 Input paper: [[1]](#footnote-1) ENG5-9.25

Input paper for the following Committee(s): check as appropriate Purpose of paper:

**□** ARM **□X** ENG **□** PAP **□X** Input

**□** ENAV **□** VTS **□** Information

Agenda item [[2]](#footnote-2) 9

Technical Domain / Task Number 2 TD#1 - Light and vision physics, Visual Signalling / 26

Author(s) / Submitter(s) Pärtel Keskküla

Finnish guidelines one leading lines

# Summary

This is translation of Finnish guidelines on design of leading lines “Vesiväylien linjalaskennan perusteet”. The guidelines are updated version of the guidelines originally compiled by Rolf Bäckström ("Linjalaskennan perusteet", Merenkulkulaitos, 30.11.1998), updated by Sami Lasma.

The guidelines present calculation methods for dimensioning of the towers, daymarks, lights and light reflectors of leading marks.

# Action requested of the Committee

The Committee is requested to:

1. Review the input paper and consider if any of parts or concepts from it could be included in the updated IALA Guidelines on Design of Leading Lines.

1. finnish guidelines on leading lines

2-2013

Finnish Transport Agency Guidelines

# principles of calculation of leading lines

Translated by Pärtel Keskküla

Estonian Maritime Administration

Valge Str. 4, 11413 Tallinn, Estonia

Phone: +372 620 5681

E-mail: [partel.keskkyla@vta.ee](mailto:partel.keskkyla@vta.ee)

Web: [www.vta.ee](http://www.vta.ee)

# Contents

[Finnish guidelines one leading lines 1](#_Toc462319727)

[1 Summary 1](#_Toc462319728)

[2 Action requested of the Committee 1](#_Toc462319729)

[ANNEX A finnish guidelines on leading lines 2](#_Toc462319730)

[principles of calculation of leading lines 3](#_Toc462319731)

[Contents 4](#_Toc462319732)

[List of Figures 4](#_Toc462319733)

[List of Tables 5](#_Toc462319734)

[1. input parameters 6](#_Toc462319735)

[1.1 Data on the terrain around the leading marks 6](#_Toc462319736)

[2. principles of calculation 7](#_Toc462319737)

[2.1 Observing height 7](#_Toc462319738)

[2.2 Dimensions of the daymarks 7](#_Toc462319739)

[2.3 Lights 8](#_Toc462319740)

[2.3.1 Night lights 8](#_Toc462319741)

[2.3.2 Day lights 9](#_Toc462319742)

[2.4 Reflectors 10](#_Toc462319743)

[2.5 Determining minimum vertical angles 10](#_Toc462319744)

[2.6 Other initial data and limiting conditions 11](#_Toc462319745)

[2.7 Calculation of angles and heights 11](#_Toc462319746)

[2.8 Final optimisation 12](#_Toc462319747)

[3. control calculations 12](#_Toc462319748)

[4. the data for the constructor 14](#_Toc462319749)

