APPROACH LIGHTING SYSTEM DESIGN GUIDE

FOR

EXEL MASTS

FOREWORD

Background

The approach lighting is a part of a system aimed to give to an approaching aircraft the required information for a safe landing. The positioning of the approach lights is tightly regulated taking into account both the visibility requirements and the local ground contour. The internationally approved standards concerning the approach lighting systems, set by ICAO, have been published in the Annex 14 Vol I, International Standards and Recommended Practices; Aerodromes. According to the standards, the masts used for placing the lights to their correct positions should be frangible upon impact.

This design guide has been written to assist you with the creation of an approach lighting system that will employ frangible Exel masts. The guide has been specifically designed so as to combine the essential requirements and recommendations governing the design of the lighting system with the determination and selection process of the required Exel masts. For an optimum lighting system these two need to be considered simultaneously. The guide does not, however, duplicate all the information provided in Annex 14 and you will find it necessary to refer to Annex 14 from time to time during the design process. Furthermore, this guide has been made as complete as possible, including all information relevant to the Exel masts, that is likely to be required during the design process.

Using this guide

The basic process is described both in a form of a condensed guide and detail guide. The detail guide is targeted primarily for those designers not previously involved in the design of approach lighting systems, but it is also likely to be highly useful to experienced designers not familiar with the Exel mast concept. The condensed guide is meant to be a quick reference for the designers having previous experience of designing approach lighting systems according to the international regulations and combining the system with the use of Exel masts.

Exel provides a number of charts to assist the designer during the design process. Also the final table where the essential data and mast selection is tabulated has been provided. It is hoped that once the designer has briefly familiarised himself or herself with the overall process, these tables and charts, as well as the guide itself, will serve to make the whole process as simple as possible. The local Exel representative will be happy to help with any further questions.

TABLE OF CONTENTS:

1. BASIC REQUIREMENTS FOR APPROACH LIGHT MASTS

1.1 Structural Performance

A long service life is expected from the approach light masts. During this life time the masts have to withstand the wind loads common to all mast type structures. In addition, the jet blast loads caused by the aircraft jet engines have to be considered, as they place additional demands on the stiffness and strength of the masts. The loading to which the Exel masts are assumed to be subjected during their life time have been reviewed in more detail in chapter 4. The minimum stiffness requirement is, however, very simple: the maximum allowed deflection of the light beam during the operation is ±2° in vertical direction and ±5° in horizontal direction.

In the case of Exel masts, these stiffness and strength requirements have been met by using composite materials (glass fibre reinforced polyester), renown for their good stiffness-to-weight and strength-to-weight ratios. Higher masts also utilise the highly efficient lattice structure. In addition to the full scale tests with complete masts, all the structural composite components have been carefully selected and thoroughly tested in order to verify the performance of each individual component.

1.2 Frangibility

Together with the stiffness and strength criteria, a further, and apparently contradictory requirement, is made of the approach light masts: if accidentally impacted by a low flying aircraft they have to break down easily with minimum damage to the aircraft, i.e. be frangible. In practice the word frangible is interpreted so that the damage caused to the aircraft does not reduce the load bearing capability of the aircraft structures. It is also required that the amount of energy absorbed during the impact is small enough so as not to be able to affect the aircraft flight path and manoeuvrability. The failure mode of the mast should not impair the aircraft in any way either, i.e. the mast structure should collapse completely.

Despite their stiffness and strength the Exel masts are brittle in the event of a sudden impact. This brittle behaviour, which is most favourable considering the frangibility, is due to the nature of the composite materials and the bonded lattice structure employed in their construction. Because of these properties, an Exel mast breaks down completely upon impact, while the damage caused to the aircraft is restricted to limited skin areas. The good stiffness-to-weight ratio of the composite lattice structure makes the Exel masts light, which in turn results in small energy absorption during the impact. In regard to aviation safety, the frangible Exel masts can be considered a most favourable solution.

The frangible behaviour of the Exel masts has been proved in full scale tests using real wing sections as impactors. The tests were supervised by the Frangibility Aids Study Group of ICAO. The results of those tests have been published in a special report, copies of which can be obtained from the Exel representatives.

2. CONDENSED DESIGN GUIDE

This condensed design guide is prepared for the designers already thoroughly acquainted with the design of approach lighting systems employing Exel masts. Using the condensed guide requires good knowledge of the both aspects. Even experienced designers not familiar with the Exel mast concept should take the trouble of going through the detail design guide and, in particular, the unique features of the Exel masts in order to fully understand how they are utilised in the overall lighting system. For the designers having no or only limited experience of the design of approach lighting systems in general, the detail guide is imperative.

The condensed guide is a straightforward step-by-step check list without any explanations in regard to the individual steps or terminology used. In the case of hesitation at any stage of the procedure, the detail guide in chapter 3 should be consulted.

The design process is given below. The heights referred to in steps 4 - 7 have been illustrated in Figure 1.

1. Determine the horizontal light positions, i.e. prepare the light lay-out.

2. Determine the vertical light positions by defining the slope angles of the lighting system.

3. Prepare the mast lay-out by suitably grouping the lights to each mast. Decide the mast position numbering system.

4. Select a datum level as a global height reference.

5. Calculate light heights from the datum level.

6. Determine the heights of the position basement levels from the datum level.

7. Calculate the local light heights from position basement levels.

8. Select the mast with the best matching light height for each position from the Mast Selection Table. (This stage may also be left to the Exel representatives).

9. Tabulate the required data to the Mast Data Sheet provided in Appendix A3.

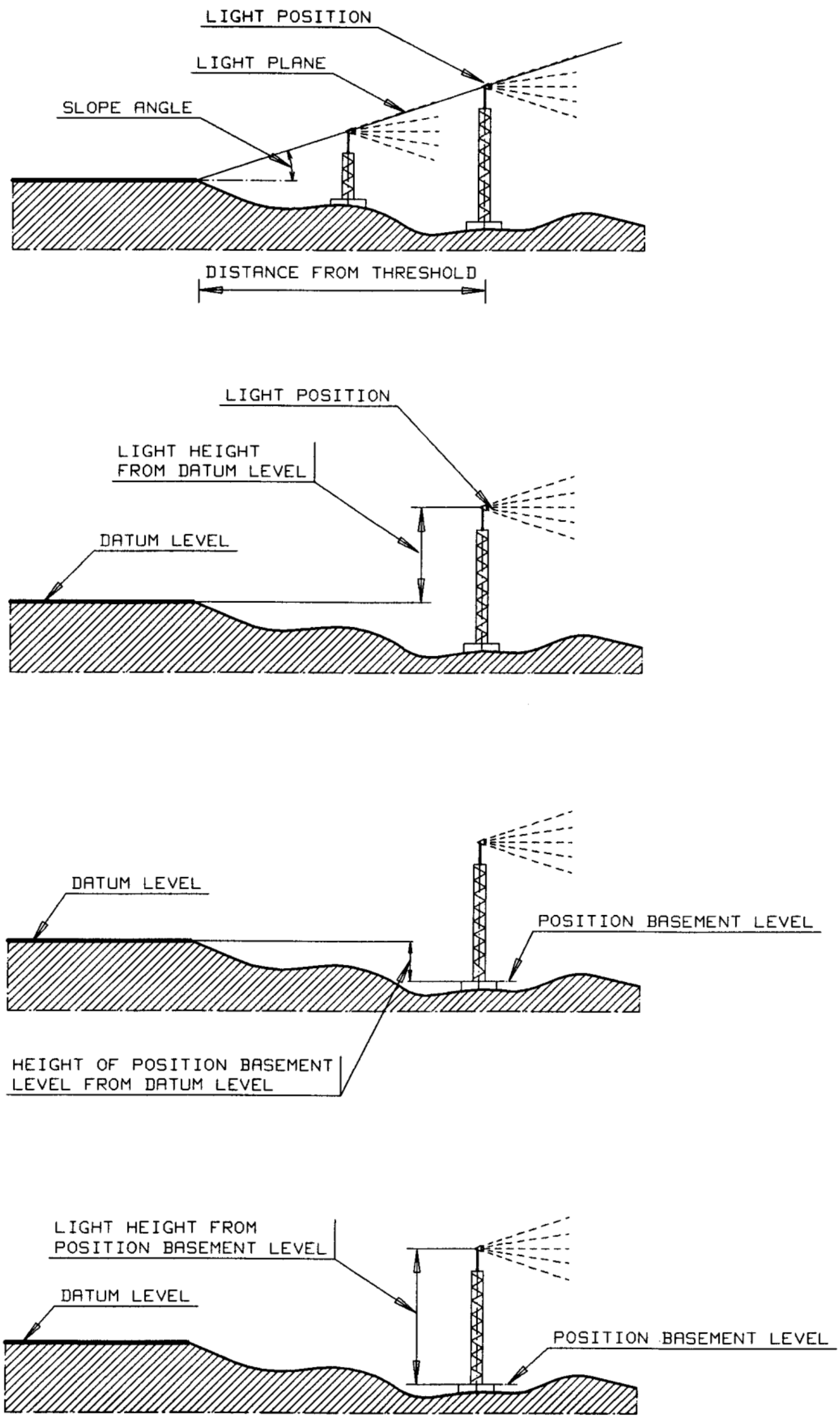


Figure 1 The basic heights and reference levels used in the design process.

3. DETAIL DESIGN GUIDE

This chapter presents the design procedure of an approach lighting system employing Exel-masts in a comprehensive format. It is prepared for the designers not familiar of the unique characteristics of Exel masts and of how they should be considered in the design. The detail guide is also an excellent starting point for those with little or no previous experience in designing approach lighting systems in general.

This detail guide has been divided into several separate sections reflecting the individual design steps. Therefore, it may also be consulted as a reference when only particular details need to be checked, while primarily following the condensed guide. The standards and recommendations of Annex 14 are referred to repeatedly. However, as all the instructions of Annex 14 have not bee duplicated, it may prove useful to have Annex 14 available throughout the design process.

Features unique to Exel masts are included in some of the design steps, so it is considered most important for the designer to get himself thoroughly familiarised with the instructions given in the following sections (3.1 - 3.4). The main steps of the design procedure are listed below and a detailed description of each step is given in the respective sections given in the parenthesis. The main steps are:

- **The horizontal positions of the lights are determined.** The *light lay-out* is largely dictated by the type and the precision approach category of the lighting system selected (section 3.1.1).

- **The vertical positions of the lights are determined.** The lights are set to form a plane of lights, typically slightly sloped off the horizontal level. Establishing the slope angle (or angles) determines the vertical positions of the lights. The work is tightly controlled by the ICAO standards (section 3.1.2).

- **The lights are suitably grouped to each mast.** The standard lattice masts may accommodate up to five lights/mast when mounted on the specially made cross-bar tubes. The smaller tubular masts only carry one light/mast (sections 3.2.1 and 3.2.2).

- **The *mast lay-out* plan is made,** based on the grouping of lights. This also gives the total number of masts required (section 3.2.3).

- **A fixed datum level is set** as a reference level for further height data. Some established height measuring systems may also be used (section 3.3.1).

- **Light heights are calculated from the datum level** using the light position data (distances) and the slope angles of the light planes (section 3.3.2).

- **Heights of the mast position basement levels are determined** from the datum line. For this, the mast lay-out plan and the results from the land survey are required (section 3.3.3).

- **The local light heights are calculated** from the basement levels at each mast position (section 3.3.4).

- **The masts,** that most closely match the required local light heights, **are selected** from the standard options given in the Mast Selection Table (section 3.4.1).

- **The mast selection is documented,** together with the cross-bar data, on the Mast Data Sheet provided in Appendix A3 (section 3.4.2).

3.1 Light Positions

3.1.1 Horizontal positions (Light lay-out)

The lay-out of lights in an approach lighting system is determined by the lighting system selected. The most common standard ICAO approach lighting systems are the Barrette Centre Line and the Distance Coded Centre Line. The type of the lighting system primarily determines the overall light pattern by giving the basic shape of the light lay-out.

The exact positions of lights are further determined by the precision approach category of the aerodrome (CAT I, II or III), which indicate the minimum operational visibility limits of the aerodrome. This classification affects only the first 300 meters of the lighting system, by requiring a denser network of lights close to the threshold for CAT II and III systems. Beyond the 300 m line, the positions of lights are only affected by the type of the system, not the category.

Together the type of the approach lighting system and the category specify the exact horizontal position of each light. It is determined by three different measurements: the horizontal distance of each light from the threshold (along the centre line), the width of the transverse rows of lights (called cross-bars) and the horizontal spacing of the lights on each cross-bar. Combined, this data enables the preparation of the *light lay-out plan*.

The lay-outs most commonly used in the precision approach systems have been illustrated in Annex 14, Appendix A, Figure A-6 and in the Figures 2a and 2b of this guide. The lighting systems shown in Figures 2a and 2b represent category I, aptly illustrating the two basic lay-out patterns. The first 300 metres of CAT II and CAT III lighting systems are shown in Figures 5-8 of Annex 14. It deserves to be noted that according to Annex 14, there is a certain amount of freedom in the exact number and location of lights within the first 300 m in CAT II and III systems. The systems illustrated in this guide represent typical alternatives, but slightly varying systems are also widely used.

A more complete description of the standard options is given in section 3.2.3 and Appendix 2 of this guide, where also the mast positions are considered. Simple approach lighting systems are shown in Figure A-5 of Annex 14, Appendix A.

