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Lightning protection risk analysis for structures

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1. Summary in Hungarian

Az emberiség fejlődése során ősidők óta folyamatos küzdelemben áll a természeti erőkkel, amelyben mindig kiemelt szerepet játszott és napjainkban is játszik az élet és vagyonvédelem. A biztonság egyik területét jelenti a mesterségesen létrehozott objektumok mindenoldalú védelme, azon belül az építmények villámvédelme, amit napjainkban a korszerű műszaki megoldások mellett már egzakt matematikai módszerekkel alátámasztott kockázatkezelési metódusok is támogatnak.

A villámvédelmi kockázatkezelés az építmények, illetve azok installációi (pl.: villámvédelmi berendezések, kábelezések, padlózat stb.) paramétereit figyelembe véve matematikai módszerekkel kiszámolja a konkrét építmény egyedileg sajátos villámvédelmi megfelelőségét. Kutatási területem a jelenleg érvényben lévő MSZ EN 62305-2:2012 szabvány feldolgozása alapján a bemenő paraméterek által determinált kimeneti eredmények összefüggéseinek feltárása különböző épülettípusok esetében, továbbá azok analízise által megállapított, az emberi élet elvesztése kockázatának beazonosítása és kiszámítása. Kutatási tervemben a későbbiekben definiált részletes kutatási célokra, hipotéziseimre alapozva azt a kutatási irányt tűztem ki, hogy az építmények villámvédelmi kockázatkezelése során a bemenő paraméterekre vonatkozóan egy eddig nem alkalmazott csoportosítási lehetőséget állapítsak meg tipizálható, jelentős emberi létszámot befogadó épületekkel kapcsolatban (pl.: társasház, irodaépület, gyártó csarnok). Kutatási területem tehát az építmények villámvédelmi kockázatelemzésére, különös tekintettel a szabvány által meghatározott bemeneti paraméterek, illetve azok változásainak kimenetre gyakorolt hatásai vizsgálatára terjedt ki a kiválasztott három épülettípus esetében. Ezt a tevékenységemet az általam írt kockázatszámítási informatikai program alapján végeztem. A programom a jelenlegi szabvány számítási metódusaival kiszámolja a kiválasztott épületek esetében a bemeneti paraméterek kialakított variánsaihoz tartozó kockázati értékeket. Az elméleti és gyakorlati érzékenységi vizsgálataim 51 840 számításával bebizonyítottam, hogy a mindhárom vizsgált objektum esetében melyek azok a bemeneti paraméterek, amelyek döntő mértékben befolyásolják az építmény villámvédelmi „Megfelelő” vagy „Nem megfelelő” besorolását.

Disszertációmban néhány sajátos építmény (pl.: hidak, hajók, nem-fém karosszériás jármű stb.), továbbá infrastruktúra és kritikus infrastruktúra esetében rávilágítottam azok villámvédelmének fontosságára, bemutatva a villámcsapáskor kialakuló elsődleges és másodlagos hatások speciális következményeit és javaslatot tettem azok megoldásának néhány elvi, műszaki megoldási lehetőségére. Mindezek alapján az elért eredményeim az iparban, a szabványosításban, az oktatásban és a tudományos kutatás számos területén konkrétan hasznosíthatóak és felhasználhatóak, hiszem az ember és az általa épített környezet folyamatosan egyidejű kölcsönhatásban van a természettel.

2. The antecedents of research and motivations

Mankind has been in constant struggle with the forces of nature since ancient times. The life and property protection have played a key role in this struggle and continue to play today as well. In this struggle, the all-round protection of artificially created objects has played and also today is playing a prominent role, one of the main areas of which is the lightning protection of structures.

As the **research questions** formulated in myself both there is a directing principle that can be used to demonstrate the possibly more dominant effect of certain input parameters as an output result on the lightning protection adequacy of structures and whether it may be justified to intervene in the process professionally in cooperation with the stakeholders during the design phase of the structures by controlling?

My research activities were determined by **personal, technical and scientific motivations** at the same time as well. My **personal motivation** was the technical interdisciplinary relationship between human and his built environment based on norms and normatives which is also embodied in standardization with regard to the safety of human life and property. My **technical motivation** was given by the topic of my bachelor thesis which I had written about arc flash analysis[1] at our University in 2013. Based on these two pillars, my **scientific motivation** was given by the scientific need contributing to the theoretical research of lightning-related issues and to the standardization closely related to the practical solutions of lightning protection. Both studying the MSZ 274 additionally the currently valid MSZ EN 62305 standard family and seeing lots of input parameters, I arose the need to examine their simultaneous and combinatorial mechanisms of action in the risk management of the lightning protection in buildings focusing on just the protection of the human life.