# List of Figures

**Ei leia illustratsiooniloendi kirjeid.**

# List of Tables

**Ei leia illustratsiooniloendi kirjeid.**

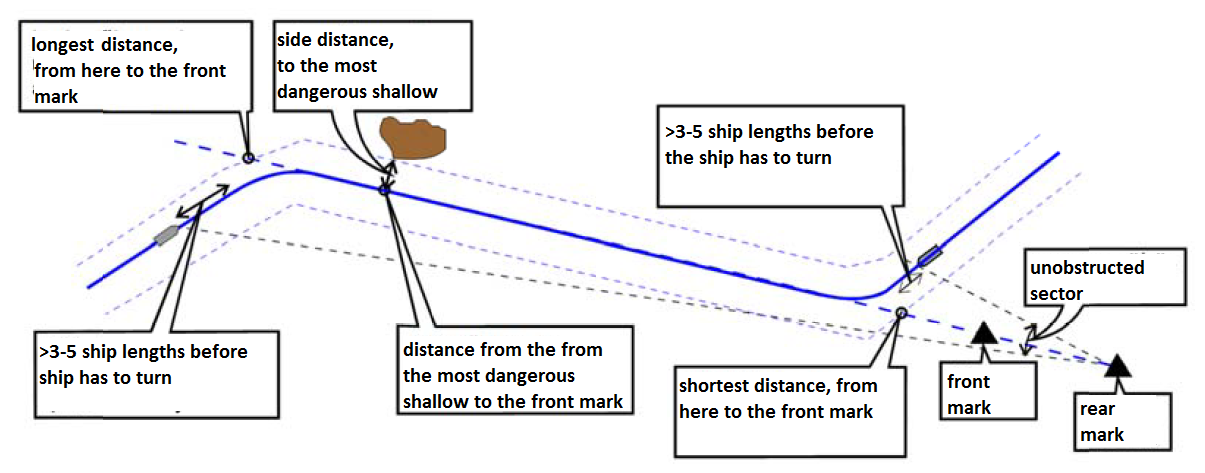
# input parameters

Design of leading marks begins with defining initial parameters, most of which are derived from fairway design charts. Additional data is derived from topographic maps and field surveys. First, the following basic data is determined (figure 1):

* Distance between the far end of the useful segment and the front mark. The distance is measured from the farther side of the previous section of the fairway, or longest distance (dk).
* Distance between the near end of the useful segment and the front mark. The distance is measured from the nearer side of the previous section of the fairway, or shortest distance (dl).
* Distance between the most dangerous shallow and the front mark.
* Distance between the most dangerous shallow and the centre line of the fairway.

Most dangerous is the shallow at which the horizontal angle between the centre line of the fairway and the shallow is smallest, when observed from the front mark.

* The heights of the locations of the marks from the sea level.

Figure 1:1 Fairway design

## Data on the terrain around the leading marks

The terrain is surveyed in the sector that is formed if you imagine that the marks are visible at least 3…5 of ship lengths before the start of the turning, when ship approaches to the fairway section marked by the leading line (Figure 1:1). Aim of the survey of the terrain is to get sufficient data for the design and construction already on the first time. It is, however, important to look only for important things so that the survey will not expand unduly. The surveyors have to have some experiences with design of leading lines in order to get necessary “whole picture”.

When determining locations for construction of mark the first choice are the locations where construction is the cheapest when considering the total costs (higher place, strong ground, etc). Also access for service and the effect of surroundings on the heights of the marks have to be considered. One has to try to find the solution where surrounding vegetation has to be cut or trimmed as little as possible both at the time of construction and afterwards.

Access for service has to be designed so that landing is possible with dry feet and the walking on the land is as short and easy as possible.

When surveying the heights of the surrounding landscape (incl trees) it has to be borne in mind that daymarks of both marks have to be fully visible above the landscape in front of and between the marks in both far and near end of the useful segment of the leading line. Furthermore, the rear daymark is to be visible so that at least half of it is visible above the forest or landscape on the background when observed at the far end. If cross sections of the terrain with locations of the leading marks can be compiled during the terrain survey, they can facilitate the designing (figures 3:1, 3:2).

With data about the terrain also the data about the type and the density of the forest is collected, e.g is it a precious forest. In principle the marks are not intended to be located in places near summer cottages and beaches, and in any case so that the potential compensations are minimal.

# principles of calculation

The principles of calculation of leading lines are presented shortly in the following. There are many variables and the optimisation of the figures is so laborious task that it is recommended to be done only by a computer.

## Observing height

Observing height is usually taken 5 m on commercial fairways at sea and 2 m at inland fairways and small vessel routes. If the fairway is used by both commercial vessels and unusually heavy small vessel traffic which cannot use alternative routes, judgement should be used when choosing the observing height. It must be remembered that smaller observing height means usually higher construction costs.

If the observing height of the vessels using the leading line is known exactly, custom heights may be used. In such cases, usually the lowest height is chosen.

## Dimensions of the daymarks

Dimensions of the daymarks are calculated with the following formulas:

K = D × 0.00052 + v1 (2.2:1)

L = D × 0.0004 + v2 (2.2:2)

where

k = height of the daymark (m)

l = width of the daymark (m)

d = observing distance (m)

v1, v2 = constants

Observing distances:

* Front mark: d = longest distance (dk)
* Rear mark: d = longest distance (dk) + distance between marks (dR)

The constants:

* Commercial fairways at sea: v1 = 1.9, v2 = 1.4
* Inland fairways and small vessel routes: v1 = 1.3, v2 = 0.9

On commercial fairways at sea the minimum dimensions of a daymark are k × l = 4.5 × 3.0 m2 and on inland fairways and small vessel routes 1.5 × 1.0 m2. In special cases rear daymark can be significantly higher. The practical upper limit for daymark size is ca 100 m2.