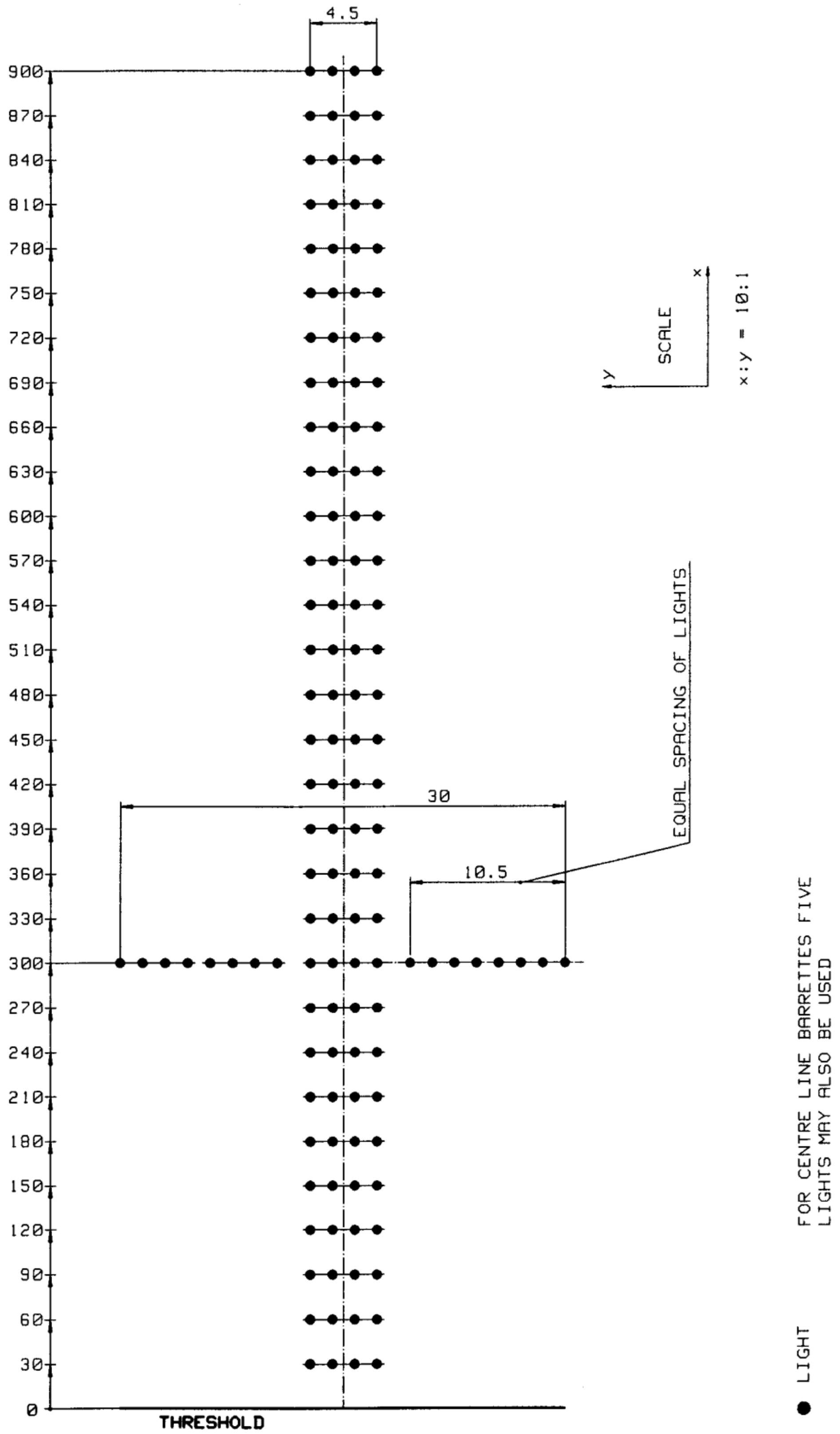


Figure 2a A Barrette Centre Line for category I (CAT 1) lighting systems (dimensions in metres).

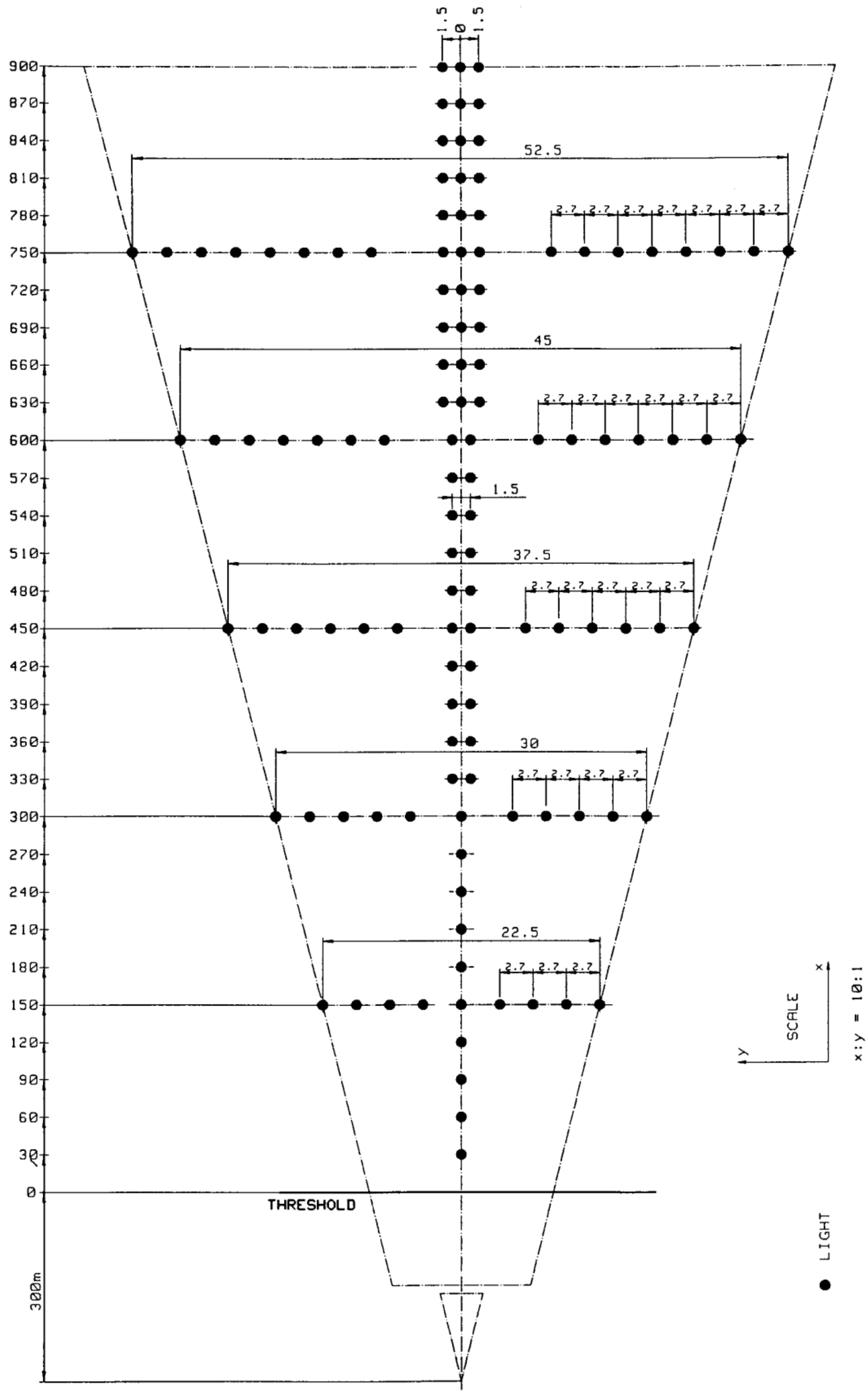


Figure 2b A Distance Coded Centre Line for category I (CAT I) lighting systems (dimensions in metres).

3.1.2 Vertical positions

The lights of an approach lighting system are positioned so, that together they form a plane of lights. This light plane is typically sloped in a moderate angle towards the threshold. The slope angle is often incrementally changed at definite points along the centre line. The actual system thus consists of several light planes having slightly different slope angles. In order to specify the vertical positions of the lights, the slope angles need to be defined (see Figure 3).

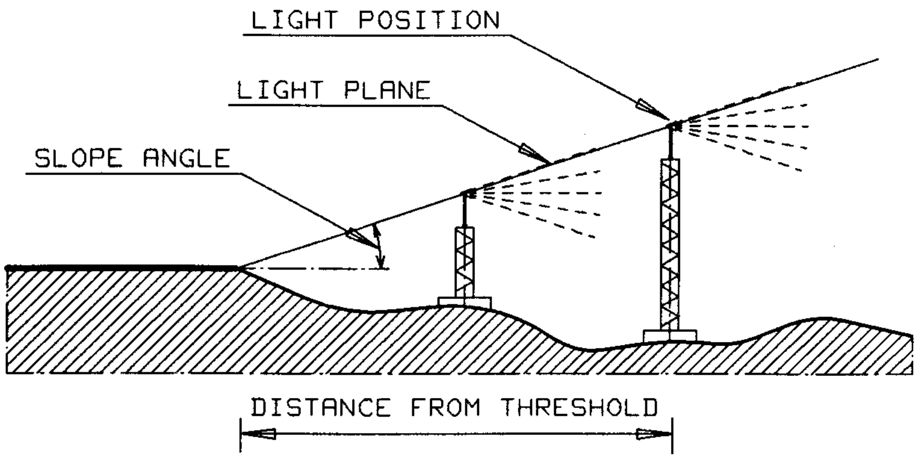


Figure 3 A sketch illustrating how the slope of the light plane determines the vertical positions of individual lights

A condensed list of those instructions directly related to the slope angles and vertical positions of the lights is given below. The instructions are further illustrated in Figures 4a and 4b, where also the slopes of two imaginary approach lighting systems have been shown as examples. It is advised, however, that the designer should carefully read all the recommendations given in Annex 14 concerning the slope angles and light heights, since not all the instructions of Annex 14 have been included in the following list (see Annex 14, section 11.2 and Figure A-7 of Appendix A). The essential requirements, instructions and recommendations of Annex 14 are:

General requirements:

- The ideal arrangement is to mount all the approach lights in a horizontal plane passing through the threshold. Given the visibility requirements of the lights, this aim may be difficult or impossible to achieve.

- The typical arrangement is to have all the lights in a plane suitably sloped to ensure good visibility. The slope angle may vary along the lighting system within a given range, the system thus consisting of two or more light planes.

Detail requirements:

- In the case of rising ground, within the first 300 metres from the threshold, the slope angles, i.e. rising gradients, should be less than 1 in 66 (0.87°).
- Outwards from the 300 m point the rising gradient should be less than 1 in 40 (1.43°).
- In the case of falling ground, negative slopes may be used, but the lights should not be mounted below a gradient of 1 in 66 (0.87°) between the threshold and 300 m line, and below a gradient of 1 in 40 (1.43°) beyond the 300 m line.
- For precision approach category II and III lighting systems more stringent criteria may be necessary, e.g. negative slopes not permitted within the first 450 metres from the threshold.
- The slopes of the lighting system in any section should be as small as practical, and the changes in gradients should be as few and small as can be arranged. The change in gradient should not exceed 1 in 60 (0.95°). In practice, this limitation is faced only if the ground contour changes drastically along the centre line.
- Transverse gradients on the cross-bars should be avoided. It is permissible, however, to mount the lights on a transverse gradient not more than 1 in 80 (0.72°), if this enables lights within stopway or clearway to be mounted nearer to the ground where there is a cross-fall.
- Masts in excess of 12 m should be avoided by changing the slope.

Following the instructions given above and in Annex 14, as well as the restrictions caused by the surrounding ground contour, the sloping of the lighting system can be decided.

So far in the design process, the horizontal distances of the light positions have been defined by the choice of the lighting system, and the vertical positions of the lights have been fixed by the selected slopes. Together these determine the exact location of each light.

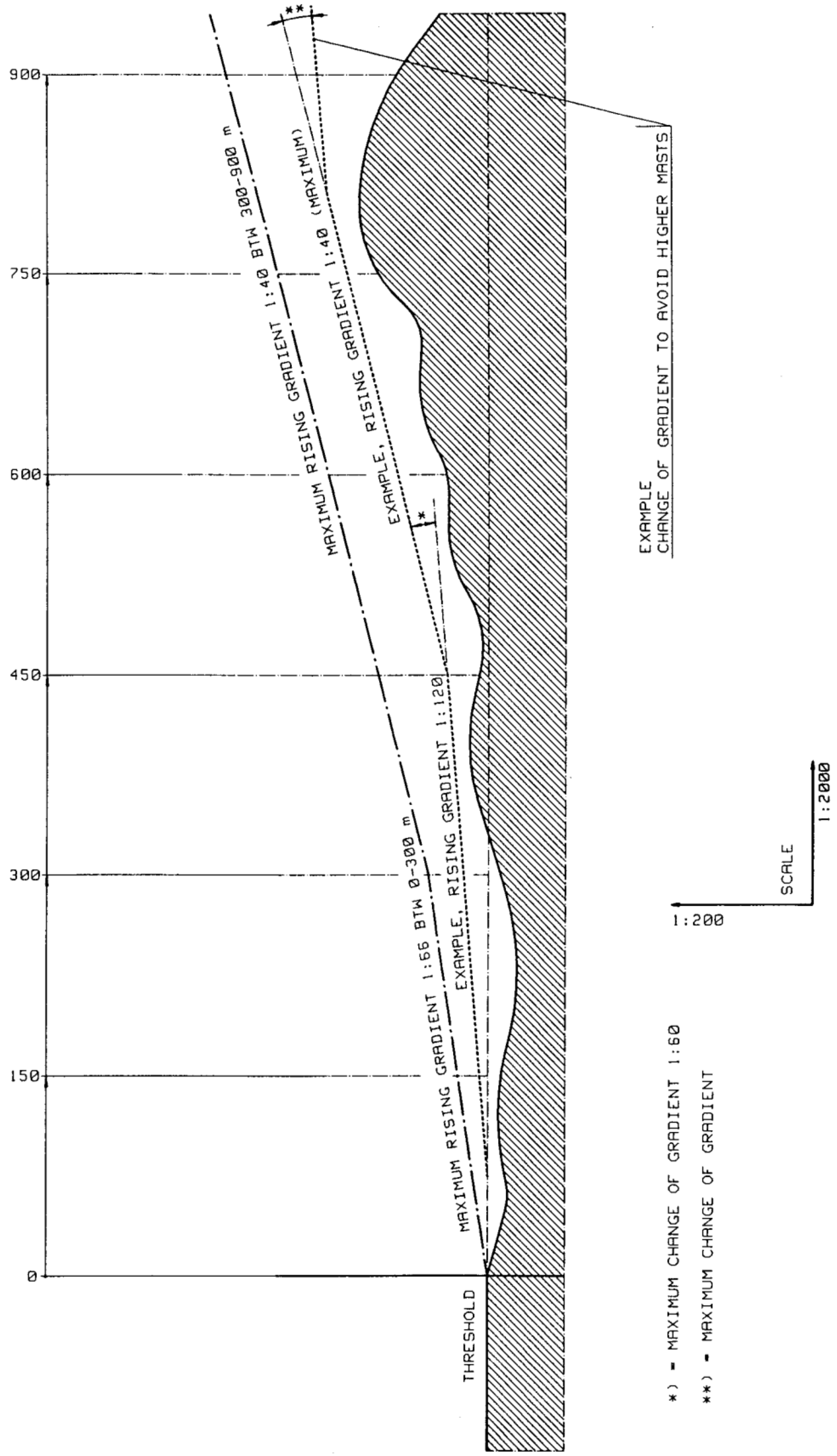


Figure 4a The permissible and recommended gradients in the case of rising ground or level ground. Gradients of an imaginary lighting system are shown as examples.

