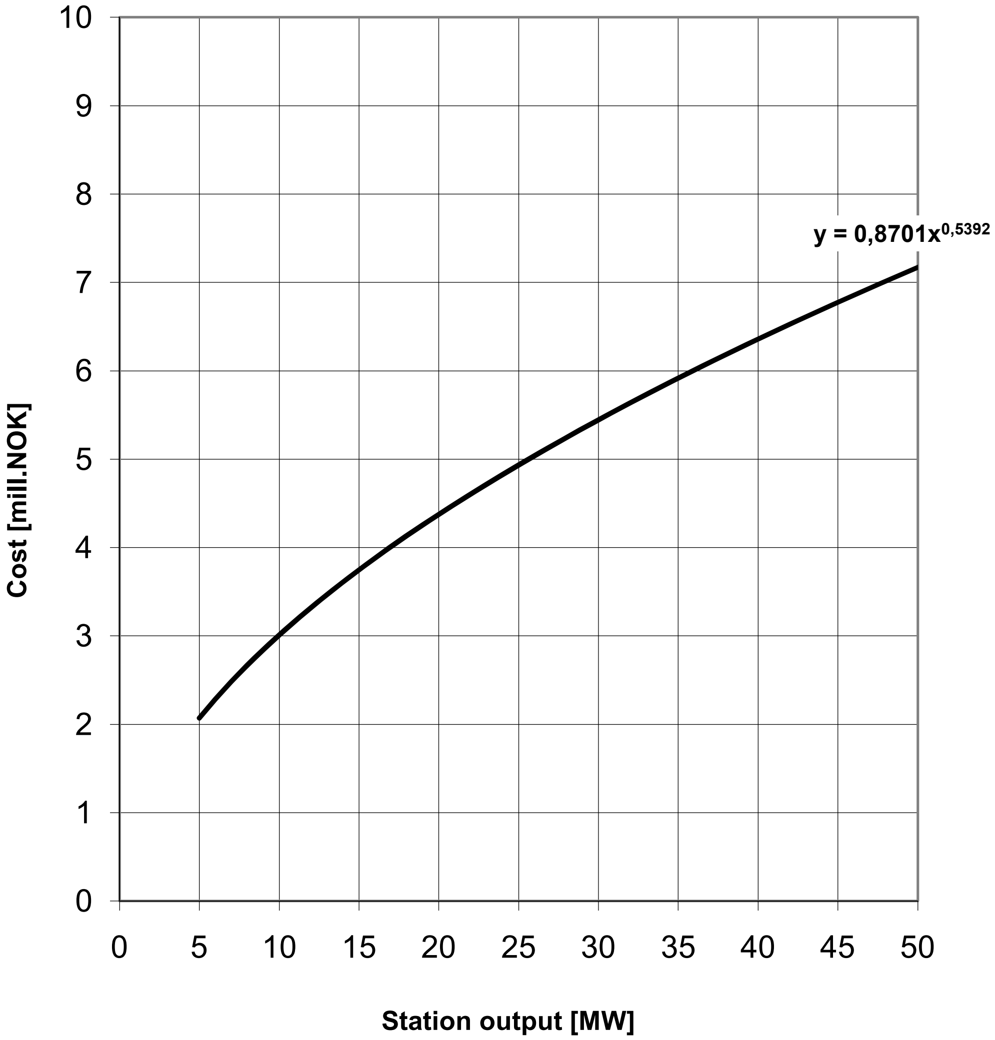
AUXILIARY SYSTEMS
STATION OUTPUT 5-400 MW

Fig. E.5.1a
1 January 2010



COMMENTS:

1. Price level January 2010

2. Adjust the costs in the curve by adding the following (figures in 1000 NOK):

For each 100 metre access and cable tunnel	:150
For each 230/ 400 V field incl. local control	:150
For each 12/ 24 kV field incl. local control	:300
For each radio line connection (both ends)	:1000
For each fibre-optic connection (both ends)	:300

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AUXILIARY SYSTEMS
STATION OUTPUT 5-50 MW

Fig. E.5.1b
1 January 2010

E.6 CABLE SYSTEMS

E.6.1 The scope of the analysis

This analysis is meant to cover cable systems that transmit output from the generator to a Switchgear in power and transformer stations. Cable systems that transmit power through underground cables between stations have thus not been included.

E.6.2 The price curves

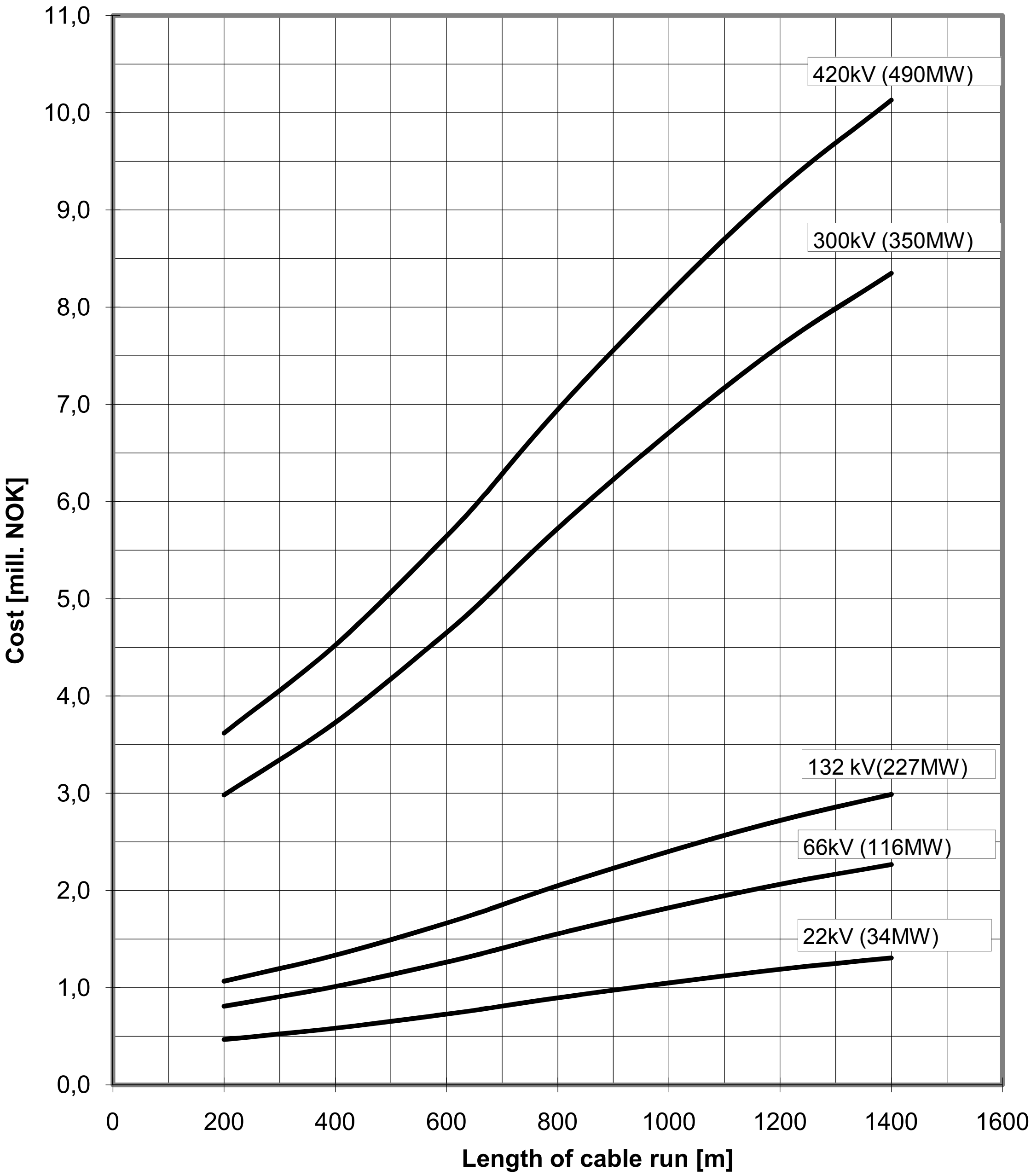
The price curves indicate the price for a complete cable system when the voltage level and the length of the cable run are given. Prices include installation and testing/startup. We have for the various voltage levels indicated the rough MW effect that the cable is able to transmit, if the cable has a cross-section of 800 mm^2. We are then assuming a voltage of 750 A for the 300 kV and 420 kV PEX cables, and 1000-1100 A for the PEX cables of 22, 66 and 132 kV.

E.6.3 Price level

The prices stated represent the price level in January 2010. For all cable systems, the price is for a PEX-insulated cable.

E.6.4 Costs included / not included

The price does not include a spare cable or spare material.



COMMENTS:

1. Price level January 2010

2. Tolerances ±20 %.

3. The costs apply for a cable system installed and tested. Cross-section of cable 800 mm^2. Al.

4. The costs for all voltage levels is for PEX-cables.

5. The rough load capacity in megawatt is given on the assumtion of (j) = 0.9.

6. In case of extremely short or long cable routes, a quote should be obtained from the supplier. This also applies to 300 and 420 kV systems.

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CABLE SYSTEM
CABLE CROSS-SECTION
800 mm2 Al

Fig. E.6.1
1 January 2010

E.7 POWER LINES

E.7.1 The scope of the analysis

This analysis covers lines for system voltages of 24, 72.5, 145 and 300/420 kV. For these voltage levels one can find the costs for lines with wooden pylons and with steel pylons.

The figures E.7.1. to E.7.4 show the total costs that should be expected when an electric company builds power lines on its own, so that material costs as well as payroll costs have been included.

E.7.2 Cost variations

The figures reflect cost variations ranging from easy to difficult terrains. The line route must be assessed in each case.

The diagrams show 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 by assuming that 90% of the price varies proportionally with the length of the line, while 10% is fixed. By "difficult terrain" we mean major differences in elevation and a rugged terrain. By "easy terrain" we mean construction in the lowlands and near a road.

E.7.3 Price level

Prices for 22 kV overhead lines have increased markedly from 2005 to 2010, largely due to increased personnel costs and material costs. The price increase for 300 kV and 420 kV lines has been moderate. One reason for this might be the increasing international competition for work on the highest voltage levels. The stated prices reflect the price level in January 2010.

E.7.4. Costs included / not included

Costs for a necessary Switchgear at the far end of the line have <u>not</u> been included.

Land compensation has <u>not</u> been included.

E.7.5. 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. E.7.1-E.7.4 on the assumption that only the line cross-section will vary. This approach leads to major 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 relation to the total cross-section. The lowest figures are used for the smallest cross-sections and vice versa.

E.7.6 Choice of voltage and line cross-section

Today practically all lines are made of steel/aluminium (FeAl). The cross-section is indicated by a figure that describes the copper cross-section in mm^2 that has 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 E.7.5 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 attention must be paid to the transmission grid which already exists in the area.

E.7.7 Transmission capacity for 300-4420 kV power lines

In general on dimensioning criteria for longer lines:
When one is planning power lines over longer distances, many considerations must be borne in mind. One always starts with the fact that a certain effect (MW) must be transmitted.

First of all, one must choose the voltage level for the transmission. The higher voltage one chooses, the lower current will go at the same effect, and consequently the loss will also be less. 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 300 and 420 kV) there will be problems with corona noise if the line diameter is too low. This means that 420 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 on 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 strains that arise due to the weight of the line and extra strains caused by wind and ice settling on the line.

Transmission capacity, thermal limit load:
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

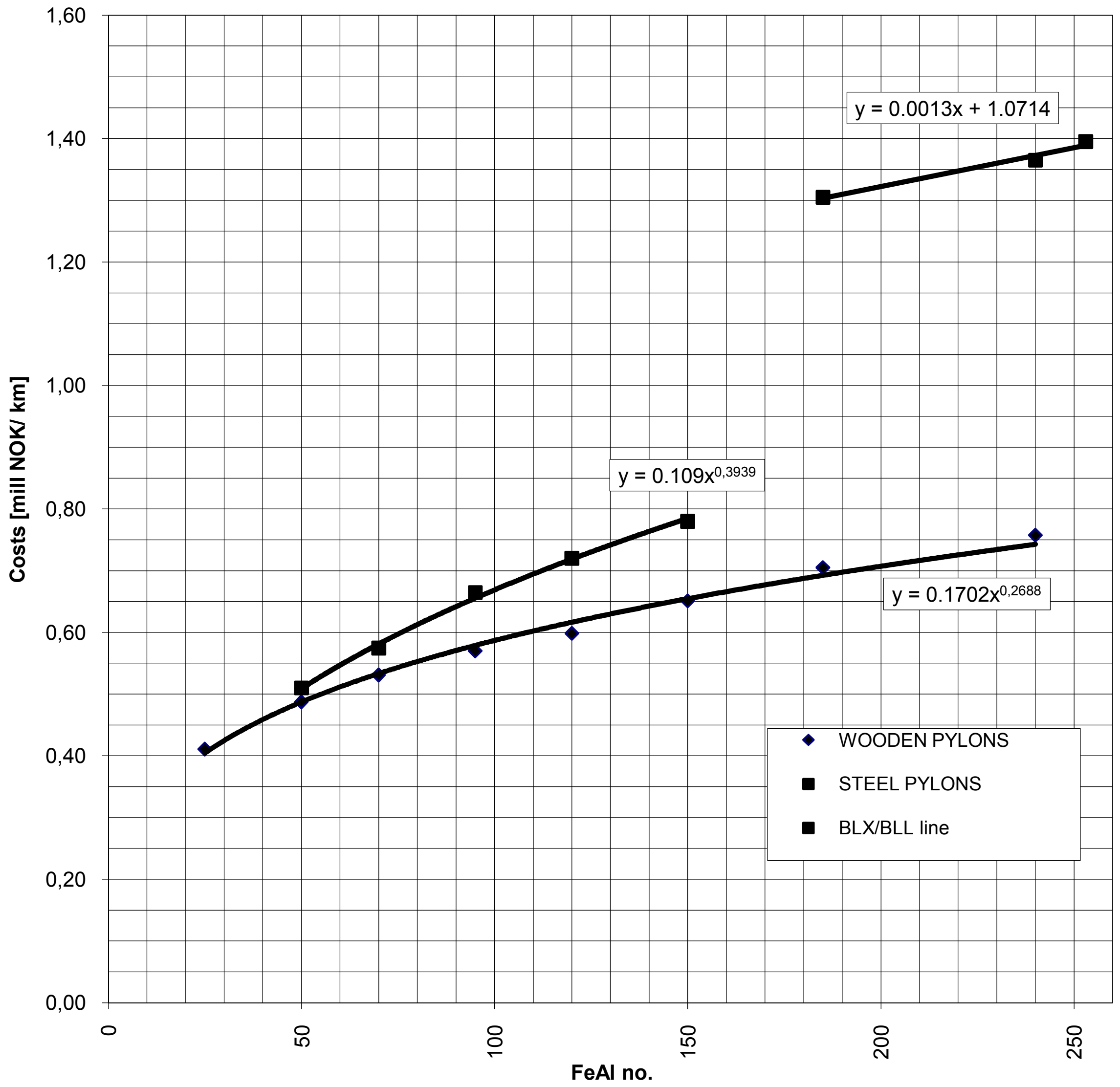
Table 1.
Thermal limit load for various line cross-sections depending on the voltage level and ambient temperature at a line temperature of 80 ˚C. Assumptions: 0.6 m/sec wind, thermal absorption and emission coefficient equals 0.5 blank line and no sun on the line. Source: Statnett

Limited transmission capacity due to voltage drop:
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 per cent. The need for compensation is to a great extent 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 systems will adjust the supply of reactive effect according to the need.