A daymark consists of three vertical stripes of the same width, the middle of which is white or yellow and lateral ones red, or vice versa.

## Lights

The ranges of the lights published in list of lights are nominal ranges. Nominal range of a leading light is the range at which the light produces threshold illuminance E at the observer’s eye:

* 1×10-6 lx (night lights)
* 1×10-3 lx (day lights)

Nominal range is calculated using the effective intensity of the light source which is obtained by considering the light character, weakening of the light due to filtering factors (colour filters, outer glazing), and effect of possible service factor. Also it is assumed that the meteorological visibility is 10 NM or 18 520 m. Determining the effective intensity is not covered in this guideline.

Effective intensity is calculated by the formula:

Ie = d2 × E / 0.05d/18520 (2.3:1)

For threshold illuminance the formula is:

E = Ie × 0.05d/18520 / d2 (2.3:2)

The aim is to get the front and the rear lights to be visible with equal brightness at the far end of the useful segment of the leading line.

In selecting the lantern also light character, colour, sufficient horizontal divergence (assessed with the same principle as visibility sector in terrain surveys) and energy consumption are taken into account.

## Night lights

It is started with calculation of the intensity of the front light with the formula (2.3:1):

* Minimum light intensity, if E = 1×10-6 lx and d = longest distance (dk)
* Maximum light intensity, if E = 1.0 lx and d = shortest distance (dl)

For the front light the lantern is chosen which has the intensity between these two values. The E value of the front light with the selected lantern at the far end of the useful segment (E1) is calculated with the formula (2.3:2).

Next the intensity for the rear light is calculated with the formula (2.3:1):

* Light intensity when E = E1 and d = longest distance (dk) + the distance between the marks (dR)
* Maximum light intensity when E = 1.0 lx and d = shortest distance (dl) + the distance between the marks (dR)

The lantern is chosen for the rear light which has the intensity as near as possible to the calculated value and in any case less than the maximum intensity. Lastly E is calculated for the rear light at far end (E2) of the useful segment with the selected lantern.

***Background illuminance***

Background illuminance is taken into consideration in calculation of the illuminances as it affects considerably observing of the leading lights at night. Depending on the intensity of the background illuminance the coefficients for threshold illuminance in the table 2.3:1 are used.

|  |  |  |  |
| --- | --- | --- | --- |
| **Intensity of background illuminance** | **Coefficient** | **Threshold illuminance E**  **(10-6 lx)** | **Description** |
| None | 1 | 1 | Only other lighted AtoNs or no lights at background |
| Minor | 2 | 2 | Sparse or dim lights. E.g residential area |
| Substantial | 10 | 10 | Many (hundreds) and bright lights. E.g a city, parking area, highway, factory, big port or factory area. |

Table 2.3:1 Background illuminance dependent coefficients for threshold illuminance for night lights

If needed bigger coefficients can be used. IALA recommends coefficient 10 for minor background illuminance and 100 for substantial background illuminance. So big coefficients can be used only for quite short leading lines. Also possibility of glare must be considered.

## Day lights

It is started with calculation of the intensity of the front light with the formula (2.3:1):

* Minimum light intensity, if E = 1×10-3 lx and d = longest distance (dk)

The lantern is chosen for the front light which has the effective intensity at least equal to the minimum intensity. The E value of the front light with the selected lantern at the far end of the useful segment (E1) is calculated with the formula (2.3:2).

Next the intensity of the rear light is calculated with the formula (2.3:1):

* The intensity if E = E1 and d = longest distance (dk) + the distance between the marks (dR)

The lantern is chosen for the rear light which has the intensity as near as possible to the calculated value. At last E is calculated for the rear light at far end of the useful segment (E2) with the selected lantern.

As a day light’s intensity is much higher than a night light’s intensity, for avoiding glare, systems should be used where intensity of the light changes automatically between the day and night modes.