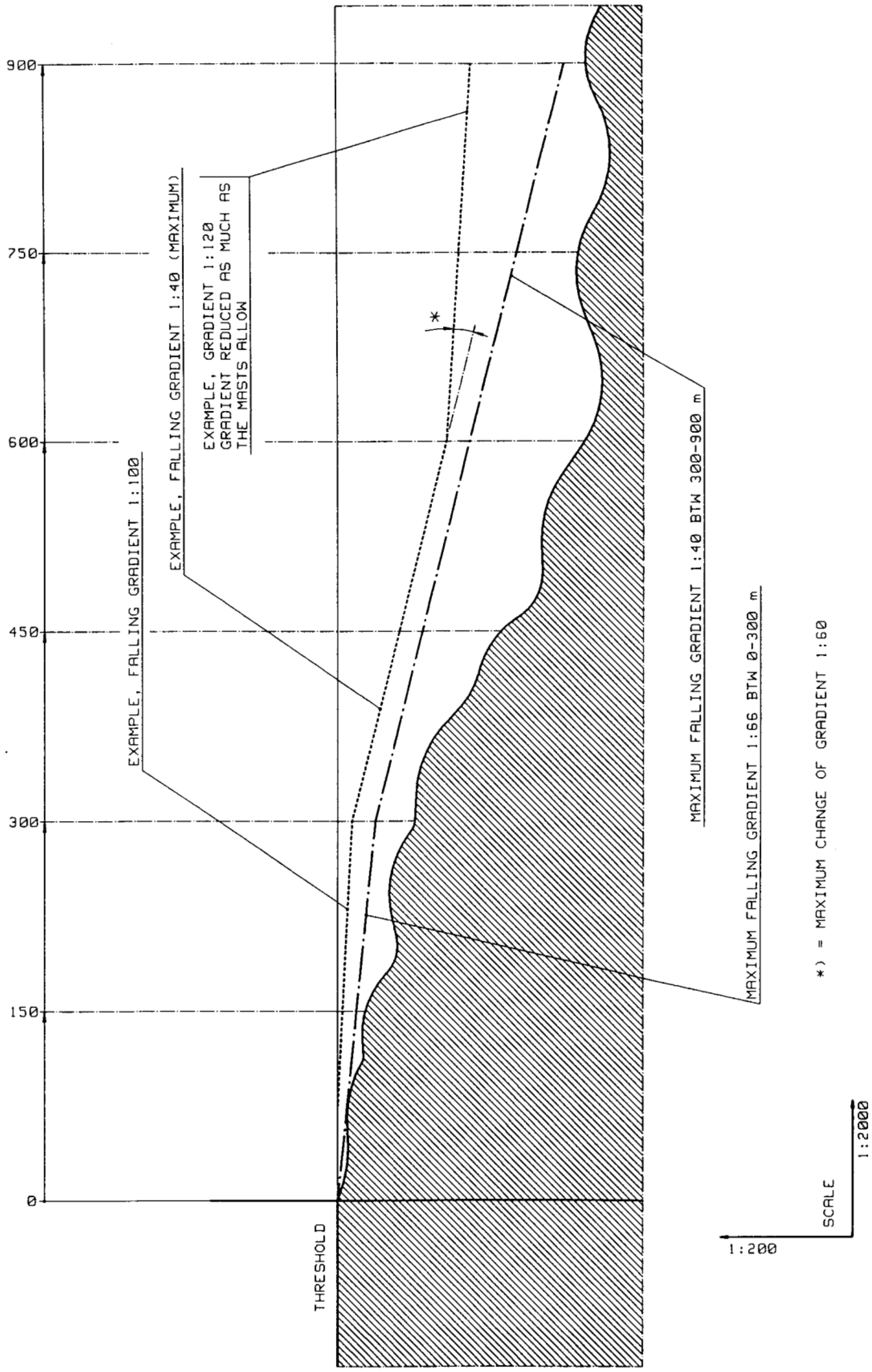


Figure 4b The permissible and recommended gradients in the case of falling ground. Gradients of an imaginary lighting system are shown as examples.

3.2 Mast Positions

An approach lighting system employing Exel-masts typically consist of two different types of masts: *tubular masts* and *lattice masts*. The tubular masts may only carry a single light on each masts, while up to 5 lights may be accommodated on a lattice mast. Therefore, translating the light positions into *mast positions* requires that the decision between the two options is made throughout the system. The selection and application of the both concepts are explained in the following two sections. Instructions for preparing the final *mast lay-out drawing* are given in section 3.2.3.

3.2.1 Tubular Masts

Single light tubular masts are typically the most practical solution when the required masts turn out to be relatively low, say below 2.5 - 4.0 m. Because the light plane is sloped down to the threshold, the shortest masts are typically required in the region close to the threshold. This trend is often emphasised by rising ground, that pushes the area of higher masts even further away from the threshold.

There is no universal rule to determine whether the tubular or lattice masts are more efficient in a particular case. The decision needs to be made case by case, judging factors like the cost of tubular masts and their foundations vs. the cost of a lattice mast able to accommodate the same number of lights on a single mast, but requiring a bigger foundation. Other factors to be considered may include such as the ease of installation and overall outlook of the lighting system. The maximum height limit for tubular masts is typically around 4 m, the exact value depending on the light size and wind load. The combined use of the both concepts is illustrated later in Figures 6a-d.

3.2.2 Lattice Masts with Cross-bar Tubes

When employing Exel masts of lattice structure, it is possible to use horizontal tubes - called cross-bar tubes - in order to mount from 1 to 5 lights on a single mast. This option may be used to reduce the total number of masts required, as shown in Figure 5. As the lights have to be mounted symmetrically on the masts, grouping of the lights on different masts dictates the final mast positions. Furthermore, the grouping determines the total number of masts needed. As a result, the use of the cross-bar tubes has to be decided before the final lay-out plan can be made.

According to Annex 14, in CAT I approach lighting systems the number of lights and their horizontal spacing is practically fixed by the type of the lighting system. This has enabled to construct a limited number of optimised grouping alternatives for CAT I systems, as listed in Table 1 (page 16). Lay-out plans for CAT I Distance Coded and Barrette lighting systems, based on the standard configurations, are shown in Figures 6a and 6b. In Barrette Centre Line systems (Fig. 6b) it needs to be noted that

Annex 14 only states the barrette widths, leaving the exact number of lights open. Typically, 4 or 5 lights are used in the centre line barrettes and 3 or 4 lights in the side row barrettes. The gap between the centre line and side row barrettes may then be filled with 2 to 4 lights.

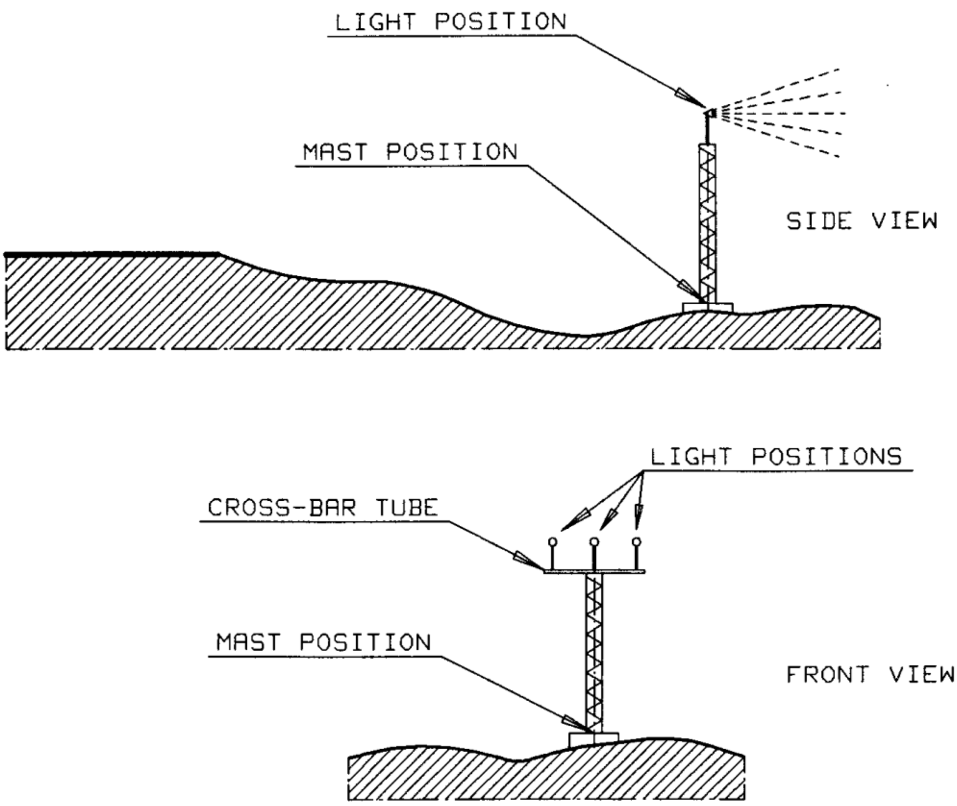


Figure 5 Several lights can be mounted on one mast by using a cross-bar tube. The method of grouping the lights determines the mast positions, as the lights need to be positioned symmetrically.

Within the first 300 meters of CAT II and III systems, Annex 14 allows a certain amount of flexibility in the exact spacing and number of lights at each cross-bar (as discussed in section 3.1.1). Therefore, it is impossible to cover all the possibilities with a limited number of fixed designs. Table 1 lists some typically used grouping alternatives and indicates the maximum cross-bar/light arrangements. The variations and non-standard configurations should be constructed within these limitations. The ready-made lay-outs provided in Figures 6c and 6d show typical solutions for both systems.

Exceeding the limits given in Table 1 may be possible in certain cases, but has to be always agreed upon in co-operation with the Exel representatives. The limitations for the maximum number of lights and their spacing may become even stricter in the case of lights with unusually large surface area or exceptionally high calculation wind loads. Any additional special light (such as a flash) is to be included in the total number of lights.

Table 1 Maximum — Typical cross-bar tube arrangements used in different lighting systems. spacing indicated when relevant.

	Number of lights	Horizontal spacing m	Cross-bar tube length m	Strut arm length m
Barrette CAT I				
	2	2.625	3.00	-
	3	max. 2.625	5.50	2.5
	4	1.33	4.30	1.9
	4	max. 1.50	4.80	2.2
	4+1*	max. 1.50	4.80	2.2
	5	max. 1.125	4.80	2.2
Distance Coded CAT I				
	1	-	0.51	-
	2	1.50	1.80	-
	2	2.70	3.00	-
	3	1.50	3.30	-
	3	2.70	5.70	2.5
CAT II and CAT III, first 300 m				
	2	2.7	3.00	-
	3	1.50	3.30	-
	3	1.625	3.55	-
	3	max. 2.625	5.50	2.5
	4	1.33	4.30	1.9
	4	max. 1.50	4.80	2.2
	4+1*	max. 1.50	4.80	2.2
	5	max. 1.125	4.80	2.2

* *special light, separately mounted*

3.2.3 Mast Lay-out

After the use of lattice and tubular masts has been decided, a *mast lay-out* plan is made. The lay-out drawing produced forms the basis for all the further design work. Without a proper lay-out plan, the process becomes confusing and leads easily to errors. The partially unfilled lay-out drawings supplied in Appendix 2 of this guide may be used as starting points. Modifications are likely to be necessary in order to indicate the use of tubular and lattice masts correctly. Presently, the supplied drawings assume tubular masts all the way from threshold up to 120 m line, and beyond that lattice masts throughout.

The lay-out drawing should clearly indicate at least the following:

- Overall light pattern (Barrette, Distance Coded etc.)
- Use of tubular and lattice masts
- Grouping of lights on each lattice mast
- Distance of each mast position from the threshold and centre line
- Location of the lights on each cross-bar, so that the light spacing may easily be determined.

In addition, the lay-out drawing should also exhibit a clear system for numbering the mast positions. Later in the design process, the identification of the selected masts will be based on the mast position numbers. One possible system is proposed in Figures 6a-d. The designer is free to select any numbering system he wishes to, provided that each mast position have a different number and there is only one number for each mast position, regardless of the number of lights mounted on the mast.

For the consistency, the following symbols should be used in a lay-out drawing (illustrated in the ready-made drawings in Appendix 2):

- Each light is marked with a black point
- Each lattice mast is indicated by a square surrounding the light
- Each tubular mast is indicated by a circle surrounding the light
- Each cross-bar tube is indicated by a wide rectangular enclosing all the lights mounted on that cross-bar tube.