When longer power lines are planned, it is necessary to conduct load flow analyses where the entire surrounding grid is entered into a computer model. It will then be possible to predict how active and reactive effect will flow in a planned line with a light load (summer) and a heavy load (winter), and 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.



COMMENTS:

1. Price level January 2010
2. Total costs
3. Normal terrain
4. Tolerances: ±20%
5. Difficult terrain: +50%

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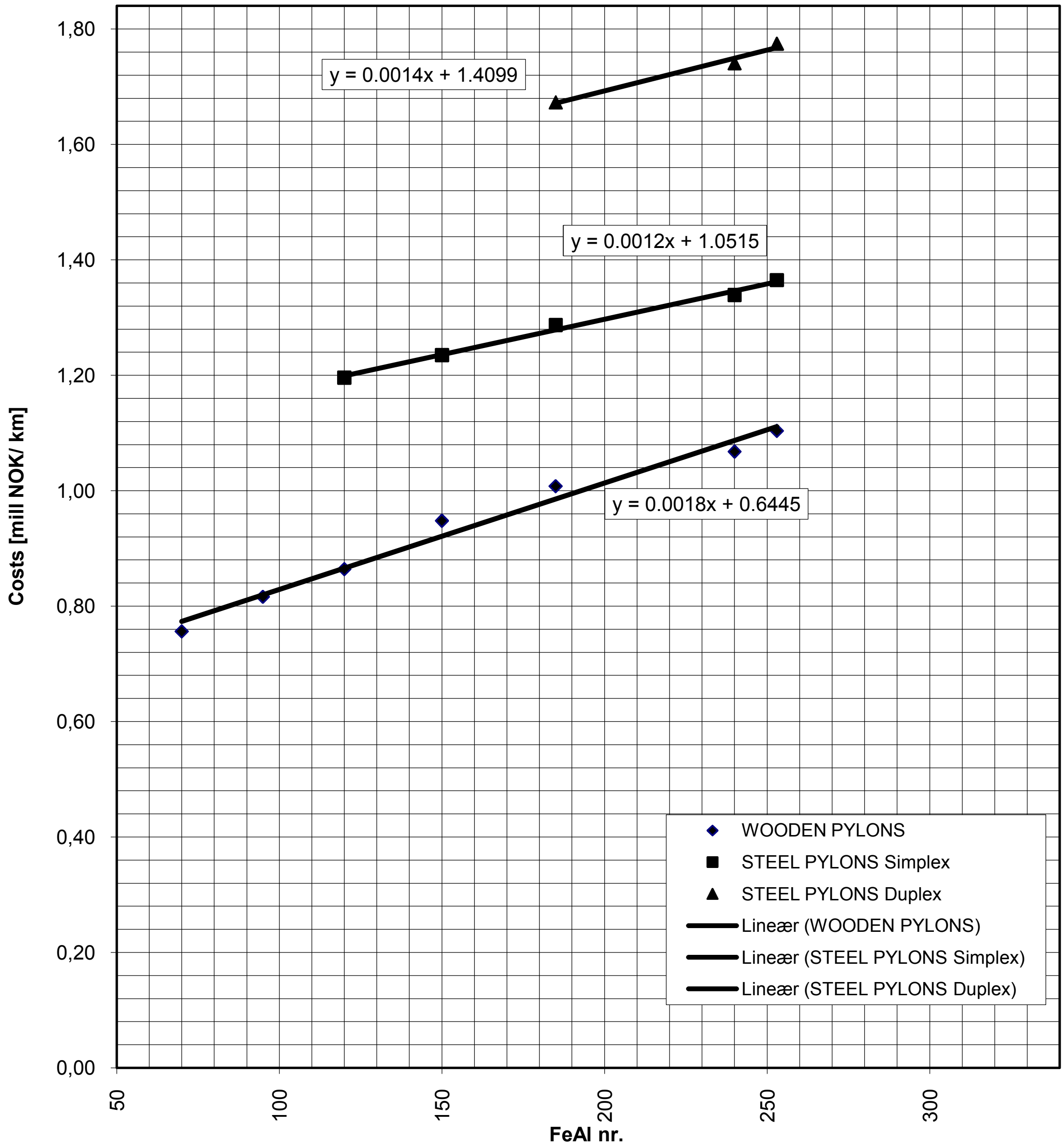
OVERHEAD LINE WITH SYSTEM VOLTAGE 24 kV

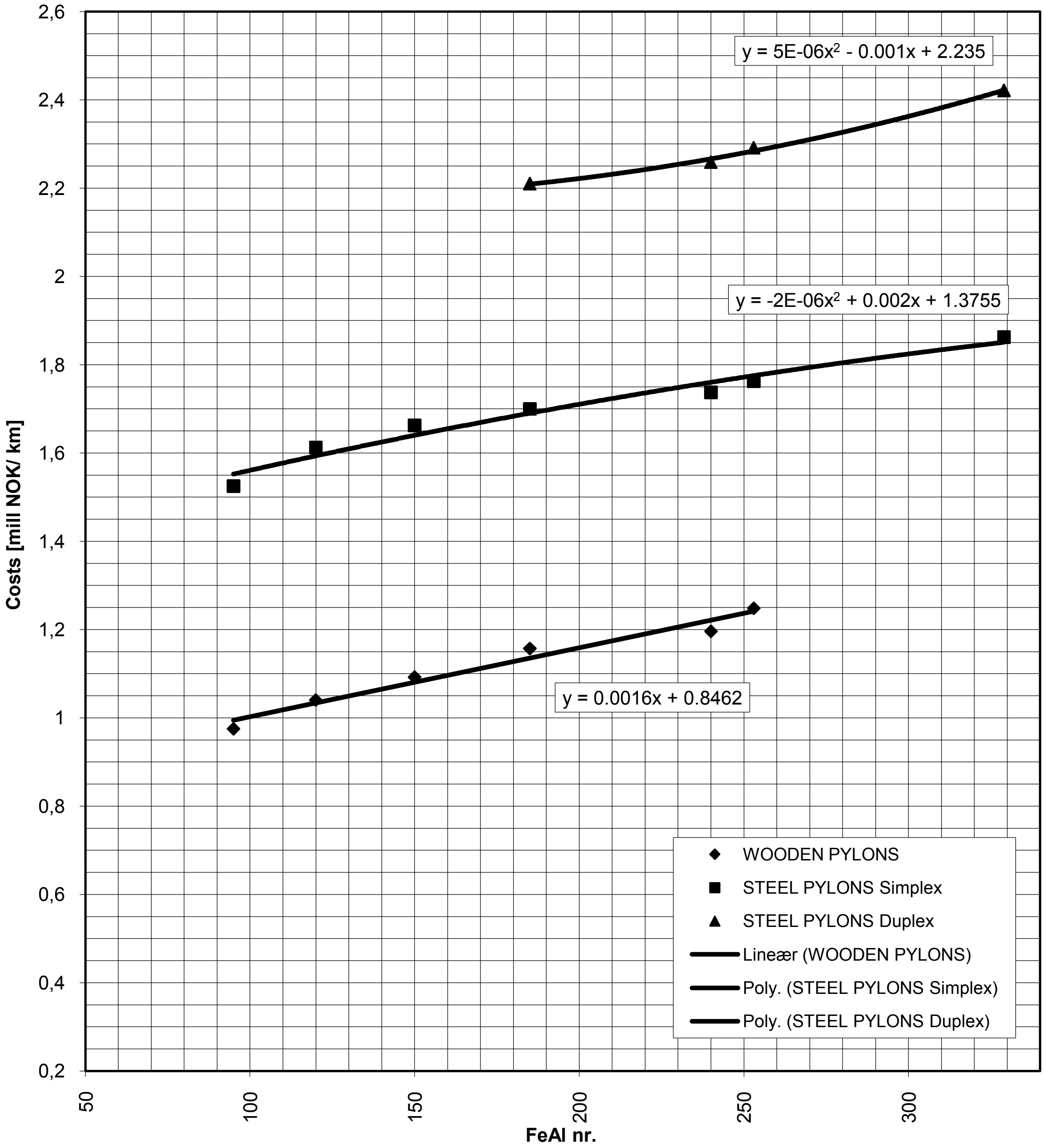
FIG. E.7.1
1 January 2010



COMMENTS:

1. Price level January 2010
2. Total costs
3. Normal terrain
4. Tolerances: ±20%
5. Difficult terrain: +50%

NVE Norwegian Water Resources and Energy Directorate	OVERHEAD LINE WITH SYSTEM VOLTAGE 72.5 kV	FIG. E.7.2 1 January 2010



COMMENTS:

1. Price level January 2010
2. Total costs
3. Normal terrain
4. Tolerances: ±20%
5. Difficult terrain: +50%

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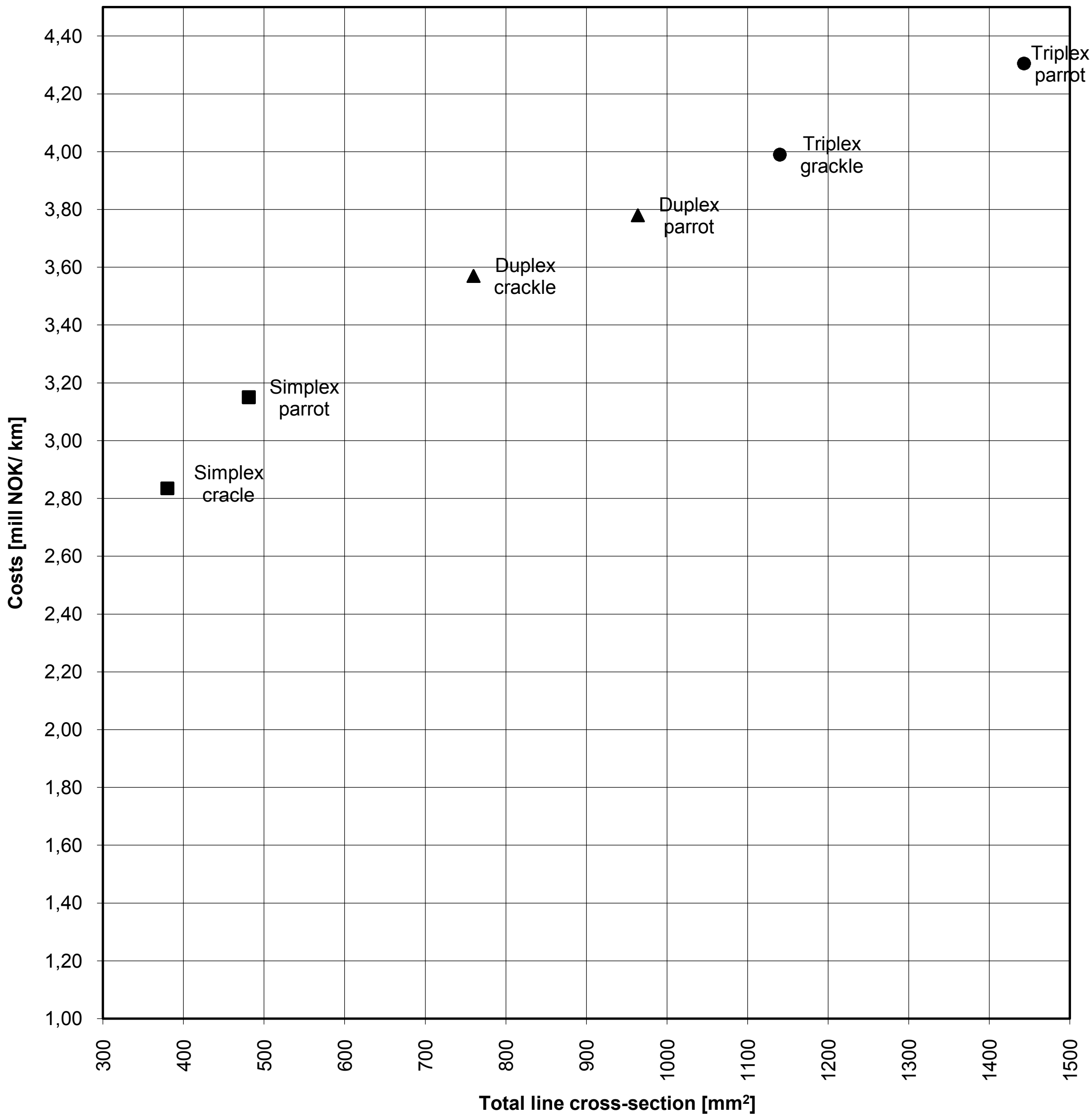
OVERHEAD LINE WITH SYSTEM VOLTAGE 145 kV

FIG. E.7.3
1 January 2010

Total costs for overhead lines
with system voltage 300/ 420 kV, normal terraing



COMMENTS:

1. Price level January 2010
2. Total costs
3. Normal terrain
4. Tolerances: ±20%
5. Difficult terrain: +30%

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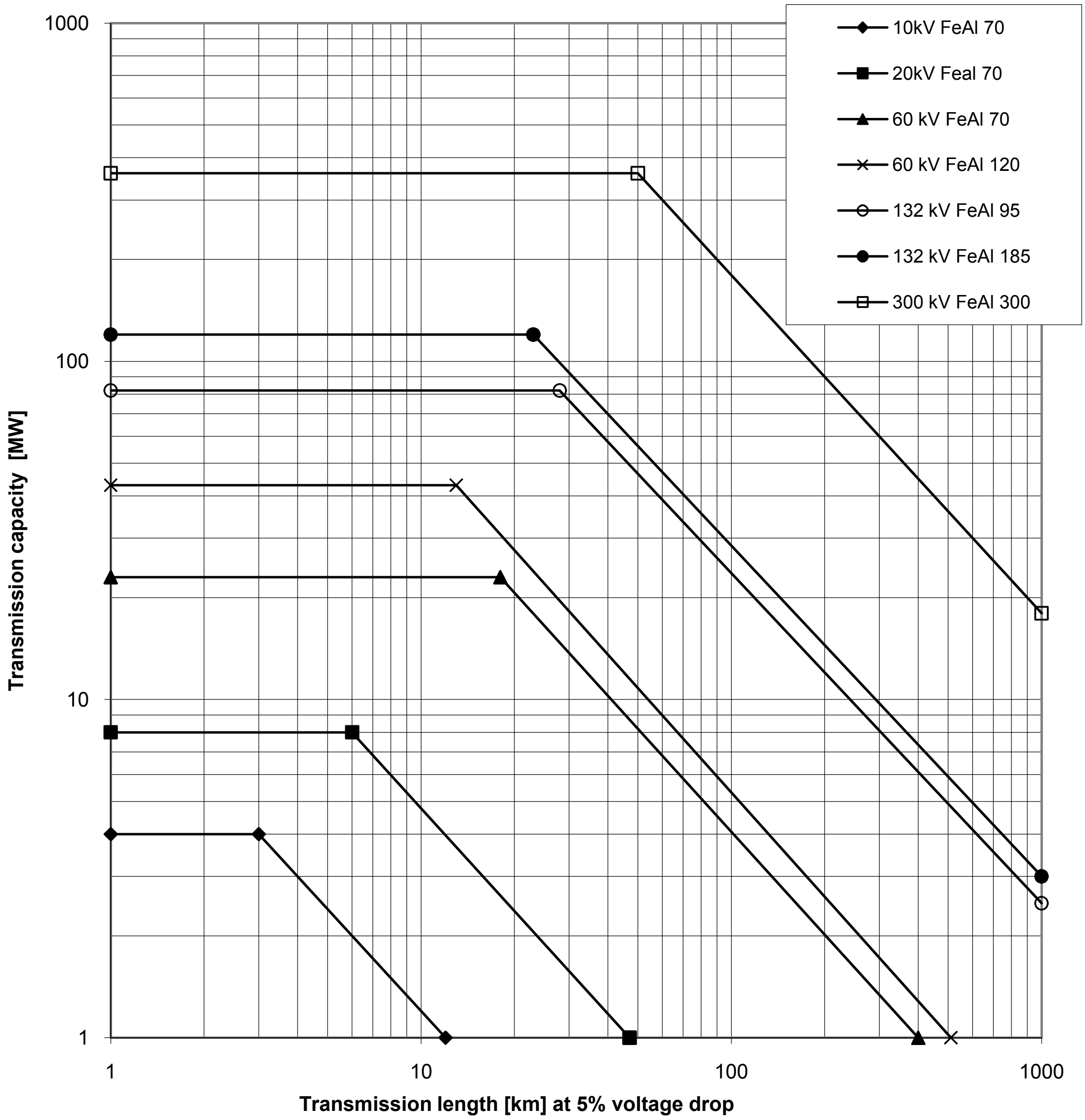
OVERHEAD LINE WITH SYSTEM VOLTAGE 300/ 420 kV

Fig. E.7.4
1 January 2010



COMMENTS:

Norwegian Water Resources and Energy Directorate NVE	TRANSMISSION CAPACITY FOR POWER LINES	Fig. E.7.5

E.8 TOTAL COSTS

E.8.1 General

This chapter describes the total costs for electro-technical 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.

