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SOLUTION MODELING OF A COLLISION FOR AIRPORT APPROACH LIGHTS AND ACCESS ROAD AT TIVAT AIRPORT

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ABSTRACT

Construction of a new road has been planned in the approach area of Tivat Airport in Montenegro. The route of the new road collides with the existing approach lights of the airport, which are part of the lighting system for the safe landing of aircraft. This paper presents a solution for collision issues using modelling methods. The initial hypothesis was confirmed at the Department of Electrical Engineering, Zagreb University of Applied Sciences, and is based on scientific Elaborations using the Image-Based Lighting Model. The model analyses and processes the airport approach light plane and approximates it using an image of global illumination (Global Illumination Model). The large-source light image model is applicable to airport approach lighting systems that are viewed as separate entities. The modelling parameters include legislative requirements for: a) road traffic safety, b) air traffic safety at the airport for both the existing and newly designed state, c) the approach lights and d) the access road. A detailed study using project solutions (both available and new projects) and the existing state of the airport approach lighting system was conducted. The conclusion is the synthesis of all safety restrictions, which solved the collision problems between the new road and the existing airport approach lighting pillars.

Key words: airport approach lights, image-based lighting model

1. INTRODUCTION

The approach lighting system at Tivat Airport (AP LYTV) is a precise non-instrumental landing direction system LD 32 that covers an area of 900 m long from the runway threshold and is standard for all categories of airports (CAT I-III). The configuration of such a lighting system is made up of 30 crossbars placed at 30m intervals. On each crossbar, there are five high-intensity lamps (light sources). The position of the AP LYTV approach light crossbars in space in relation to the existing road is in collision with the new access road (Figure 1).

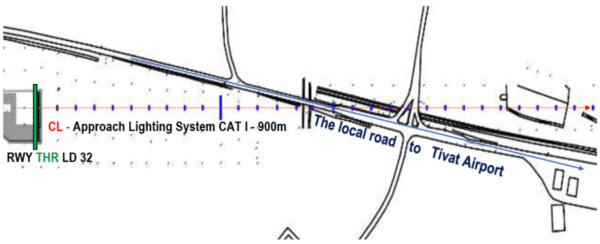


Figure 1 *Spatial representation of the approach light crossbars at Tivat Airport, [12]*

The positions of the approach lighting columns were addressed and solved by previous projects, and the lighting is installed according to them. For the new road, which has a modified route, the issue of collision with the existing airport approach lighting system, which needs to be modernized, has arisen. An analysis of the designed solutions (available and new projects) and the existing state of the AP LYTV approach lighting system CAT I indicated the limitations within which the problem can be resolved. The legislative requirements that are established and immutable refer to the:

- direction (orientation) of the central line of the approach lights in a 900m length area from the threshold, in line with the central line of the runway,

- configuration of the lighting system with thirty crossbars at equal intervals, and
- gradient of height limitations for the pillars, on which the crossbars, with approach lights are mounted for the terrain configuration with an uphill slope.

The approach to analyzing project solutions involves the obligation to meet the requirements of relevant legislation [1-3]. Certain deviations have been observed in the implemented approach lights AP LYTV, so it is very important that the new road design accepts legislative restrictions within which the subject problem can be resolved. The initial hypothesis for resolving the problem was based on scientific developments and conducted through scientific, research and thesis work at the Department of Electrical Engineering, Zagreb University of Applied Sciences. The hypothesis is based on an image-based lighting (IBL) model. This set of lighting techniques does not use analytical light sources, but analyzes one global light source. The model has been confirmed on actual systems of approach lighting [4-5]. It is promoted as a model that can be used for a more precise representation of airport signaling lights confirmed by a flight check. Approach airport lighting as a system approximated and modeled by global illumination (GL), uses relevant parameters of legislative diagrams of flight paths used by pilots during approach and landing, but also parameters of databases for predictive maintenance of airport lighting, [6-8].