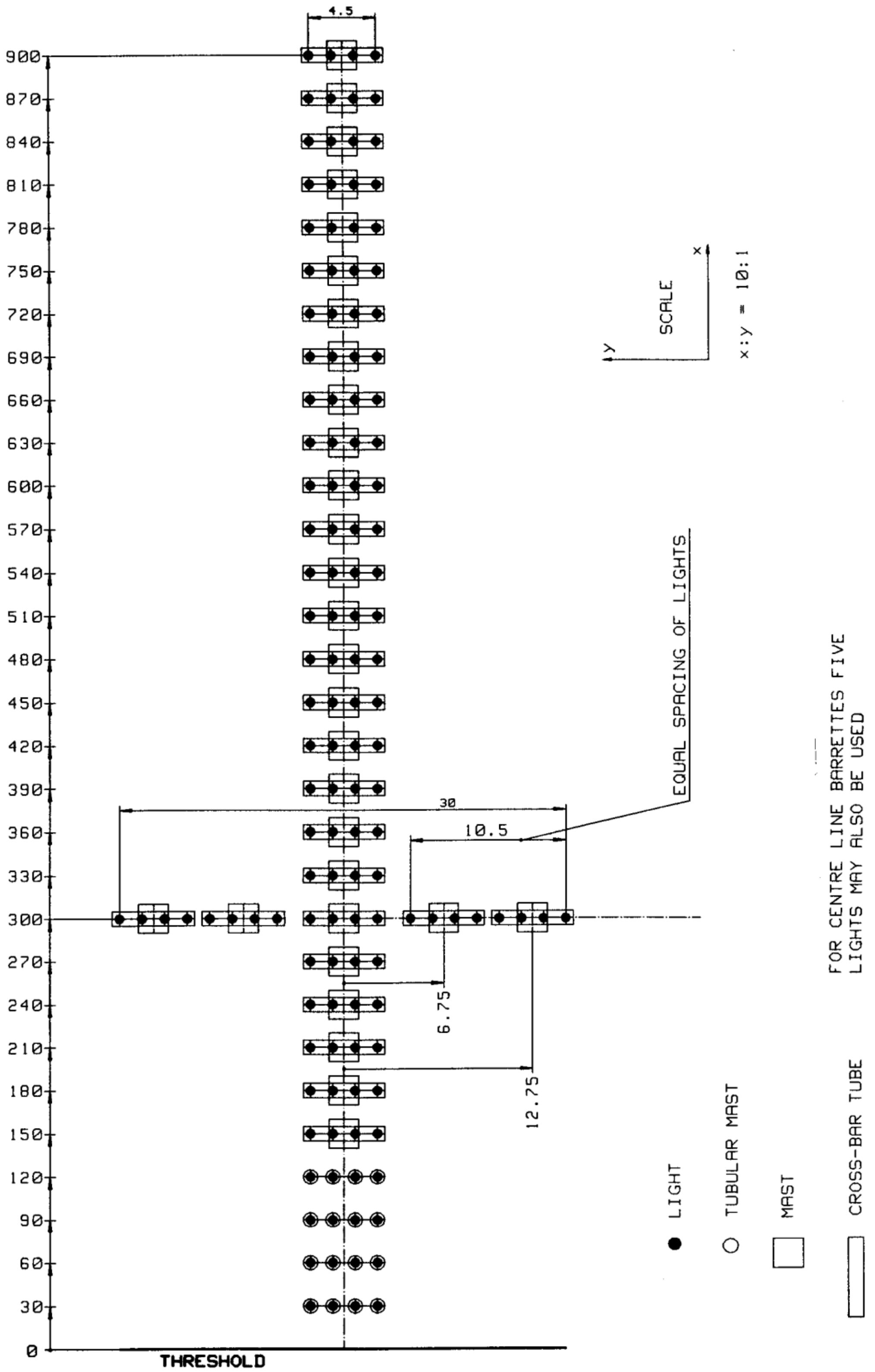


Figure 6a Light and mast positions in a "Barrette Centre Line" CAT I lighting system. Tubular masts are assumed from threshold to 120 m line, lattice masts with cross-bar tubes from 120 m line onwards. A suggested position numbering system is presented.

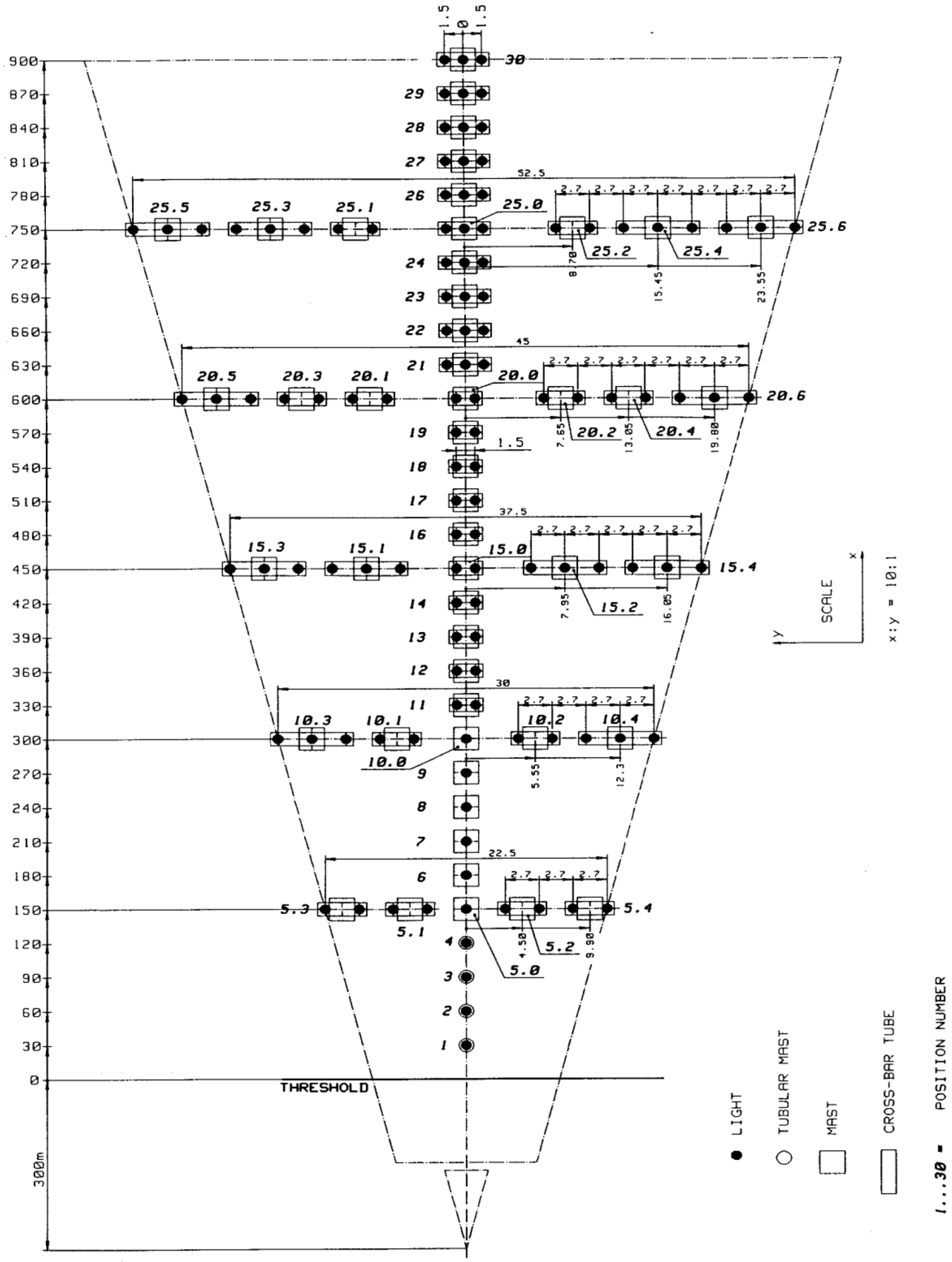


Figure 6b Light and mast positions in a "Distance Coded Centre Line" CAT I lighting system. Tubular masts are assumed from threshold to 120 m line, lattice masts with cross-bar tubes from 120 m line onwards. A suggested position numbering system is presented.

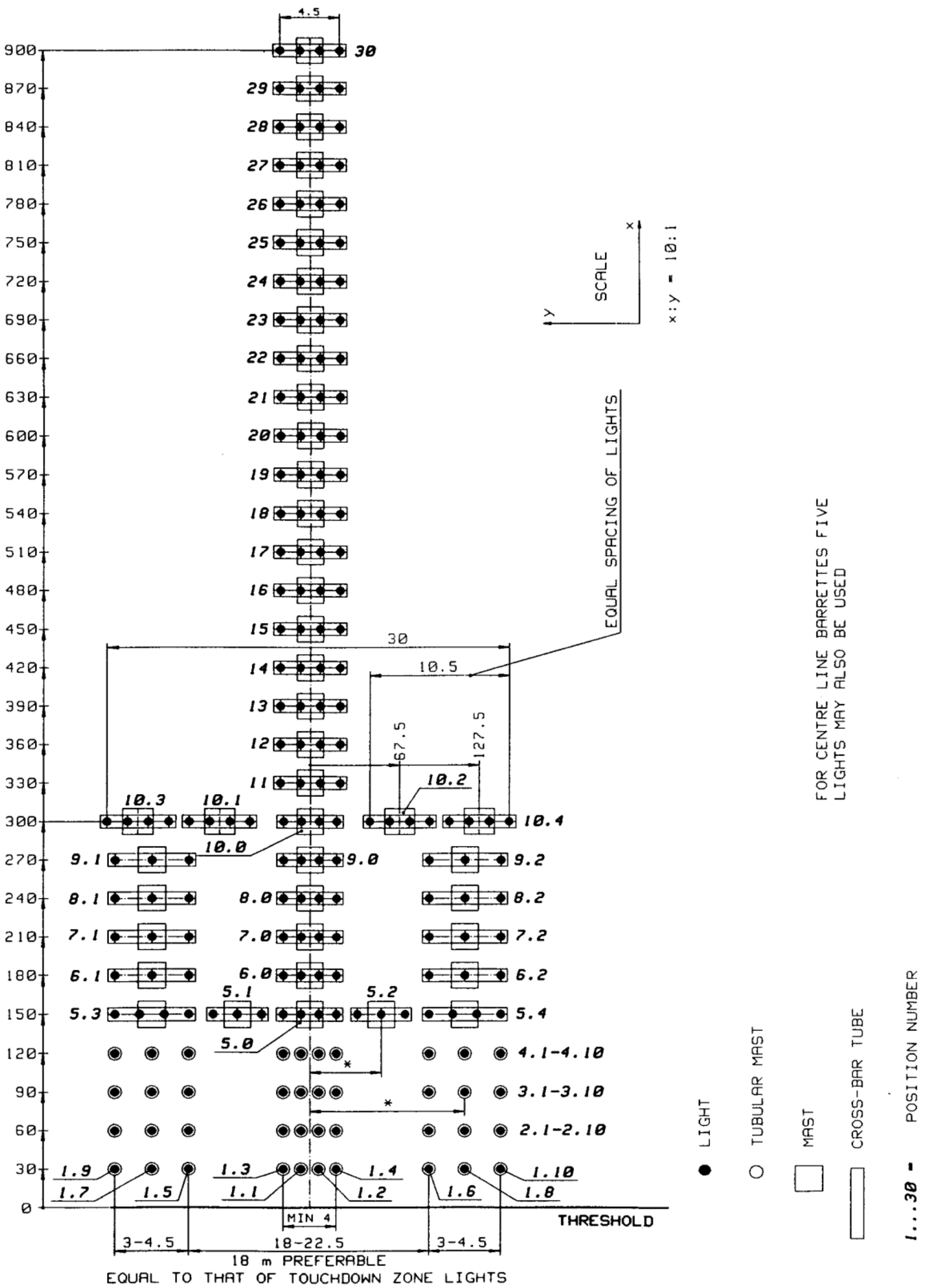


Figure 6c Light and mast positions in "Barrette Centre Line" CAT II and III lighting systems. Tubular masts are assumed from threshold to 120 m line, lattice masts with cross-bar tubes from 120 m line onwards. A suggested position numbering system is presented.