E.8.2 Plants from 5 MVA and up

As a basis for our estimate, we have chosen a power plant with the following main features:

- 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
- Switchgear of a conventional type with a single bus bar and one circuit breaker. If an SF_6 station is wanted, extra costs must be added for this, cf. Fig. E.3.3 High-voltage Switchgear.
- For stations above ca. 150 MW we have assumed the use of enclosed bus bar 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. 3.1. In other cases, two power units might for example share one transformer that covers the overall generator output.

E.8.3 Variations in plant design

Besides plant output (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 Switchgear
- The length, type and number of cables

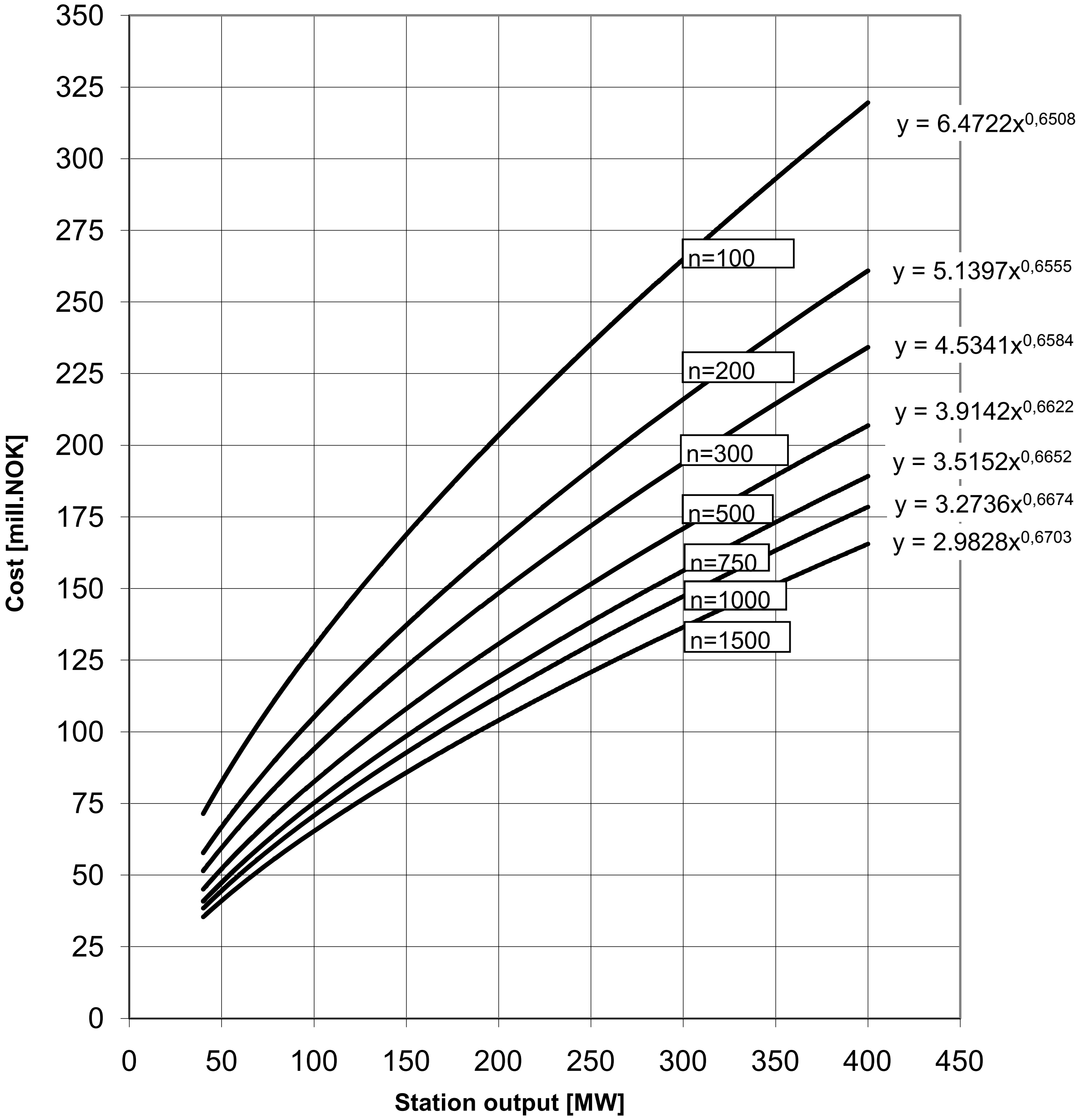
In principle, the scope of and hence the price of electro-technical equipment for a power plant will be the same whether the station is built above ground or underground. For a surface plant, however, it will often be possible to locate the high-voltage system so near the transformers that one avoids 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. E.6.1.

E.8.4 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. Ch. E.7. For stations with large regulated areas, power supply and communication in these areas might be costly.

E.8.5 Plants with more than two power units

Fig. E.8.1 and E.8.2 show the costs of electro-technical 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.



COMMENTS:

1. **Price level January 2010**
2. **Tolerances ±20%.**
3. **The estimates apply for total electro-technical equipment including control/ auxiliary system for a medium size underground station**
4. **The estimates include 800 m of cable. Voltage levels vary from 22 kV to 420 kV according to the**
5. **Telecom system and power lines are not included, see Ch. E.5.0.**
6. **If an SF6 station is chosen the difference betweem SF6 and a conventional station must be added, cf. Fig. E.3.3.**

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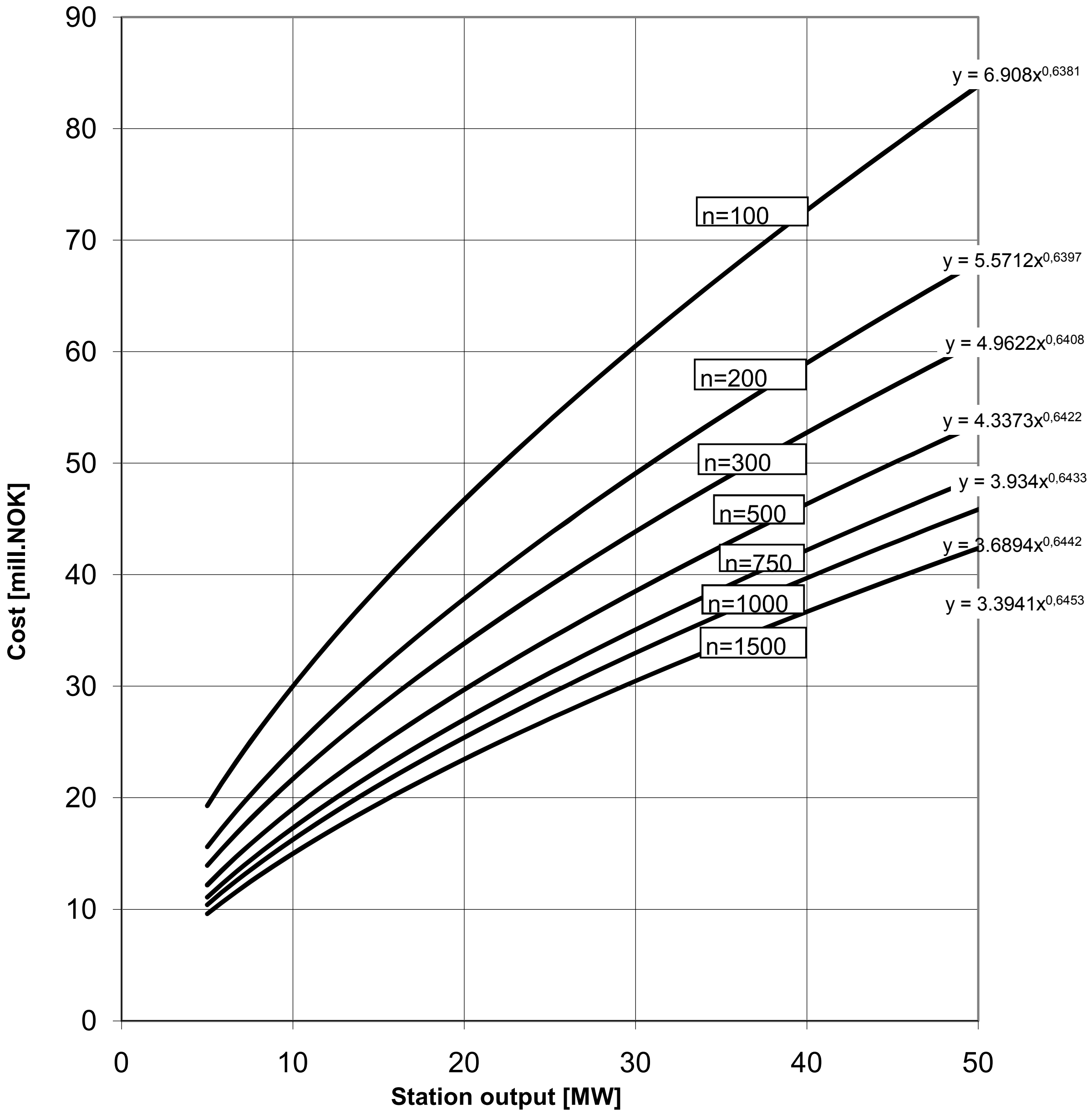
TOTAL COSTS FOR ELECTRO-TECHNICAL EQUIPMENT IN A POWER PLANT OUTPUT WITH ONE GENERATOR

Fig.E.8.1a
1 January 2010



COMMENTS:

1. Price level January 2010

2. Tolerances ±20%.

3. The estimates apply for total electro-technical equipment including control/ auxiliary system for a medium size underground station.

4. The estimates include 800 m of cable. Voltage levels vary from 22 kV to 420 kV according to the output (MW).

5. Telecom system and power lines are not included, see Ch. E.5.0.

6. If an SF6 station is chosen the difference between SF6 and a conventional station must be added, cf. Fig. E.3.3.

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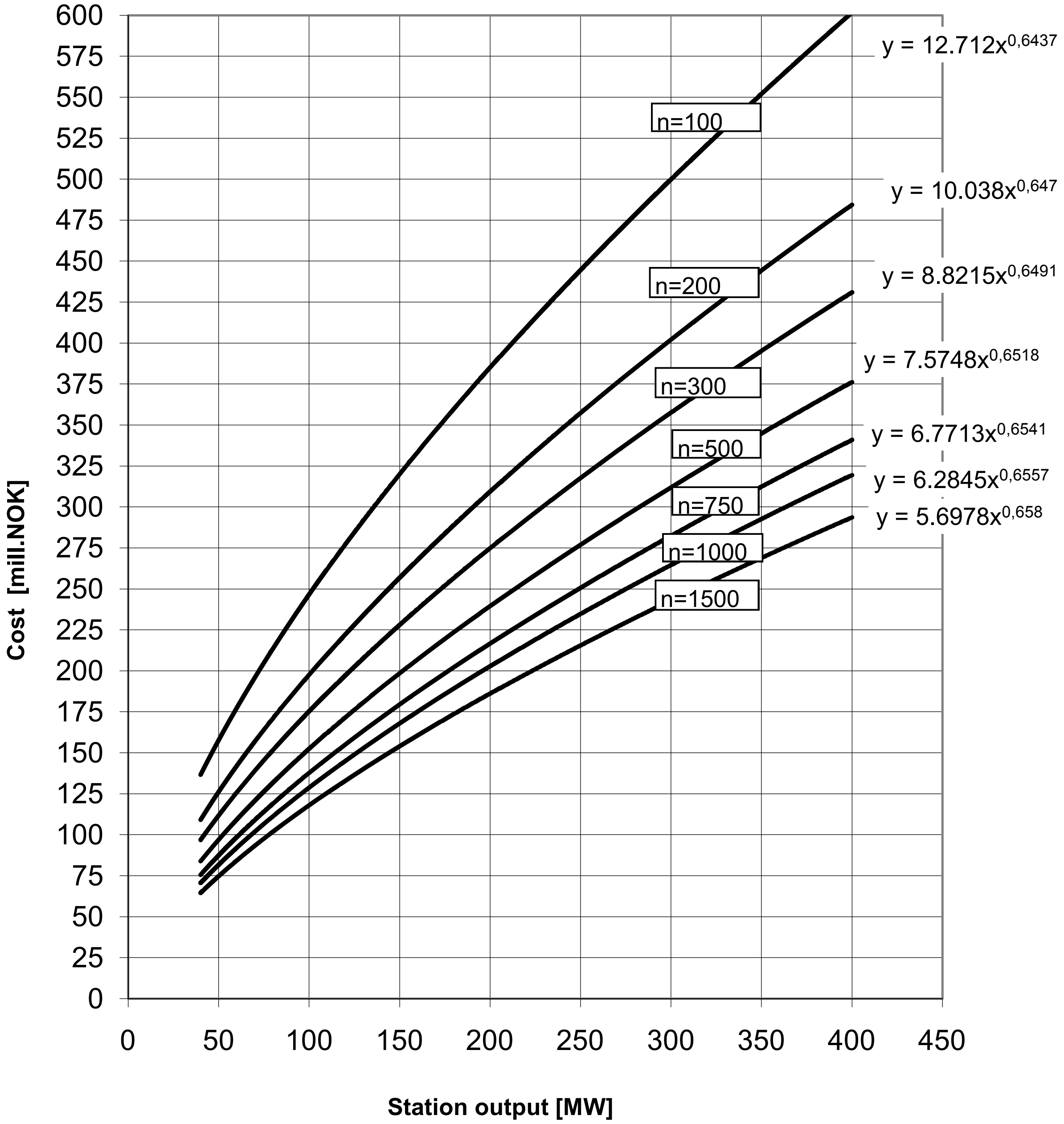
TOTAL COSTS FOR ELECTRO-TECHNICAL EQUIPMENT IN A POWER PLANT OUTPUT WITH ONE GENERATOR

Fig.E.8.1b
1 January 2010



COMMENTS:

1. Price level January 2010
2. Tolerances ±20%.
3. The estimates apply for total electro-technical equipment including control/ auxiliary system for a medium size underground station.
4. The estimates include 800 m of cable. Voltage levels vary from 22 kV to 420 kV according to the output (MW).
5. Telecom system and power lines are not included, see Ch. E.5.0.
6. If an SF6 station is chosen the difference between SF6 and a conventional station must be added, cf. Fig. E.3.3.