2. ANALYSIS OF THE ACTUAL CONDITION AND NEW PROJECT SOLUTIONS

The specificity of the approach lighting as part of the AP LYTV lighting system is related to the location of the collision with the existing and future road, and has been addressed in project documentation [9-13]. The existing AP LYTV Approach lighting system extends through two boundaries of the approach lights area within the airport's property. Crossbars 1- 14 and 21 -30 are on land fenced for airport needs, and crossbars 15-20 are located precisely in the road collision area (Figure 2).

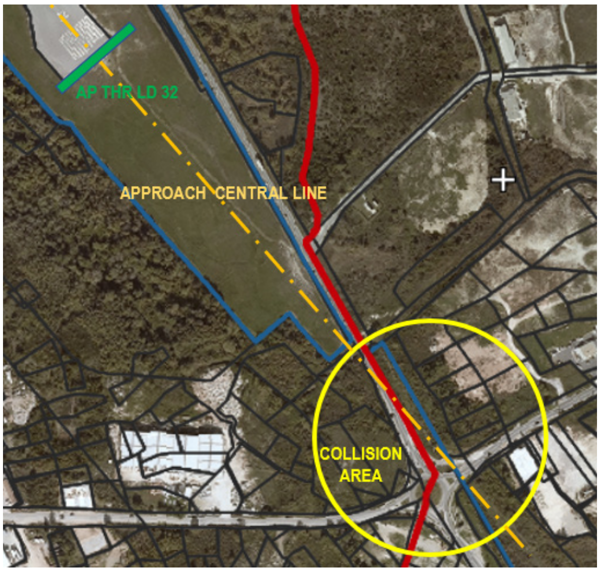


Figure 2 *Cadastral area of the Tivat Airport approach lights in the collision zone with the access road, [13]*

A special analysis is conducted for the collision area. A specific feature is the 16th crossbar of the approach lights from the runway threshold, which are installed on a portal above the road (Figure 3).

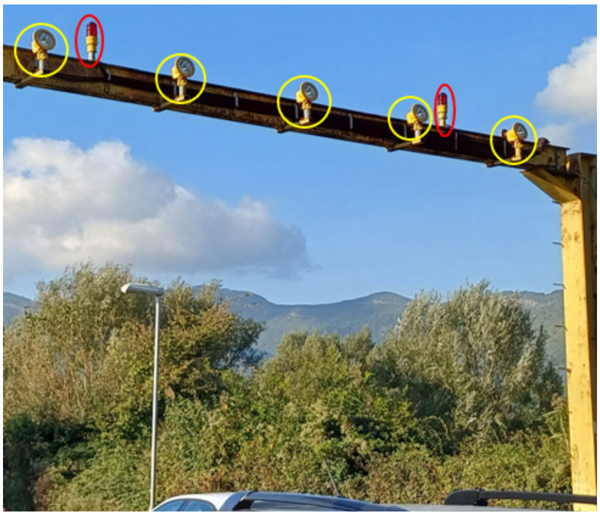


Figure 3 Portal over the road with a removable crossbar and five approach lights and two obstacle marking lights of the Tivat Airport, [13]

Relevant parameters related to the existing portal have been determined for processing. The analysis covered:

- Air traffic safety requirements at the airport,
- Road traffic safety requirements, and
- The need to dismantle the portal crossbar in case of the passage of oversized vehicles underneath it, (Figure 4), (Table 1).

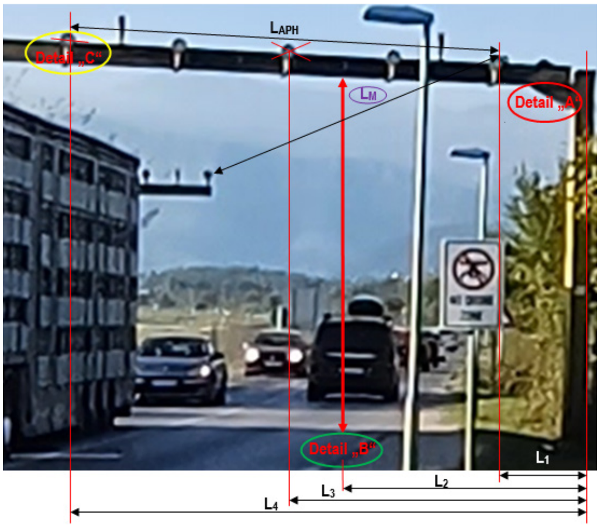


Figure 4 *The characteristic parameters for safety requirements highlighted on the portal with the crossbar of the Tivat Airport approach lights, [13]*

The meaning of the parameters in Figure 5 is described in Table 1.