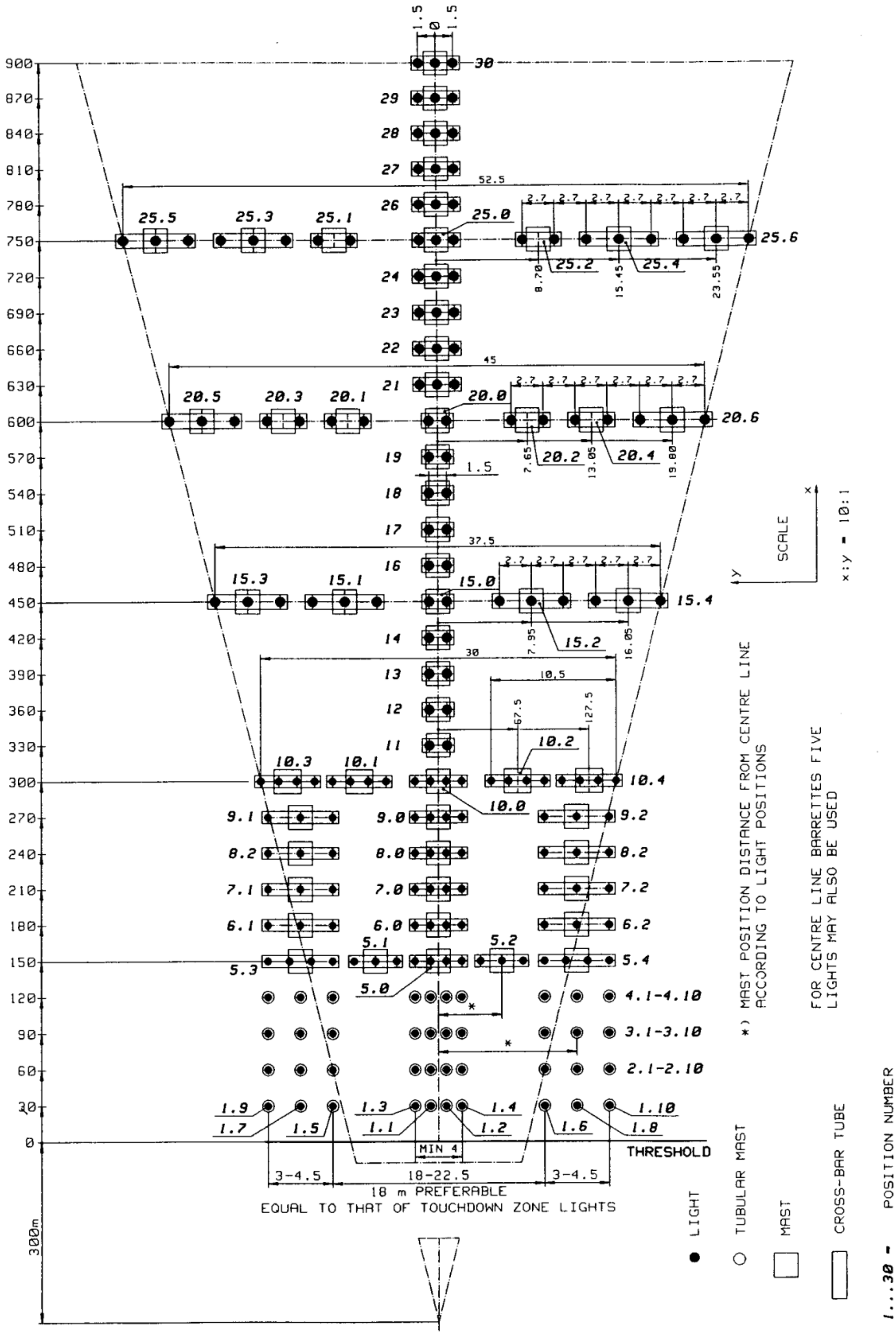


Figure 6d Light and mast positions in "Distance Coded Centre Line" CAT II and III lighting systems. Tubular masts are assumed from threshold to 120 m line, lattice masts with cross-bar tubes from 120 m line onwards. A suggested position numbering system is presented.

3.3 Heights

3.3.1 Datum Level

As a result of the previous steps, the exact positions of the lights are now defined, but the information is given in the form of the distance from the threshold and the slope angle. In order to determine the heights of the actual masts, the light positions have to be expressed locally as distances from the ground.

The first task is to tie together all the height data determined earlier. This can be made by nominating a certain fixed level as reference level, called the ***datum level***, to which all other heights are then referred to. Often the threshold level is selected as the datum level, as illustrated in Figure 7. Also some established height system typically used in ground surveying may be applied. In the following procedure the method of establishing a fixed datum level (threshold) is employed, but the principles of the procedure are independent of the height reference system.

3.3.2 Light Heights from the Datum Level

Once the datum level is determined, the height of each light from that level can be calculated using the known distances and slope angles. This is essential considering the later stages of the process, as the local light heights at each mast position can only be determined after knowing the heights from a universal reference level.

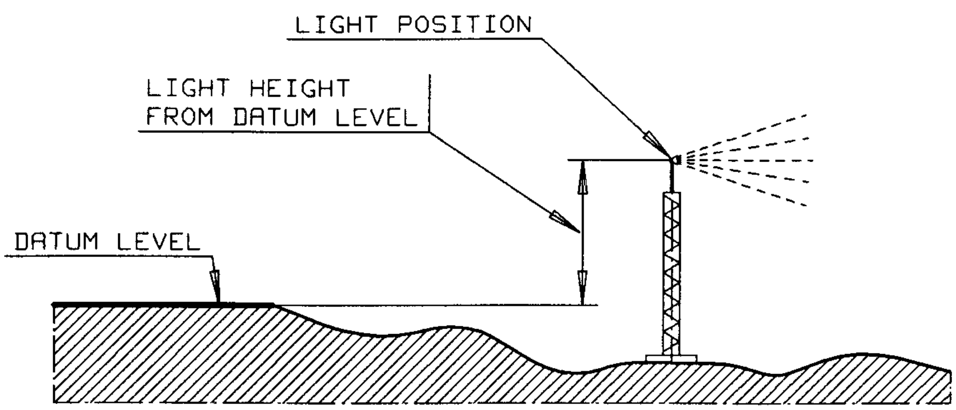


Figure 7 A fixed datum level is selected from which the light heights are calculated.

3.3.3 Position Basement Level

In order to determine the local light and mast heights, the ground contour needs to be considered. The overall ground contour was already taken into account when defining the slope angles, but at this stage the ground level at each mast position needs to be known. This can be determined by combining the results of the ground survey and the locations of the masts positions given in the mast lay-out (see Figure 8). It may be difficult to define the precise level of the ground at each position, and this is not even required, as long as it is known with a reasonable accuracy.

Based on the ground level, it is then decided at which level the foundation is set. The level that needs to be defined accurately is the top surface of the foundation, called the *position basement level*. To minimise the size and cost of the foundation it is advisable to set this basement level close to the ground. Also the possible submerging of the steel base frame of the mast should be considered at this stage. The height of the base frame with fittings is 110 mm (see Figure 11).

When the position basement levels have been decided, they are expressed as heights from the datum level. It should be indicated with + and - signs whether the basement levels are above or below the datum level.

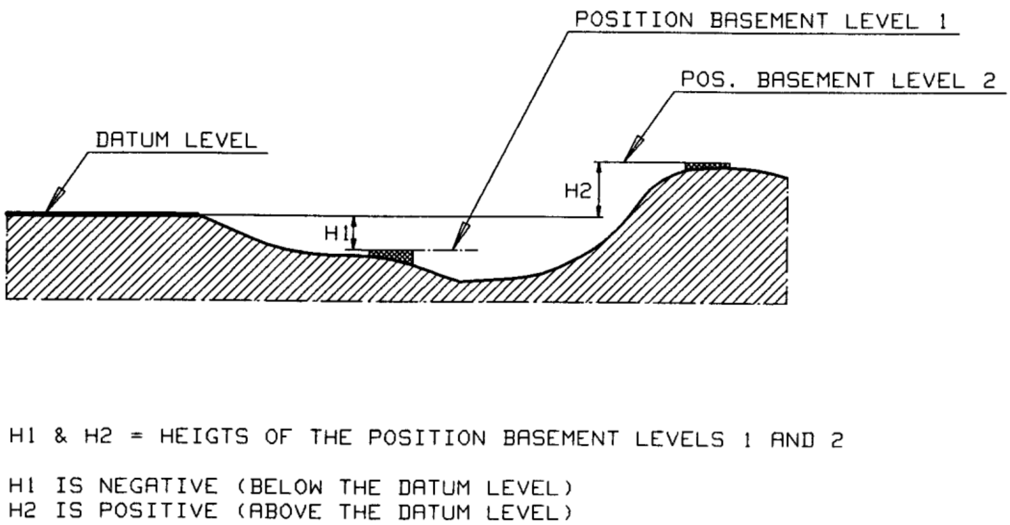


Figure 8 The position basement level (the foundation top surface) is set close to the ground. This level needs to be accurately defined.

3.3.4 Light Heights at Mast Positions

Now that the light heights and the basement levels at each mast position have been established as heights from the same datum level, the local light heights for each mast position may be easily calculated, as illustrated in Figure 9.

When establishing the local light heights, the lay-out plan should be carefully followed to ensure that each light is related to the correct mast. Since the cross-bar tubes are set horizontally, all the lights mounted on the same mast should have the same height from the basement level. The selection of masts is based on these local light heights, so it is most important that they have been determined correctly.

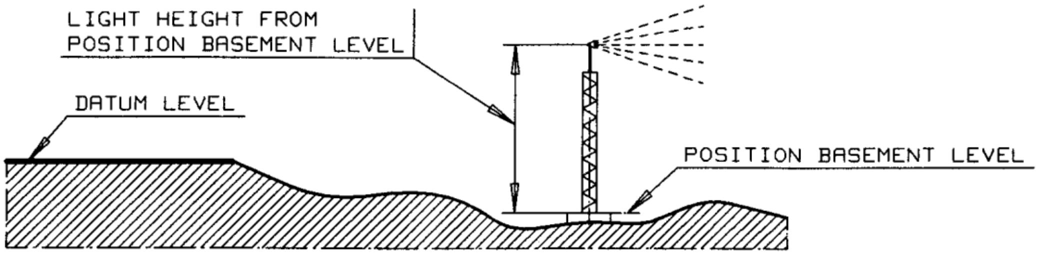


Figure 9 The use of position basement level to express the light height locally.

3.4 Mast Selection

3.4.1 Selecting the Right Masts

The selection of the correct masts is the most essential step in the design of an approach lighting system employing Exel masts. The selection may also be left to the Exel representatives, provided that all the necessary height and position data is supplied in the appropriate form, as defined in section 3.4.2. It is recommended, however, the selection to be made by the actual designer, as this is the best way to ensure that all the customer needs and wishes are fulfilled. The designer is also best aware of any local circumstances, that might make the standard solutions less optimal. The decision between tubular or lattice masts should be made in co-operation between the designer and Exel representatives, as cost and other factors from both sides need to be judged.

Once the selection between lattice or tubular masts has been made, the selection process is different for the two cases. Therefore, the selection process has been explained separately for both cases in the following two sub-sections. As features characteristic to Exel masts needs to be considered in the selection process, these sections also contain brief introductions to the both mast concepts.

Tubular Masts

The Exel tubular masts consist of one to three composite tubes of different diameter (see Figure 10). The top section, to which the light is fitted, is always a diameter 51 mm tube (marked later as D51). If the mast height is below 1.6 m, the mast is a single D51 tube. Between 1.6 - 2.5 m the tubular masts typically consist of two tubes, D86 tube as a lower section and the D51 mm tube on top. Higher tubular masts have a further lower element of 106 mm diameter (D106), and the D86 and D51 elements are placed on top of that. The maximum height of the three-section masts is about 4 m. The height limits are only indicative, as the right combination needs to be decided separately case by case, depending on the local circumstances and requirements. It is recommended that the final selection of the exact type of the tubular masts is left to the Exel representatives, unless there are particular customer wishes other than the light height.

The selection of the right tubular masts is simple: a mast is sufficiently defined when the desired light height is known. At the selection stage it is possible to reach any required height without a further adjustment, as the tubular masts are delivered 200 mm overlength and are cut to the exact heights on-site. Once a tubular mast has been delivered on-site, the possible height adjustment range is limited by the height of the D51 tube.

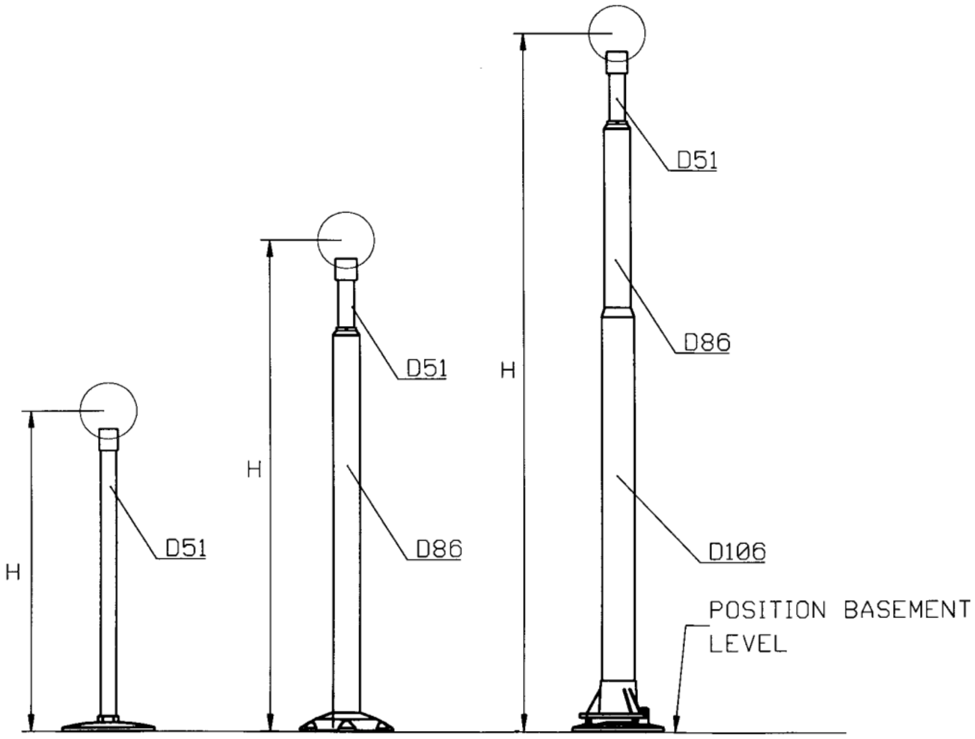


Figure 10 Exel tubular masts.

Lattice Masts

The Exel lattice masts consist of one or two mast modules of lattice structure with a square cross-section. If the height of the mast is below 6 - 8 m, only one module of 400 mm width is used. Masts higher than 6 - 8 m are constructed of two modules. The upper section, being a standard 400 mm module, is mounted on top of a stiffer lower section of 500 mm width. The two modules are connected by a conical joint element of composite structure. The mast modules are manufactured to standard heights at 250 mm intervals.

In both cases the cross-bar tube is mounted on top of the 400 mm module. The lights are fitted to the cross-bar tubes via special *adjustment tubes*. The adjustment tubes make it possible to reach any required light height, although the mast modules are only manufactured to certain fixed heights. The adjustment range of ±250 mm is sufficient to compensate the maximum height error of 125 mm arising from the fixed modular height (the maximum error being a half of the height interval).