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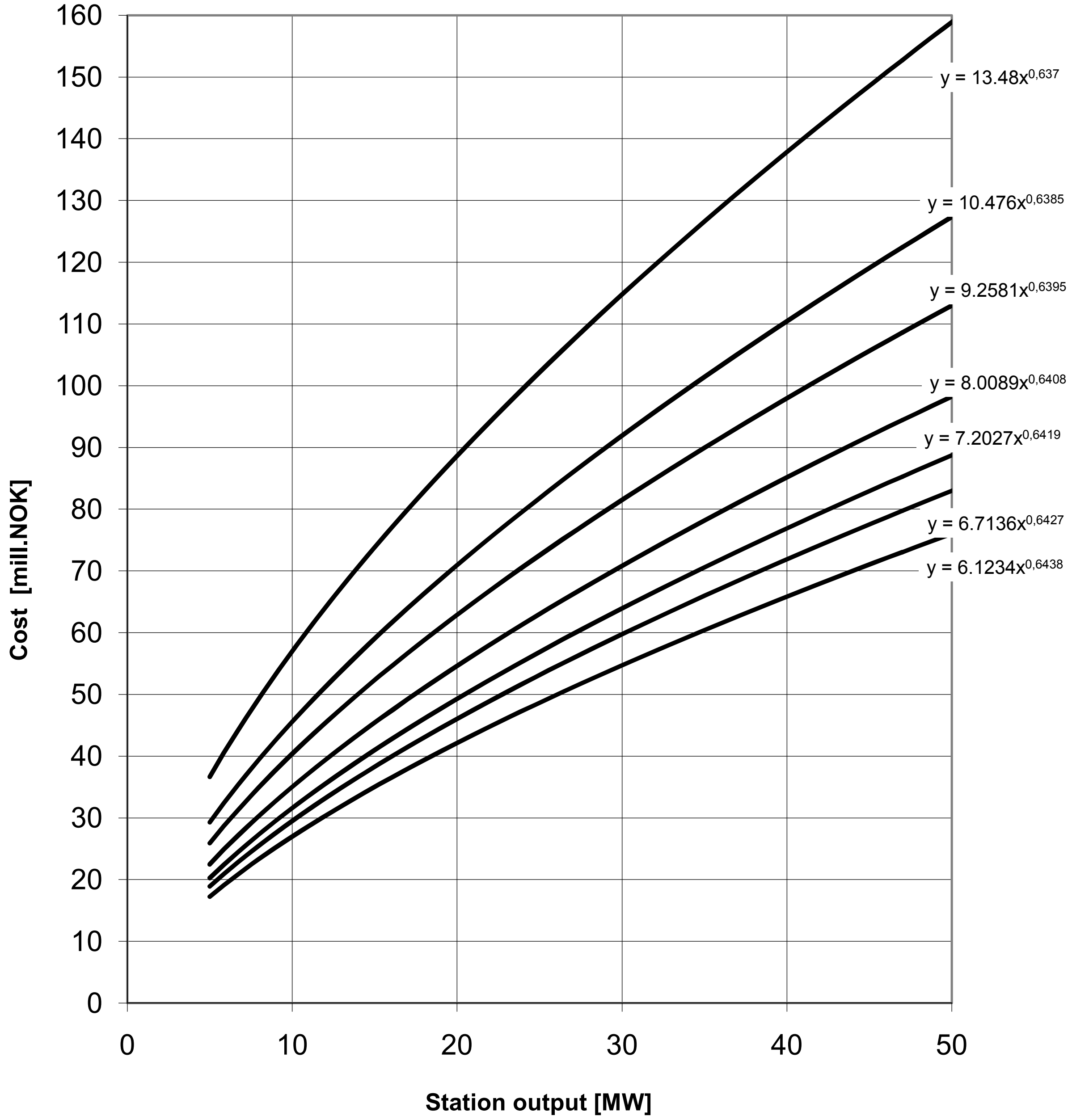
TOTAL COSTS FOR ELECTRO-TECHNICAL EQUIPMENT IN A POWER PLANT OUTPUT SPLIT BETWEEN TWO GENERATORS

Fig.E.8.2a

1 January 2010



COMMENTS:

1. **Price level January 2010**
2. **Tolerances ±20%**
3. **The estimates apply for total electro-technical equipment including control/ auxiliary system for a medium size underground station.**
4. **The estimates include 800 m of cable. Voltage levels vary from 22 kV to 420 kV according to the output (MW).**
5. **Telecom system and power lines are not included, see Ch. E.5.0.**
6. **If an SF6 station is chosen the difference between SF6 and a conventional statiom must be added, cf. Fig. E.3.3.**

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TOTAL COSTS FOR ELECTRO-TECHNICAL EQUIPMENT IN A POWER PLANT OUTPUT SPLIT BETWEEN TWO GENERATORS

Fig.E.8.2b
1 January 2010

E.9 CONSTRUCTION POWER

E.9.1 General

Power supply for construction work varies a great deal and depends on how much power is consumed and the complexity of the plant. We have therefore been unable to prepare graphs or tables for a precise 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 builder's expenses and outside the scope of this report. We have indicated prices for individual components that form part of the construction power supply below.

E.9.2 High-voltage line

Please see Ch. E.7.

E.9.3 Cable system

We assume that 3 x 50 mm^2 Al is used. Ready installed, one can assume approx. NOK 250 per metre. If a cable with a suspension line is used, add approx. NOK 75 per metre.

E.9.4 Kiosks

A high-voltage power supply kiosk of a transportable type may be obtained for NOK 150,000-200,000 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 75,000 to 125,000 exclusive of transformer.

E.9.5 Price level

The prices stated represent the price level in January 2010.

M MECHANICAL ENGINEERING

M.0 General

M.0.1 Average foreseeable costs and uncertainty

This chapter provides a basis for calculating the average foreseeable costs for Mechanical equipment deliveries.

The stated costs have an estimated accuracy of ±20%. The real costs are just as likely to be higher as lower.

M.0.2 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 in Norway, including transport insurance
- Spare parts
- Installation and painting, board and lodging for the installer
- Casual labour assistance (5% of overall costs)
- The supplier's technical service during installation and commissioning
- 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

M.0.3 Builder's expenses

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

- 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" have not been included.

M.0.4 Price level

The stated prices refer to January 2010. The prices are mainly based on signed contracts, budget prices and discussions with suppliers. It must be said that few new plants have been built since 2005, and thus there is little on which to base an assessment of price trends.

During the 2005-2010 period, there has been considerable variation in the cost increase for the different components.

Turbine components are manufactured in a number of countries across the world, and the price is therefore affected by international price trends. Stainless steel in particular has had a considerable price increase 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 level as for small power plants.

There has been a relatively strong cost increase for gates and adit gate. The price of these depends heavily on the use of stainless steel.

Price trends for steel pipes are somewhat uncertain, as we have limited information.

Please note that extensive use of subcontractors might lead to problems with a lower quality in the Mechanical equipment components. This means that the developer should spend more money on quality control of the equipment he purchases. This factor has not been included in the cost estimate.

M.1 TURBINES

M.1.1 General

Turbine prices are given as NOK/kW maximum output and as a function of the maximum discharge Q, the mean net 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 absorption 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 quite natural price jumps in the grey zone between 8 and 12 MW, and the jumps are mainly caused by size and pressure. This has an impact on the design of the power unit. The smaller turbines also come with some mass-produced equipment that makes them cheaper (compact units).

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.

Spare turbine runner has not been included in the prices. For all vertical machines the turbine guide bearing has been included, but not the axial thrust bearing. For horizontal machines, neither the radial bearing nor the axial bearing has been included. The bearings that have not been included are normally included in the generator delivery.

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 effect is estimated to be roughly 3-4% below the turbine effect due to loss in the generator and transformer.

M.1.2 Pelton turbines with an output above approx. 10 MW, Fig. M.1.A

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

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

The Pelton wheel must always remain above the highest tailwater level. The turbines in the diagram must remain around one to four metres above, depending on their size and whether it is a horizontal or a vertical machine.

For heads less than around 650 metres and great water masses, a Francis turbine might be an option.

M.1.3 Francis turbines with an output above approx. 10 MW, Fig. M.1.B.

The price curves apply for turbines with a steel spiralcasing, inlet valve and frequency governor.

The prices apply for turbines with a runner centre moderately submerged in relation to lower tailwater levels. If it is necessary for the turbine not to be submerged, the price will normally rise, but this depends to some extent on how close one is to the rotational speed limits.

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

M.1.4 Kaplan turbines with an output above approx. 6 MW, Fig. M.1.C and D.

The price curves apply for vertical turbines with a frequency governor.

Two different price estimates have been given; one for Kaplan with a steel spiralcasing, a head range of about 35-50 m, and one for Kaplan with a concrete spiralcasing 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 smaller discharge and little variation in the water flow. In the lower head range it might also be possible to use bulb turbines, if that gives sufficient stability. This will not alter the prices significantly, but the rotational speed will be 10-20% higher than shown in the diagram.

For Kaplan turbines with steel spiralcasing and discharge below approx. 80-100 m^3/s, a butterfly valve might be used in front of the turbine inlet instead of an intake gate. The inlet valve represents 20-30% of the turbine price.

M.1.5 Small turbines, Fig. M.1.E, F and G, have been removed as 10MW turbines are discussed in Handbook 1.

M.1.6 Pump turbines

Pump turbine prices can be calculated by taking the price for a Francis turbine with similar discharge 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 is on average 1.25.

M.1.7 Methods to improve turbine efficiency

Pelton:

Methods that can be taken to increase turbine efficiency:

- New runner
- New needle and nozzle assembly with greater capacity
- Modifying the turbine casing to reduce ventilation losses

The potential improvement in efficiency would be up to 3% for older turbines and 1% for newer ones (from about the 1970s). 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 that have been mentioned might make up about 10% of the costs of a new turbine. If the discharge is increased, the turbine's mechanical regulation system might also have to be replaced or upgraded.

The discharge can normally be increased by 5-10%, and is in particular limited by the requirements for ventilation loss, backwater in the outlet and the generator's maximum output.

Francis:
Methods that can be taken to increase turbine efficiency:

- New runner with altered geometry and optimum capacity
- New labyrinth seals
- New and expanded outlet from the runner and in the draft tube cones will increase the discharge capacity
- New guide vanes and possibly guide vane seals
- Adjusting the stay vanes with regard to intake and outlet angles/leading and trailing edges..

The potential improvement in efficiency would be up to 3% for older turbines and 1.5% for newer ones (from about the 1960s). If there has been much wear and tear, the improvement will of course be even greater. The discharge capacity can normally be increased by 5-10%, and is in particular limited by the requirements for submersion, permitted pressure rise 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 discharge capacity is increased, the turbine's mechanical regulation system might also have to be replaced or upgraded.

Kaplan:
Methods that can be taken to increase turbine efficiency:

- New runner with altered geometry and optimum capacity
- New guide vanes for increased discharge capacity and reduced friction
- New and expanded outlet from the runner and the runner chamber increases the discharge capacity. Expanding the runner chamber may be a demanding job. When the discharge capacity is increased, the geometry and friction of the turbine runner normally also change and the optimum capacity shifts towards higher output.
- Adjusting the stay vanes with regard to intake and outlet angles/leading and trailing edges.

The potential improvement in efficiency is up to 2% for older turbines and 1.0% for newer ones (from about the 1960s). If there has been much wear and tear, the improvement will of course be even greater. It is difficult to verify Kaplan turbines through prototype measurements. Measuring based on a model turbine may be the cheapest and best method for verifying the efficiency. The discharge capacity can normally be increased by 5-10%, and is in particular limited by the requirements for submersion and the generator's maximum output.

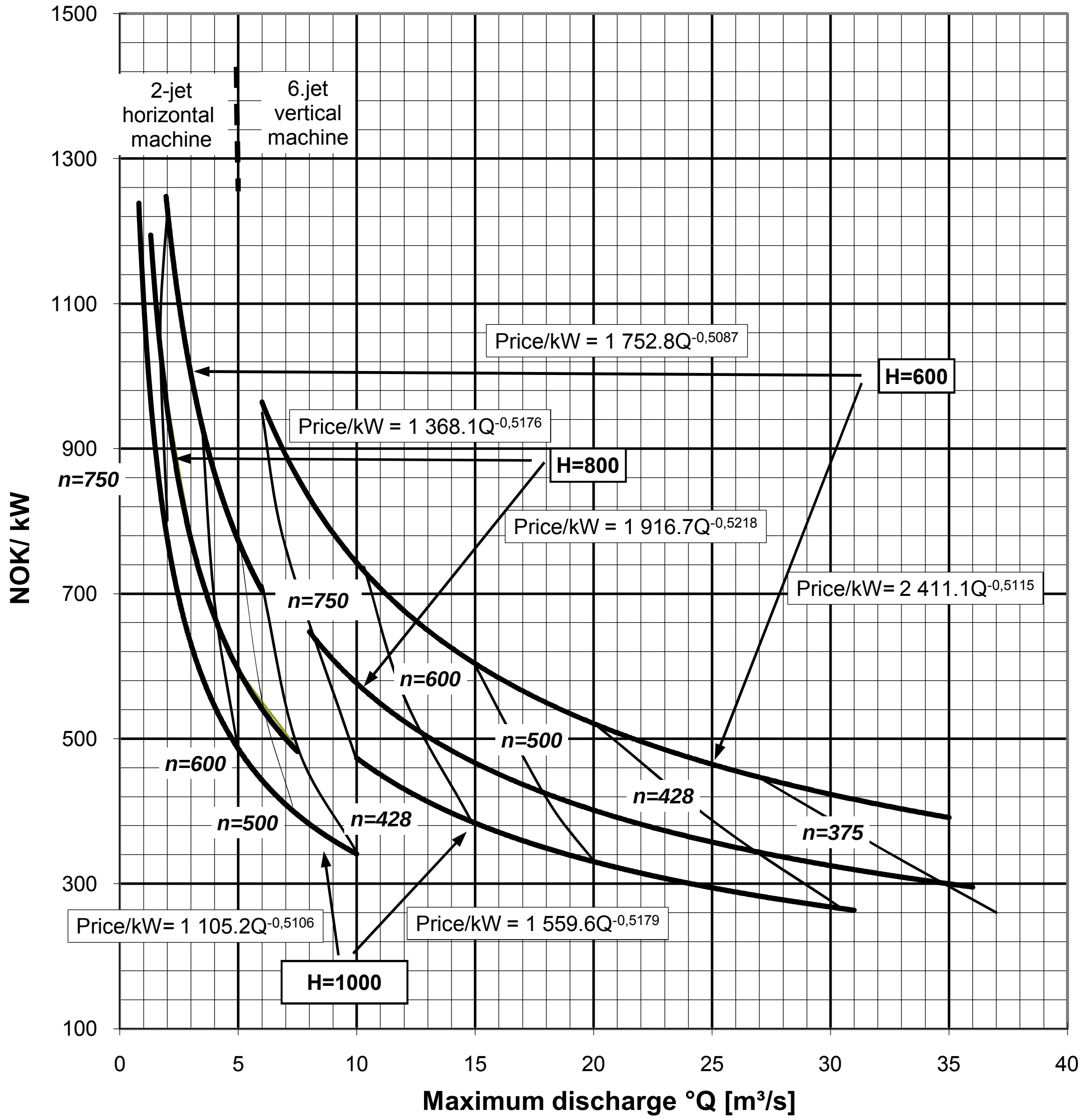
The cost of the runner comprises about 15-30% of a new turbine. The price will be affected by the technical choices made. The other components that have been mentioned might make up about 10% of the cost of a new turbine. If the discharge capacity is increased, the turbine's mechanical regulation system might also have to be replaced or upgraded.