Table 1 *The meaning of individual parameters of the safety requirements from Figure 5*

L_M-	distance between the crossbars of the approach light
L1-	distance of the first crossbar light from the portal pillar
L2-	distance of the roadside from the portal pillar
L3-	distance of the central light of the crossbar from the portal pillar
L4-	distance of the rear light of the crossbar from the portal pillar
L_{APH}	crossbar width, (distance from the first to the fifth light of the crossbar)
Detail „A"	defines the structural solution of the portal, crossbar and pillar construction, (DR)*
Detail „B"	defines the distance from the road, (pillar position to the edge of the road, (RT)**
Detail „C"	defines the height of the crossbar to the road, (critical height of passage - RT safety requirement)
Detail „L_M"	defines the position and height of the portal, (lighting plane of the approach – (ICAO)***

LEGEND: *- Disassembly Requirement, (DR);
**- Road Traffic Safety Requirement, (RT);
***- ICAO Safety Requirement, (ICAO)

In the collision area with the existing road, there are pillars and portals with crossbars of approach airport lighting. Different construction solutions for specific locations have met the safety requirements (ICAO, RT, DR), and the aeronautical specificities for airport lighting system in various ways. An example is the protection of a pillar located near the road edge (Figure 5).

Figure 5 *"T" pillare with five lights on the approach lighting crossbar Tivat Airport alongside the road, [13]*

An example is the portal over the stream with a maintenance platform (Figure 6).

Figure 6 *Compact portal over the stream with crossbar of the Tivat Airport approach lighting with maintenance platform, [13]*

An example is the installation of obstacle lights next to the lights of the central line of the approach airport lighting (Figure 7).

Figure 7 *Pillar type "T" with approach lights and a single light for obstacle marking Tivat Airport, [13]*

An example of a pipe-structure pillar (Figure 8)

Figure 8 *Pillar type „Π“ with pipe-structure and crossbar for the approach lights of Tivat Airport, [13]*

The information provided explains that geodetic surveys were conducted for the existing condition, and two groups of recorded parameters are available (crossbars 13 to 23). Certain legislative non-compliances and deviations in the airport approach lighting system were observed, such as:

- significant differences in the spacing between individual crossbars,
- variations in the heights of the light source focus on individual crossbars,
- and the exceeding of the maximum gradient for the increase in the maximum height of the focus.

Additionally, it mentions that new project documentation [14], includes the design of a new, larger roundabout in the collision zone. The direction of the central line and the spacing between the crossbars for the existing configuration of the approach lights were determined on the roundabout (Figure 9).

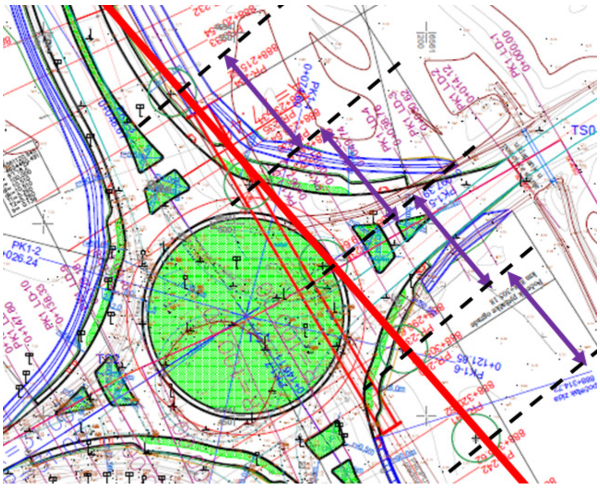


Figure 9 *New circular traffic with the marked direction of the central line of approach airport lights, [14]*