Because of the cross-bar and the adjustment tubes, the actual light height is always greater than the height of the plain mast. If the light is positioned in the midpoint of the adjustment range, the light is 610 mm above the mast top. The base frame lifts the light up further 110 mm (see Figure 11). Altogether, the mast

light height from the basement level is thus 650 mm greater than height of the mast modules.

The 400 mm mast modules are produced in lengths between 1250 mm and 6000 mm at 250 mm intervals (in special cases up to 8000 mm). 500 mm mast modules are produced in 3000/4000/5000 and 6000 mm lengths only. By combining these two types, any light height between 1900 mm and 12 650 mm can be constructed of the standard modules. Taking into account the ±250 mm adjustment range, the possible range in terms of the light height is approximately 1650 - 12900 mm. All the Exel masts based on the modularity concept and the respective mast modules, arranged by their heights, are listed in the Mast Selection Table (Table 2).

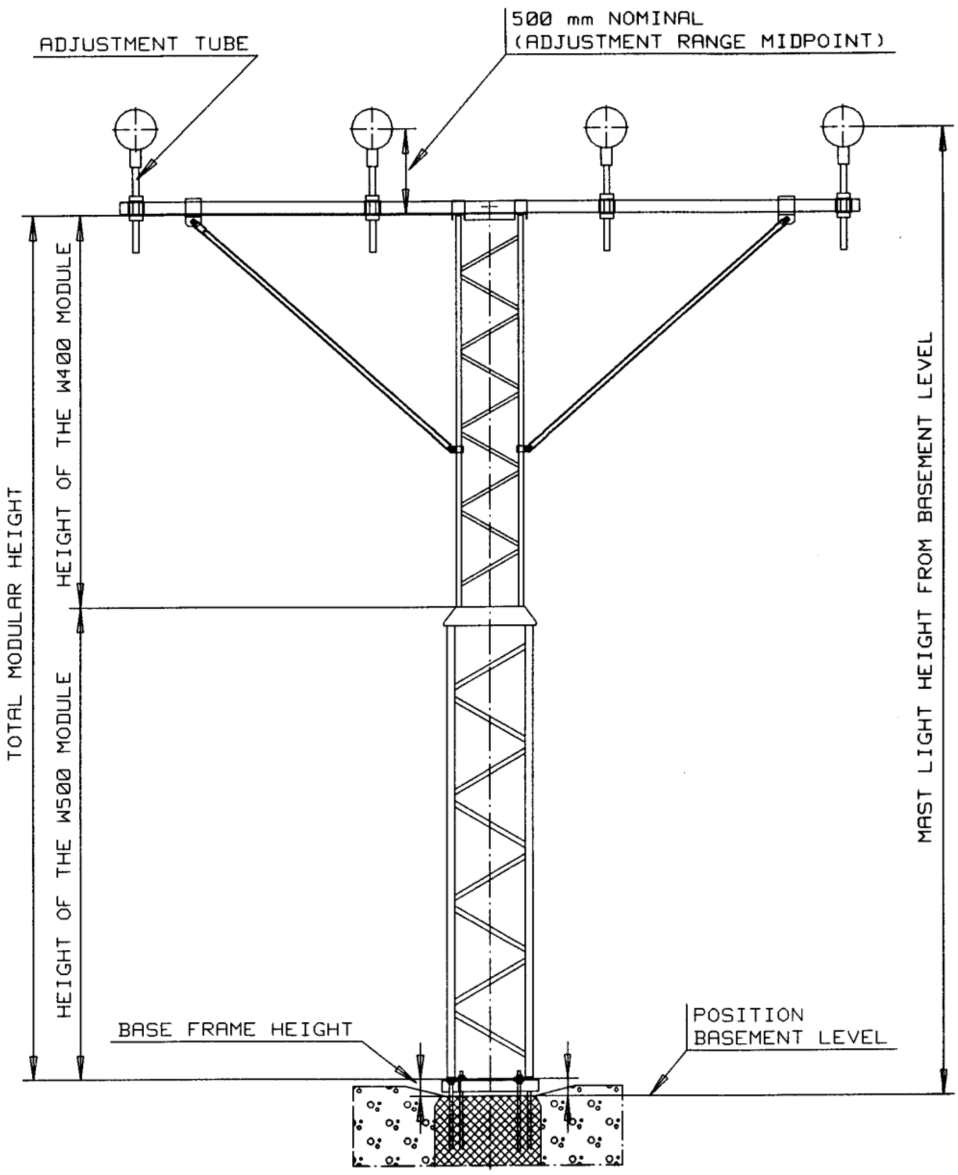


Figure 11 The main dimensions of an Exel lattice mast. The foundation top surface is used as a base point for the dimensions.

The final mast selection is now simple: the Exel mast with the light height matching most closely to the desired light height is selected from the Mast Selection Table. All the masts available for standard designs are listed in Table 2, and other options are not routinely available. However, in special cases it may be possible to use higher masts with a reduced top load, the wind loads permitting. This should be discussed with the Exel representatives as the need arises.

In the case that exact match is required between the nominal mast light height and the desired light height, a correction procedure is presented in section 3.4.3.

The module combinations given in the Mast Selection Table have been optimised for typical approach lighting systems. As a general rule these combinations produce the most cost effective designs. There may be, however, situations where other considerations become dominating in the design and selection of the right masts. Based on the past experience, there seems to be a strong desire towards lighting systems that are - not only structurally effective - but also aesthetically pleasing. This may require the use of alternative 500/400 mm combinations, for example, in order to bring the joint elements of the centre line masts closer to the same sloped line. Furthermore, when the selected masts are later transported and delivered, it may be possible to significantly increase the space utilisation in the cargo containers by re-configuring the standard module combinations, thus reducing transportation costs. Should modifications in the standard combinations be found beneficial, alternative combinations will be presented by the Exel representatives. The light heights will always remain unaffected.

Table 2 Mast Selection Table showing the available lattice masts (complete version shown in Appendix 1).

MAST LIGHT HEIGHT from position basement level			Total modular height	MODULES		COMBINATIONS
Midpoint mm	Range min	max	mm	400 mm module height mm	500 mm module height mm	400 mm module height + 500 mm module height mm
1900	1650	2150	1250	1250		
2150	1900	2400	1500	1500		
2400	2150	2650	1750	1750		
2650	2400	2900	2000	2000		
2900	2650	3150	2250	2250		
3150	2900	3400	2500	2500		
3400	3150	3650	2750	2750		
3650	3400	3900	3000	3000	3000	
3900	3650	4150	3250	3250		
4150	3900	4400	3500	3500		
4400	4150	4650	3750	3750		
4650	4400	4900	4000	4000	4000	
4900	4650	5150	4250	4250		
5150	4900	5400	4500	4500		
5400	5150	5650	4750	4750		
5650	5400	5900	5000	5000	5000	2000 + 3000
5900	5650	6150	5250	5250		2250 + 3000
6150	5900	6400	5500	5500		2500 + 3000
6400	6150	6650	5750	5750		2750 + 3000
6650	6400	6900	6000	6000	6000	3000 + 3000
6900	6650	7150	6250	6250		3250 + 3250
7150	6900	7400	6500	6500		3500 + 3000
7400	7150	7650	6750	6750		3750 + 3000
7650	7400	7900	7000	7000	7000	3000 + 4000
7900	7650	8150	7250	7250		3250 + 4000
8150	7900	8400	7500	7500		3500 + 4000
8400	8150	8650	7750	7750		3750 + 4000
8650	8400	8900	8000	8000		3000 + 5000
8900	8650	9150	8250			3250 + 5000
9150	8900	9400	8500			3500 + 5000
9400	9150	9650	8750			3750 + 5000
9650	9400	9900	9000			4000 + 5000
9900	9650	10150	9250			4250 + 5000
10150	9900	10400	9500			4500 + 5000
10400	10150	10650	9750			4750 + 5000
10650	10400	10900	10000			5000 + 5000
10900	10650	11150	10250			5250 + 5000
11150	10900	11400	10500			5500 + 5000
11400	11150	11650	10750			5750 + 5000
11650	11400	11900	11000			5000 + 6000
11900	11650	12150	11250			5250 + 6000
12150	11900	12400	11500			5500 + 6000
12400	12150	12650	11750			5750 + 6000
12650	12400	12900	12000			6000 + 6000

NOTE: A 500 mm module may only be used in combination with a 400 mm module
The shaded alternatives may only be used in special cases

3.4.2 Filling the Mast Data Sheet

The essential design data and the final mast selection need to be carefully documented. The document to be prepared now acts as the input data sheet for Exel, and the whole mast delivery is based on this documentation. The data is to be documented on a special *Mast Data Sheet*, provided in Appendix 3. A scaled down copy of a section of the Mast Data Sheet is also shown here in Table 3. This section explains how the Mast Data Sheet is filled.

The Mast Data Sheet is divided into two main parts. On the left are the necessary basic information on which the mast selection is based. The actual selection is then documented on the right-hand side columns. The necessary input data contains the following four columns (the four *left-hand side* columns in Table 3):

- ***Position identification*** in the form of the position number and distance from the threshold. (The ***latter*** may be omitted if the position numbering and the distances are ***both*** clearly shown in the mast lay-out drawing.)

- ***Light height*** given from the position basement level

- ***Mast type***, i.e. lattice or tubular mast (indicated with L or T)

- ***Cross-bar tube arrangement***, i.e. the number of lights on each cross-bar tube and their horizontal spacing.

  [Note: Separately mounted special lights, such as a flash or low intensity light, are indicated separately; for example as 4+1 in the case of four ordinary approach lights and one special light. Special lights are not considered in the given spacing.]

All this information is essential for the selection, manufacture and delivery of the correct masts, regardless of who makes the actual mast selection. Without this data, the process cannot be continued. The data may be tabulated gradually during the process, or at one go at the end.

The *right-hand side section* (four sub-columns) is reserved for documenting the mast selection. As discussed in the section 3.4.1, the selection may be left entirely to the Exel representatives, but it was recommended that at least the lattice masts are selected by the designer. The selection will be checked later by Exel and alternative suggestions will be made in the case that other selections would produce more efficient designs.

The documentation of the mast selection is slightly different for each case and is explained in detail on the following page. The explanations refer repeatedly to the Mast Data Sheet, a copy of which is presented in Table 3.

- **Tubular masts:**

1. Only a one-section mast is required (typically up to 1.6 m):
   - Only the two columns marked "Upper" are filled in:
     - The diameter is marked in the width column as D51
     - The height column is left unfilled.
2. A two-section mast is required (typically between 1.6 - 2.5 m):
   - Only the two columns marked "Upper" are filled in:
     - The diameter is indicated as D86 in the width column. The D51 tube is not marked at all, as it is unavoidably needed for fitting the lights
     - The height column is left unfilled.
3. A three-section mast is required (typically between 2.5 - 4.0 m):
   - First, the two columns marked "Upper" are filled in:
     - The diameter is indicated as D86 in the width column. The D51 tube is not marked at all, as it is unavoidably needed for fitting the lights
     - The height column is left unfilled.
   - Following that, the two columns on right marked "Lower" are filled in:
     - The diameter is indicated as D106 in the width column
     - The height column is left unfilled.

- **Lattice masts:**

1. Only a 400 mm wide module is required:
   - Only the columns marked "Upper" are filled in:
     - The module width is indicated in the width column as W400
     - The module height is written in the height column as given in the Mast Selection Table.
2. A mast consisting of two modules of 400 mm and 500 mm widths is required:
   - First, the columns marked "Upper" are filled in:
     - The module width is indicated in the width column as W400
     - The module height is written in the height column as given in the Mast Selection Table.
   - Following that, the selected 500 mm lower section is indicated in the two columns marked "Lower":
     - The width of the 500 mm module is indicated in the width column as W500
     - The height of the 500 mm module is written to the height column as given in the Mast Selection Table.

The Exel representatives will complete the table with the heights of the individual tubular elements, taking into account the overlaps at the connections and the additional reserve length.

Table 3 A copy of a section of the Mast Data Sheet, used for documenting the necessary input data and the mast selection (see also Appendix 3).

PROJECT:	DATE:	PAGE:
Type of approach light system:		CAT

POSITION	LIGHT	MAST TYPE	CROSS-BAR TUBE		SELECTED MAST MODULES*			
					Upper		Lower	
Pos.no/ distance	From position foundation	L=Latt. T=Tube	Number of lights	Spacing (mertres)	Width W400 D86 or D51	Height	Width W500 D106	Height

*Selection may be left to EXEL

3.4.3 Matching the Heights by Adjusting the Basement Level (Optional)

Due to the use of standard lattice modules of fixed heights, the nominal light height hardly ever coincides exactly with the desired light height (measured from the basement level). As explained earlier, this is taken care of by the adjustment tubes provided. This means, however, that the full adjustment range is not available for later in-service corrections. There might be cases where it is desirable to have the full adjustment capability available for the operational use, for example to compensate possible errors in the earth moving operations or in casting the foundations. It would also enable the later changing of the light heights of the whole system, should this be required.

To achieve this, the required light height (from position basement level) and the light height of the closest matching mast may be forced to be equal. This is done by adjusting the level of the foundation. The correction procedure is as follows:

- The closest matching mast is selected. The maximum height difference between the mast light height and required height is then ±125 mm.

- The position basement level is re-defined by lifting or lowering the foundation by a correction equal to the detected height difference (see Figure 12). For example:
  - If the light height of the selected mast is 75 mm less than the required height, the basement level is lifted up by 75 mm
  - Respectively, if the mast light height is, say, 120 mm greater than the required height, the position basement should be set 120 mm lower than originally thought.