Improvements generally:
Improving the turbines through upgrades and modernisation 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%. This, of course, entails 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 case the discharge capacity may also be increased significantly.

An evaluation of the significance of this measure for electrical components:

If the turbine efficiency is improved by 1-5%, i.e. an effect increase of 1-5%, equipment like the generator, transformer and other high-voltage equipment will in most cases already be dimensioned for this. 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 the increased output.



COMMENTS:

1. Price level January 2010

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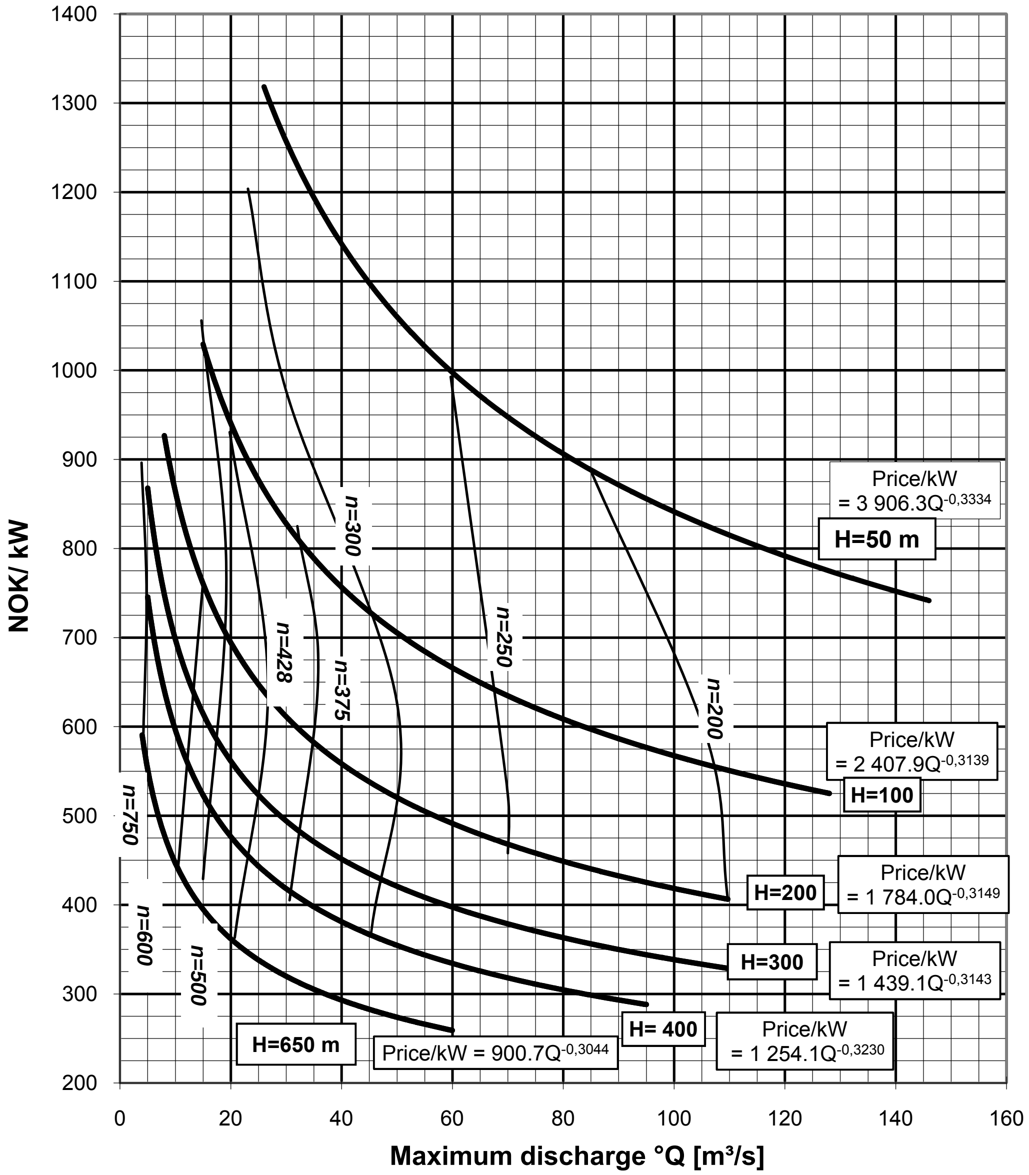
PELTON TURBINE

Fig. M.1.A
1 January 2010



COMMENTS:

1. Price level January 2010
2. The turbine centre is located approximately 3 m below the lowest tailwater level.

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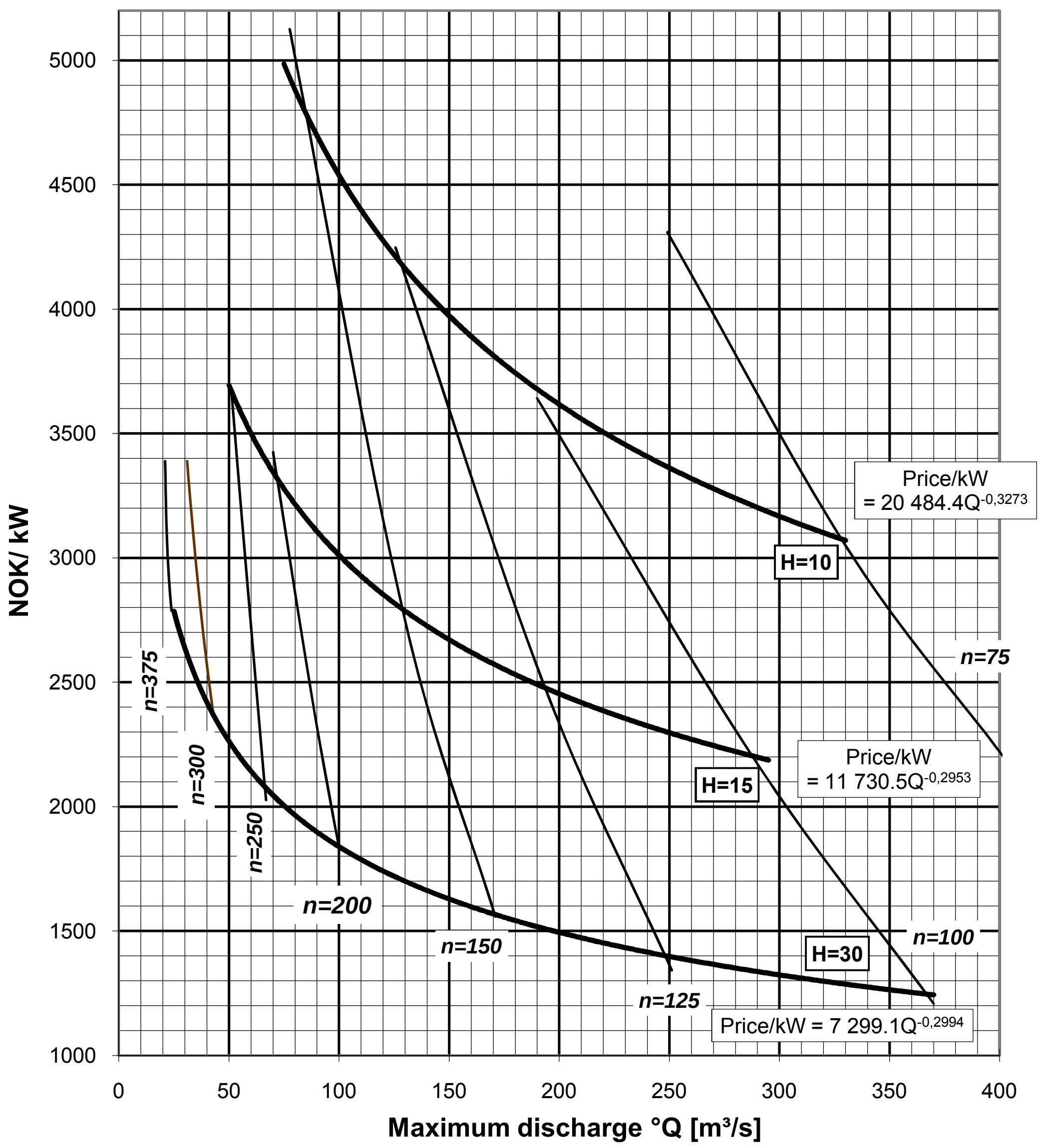
FRANCIS TURBINE

Fig. M.1.B
1 January 2010



COMMENTS:

1. Price level January 2010
2. The curves apply for vertical units with a concrete spiral.

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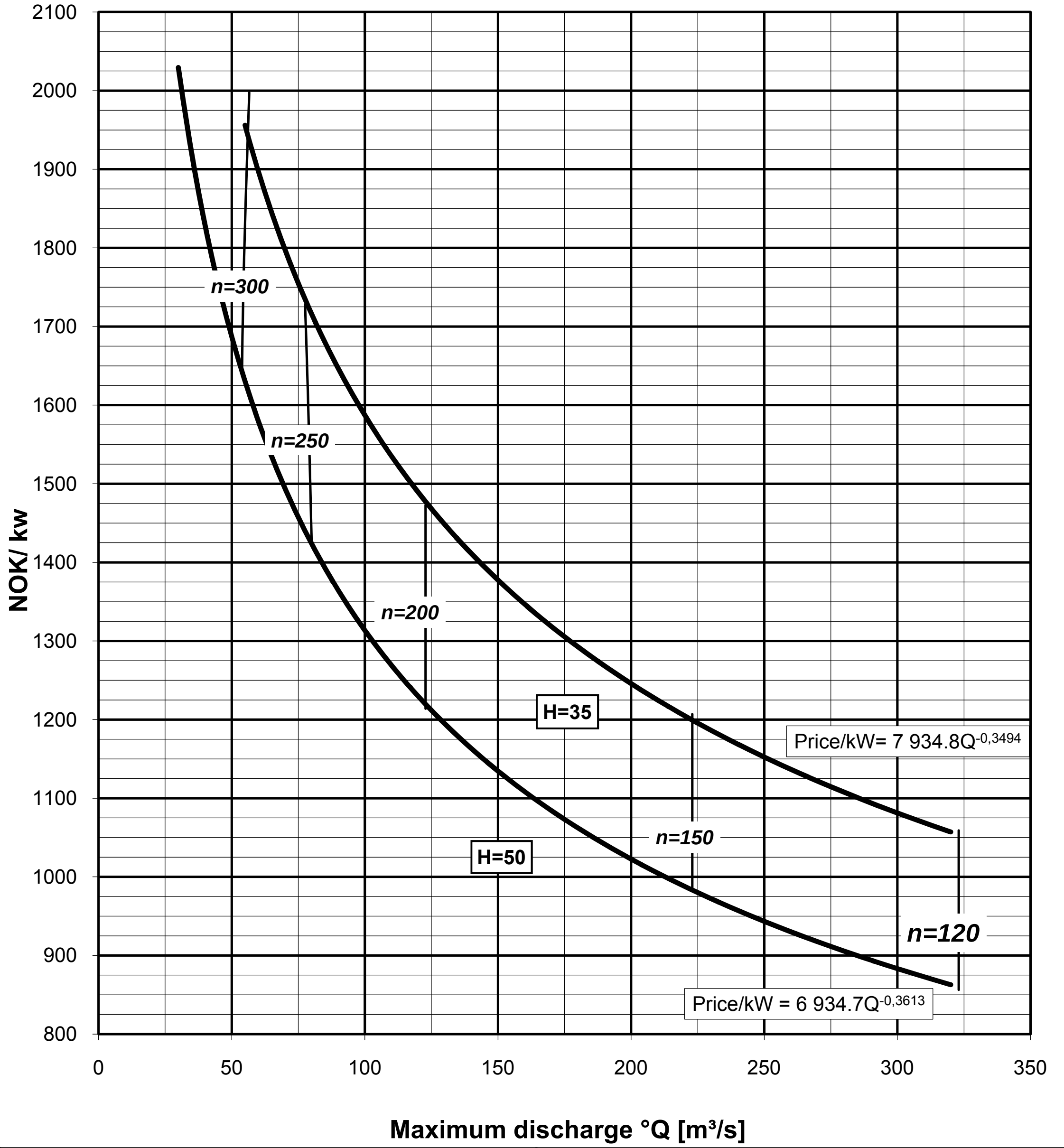
KAPLAN TURBINE
WITH CONCRETE SPIRAL

Fig. M.1.C
1 January 2010



COMMENTS:

1. Price level January 2010

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NVE

KAPLAN TURBINE
WITH STEEL SPIRAL

Fig. M.1.D
1 January 2010

M.2 PUMPS

Prices on pumps have been stated as NOK/kW stamped motor size, and as a function of the maximum water flow and pump height H_e. The prices apply for the range from 100 l/s and as far as the curves go. The cost curves have been brought as far to the right as the standard programmes for most of the relevant pump suppliers will go.

The efficiency increases with increasing water flow from approx. 0.75 at 0.1 m^3/s to 0.9 over 2 m^3/s.