3. ELABORATION, MODELING AND SOLUTION PROPOSAL

The analysis Elaborates on three potential approaches for solving the collision problem:

- Option A - Complete resolution of the collision problem can be achieved with a new approach lighting project that addresses all 30 approach lighting crossbars. Utilizing the Total Image-Based Lighting/Global Illumination Model (IBL/GI), this approach would encompass the analysis of differences and non-compliances including the position of the: 1. threshold (elevation 4,935m) and threshold lights (±ΔTHR= ± 2.3m), 2. the largest deviations in spacing between the crossbars (> 6.7/5m), 3. deviations in the elevation of lights on the crossbars (> 1.2m/0.8m) and 4. the sub-positioning of obstacle lights and approach lighting, as well as other factors.
- Option B - Segmental intervention in the approach lighting system using the same IBL/GI model, targeting specific areas with significant deviations and non-compliances to overlay the modeling onto the existing lighting picture.
- Option C - Optimization processing in the collision zone - "ad hoc" approach, using the IBL/GI model. This model would involve adapting the existing mounting locations for the new project design through the optimization of construction solutions for foundations, pillars, and portals. The modeling would overlay the optimal solution onto the existing approach lighting.

It is important to note, that each of the options for reinstating the lighting system, involves interventions on the complete approach lighting equipment, taking into account its condition and service life. These interventions encompass all electrical, mechanical, and construction works, and two scenarios are possible:

- **Restoration of the existing equipment**, which must include all approach lighting crossbars and ensure that legislatively compliant lighting characteristics are achieved, justifying the solutions from the originally designed and implemented condition

- **Replacement of the existing equipment** involves the selection and application of all compatible types of replacement equipment and components of the lighting signaling system (lamps, light sources, installation of series circuits, cable, etc.).

3.1. LEGISLATIVE BASES FOR NEW APPROACH LIGHTS PROJECTS

The resolution of the pillars of the approach lighting system at AP LYTV, which are in the collision zone with the new road, is processed according to the flight path envelopes in accordance with the legislation (Figure 10).

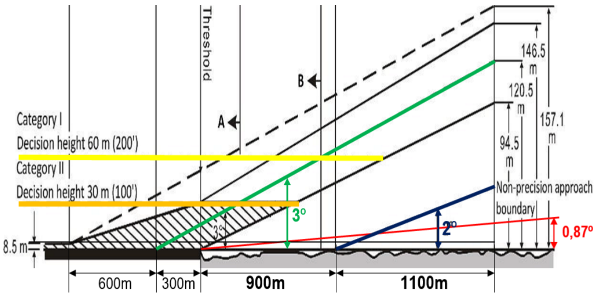


Figure 10 *Flight path envelope examples for airport lighting design, (CATI-III operations),[1]*

The appropriate approach lighting system supports pilots during landing, helping them to decide whether to continue the landing or abort it. This is the moment known as the decision height which, depending on the type of approach, takes into account factors of weather conditions and the categories of equipment on the ground and in the air. The length of the approach lighting system supporting all approach categories is 900 meters. The Decision Height, (DH) in Figure 10, is 60m for CAT I (A), 30m for CAT II (B), and 0m for CAT III (C). The non-precise approach, defined as a theoretical base for modeling, proposes a method for determining the positions of the approach lights at AP LYTV, with a distance two kilometers before the USS threshold. Considering the current state, a comprehensive verification and confirmation of all related components are necessary for the complete functionality of the airport approach lighting system. This includes primary and secondary power supply, control monitoring system, photometry, and flight checks, all in accordance with legislative requirements (Table 2).