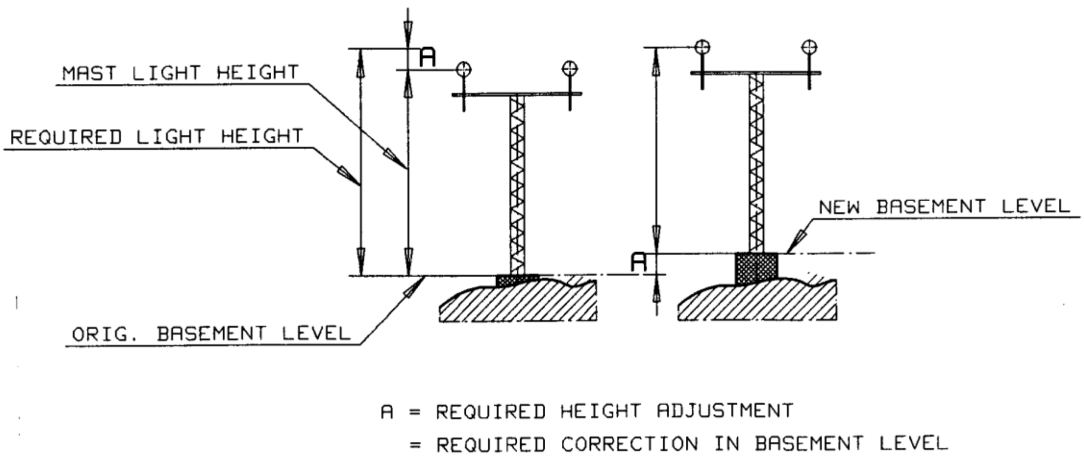


Figure 12 The correction required for matching the desired light height exactly with the mast light height.

This correction is noted in the documentation by replacing the earlier heights of the basement levels with the re-defined heights. This ensures that the new basement heights will eventually take effect.

The lights are now set automatically to the right heights, when the lights are located in their nominal midpoint positions. Installation tolerances may require minor adjustment, but basically the whole adjustment range is available for possible later needs.

3.5 Foundation Design

The concrete foundation has to be strong enough to carry the maximum loads that may be transmitted through the mast. The predominant loads are the bending moment and the shear force. The magnitude of these loads is determined by the mast height, total wind area of the mast structures (incl. the mounted devices) and the wind loads. In addition to the external loads, the dimensions of the foundation are affected by the local soil type and environmental factors, such as the annual frost.

If found necessary for dimensioning the foundations, Exel representatives are ready to provide the necessary calculation loads at the base of each mast (shear force and bending moment). It is recommended that a local civil engineer is consulted about the actual foundation construction.

4. MAST STRUCTURAL DESIGN PRINCIPLES

The masts have to be sufficiently strong and stiff. The minimum stiffness is, to a great extent, dictated by the permissible angular deflections of the light beams. The external and internal loads set strength requirements separately to each structural component as well as the mast as a whole. In the structural design of the available mast combinations, the calculation loads each element is subjected to have been compared against the characteristic strength values. The strength values have been obtained by performing numerous structural tests on each component. A sufficient strength reserve has been provided by applying specially determined safety factors.

The calculated performance is strongly dependent on the design wind load. Throughout the world highly varying wind loads are applied. The required wind loads are typically based on local mean occurrences of certain strong winds, thus being different for each climatic region. Furthermore, the design wind loads are affected by the natural protection provided by the surrounding area. Therefore, the coast line areas typically have the highest design wind loads. The mast combinations made available in this guide have been dimensioned to withstand the maximum wind loads occurring in Northern Europe at coast lines and large open areas. As a result, the maximum expected wind velocities used in the stress calculations have been 40,0 m/s for a short term gust load and 25,8 m/s for a constant fatigue load.

Higher strength against wind loads is often required. In such cases the maximum possible mast heights with maximum cross-bar loads need to be checked separately. It is most important that required design wind velocities are discussed with the Exel representatives at the design stage, as typically the higher wind loads force to reductions in the maximum height/load combinations.

Higher wind velocities may also be caused by the jet blasts produced by low flying aircraft. In the design of the Exel masts, the calculation jet blast loads have been based on the ICAO instructions detailing gust velocity curves behind a heavy transport aircraft, with jet engines at maximum thrust. The jet blast effect is highly dependent on the distance from the engine. In this case the calculation distances from the engines to the masts have been based on the minimum performance requirements of FAR 25 (the lowest allowable flight path in take-off) and on the performance data of a real transport aircraft. In the structural design the jet blasts have been treated as additional wind gust loads.

It has been found that the jet blasts need to be considered within the first 240 m from the threshold, the jet blasts preventing the use of high masts with heavy cross-bar loads within this area. The available mast combinations within this area are given in the complete set of Mast Selection Tables in Appendix 1, the first table covering the most severe area from the threshold to 150 m, and the second one extending from 150 m to 240 m. If higher masts are required in these areas, they have to be considered as exceptions and discussed case by case with the Exel representatives.

5. SUMMARY

This guide has been developed to assist in the design process of an approach lighting system employing Exel masts. This guide has been created to combine the essential ICAO requirements and recommendations with the selection process of the Exel masts, in order to build up a single design procedure.

This guide has not been intended to relieve the designer of reading Annex 14. In some cases, certain figures or chapters of Annex 14 are only referred to, since it would not have been justifiable to repeat all the requirements of Annex 14 in this guide. Although the most essential stages of the design have been included, Annex 14 is still needed for checking details, as well as sorting out the special cases. In this guide the determination of the correct heights for the lights, masts and foundations have been dealt with in great detail. The given instructions need to be followed in order to reach the optimum results. To assist the design process, a ready-made table, called Mast Data Sheet, has been provided in Appendix 3 for documenting the essential data.

In addition to filling the data sheet, a lay-out plan showing the mast and light positions has to be made. A base for the actual lay-out drawing has been provided in Appendix 2 with the necessary information for completing it.

If further information is required about any of the matters contained in this guide or indeed about Exel masts, the Exel personnel will be delighted to provide it. The necessary contact information can be found in Appendix 4.

APPENDICES

A1. Mast Selection Table 1: Available lattice mast modules and combinations (distance from the threshold not less than 240 m)

MAST LIGHT HEIGHT from position basement level			Total modular height	MODULES		COMBINATIONS
Midpoint mm	Range min	max	mm	400 mm module height mm	500 mm module height mm	400 mm module height + 500 mm module height mm
1900	1650	2150	1250	1250		
2150	1900	2400	1500	1500		
2400	2150	2650	1750	1750		
2650	2400	2900	2000	2000		
2900	2650	3150	2250	2250		
3150	2900	3400	2500	2500		
3400	3150	3650	2750	2750		
3650	3400	3900	3000	3000	3000	
3900	3650	4150	3250	3250		
4150	3900	4400	3500	3500		
4400	4150	4650	3750	3750		
4650	4400	4900	4000	4000	4000	
4900	4650	5150	4250	4250		
5150	4900	5400	4500	4500		
5400	5150	5650	4750	4750		
5650	5400	5900	5000	5000	5000	2000 + 3000
5900	5650	6150	5250	5250		2250 + 3000
6150	5900	6400	5500	5500		2500 + 3000
6400	6150	6650	5750	5750		2750 + 3000
6650	6400	6900	6000	6000	6000	3000 + 3000
6900	6650	7150	6250	6250		3250 + 3250
7150	6900	7400	6500	6500		3500 + 3000
7400	7150	7650	6750	6750		3750 + 3000
7650	7400	7900	7000	7000	7000	3000 + 4000
7900	7650	8150	7250	7250		3250 + 4000
8150	7900	8400	7500	7500		3500 + 4000
8400	8150	8650	7750	7750		3750 + 4000
8650	8400	8900	8000	8000		3000 + 5000
8900	8650	9150	8250			3250 + 5000
9150	8900	9400	8500			3500 + 5000
9400	9150	9650	8750			3750 + 5000
9650	9400	9900	9000			4000 + 5000
9900	9650	10150	9250			4250 + 5000
10150	9900	10400	9500			4500 + 5000
10400	10150	10650	9750			4750 + 5000
10650	10400	10900	10000			5000 + 5000
10900	10650	11150	10250			5250 + 5000
11150	10900	11400	10500			5500 + 5000
11400	11150	11650	10750			5750 + 5000
11650	11400	11900	11000			5000 + 6000
11900	11650	12150	11250			5250 + 6000
12150	11900	12400	11500			5500 + 6000
12400	12150	12650	11750			5750 + 6000
12650	12400	12900	12000			6000 + 6000

NOTE: ***A 500 mm module may only be used in combination with a 400 mm module***
The shaded alternatives may only be used in special cases

Mast Selection Table 2: Available lattice mast modules and combinations (distance from the threshold btw 150-210 m)

MAST LIGHT HEIGHT from position basement level Midpoint mm	Range min	max	Total modular height mm	MODULES 400 mm module height mm	500 mm module height mm	COMBINATIONS 400 mm module height + 500 mm module height mm
1900	1650	2150	1250	1250		
2150	1900	2400	1500	1500		
2400	2150	2650	1750	1750		
2650	2400	2900	2000	2000		
2900	2650	3150	2250	2250		
3150	2900	3400	2500	2500		
3400	3150	3650	2750	2750		
3650	3400	3900	3000	3000	3000	
3900	3650	4150	3250	3250		
4150	3900	4400	3500	3500		
4400	4150	4650	3750	3750		
4650	4400	4900	4000	4000	4000	
4900	4650	5150	4250	4250		
5150	4900	5400	4500	4500		
5400	5150	5650	4750	4750		
5650	5400	5900	5000	5000	5000	2000 + 3000
5900	5650	6150	5250	5250		2250 + 3000
6150	5900	6400	5500	5500		2500 + 3000
6400	6150	6650	5750	5750		2750 + 3000
6650	6400	6900	6000	6000	6000	3000 + 3000
6900	6650	7150	6250	6250		3250 + 3250
7150	6900	7400	6500	6500		3500 + 3000
7400	7150	7650	6750	6750		3750 + 3000
7650	7400	7900	7000	7000	7000	3000 + 4000
7900	7650	8150	7250	7250		3250 + 4000

NOTE: A 500 mm module may only be used in combination with a 400 mm module
The shaded alternatives may only be used in special cases

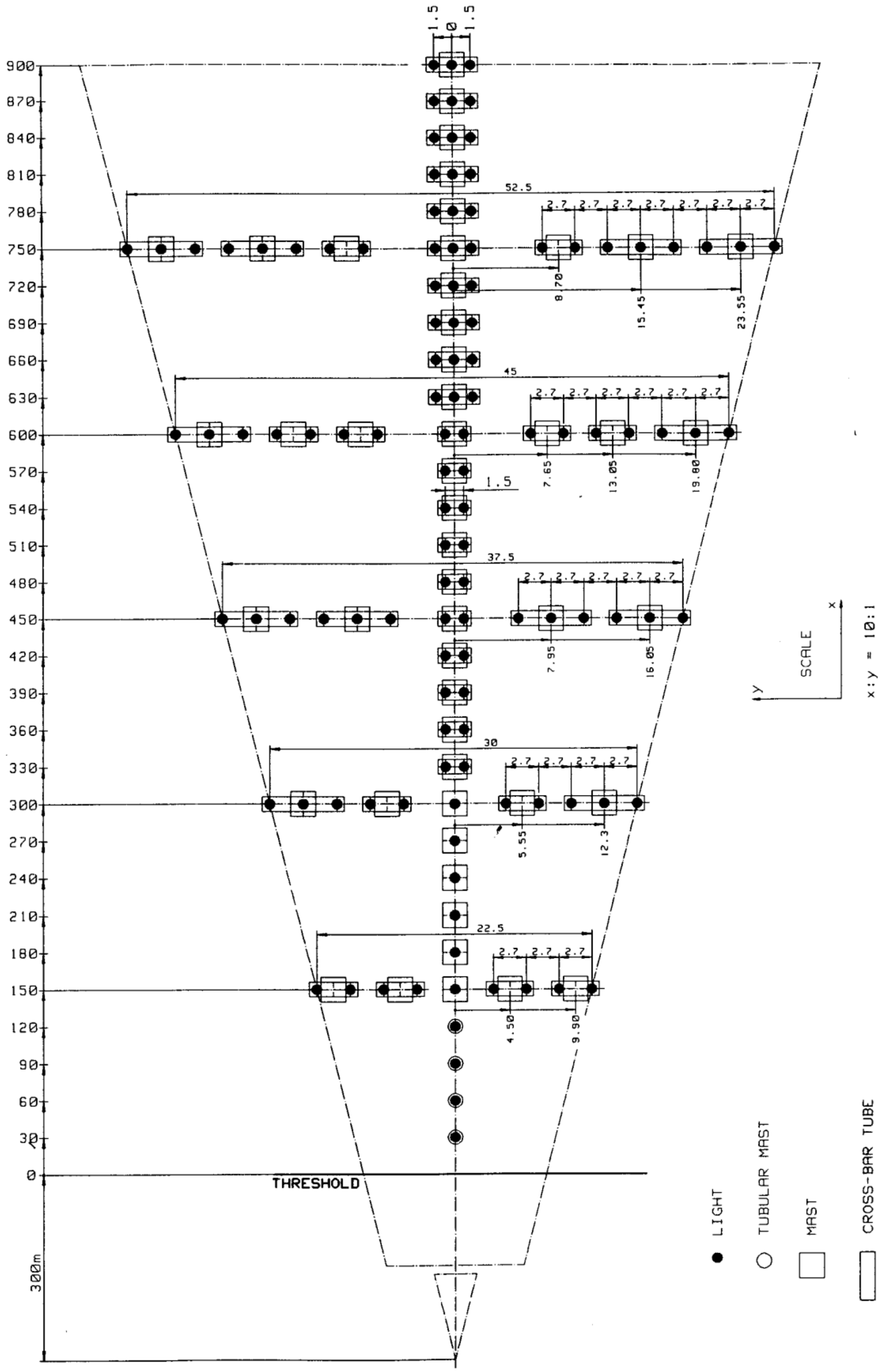
Mast Selection Table 3: Available lattice mast modules and combinations (distance from the threshold btw 30-120 m)