***Meteorological conditions***

Meteorological conditions as well as orientation of the leading line can affect the perception of day lights. Range of day lights in different conditions can be estimated on the basis of threshold illuminances in table 2.3:2. Smaller values than E = 1×10-3 lx should not be used in calculations. Higher values can be used for ensuring visibility, if needed.

\* The sky is almost fully covered with clouds (90-100%), no isolated clouds seen (overcast sky).

|  |  |  |
| --- | --- | --- |
| **Meteorological conditions** | **Background illuminance**  **(cd/m2)** | **Threshold illuminance E**  **(10-6 lx)** |
| Very dark cloudy sky\* | 100 | 0.013 |
| Dark cloudy sky\* | 200 | 0.024 |
| Normal cloudy sky\* | 1000 | 0.107 |
| Bright cloudy sky or clear sky away from the direction of sun | 5000 | 0.506 |
| Bright clouds (illuminated by sun) or clear sky near the direction of sun | 10 000 | 1 |
| Very bright clouds | 20 000 | 1.98 |
| Glaring bright clouds | 50 000 | 4.91 |

Table 2.3:2 Background illuminance dependent coefficients for threshold illuminance for night lights

## Reflectors

Reflectors are used as alternatives for light at small vessel routes and other less important fairways. They have importance on lighted fairways as well, e.g. in case of lantern defects. The leading line is still usable if the user has a search light. It is assumed that a boat has a search light with the intensity of ca 10 000 cd and a ship has one with the intensity of ca 100 000 cd.

Minimum area of a reflector is calculated with the formula:

A = Ed4 / (IR × 0,052d/18520) (2.4:1)

For threshold illuminance the formula is

E = AIR × 0,052d/18520 / d4 (2.3:2)

where

A = surface area of the reflector (m2)

E = threshold illuminance (lx)

D = observing distance (m)

I = intensity of the light of the search light (cd)

R = retro-reflective coefficient of the reflecting film (lx/m2/cd)

In principle the calculations are made as for the lights, but as the problem is mostly achieving sufficiently strong reflection calculation of maximum values is not necessary. Reflecting film is placed so that it covers ¾ of the middle stripe, in which case its area is ¼ of the area of the whole dayboard. The reflector of the front mark starts from the lower edge of the dayboard and the rear mark’s reflector starts from the upper edge of the dayboard (so the reflectors will not blur which hinders following the line). Reflection decreases very fast with the increase of the distance. Maximum distance is ca 4000 m even with powerful searchlights, but the distances are 0…2500 m in practice. The colour of the reflector is always white. When reflecting areas are determined, the final E values are calculated for both marks.

## Determining minimum vertical angles

For both lights and reflectors minimum vertical angles are calculated at the far end of the useful segment. Vertical angle must be at least so large that will avoid blurring of the lights.

 (2.5:1)

where

γm = minimum vertical angle (rad)

E2 = illuminance in the observer’s eye in the far end for the rear light (lx)

E1 = illuminance in the observer’s eye in the far end for the front light (lx)

E+ = bigger of E1 and E2 (lx)

If the result is less than 1.5 mrad, γm = 1.5 mrad is chosen for the result.

## Other initial data and limiting conditions

The following are other initial data and limiting conditions:

* The height of the lower edge of a daymark must be at least 1.0 m, so that snow, bushes etc. will not cover the daymark too easily.
* Height of the front light from the ground must be at least 3.5 m (sea fairways) or 2.5 m (inland fairways). The height must, however, be as small as possible, as this amplifies at the rear light.
* The front light must not be more than 0.5 m higher than upper edge of the daymark, or lower than the lower edge of the daymark.
* Rear light is usually 0.5 m higher than the upper edge of the daymark, but it can be lower, however, not lower than lower edge of the daymark.
* At least 3 m (or the whole height, if this is lower) or 66% of the rear daymark (whichever is smaller) must be visible above the front daymark in the near end.
* Vertical angle between the daymarks in far end (γPK) is at least 0.2 mrad, but not more than 1.0 mrad.
* In general, leading lines longer than 12 000 m are not designed, but other alternatives are considered.
* K-number is set between 1.5… 4.5, if possible.
* Whole front daymark is to be visible above the landscape both in front of and between the marks in both near and far ends.
* Whole rear daymark is to be visible above the landscape both in front of and between the marks in far end. In near end as much of the rear daymark must be visible above the front daymark as is hidden behind it.
* Rear daymark is placed so that at least half of it is visible above the background landscape in far end.
* Sight obstructions are to be considered also for approaching the fairway section so that safe turning to the line is possible.
* In sea areas maximum 4 m and on inland waters maximum 1 m waves are taken into account as sight obstructions.
* When designing leading lines for harbours also the obstructing effect of moored ships must be considered. Obstructions can also be behind the rear mark. At least half of the rear daymark must be visible above the obstructions or the forest.
* If the longest distance is less than 50 m, it is taken 50 m.
* Geographic range is…