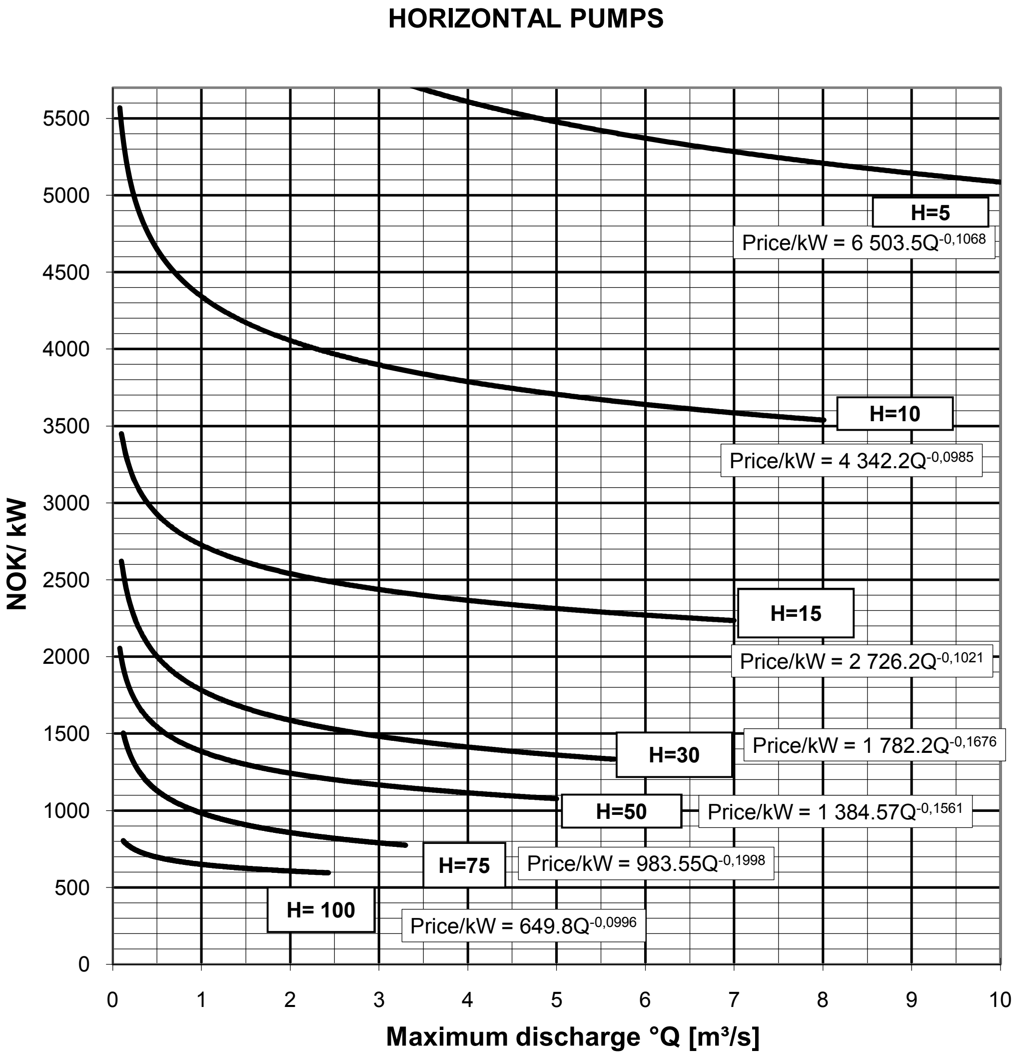
The rotational speed given is an indication only, and may in practice turn out to be one or even two levels different in either direction, depending on the submersion, design of the pump runner and the number of pump stage/runners.

Unless one is buying more than three pumps for the same station, no bulk discount should be expected.

Pumps and electro-technical equipment will often be part of the same delivery.

The cost curves assume single-acting suction pumps with the inlet and outlet at right angles to each other, or alternatively double-acting 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.



COMMENTS:

1. Price level January 2010
2. Prices include motor and el. cabinet

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PUMPS

Fig. M.2.A
1 January 2010

M.3 GATES

M.3.1 General

Gate prices have been provided in NOK in relation to the gate size 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. Price curves have been prepared for the following:

Radial gates	Fig. M.3.A
Flap gates	Fig. M.3.B
Wheel gates	Fig. M.3.C
Slide gates	Fig. M.3.D
Adit gates	Fig. M.3.E

It should be noted that wheel gates are unsuitable as discharge gates.

One should be thinking in terms of wheel gates if there are requirements for closure in the event of one-sided pressure, and when the pressure (m) x area (m^2) is higher than 500.

As for wheel gates and slide gates, one often has an inspection gate immediately upstream of the main gate with a retraction arrangement in the same shaft. This makes it easy to rehabilitate the main gate. The price curves do not include an inspection gate, however.

The estimated addition to the price would be:

For wheel gates	approx. 50%
For slide gates	approx. 70%.

M.3.2 Rubber gates

It will sometimes be possible to use rubber gates instead of flap gates, radial gates, sector gates and needle closures. Rubber gates will mainly be used where there is not a large reservoir behind, so that the consequences of a breakdown would not be too serious.

The advantages and disadvantages of rubber gates are primarily as follows:

<u>Advantages</u>

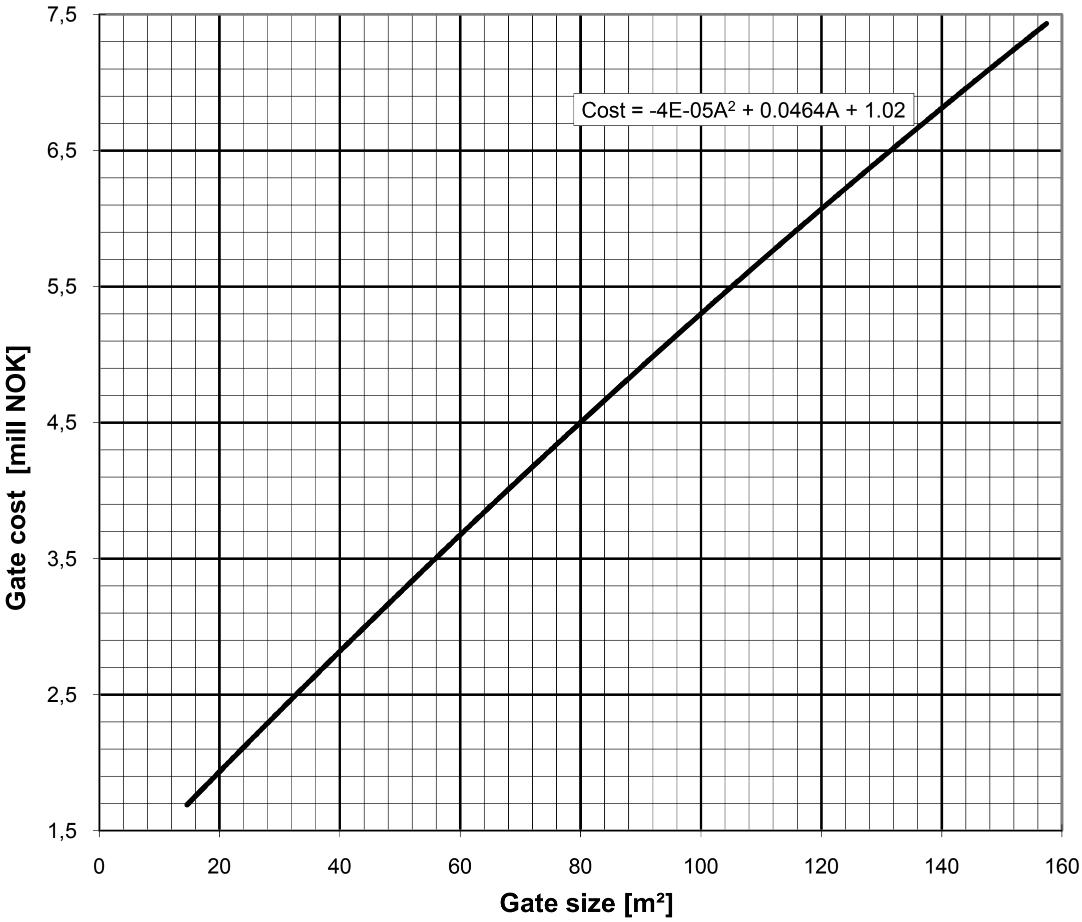
1. Favourable price for longer lengths.
2. Simpler construction
3. Little maintenance costs
4. Low operating costs
5. Less visible in the terrain
6. Can be made for very long lengths
7. Good sealing

<u>Disadvantages</u>

1. Regulation with section opening is not recommended
2. Vibration problems might occur in the event of more than 20-30% overtopping for air-filled gates and 30-40% overtopping for water-filled gates
3. Can only be used as surface gates
4. Height limitations.

In terms of price, it is clear that rubber is unable to compete with steel for smaller gates. For surface gates the length must probably be more than 15 m before the price really will favour rubber gates. With the length increasing beyond approximately 15 m, the price difference will be greater.

As a rough price estimate, one can think in terms of about 26,000 NOK/m^2 net gate area. This is the price for a gate with a compressor system, pipes, control, steel anchorage, etc. ready installed. The price excludes civil works.



COMMENTS:

1. Price level January 2010

2. Costs apply for dam gates without top seal

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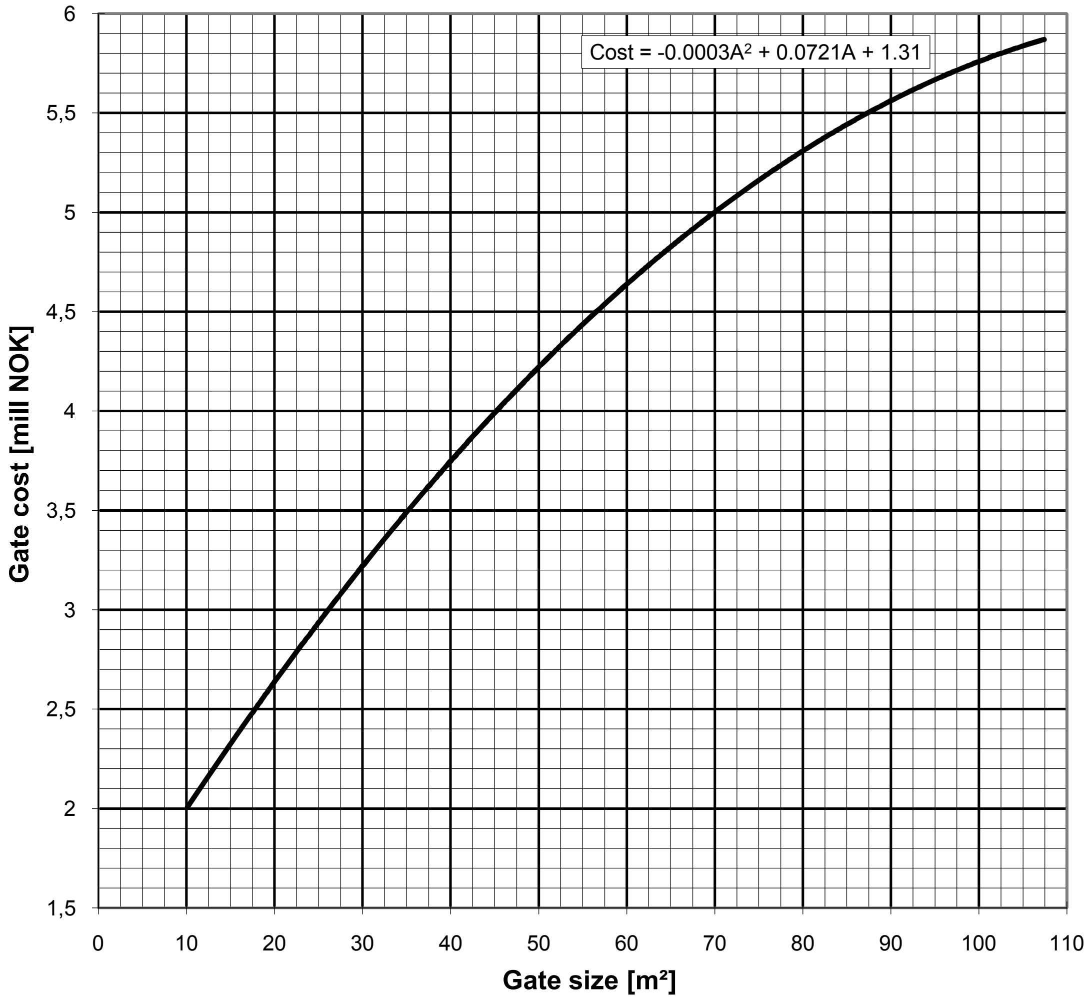
RADIAL GATES

Fig. M.3.A
1 January 2010



COMMENTS:

1. Price level January 2010

2. Treshold pressure < 5 m

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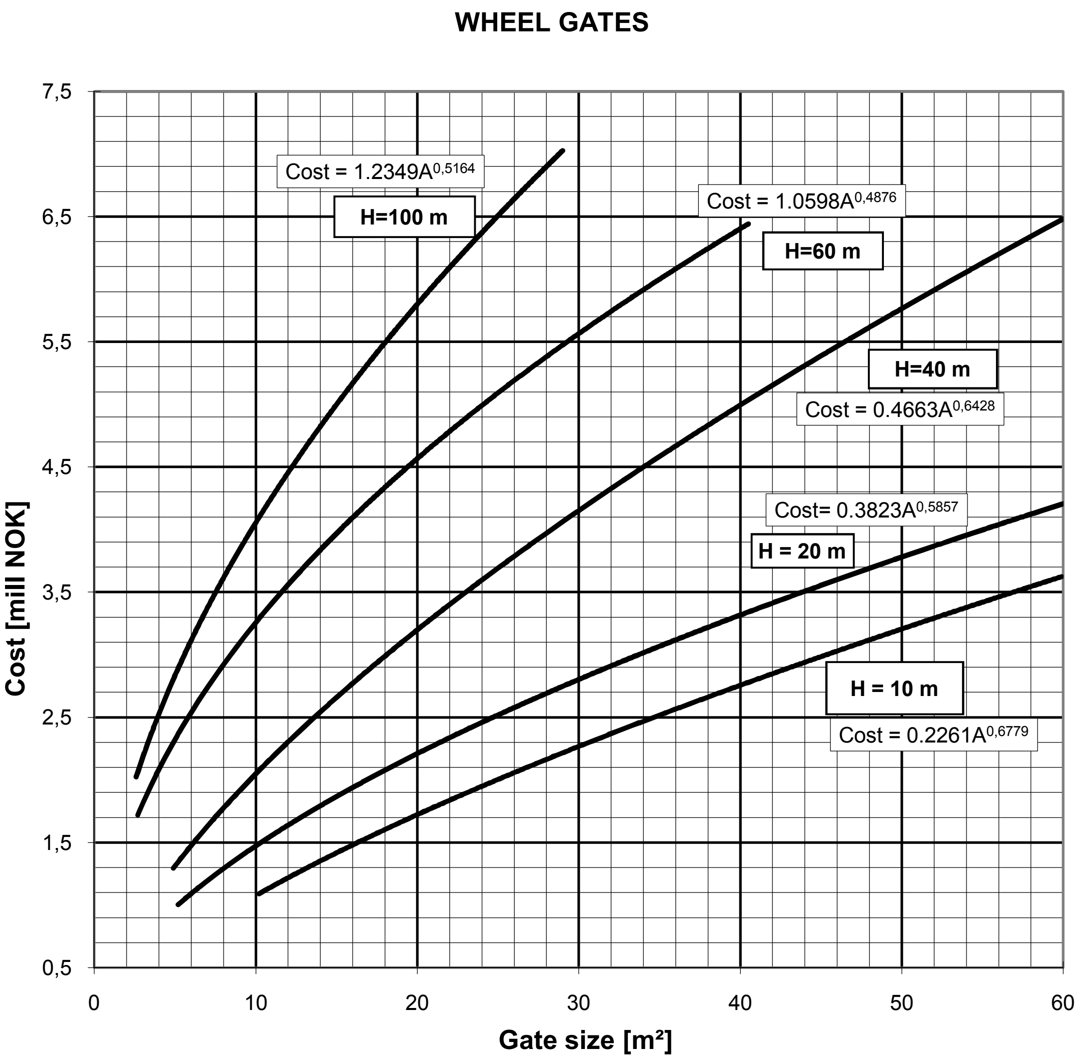
FLAP GATES