Table 2 *Overview of the legislative requirements for all parts of the Airfield lighting system, [13]*

Part system/ Equipment	FO /N	M	A	Legislation EASA*/ICAO**
Approach lighting system LD 32				CS ADR-DSN.N.775 /CS ADR-DSN.M.615,625, 626, 640/ CS ADR-DSN.Q.840, 841, 845-852/ CS ADR-DSN.U.925, 930, 935/GM1 ADR-DSN.T.910, 915
Grounding system				GM1 ADR-DSN.K.490, T910/CS ADR-DSN.S.880, GM1-S885/ ICAO Doc 9157:1. Ch.5, 9,10,13-15
Cable Pipes Manholes				ICAO Doc 9157, AN/901, Part 5, Ed. 1st Ch.4–5
Control and Monitoring System				CS ADR-DSN.S.880/ GM1 ADR-SN.S.890,895 ICAO Doc 9157: Ch.10
Series Circuits				ICAO Doc 9157, AN/901, Part 4 & 5, Ch.1 – 5
Constant Current Regulators				ICAO Doc 9157, AN/901, Part 4 & 5Ch.1 – 5
Power Supply Systems				ICAO Doc 9157, AN/901, Part 4 & 5
Light Characteristics				CS ADR-DSN.E,H,J,M
Cable Resistance				ICAO Doc 9157, AN/901, Part 4 & 5
Maintenance documentation				EASA-CS-ADR-DSN/ ICAO Annex 14- Design

LEGEND: *- Book/Chapter; **- Doc/Part/Chapter; - FO - out of function; M- Measurement, (assessment); A- Analysis, (functionality testing); N- Status unknown

3.2. MODELING OF THE CROSSBAR POSITIONS IN THE APPROACH LIGHTS COLLISION ZONE

Legislative requirements for airport categories, AP LYTV – CAT I, are related to the light intensity requirements for each individual lighting unit in airport lighting systems. These requirements must be met by manufacturers of equipment placed on the market, which they prove with their testing protocol along with catalogue data. During operation, the airport operator must ensure that the light intensity of each individual lighting unit in the airport lighting systems is within the acceptable limits that are in function of air navigation safety at the airport. According to analyzed catalogue data of lighting unit types that are part of the approach lighting system of Tivat Airport, the legislative requirements were met for the new lighting for the approach lighting system configuration, which

was set up so that the light approach plane starts from the threshold (fulfilling the general objective to the extent permitted by local conditions).
From the position of the lighting units, the image of the light plane must not be disturbed by the obscuration of individual light sources from the pilot's field of view. Nor must the image of the light plane be disturbed by the degraded measures of the approach lighting crossbars installed. For these reasons, modeling is conducted based on the synthesized subject matter associated with operational and empirical data from research and development projects and studies, as well as with the maintenance parameters of the airport, which have been determined as referential in relevant treatments, [15-21]. Modeling to solve the position of the approach lighting pillars in relation to the newly designed route of the future road in the collision area includes:

1. correction of the positions of the bases of the approach lighting pillars,
2. reconstruction of the installation of approach lighting lamps at the optimal height,
3. a solution for the construction of pillars at the optimal distance from the edge of the road,
4. a solution to optimize the height and direction of the approach lighting in the collision area in respect to the legislative requirement of the CAT I flight path diagram.

Modeling to address the issues of the approach lighting system AP LYTV is carried out using a Spreadsheet calculator based on Elaborated mathematical calculations confirmed by simulations using computer program algorithms. Modeling and programs have been validated at several airports on more demanding precision approach path indicators, [22-24]. The decision-making procedure about landing is confirmed by visual contact of the pilot with the lighting signal system. Mathematically, this is 1° below the incline of the PAPI approach path, which is most often 3°. The gradient of the light plane inclination of the approach lighting system for an uphill slope like that for AP LYTV is 0,87°, which is significantly lower and involves checking the obstacle clearance plane on the approach as precisely marked on figure 11. Computer modeling is conducted as an iterative optimization process, in this case, the position of the approach lighting crossbar pillars. Review of modeling parameters, (Table 3) with modeling equations:

$$LHT = tg\ (grad\ 66/1) \tag{1}$$

$$LRH = H_{pillar} + H_{FLS} + \Delta H \tag{2}$$

Table 3 *Overview of parameters for modeling the pillars positions of Airports approach lighting system, [13]*