3. Research objectives, topicality, hypotheses and limitations

The significance and topicality of the research topic are given by the fact that in the constant system of relations between man and his built environment the protection of human life and property coincides with the development of societies, to which the protection of structures against lightning strikes is closely and inextricably linked. However, the detailed research goals defined in my dissertation as well as my hypotheses I set the research direction to establish a special grouping from all input parameters that has not been used so far during the lightning protection risk management of

[1] **Arc flash analysis**, Óbuda University, Kandó Kálmán Faculty of Electrical Engineering, Budapest, 2013.

buildings based on their input parameters. The research hypotheses were determined by the technical, economical and construction problems encountered in the design of lightning protection of buildings. After performing risk calculations and analysing the results afterwards, some risk factors came into focus. After reading the standards, several technical issues have come to light. I performed some risk calculations due to constructions in real life and encountered some ideas for my research. My ideas also made an interest into the examination of the draft version of the standard for the future so, I decided to extend my research. When I started my research and my work I got to know about other technical "co-areas".

Based on these, I have sought answers to my research questions by formulating the following hypotheses since 2017:

Hypothesis 1 (H1): During lightning protection risk management of MSZ EN 62305-2:2012, **not all input parameters may affect the output equally**, therefore they **may be grouped** into strong and non-strong categories.

Hypothesis 2 (H2): Within the strong parameters group, **some extremely strong parameters may be identified.**

Hypothesis 3 (H3): Final Draft IEC (FDIS)[2] 62305-2:2018 **incorrectly takes into account** the time spent on the type of roofs where persons can stay any time but not all protection measures have been taken into account in order to reduce human grouping in different cases.

Hypothesis 4 (H4)[3]: The input parameters of the Final Draft IEC (FDIS)[2] 62305-2:2018 **may also be grouped into the strong and non-strong categories.**

Research limitations

During my limitations, I applied **thematic and time constraints**. Determining the location (point of impact) of the lightning strike using neither rolling sphere nor safety angle method for the selected structures were the subjects of the research **as a thematic limitation.** Accepting the lightning strike as a fact, I made only reasonable references to them during the lightning protection

[2] 81/607/**FDIS** of 62305-2:2018 ED3: **F**inal **D**raft **I**nternational **S**tandard, Edition-3

[3] **H4 hypothesis** was formulated in July 2018, due to draft version of IEC 62305 Edition 3, version IEC FDIS 62305-2:2018. There wasn't available this version till at my **closing date of my scientific research on 30th of June 2020.**

risk management of the structures. I limited the theoretical and practical sensitivity tests only to the calculations and presentation of the results of the sample examples that theoretically support my scientific results due to the extremely large number of variations in the values and degrees of the input parameters and their grouping. The new contents of technical and fire protection etc. which are generated by changing the input parameters and their economical effect on investments were also not the subject of my research. Neither the other parts of MSZ EN 62305 standard family nor the codification process were the part of my research. By **timely limitation**, I mean the closing date of my scientific research process on **June 30, 2020.**

4. Research methods

I divided my research **activity into three main parts** and used different research methods in these parts.

In the first part of my research I studied both the documents of the standard family and the standards under modification which are related to lightning protection. I delimited the subject of my research based on not only the extensive literature search additionally processing of the domestic and international literature but also on the publications relevant to the topic as well.

In the second part of my research I performed the sensitivity tests on the risk of loss of human life in accordance with the requirements of the valid MSZ EN 62305-2:2012 standard. Seeing the multitude of input parameters, I decided that it is expedient to form some grouping with analysis. To form the groups I performed theoretical and practical sensitivity tests using the method of mathematical analysis by calculating the slopes about value sets of multivariate function[4] variable-by-variable[5] for the risk of loss of human life. I determined 22, 22 and 25 pieces of dominant input parameters based on the theoretical sensitivity test[6], which are named as the theoretical strong parameters groups by me. Selecting some parameters from this group, thus forming variation cases - considering the others constant until then - I calculated the value of the risk of loss of human life (R_1[4]) for the three chosen building types about the research. Based on these, I identified 8 pieces of strong input parameters of the practical sensitivity test. I also identified 2 pieces extremely strong input parameters. The research needed 51 840 calculations for the condominium, for the office