Lower edge of the front daymark with the minimum height of 1.0 m begins to be below the horizon from the distance ca 9300 m if the height of the observer is 2 m, and at the distance 12 400 m if the height of the observer is 5 m. If the line is longer than this, front daymark must be risen above the minimum value.

* For unlighted day leading lines the same limiting conditions and calculating principles are applied, but lights and reflectors does not have to be taken into account.

## Calculation of angles and heights

All heights and vertical angles are calculated with the same formula modified in three ways. It is used for calculating both lights and upper and lower edges of the daymarks.

Height of the nearer object as a function of the distance and the height of the further object:

 (2.7:1)

Height of the further object as a function of the distance and the height of the nearer object:

 (2.7:2)

Vertical angle:

 (2.7:3)

where

d1 = observing distance to the nearer object (m)

d2 = distance between the objects (m)

H1 = height of the nearer object (m)

H2 = height of the farther object (m)

γ = vertical angle (rad)

Hk = observing height (m)

## Final optimisation

When the observing height is determined and size of daymarks, intensities of the lights, area of the reflectors and minimum angle are calculated, the calculations proceed with optimisation.

First the minimum heights of the masts are determined, in general it is height of the daymark + 1 m, and minimum height of the front light 3,5 or 2,5 m (see above, which one). In determining minimum height also terrain and limiting conditions are taken into account with the formulas (2.7:1) and (2.7:2).

The real optimisation starts with ensuring that the lower edge of the front daymark is visible above the horizon. The lower edge is risen, if necessary. In this stage also possible waves are taken into account so that lower edge of the front daymark is visible in the far end despite of waves (2.7:1).

Next the height of the rear light is determined so that minimum vertical angle is achieved (2.7:2).

After that it is checked that the rear daymark is visible in the extent necessary (2.7:2). If the condition cannot be satisfied without raising the daymark, the daymark is risen. New height for the front light (2.7:1) is determined taking into account the limiting conditions. In case the rear daymark is already quite high due to height of the terrain or other reasons, the front mark and the front light respectively are risen so that the conditions are satisfied (2.7:1). There can be occasions where differences in heights of the terrain are big and the smallest distance is small. Then the vertical angle between the daymarks in the far end becomes quite big (2.7:3). This is fixed with extending the rear daymark downwards so that the vertical angle between the daymarks in the far end is <1 mrad.

Optimising stage may need many rounds of calculations before satisfying compromise is found. Harbour leading lines are especially laborious.

# control calculations

For the solutions from the chapter 2 K-number is calculated.

First the safety angle is calculated with the formula:

If γY≤5.0×10-3 rad:

 (3:1)

If 5.0×10-3 ≤ γY ≤ 20.0×10-3 rad:

 (3:2)

(3:3)

where

γY = vertical angle between the light at the most dangerous shallow (formula 2.7:3) (rad)

ΘD , Θ’1 , Θ’2 = safety angle (rad)

The final safety angle ΘD is the biggest of Θ’1 and Θ’2.

Safety distance or distance that is left to the most dangerous shallow at the moment the line is seen “open” (the lights are not on the line) is calculated with the formula:

 (3:4)

where

S = safety distance (m)

Y = distance from the centre line of the fairway to the most dangerous shallow (m)

ΘD = safety angle (rad)

dY = distance from the front mark to the most dangerous shallow (m)

dR = distance between the marks (m)

The safety distance is assessed so that there must be e.g at least 0.5…2.0 ship widths left between the ship and the shallow, considering that the observer stands in the middle of the vessel. If the safety distance is too small, the leading line can be essentially improved only by increasing the distance between the marks or removing the shallow.