Fig. M.3.B
1 January 2010



COMMENTS:

1. Price level January 2010

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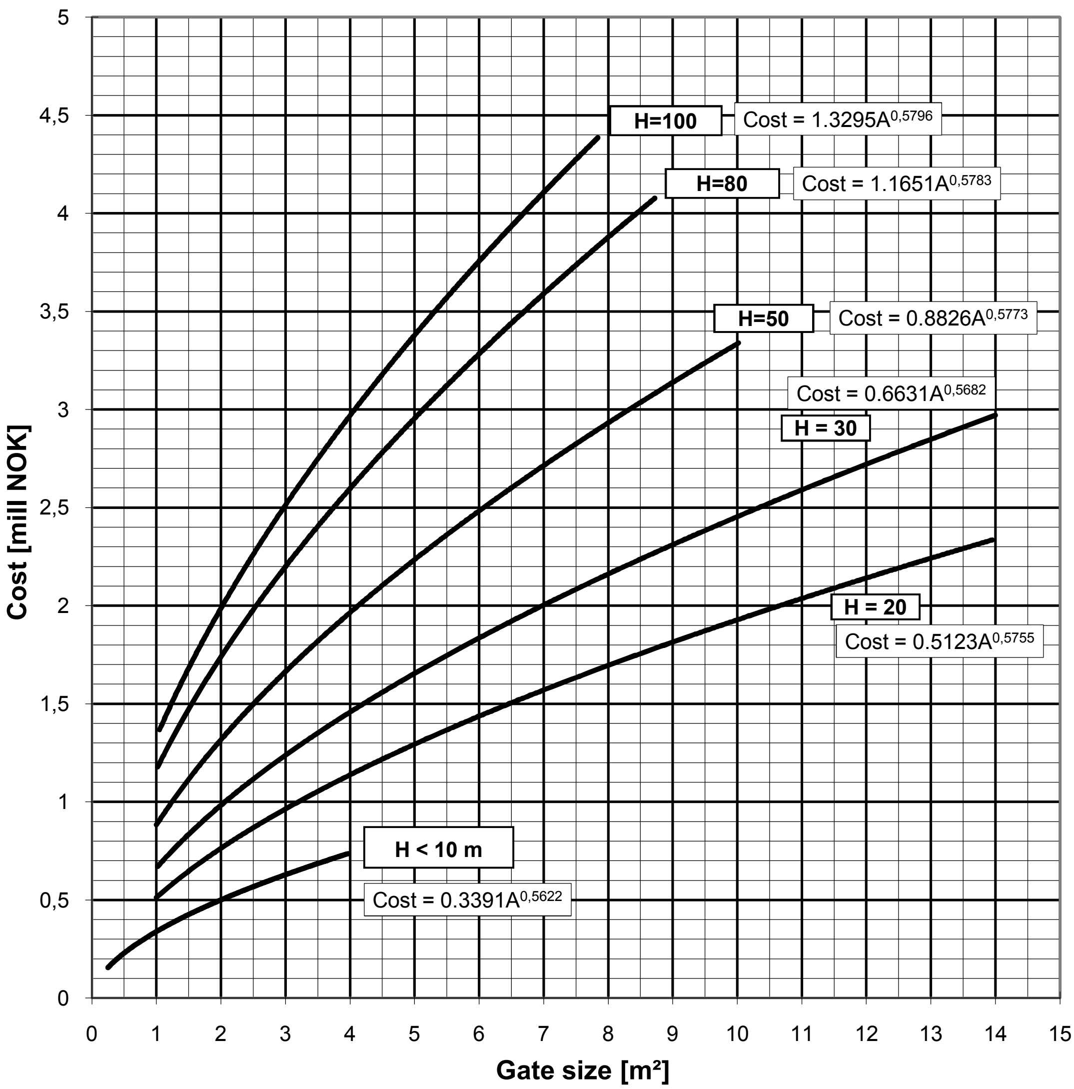
WHEEL GATES

Fig.M.3.C
1 January 2010



COMMENTS:

1. Price level January 2010
2. The length of the retraction rod has been set as equal to the design pressure
3. Standard gates have been assumed for a design pressure < 10 mwc

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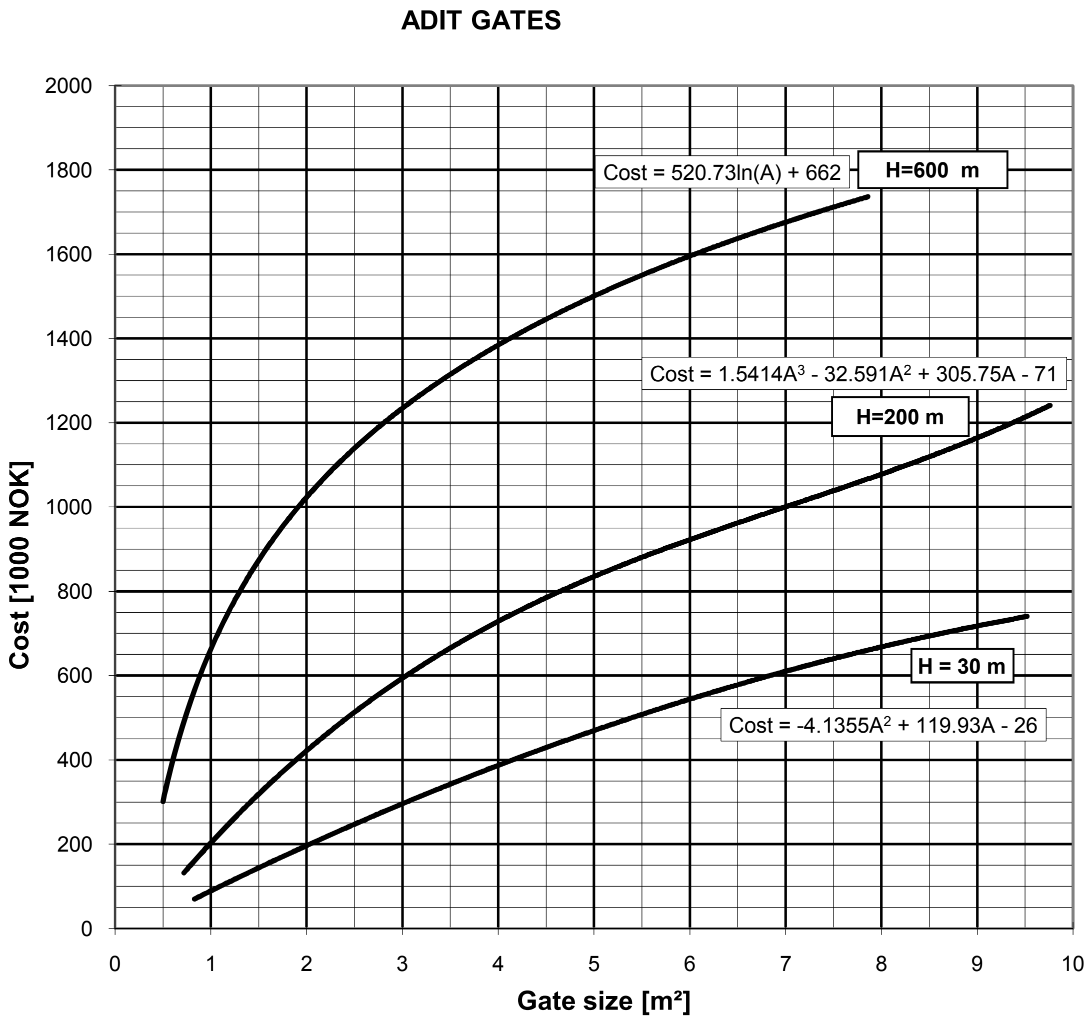
SLIDE GATES

Fig. M.3.D
1 January 2010



COMMENTS:

1. Price level January 2010

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ADIT GATES

Fig. M.3.E
1 January 2010

M.4 MISCELLANEOUS EQUIPMENT, FIG. M.4.A

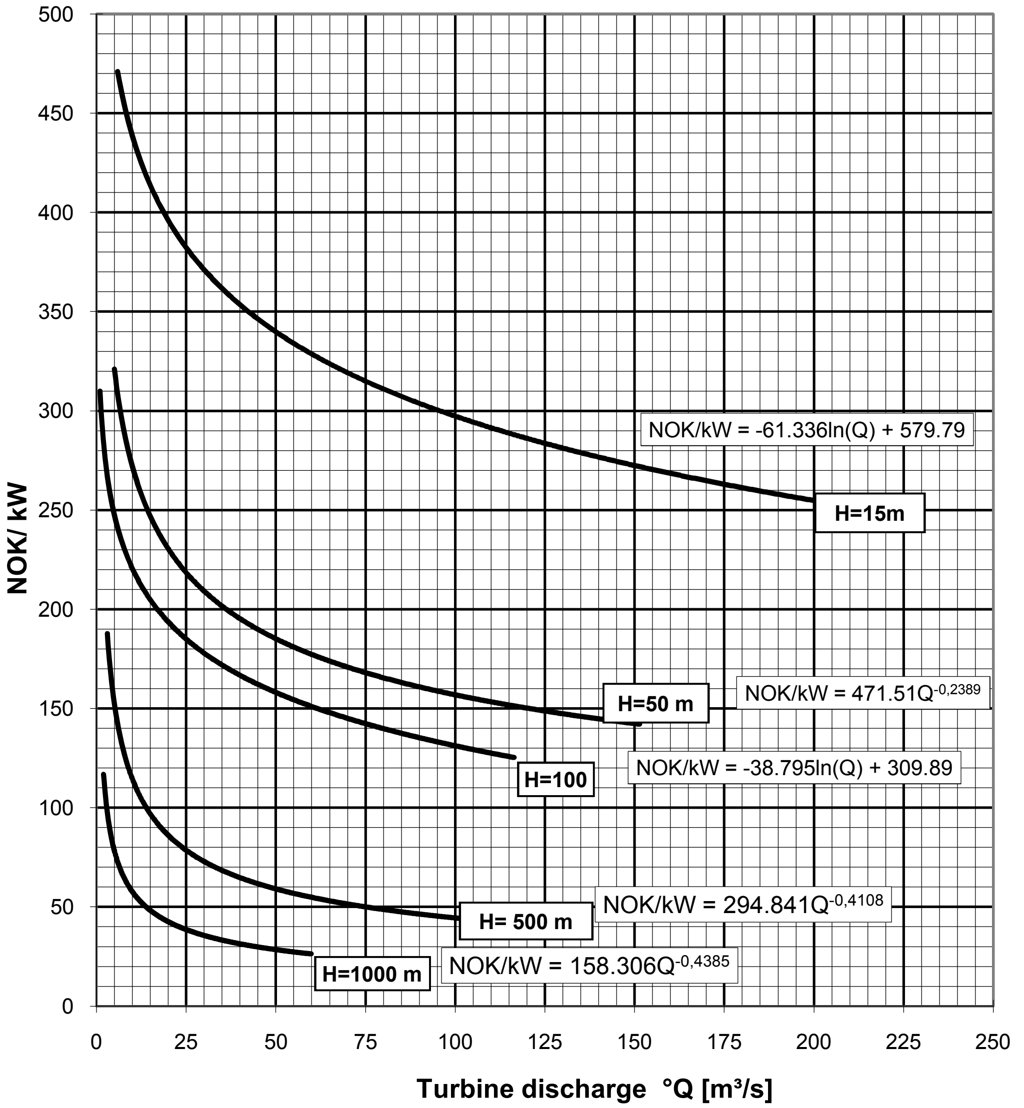
The price curves show the prices in NOK/kW for miscellaneous equipment which can be added up at an early stage of the planning, regardless of the turbine water flow in Q and the head H. With two power units in the same station, the price per kW will fall by about 25%.

The curves include intake thrashracks dimensioned for approx. 10 m differential pressure, 1 m/s speed and daylight opening between the bars adapted for the different turbine types. Heating, thrashrack rakes, etc. have not been included.

Where Francis and Kaplan turbines are an option, draft tube gate(s) have been included.

The curves also include a machine hall crane, cooling water system and drainage system.

For heads of less than 15 m, one can get a rough estimate of the price per kW by multiplying the price for 15 m by 15/He.



COMMENTS:

1. Price level January 2010

2. Costs include machine hall crane, cooling and drainage system and intake trash rack.

3. For vertical Francis and Kaplan turbines, a draft tube gate has been included.

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MISCELLANEOUS EQUIPMENT

Fig. M.4.A

1 January 2010

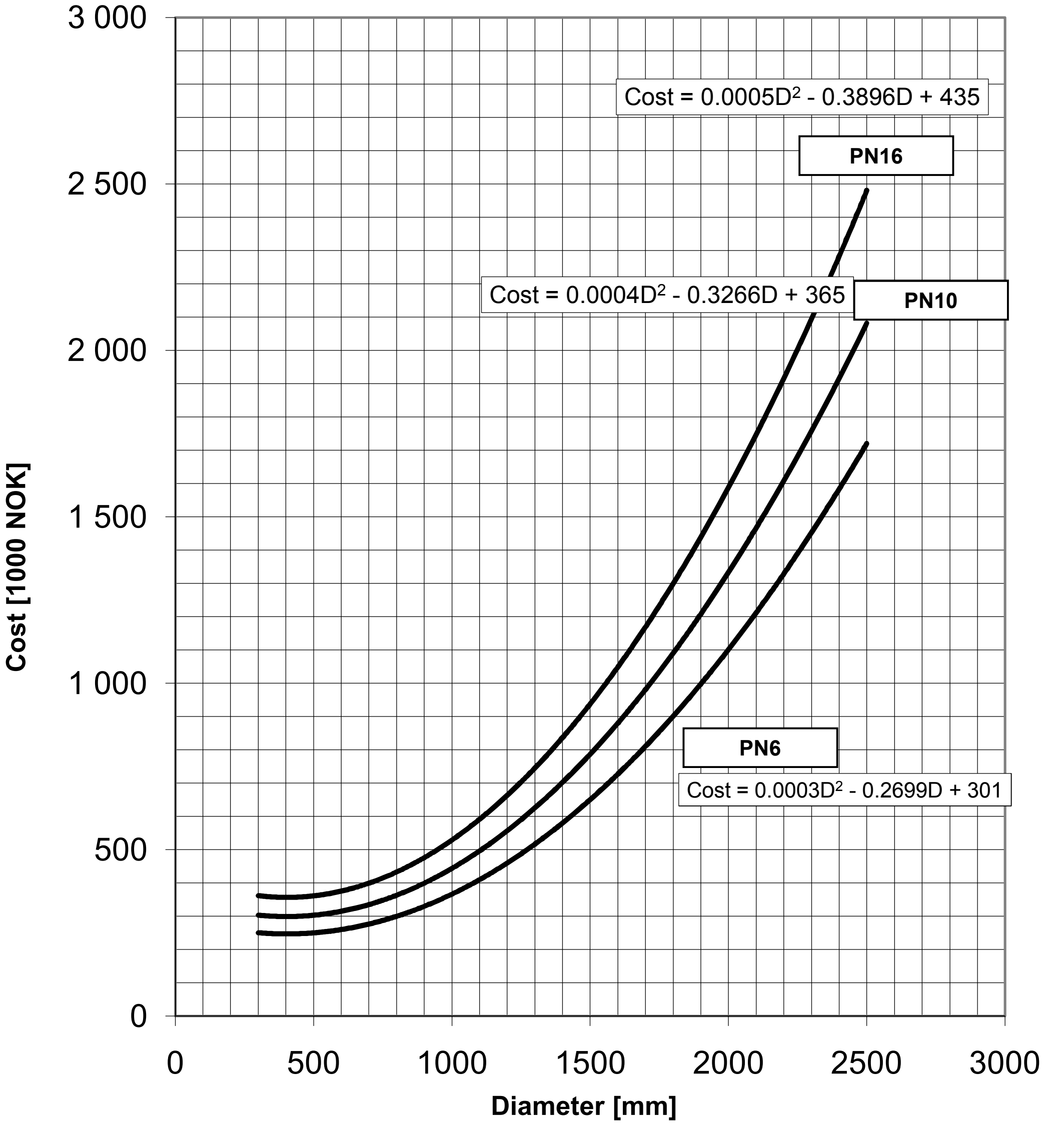
M.5 PENSTOCK EMERGENCY SHUTDOWN VALVE

The cost curves for penstock emergency shutdown valves are available in Fig. M.5.A.