[4] **Marked as R_1** in MSZ EN 62305-2:2012.
[5] The independent variables are represented by the input parameters.
[6] **See:** In the „Results of sensitivity tests" Table, p.8

building and for the assembly plant together. I performed the algebraic calculations using the VBA[7] programming language of the MS Excel application operating in the MS Office environment using my macros which were created by me. Data management in my self–developed IT program was automated by my macros (Annex I). In the case of the structures under research, the specific values of my variation calculations for the risk of loss of human life (R_1) are included in the CD data carrier attached to the end of my doctoral dissertation in a pocket (Annex III).

In the third part of my research, I examined the different and special materials used for lightning protection as a co-area of my topic. I made a theoretical engineering opinion and recommendation on the specific lightning protection requirements of non-metal (e.g.: composite) body electric cars as a possible area of the theoretical research and practical implementation in the future [P4][8] [P12][8]. Nowadays, it is not in the standardization process at the moment the performance of sensitivity tests based on model experimentation may be an area of engineering and standardization field of research in the future. I also highlighted the danger of lightning about both some special infrastructures and some halls, structures in reality auspices of the protection in with connection both our human life and our built environment. **Finally,** I performed both a comparative analysis of the systematic relationship among the research questions - hypotheses - results of their harmonised correlations and based on these I formulated my scientific results corrected with my research limitations.

5. My new scientific results

My first thesis (T1) is:

> *I proved with scientific methods that in the case of risk management according to the MSZ EN 62305-2:2012 standard, **not all input parameters affect the output equally**. Therefore, **they can be grouped** into the strong and non-strong categories.*

I calculated the slopes about the value sets of function for the 40 input parameters of the currently valid standard of MSZ EN 62305-2:2012. Both during my comparative analysis of the common results of the theoretical and practical sensitivity tests and focused on their common effects on the output as well. Based on the results of the practical sensitivity test, I discovered 8 pieces of input parameters which are dominant on the output. I have grouped and named them as the members of the strong group of the input parameters. These are shown in the Table as follows:

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[7] **VBA**: **V**isual **B**asic for **A**pplication. Details of my self-developed IT program are located in Annex I.
[8] **See:** p.20

RESULTS OF SENSITIVITY TESTS					
Theoretical test			Practical test		
Condominium	Office Building	Assembly Plant	Condominium	Office Building	Assembly Plant
L_O	L_O	L_O	L_O	L_O	L_O
r_f	r_f	L_F	r_f	r_f	r_f
L_F	L_F	r_f	L_F	L_F	L_F
r_{tu} (inside of bld)	r_{tu} (inside of bld)	LPS	LPS	LPS	LPS
LPS	LPS	r_P	r_P	r_P	r_P
r_P	r_P	r_{tu} (inside of bld)	C_D	C_D	C_D
C_D	$C_{E/T}$	C_D	N_G	N_G	N_G
N_G	C_D	N_G	h_Z (inside of bld)	h_Z (inside of bld)	h_Z (inside of bld)
h_Z (inside of bld)	N_G	$C_{E/T}$			
r_{ta} (outside of bld)	$C_{E/P}$	$C_{I/T}$			
$C_{E/P}$	h_Z (inside of bld)	$C_{E/P}$			
$C_{I/P}$	$C_{I/T}$	$C_{I/P}$			
$C_{E/T}$	$C_{LD/T}$	$C_{LD/T}$			
$C_{I/T}$	$C_{T/T}$	$C_{T/T}$			
$C_{LD/P}$	$P_{LD/T}$	$P_{LD/T}$			
$C_{T/P}$	t_Z (inside of bld.)	h_Z (inside of bld)			
$P_{LD/P}$	H (height)	r_{ta} (outside of bld)			
H (height)	$C_{I/P}$	$C_{LD/P}$			
$C_{LD/T}$	$C_{LD/P}$	$C_{T/P}$			
$C_{T/T}$	$C_{T/P}$	$P_{LD/P}$			
$P_{LD/T}$	$P_{LD/P}$	H (height)			
t_Z (inside of bld.)	r_{ta} (outside of bld)	t_Z (inside of bld.)			
-----	-----	h_Z (outside of bld)			
-----	-----	W (width)			
-----	-----	L (lenght)			