K-number is a number, or actually a quality factor that shows how sensitive the leading line is in relation to the width of the fairway. It is calculated with the formula:

 (3:5)

where

K = K-number

ΘD = safety angle (rad)

γΥ = vertical angle between the light at the most dangerous shallow (rad)

S = safety distance (m)

Y = distance from the centre line of the fairway to the most dangerous shallow (m)

If the K-number is below 1.5 the line is too “lazy”, if it is above 4.5 the line is too “sensitive” in relation to the width of the fairway. The aim is to get the value between these two numbers. This happens mostly by adjusting the distance between the marks. Due to geographic restrictions changing of the location is not always possible and worse K-number has to be accepted. K-numbers less than 1.5 are a safety risk.

In the end again the following vertical angles are calculated for checking with the formula 2.7:3:

* γH, or angle between the lower edge of the front daymark and the horizon seen from the far end of the useful segment (must be >0 mrad).
* γK, or the angle between the lights seen from the far end (must be >1.5 mrad)
* γL, or the angle between the lights seen from the near end (must be >0.75 mrad)
* γPL, or the angle between the lower edge of the front daymark and the place on the rear daymark that is 3 m or 66% lower from the upper edge (the smaller value is chosen); angle must be >0 mrad.
* γPK, or the angle between the upper edge of the front daymark and the lower edge of the rear daymark seen from the far end (must be less than 1.0 mrad but more than 0.2 mrad).

At the figures 3:1 and 3:2 the abovementioned angles can be seen in graphic mode for both daymarks lights. At obstruction (shallow) the lines are omitted for clarity. They are same as seen from the far end but drawn from the location of the obstruction.

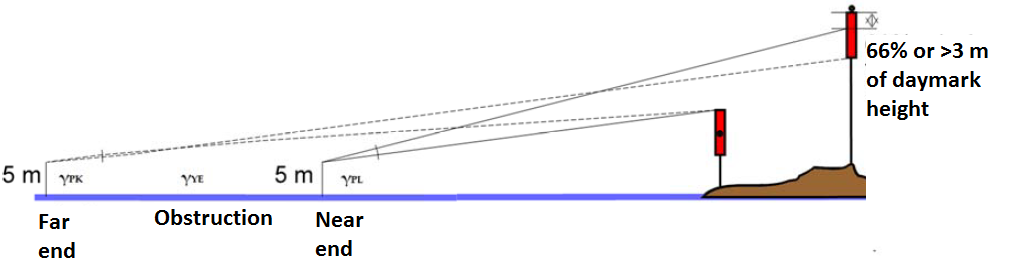


Figure 3:1 Profile view of daymarks

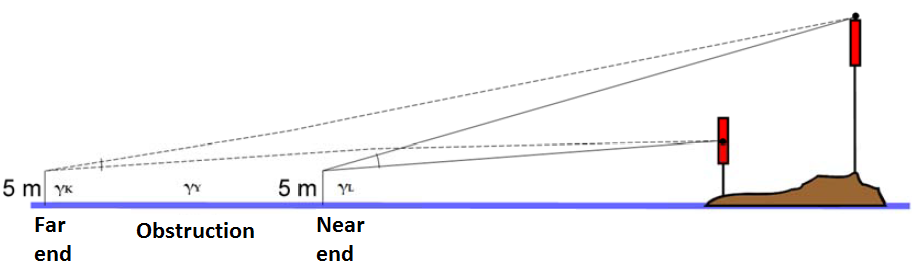


Figure 3:1 Profile view of leading lights

# data for builder

For building leading marks the following numbers and data are needed:

* Dimensions of the daymarks
* Heights of the masts from the ground and the sea level
* Heights of the lights from the ground and the sea level
* Size of the reflectors
* Statement on the trees to be cut
* Character of soil in the construction sites
* Statement and possibly initial contract for renting the land for aids to navigation
* Initial coordinates and data on fixed points

1. Input document number, to be assigned by the Committee Secretary [↑](#footnote-ref-1)
2. Leave open if uncertain [↑](#footnote-ref-2)