MAST LIGHT HEIGHT from position basement level Midpoint mm	Range min	max	Total modular height mm	MODULES 400 mm module height mm	500 mm module height mm	COMBINATIONS 400 mm module height + 500 mm module height mm
1900	1650	2150	1250	1250		
2150	1900	2400	1500	1500		
2400	2150	2650	1750	1750		
2650	2400	2900	2000	2000		
2900	2650	3150	2250	2250		
3150	2900	3400	2500	2500		
3400	3150	3650	2750	2750		

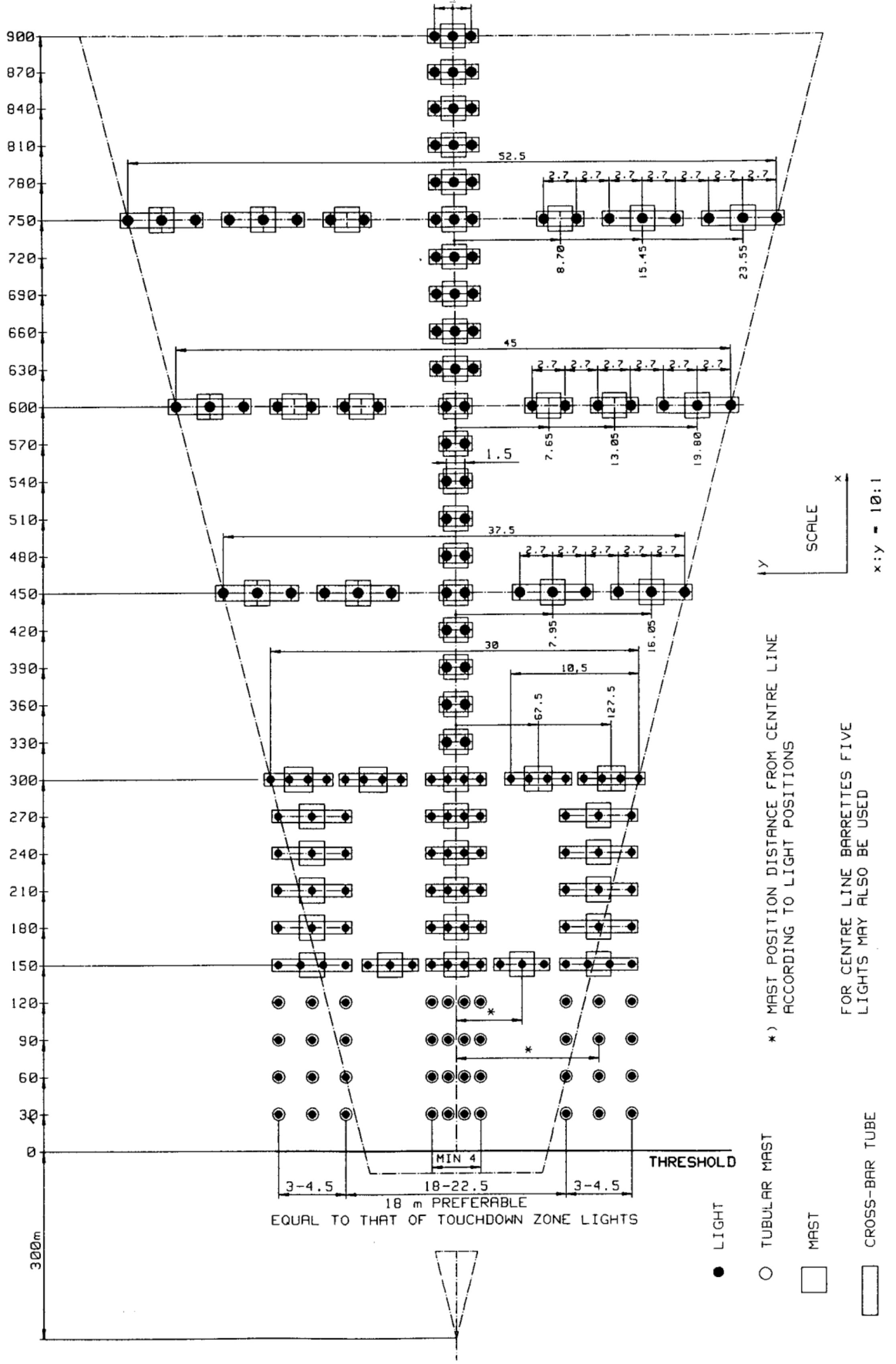
NOTE: A 500 mm module may only be used in combination with a 400 mm module
The shaded alternatives may only be used in special cases

A2. Lay-out drawings

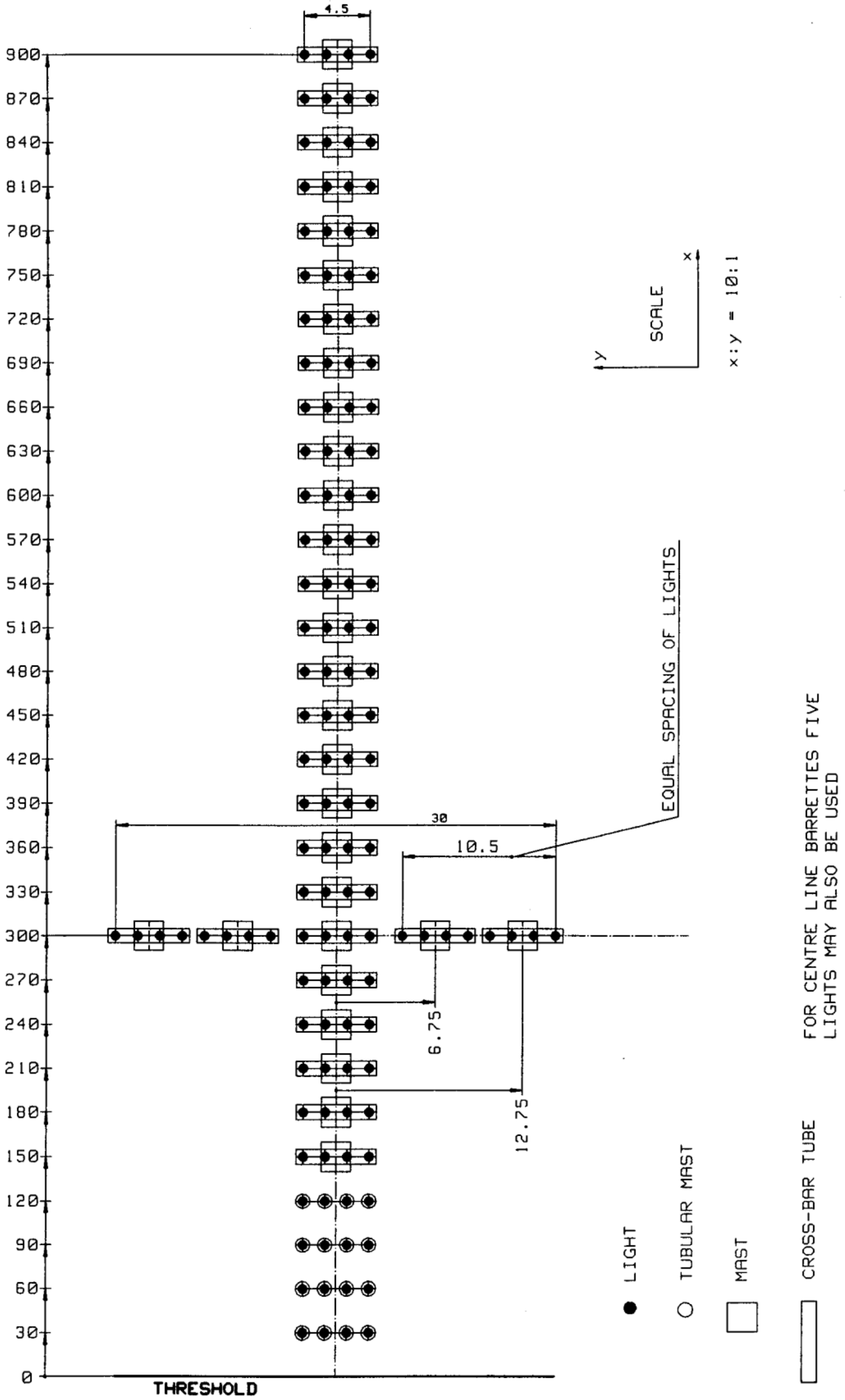
A2.1 Distance Coded Centre Line, CAT I


1.5
0
1.5
900
870
840
810
780
750
720
690
660
630
600
570
540
510
480
450
420
390
360
330
300
270
240
210
180
150
120
90
60
30
0
52.5
2.7
8.70
15.45
23.55
45
7.65
13.05
19.80
1.5
37.5
7.95
16.05
30
5.55
12.3
22.5
4.50
9.90
THRESHOLD
300m
SCALE
x:y = 10:1
LIGHT
TUBULAR MAST
MAST
CROSS-BAR TUBE

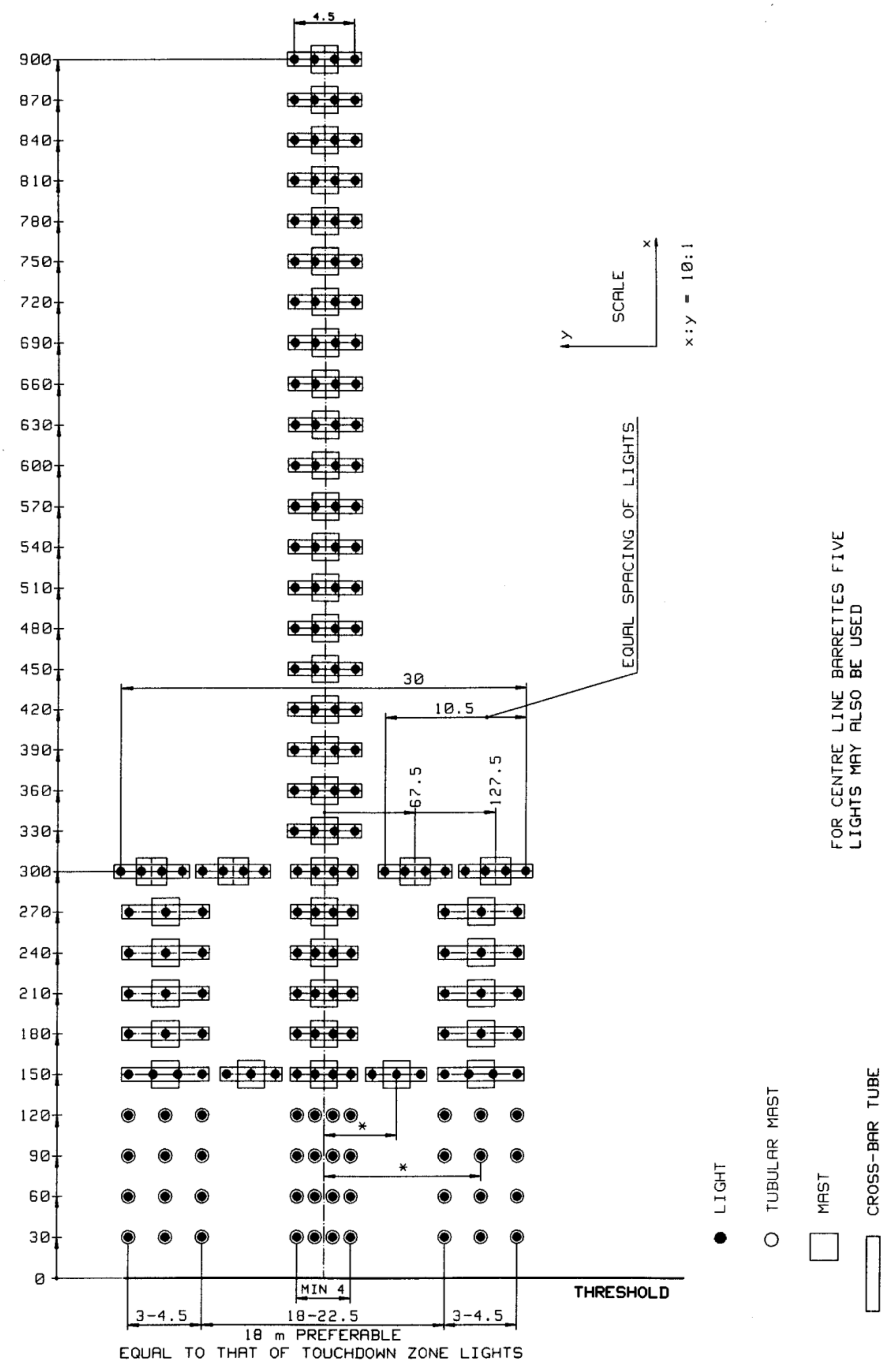
A2.2 Distance Coded Centre Line, CAT II and CAT III



A2.3 Barrette Centre Line, CAT I



A2.4 Barrette Centre Line, CAT II and CAT III



A3 MAST DATA SHEET

PROJECT:	DATE:	PAGE:
Type of approach light system:		CAT

POSITION	**LIGHT**	**MAST TYPE**	**CROSS-BAR TUBE**		**SELECTED MAST MODULES***			
					Upper		**Lower**	
Pos.no/ distance	From position foundation	L=Latt. T=Tube	Number of lights	Spacing (mertres)	Width W400 D86 or D51	Height	Width W500 D106	Height

*Selection may be left to EXEL

MAST DATA SHEET continued

PROJECT:	DATE:	PAGE:
Type of approach light system:		CAT

POSITION	LIGHT	MAST TYPE	CROSS-BAR TUBE		SELECTED MAST MODULES*			
					Upper		Lower	
Pos.no/ distance	From position foundation	L=Latt. T=Tube	Number of lights	Spacing (mertres)	Width W400 D86 or D51	Height	Width W500 D106	Height

*Selection may be left to EXEL

A4. Contact information

The Exel contact person is:

Mr. Patrick Loock

at:

Exel Composites Plc
Kivara Factory
Muovilaaksontie 2
FIN-82110 Heinävaara
FINLAND

tel. +358-(0)20 754 1200

e-mail: patrick.loock@exelcomposites.com
web: www.exelcomposites.com