Source: Edited by author

L_O – Internal System Failure (only hospital and explosion dangerous building)

r_f – Factor reducing loss depending on risk of fire

L_F – Physical damage related to the purpose of the building

LPS – Lightning protection system (class)

r_p – Fire protection measures

C_D – Location factor

N_G – Number of dangerous events

h_Z – Type of special hazard (inside of building)

The another of input parameters are forming the group (set) of the non-strong input parameters. Their impact is virtually negligible but their control during the design process may be warranted continuously. During my research, this was only minimally practically necessary in the case of the three examined structures. However, when construction and design take place roughly simultaneously and practical solutions generate new design needs, it is possible that even a continuous change in the value of a previously weak input parameter (e.g. H = building height, as a parabolic value set of function) may "delegate" itself into the strong input parameters group possibly into the extremely strong input parameters group as well. This happened several times during the construction of the Burj Khalifa when the practical solution of an architectural or technical problem made it possible to reach another significant height.

Therefore, my **T1 thesis is proved** by my results of my scientific research process which is **supported by my [P3][9] [P7][9] publications**.

[9] **See:** p.19

My second thesis (T2) is:

I proved with scientific methods and supported by the results of my calculations that ***two extremely strong input parameters can be identified*** *within the group of strong input parameters designed by me (*$\mathbf{L_O}$*[10],* $\mathbf{r_f}$*[11]).*

The theoretical and practical sensitivity testing required 17 280 pieces of each calculations for the selected three building types with variation cases of some selected strong input parameters. I proved by a mathematical method and confirmed by performing the 51 840 pieces common calculations that in the case of all three building types the **L_O and r_f** input parameters **are the extremely strong input parameters**. This means that their changes must be given special attention in the human decision-making process during the controlling of the design because their unit change has a decisive effect on the output so, they immediately result an "inadequate" rating for lightning protection of the examined building. I theoretically proved and substantiated the fact applied in practice that it is expedient to intervene in the design process of buildings. In order to ensure the "adequacy" of the lightning protection of the building, **the initiating cooperation** among the lightning protection designer, the fire protection designer and the architectural team is an **essential necessity**.

Both the changes of the integrated technical and architectural solutions of the lightning and fire protection and the applied tools, materials, procedures may have economic consequences during their co-operation of the common human decision process.

Therefore, **my T2 thesis is proved** by my results of my scientific research process **which is supported by my [P3][12] [P7][12] publications.**

During my research process I performed the calculations for my hypothesis 3 (H3) and **published my results [P3][12] [P9][13]** but since the draft standard was not published and I cannot formulate a thesis in this regard. Consequently, the research of my hypothesis 4 (H4) which was derived from it has also become obsolete unfortunately.

6. Further usage of my results

The continuous use of continuously researched results in practical life is essential. Both my achievements and my theses can be used in industry and in standardization process as well as in

[10] **L_O:** internal system failure (only hospital and explosion dangerous building).
[11] **r_f :** factor reducing loss depending on risk of fire.
[12] **See:** p.19
[13] **See:** p.20

further research related to lightning protection and in the fields of education. In light of this, my recommendation can be formulated as well. In the controlling processes already used in the design of buildings **in the industry fields**, the design process can be optimized by grouping the input parameters belonging to the legal and competence of the lightning and fire protection designers [122]. By possibly changing the input parameters, the design process can be optimized too which on the one hand reduces design time and on the other hand can ensure cost-effective simultaneous compliance with safety, the lightning and fire protection in the human decision-making system of the applicable engineering solutions for the infrastructures as well. My results can **support the standardization process** to be easier, more transparent, and more efficient by focusing on detected and grouped strong / extremely strong input parameters. It guides thinking in the theoretical and practical use of the requirements of the standard in force at any time, in the creation of new standards, thus supporting the dynamic system of national and international standardization processes. Dissemination presentations at national and international standardization conferences, professional events and in standardization bodies, committees[14], as well as in their sub-committees & working groups[15], can expand the knowledge and horizons of registered participants and can contribute to the effective and efficient professional work of lightning protection standardization working groups [123]. Both **in the national and international research process**, my results can inspire the researchers to explore new connections with the risk-based approach to lightning protection of structures, to research optimal material-technical solutions and their economic implications due to the simultaneous impact assessment of the input and output parameters defined in the standards. My publications in the database of the Hungarian Science Bibliography (HSB)[16] also contributes to the use and expansion of the domestic and international standardization knowledge base [124]. **In the fields of education**, my results can be incorporated into the basic professional topics of domestic [125] and international university education during institutional training, on one hand also into the order of retraining, and on the other hand, further training in the course system as well. Due to the individual needs (e.g. multinational companies, large industrial companies, etc.), specific planning controlling processes of the lightning protection design can be optimized on site by using mobile training groups.