Description	Parameter
C_D - Crossbar distance	nominal = 30m
Gradijent height	nominal = 1:66
Light height maximum	tg (grad 66/1)
Actual distance	measured
Δ Distance	(↔CL_{APPR})
Focus Light Source	H_{FLS} (↨CL ¬)
Crossbar construction	C_P (Δ↨)
Max. pillar height	H_{pillar} (↑)
Ref. Crossbar Position	(↔CL_{APPR}) R_{CP}
Ref. Height Light =LRH	$H_{pillar} + H_{FLS} + \Delta H$
Ref. Elevation = RE	(↨CL ¬) O_{SI} (↔)
Ref. Direction of Light	(↨CL ¬) ΔH (↑)

Parameters for modeling processing include:

- Legislative requirements,
- The determined actual executed state,
- Reference sizes,
- Limiting factors, and
- Optimization tuning boundaries.

The results of the optimization tuning, along with the limiting factors, involve the design Elaboration of the structural solutions for the pillars (Figure 11), taking into account the capabilities and dimensions of the equipment (Figure 12), and safety requirements Elaborated according to the markings on Figure 5 and description in Table 1.

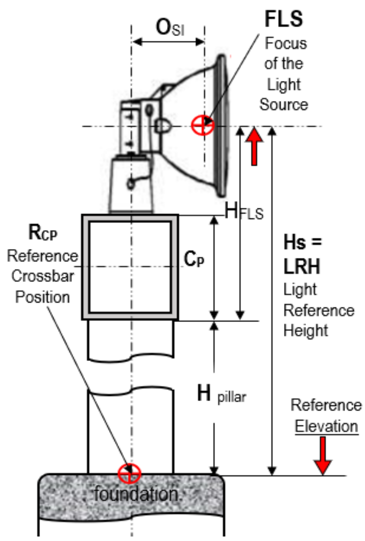
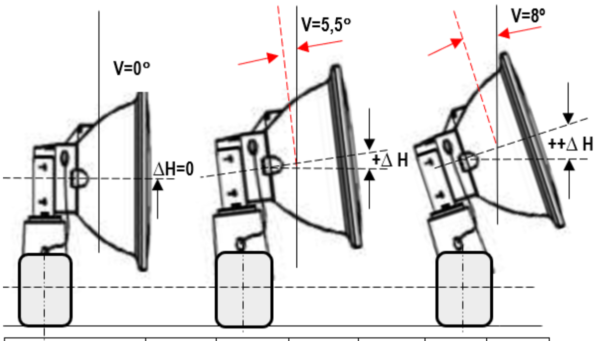


Figure 11 *Parameters for the Elaboration of structural solutions and positions of pillars, [13]*



Light position in relation to the THR	0-115m	116-215m	216-315m	316-475m	476-640m	> 641 (m)
Approach – Centre line – Crossbar	H=0° V=5.5°	H=0° V=5.5°	H=0° V=5.5°	H=0° V=6°	H=0° V=7°	H=0° V=8°

***Figure 12** Directional parameters of approach lights for optimization of pillar solutions, [13]*

The results of the modeling performed to address the position of the pillars of the approach lighting system in the collision zone with the access road are shown in Table 4. Extended modeling results can be found in Appendix 1, with reference to the method of solving through all three options, with modeling equations:

$$\Delta\ DSC = ICAO - MSR \quad (3)$$

$$LHT\ HGT = HGT_{GRD} + H_{THR} \quad (4)$$

$$\Delta\ LHT\ HGT = CLC - MSR \quad (5)$$

***Table 4** Overview of the results obtained by modeling the positions of approach lights pillars*

CRB Nr.	13	14	15	16
ICAO DCS	390	420	450	480
MSR I DSC	386,3	417,6	443,4	477,4
MSR II DSC	385,8	416,7	445,0	478,1
Δ DSC I	3,7	2,4	6,6	2,6
Δ DSC II	4,2	3,3	5,0	1,9
HGT_{GRD}	5,866	6,341	6,733	7,250
LHT HGT	10,857	11,313	11,769	12,224
LHT HGT I	11,25	12,00	12,70	12,70
LHT HGT II	11,195	11,931	12,633	13,344
Δ LHT HGT I	0,338	0,618	0,864	1,12
Δ LHT HGT II	0,393	0,687	0,931	0,931