Prices are stated in NOK, according to their diameter and design pressure.

The prices include a pipe rupture trigger device and a expansion joint.

The 2005 cost curves have not been adjusted.



COMMENTS:

1. Price level January 2010

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PENSTOCK EMERGENCY SHUTDOWN VALVES

Fig. M.5.A
1 January 2010

M.6 PIPES

M.6.1 Pipes in the open or buried, Fig. M.6.A and B

The price curves show supplier costs for pipes in the open, including installation but not building costs.

A shortage of data on steel pipe deliveries makes it difficult to assess price trends.
The 2005 cost curves (Fig. M.6.A and C) have therefore not been adjusted. This results in greater uncertainty regarding the costs of steel pipes.

The curves are basically based on two types of pipes: glass-fibre reinforced polyester pipes (GRP) and steel pipes.

The curves include the inlet cone at the upstream end, the bend at the downstream end and the outlet cone. The curves have been drawn for "longer" pipes, i.e. longer than approximately 150 m, with one bend with equipment per 150 m. For shorter pipes, or more bends, etc., costs will rise.

GRP pipes have been drawn in for the user area where they have proven to be economical. GRP pipes need twice as many foundation blocks as steel pipes, and the foundation blocks will be more expensive, while the fixed points become cheaper. The price of GRP pipes does not always follow the general price trends that apply for the other machine deliveries. 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 it is to have the option of internal corrosion protection in the future. Below approximately 500 mm and 500 m pressure, ductile cast-iron pipes might be an option.
b) *Dimension approx. 0.7 m < D < approx. 2 m, depending on the pressure*.
   Internal corrosion protection is no problem for this size, and there is quite a lot of price competition. Delivery is often based on spirally welded pipes.
c) *Large pipes,*
   where there is not so much price competition.

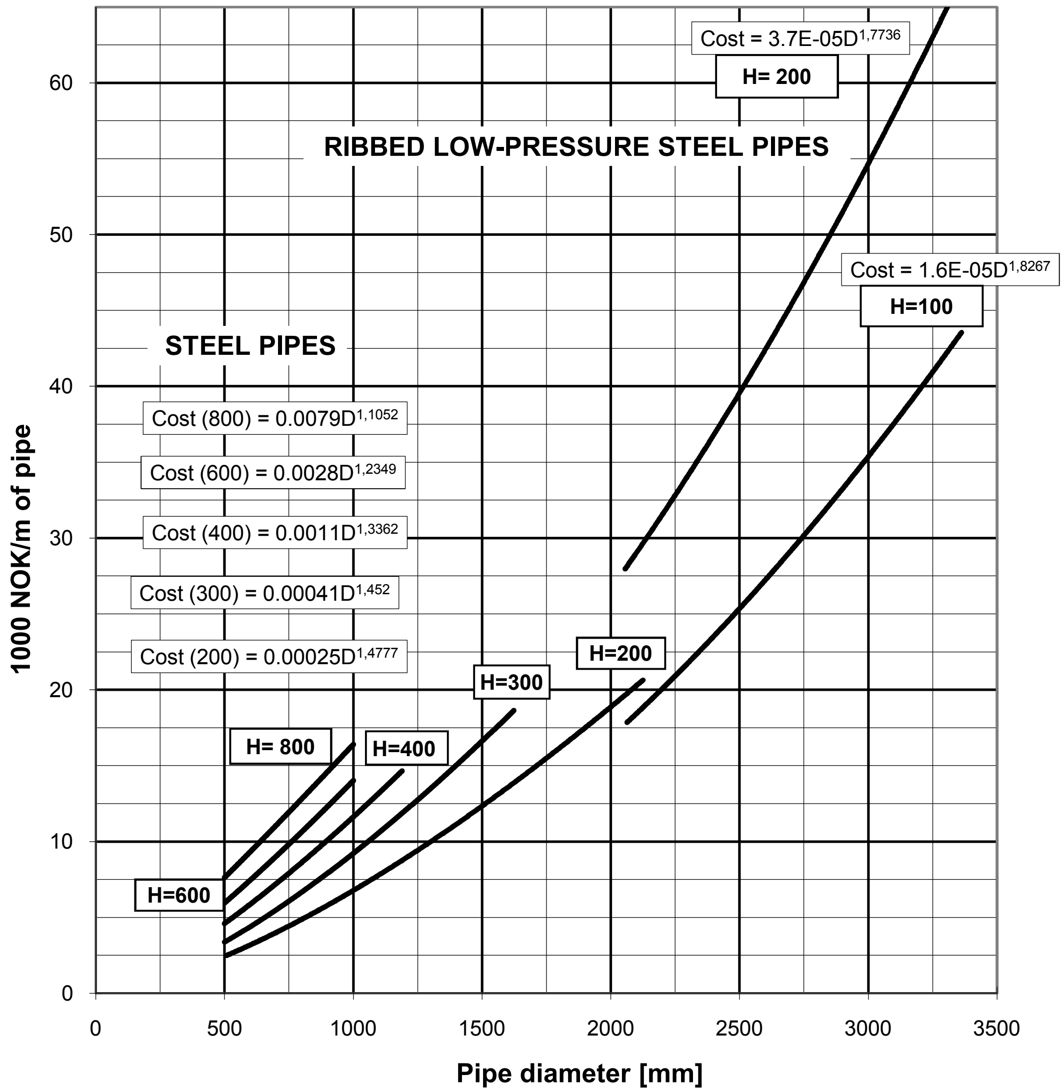
The same prices can be used for buried pipes as for pipes in the open.

Wooden pipes have been taken out of the price estimate in this revision, as this type of pipe is used very infrequently. It is therefore difficult to give a price estimate.

M.6.2 Steel-lined pressure shafts, Fig. M.6.C

The price curves give supplier costs for steel linings ready installed, according to an overall length of approximately 100 m, rock cover (in m) approximately 20% of the design pressure and with internal water pressure as dimensioning. If the external water pressure becomes dimensioning or the rock cover is less, prices will change.

The price curve includes an inlet cone with square/round transition, a bend at the downstream end and an outlet cone in front of the turbine.



COMMENTS:

1. Price level January 2010

2. H is the mean pipe pressure in m

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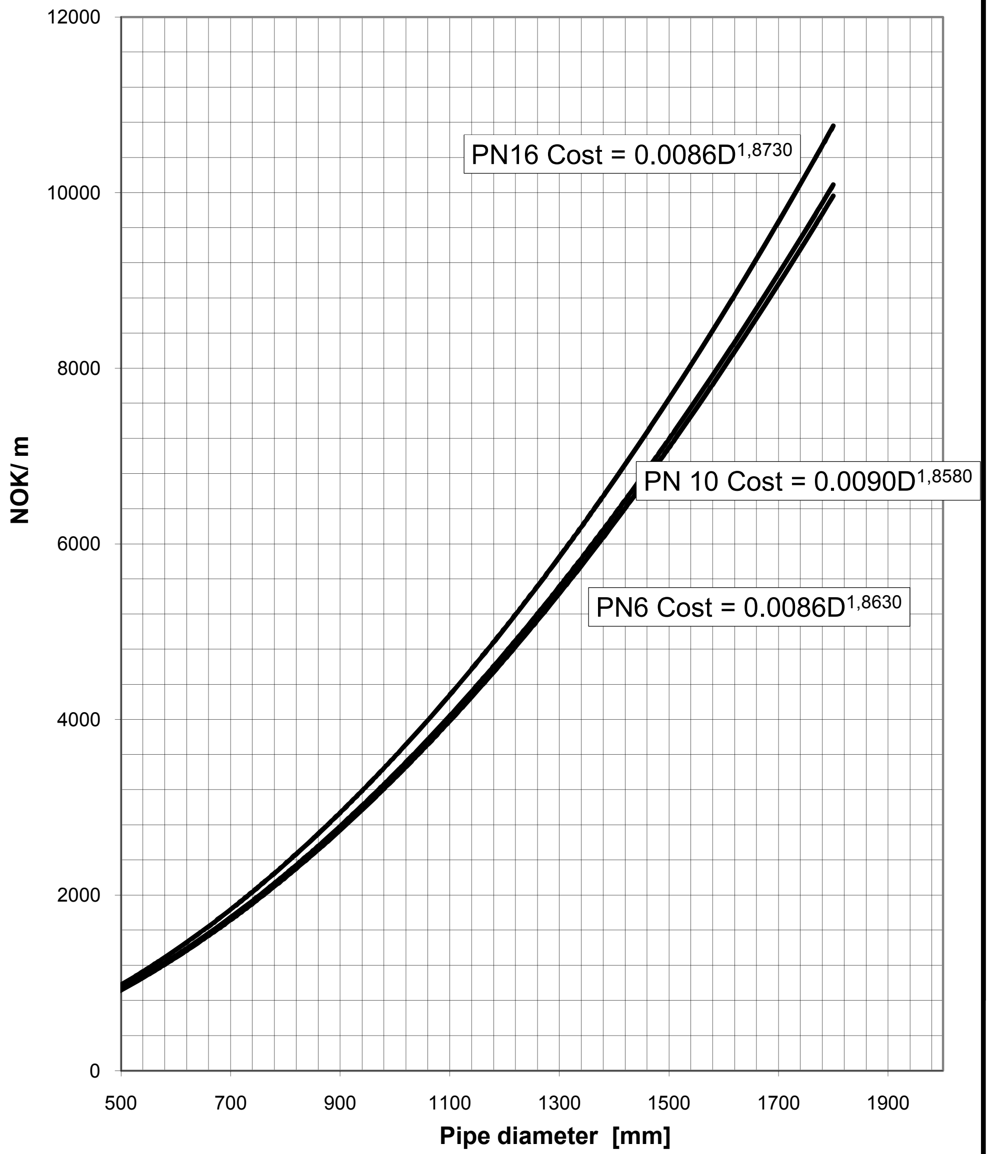
STEEL PIPES IN THE OPEN

Fig. M.6.A
1 January 2010



COMMENTS:

1. Price level January 2010

2. H is the mean pipe pressure in m

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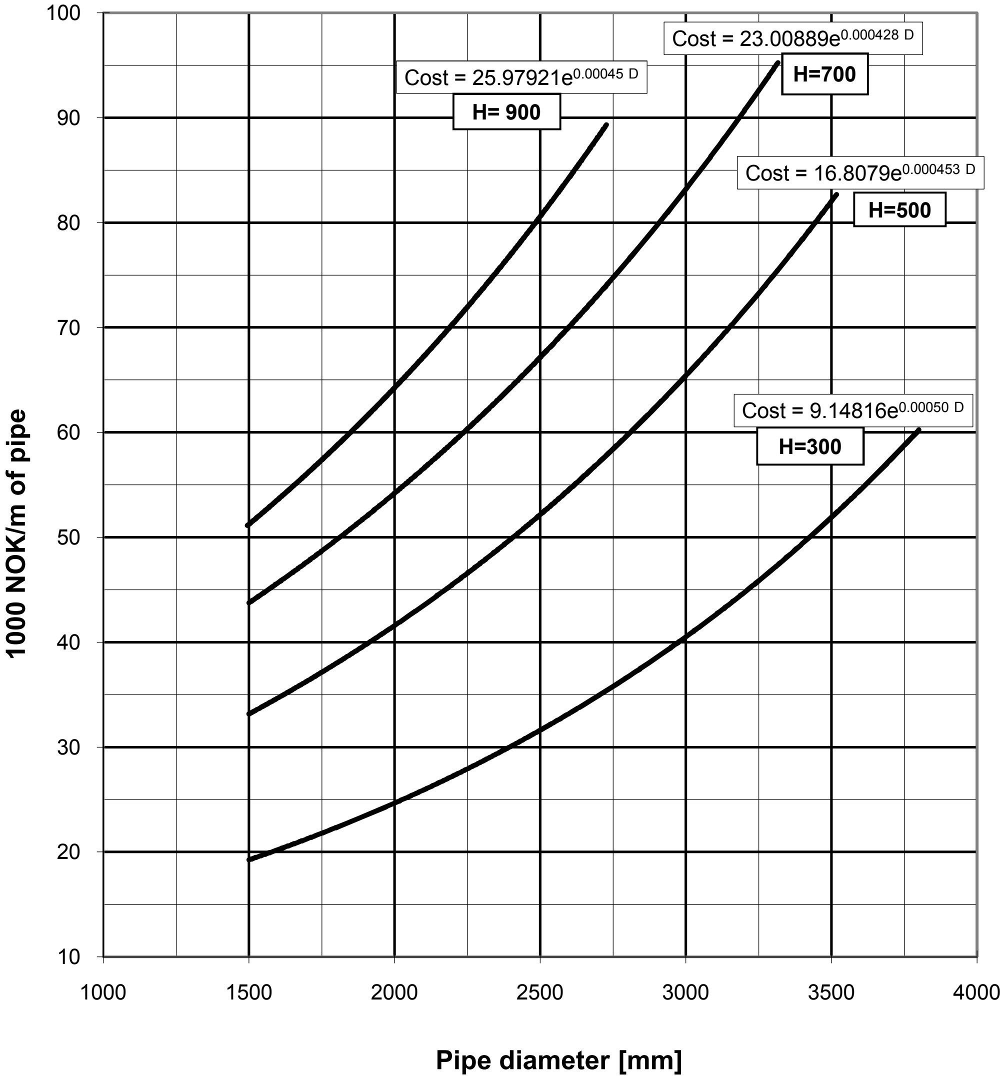
GRP PIPES IN THE OPEN

Fig. M.6.B
1 January 2010



COMMENTS:

1. Price level January 2010

2. H is the mean pipe pressure

3. The costs apply for an overall pipe length of about 100 m. For different pipe lenghts, adjust the price as follows:

Pipe length	Price factor
40 m	1,1
600 m	0,9

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EMBEDDED STEEL PIPES

Fig. M.6.C
1 January 2010

Denne serien utgis av Norges vassdrags- og energidirektorat (NVE)

Utgitt i Veilederserien i 2012

Nr. 1 Slipp og dokumentasjon av minstevannføring for små vassdragsanlegg med konsesjon (19 s.)

Nr. 2 Cost base for small-scale hydropower plants (< 10 000 kW) (90 s.)

Nr. 3 Cost base for hydropower plants (182 s.)

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