Finally, in my point of view I think that the importance of the topic justifies that lightning protection is a very important part of our human life.

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[14] e.g.: **IEC/TC 81**: **I**nternational **E**lectrotechnical **C**ommittee/**T**echnical **C**ommittee-81: Lightning Protection; **MSZT/MB 841**: **M**agyar **Sz**abványügyi **T**estület / **M**űszaki **B**izottság-841 [123].

[15] e.g.: **MT**-21:**M**aintennance **T**eam- 21, sub-committee of TC 81.

[16] **HSB: H**ungarian **S**cience **B**ibliography, in Hungarian: **M**agyar **T**udományos **M**űvek **T**ára (MTMT) [124].

Based on all this, it can be stated that my achievements in the field of protection of the human life and property can be widely used, they are closely related to the presented areas, which simultaneously and mutually intersect each other, generating further new theoretical and practical solutions and research opportunities in relation to man and his built environment.

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8. Publications, lectures and conferences

My publications and lectures can be found in the MTMT store [124].

8.1 Scientific publications related to the thesis points

[P1] Kasza, Z.: *Risk Analysis about Lightning Protection for Buildings*, International Engineering Symposium, IESB 2017: Abstracts, Budapest, Magyarország, Óbudai Egyetem, Bánki Donát Gépész és Biztonságtechnikai Mérnöki Kar, (2017) p.47

[P3] Kasza, Z., Kovacs K.: *Risk Analysis About Lightning Protection for Buildings Focusing on Risk of Loss of Human Life*, Procedia Manufacturing 32, (2019) p.458-465

[P7] Kasza, Z.: *Sensitivity analysis of condominium lightning protection risk analysis*, Interdisciplinary Description of Complex Systems 18: 3 (2020), p.375-381

8.2 Additional scientific publications

[P2] Kasza, Z.: *Épületek, mint objektumok vagyonbiztonságát veszélyeztető külső szerkezetek és építészeti megoldások értékelése*, Bánki közlemények 1: p.12-19, Óbudai Egyetem, Budapest, (2018).

[P4] Kasza, Z.: *Thoughts about the Lightning Protection of some Electric Vehicles*, Interdisciplinary Description of Complex Systems 17: 3-A p.497-502, Croatia, (2019).

[P5] Kasza, Z.: *Analyzing the Corrosion Potential of a Lightning Protection Systems*, Transactions on Advanced Research 16: 2 p.15-19, (2020).

[P6] Kasza, Z.: *Can we avoid a lightning strike if we are in an open space?*, Bánki Közlemények 3: p.13-17, Óbudai Egyetem, Budapest, (2020).

8.3 Lectures and conferences

[P8] *Építmények villámvédelmi kockázatelemzése (2017)*, IESB 2017, Óbudai Egyetem.

[P9] *Risk Analysis about Lightning Protection for Buildings (2018)*, Conference of Inter-Eng 2018, Targu Mures (Marosvásárhely), 2018.

[P10] *Introduction of research about Lightning Protection of Buildings about my science research process (2019)*, International Week, WSB University, Dabrowa Gornicza, Poland, 12th-16th August 2019.

[P11] *Introduction of Óbuda University (2019)*, International Week, WSB University, Dabrowa Gornicza, Poland, 12th-16th August 2019.

[P12] *Gondolatok egyes személygépjárművek villámvédelméről (2019)*, Okos Közlekedési Tudományos Konferencia 2019, Doktoranduszok Országos Szövetsége Műszaki Tudományok Osztály, Zalaegerszeg, 2019.

[P13] *Thoughts about the lightning protection of some electric vehicles (2019)*, SmartCity 2019 konferencia, Óbudai Egyetem, 2019. február 8.