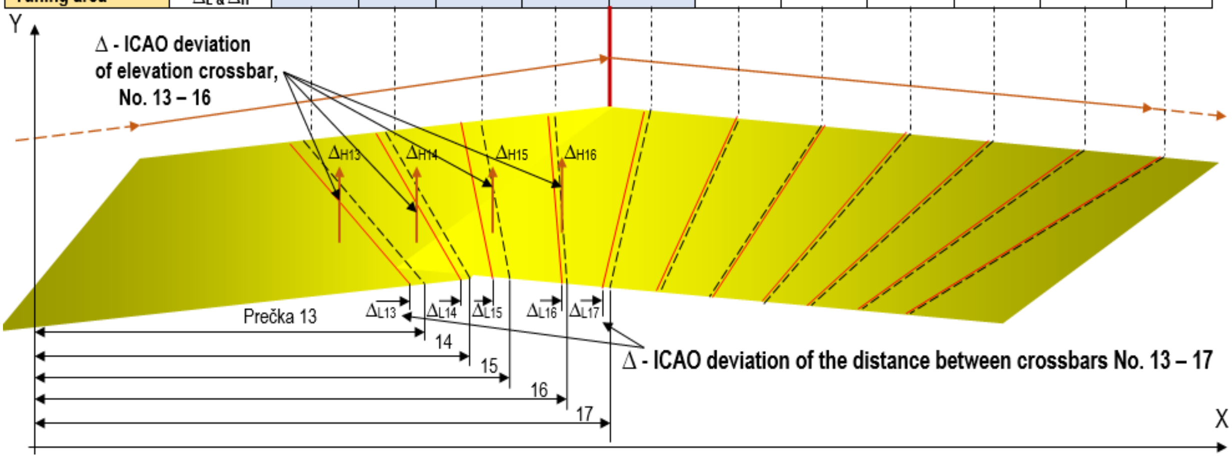
LEGEND: - calculated, (CLC); - measured, (MSR); - height, (HGT); - distance, (DSC); - HTHR = 4,935m; - Light, (LHT); - Crossbar, (CRB)
results highlighted in red refer to extreme values

4. CONCLUSION

The paper presents a method for resolving the collision issue between the new access road and the existing pillars of the Tivat airport approach lighting system through the method of modeling. Using the Image Based Lighting Model, the airport approach lights are analyzed and

***Appendix 1** Extended modeling results for the position of the approach lighting system pillars in the collision zone with the access road at Tivat Airport, [13]*

Crossbar No.		13	14	15	16	17	18	19	20	21	22	23
ICAO distance	from THR (m)	390	420	450	480	510	540	570	600	630	660	690
Average measure	from THR (m)	386,05	417,15	444,20	477,75	508,65	539,45	570,45	599,45	629,5	659,55	689,4
Difference	Δ_L	-3,95	-2,85	-5,80	-2,25	-1,35	-0,55	+0,55	-0,55	-0,50	-0,45	0,60
Gradient height	calculation	10,857	11,313	11,769	12,224	12,68	13,135	13,591	14,046	14,502	14,957	15,413
Average measure	(m)	11,2225	11,9655	12,6665	13,0220	12,5400	12,4235	12,2850	12,1720	12,0935	11,9685	11,8475
Difference	Δ_H	+0,3655	+0,6525	+0,8975	+0,7980	-0,1400	-0,7115	-1,7060	-1,8740	-2,4085	-2,9885	-3,5655
Tuning area	Δ_L & Δ_H											



processed as a light plane. This airport lighting system is approximated by a Global Illumination Image and modeled as a large light source image. The modeling aims to address the issue of collisions between the pillars of the approach lighting system at Tivat Airport and the access road using a tabular calculator. Additionally, optimization work has been carried out based on detailed mathematical calculations confirmed by simulations using computer program algorithms. The analysis of project solutions (both existing and new projects) and the existing condition has led to the synthesis of possible solutions within the established legislative constraints and practical options.

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